

## **Module 5**

# **Natural Resources: Chemistry and Environmental Sustainability**

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## **Key Terms and Concepts**

- anthracite
- biogas
- biomass
- biotic
- bitumen
- bituminous coal
- bond energy
- catalyst
- catalytic reforming
- core
- cracking
- crust
- element
- energy
- fossil fuels
- fractional distillation
- gasohol
- hydrocarbon
- inorganic
- kerogen
- liquefied natural gas (LNG)

- liquefied petroleum gas (LPG)
- metal
- minerals
- non-renewable resources
- oil
- oil shale
- ore
- plastic
- polymer
- polymerization
- renewable resource
- shale oil
- silicates
- solar energy
- strategic metals
- synthesis gas
- tar sands
- weathering

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## **Learning Objectives/Outcomes**

Upon completion of this module, you should be able to

1. identify the mineral resources of Earth's crust.
2. list some metal elements that are extracted from ores.
3. describe biomass as an alternative energy source.
4. describe the different types of fossil fuels and their formation.
5. explain how energy use by humans has changed historically.
6. describe environmental impact of resource use.

## Overview

The cost and availability of energy are probably the most important factors that determine whether a particular mineral deposit can be developed. Determination of the quantities of mineral resources in Earth's crust is a constant problem. More complete exploration, advances in technology, and increases in price have major effects on estimated exploitable reserves of any mineral. Any prediction, optimistic or pessimistic, may contain a large margin of uncertainty. Data on the rate of past industrial activity using current levels of technology can be extrapolated into the future. For example, to estimate reserves of gold, the amount of gold discovered per metre of exploratory mining can be projected. Since this method does not allow for technological breakthroughs, it may underestimate supplies of a mineral. Another approach is to relate reserves of an element to its relative abundance in the crust of the Earth. This type of data can only give order of magnitude estimates, of course, and ignores the problem of techniques for recovery from lower-grade ores. The recovery problem is illustrated by comparing iron with aluminum. Few techniques are available for recovery of the aluminum from many of its minerals.

The combustion of fossil fuels—coal, oil, and natural gas—provides by far the largest portion of the current supply of energy. The production of synthetic organic chemicals is also based almost entirely on fossil materials. Because of the large investment of economic capital in machinery and industrial plants that have been designed around fossil fuels, it would be difficult to switch instantaneously to another resource base. The human resources and materials to construct the plants or other devices necessary for solar or nuclear energy to replace fossil fuels could not be mobilized immediately. Experience suggests that a period of 20–40 years is required for one energy technology to replace another, so considerable lead time must be allowed for alternative resources to supplant dwindling supplies of fossil fuels. Environmental degradation associated with fossil fuels will persist for a number of decades even if “limitless” supplies of “clean” energy become available.

The world's human population continues to grow at an ever-increasing rate, and with it grows the demand not only for food but also for material goods. To meet these material needs, metals and other non-renewable resources are being consumed at an increasing rate, one that will rise as the developing nations become more industrialized. The industrialized nations currently consume a disproportionate amount of Earth's mineral reserves. The North American continent, for example, has less than 10% of the world's population, but it consumes more than 50% of the world's production of aluminum. The same disproportionate usage rate holds true for many other metals.

It is possible that new oil and mineral deposits will be discovered in the future. However, since most of Earth's surface has already been thoroughly explored by geologists, it is unlikely that significant quantities will be found. One source that has not been fully explored is the ocean floor. Areas where new floor is being formed have been shown to be rich in sources of metals. As deep-sea mining technology develops, sites on the ocean floor may well provide a new source. However, the world's fisheries are already endangered and mining would create another environmental stress.

One of the most important ways to conserve mineral supplies is to recover metals by recycling. More and more communities are collecting metal, glass, and paper for recycling, which saves energy as well as conserves natural resources. Approximately half as much energy is required to make new aluminum cans from old cans as is needed to make them from bauxite.

## Lecture

### Natural Resources and Ores

The rocks that make up the hard surface of the Earth—the lithosphere—are composed of substances called minerals. A mineral is a naturally occurring mixture, usually crystalline, that has a restricted range of composition; they may be either elements or compounds. Minerals are from the inorganic part of the Earth's crust; materials derived from the decayed remains of plants and animals make up the organic part.

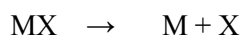
Some minerals have been known and used since ancient times. There is evidence that early in human history, flint and obsidian (a volcanic glass) were shaped to make weapons and primitive knives; clay was formed into pottery and bricks. Gold, silver, copper, and brightly coloured minerals such as jade and amethyst were fashioned into jewellery. Pigments were made from red and black iron oxides (compounds in which oxygen is bonded to iron). More than 2,000 distinct minerals have been identified, but only a few of them are distributed widely over the Earth's surface. In the Arctic, the more valuable minerals are found in only a few limited regions, where they became concentrated as a result of the upheaval and subsidence of crust materials and other rock-forming processes that have gone on for millions of years. Rocks and minerals are natural resources. A natural resource is anything taken from the physical environment to meet the needs of society. Such resources may be renewable or non-renewable. Resources such as soil, natural vegetation, fresh water, and wildlife are all renewable. Rocks and minerals, as well as oil, natural gas, and coal, are non-renewable. They are present in the Earth in fixed amounts and are not replaced as they are used. Rocks and minerals are quarried and used often in modified form in the construction as well as the chemical industries.

Because metal ores are unevenly distributed in Earth's crust, many nations must depend on imports for their supplies. Within the United States, for instance, there are few deposits of ores of many strategic metals, metals that are essential for industry and defence. Large reserves of chromium (Cr), manganese (Mn), and the platinum (Pt) group of metals (platinum, palladium, rhodium, iridium, osmium, and ruthenium)—which are needed for the manufacture of specialty steels, heat-resistant alloys, and industrial catalysts—are found only in the Arctic nations of Russia and Canada.

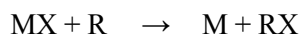
## General Chemical Principles of Metal Extraction

The crustal abundances of silicon, aluminum, iron, calcium, magnesium, sodium, and potassium are low, that is, less than 7%. Many ore-bearing minerals are oxides or silicates and also contain, as impurities, the other metals. The next largest class of ores consists of sulfides (the chalcophiles); and other ores contain sulfates, hydrated oxides, or carbonates. In only a few cases (platinum, gold, and copper) metals are found in “native” (unoxidized) form.

There are two issues in extracting a metal from its ore. First, the metal must be chemically reduced to elemental form. Such a reduction is usually accompanied by a positive free-energy change ( $\Delta G$ ):



The greater the affinity of the metal for X, the larger the value of  $\Delta G$ . Reduction can be made to occur by supplying free energy in either of two forms. A reducing agent, R, can release free energy upon combination with X, driving the following reaction:



Or electrical energy may be employed to force the reaction.

The other aspect of metallurgical extraction is the removal of impurities that may remain dissolved in the metal of interest after reduction. Such refining often involves the use of slags—mixtures of oxides that can dissolve away the unwanted constituents from the metal solution. The composition of a slag is carefully designed so that at the high temperatures of reactions it is immiscible with the metal and sufficiently fluid to be poured or skimmed from the metal surface. Most oxides or silicates are much less dense than most metals; thus, slags collect at the top of a reaction vessel. Because the melting point of a pure substance is decreased by a solute, mixtures of oxides are often used in slags, allowing them to remain liquid at lower temperatures and minimizing the heat requirements of the process. Acidic and basic oxides may be employed to dissolve specific impurities, and hence a slag is often designated as “acidic” or “basic.” The mass of slag used should be minimal to avoid trapping metal, reduce the quantity of heat needed for melting, and minimize disposal problems.

Since silicon is the second most abundant element in the Earth's crust, it is the commonest impurity in ores; most slags contain primarily  $\text{SiO}_2$ , with smaller amounts of the oxides of aluminum, iron, calcium, magnesium, sodium, and potassium. Because it is more electronegative than most metals, silicon forms covalent bonds with oxygen, and in  $\text{SiO}_2$  the atoms are connected in a three-dimensional network. When the solid melts, the melt contains polymeric giant ions. Because such large ions have difficulty diffusing around one another, a silica melt tends to be highly viscous.

The addition of certain metal oxides to molten silica has the effect of reducing viscosity and making the melt more basic. Oxides having the general formula  $\text{RO}$  (where  $\text{R} = \text{Ca}, \text{Mg}, \text{Fe}, \text{Na}_2, \text{K}_2$ ) are basic. They react with water to give hydroxide compounds, and in molten salts they liberate  $\text{O}^{2-}$ , which is a strong Lewis base. On the other hand, the polymeric ions produced when  $\text{SiO}_2$  melts can accept pairs of electrons from oxide ions, thus behaving as Lewis acids. Part of the acidity of  $\text{SiO}_2$  is therefore neutralized. At the same time, the degree of polymerization of the giant ions in the silica melt is reduced, decreasing viscosity. An acid slag, which contains acidic oxides, is useful for removing impurities such as calcium, magnesium, sodium, potassium, or iron (which form basic oxides) from molten metals. Conversely, basic slags containing excess alkali, or alkaline Earth oxides, can be used to remove the acidic oxides of silicon, phosphorus, or sulfur during ore-refining processes.

The basic unit of all silicates is the  $\text{SiO}_4$  tetrahedron, in which a silicon atom at the centre is bonded (joined) to four oxygen atoms located at the corners of a four-sided pyramid. Because each oxygen atom can bond to two silicon atoms, adjacent  $\text{SiO}_4$  units can be linked through shared oxygen atoms. This linking allows long chains, sheets, and even three-dimensional networks of  $\text{SiO}_4$  units to be formed. The mineral quartz is composed entirely of  $\text{SiO}_4$  units joined together to form a three-dimensional network. In micas, the  $\text{SiO}_4$  units form sheet-like arrays in which each tetrahedron is joined to three others; micas are easily cleaved into thin sheets. A common mica is muscovite, a pearly white mineral that was used to make windowpanes in medieval Europe, before glass became readily available. Other micas include talc, a soft mineral used to make talcum powder, and kaolinite, a clay mineral.

Asbestos is a general term for a number of natural silicates formed from double chains of  $\text{SiO}_4$ . Chrysotile, the most abundant type of asbestos, takes the form of curly fibres. The much rarer crocidolite crystallizes as sharp, narrow needles. Asbestos is a very versatile material. It is strong, flexible, and resistant to corrosion; and it serves as an excellent thermal insulator in the Arctic. Until the 1970s, when as a fine fibre it was identified as a serious health hazard, asbestos was widely used to insulate steam pipes and other heating units and to make protective clothing for firefighters, welders, and other people exposed to high temperatures.

Workers exposed to large amounts of fine airborne asbestos fibres over a considerable period of time develop serious lung disorders. These disorders include asbestosis, a disease that makes breathing very difficult, and lung cancer. The process of asbestos removal is extremely costly and may release fibres into the air and expose removal workers to high levels of airborne fibres. The US Environmental Protection Agency (EPA) now recommends that, unless it is crumbling, asbestos be left in place and encapsulated in a plastic coating.

Besides refining and asbestos, silicates have other important uses in the daily lives of people. Silicates were first used to fashion cutting tools and were later modified and transformed into pottery utensils. Silicates are starting materials for a wide range of products, including bricks, china, glass, cement, and other materials that have wide usage as specialized properties.

## Iron and Steel

Iron, the fourth most abundant element in the Earth's crust, is the metal used in greatest quantity by industrialized nations. The ores from which it is extracted usually contain a mixture of two iron oxides: hematite ( $\text{Fe}_2\text{O}_3$ ) and magnetite ( $\text{Fe}_3\text{O}_4$ ). The majority of the iron extracted from ores is used to manufacture steel and alloys of iron, which contain a small amount of carbon. The percentage of carbon determines the properties of steel. Low-carbon steel (less than 0.25% carbon) is relatively soft and suitable for making cans and wire. High-carbon steel (up to 1.5% carbon) is very hard and strong and is used for making tools and surgical instruments. Steels with a variety of properties and uses are made by alloying iron with small amounts of other metals.

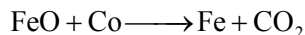
World reserves of iron are still large, and the Arctic has an abundant supply. The carbon reduction method can be used to recover iron for steelmaking. Hematite ( $\text{Fe}_2\text{O}_3$ ), magnetite ( $\text{Fe}_3\text{O}_4$ ), limonite (hydrated  $\text{Fe}_2\text{O}_3$ ), and siderite ( $\text{FeCO}_3$ ) are the principal iron ores. Since most of these contain relatively high concentrations of the metal, little preliminary treatment is required, and reduction by carbon in a blast furnace is the first major step. The modern blast furnace is based on techniques discovered in the fourteenth century; except for vast increases in scale and some substitutions of materials, it has not changed greatly.

A mixture consisting of iron ore, coke, and limestone enters the top of the furnace, and preheated ( $\sim 1,000^\circ\text{C}$ ) air is simultaneously forced through blowpipes at the bottom of the furnace. The blast of air passes up the shaft, reacting with some of the carbon in the coke to form  $\text{CO}$  and  $\text{CO}_2$  and thereby heating the mixture. The exhaust gases, which contain a high concentration of  $\text{CO}$ , can be trapped above the furnace and, after cleaning, may be burned to run the preheaters. Liquid iron, and a layer of slag that floats on top of it, collect at the bottom of the furnace. About 90% of the iron content of the ore is recovered as molten iron.

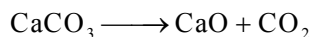
Most ore in the lower portion of the furnace shaft is reduced by direct reaction with carbon:



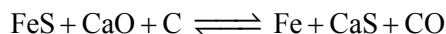
Higher in the shaft, where the air is cooler, indirect reduction by CO instead of C occurs:



The high temperature of the furnace changes limestone to lime:



Lime (CaO) reduces the melting points of the silicon and aluminum oxide impurities. The basic character of CaO neutralizes the acid slag of SiO<sub>2</sub> and Al<sub>2</sub>O<sub>3</sub>, and, importantly, removes sulfur from the iron:



This reaction may reverse when large concentrations of CaS build up in the slag. Most low-sulfur coal available has been allocated to metallurgical use—hence, the incentive to use “dirtier” coal for electric power-plant supply. This leads to SO<sub>2</sub> being released in the atmosphere.

The chief pollution problems associated with blast furnaces are solid wastes (slag) and particles suspended in the air blast. Older blast furnaces were extremely bad air polluters, and some regions are still dotted with old slag heaps, which support little or no plant life. Production of coke also generates H<sub>2</sub>S and SO<sub>2</sub>. Slags are sometimes used as aggregate for cement, and air pollution can be controlled by bag houses, wet scrubbers, and electrostatic precipitators. Water is required to quench coke and slag and for scrubbing particulates, so water pollution is a secondary problem unless effluents are treated in sedimentation ponds.

The pig iron produced by a blast furnace is brittle and suitable only for casting because of its high carbon content. The usual analysis of impurities shows 4% carbon, 2% phosphorus, 2.5% silicon, 2.5% manganese, and 0.1% sulfur. Pig iron is converted to steel by oxidation of these impurities in preference to iron.



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## Student Activity

1. What metal ores are extracted from the land nearest your community?
  2. How are these metals used in the world?
  3. How are they extracted from the Earth?
  4. What are the associated pollution problems with the extraction of these resources?
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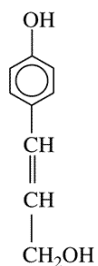
## Fossil Fuels

### Origin and Chemistry of Coal

Coal is a complex mixture of organic compounds. It is composed primarily of hydrocarbons and small amounts of oxygen-, nitrogen-, and sulfur-containing compounds. Compared with petroleum, coal contains a much higher percentage of aromatic hydrocarbons, including many polycyclic aromatic compounds. The composition of coal varies with its type and the location of the deposit.

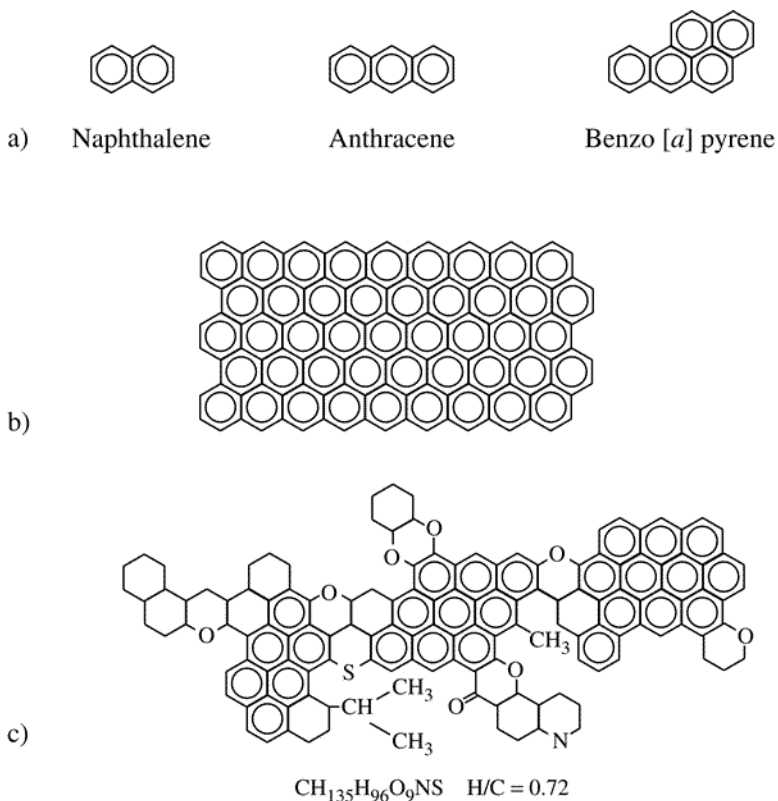
A small fraction of the total amount of carbon reduced by photosynthesis has been accumulating in sedimentary deposits over geological time. Formation of coal deposits requires special conditions, so only a small portion of this total reduced carbon is involved. Some forms of lignite may be no older than 2 million years; bituminous coals range from 100 to 300 million years, and some anthracite coals may be much older. Coal has been formed from the remains of terrestrial plants that were deposited in swamps and covered rapidly enough so that there was little oxidization by atmospheric air. Biochemical and physical processes then transformed this plant debris into various types of coal.

Terrestrial plants of the carboniferous period (300 million years ago), during which many bituminous coals were deposited, had composition similar to today's vegetation. The material from which coal was generated probably consisted of ~15% protein, 20%–55% cellulose, 10%–35% lignin, and ~10% inorganic salts. The first stage in coal formation was conversion of this plant material to peat by aerobic and anaerobic bacterial degradation. Much of the protein apparently was incorporated in micro-organisms, and the cellulose was converted to CO<sub>2</sub> and H<sub>2</sub>O by their metabolism, leaving behind lignin, a complex polymer of *p*-coumaryl-like alcohols, which are difficult to decompose (see fig. 5.1).



**Fig. 5.1** *p*-Coumaryl alcohol

The next stage of coal formation involved geological metamorphism. After the lignin and the remains of the bacteria had been buried under many other layers of sediment, high temperatures and pressures drove off additional H<sub>2</sub>O and CO<sub>2</sub>, leaving behind mostly carbon, with smaller quantities of hydrogen, oxygen, nitrogen, and sulfur. The structural change involved *aromatization*, the formation by dehydrogenation of six-membered rings of carbon atoms. (See fig. 5.2.)

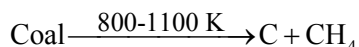


**Source:** Redrawn from Manskaya and Drozdova (1968, 131)

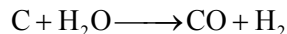
**Fig. 5.2** Comparison of a proposed coal structure with a single layer of graphite: (a) polynuclear aromatic hydrocarbons; (b) molecular structure of a single layer of graphite; and (c) proposed molecular structure of coal (hydrogens not shown).

Several techniques can be envisioned for reducing environmental degradation associated with coal combustion: (a) supplies of fuel (low-sulfur coal, natural gas) that do not contain the precursor (sulfur, metals) of pollutants may be sought, or entirely new free-energy sources may be developed; (b) contaminants (such as iron sulfide) may be removed prior to combustion; or (c) pollutants may be extracted from effluents after combustion.

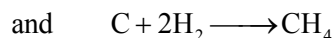
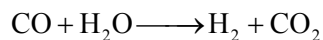
Nearly all of the sulfur can be removed from coal during a process known as gasification. The first step in the process is similar to the formation of coke and is usually referred to as devolatilization:



Although a relatively high temperature is required for devolatilization to occur rapidly, it is exothermic and represents a continuation of the spontaneous loss of hydrogen and oxygen, as in of the formation of coal. Because most coals contain only a small percentage of hydrogen (the number of hydrogen atoms present is usually less than the number of carbon atoms), less than one-quarter of the total carbon in the coal can be converted to methane (natural gas). Water is added to supply hydrogen. At temperatures higher than 1,000°C, catalysts improve this process of gasification.



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Conversion of coal to more convenient gaseous fuels requires additional cost to reduce potential pollutants.

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## Student Activity

Conduct some research on alternative sources of energy. Are there any that would work well in the Arctic?

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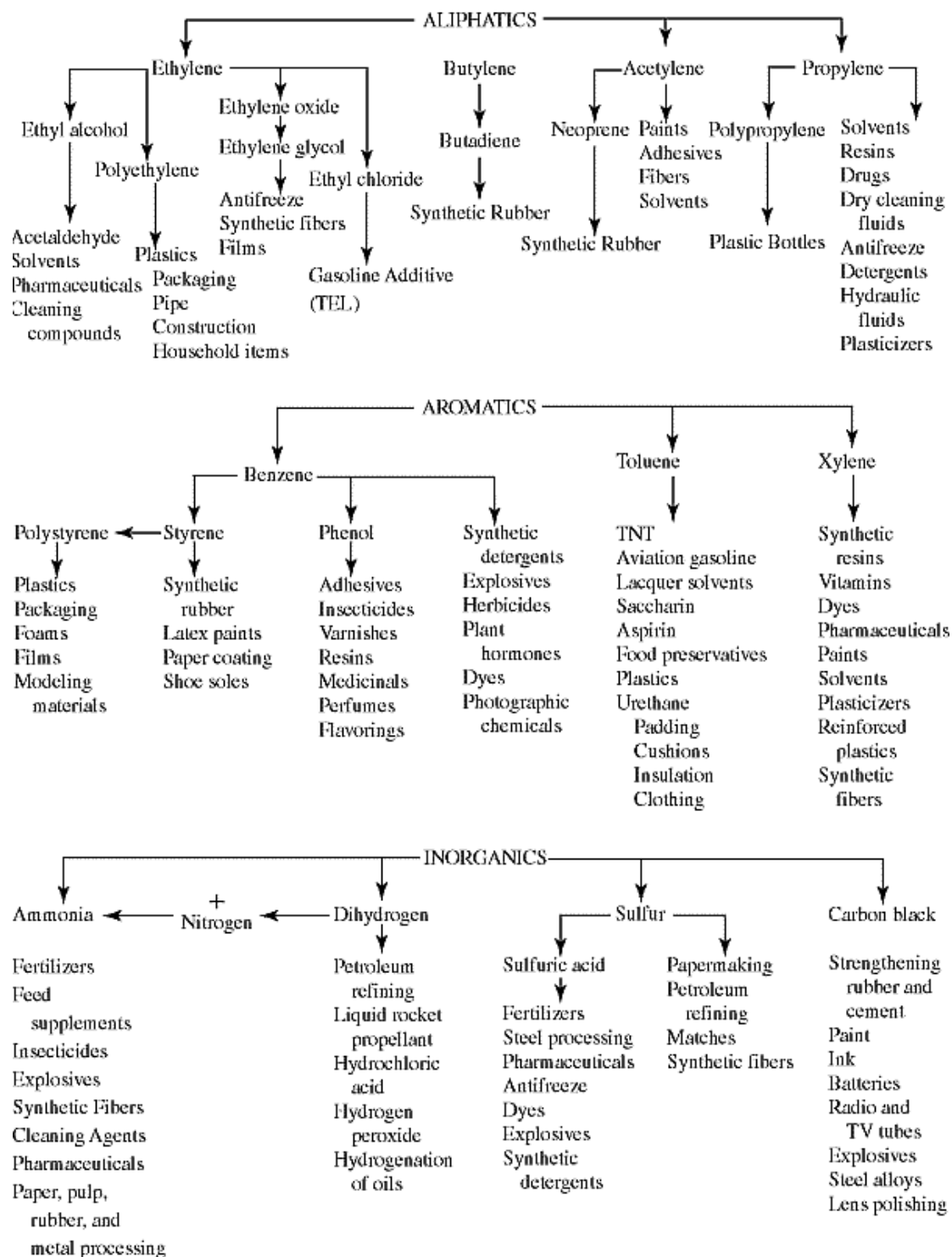
## Origin and Chemistry of Petroleum and Natural Gas

Petroleum originated through the deposition of organic matter from plants and animals at the bottoms of ancient seas. Such organic matter was decomposed by anaerobic bacterial action, which removed much of the oxygen, sulfur, and nitrogen. The hydrocarbon compounds produced in this way were probably concentrated by being dissolved in water and transported through sedimentary rocks; the deposits were then trapped in dome-shaped chambers from which they can be obtained by drilling wells.

Petroleum is a relatively easy to recover, handle, and transport; but natural gas is also relatively free of pollution-causing impurities. Natural gas is mostly methane. Natural gas consumption is outpacing the discovery of new reserves in the world. New discoveries—even those as large as the Alaska North Slope—will only postpone consumption of the resource by a few years. Both Europe and the United States have to import large quantities of petroleum and natural gas; however, over a longer time, even natural gas imports will become hard to obtain. It is estimated that 50% of the world's recoverable reserves have been consumed.

The formation and concentration of petroleum deposits required highly specific conditions of temperature; mineral nutrients for the plankton whose remains would be converted into oil; and appropriate geological factors controlling formation and preservation of the resource. Most large oil fields have probably already been discovered, and returns of gas or oil per metre of new drilling have been decreasing. It is difficult to predict future quantities from known oil fields as recovery technology improves.

Two resources related to petroleum that have not yet been exploited are tar sands and shale oil. They constitute a large reservoir of energy, although both resources are small by comparison with coal. Tar sands consist of extremely viscous, liquid hydrocarbons found in association with sand deposits. Oil shale contains about 20% solid hydrocarbon (kerogen) and 80% ordinary shale. Because the treated shale occupies greater volume than the material originally strip-mined, and since large quantities of water are required for the retorting process, considerable disturbance of the environment is inevitable in shale development. (See fig. 5.3.)



Source: Amer. Petrol. Inst., Washington, D.C.

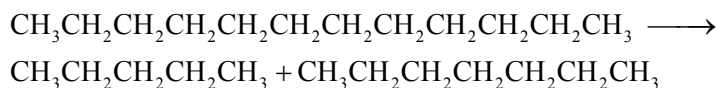
**Fig. 5.3** The petrochemical family tree. Fuels constitute the majority of the easily recoverable supply of reduced carbon on Earth. A variety of useful materials, including plastics, can be manufactured from hydrocarbons or coal.

Crude oil is a mixture of a wide variety of hydrocarbon compounds, which can be classified on the basis of structural type or number of carbon atoms. Paraffins have the general formula  $C_nH_{2n+2}$  and straight or branched carbon chains but no rings or multiple bonds. Naphthenes contain primarily five- and six-membered rings. Taken together, paraffins and naphthenes are classed as aliphatic hydrocarbons. Aromatic compounds contain benzene rings.

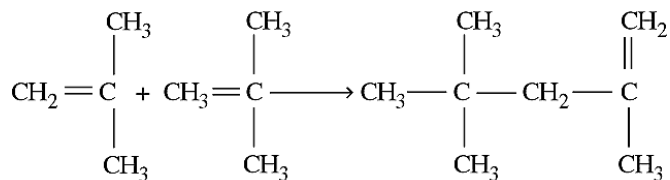
Hydrocarbons may be separated on the basis of molecular weight by distillation. The vapour pressures of these non-polar substances depend on the intermolecular attractions resulting from weak non-covalent bonding forces, such as Van der Waals forces. Hydrocarbons having similar numbers of carbon atoms have similar boiling points. The simplest and most common method of refining petroleum involves a fractionating tower. Distillation separates crude petroleum into the fractions. The transportation industry uses the gasoline and kerosene fractions and these fractions are most profitable for the petroleum industry (which works closely with the automobile industry).

In refining petroleum for the present gasoline combustion-oriented economy, it is necessary to increase the gasoline fraction (i.e., refine it into smaller molecules). Hydrocarbons having more than ten carbon atoms should be converted into gasoline. Also, within the gasoline fractions, as many high-octane compounds as possible should be produced. This means converting straight-chain paraffins to branched chains, naphthenic, or aromatic compounds. The most common petroleum-refining processes can be divided into five categories: cracking, polymerization, alkylation, catalytic reforming, and hydrocracking.

The cracking process consists of breaking down large molecules into smaller fragments, producing greater amounts of molecules that are in the gasoline fraction range  $C_5$ – $C_9$ . An example of a cracking reaction is as follows:

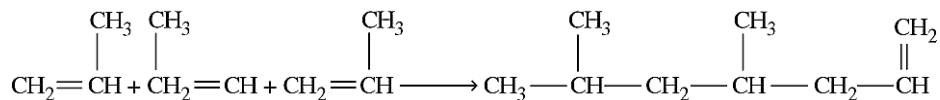


In the process of polymerization, hydrocarbons having fewer than five carbon atoms are connected together to produce molecules in the gasoline fraction (see fig. 5.4).



**Fig. 5.4** Gasoline fraction

Another example of polymerization is the transition of propylene to a longer branch-chain compound (see fig. 5.5):



**Fig. 5.5** Transition of propylene to a longer branch-chain compound

In alkylation, catalysts that are strong acids, like sulfuric acid and aluminum trichloride, are used. A compound having a double bond reacts with a carbon-hydrogen bond to form a somewhat higher molecular weight product. Ethylbenzene can be produced from ethylene and benzene, and isooctane can be formed from isobutane and isobutene.

In catalytic reforming, paraffin hydrocarbons converted to aromatic compounds. An example is aromatization, where *n*-hexane is converted first to cyclohexane and finally into benzene. Catalysts for reforming often consist of molybdenum oxide or platinum on fluoride-containing clay.

In a process known as hydrocracking, hydrogen is added to the double bonds produced in the cracking reaction. Smaller amounts of tar and other less-desirable high-molecular weight compounds, which occur as a result of polymerization of compounds containing double bonds, are produced. Another advantage of hydrocracking is that sulfur contained in the petroleum will be converted through reaction with dihydrogen to hydrogen sulfide.

Environmental degradation resulting from fossil fuel combustion consists of thermal pollution and air pollution. Production, refining, and shipping of petroleum have significant environmental consequences, too. Offshore drilling, supertankers, and loading and unloading procedures at refineries contribute to the magnitude of the oil spill problem, and the construction of pipelines has an impact. Effluents from petroleum refineries include carbon monoxide, hydrocarbons, hydrogen sulfide, and other air pollutants. The chief hazard of natural gas from leaks is explosions.

The total influx of oil into the ocean from human activities is estimated at 5 million tons annually. These include pumping of sea-water ballasts from tankers, pumping of bilges of cargo ships, losses during loading and unloading operations, and accidents involving the vessel or offshore drilling. In addition, approximately 2 million tons of lubricating oil is consumed every year in the United States alone. Much of this probably finds its way into the freshwater environment when it drains from big cities.

A significant cause of oil pollution is improper disposal of lubricating oil from machines and automobile crankcases. Many car owners who change their own motor oil pour the used oil into storm sewers and other areas that drain into creeks, rivers, and groundwater. Few realize that as little as one quart (1 litre) of oil can contaminate 2 million gallons (7.5 million litres) of drinking water; or that one gallon (3.8 litres) of oil can form an oil slick measuring nearly 8 acres (3.2 hectares). Because of this danger, many communities have set up collection centres to which used oil can be brought for recycling.

Damage to water birds, whose feathers become coated, and to shoreline plants, which are smothered by oil, are common. Low molecular weight and relatively soluble aromatic substances are the most dangerous. In addition to short-term environmental degradation and toxicity, one can expect chronic effects resulting from low levels of petroleum compounds. These may include behavioural changes in marine predators by blockage of odour and taste receptors, as well as carcinogenic effects. Non-polar hydrocarbons are readily concentrated along food chains and may also serve as a concentrating medium for other fat-soluble poisons, such as pesticides.

Despite numerous attempts to devise cleanup techniques, the best cure for oil spills still appears to be prevention. Because the non-polar molecules cannot mix readily with water, oil may be tracked by floating booms and skimmed from the surface. Such techniques do not work well in rough water, which often accompanies large-scale spills; and they cannot remove the more water-soluble aromatics, which present the greatest problems of toxicity.

Another environmental concern is the waste water that is brought up with the oil produced from below the ocean floor. This ancient water contains barium, zinc, lead, and trace amounts of radioactive materials; when it is returned to the ocean, it can destroy nearby natural habitats. Also, the clay mud that is used as a drill lubricant contains lignite, barium, and other chemicals and in the past has been dumped at sea after use. The clay can bury and destroy bottom-dwelling organisms that form an essential part of the marine food chain. A serious effect of offshore drilling probably occurs along the shore, where facilities built to receive the oil destroy wetlands.

Motorboats are a source of oil pollution on recreational waters. Many outboard motors run on a mixture of oil and gasoline and emit this fuel half-burned through their exhaust systems. For many years motorboat emissions were not regulated, but now emission controls for new outboard motors are under review in many places.



## Natural Gas

The geological conditions necessary for the formation of natural gas are similar to those required for the formation of oil. In the formation of natural gas, part of the original, buried organic material was converted to light gaseous hydrocarbons. Natural gas is composed chiefly of methane and small amounts of ethane, propane, and butane. Typically it contains 60%–80% methane, but the exact composition varies with the source. Crude natural gas also contains small quantities of larger alkanes, carbon dioxide, nitrogen, hydrogen sulfide ( $\text{H}_2\text{S}$ ), and helium. Before natural gas can be used as a commercial fuel it must be treated to remove carbon dioxide, sulfur compounds, water vapour, and the hydrocarbons of molecular weights greater than that of ethane ( $\text{C}_2\text{H}_6$ ). Propane ( $\text{C}_3\text{H}_8$ ) and butane ( $\text{C}_4\text{H}_{10}$ ) are useful by-products. After they have been removed from the crude and natural gas, these by-products are converted to a liquid known as liquefied petroleum gas (LPG) and marketed as heating fuel. Natural gas is non-toxic and safe, but many people mistakenly believe that it is dangerous. This misconception dates from the early part of the twentieth century, when coal gas, a toxic mixture of carbon monoxide and hydrogen, was piped into homes. Of course, if natural gas accumulates in a confined space, a spark can ignite it explosively. Natural gas is relatively inexpensive. It is a superior fuel and has many advantages over coal and petroleum. It burns cleanly and leaves little residue; weight-for-weight it provides a higher heat output than any other fossil fuels. It emits less carbon dioxide per unit of energy and generally produces no sulfur oxides.

## Biomass and Other Energy Sources

### Biomass

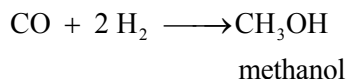
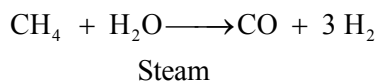
Biomass, which is defined as any accumulation of biological materials, can be used as a source of energy. Examples of biomass are wood and crop residues. Like fossil fuels, biomass can be burned directly to provide energy in the form of heat. It can also be converted to methane (natural gas) and liquid fuels like methanol and ethanol.

Wood, a form of biomass, is the major source of energy for cooking and heating for about 80% of people in the less developed nations of the world. In many areas of these countries, the constant search for firewood has led to excessive deforestation, with resulting erosion and degradation of the soil. A number of cities in the Arctic and Subarctic burn municipal trash, which is generally about 40% waste paper, as a source of energy. The heat involved in a typical modern waste incinerator can generate electricity.

Crop residues are the source of energy that can be exploited. In Hawaii, the fibrous residue from sugar cane is burned to produce electricity. Another possibility is raising crops of fast-growing, high-energy-yield plants specifically to be used as fuel. However, these “energy plantations” have several disadvantages. Large areas of land are needed, and because of the energy that must be expended to raise, harvest, and dry the crop, net energy yield is low.

Plants, organic wastes, moose manure, and other forms of biomass can be used as sources of methane. The process of converting biomass to methane (or other fuels) is called bioconversion. In the absence of air, digestion of the organic materials in biomass by anaerobic bacteria produces biogas, which is about 60%–70% methane. The most suitable starting materials are sewage sludge or manure. In India, 2 million people are producing biogas from cow dung. The biogas is used for cooking, lighting, and heating, or is used to generate electricity. Production of biogas is economically feasible only in locations where there is a large concentration of the starting materials.

The methane and biogas can be converted to methanol as shown in the following equations:



Natural gas or methane produced by coal gasification is converted to methanol in the same way. Methanol can also be produced by destructive distillation of wood. Although it is unlikely that bioconversion will ever become a major source of energy, it is a useful way to supplement other sources. It is particularly valuable as a means of converting plant and animal agricultural wastes, and waste paper in municipal garbage, to usable energy.

## Wind Power

Wind power was one of the earliest forms of energy humans harnessed to do useful work. Until the 1930s, rural regions relied heavily on windmills for pumping water, grinding corn, and general electricity. Then, as electrification projects brought cheap power to rural communities, most windmills fell into disuse. Now, windmills, which are called wind turbines, are having an impact in Alaska and the Arctic.

A modern wind turbine consists of three fibreglass blades mounted on a steel tower. The blades are much stronger and lighter than older conventional ones, and the whole system is automated and very reliable. The turbines are usually

arranged in wind farms consisting of several hundred turbines, each with blades measuring about 45 feet (15 m), and capable of producing 10–15 kilowatts of electricity (1kW = 0.001MW). Single units can be used for individual homes, but arrays of units are more efficient in the Arctic where there is plenty of space.

For wind power to be cost-effective, winds should blow fairly steadily at about 10 miles per hour (16 km per hour). Many areas in the Arctic meet this criterion, and wind power has great promise for those villages that lack large access to fossil fuels, such as Point Hope, Alaska.

Because of dramatic decreases in the cost of the technology in many areas, electricity can now be generated more cheaply from the wind than from coal. It is projected that wind power will supply more than 10% of the world's electrical energy by 2050. Wind is free and abundant, and wind power produces no pollutants and no carbon dioxide. However, wind does have a number of disadvantages: it is intermittent, making it necessary to have a storage system or alternative source of energy when the wind is not blowing; and wind turbines pose a danger to birds if the turbines are located along migratory routes.

## **Tidal Power**

The twice-daily rise and fall of the ocean tides represents an enormous potential source of energy. This tidal power can be exploited by building a dam across the mouth of a bay or inlet. The incoming tide generates electricity as it flows through turbines constructed in the dam. The turbine blades are then reversed so that the outgoing tide also produces electricity. To be practical, the difference in levels between low and high tides must be 20 feet (6 metres), or more. Two tidal power plants have been built: one in Canada, and the other in the former Soviet Union. Tidal power plants may alter the normal flow of water and may disrupt the natural environment.

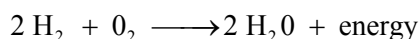
## **Energy from Hydrogen**

A fuel that could possibly replace oil and natural gas is hydrogen gas. Hydrogen could be transported through pipes like natural gas. It could be used for heating homes and for heating water to produce steam for electric power generation. With minor changes to the carburetor, today's cars could run on hydrogen. Hydrogen burns cleanly, combining with oxygen in the air to produce water vapour; and it releases more energy, gram for gram, than coal, gasoline, or natural gas.

A promising technique that is being investigated is absorption of hydrogen by certain metals to form hydrides, which then readily release the hydrogen as it is needed. A major problem is that practically no free hydrogen exists on Earth. Hydrogen, along with oxygen, can be produced by the electrolysis of water, but

this process requires the input of energy. In fact, because of the second law of thermodynamics, it requires more energy to break the bonds between hydrogen and oxygen atoms in water molecules than is released when hydrogen is burned. However, the tidal power or solar cells as a source of electricity can make it economical to produce hydrogen by electrolysis. Sea water could provide an almost inexhaustible source of water.

Fuel cells are also a promising way of using hydrogen as an energy source. Instead of fuelling the vehicle by burning hydrogen gas, electricity generated by the oxidation of hydrogen in a fuel cell is used as a source of power. Fuel cells are lightweight and are well suited for producing electricity in spacecraft. Fuel cells depend on an oxidation-reduction reaction that converts chemical energy directly into electrical energy. The oxidation of hydrogen is the basis of the fuel cells used in space:



## Glossary of Terms

anthracite	hard coal that produces the greatest amount of heat and little smoke when burned.
aromatic	a compound that contains benzene rings.
asbestos	a class of fibrous long-chain silicates.
bauxite	a claylike mineral containing varying proportions of alumina, the chief source of aluminum.
biogas	a mixture of gases, about two-thirds methane and one-third carbon dioxide, that results from anaerobic digestion of organic matter; the methane content allows it to be used as a fuel.
biomass	the total mass of combustible material in an ecosystem.
biotic	living or derived from living things.
bitumen	heavy black oil, high in sulfur, that is extracted from tar sands.
bituminous coal	soft coal that produces low amounts of heat and has a high production of smoke.
bond energy	the energy needed to separate two covalently bonded atoms.
catalyst	a substance that affects the rate at which a chemical reaction occurs.

catalytic reforming	a process that increases the octane rating of gasoline by increasing its content of branched-chain and aromatic hydrocarbons.
core	the central portion of the Earth.
cracking	the process used in petroleum refining in which long-chain hydrocarbons are broken down into shorter-chain hydrocarbons.
crust	the outer-most layer of the Earth.
element	the fundamental building block of matter that cannot be broken by chemical means.
energy	the ability to do work; energy has many forms such as heat, chemical, and radiant energy.
fossil fuels	fuels formed by the breakdown over millions of years of plant and animal material.
fractional distillation	the separation of components of petroleum by boiling, followed by condensation into fractions with similar boiling points; small molecules with low-boiling points emerge first.
fuel	a substance that burns readily and releases a relatively large amount of energy on burning.
gasohol	a mixture of gasoline and 10%–20% (by volume) ethanol that produces low levels of carbon monoxide when burned.
hydrocarbon	an organic compound composed of only carbon and hydrogen atoms.
immiscible	<i>adjective</i> (often followed by <i>with</i> ) unable to be mixed.
inorganic	material consisting of compounds of elements other than those of carbon.
kerogen	a hydrocarbon material contained in oil shale that vaporizes when heated and can be recondensed into a material similar to crude oil.
liquefied natural gas (LNG)	natural gas that has been cooled and condensed into liquid form.
liquefied petroleum gas (LPG)	liquefied propane and butane gas used as heating fuel.
lithosphere	the outer shell of the Earth; composed of the crust and the solid layer above the upper mantle.
mantle	the portion of the Earth beneath the crust and surrounding the core.

metal	a malleable element with a shiny appearance that is a good conductor of electricity and heat.
mineral	a naturally occurring inorganic substance found in the Earth's crust as solid material.
non-renewable resource	a resource (such as fossil fuel) that exists as a finite deposit in the Earth's crust.
oil	a naturally occurring combustible liquid composed of hundreds of hydrocarbons; also known as petroleum.
oil shale	a rock that contains oil.
ore	a mineral, rich in a metal (such as iron) that can be mined and refined to produce the metal.
plastic	a polymeric substance that can be moulded into various shapes and forms.
polymer	a large organic molecule made up of repeating units of smaller molecules (monomers).
polymerization	a reaction in which monomers combine to form a polymer.
renewable resource	a biological resource (such as trees) that may be replaced by reproduction and regrowth.
shale oil	a brown liquid that is obtained from kerogen in oil shale and can be refined like petroleum.
silicates	minerals composed of silicon and oxygen combined with other elements.
strategic metal	metal required for defence and high-technology industries; it is stockpiled.
synthesis gas	a gas, usually methane, that is produced by treating crushed coal with superheated steam.
tar sands	sedimentary material containing bitumen.
weathering	the gradual breakdown of rock into smaller particles caused by natural factors.

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