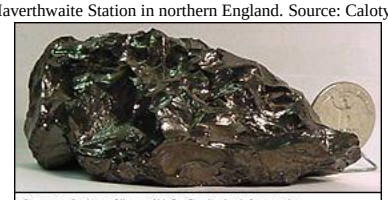
Coal

Coal Tip, Haverthwaite Station in northern England. Source: Calotype46/Flickr



Source: Andrew Silver (U.S. Geological Survey)
Anthracite coal (U.S. 25 cent coin shown for scale).

Coal is a carbon-containing rock formed by the debris from the decay of ferns, vines, trees and other plants which flourished in swamps millions of years ago. Over time, the debris became buried and the actions of bacteria, heat and pressure transformed the debris first into peat (a precursor of coal) and then into the various types of coal as we know them today. In more technical terminology, that process of transformation is referred to as*metamorphosis*, *coalification* or *lithification*.

Coal is extracted by mining from deposits that exist deep underground as well as deposits that are essentially at or near the surface of the ground. Because of the various degrees of transformation that occurred during the forming of coal deposits in different locations, the composition of coal varies from one deposit to another. No two coals are the same in every respect. In general, coal consists of carbon,hydrogen, nitrogen, sulfur and mineral matter (including compounds of silicon, aluminum, iron, calcium, magnesium and others). Combustion of coal provided warmth that enabled the human population to move into northern latitudes as Earth emerged from the most recent ice age. Coal has been used to heat homes, cook food, raise steam, and make hundreds of consumer products – from dyes to pharmaceuticals, synthetic rubber and plastics to fibers, kerosene to solvents and fuels. Mining of coal has provided jobs for people throughout the world, but has also cut short the life of miners due to prevailing safety and health practices. A worldwide abundance of coal provides many countries of the world with opportunities for economic development. Today, in North America, coal is the predominant source of energy used to generate electricity. With advances in clean coal technology, coal is expected to serve as a dominant source of energy well into the future.

Coal classification

There are many compositional differences between the coals mined from the different coal deposits worldwide. The different types of coal are most usually classified by ***rank*** which depends upon the degree of transformation from the original source (i.e., decayed plants) and is therefore a measure of a coal's age. As the process of progressive transformation took place, the heating value and the fixed carbon content of the coal increased and the amount of volatile matter in the coal decreased. The method of ranking coals used in the United States and Canada was developed by the American Society for Testing and Materials (ASTM) and is based on a number of parameters obtained by various prescribed tests:

- ***Heating value***: The energy released as heat when coal (or any other substance) undergoes complete combustion with oxygen.

- ***Volatile matter***: The portion of a coal sample which, when heated in the absence of air at prescribed conditions, is released as gases. It includes carbon dioxide, volatile organic and inorganic gases containing sulfur and nitrogen.
- ***Moisture***: The water inherently contained within the coal and existing in the coal in its natural state of deposition. It as measured as the amount of water released when a coal sample is heated at prescribed conditions. It does not include any free water on the surface of the coal. Such free water is removed by air-drying the coal sample being tested.
- ***Ash***: The inorganic residue remaining after a coal sample is completely burned and is largely composed of compounds of silica, aluminum, iron, calcium, magnesium and others. The ash may vary considerably from the mineral matter originally present in the coal (such as clay, quartz, pyrites and gypsum) before being burned.
- ***Fixed carbon***: The remaining organic matter after the volatile matter and moisture have been released. It is typically calculated by subtracting from 100 the percentages of volatile matter, moisture and ash. It is composed primarily of carbon with lesser amounts of hydrogen, nitrogen and sulfur.

The ASTM ranking system is presented in the table below:

Class or Rank	Group	Fixed Carbon [b] (wt % dry mmf)		Volatile Matter [b] (wt % dry mmf)		Gross Heating Value [c] (MJ/kg moist mmf)	
		Equal or greater than	Less than	Greater than	Equal or less than	Equal or greater than	Less than
Anthracitic	Metaanthracite [d]	98			2		
	Anthracite [d]	92	98	2	8		
	Semianthracite [d]	86	92	8	14		
Bituminous	Low-volatile bituminous [d]	78	86	14	22		
	Medium-volatile bituminous [d]	69	78	22	31		
	High-volatile A bituminous		69	31		32.55	
	High-volatile B bituminous					30.23	32.55
	High-volatile C bituminous [e]					26.74	30.23
	High-volatile C bituminous [f]					24.41	26.74
Subbituminous	Subbituminous A					24.41	26.74
	Subbituminous B					22.09	24.41
	Subbituminous C					19.30	22.09
Lignite	Lignite A					14.65	19.30
	Lignite B						14.65

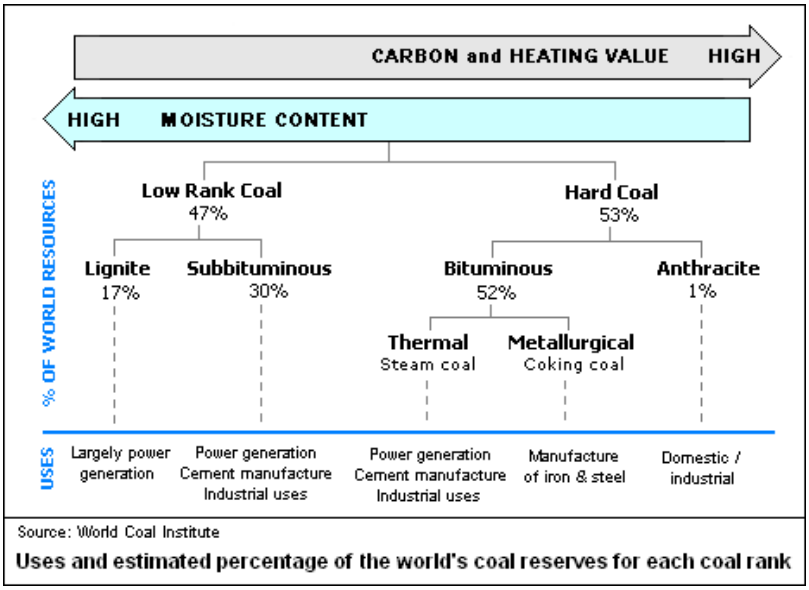
(a) This classification does not include a few coals (referred to as unbanded coals) having unusual physical and chemical properties falling within the fixed carbon and heating value ranges of the high-volatile bituminous and subbituminous ranks.
(b) Percentage by weight on a dry and mineral matter free basis (mmf).
(c) Gross Heating Value on a moist and mineral matter free basis. Moist refers to the natural inherent water contained in a coal but does not include visible water (if any) on the surface of the coal. Multiply MJ/kg by 430.11 to convert to Btu/lb.
(d) Coals containing 69 wt % or more fixed carbon on a dry mmf basis are ranked according to their fixed carbon content regardless of their Gross Heating Value.
(e) A high-volatile C bituminous coal that may be agglomerating or non-agglomerating.
(f) A high-volatile C bituminous coal that is an agglomerating coal, which means that it tends to become sticky and to *cake* when heated. The agglomerating character of a coal is determined by heating a sample to 950 °C under certain conditions. If the residue is coherent and supports a weight of 500g without pulverizing, the coal is classified as being agglomerating.

Source: Don W. Green, and Robert H. Perry, (Editors) (1997), Perry's Chemical Engineers' Handbook, 6th Edition, McGraw-Hill. Frank Kreith (Editor) (1998), The CRC Handbook of Mechanical Engineering, 1st Edition, CRC.

Classification of coals by rank [a]

The anthracitic coals, with the highest contents of fixed carbon and lowest contents of volatile material, have the highest rank. The lignite coals, with the lowest contents of fixed carbon and highest contents of volatile matter, have the lowest rank. The bituminous and subbituminous coals (in that order) are ranked between the anthracitic and lignite coal. The diagram below provides the estimated percentage of the world's coal reserves for each coal rank. It also provides the typical uses of each coal rank.

As a broad generality, the anthracitic coals have the highest heating value and the lignite coals have the lowest heating values.



There are other coal classification systems developed by the International Organization for Standardization (ISO), the United Kingdom and perhaps others.

Coal analysis

The composition of a coal is usually reported in terms of its ***proximate*** analysis and its ***ultimate analysis***:

- The proximate analysis consists of four items: fixed carbon, volatile matter, moisture and ash, all on a weight percent basis.
- The ultimate analysis provides an element-by-element composition of the coal's organic fraction, namely: carbon, hydrogen, oxygen and sulfur, all on a weight percent basis.

Both proximate and ultimate analyses may be reported on an ***as received (ar)*** basis, a ***dry (d)*** or ***moist***basis, an ***ash-free (af)*** basis, a ***mineral matter-free (mmf)*** basis and various combinations of those bases. For example, an analysis may report the basis to be: as ***received (ar)***, ***dry and ash-free (daf)***,***moist and ash-free (maf)***, ***dry and mineral matter-free (dmmf)*** or ***moist mineral-matter free (moist mmf).***

Ash and mineral matter are two distinctly different entities. Mineral matter consists of the various minerals contained in the coal. Ash is the inorganic solids remaining after the coal is completely combusted. The ash is usually less than the mineral matter because of the weight changes that take place during coal combustion such as the loss of gaseous carbon dioxide from mineral carbonates, loss of water from silica minerals and loss of sulfur (as gaseous sulfur dioxide) from iron pyrites (iron sulfide).

Some examples of proximate and ultimate analyses are given in the table below:

Coal Rank	Proximate Analysis (wt % ar)				Ultimate Analysis (wt % maf)					Net Heating Value (maf) (MJ/kg)
	Fixed carbon	Volatile matter	Moisture	Ash	C	H	O	N	S	
Anthracite	81.8	7.7	4.5	6.0	91.8	3.6	2.5	1.4	0.7	36.2
Bituminous	54.9	35.6	5.3	4.2	82.8	5.1	10.1	1.4	0.6	36.1
Subbituminous	43.6	34.7	10.5	11.2	76.4	5.6	14.9	1.7	1.4	31.8
Lignite	27.8	24.9	36.9	10.4	71.0	4.3	23.2	1.1	0.4	26.7

Notes:
- wt % = percent by weight ar = as received maf = moisture and ash free
- C = Carbon H = Hydrogen O = Oxygen N = Nitrogen S = Sulfur
- Multiply Net Heating Values in MJ/kg by 430.11 to convert to Btu/lb.

Source: Chris Higman and Maarten van der Burgt (2008). Coal Gasification, 2nd Edition. Gulf Professional Publishers.

Examples of Proximate and Ultimate Analyses

Coal reserves and production statistics

Economically recoverable coal deposits exist in more than 70 nations and in every major region of the world (Africa, Asia, Australia, Europe, North America, and South America). It has been estimated that the worldwide proven reserves of coal amounted to about 848 gigatonnes (Gt) as of 2007. Proven coal reserves are defined as those coal deposits that have been confirmed by exploration, drilling and other means, and which are economically and technically extractable.

It has also been estimated that the worldwide production (i.e., mining) of coal amounted to about 5.5 gigatonnes (Mt) as of 2007. If that rate of production remains constant, the proven reserves will last about 150 years.

The tables below list the distribution of coal reserves and coal production as of 2007:

Nation	Reserves (Gigatonnes)
United States	245
Russia	151
China	125
Australia	75
India	51
South Africa	50
Ukraine	35
Others	116
Total	**848**

Nation	Production (Megatonnes)
China	2549
United States	981
India	452
Australia	323
South Africa	244
Russia	241
Indonesia	231
Others	522
Total	**5543**

Source: World Energy Council and World Coal Institute

Proven coal reserves and coal production (worldwide, 2007)

The use of coal as a fuel

Due to its relatively high carbon content and solid, easily-handled form, coal is used for fuel, and has been for hundreds of years. As a fuel, coal is the largest source of energy for the generation of electricity worldwide. In 2005, coal fuelled 40% of the world's electricity generating power plants.

A major component of the combustion flue gases produced by burning coal as a fuel is carbon (CO_2), which is not a pollutant in the traditional sense since it is essential to support photosynthesis for all plant life on Earth. However, carbon dioxide is a ***greenhouse gas*** considered to be a contributor to ***global warming***. It is the most abundant anthropogenic (human caused) greenhouse gas in the Earth's atmosphere. As shown above, coal may contain from about 70 to more than 90 weight percent carbon, which burns almost completely to carbon dioxide. Hence, coal is the

Currently in the United States

Coal-fired power plants provided about 50 percent of the electric power generated in the United States during 2007. About 92% of the coal mined in the United States is burned to produce electricity.

The consumption of coal in the United States by sector (as a percentage of the total coal mined in 2007) was 92.7 % for electric power generation, 2.0 % for production of coke, 5.0 % for use in other industries and 0.3 % for residential and commercial heating.

Currently in China

Coal produces over 80% of China's energy; 2.3 billion metric tons of coal were mined in 2007. Despite the health risks posed by severe air pollution in cities and international pressure to reduce greenhouse emissions, China's coal consumption is projected to increase in line with its rapid economic growth. Most of the coal is mined in the western provinces and the northwestern region of Inner Mongolia. However most coal customers are located in the industrialized southeastern and central coastal provinces, so coal must be hauled long distances on China's vast but overextended rail network. More than 40% of rail capacity is devoted to moving coal, and the country has been investing heavily in new lines and cargo-handling facilities in an attempt to keep up with demand. Despite these efforts, China has suffered persistent power shortages in industrial centers for more than five years as electricity output failed to meet demand from a booming economy. Demand for electricity increased 14% in 2007.

Other uses of coal

Coal can be converted to coke by the process of destructive distillation which removes the volatile matter and alters the physical properties to provide a more uniform and more combustible product with a higher carbon content. The process is often referred to as the *coking* or *carbonization* of coal. One of the major uses of coke is in the making of steel where coke is utilized in blast furnaces to reduce iron ore to molten pig iron, a form of iron with a high carbon content. Removal of most of the carbon from the pig iron yields steel that is used for construction of bridges, high-rise buildings, manufacturing of automobiles and major household appliances (refrigerators, cooking stoves and washing machines), and a host of other products. Coke is also used in the production of phosphorus and of calcium carbide.

Coal can be converted, by a process known as *coal gasification*, into a gas with the same heat of combustion as many natural gases and referred to as *synthetic natural gas* (SNG). Coal gasification can also be used to produce a mixture of carbon monoxide and hydrogen gases referred to as *synthesis gas* (or *syngas*) which has a heating value that is much less than that of natural gas. Syngas can be burned as a fuel or it can be converted into automotive fuels like gasoline and diesel oil through the Fischer-Tropsch process.

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- **Note:** Many petroleum refineries produce a coke product, called *petroleum coke*, by a process known as*delayed coking*.

Source:
http://www.eoearth.org/view/article/51cbed487896bb431f6910ce/?topic=51cbfc98f702fc2ba812eaa6