PART I

ORIGIN AND PROPERTIES

1

History, Occurrence, and Resources

1.1 Introduction

An ever-expanding human population is matched by an ever-increasing demand for energy to the extent that the world is presently faced with the situation of energy demand exceeding the energy in circulation and the energy production even from a variety of sources (Speight, 2011a, 2020). The production and consumption of energy have been associated with adverse environmental impacts such that the United Nations conference in Kyoto, Japan, in 1997 had to have what is known as the Kyoto Protocol that sets limits on carbon dioxide emissions into the atmosphere (Hordeski, 2008; Irfan *et al.*, 2010).

Coal (the term is used generically throughout the book to include all types of coal), geographically spread across all inhabitable continents of the world, is a black or brownish-black organic sedimentary rock of biochemical origin which is combustible and occurs in rock strata (coal beds, coal seams) and is composed primarily of carbon with variable proportions of hydrogen, nitrogen, oxygen, and sulfur. Coal is the most plentiful fuel in the fossil family and, in the current context, the United States has more coal reserves than any other country in the world. In fact, one-fourth of all known coal in the world is in the United States, with large deposits located in 38 states, which represents almost as much energy in coal that can be mined as the rest of the world has in oil that can be pumped from the ground. Also, in the context of this book, the more efficient use of coal is the focus since electricity from coal represents more than 50% of current electricity generation in the United States.

Coal has been a vital energy source to human populations for millennia. For example, in approximately 1000 BC, the Chinese relied on coal to smelt copper that served as the basis for their currency, and the Greek philosopher Aristotle made reference to it in his writings when he alluded to a dark charcoal-like rock (World Coal Institute, 2008). Furthermore, the discovery of coal cinders among Roman ruins in England suggests that the Romans relied on coal as a source of energy prior to AD 400.

The first written record of coal in the Americas was taken in 1673 by Louis Joliet who noted *carbon de terra* while mapping out the Illinois River region. In more recent times, the Nanticoke Indians, a Native American tribe who lived in Pennsylvania, were using local anthracite coal as a source for energy and jewelry during the 1760s (Dublin and Licht, 2005). This energy resource that provided fuel for ancient civilizations is all but history. In the modern world, steam coal, metallurgical coal, and industrial coal all play a vital role in the economy of many countries, especially the United States.

Coal continues to power vital industries. The iron industry still relies on basic oxygen furnaces that require a special type of coal known as metallurgical or coking coal to produce steel. Coke from coking coal is combined with limestone in a furnace where iron ore is blasted with

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pure oxygen and converted to steel. However, more pertinent to the present text, the electricity that powers electric arc furnaces is usually generated by burning pulverized thermal coal.

Coal was the key energy source for the Industrial Revolution, which has provided amenities that most people in the modern world take for granted – including electricity, new materials (steel, plastics, cement, and fertilizers), fast transportation, and advanced communications. Coal replaced wood combustion because of (i) abundance of coal, (ii) higher volumetric energy density of coal, and (iii) the relative ease of transportation of coal (Ashton, 1969; Freese, 2003).

The Industrial Revolution itself refers to a change from hand and home production to machine and factory. The first Industrial Revolution was important for the inventions of spinning and weaving machines operated by water power which was eventually replaced by steam. This helped increase growth and changed late 18th century society and economy into an urban-industrial state. New fuels such as coal and crude oil were incorporated into new steam engines, which revolutionized many industries including textiles and manufacturing.

The demand for coal decreased for transportation and heating purposes due to intensified competition from crude oil, and activity increased in the post-World War II industrial sector as well as the electricity generation sector after the 1960s. As the demand for power increased, the demand for coal has continued to rise over the years.

The 1973 oil embargo renewed interest in the vast domestic coal reserves of the United States. This sharp rise in coal production helped solve the growing problem of scarce oil resources that were in high demand.

The demand for coal was also impacted by the Power Plant and Industrial Fuel Use Act (FUA) of 1978, which required most oil or natural gas burning power plants to switch to coal. As a result, the energy of the United States became significantly more dependent on coal. After repeal of FUA in 1987, natural gas use in electric power plants increased by 119% between 1988 and 2002. Indeed, the spike in natural gas consumption goes to show the influence the FUA had on increasing US reliance on coal as a source of energy.

As developing countries such as China and India require more energy to meet their rapidly growing demand, competition for coal will continue to increase. The United States has 96% of the coal reserves in North America, which accounts for approximately 26% of the total known coal reserves. As a result, the United States will be expected to export more coal to meet the strong demand from the world market. In doing so, the price of coal will remain stable, and developing countries will be able to meet their energy needs.

Coal is currently responsible for generating approximately 50% of the world electricity. In fact, the demand for coal in the United States is primarily driven by the power sector, which consumes 90% of all domestic coal production. In 1950 however, only 19% of coal was used by the power sector due to its high demand by other sectors such as industry, residential and commercial, metallurgical coke ovens, transportation, and electric power, which all accounted for an amount on the order of 5 to 25% of the total coal consumption at the time. Of the coal produced worldwide, approximately 65% is shipped to electricity producers and 33% to industrial consumers, with most of the remainder going to consumers in the residential and commercial sectors. The total share of total world energy consumption by coal is expected to increase to one-third (approximately 30 to 33%) in 2035, although growth rates of coal consumption are not expected to be even in all countries where coal is used as an energy source (International Energy Agency, 2010; Energy Information Administration. 2011, 2012a, 2012b).

Coal-fired power plants, also known as electricity generations plants and power stations, provide approximately 42% of US electricity supply and more than 42% of global electricity supply. In fact, the electricity generation sector is essential to meeting current and future energy needs (MIT, 2007; EIA, 2012a, 2012b; Speight; 2013, 2020).

Furthermore, global demand for electricity will continue to rise steeply until at least 2040, as the fuels used for electricity generation continue to shift to lower-carbon sources, such as natural gas, nuclear and renewables. Even now, the demand for electricity continues to rise in all parts of the world. Population and economic growth are two main reasons, just as they are for the projected demand growth in other fuels. There is a switch to electricity from other forms of energy, such as oil or biomass for lighting and heating in the home, or coal in the industrial sector. The key to this growing demand is to make electricity generation more efficient than is currently observed.

As a result of current trends in the electric power market, many coal-fired generators in the United States are slated for retirement (Energy Information Administration, 2010, 2011, 2012a, 2012b). Most of the coal-fired power plants projected to retire are older, inefficient units primarily concentrated in the Mid-Atlantic, Ohio River Valley, and southeastern United States where excess electricity generating capacity currently exists. Lower natural gas prices, higher coal prices, slower economic growth, and the implementation of environmental rules all play a role in the retirements. Coal-fired generators in these regions, especially older, less efficient ones that lack pollution control equipment, are sensitive to changing trends in fuel prices and electricity demand, which are two key factors that influence retirement decisions.

The coal-fired power plants vulnerable to retirement are older power plants generators with high heat rates (lower efficiency) that do not have flue gas desulfurization (FGD) systems installed. Approximately 43% of all coal-fired plants did not have flue gas desulfurization systems installed as of 2010 and such plants will be required to install either a FGD or a dry sorbent injection system to continue operating in compliance with the mercury and air toxics standards (MATS).

Coal capacity retirements are sensitive to natural gas prices. Lower natural gas prices make coal-fired generation less competitive with natural gas-fired generation. Because natural gas is often the marginal fuel for power generation, lower natural gas prices also tend to reduce the overall wholesale electricity price, further reducing revenues for coal-fired generators.

Installation of environmental control systems will add internal energy requirements, reducing the efficiency of the plant. There are some changes that can be employed to make an existing unit more efficient. However, these changes typically will only result in an improvement to efficiency of a percentage point or so. In order to produce higher efficiency ratings, higher pressure and temperatures are required. This increases the cost of the plant as special alloy materials will be needed. Technology improvements can assist by lowering the cost of these special materials through discovery and better manufacturing process.

Electricity generation in a coal-fired power station requires combustion of the coal, after which the energy released during the combustion is used to generate steam which is then used to drive the turbine generators that produce electricity. The power station can be conveniently divided in four separate but, in reality, integrated operations: (i) the combustor or firebox, (ii), the boiler, (iii) the turbine generator, and (iv) the condenser.

Before the coal is burned in the *combustor*, it is pulverized (often to an extremely small size that has been stated to have the appearance of a black talcum powder) after which the coal is mixed with hot air and blown into the combustor. The coal is burned in suspension and provides the most complete combustion and maximum heat possible.

In the *boiler*, purified water is pumped through pipes inside the boiler which converts the water to steam. At temperatures up to 540°C (1000°F) and under pressures up to 3500 psi, the steam is piped to the *turbine* where it contacts a series of turbine blades and turns the turbine shaft. The turbine shaft is connected to the shaft of the generator, where magnets spin within wire coils to produce electricity. The steam is then drawn into a condenser which condenses the steam back into water so that it can be used over and over again in the plant. Millions of gallons of cooling water are pumped through a network of tubes that runs through the condenser and after the steam is condensed, it is pumped to the boiler again to repeat the cycle.

Coal quality is the term used to refer to the properties and characteristics of coal that influence its behavior and use. Coal quality has an impact on many parts of a power plant including the coal handling facilities, pulverizing mills, boiler, air heater, electrostatic precipitator, ash disposal as well as stack emissions. Because coals have different characteristics and heat content, the behavior of a coal in a boiler is strongly influenced by the rank of the coal as well as and by the content (and type) of the mineral matter and other impurities associated with it. Coal properties can affect the efficiency, reliability, and availability of both the boiler and the emissions control units, and therefore, the properties affect the economics as well as the short- and long-term operation of the plant.

Among the coal-quality characteristics that are important for coal-fired power plants are the concentrations, distribution, and forms of the many elements contained in the coal feedstock. Knowledge of these quality characteristics in coal deposits may allow us to use this essential energy resource more efficiently and effectively and with less undesirable environmental impact.

In fact, the performance of power plants and the costs of power generation are influenced by many coal properties. Specifically, coal quality impacts not only coal cost but also net power output as well as capital and operating and maintenance costs and waste disposal costs. In fact, coal quality impacts the coal chain in a power plant and their relationship to power generation costs.

Thus, an essential part of power plant development is the rigorous analysis of information which should be internally consistent and verifiable, such as coal quality, coal consumption and electricity output. It is, therefore, necessary to understand operating information for units at coal-fired power plants not only for the purposes of determining, monitoring, reporting, comparing, and projecting coal-fired power plant efficiencies but also for monitoring carbon dioxide emissions (as well as the emission of other noxious gases and particulate matter).

Thus, to develop combustion technology for efficient production of electricity, the influences of the coal properties, such as the (i) the elemental composition of the coal, (ii) rank of the coal, the mineral matter content of the coal, (iii) the size of the pulverized coal particles, and (iv) the tendency of the combustion system to produce fly ash and bottom slag are all of considerable importance and need to be addressed in assessing the potential performance of a coal-fired electricity generating plant.

Briefly, the degree of alteration (or metamorphism) that occurs as a coal matures from peat to anthracite is referred to as the *rank* of the coal (Table 1.1). Low-coal includes lignite

Table 1.1 Coal ranks*.

Rank	Description
Lignite	The largest portion of the coal reserves of the world. A soft, brownish-black coal which is the lowest level of the coal family. The texture of the original wood can even be seen in some pieces primarily found west of the Mississippi River.
Subbituminous coal	A dull black coal which, when burned, releases more energy (heat) than lignite when burned; mined mostly in Montana, Wyoming, and a few other western states.
Bituminous coal	Sometimes called *soft coal*; found primarily east of the Mississippi River in midwestern states such as Ohio and Illinois and in the Appalachian mountain range from Kentucky to Pennsylvania.
Anthracite	The hardest coal and gives off the greatest amount of heat when burned; the reserves of anthracite in the United States are located primarily in Pennsylvania.

*As mined in the United States.

and sub-bituminous coal which have a lower energy content (because of the low carbon content) and relatively high moisture content. High-rank coals, including bituminous and anthracite coals, contain more carbon than lower-rank coals which results in a much higher energy content. The high-rank coals also have a more vitreous (shiny) appearance and lower moisture content then lower-rank coals.

However, before turning to a fuller description of coal properties and power generation (Chapters 5, 6, 11), it is necessary to understand the occurrence of coal and whether or not present estimates are sufficient to produce the electric power necessary for the next several decades.

Production of steel accounts for the second-largest use of coal. Minor uses include cement manufacture, the pulp and paper industry, and production of a wide range of other products (such as coal tar and coal chemicals). The steel industry uses coal by first heating it and converting it into coke, a hard substance consisting of nearly pure carbon (Speight, 2013). The coke is combined with iron ore and limestone, and then the mixture is heated to produce iron. Other industries use different coal gases emitted during the coke-forming process to make fertilizers, solvents, pharmaceuticals, pesticides, and other products.

Finally, in order to generate electric power using the maximum energy in coal, all aspects of a coal need to be understood, including (i) handling and storage characteristics, (ii) pulverizing behavior, (iii) combustion behavior, (iv) mineral matter and ash chemistry interactions in addition to the characteristics of the coal and its ash in terms of environmental factors such as dust, self-heating and emissions components. In order to ensure that quality is controlled, the coal chain must be regularly sampled and adjusted in accordance with the analytical results (Chapters 5, 6). Key control parameters, which when monitored, can provide a reliable indication of quality in terms of both specification and consistency requirements.

Finally, the International Energy Agency (IEA) predicts that world energy demand will grow around 60% over the next 30 years, most of it in developing countries. China and India are large countries in terms of both population and land mass, and both have substantial quantities of coal reserves – cumulatively, China and India account for 70% of the projected increase in world coal consumption. Strong economic growth is projected for both countries (averaging 6% per year in China and 5.4% per year in India from 2003 to 2030), and much of the increase in their demand for energy, particularly in the industrial and electricity sectors, is expected to be met by coal.

Even as demand grows, society expects cleaner energy with less pollution and an increasing emphasis on environmental sustainability. The coal industry recognizes it must meet the challenge of environmental sustainability. In particular the industry must reduce the greenhouse gas emissions if the industry is to remain a part of a sustainable energy future. The quality of coal needs to be assessed so that it can be suitably used in different industries. The mineral matter content and its type will give an idea related to the coal preparation practice that will be required to be adopted for coal cleaning and subsequent use.

Investigation of physical properties such as Hardgrove grindability index will help in deciding the type and capacity of crushing and grinding machine required in coal beneficiation plants. Spontaneous heating susceptibility studies of coal will help in deciding the coal in a judicious manner such that the coal is utilized before it catches fire. Keeping this in view the current text, it will become obvious that determination of coal quality and coal behavior are necessary to ensure that coal is utilized in the most optimum and environmentally acceptable manner.

1.2 Origin of Coal

Discussions of the origin of coal are typically restricted to geochemical texts or to more theoretical treatises that focus on coal chemistry. However, combustion of coal (as performed in a coal-fired power station) involves knowledge of combustion chemistry and the behavior of different coals in coal-fired power stations. Thus, it is the purpose of this section to focus on the origin of coal as it influences coal chemistry, particularly the combustion chemistry and behavior (Chapter 7).

Coal is a combustible sedimentary organic rock that is formed from decayed plant remains, and other organic detritus. Although coal forms less than 1% of the sedimentary rock record, it is of foremost importance to the energy requirements of many countries and the origin of coal as it influences behavior has received much attention (Speight, 2013, 2020). However, coal is also a compact stratified mass of plant debris which has been modified chemically and physically by natural agencies, interspersed with smaller amounts of inorganic matter. The natural agencies causing the observed chemical and physical changes include the action of bacteria and fungi, oxidation, reduction, hydrolysis, and condensation – the effect of heat and pressure in the presence of water.

Coal has also been considered to be a *metamorphic rock*, which is the result of heat and pressure on organic sediments such as peat. However, the discussion is in favor of coal as a sedimentary rock because most sedimentary rocks undergo some heat and pressure and the association of coal with typical sedimentary rocks and the mode of formation of coal usually keep low-grade coal in the sedimentary classification system. Anthracite, on the other hand, undergoes more heat and pressure and is associated with low-grade *metamorphic rocks* such as slate and quartzite. Subducted coal may become graphite in igneous rocks or even the carbonate rich rocks such as carbonatites, which are intrusive or extrusive igneous rocks characterized by mineralogical composition and consisting of greater than 50% w/w carbonate minerals).

Coal is a sedimentary black or dark-brown rock that varies in composition. Some types of coal burn hotter and cleaner, while others contain high moisture content and compounds that, when burned, contribute to acid rain and other pollution. Coals of varying composition are used around the world as a combustible fossil fuel for generating electricity and producing steel. Because peat is not a rock and the unconsolidated plant matter is lacking the metamorphic changes found in coal, it is not typically classified as coal. Thus, coal is classified into four main types, depending on the amount of carbon, oxygen, and hydrogen present (i) lignite, (ii) sub-bituminous coal, (iii) bituminous coal, and (iv) anthracite.

The degree of alteration (or metamorphism) that occurs as a coal matures from lignite to anthracite is referred to as the rank of the coal, which is the classification of a particular coal relative to other coals, according to the degree of metamorphism, or progressive alteration, in the natural series from lignite to anthracite (ASTM D388). However, because of the chemical process involved in the maturation of coal, it is possible to broadly classify into three major types namely (lignite, bituminous coal, and anthracite). However, because of other differences, and the lack of other differences (with overlap between borderline coals) there is no clear demarcation between the different coals and other classifications such as semi-anthracite, semi-bituminous, and subbituminous are also used.

There are two predominant theories that have been proposed to explain the formation of coal: (i) the plant remains which eventually form coal were accumulated in large freshwater swamps or peat bogs during many thousands of years, which supposes that growth-in-place of vegetable material – the *autochthonous theory*, also often referred to as the *swamp theory*, and (ii) the coal strata accumulated from plants which had been rapidly transported and deposited under flood conditions – the *allochthonous theory*, also often referred to as the *drift theory*.

It is believed that major autochthonous (*in situ*) coal fields generally appear to have been formed either in brackish or fresh water, from massive plant life growing in swamps, or in swampland interspersed with shallow lakes. The development of substantial *in situ* coal measures thus requires extensive accumulations of vegetable matter that is subjected to widespread submersion by sedimentary deposits.

However, the types of fossil plants found in coal do not clearly support the autochthonous theory – for example, the fossil lycopod trees (such as *Lepidodendron* and *Sigillaria*) and giant ferns (especially *Psaronius*) that are common in Pennsylvanian coals may have had some ecological tolerance to swampy conditions, yet other Pennsylvanian coal plants (e.g., the conifer *Cordaites*, the giant scouring rush *Calamites*, the various extinct seed ferns) by their basic construction may have preferred existence in well-drained soils and not in the proverbial *peat swamp*. The anatomy of coal-forming plants is considered by many coal geochemists to indicate that initiation of the coalification lay down occurred in a tropical or subtropical climate, a conclusion which can be used to argue against autochthonous theory, for modern swamps are most extensive and have the deepest accumulation of peat in the higher-latitude cooler climates.

By way of explanation, coalification or metamorphosis of coal is defined as gradual changes in the physical and chemical properties of coal in response to temperature and time. The coal changes from peat through lignite and bituminous coal to anthracite. With extreme metamorphism and the changes, with increasing rank, include an increase in carbon content, and decreases in moisture content and volatile matter (Table 1.2). However, the data presented in the table (Table 1.2) are for illustrative purposes only and should not be construed to be precise since other effects (such as the mix of the coal precursors) will also play a role in the coalification process and the process is site specific (Speight, 2013).

In more general terms, the coalification of coal is a consequence of thermal effects and pressure through compaction of the sediment, which depending upon the initial events – including the composition of the coal purposes, will be site specific. However, the coalification processes involved in coal formation are marked by a well-*defined progression* of *increasing* rank that does increase with depth, and the combination of depth of burial and geothermal gradient essentially determine the rank of coal. Water, carbon dioxide and methane are generated during the progressive coalification.

Methane is the predominant gas generated in the bituminous coal and anthracite stages of coalification, and the carbon dioxide produced at lower ranks is typically flushed out of the coal by methane. The sorption capacity of coal increases with rank. Typically, high-rank coal can absorb more gas and the adsorptive capacity of coal for methane increases with coal rank. The sorption capacity of coal can be influenced by different intrusions and by the tectonic events such as folding and faulting. Coals near igneous intrusions, such as dykes, may contain calcites and pyrites which are likely to influence the ability of gases to drain.

To follow on from above, it was the difference in coal properties of Gondwana (Indian) coals that led to the formation of the *drift theory*. The mode of deposition of coal forming can be explained as follows: (i) coal is formed largely from terrestrial plant material growing on dry land and not in swamps or bogs, (ii) the original plant debris was transported by water and deposited under water in lakes or in the sea, (iii) the transported plant debris, by its relative low density even when water logged, was sorted from inorganic sediment and drifted to a greater distance in open water – the sediments, inorganic and organic, settled

Table 1.2 Illustration of the effects that can contribute to the coalification process.*

Coal rank	DoB	MT	C	VM	CV	M
Lignite	650-4,900	25-45	60	49-53	23,000	30-50
Subbituminous	4,900-8,200	45-75	71-77	42-49	29,300	10-30
Bituminous	8,200-19,500	75-180	77-87	29-42	36,250	5-10
Anthracite	>19,500	>180	87-92	8-29	>38,000	<5

Key:
DoB: approximate depth of burial, feet.
MT: approximate maximum temperature during burial, °C.
C: approximate carbon content, % w/w dry ash-free basis.
VM: approximate volatile matter, % w/w dry, ash-free basis.
CV: approximate calorific value (heat content), ash-free basis.
M: approximate moisture content, % w/w (*in situ*).
*The data are for illustrative purposes only; the actual conditions may vary somewhat from the data presented here.

down in regular succession, (iv) the process of sedimentation of the organic and inorganic materials continues until the currents can deposit the transported vegetation in the locations, (v) these deposits are covered subsequently by mineral matter, sand, and results in coal seams, (vi) the depositions can also stop for a particular period and again begin to occur when tidal and current conditions are correct, and (vii) even within coal rank, coal properties vary widely due to the varied types of vegetation deposited.

It is also factual that marine fossils such as fish, mollusks, and brachiopods occur in coal. *Coal balls*, which are rounded masses of matted and exceptionally well-preserved plant and animal fossils (including marine creatures) are found within coal strata and associated with coal strata (Mamay and Yochelson, 1962). Since there is little anatomical evidence suggesting that coal plants were adapted to marine swamps, the occurrence of marine animals with non-marine plants suggests mixing during transport, thus favoring the allochthonous model (Rupke, 1969; Cohen, 1970).

Many factors determine the composition of coal: (i) the mode of accumulation and burial of the plant debris forming the deposits, (ii) the age of the deposits and the geographical distribution, (iii) the structure of the coal-forming plants, particularly details of structure that affect chemical composition or resistance to decay, (iv) the chemical composition of the coal-forming debris and its resistance to decay, (v) the nature and intensity of the peat-decaying agencies, and (vi) the subsequent geological history of the residual products of decay of the plant debris forming the deposits. In short, coal composition is subject to site-specific effects and is difficult to generalize on a global basis (Speight, 2013).

In summary, there are advantages and disadvantages of both theories. While the coal purist may favor one or the other, there are the pragmatists who will recognize the merits of both theories. Whichever theory is correct (if that is possible) and whatever the origin of coal, there are expected to be differences in properties and behavior.

Finally, *Hilt's law* is a geological term that states the deeper the coal seam, the deeper the rank (grade) of the coal – i.e., anthracite would be expected to lie in deeper buried seams than lignite (Figure 1.1) (Elphick and Suggate, 1964; Suggate, 1974; Ward, 2008). The law holds true if the thermal gradient is entirely vertical, but metamorphism may cause lateral changes of rank, irrespective of depth. Furthermore, increasing depth of burial results in a decrease in the oxygen content of the coal.

Chemically, coal is a hydrogen-deficient hydrocarbon with an atomic hydrogen-to-carbon ratio near 0.8, as compared to crude oil hydrocarbon derivatives, which have an atomic hydrogen-to-carbon ratio approximately equal to 2, and methane (CH_4) that has an atomic carbon-to-hydrogen ratio equal to 4. For this reason, any process used to convert coal to alternative fuels must add hydrogen or redistribute the hydrogen in the original coal to generate hydrogen-rich products and coke (Speight, 2013).

The chemical composition of the coal is defined in terms of its proximate and ultimate (elemental) analyses (Chapter 5) (Speight, 2013, 2020). The parameters of proximate analysis are moisture, volatile matter, ash, and fixed carbon while the ultimate analysis (also referred to as the elemental analysis) encompasses the quantitative determination of carbon, hydrogen, nitrogen, sulfur, and oxygen within the coal. Additionally, specific physical and mechanical properties of coal and particular carbonization properties are also determined.

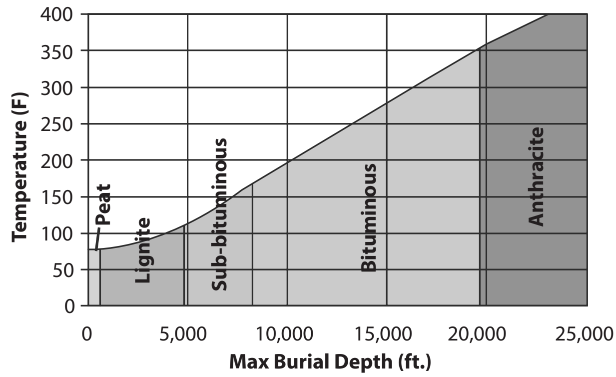

Figure 1.1 Schematic showing tendency of coal rank to increase with depth of burial*.
*Numbers are approximate and used for illustration only; peat is included only for comparison and it should not be construed for this diagram that peat is a type of coal.

1.3 Occurrence

The current estimates for the longevity of each fossil fuel are estimated from the reserves/production ratio (BP, 2019) which gives an indication (in years) of how long each fossil fuel will last at the current rates of production. The estimates vary from at least 50 years of crude oil at current rates of consumption with natural gas varying upwards of 100 years. On the other hand, coal remains in adequate supply and at current rates of recovery and consumption, the world global coal reserves have been variously estimated to have a reserves/production ratio of at least 155 years. However, as with all estimates of resource longevity, coal longevity is subject to the assumed rate of consumption remaining at the current rate of consumption and, moreover, to technological developments that dictate the rate at which the coal can be mined. But most importantly, coal is a fossil fuel and an *unclean* energy source that will only add to global warming. In fact, the next time electricity is advertised as a clean energy source just consider the means by which the majority of electricity is produced – almost 50% of the electricity generated in the United States derives from coal (Energy Information Administration, 2007; Speight, 2013).

Coal is the most abundant and widely distributed fossil fuel in the world and possibly the least understood in terms of its importance to the world economy. Currently, approximately five billion tons are mined in more than 40 countries. Coal provinces (clustering of deposits in one area) occur in regional sedimentary structures referred to as *coal basins*. More than 2,000 sedimentary, coal-bearing basins have been identified worldwide but less than a dozen contain reserves of more than 200 billion tons.

Although the majority of mined coal continues to be consumed within the country of production, the value of traded coal is increasing. The United States and Australia account for approximately 50% of world coal exports. This figure increases to 70% if exports from South Africa and Indonesia are included. Japan is the largest recipient of exported coal – approximately 25% of the world coal trade – and as such, agreements with coal suppliers and Japan can have a great influence the world coal price. Japan, Taiwan, and South Korea together import approximately 45% of all coal exports and countries of the European Union account for another 30% of total coal exports.

Coal is burned to produce energy – in the United States, coal still accounts for over 50% of the domestic electricity generating industry requirements, all from domestic production. The European Union, on the other hand, must import approximately 50% of its energy requirements (in the form of oil, gas, uranium, and coal).

Production of coal is both by underground and open pit mining (Speight, 2013). Surface, large-scale coal operations are a relatively recent development, commencing as late as the 1970s. Underground mining of coal seams presents many of the same problems as mining of other bedded mineral deposits, together with some problems unique to coal. Current general mining practices include coal seams that are contained in beds thicker than 27 inches and at depths less than 1,000 feet. Approximately 90% of all known coal seams fall outside of these dimensions and are, therefore, not presently economical to mine. Present coal mine technology in the United States, for instance, has only 220 billion tons (220×10^9 tons) of measured proven recoverable reserves out of an estimated total resource of three to six trillion tons (3 to 6×10^{12} tons) tons.

Problems specific to coal mining include the fact that coal seams typically to occur within sedimentary structures of relatively moderate to low strengths. The control of these host rocks surrounding the coal seams makes excavation in underground mining a much more formidable task than that in hard, igneous rocks in many metal mines. Another problem is that coal beds can be relatively flat-lying, resulting in workings that extend a long distance from the shaft or adit portal (an almost horizontal entrance to mine). Haulage of large tonnages of coal over considerable distance, sometimes miles, is expensive.

Coal, being largely composed of carbonaceous material can also catch fire, in some cases spontaneously (Speight, 2013). Coal, for the miner, has not been an attractive occupation. Interestingly though, the problem of methane, may in the future become a profitable by-product from closed coals mines. Many countries are reported to millions of cubic feet of coal bed methane trapped in abandoned coal mines.

As coal contains both organic and inorganic components, run-of-mine coal contains both these components in varying amounts. In many instances coal beneficiation is required to reduce the inorganic matter (ash) so that a consistent product can be more easily marketed. Most coal beneficiation consists of crushing in order to separate out some of the higher ash content, or washing that exploits the difference in density between maceral and inorganic matter.

Coal is far from being a worn-out faded commodity and offers much promise for future energy supply (Kavalov and Peteves, 2007; Malvić, 2011; Speight, 2011b, 2013, 2020). Much research has gone into improving the efficiency of coal use, especially the implementation of coal-fired plants based on clean coal technology (pressurized fluidized-bed combustion).

However, there is considerable uncertainty related to the actual amount of proved coal reserves in many coal-producing countries because there are often conflicting views among the experts related to the level of availability of coal. Although reserves are often defined for each coal field based on techno-economic-geological analysis, tentative estimates of extractable resources (i.e., reserves) can be presented by making various assumptions related to extractability and confidence levels for established coal inventory using a recognized organization with little error in the means of estimation. For example, it is only relatively recently that the crude oil reserves of several OPEC countries were adjusted upwards for reasons unknown – the truth of these adjusted data are subject to question (Speight, 2011b). Thus, any estimates (tentative or otherwise) of extractable coal resources need to be strengthened through sound and unquestionable better analysis rather than leaving the estimates subject to mathematical maneuvering.

Better energy planning and policies for any country require a good understanding of domestic coal reserves, and therefore it is important to reduce existing uncertainties related to coal by making better reserve assessments. It is likely that much of the uncertainty could be reduced when the current coal resource inventory is reclassified according to recognized and acceptable categories. Furthermore, uncertainty related to domestic coal resources will impact the long-term energy supply trajectory of any country, which in turn has significant implications for coal longevity.

1.4 Coal Utilization and Coal Types

Coal is a combustible organic sedimentary rock that is formed from the accumulation and preservation of plant materials, usually in a swamp environment (Speight, 2013). Along with crude oil and natural gas, coal is one of the three most important fossil fuels, such as for the generation of electricity and provides approximately 40% of electricity production on a worldwide basis.

For the past two centuries, coal played this important role – providing coal gas for lighting and heating and then electricity generation with the accompanying importance of coal as an essential fuel for steel and cement production, as well as a variety of other industrial activities. In fact, subject to environmental concerns, coal remains an important source of energy in many countries, but this does not give the true picture of the use of coal for electricity production. During that time, the coal industry has been pressured into serious considerations related to the environmental aspects of coal use and has responded with a variety of on-stream coal-cleaning and gas-cleaning technologies (Speight 2013, 2020).

In fact, coal has a long-term history of use (Table 1.3) (Freese, 2003). For example, outcrop coal was used in Britain during the Bronze Age (3000 to 2000 BC), where it has been detected as forming part of the composition of funeral pyres. The earliest recognized use (approximately 4000 BC) is from the Shenyang area where Neolithic inhabitants had begun carving ornaments from black lignite, but it was not until the Han Dynasty (202 BC to AD 220) that coal was also used for fuel.

Using Britain we find examples of the longevity of coal use. In Roman Britain the Romans exploited coal from all the major coalfields in England and Wales by the end of the 2nd century AD. Evidence of trade in coal (dated to approximately AD 200) has been found at the inland port of Heronbridge, near Chester, and in the Fenlands of East Anglia, where coal from the Midlands was transported for use in drying grain. Coal cinders have been found in the hearths of villas and military forts, particularly in Northumberland, dated to approximately AD 400. In the west of England contemporary writers described the wonder of a permanent brazier

Table 1.3 History of coal use.

Time frame	Use
Stone Age	Coal may have been used for heating and cooking.
AD 100-200	The Romans use coal for heating.
1300s	In the American southwest, Hopi Indians use coal for heating.
1673	Explorers to America discover coal.
1700s	The English find coal produces a fuel that burns cleaner and hotter than wood charcoal.
1740s	Commercial coal mines begin operation in Virginia.
1800s	James Watt invents the steam engine and uses coal to produce the steam to run the engine. The Industrial Revolution spreads to the United States as steamships and steam-powered railroads become the main forms of transportation, using coal to fuel their broilers. During the Civil War, weapons factories begin using coal. By 1875, coke replaces charcoal as the primary fuel for iron blast furnaces to make steel. 1880s: Coal is first used to generate electricity for homes and factories.
1900s	Coal accounts for more than three-quarters of the total energy used in the United States, but is later supplanted by oil and natural gas for transportation and residential applications. Coal reemerges later as an affordable, abundant domestic energy resource to support the growing demand for electricity. In the late 1900s, environmental issues force a reduction in the amount of coal used for power generation. Clean Coal technologies were developed in the United States to allow coal to be used in an environmentally friendly manner.

of coal on the altar of Minerva at Aquae Sulis (Waters of Sulis; modern-day Bath) although in fact easily accessible surface coal from what became the Somerset coalfield (southwest England) was in common use in quite lowly dwellings locally. There is also evidence of the use of coal for iron-working in the city during the Roman period.

The Somerset coalfield included pits in the north Somerset, England, area where coal was mined from the 15th century until 1973. It is part of a wider field which covered northern Somerset and southern Gloucestershire in England. There is documentary evidence of coal being dug from this coalfield in the 14th century and continuing until the 16th century. During the early part of the 17th century coal was largely obtained by excavating the outcrops or driving an incline, which involved following the seam into the ground. Only a small amount of coal could be obtained by these methods and so bell pits took their place – a bell pit is so-named because in cross section the pit resembles an upturned bell. The bell pit is a primitive method of mining coal where the coal lies near the surface on flat land.

A shaft is sunk to reach the coal which is then excavated and removed by means of a bucket (much like a well). No supports are used and mining continues outward until the mine becomes too dangerous (or collapses) at which point another mine is started.

Mineral coal came to be referred to as *sea coal* (seacoal), probably because it came to many places in eastern England, including the northeast coast 50 to 100 miles south of the Scottish border. This is accepted as the more likely explanation for the name of the coal, having fallen from the exposed coal seams above or washed out of underwater coal seam outcrops. These easily accessible sources had largely become exhausted (or could not meet the growing demand) by the 13th century when underground mining from shafts or adits was developed. An alternative name was *pit coal* (pit coal), because it came from mines. It was, however, the development of the Industrial Revolution (18th century to 19th century) that led to the large-scale use of coal, as the steam engine took over from the water wheel. Looked at from another angle, the Industrial Revolution was impossible without coal.

Currently, in the United States, coal is used primarily to generate electricity. The coal is burned in power plants to produce almost 40% of the electricity that is used each year. Coal is also used in the industrial and manufacturing industries. For example, the steel industry uses large amounts of coal – the coal is baked in hot furnaces to make coke, which is used to smelt iron ore into the iron needed for making steel. The high temperatures created from the use of coke gives steel the strength and flexibility needed for making bridges, buildings, and automobiles. The heat and the by-products produced from coal are also used to produce a variety of products such as methanol (methyl alcohol, CH_3OH) and ethylene ($CH_2=CH_2$) which can then be used to produce plastics, synthetic fibers, fertilizers, and medicines.

Certain characteristics of coal ensure its place as an efficient and competitive energy source and contribute to stabilizing energy prices. Key factors include (i) the large reserves without associated geopolitical or safety issues, (ii) the availability of coal from a wide variety of sources, (iii) the facility with which coal can be stored in normal conditions, and (iv) the non-special and relatively inexpensive protection required for the main coal supply routes. Furthermore, retirements of older units, retrofits of existing units with pollution controls, and the construction of some new coal-fueled units are expected to significantly change the coal-fueled electricity generating fleet, making it capable of emitting lower levels of pollutants than the current fleet but reducing its future electricity generating capacity (GAO, 2012).

Deposits of coal, sandstone, shale, and limestone are often found together in sequences hundreds of feet thick. This period is recognized in the United States as the Mississippian and Pennsylvanian time periods due to the significant sequences of these rocks found in those states (i.e., Mississippi and Pennsylvania) (Table 1.4). Other notable coal-bearing ages are the Cretaceous, Triassic and Jurassic Periods. The more recently aged rocks are not as productive for some reason, but lignite and peat are common in younger deposits but generally, the older the deposit, the better the *grade* (higher rank) of coal (Ward, 2008).

As with many industrial minerals, the physical and chemical properties of coal beds are as important in marketing a deposit as the *grade*. The grade of a coal establishes its economic value for a specific end use. Grade of coal refers to the amount of mineral matter that is present in the coal and is a measure of coal quality. Sulfur content; ash fusion temperatures, i.e., measurement of the behavior of ash at high temperatures; and quantity of trace elements in coal are also used to grade coal. Although formal classification systems have not been developed around grade of coal, *coal grade* is important to the coal user.

Table 1.4 The Geologic timescale.

Era	Period	Epoch	Duration ($x 10^6$)	Years ago ($x 10^6$)
Cenozoic	Quaternary	Holocene	10,000**	
		Pleistocene	2	.01
	Tertiary	Pliocene	11	2
		Miocene	12	13
		Oligocene	11	25
		Eocene	22	36
		Paleocene	10	58
Mesozoic	Cretaceous		71	65
	Jurassic		57	136
	Triassic		35	190
Paleozoic	Permian		50	225
	Carboniferous		65	280
	Devonian		60	345
	Silurian		25	405
	Ordovician		65	425
	Cambrian		70	500
Precambrian			3,400	600

Approximate
**To the present

In terms of *coal grade*, the grade of a coal establishes its economic value for a specific end use (Ward, 2008). Grade of coal refers to the amount of mineral matter that is present in the coal and is a measure of coal quality. Sulfur content, ash fusion temperature (i.e., the temperature at which measurement the ash melts and fuses), and quantity of trace elements in coal are also used to grade coal. Although formal classification systems have not been developed around grade of coal, grade is important to the coal user.

Another means by which coal is evaluated is through the *rank* of the coal, which is the most fundamental characteristic relating both coalification history and utilization potential of a coal. Volatile matter and maximum vitrinite reflectance are important values used to determine the worth of coking coals. However, because volatile matter is dependent on both rank and composition, coals of different composition may be assigned to the same rank value even though their levels of maturity may differ.

Volatile matter is not considered to be a component of coal as mined but a product of the thermal decomposition of coal. Volatile matter is produced when coal is heated to 950°C (1740°F) (ASTM D3175) in the absence of air under specified conditions and contains, in addition to moisture, typically a mixture of low-to-medium molecular weight aliphatic hydrocarbon derivatives, aromatic hydrocarbon derivatives, with higher boiling oil and low-volatile tar. Volatile matter decreases as rank increases and when determined by the standard test method (ASTM D3175) can be used to establish the rank of coals, to indicate coke yield on carbonization process, to provide the basis for purchasing and selling, or to establish burning characteristics.

All types of coal contain fixed carbon, which provides stored energy, plus varying amounts of moisture, ash, volatile matter, mercury, and sulfur. However, the physical properties of coal vary widely, and coal-fired power plants must be engineered to accommodate the specific properties of available feedstock and to reduce emissions of pollutants such as sulfur, mercury, and dioxins which reduce power plant efficiency. The efficiency of a coal-fired power plant is typically represented defined as the amount of heat content in (Btu) per the amount of electric energy out (kWh), commonly called a heat rate (Btu/kWh). Expected improvements in power plant efficiency mainly arise from the substitution of older power plants with new plants that have higher efficiency.

Calorific value is one of the principal measures of the value of a coal as a fuel and is directly influenced by mineral impurities. Coal mineralogy is not only important to combustion characteristics, but also as materials that can be passed on to secondary products such as metallurgical coke. Alkali-containing compounds derived from coal minerals can contribute to excessive gasification of coke in the blast furnace and attack of blast furnace refractories, whereas phosphorus and sulfur from coal minerals can be passed on to the hot metal, thus reducing its quality for steelmaking.

Mineral matter may occur finely dispersed or in discrete partings in coal and is generally grouped according to origin. A certain amount of mineral matter and trace elements are derived from the original plants. However, the majority enters to coal precursor either during the initial stage of coalification (being introduced by wind or water to the peat swamp) or during the second stage of coalification, after consolidation of the coal by movement of solutions in cracks, fissures, and cavities. Mineral components of plant origin are not easily recognized in coals because they tend to be disseminated on a submicron level. The primary mineral components incorporated during plant deposition tend to be layered with and intimately inter-grown with the organic fraction, whereas the secondary mineral matter tends to be coarsely inter-grown and associated with cleat, fractures, and cavities. Therefore, secondary minerals may be more readily separated (cleaned or washed) from the organic matrix to improve the value of the material.

More information related to coal character and properties is derived from geological studies of coal – which includes a wide variety of topics, including coal formation, occurrence, and properties but which is outside of the purview of this book but is described in detail elsewhere (Speight, 2013).

1.4.1 Lignite

Lignite (brown coal) is the least mature of the coal types and provides the least yield of energy; it is often crumbly, relatively moist, and powdery. It is the lowest rank of coal, with a heating value of 4,000 to 8,300 Btu per pound (ASTM D388) and is mainly used to produce electricity. With increasing rank (i.e., progressing from lignite to subbituminous coal to bituminous coal to anthracite) the moisture content decreases while the carbon content and the energy content both increase.

Lignite contains the lowest level of fixed carbon (25 to 35%) and highest level of moisture (typically 20 to 40% by weight, but can go as high as 60 to 70%) of all of the coal types (Chapters 2, 5). Ash produced from mineral matter during combustion varies up to 50% w/w. Lignite has low levels of sulfur (less than 1% w/w) and mineral matter (approximately 4% w/w), but has high levels of volatile matter (>32% w/w) and produces high levels of air pollution emissions. Because of its high moisture content, lignite may be dried to reduce moisture content and increase calorific fuel value. The drying process requires energy, but can be used to reduce volatile matter and sulfur as well.

Approximately 7% of coal mined in the United States is lignite and it is found primarily in North Dakota (McLean, Mercer, and Oliver counties), Texas, Mississippi (Kemper County), and to a lesser degree, Montana. The top 10 countries that produce brown coal are (ranked from most to least): Germany, Indonesia, Russia, Turkey, Australia, United States, Greece, Poland, Czech Republic, and Serbia.

With the growing concern for the environment due to emissions from coal utilization, lignite could as well be used in the production of combustible gases (including hydrogen) through underground coal gasification processes (Chapters 9, 10).

1.4.2 Subbituminous Coal

Subbituminous coal is often brown in color but more like bituminous coal than lignite. It typically contains less heating value (8,300 to 13,000 Btu per pound) and more moisture and volatile matter than bituminous coals, but lower sulfur levels (ASTM D388).

Subbituminous coal is considered a black coal, although its appearance varies from bright black to dull dark brown. Its consistency ranges from hard and strong to soft and crumbly, because it is an intermediate stage of coal between bituminous and brown coal (lignite). It is widely used for generating steam power and industrial purposes. Sometimes called *black lignite*, subbituminous coal is not stable when exposed to air and tends to disintegrate.

Subbituminous coal is non-coking and has less sulfur but more moisture (approximately 10 to 45% w/w) and volatile matter (up to 45% w/w) than bituminous coals. The carbon content is 35 to 45% w/w and mineral matter ranges up to 10% w/w. The sulfur content is generally under 2% w/w and the nitrogen content is on the order of 0.5 to 2% w/w. The combustion of subbituminous coal can lead to hazardous emissions that include particulate matter (PM), sulfur oxides (SOx), nitrogen oxides (NOx), and mercury (Hg).

Subbituminous coals produce combustion ash that is more alkaline than other coal ash. This characteristic can help reduce acid rain caused by coal-fired power plant emissions. Adding subbituminous coal to bituminous coal introduces alkaline by-products that are able to bind sulfur compounds released by bituminous coal and therefore reduce acid mist formation.

When subbituminous coal is burned at higher temperatures, its carbon monoxide emissions are reduced. As a result, small combustion units and poorly maintained ones are likely to increase pollution output. People who use subbituminous coal in a home furnace or firebox say that bigger lumps produce less smoke and no clinkers – however, high ash content can be a disadvantage.

Approximately 30% of available coal resources in the United States are subbituminous, a figure that surpasses other countries in its quantity of subbituminous coal resources, with estimated reserves of approximately 300,000 to 400,000 million ton (1 ton = 2,000 lbs) predominantly located in Wyoming, Illinois, Montana, and other locations west of the Mississippi river. Other countries with notable resources include Brazil, Indonesia, and Ukraine.

1.4.3 Bituminous Coal

Bituminous coal is the black, soft rock and the most common coal used around the world. Formed of many thin layers, bituminous coal looks smooth and sometimes shiny. It is the most abundant type of coal found in the United States and has two to three times the heating value of lignite. Bituminous coal contains 11,000 to 15,500 Btu per pound. Bituminous coal is used to generate electricity and is an important fuel for the steel and iron industries.

Bituminous coal lights on fire easily and can produce excessive smoke and soot (particulate matter) if improperly burned. The high sulfur content of the coal contributes to acid rain.

Bituminous coal commonly contains the mineral pyrite, which can serve as a host for impurities such as arsenic and mercury. Combustion of bituminous coal releases traces of mineral impurities into the air as pollution. During combustion, approximately 95% of the sulfur content of bituminous coal is oxidized and released as gaseous sulfur oxides.

Hazardous emissions from bituminous coal combustion include particulate matter (PM), sulfur oxides (SOx), nitrogen oxides (NOx), trace metals such as lead (Pb) and mercury (Hg), vapor-phase hydrocarbon derivatives (such as methane, alkane derivatives, alkene derivatives, and benzene derivatives) and polychlorinated dibenzo-p-dioxin derivatives and polychlorinated dibenzofuran derivatives. When burned, bituminous coal can also release hazardous gases such as hydrogen chloride (HCl), hydrogen fluoride (HF), and polycyclic aromatic hydrocarbon derivatives (typically represented as PAHs or PNAs). Incomplete combustion leads to higher levels of and polycyclic aromatic hydrocarbon derivatives (which are carcinogenic) but burning bituminous coal at higher temperatures reduces its carbon monoxide emissions. Therefore, large combustion units and well-maintained ones generally have lower pollution output. Bituminous coal has slagging and agglomerating characteristics.

Bituminous coal combustion releases more pollution into the air than subbituminous coal combustion, but due to its greater heat content, less of the fuel is required to produce a given output of electricity. Therefore, bituminous, and subbituminous coals produce approximately the same amount of pollution per kilowatt of electricity generated.

Bituminous coal is the most common coal – bituminous coal and subbituminous coal represent (cumulatively) more than 90% of all the coal consumed in the United States. When burned, bituminous coal produces a high, white flame. Bituminous coal includes two subtypes: thermal and metallurgical.

Thermal coal is sometimes called *steam coal* because it is used to fire power plants that produce steam for electricity and industrial uses. Locomotive trains that run on steam may also be fueled with *bit coal* (bituminous coal). However, *steam coal*, which is not a specific rank of coal, is a grade of coal that falls between bituminous coal and anthracite, once widely used as a fuel for steam locomotives. In this specialized use it is sometimes known as *sea coal* in the United States. Small steam coal (*dry small steam nuts*, DSSN) was used as a fuel for domestic water heating. In addition, the material known as *jet* is the gem variety of coal. Jet is generally derived from anthracite and lacks a crystalline structure so it is considered to be a mineraloid. Mineraloids are often mistaken for minerals and are sometimes classified as minerals, but lack the necessary crystalline structure to be truly classified as a mineral. Jet is one of the products of an organic process but remains removed from full mineral status.

Coking coal (also known as *metallurgical coal*) is able to withstand high heat and is used in the process of creating coke necessary for iron and steel-making. Coking coal is able to withstand high heat. Coking coal is fed into ovens and subjected to oxygen-free thermal decomposition (pyrolysis), a process in which the coal is heated to approximately 1100 C (2010°F). The high temperature melts the coal and drives off any volatile compounds and impurities to leave pure carbon. The purified, hot, liquefied carbon solidifies into coke (a porous, hard black rock of concentrated carbon) that can be fed into a blast furnace along with iron ore and limestone to produce steel.

Bituminous coal contains moisture up to approximately 17% w/w and has a fixed carbon content on the order of 85% w/w with a mineral matter content up to 12% w/w. Bituminous coal can be categorized further by the level of volatile matter it contains; high-volatile A, B, and C, medium-volatile, and low-volatile. Approximately 0.5 to 2% w/w of bituminous coal is nitrogen.

More than half of all available coal resources are bituminous and, in the United States occur in Illinois, Kentucky, West Virginia, Arkansas (Johnson, Sebastian, Logan, Franklin, Pope, and Scott counties), and locations east of the Mississippi river.

Particles of waste bituminous coal that are left over after preparation of commercial-grade coal (*coal fines*), which are light, dusty, and difficult to handle, traditionally were stored with water in slurry impoundments to keep them from blowing away.

New technologies have been developed to reclaim fines that were formerly considered waste. One approach is to use a centrifuge to separate the coal particles from slurry water. Other approaches have been developed to bind the fines together into briquettes that have low moisture content, making them suitable for fuel use.

1.4.4 Anthracite

Anthracite (also known as *hard coal*) is the highest rank of coal (ASTM D388) and is the oldest coal from geological perspective – it is actually considered to be metamorphic. It is a hard coal composed mainly of carbon with little volatile content and practically no moisture.

Anthracite is deep black and often appears to be of a metallic nature because of the glossy surface. Compared to other coal types, anthracite is much harder, brittle, and has a glassy luster, and is denser and blacker with few impurities. When burned, anthracite produces a hot blue flame and, as a result, is primarily used for space heating by residences and businesses in and around the northeastern region of Pennsylvania, where much of it is mined.

Anthracite is considered the cleanest burning of all coal types and produces more heat and less smoke than other coals, and is widely used in furnaces. It is largely used for heating domestically as it burns with little smoke. Some residential home heating stove systems still use anthracite, which burns longer than wood.

Anthracite burns at the highest temperature of any coal and typically produces up to 13,000 to 15,000 Btu per pound. Waste coal discarded during anthracite mining (called *culm*) and has a heat content has less than half the heat value of mined anthracite and a higher ash and moisture content. It is used most often in fluidized bed combustion (FBC) boilers.

Anthracite has a high fixed carbon value (80 to 95%) (Chapters 2, 5) and a low sulfur as well as a low nitrogen (less than 1% each). Volatile matter is low at approximately 5% w/w, with 10 to 20% w/w of mineral ash produced by combustion. The moisture content is approximately 5 to 15% w/w and the coal is slow-burning and difficult to ignite because of the high density – consequently few pulverized coal-fired plants use anthracite as the fuel.

Anthracite is considered *non-clinkering* and free burning because (when ignited) it does not coke or expand and fuse together. It is most often burned in underfeed stoker boilers or single-retort side-dump stoker boilers with stationary grates. Dry-bottom furnaces are used because of the high ash fusion temperature of anthracite. Lower boiler loads tend to keep heat lower, which in turn reduces nitrogen oxide emissions.

Particulate matter, or fine soot, from burning anthracite can be reduced with proper furnace configurations and appropriate boiler load, under-fire air practices, and fly ash reinjection. Fabric filters, electrostatic precipitators (ESP), and scrubbers can be used to reduce particulate matter pollution from anthracite-fired boilers. Anthracite that is pulverized before burning creates more particulate matter.

Furthermore, it is worthy of note that even in the terminology of anthracite there are several variations which, although somewhat descriptive, do not give any detailed indications of the character of the coal. For example, some of the terms which refer to anthracite are: black coal, hard coal, stone coal, which should not to be confused with the German *steinkohle* or the Dutch *steenbok*, which are terms that include all varieties of coal with a stone-like hardness and appearance, blind coal, Kilkenny coal, crow coal (from its shiny black appearance), and black diamond. However, as the importance of the coal trade increased, it was realized that some more definite means of classifying coals according to their composition and heating value was desired because the lines of distinction between the varieties used in the past were not sufficiently definite for practical purposes (Thorpe *et al.*, 1978; Freese, 2003).

Anthracite is scarce and only a small percentage of all remaining coal resources are anthracite. Pennsylvania anthracite was mined heavily during the late 1800s and early 1900s, and remaining supplies became harder and harder to access because of their deep location. The largest quantity of anthracite ever produced in Pennsylvania was in 1917.

Historically, anthracite was mined in a 480-square-mile area in the northeastern region of Pennsylvania, primarily in Lackawanna, Luzerne, and Schuylkill counties. Smaller resources are found in Rhode Island and Virginia.

1.5 Resources

As the 21st century matures, there will continue to be an increased demand for energy to support the needs of commerce industry and residential uses – in fact, as the 2040 to 2049 decade approaches, commercial and residential energy demand is expected to rise considerably – by approximately 30% over current energy demand. This increase is due, in part, to developing countries, where national economies are expanding and the move away from rural to city living is increasing. In addition, the fuel of the rural population (biomass) is giving way to the fuel of the cities (transportation fuels, electric power) as the lifestyles of the populations of developing countries change from agrarian to metropolitan. Furthermore, the increased population of the cities requires more effective public transportation systems as the rising middle class seeks private means of transportation (automobiles). As a result, fossil fuels will continue to be the predominant source of energy for at least the next 50 years.

In general terms, coal is a worldwide resource; the latest estimates, which seem to be stable within minor limits of variation (Hessley, 1990), show that there is in excess of 1,000 billion (109) tons of proven recoverable coal reserves throughout the world (Energy Information Administration, 2011). In addition, consumption patterns give coal approximately 30% or more (depending upon the source) of the energy market share (Energy Information Administration, 2011). Estimates of the total reserves of coal vary within wide limits, but there is no doubt that vast resources exist and are put to different uses (Horwitch, 1979; Hessley, 1990; EWG, 2007; Speight, 2013). However, it is reasonable to assume that, should coal form a major part of any future energy scenario, there is sufficient coal for many decades (if not hundreds of years) of use at the current consumption levels. Indeed, coal is projected as a major primary energy source for power generation for at least the next several decades and could even surpass oil in use, especially when the real costs of energy are compared to the costs of using the indigenous coal resources of the United States (Hubbard, 1991; Speight, 2020).

In order to understand the politics of coal use and production, it is necessary to put coal into the perspective of oil and gas. In the early days of the oil industry, the United States was the major producer and was predominantly an exporter of crude oil, thereby serving as the "swing" producer insofar as production was adjusted to maintain stability of world oil prices. However, oil production in the United States peaked in 1972 and has been in decline ever since and the mantle of oil power has shifted to the Middle East, leading to new political and economic realities for the world. From the 1970s, oil prices have been determined more by international affairs (geopolitics) than by global economics (Yergin, 1991).

In contrast to current US oil production and use patterns, the United States is not a significant importer of natural gas. Trade agreements with Canada and with Mexico are responsible for the import of natural gas but these are more of a convenience for the border states rather than for the nation as a whole.

In the United States, the use of coal increased after World War II with the majority of the production occurring in the eastern states close to the population centers. The majority of the recovery methods used underground mining techniques in the seams of higher quality, i.e., the minerals and water content of the coal was relatively low and the coal had a high heat-content (Chapters 5, 6). However, by the late 1960s, natural gas and crude oil had captured most of the residential, industrial, and commercial market, leaving only power generation and metallurgical coke production as the major uses for coal.

On a global scale, the United States is a major source of coal (Figure 1.2) as well as a coal producer and coal exporter (Chadwick, 1992). There are many coal-producing states in the United States but the passage, and implementation, of the Clean Air Act in the early 1970s opened up new markets for the easily (surface) mined low-sulfur coals (Table 1.5, Table 1.6, Figure 1.3) from the western United States and captured a substantial share of the energy

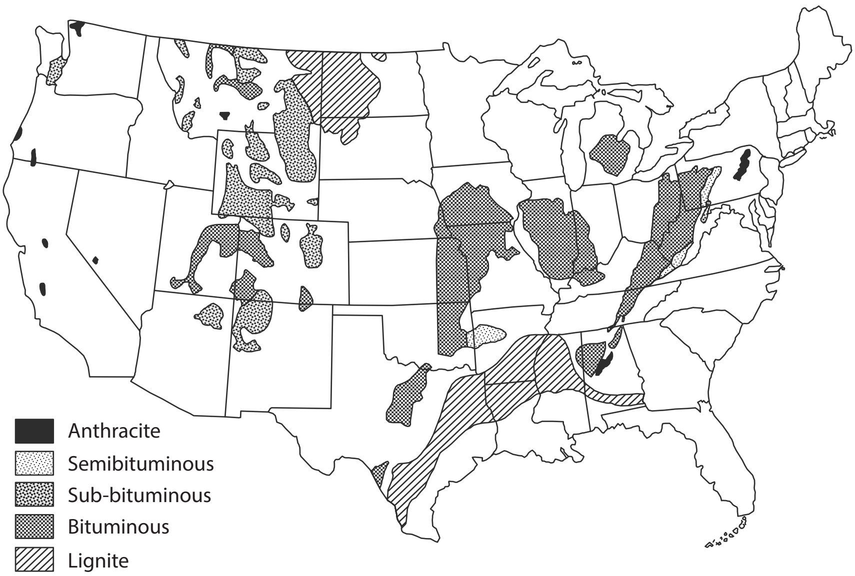

Figure 1.2 Coal types and distribution in the United States.

Table 1.5 Distribution of US Coal Reserves (% of total) (Energy information Administration, 2011).

Region*	Underground minable (%)	Surface minable (%)	Total (%)
Eastern United States	36.9	8.2	45.1
Western United States	30.8	24.1	54.9
Total United States	67.7	32.3	100.0

*Mississippi River is dividing line beteween East and West.

Table 1.6 Sulfur content of US Coals by Region (Energy information Administration, 2011).

Region	No. of samples	Organic S (%)	Pyritic S (%)	Total (%)
N. Appalachia	227	1.00	2.07	3.01
S. Appalachia	35	0.67	0.37	1.04
E. Midwest	95	1.63	2.29	3.92
W. Midwest	44	1.67	3.58	5.25
Western	44	0.45	0.23	0.68
Alabama	10	0.64	0.69	1.33

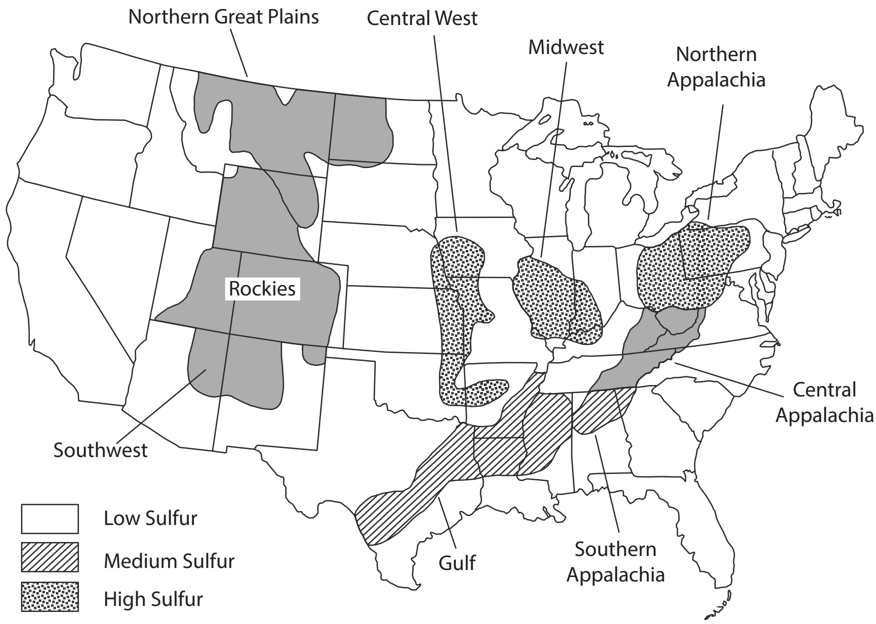

Figure 1.3 Distribution of Sulfur content of US Coals (Energy information Administration, 2011).

(specifically, the electrical utility) markets. In addition, states such as Wyoming were the major beneficiaries of the trend to the use of low-sulfur coal and occupy a significant position in the coal reserves and coal production scenarios of the United States (Speight, 2013, 2020).

Furthermore, the two oil shocks of 1973 and 1979, as well as the political shock that occurred in Iran in 1979, were related to the rediscovery of coal through the realization that the United States and other Western countries had developed a very expensive habit insofar as they not only had a growing dependence upon foreign oil but they craved the energy-giving liquid! The discovery of the North Sea oil fields gave some respite to an oil-thirsty Europe but the resurgence of coal in the United States continued with the official *rebirth* of coal in 1977 as a major contributor to the National Energy Plan of the United States. It is to be hoped that future scenarios foresee the use of coal as a major source of energy; the reserves are certainly there and the opportunities to use coal as a clean, environmentally acceptable fuel are increasing.

The question to be asked by any country, and Canada did ask this question in the early 1970s, is "What price are we willing to pay for energy independence?" There may never be any simple answer to such a question. But, put in the simplest form, the question states that if the United States, or, for that matter, any energy consumers, are to wean themselves from imported oil (i.e., nonindigenous energy sources) there will be an economic and environmental cost if alternate sources are to be secured (NRC, 1979; NRC, 1990). In this light, there is a study which indicates that coal is by far the cheapest fossil fuel. However, the costs are calculated on a cost per Btu basis for electricity generation only and whilst they do show the benefits for using coal for this purpose, the data should not be purported to be generally applicable to all aspects of coal utilization.

Nevertheless, the promise for the use of coal is there insofar as the data do show the more stable price dependability of coal. If price stability can be maintained at a competitive level and the environmental issues can be addressed successfully, there is a future for coal – a long future and a bright future.

Finally, the issues logic of distinguishing between *resources* (which include which include additional amounts of coal such as inferred/assumed/speculative reserves) and *proven reserves* (which are defined as being proved) is that over time production and exploration activities allow resources to be reclassified into *proven reserves*.

1.6 Reserves

The coal reserves and resources of the world are difficult to assess because of the lack of accurate data for individual countries. Two fundamental problems make these estimates difficult and subjective. The first problem concerns differences in the definition of terms such as *proven reserves* (generally only those quantities that are recoverable) and *geological resources* (generally the total amount of coal present, whether or not recoverable at present).

Thus, in any text dealing with coal, there must be recognition, and definition, of the terminology used to describe the amounts, or reserves of coal available for recovery and processing. But the terminology used to describe coal (and for that matter any fossil fuel or mineral) resource is often difficult to define with any degree of precision (Speight, 2011b, 2014, 2020).

Different classification schemes (Chapter 2) often use different words which should, in theory, mean the same but there will always be some difference in the way in which the terms can be interpreted. It might even be wondered that if the words themselves leave much latitude in the manner of their interpretation, how the resource base can be determined with any precision. The terminology used here is that more commonly found although other systems do exist and should be treated with caution in the interpretation.

Generally, when estimates of coal supply are developed, there must be a line of demarcation between coal *reserves* and *resources*. Reserves are coal deposits that can be mined economically with existing technology, or current equipment and methods. Resources are an estimate of the total coal deposits, regardless of whether the deposits are commercially accessible. For example, world coal reserves were estimated to be in excess of one trillion tons (1×10^{12} tons) and world coal resources were estimated to approximately 10 trillion tons (10×10^{12} tons) and are geographically distributed in Europe, including all of Russia and the other countries that made up the former Soviet Union, North America, Asia, Australia, Africa, and South America (Table 1.7).

However, there are definitions that go beyond *reserves* and *resources*. To begin at the beginning, the energy resources of the Earth are subdivided into a variety of categories (Figure 1.4) and the resources of coal (as well as each of the other fossil fuel resources) can be further subdivided into different categories (Figure 1.5) (Speight, 2013, 2014, 2020).

1.6.1 Proven Reserves

The proven reserves for any commodity should provide a reasonably accurate estimate of the amount that can be recovered under existing operating and economic conditions. To be economically mineable, a coal seam (coalbed, also called a coalbed, hence coal bed methane) bed

Table 1.7 Estimated Coal Reserves by Country (Energy information Administration, 2011).

Coal	
United States	27.5%
Russia	18.3%
1. China	13.3%
Other Non-OECD Europe and Eurasia	10.7%
Australia and New Zealand	8.9%
India	7.0%
OECD Europe	6.5%
Africa	3.7%
Other Central and South America	0.9%
Rest of World	3.2%
Total	100.0%

Source: US Energy Information Administration, International Energy Outlook, September 2011.

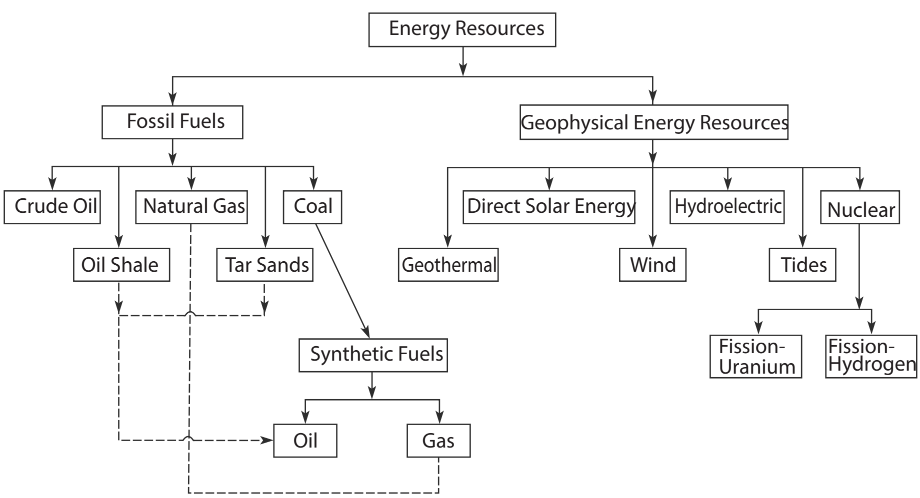

Figure 1.4 Energy Resources of the Earth (Speight, 2013).

must have a minimum thickness (approximately 2 feet) and be buried less than some maximum depth (approximately 6,600 feet) below the surface of the Earth. These values of thickness and depth are not fixed but change with criteria such as (i) coal quality, (ii) coal demand, (iii) the ease with which overlying rocks can be removed for surface mining or a shaft sunk to reach the coal seam for underground mining. The development of new mining techniques may increase the amount of coal that can be extracted relative to the amount that cannot be

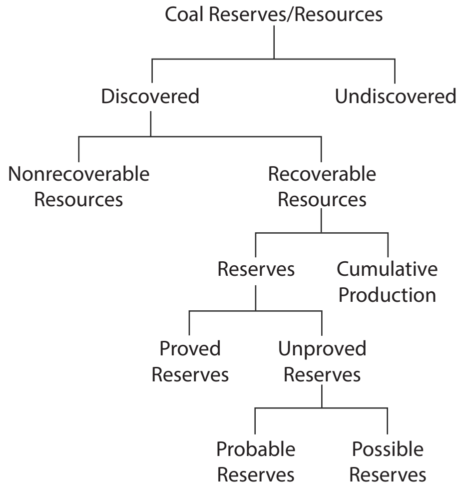

Figure 1.5 Resource and reserve terminology (Speight, 2013).

removed. For example, in underground mining, which accounts for approximately 60% w/w of world coal production, conventional mining (pillar mining) methods leave behind large pillars of coal to support the overlying rocks and recover only about half of the coal present. On the other hand, longwall mining, in which the equipment removes continuous parallel bands of coal, may recover almost all the coal present in the seam.

In addition, an issue which concerns the estimation of reserves, is the rate at which the coal is consumed. When considering the worldwide reserves of coal, the number of years that coal will be available may be more important than the total amount of coal resources. For example, the coal reserves may be estimated using the current rates of consumption, which may indicate that the world coal reserves should last more than 300 to 500 years. However, a large amount of additional coal is present in Earth but cannot be recovered using current technology and these resources, sometimes called geologic resources, are even more difficult to estimate, but may be much greater than the amount of proven reserves.

Thus, in the current context, the proven reserves (*proved reserves*) are those coal reserves that are actually found (proven), usually by drilling and coring. The estimates have a high degree of accuracy and are frequently updated as the mining operations proceed. However, even though the coal reserves may be proven, there is also the need to define the resources on the basis of what further amount of coal might be recoverable (using currently available mining technology without assuming, often with a very high degree of optimism) extravagantly, that new technology will miraculously appear or will be invented) and *non-recoverable* coal reserves will suddenly become *recoverable*.

If economic aspects are not considered, the term for the total technologically extractable amount of coal is the *producible fraction*, which is often confused with the *proven reserves*. The term *proven reserves* is further subdivided into *proved developed reserves* and *proved undeveloped reserves*. This should not be confused with *unproven reserves*, which are broken down into *probable reserves* and possible reserves – those reserves that only have a 10% likelihood of being recoverable.

These reserve categories can, as in the crude oil industry (Speight, 2011b, 2014), be cumulatively summed by the measures 1P, 2P, and 3P, which are inclusive, so include the previous safer measures as (i) 1P reserves – proven reserves consisting of both proved developed reserves plus proved undeveloped reserves), (ii) 2P reserves – consisting of 1P proven reserves plus probable reserves, and (iii) 3P reserves – consisting of the sum of 2P reserves plus possible reserves.

On the other hand, the estimated ultimate recovery of coal (or any resource) is the sum of the proven reserves at a specific time and the cumulative production up to that time.

1.6.2 Inferred Reserves

The term *inferred reserves* (*unproved reserves*) is commonly used in addition to, or in place of, *potential reserves*. The inferred coal reserves are regarded as being of a higher degree of accuracy than the potential reserves and the term is applied to those reserves that are estimated using an improved understanding of seam structure (see *Proven reserves* – above).

In the United States, inferred reserves (reserve growth) include those resources expected to be added to reserves as a consequence of extension of known fields, through revisions of reserve estimates, and by additions of seams (or coal strata) in discovered coal domains. Also included in this category are resources expected to be added to reserves through application of improved mining techniques.

This category thus includes both the *indicated reserves* and the *inferred reserves* described in earlier United States Geological Survey assessment publications. Predictions of reserve growth may refer to coal fields found before a specified year and the analysis of reserve growth in discrete conventional coal accumulations is based on the definitions and reports of the United States Energy Information Administration (EIA). In summary, inferred reserves are assessed by preliminary exploration and are part of probable reserves – the level of their probability assessment is low.

1.6.3 Potential Reserves

Potential reserves (*probable reserves*, *possible reserves*) are the additional reserves of coal that are believed to exist in the earth. The data are estimated (usually from geologic evidence) but have not been substantiated by any drilling or coring operations. Other terminology such as *probable reserves* and *possible reserves* are also employed but fall into the subcategory of being unproven.

In summary, potential reserves are those contingent reserves that, as of a specified date, are potentially recoverable from *known* accumulations coal fields but the applied project(s) are not yet considered mature enough for commercial development due to one or more contingencies. Potential reserves may include, for example, projects for which there are currently no viable markets, or where commercial recovery is dependent on technology under development, or where evaluation of the accumulation is insufficient to clearly assess commerciality.

1.6.4 Undiscovered Reserves

One major issue in the estimation of coal (or for that matter any fossil fuel or mineral) resource is the all too frequent use of the term “undiscovered” resources. Caution is advised when using such data, as might be provided to "substantiate" such reserves, as they are very speculative and are regarded as many energy scientists as having little value other than being unbridled optimism. And perhaps, opportunism and/or charlatanism are being applied depending upon the resource under speculation and the potential market for the product.

The differences between the data obtained from these various estimates can be considerable but it must be remembered that any data related to the reserves of natural gas (and, for that matter, related to any other fuel or mineral resource) will always be open to questions related to the degree of certainty (Speight, 2104).

There are three important items that counteract the guesswork applied to *undiscovered* resources: (a) the actual discoveries of new coal reserves; (b) the development of improved mining technologies for already known coal reserves; and (c) estimates of the coal resource base that are derived from known resource properties where the whole of the resource is not explored.

It should also be remembered that the total resource base of any fossil fuel (or, for that matter, of any mineral) will be dictated by economics (Nederlof, 1988). Therefore, when coal resource data are quoted some attention must be given to the cost of recovering those reserves. And, most important, the economics must also include a cost factor that reflects the willingness to secure total, or a specific degree of, energy independence, including some serious consideration of the very real environmental aspects of coal usage.

On the basis of these definitions, the total recoverable reserves of coal around the world are estimated to be on the order of at 950 billion tons (950 x 10^9 tons), indicating a reserves-to-production ratio of 126 years (International Energy Agency, 2010; EIA 2010, 2011, 2012a, 2012b). Furthermore, because recoverable reserves are a subset of total coal resources, recoverable reserve estimates for a number of regions with large coal resource bases (notably, China and the United States) could increase substantially as coal mining technology improves and additional geological assessments of the coal resource base are completed.

Although coal deposits are widely distributed, the majority (approximately 79%) of the recoverable reserves of the world are located in five regions: (i) the United States, (ii) Russia, (iii) China, (iv) Europe and Eurasia outside of Russia, and (v) Australia and New Zealand. By rank, anthracite, and bituminous coal account for approximately 47% of the estimated worldwide recoverable coal reserves on a tonnage basis, subbituminous coal accounts for 30%, and lignite accounts for 23%. As these numbers indicate, the United States has a vast supply of coal (approximately 28% of world reserves and more than 1,600 billion tons – 1,600 x 10^9 tons – of the remaining coal resources. The United States is also the second-largest coal producer in the world (after China) and annually produces more than twice as much coal as India, the third-largest producer of coal (Höök and Aleklett, 2009; EIA, 2010, 2011, 2012a, 2012b).

The quality and geological characteristics of coal deposits are important parameters for coal reserves. Coal is a heterogeneous source of energy, with quality (for example, characteristics such as heat, sulfur, and ash content) varying significantly by region and even within individual coal seams. At upper levels of coal quality are premium-grade bituminous coals, or coking coals, used to manufacture coke for the steelmaking process. Coking coals produced in the United States have an estimated heat content of 26.3 million Btu per ton and relatively low sulfur content of approximately 0.9% by weight. At the other end of the spectrum are reserves of low-Btu lignite – on a Btu basis, lignite reserves show considerable variation (International Energy Agency, 2010; EIA, 2010, 2011, 2012a, 2012b).

1.6.5 Other Definitions

While the definitions presented above are in common use, there are other systems of resource/reserve definition and nomenclature that are similar to the definitions used above (EWG, 2007) and also deserve mention here.

The definition of *resources* according to the scheme of the World Energy Council (WEC) involves the *estimated additional amount in place***,** which is the indicated and inferred tonnage of coal additional to the proved amount in place that is of foreseeable interest. This definition includes estimates of amounts that could exist in unexplored extensions of known deposits or in undiscovered deposits in known coal-bearing areas, as well as amounts inferred through knowledge of favorable geological conditions. Speculative amounts are not included.

The definition of *reserves* according to the scheme of the WEC is *the proved amount in place*, which is the resource remaining in known deposits that has been carefully measured and assessed as exploitable under present and expected local economic conditions with existing available technology. On the other hand the *proved recoverable reserves* is the tonnage of coal within the proved amount in place that can be recovered in the future under present and expected local economic conditions with existing available technology.

The *estimated additional reserves recoverable* is the tonnage of coal within the estimated additional amount in place that geological and engineering information indicates with reasonable certainty might be recovered in the future.

The International Energy Agency (IEA), BP Statistics (as in the BP Review of World Energy) and most other organization typically use the term *Proved reserve* (*proven reserve*) which is equivalent to the *proved recoverable reserves* as defined by the World Energy Council.

The US Energy Information Agency (EIA) uses nomenclature such as the *demonstrated reserve base***,** which covers publicly available data on coal mapped to measured and indicated degrees of accuracy and found at depths and in thick coal-beds considered technologically minable at the time of determinations. On the other hand, the *estimated recoverable reserves* (which corresponds to the *proved recoverable reserves* of the World Energy Council and to the *proved reserves* of the BP Review of World Energy) cover the coal in the demonstrated reserve base considered recoverable after excluding the coal estimated to be unavailable due to land use restrictions or currently economically unattractive for mining, and after applying assumed mining recovery rates. In addition, the *recoverable reserves at producing mines* represent the quantity of coal that can be recovered (i.e., mined) from existing coal reserves at reporting mines.

Other national geological agencies use different definitions, such as the German *Bundesanstalt für Geowissenschaften und Rohstoffe (BGR),* which uses the terms (i) *reserves*, which is equivalent to the *proved recoverable reserves* (WEC), and (ii) resources, which include discovered but not yet economically producible amounts and undiscovered but estimated accumulations of coal. This includes the *resources* as defined by the WEC as well as any other possible coal deposits.

1.7 Energy Independence

Energy independence has been a political non-issue in the United States since the first Arab oil embargo in 1973. Since that time, the speeches of various presidents and the Congress of the United States have continued to call for an end to the dependence on foreign oil by the United States. The congressional rhetoric of energy independence continues but meaningful suggestions of how to address this issue remain few and far between.

Energy interdependence also makes the domestic economy more susceptible to disruptions in distant and unstable regions of the globe, such as the Middle East, South America, and Africa. In fact, in many countries with proven reserves, oil production could be shut down by wars, strikes, and other political events, thus reducing the flow of oil to the world market. If these events occurred repeatedly, or in many different locations, they could constrain exploration and production, resulting in a peak despite the existence of proven oil reserves.

Even in the United States, political considerations may affect the rate of exploration and production of energy sources. For example, restrictions imposed to protect environmental assets mean that some oil may not be produced. In addition, policies on federal land use need to take into account multiple uses of the land including environmental protection. Environmental restrictions may affect a peak in oil production by barring oil exploration and production in environmentally sensitive areas.

The government must adopt policies that ensure energy independence. The US Congress is no longer believable when the members of the Congress lay the blame on foreign governments or events for an impending crisis. In the United States, crude oil imports are considered a threat to national security but there is also the line of thinking that the level of imports has no significant impact on energy security, or even national security. However, the issue becomes a problem when import vulnerability increases as crude oil imports rise, which occurs when oil-consuming countries increase the share of crude oil imports from politically unstable areas of the world.

Currently, the United States is an exporter of crude oil and crude oil products but the question remains related to the longevity of such a situation. In addition, US dependence on crude oil has increased in recent years and this indicates two possible areas of concern regarding the extent to which crude oil influences energy security: (i) the increase in the crude oil share of energy use, and (ii) the inability or unwillingness of the United States to reduce dependence on oil. It is because of such variations that the potential of gasification must be considered as an option for energy production, particularly for the production of liquid fuels and chemicals.

For many decades, coal has been the primary feedstock for power generation but due to recent concerns related to the use of fossil fuels and the resulting environmental pollutants, irrespective of the various gas cleaning processes and gasification plant environmental cleanup efforts, there is a move to feedstocks other than coal for gasification processes (Speight, 2013). Indeed, the mounting interest in the use of mixed-coal feedstocks and non-coal feedstocks for power generation reflects the potential for lower cost control of greenhouse gases than other coal-based systems.

Furthermore, power generation units can accept a variety of feedstocks but the reactor must be selected on the basis of feedstock properties and behavior in the process. Also, the disposal of municipal and industrial waste has become an important problem because the traditional means of disposal, landfill, are much less environmentally acceptable than previously. Much stricter regulation of these disposal methods will make the economics of waste processing for resource recovery much more favorable. A method of processing waste streams is to convert the energy value of the combustible waste into a fuel. One type of fuel attainable from waste is a low heating value gas, usually 100 to 150 Btu/scf, which can be used to generate process steam or to generate electricity.

Waste may be municipal solid waste (MSW) which had minimal presorting, or refuse-derived fuel (RDF) with significant pretreatment, usually mechanical screening, and shredding. Other more specific waste sources (excluding hazardous waste) and possibly including crude oil coke, may provide niche opportunities for co-utilization. The traditional waste to energy plant, based on mass-burn combustion on an inclined grate, has a low public acceptability despite the reduction in the emissions achieved over the last decade with modern flue gas clean-up equipment. This has led to difficulty in obtaining planning permissions to construct needed new waste to energy plants. After much debate, various governments have allowed options for advanced waste conversion technologies (gasification, pyrolysis, and anaerobic digestion), but will only give credit to the proportion of electricity generated from non-fossil waste.

Co-utilization of waste and biomass with coal may provide economies of scale that help achieve the above identified policy objectives at an affordable cost. In some countries, governments propose mixed feedstock processes as being *well suited for community-sized developments,* suggesting that waste should be dealt with in smaller plants serving towns and cities, rather than moved to large, central plants (satisfying the so-called *proximity principal*).

Use of waste materials as feedstocks for power generation may attract significant disposal credits. Cleaner biomass materials are renewable fuels and may attract premium prices for the electricity generated. Availability of sufficient fuel locally for an economic plant size is often a major issue, as is the reliability of the fuel supply. Use of more-predictably available coal alongside these fuels overcomes some of these difficulties and risks. Coal could be regarded as the *flywheel* which keeps the plant running when the fuels producing the better revenue streams are not available in sufficient quantities.

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