# COAL, OIL, AND GAS FOR THE TWENTY-FIRST CENTURY

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## Contents



## Summary

The world contains vast quantities of solid, liquid, and gaseous fossil fuels (coal, oil, and natural gas) that we are producing at very high and ever increasing rates to support our global economies. The economies of the industrialized countries of the world depend greatly upon the availability of these hydrocarbon fuels and at relatively low prices.

The world's fossil hydrocarbon resources are finite and are distributed unevenly around the world. Depletion of energy resources occurs at all geographic levels, locally, regionally, nationally and ultimately, internationally. Many of the deposits that were discovered during the past two centuries have been depleted or are being rapidly depleted today. Depletion is almost entirely economic, and large amounts of fossil fuels commonly remain in the ground after extraction ceases.

It is anticipated that near-term intermittent interruptions in supply on a global basis from net producers to the industrialized countries, as well as comparatively long-term economic depletion and large price increases, could have a significant impact on world economic and social systems as we move from traditional fossil fuels to lower grade resources and synfuels. Technological innovation and the evolution of fossil fuel utilization from the high-grade resources of today, perhaps to the use of synfuels derived from the more abundant but lower grade hydrocarbon resources (methane hydrates, oil shale, tar sands), and ultimately to the development of synfuels generated from biomass may be a path to an energy-rich future that is not based on fossil fuels.

## 1. Introduction

Fuels commonly consumed by man range from biogenic materials that include plant material (chiefly wood), animal waste (dung), and biogenic methane from land fills, to fossil fuels and the radioactive minerals that serve as fuels for nuclear power plants. This section of the Encyclopedia describes the major fossil fuels that have been used by man, initially in only small quantities for several thousand years or more, and currently in great amounts to support and maintain our complex economic systems worldwide (see Charpentier and Ahlbrandt, Taylor, Ward, and Warwick, this volume). Fossil fuels, which include coal, crude oil, and natural gas, are solid, liquid, and gaseous hydrocarbons that commonly contain mixtures of other elements and compounds. Hydrocarbons that may be generated from other fossil fuel sources, such as tar sands, oil shale, and methane hydrates, are considered elsewhere in the Encyclopedia. The purpose of this article is to give a brief historical synopsis of the worldwide distribution, production, and consumption of the major fossil fuels and the outlook for the near term future. As used in this paper, the term "reserves" may have several different meanings. In the United States, proved reserves of oil and gas "includes those estimated amounts of oil and gas that geological and engineering data demonstrate with reasonable certainty to be recoverable in the future from known natural oil and gas reservoirs under existing economic and operating conditions." The definition of "reserves" may or may not have a different meaning in other countries, but generally implies that the commodity discussed at least has the potential to be economically recoverable some time in the future. Similarly, as commonly used the term "coal reserves" generally implies potential economic recoverability at some time in the future.

Much of the world's hydrocarbon resources are concentrated in major sedimentary basins of Paleozoic, Mesozoic, and Cenozoic age. Crude oil and natural gas are derived from great concentrations of organic material (algae, plankton) that accumulated generally within lacustrine or marine sediments on the surface of the earth. As these deposits, called "source rocks" by petroleum geologists, were buried progressively deeper within the earth, the organic material was "cooked" by the elevated temperatures and pressures within the earth until liquid and gaseous hydrocarbons were generated. From these "hydrocarbon kitchens" the hydrocarbons have migrated along porous beds or fractures to where they are trapped by seals and preserved in geologic reservoirs.

In contrast, coal is derived from peat accumulations that form on the surface of the earth, more commonly in tropical or subtropical regions that have abundant rainfall. In areas where peat deposits are buried deeply by thick deposits of overlying sediments, the peat is compacted and loses water and gaseous hydrocarbons as it is altered progressively through stages of lignite and bituminous coal to anthracite. Methane gas, which is commonly associated with coal beds, may be generated by biogenic processes at or near the earth's surface or by thermogenic processes deep within the earth. This methane commonly remains associated with its reservoir, where it accumulates within the pore space and fractures of the coal bed. The coal bed is, thus, a self-sourced or "autogenic" reservoir for coalbed methane.

Production, transportation, and use of these fossil fuels are not without adverse environmental consequences. Because elements, such as sulfur, adversely impact the environment during the use of fossil fuels, some of these fuels may be cleaned and/or refined prior to and/or during utilization. In places where large amounts of impure hydrocarbons are burned without cleaning, the pollution of ambient air and water with undesirable chemicals and particulate matter may be great.

Large-scale coal mining, both surface and underground, may adversely affect future land use and the quality of surface and groundwater supplies. Coal washing prior to combustion and the use of flue gas desulfurizers (scrubbers) may produce large amounts of solid waste that contains heavy metals. Flue gases that contain significant amounts of carbon dioxide, nitrous oxides, and sulfur dioxide may contribute to the potential for global warming and to regional acidic rain.

The production and consumption of oil and gas on a global scale require the development of a complex industrial infrastructure that involves deep drilling in almost all regions of the earth, the transportation of liquid and gaseous hydrocarbons from well bore to refinery to end user, and the use of those hydrocarbons as fuels and as feed stock for a multitude of products. Opportunities for environmental pollution abound in these activities, and they range from the potential for local contamination at many tens of thousands of the sites drilled, to major oil spills from leaky pipelines and tankers, and to the abundant vehicle-produced air pollutants that occur in many major cities.

In spite of the complex industrial infrastructure required to market fossil fuels, their unit costs are low because the volumes consumed are so great. Nevertheless, these resources are finite and production of oil and gas may begin an irreversible decline during this century, with great negative effects on the economies of the industrialized world unless alternative energy sources are soon developed.

## 2. The Globalization of Fossil Fuels

During the latter part of the twentieth century, many economic enterprises of various nations, especially the manufacturing, distribution, and marketing of goods, have been integrated progressively into a single, but complex, global economy. Similarly, the exploration, development, transportation, and marketing of fossil fuels, especially oil and natural gas, have emerged as global activities that are pursued by international energy companies. Fossil fuels are used in large quantities worldwide and consumption is expected to increase during the next several decades as populations and industrialization increase. In 1999 approximately 3.8 billion cubic meters (Bcm) of crude oil, 2.4 Trillion cubic meters (Tcm) of natural gas, and 4.3 billion tonnes of coal were produced worldwide.

The U.S. Energy Information Administration (EIA) projects world petroleum consumption to grow to about 6.9 Bcm annually by 2020, gas use is expected to increase to 4.6 Tcm by 2020, and EIA projects world coal use to increase to about 5.8 billion tonnes by 2020. Much of the increase in demand for oil and coal is expected to occur in developing Asia, especially China and India. Annual oil consumption in China and India is expected to increase by 350 million cubic meters (Mcm) and 334 Mcm, respectively, by 2020, mostly for transportation. China and India account for 92 percent of the world's projected increase in coal use (on a Btu basis). Significantly, EIA reports that 59 percent of the projected growth in the use of coal in China by 2020 would occur in industrial applications and in the use of coke for manufacturing steel and pig iron. In contrast, EIA projects most of the growth in the use of coal by India to occur in the electric power industry. By 2020, major increases in annual consumption of natural gas are projected to occur in Eastern Europe and the former Soviet Union (425 Bcm), developing Asia (425 Bcm), North America (425 Bcm), western Europe (340 Bcm) and Central and South America (329 Bcm), with much of the increase to be utilized for electric power generation.

Of the three fossil fuels, crude oil is the most mobile and is readily transported by pipeline or by ocean-going tanker from where it is produced to distant refineries, where it is processed into a variety of liquid and gaseous fuels and associated products that range from plastics to road tar. Like petroleum (crude oil), the marketing of natural gas requires the development of gathering pipelines from many production platforms that are in turn combined into pipelines that distribute the product, perhaps for many hundreds of kilometers and across difficult terrain, to distant markets. This distribution system works well where the pipelines are secure within large national boundaries or transect cooperating friendly countries, but may be difficult to maintain elsewhere. Alternatively, natural gas may be liquefied under pressure (LNG) and transported overland or across oceans by tanker.

## 3. World Primary Energy Production – a Measure of the Economic Health of the World

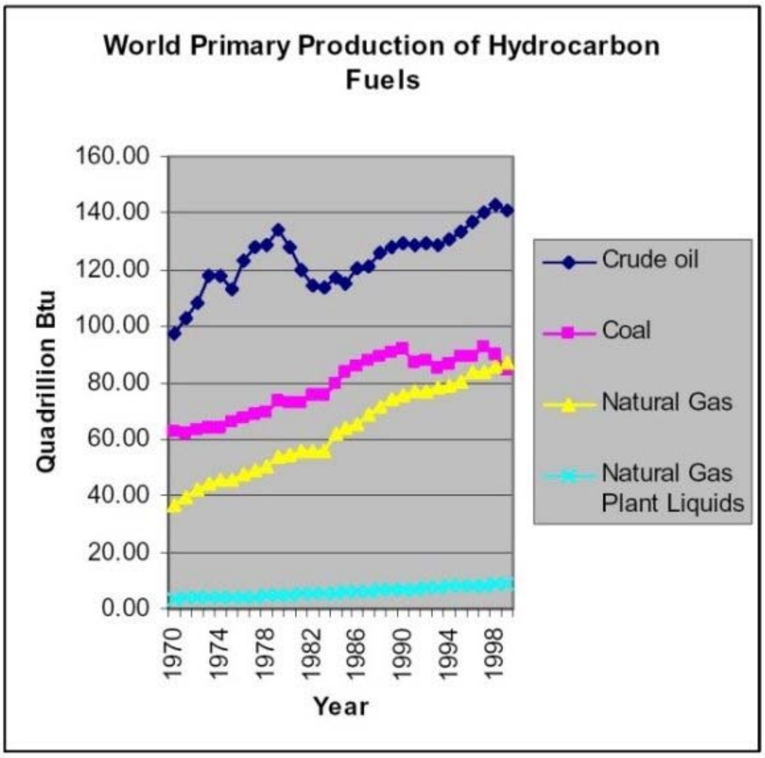


Figure 1: World primary production of hydrocarbon fuels, 1970 – 1999 (EIA, 2001b, Table 11.2). One Btu equals 1,054.198 joules

As defined by EIA, the primary sources of the world's energy are coal, natural gas, crude oil, nuclear electric power, hydroelectric power, and geothermal and other renewable energy resources. Of these, fossil fuels constitute about 85 percent of the energy produced. As of 2001, crude oil provides most of the energy needs of the world, followed by natural gas and then by coal (Figure 1). It has been only in the past year that natural gas has surpassed coal as an energy source on a worldwide basis, mainly because of the recent decline of coal production in the former Soviet Union and China.

The primary energy production from the major producing regions of the world for the period 1990 to 1999, measured in quadrillion Btu's, is shown in Figure 2. In general, energy production increased for all regions during this period, except for the general decline for Eastern Europe (EE) and the former Soviet Union (FSU). This decline reflects the economic adjustment that occurred following the separation of the Soviet Union into its component states. The decline in energy production in EE & FSU appears to have stabilized by the end of the decade and overall energy production in that region even increased a little from 1998 to 1999. Energy production declined significantly in the Far East, primarily because of a decline in China's energy production (chiefly coal) during the last half of the decade.

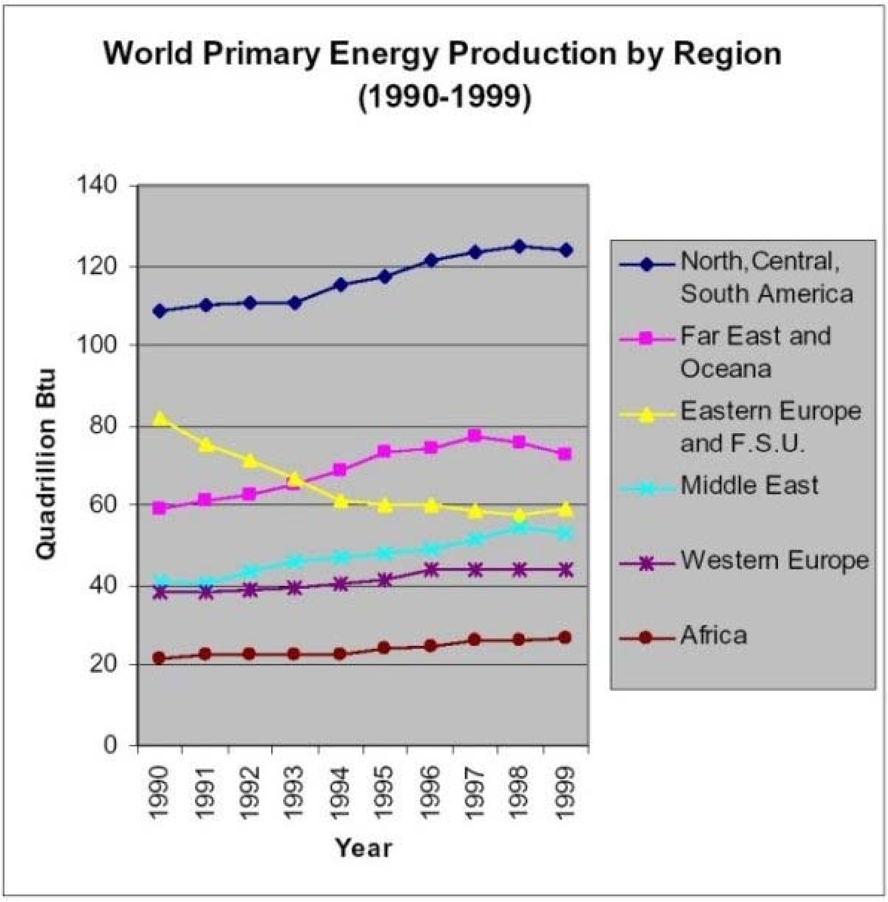


Figure 2: World primary energy production by region, 1990 – 1999 (EIA, 2001b, Table 11.1). One Btu equals 1,054.198 joules

## 4. The Production Life Cycle of Fossil Fuels

When will we run out of our fossil fuels, oil, natural gas, and coal? Perhaps the best answer is “never”. We will always have enough for those who can afford them in commercial quantities, even if the amounts are small relative to today’s production and consumption, and if we are willing to tolerate the impact of extraction and utilization. In addition, in the future there almost certainly will be some entrepreneurial production of small quantities of fossil fuels where they had occurred naturally in great abundance, even if these fuels no longer could be produced commercially. In a very real sense, much of the world has already “run out” of fossil fuels. Millions of rural peasants, as in South Asia, China, and Indonesia, who subsist day to day, living off of the land and from the agricultural products that they can produce with the assistance of their domestic animals, receive few economic benefits from fossil fuels. They cannot afford automobiles and the gasoline needed to run them. They cannot afford bus and airline tickets and the benefits of public transportation. Their most common household fuels are dried animal dung and the bits of wood that they can gather from nearby forests. Even in the industrialized part of the world there are millions of people who cannot afford their winter heating bills and rely on public assistance to survive. With time, as the more abundant and economically viable fossil fuel resources become more costly to produce, they will “run out” for a progressively greater proportion of the world’s population. Nevertheless, with increasing urbanization in the next several decades, fossil fuels are expected to be used in greater amounts in the developing world than they are at present. Indeed, some fossil fuel costs, especially those for U.S. coal, are predicted to decline as mining operations become more and more efficient.

### 4.1. Non-renewable Resources

Fossil fuels are non-renewable resources. At all levels of aggregation of production data, from single wells or mines to pools, fields, mining districts, and to counties, countries, and continents, the life cycle of the resource begins when it is first produced, increases to some maximum amount as associated production and transportation infrastructure and markets develop, and then declines to zero as the resource is depleted and as the infrastructure ages, deteriorates, and is not replaced. In almost all instances, depletion is defined economically, rather than by the total exhaustion of the resource. In general, large amounts of oil and gas and coal may be abandoned in the ground in pools, fields, and mining districts as too costly to produce under existing social, technological, and environmental conditions, or because of effective competition from other fuels for the same markets. Economic depletion of fossil fuels occurs when the cost to produce, refine, and market a fuel exceeds the selling price of the product. The three examples that follow, the Richmond coalfield, Pennsylvania anthracite, and United States oil production, are provided as examples of economic depletion of fossil fuel resources at local, regional, and national levels in one country. Indeed, there are many examples of economic depletion of such non-renewable resources worldwide. Together they portend the ultimate worldwide decline in the production of oil, natural gas, and coal, and the associated economic perturbations that may occur as we move to other energy sources within this and the next century.

### 4.2. The Evolution of a Resource - The Richmond Coalfield: an Example of Coal Production and Depletion

Technology has been the major economic factor that controls the progressive development and production of fossil fuel deposits. Early coal mining in the United States (and in other countries) was labor intensive and animals (dogs, horses, and donkeys) commonly were used for transportation in and around underground mines. In the United States, Huguenot settlers first mined coal, of Triassic-age, in about 1703 near Richmond, Virginia. The first mines were relatively shallow and were developed by slopes into the gently to moderately inclined coal beds rather than by shafts. Adequate ventilation underground was difficult to establish, and in some mines ventilation was maintained only by the draft from coal-fired smoke stacks that were attached to the mines. The mines were gassy and the ventilation was not always able to reduce methane concentrations below explosive levels. Consequently, in some mines at the beginning of the day "Fire Bosses" were dressed in leather clothing and were doused with water before they entered the mines to burn off the methane that had accumulated at the face. Caged canaries were used as early warning signals for bad air.

At first, the coal was undercut by hand and then wedged downward in order to break it into manageable pieces. Eventually, when explosives were used underground, shot holes were drilled by hand, and in thin coal beds miners lay on their sides as they chopped and shoveled loose coals into baskets that were then transported to the mine entrance by burro. Most of the coal production from the Richmond Basin occurred from about 1790 to 1905. Production reached a maximum of 182,888 tonnes in 1835, and after 1905 mining occurred only sporadically until 1923, when it ceased altogether.

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**Biographical Sketch**

**R.C. Milici** is currently employed as a research geologist in the Eastern Energy Resources Team, by the U.S. Geological Survey in Reston, VA (1992-Present). Formerly Milici was employed as Commissioner of Mineral Resources and State Geologist of Virginia (1979-1991), and as a regional geologist for the Tennessee and Virginia geological surveys from 1958-1978. He has worked in the general area of the geology of fossil fuels (coal and oil and gas) since 1973 – and during the past 11 years has worked on assessments of coal and oil and gas resources in the Appalachian basin, as well as on a coal project in central India and a natural gas resource assessment of Bangladesh.