Chapter 1
Fossil Energy, Introduction

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To many in the sustainability community, fossil energy is an anathema. Continued use of fossil resources – oil, coal, and natural gas – poses threats to the environment through the emission of pollutants and greenhouse gases. The fact that they are a limited or exhaustible resource means that in the future we could either run out of them or their extraction will get progressively harder to a point that it takes more energy to extract them than would be derived from their use. Using fossil energy is clearly not sustainable, and the world has to look to renewable resources for long-term survival.

This is an encyclopedia about the science and technology of sustainability. The word, *sustainability* shares its root with *sustenance*. Any discussion of sustainability must therefore include discussions of sustenance, and in the context of modern society, sustenance stems from the use of energy. We derive energy from a number of different sources. Annual global consumption of energy is currently on the order of 500 exajoules (EJ), about 85% of which comes from fossil resources. From 500 EJ/year, the global energy demand is expected to rise to somewhere between 1,000 and 1,500 EJ/year by the middle of this century. The drivers for this increased demand are already in place. Large segments of China, India, and Brazil are poised to increase their standard of living – and the concomitant energy demand – substantially. If the average energy consumption in the Asia-Pacific region were to reach the current global average, which is about half of what is consumed in Europe and Japan, the demand would increase by an amount equal to the total energy consumption in the North America region. The challenge of achieving a sustainable future is in being able to balance the energy requirements for the

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billions of people so they can lead healthy and productive lives against the need to preserve the environment by not running into its limits in its ability to supply the resources or act as a sink for the waste [1]. The entries in this section examine the current status, assess the resource potential of the various fossil fuels, examine the technologies for using them, and review the environmental impact of their use.

Petroleum and natural gas have similar origin and often occur together in geologic formations, and their global distribution and production is discussed together in the entry by McCabe (▸Oil and Natural Gas: Global Resources). This entry makes clear the distinction between reserves and resources. Reserves represent only that fraction of the resource base that can be economically recovered using current technology. These are not fixed quantities as both technology and economics change over time. Global annual production (and consumption) of oil in 2010 was 31 billion barrels and of natural gas was around 120 trillion cubic feet. In energy units, they correspond to 180 EJ of oil and 120 EJ of natural gas [2]. The current reserves are estimated at 1,236 billion barrels of conventional oil (7,500 EJ) and 6,545 tcf of natural gas (6,500 EJ). The current reserves to production ratio (R/P) is about 40 for oil and about 55 for natural gas. The R/P ratio has often been mistakenly taken as the time to exhaustion, but new discoveries as well as advances in technology add to the reserves. In the case of oil, for example, the R/P ratio has stayed around 40–50 years for more than 60 years even with the steadily increasing oil consumption. In addition, there are also unconventional accumulations of these hydrocarbon resources and extracting them requires development of new technologies. In the case of oil, the unconventional resources are oil sands, oil shale, and heavy oil. Unconventional resources of natural gas are coal bed methane, tight gas, shale gas, and gas hydrates. These unconventional resources are vast and have the potential of more than doubling our resource endowment.

Exploration and production of oil from sedimentary deposits and oil sands is the subject of an entry by Speight (Petroleum and Oil Sands Exploration and Production). The processes for recovering oil could be a simple matter of drilling into the formation with the oil flowing to the surface under its own pressure, or it may require injection of gases, fluids, and surfactants to coax it to flow. In extreme cases, it may even require underground combustion of a portion of the resource to release the oil. Speight describes the chemical and physical factors that govern the flow of oil and the technology options currently available. In a different entry, Speight (▸Petroleum Refining and Environmental Control and Environmental Effects) provides and account of the different processes such as distillation, catalytic cracking, hydrotreating, reforming, and deasphalting used in the refining of crude oil. This entry also deals with environmental effects of the gaseous, liquid, and solid effluents from these processes. Production of oil from shale is principally achieved by retorting of shale, or other thermal processes including in situ pyrolysis. Oja and Suuberg (Oil Shale Processing, Chemistry and Technology) detail the chemistry and technology of these processes in the entry.

Gas hydrates represent a particularly noteworthy resource and are reviewed in the entry by Patil (Alaska Gas Hydrate Research and Field Studies). They are naturally occurring ice-like substances in which methane or other light gases are trapped in the cage structures formed by water molecules. They are stable under certain conditions of temperature and pressure, and can be found at many places around the world at depths of several hundred meters below the seabed and in the permafrost in the polar region. Global estimates of gas hydrates are on the order of 500,000 tcf, about a hundred times the proved reserves of natural gas. Apart from being a potentially very important source for energy in the future, the gas hydrates are also important from the perspective of climate change. A general warming could release substantial amounts of methane, which – being a potent greenhouse gas – would reinforce any global warming.

Oil remains the prized fuel. It has a high energy density and as a liquid it is well suited for transportation. The transportation sector relies on oil for over 90% of its energy needs (the remainder being mostly furnished by coal – via electricity) [3]. Given the importance of liquid fuels, there is considerable interest in converting coal and natural gas, the other hydrocarbon resources, into oil. In a pair of entries, Araso and Smith (Gas to Liquid Technologies and Coal to Liquids Technologies) provide an overview of the various processes for converting natural gas and coal to liquids. These reviews cover the basic chemistry and catalytic technologies behind the different approaches. The entry on Gas to Liquid Technologies deals with steam reforming of methane, autothermal reforming, and partial oxidation approaches for producing syngas, including strategies for managing the heat and mass transfer through the use of different reactor technologies. The entry next covers the conversion of syngas into liquids by Fischer-Tropsch (FT) synthesis. The entry on Coal to Liquids Technologies reviews the different approaches like pyrolysis, direct liquefaction, coprocessing with petroleum, and indirect liquefaction that first converts coal into syngas and then uses FT or other conversion processes to make liquid fuels.

The internal combustion engines that power these vehicles covert only about 20–30% of the energy in the fuel to motive power. Increasing the efficiency of the engines used in transportation represents a significant opportunity to reduce future demand for oil, as well as reduce the carbon footprint of the cars, trucks, and planes. Jacobs (Internal Combustion Engines, Developments in) provides a detailed account of the thermodynamics of the different kinds of engines and of the various technologies under development for improving the efficiency of the internal combustion engines. These include strategies such as engine downsizing, turbocharging, better controls, variable geometry engines, variable valve timing, homogeneous charge compression engines, and waste heat recovery.

Höök (Coal and Peat: Global Resources and Future Supply) reviews the global coal and peat resources, which are substantially larger than conventional oil and gas resources. Peat and coal are also distributed more evenly around the globe. The proved reserves of coal are estimated at between 800 billion and a trillion metric tons, representing roughly 20,000 EJ. Most coal is derived from trees and ferns that grew some 250–300 million years ago during the carboniferous period. Aerobic bacteria generally decompose most plant matter into CO_2, but when a tree fell into a swamp and was buried with limited exposure to oxygen, it could be partially preserved. That phenomenon occurs even today and is evidenced in the formation of peat (very young coal) in bogs. Unlike coal, peat has a low calorific content and its commercial use as an energy resource is limited. However, peat is important from global carbon cycle. Peat bogs store vast amounts of carbon, but the product of anaerobic decomposition, methane, contributes to greenhouse gases in the atmosphere such that under steady state conditions they comprise only a slight sink of carbon. The situation changes with fires as peat bogs become major source of carbon in the atmosphere. Human activities, such as drainage of the area for agriculture, exacerbate the situation, as more peat gets exposed and the swamp is not wet-enough to squelch the fire. Estimates of the amounts of carbon released from peat are on the order of several billion tons, the same order of magnitude as from fuels used in transportation or power production.

As coal resources are vast, they are likely to continue to contribute substantially to global energy mix. However, their use also presents a number of challenges, beginning with mining, and through coal preparation and use. Mining operations result in excavation of billions of tons of earth, and depending on the nature of the waste rock and how it is handled it can lead to contamination of air, water, and soils systems. The wide-ranging nature of environmental impact necessitates a commensurately broad portfolio of technologies for the remediation, restoration and reclamation. Chattopadhyay and Chattopadhyay (Mining Industries and Their Sustainable Management) provide an overview of the environmental impact of coal mining, and mining processes in general, as well as review the range of the chemical and biochemical strategies to mitigate the impact.

The run-of-mine coal is often laden with noncombustible minerals such as shale and clays that reduce its heating value. Cleaning and washing of coals removes many of these impurities and upgrades the coal into a marketable resource, improve the performance of power plants, and also reduce potential of harmful emissions and dust. Luttrell and Honaker (Coal Preparation) review these cleaning and preparation operations, and point out the importance of cheap preparation in extending the resource base.

Electricity is one of the most useful forms of energy; its importance to the way we live cannot be over emphasized. It can be used to perform all kinds of useful functions and services that people desire, and at the point of use it produces no pollution. Electricity is a secondary source of energy, as it must be produced from primary sources such as coal, natural gas, oil, nuclear, hydro and, of late, increasingly from wind and solar. In 2010, the global production of energy was 21,325 trillion kWh, which is equivalent to 77 EJ. However, since 68% of electricity is derived from burning fossil fuels at an average efficiency of 38%, the total primary energy the world consumed as electricity amounts to 135 EJ, or roughly 27% of the total energy consumed. Electricity demand in the world is projected to rise at a rate greater than for total energy, and meeting that need for additional sources for producing electricity is critical human welfare.

Several entries in this section are devoted to the production of electrical power. As the fuel with the lowest levelized cost of electricity, coal remains the dominant fuel for producing electricity, and furnishes over half of the electricity. It results in the emission of about 900 g CO_2 per kWh, highest of any fossil resource.

The development of coal power in future is going to be constrained by the concerns of CO_2 emissions, and Beer (CO_2 Reduction and Coal-Based Electricity Generation) discusses the different technology options for increasing the efficiency of coal-fired power plants and reducing the CO_2 emissions. Ultra supercritical steam cycles and combined heat and power applications are relatively straightforward to apply, and have the potential to reduce the largest tonnage of emissions.

Of course, there are other pollutants also that are emitted when coal is used for power productions. Chief among them are oxides of sulfur and nitrogen and toxic metals such as mercury, selenium, and arsenic, as well as carcinogenic PAH-containing soot aerosols. Moyeda (Pulverized Coal-Fired Boilers and Pollution Control) reviews the technologies for scrubbing the stack gas emissions. The deployment of scrubbers for the nitrogen and sulfur oxides following the Clean Air and Water Act in the 1980s greatly improved the quality of air and water systems.

Natural gas is the other major fuel for producing electric power. When used in a gas-fired combined-cycle mode, it produces only 380 g CO_2/kWh. Smith and Gülen (Natural Gas Power) review the technology for power generation from natural gas. They discuss the different sources of natural gas, provide a brief history followed by detailed thermodynamics of gas turbines, and modern power plants designs that incorporate combined cycle for maximum overall efficiency. They also review emissions from NGCC plants, notably NO_x, and strategies for minimizing them. The entry concludes with a discussion of power plant economics.

Carbon capture and sequestration (CCS) as a strategy for stabilizing atmospheric CO_2 levels is receiving considerable attention. Friedman (CO_2 Capture and Sequestration) provides an overview of the state of technology and the different embodiments of CCS. These cover various strategies for first capturing the CO_2, which may be performed pre- or post-combustion, or from the atmosphere. He discusses the energy requirements under these different scenarios. The entry also reviews the geochemistry of various options for sequestering the captured CO_2, either in deep saline aquifers or in other geological formations.

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