Part I Setting the scene

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Excerpt
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Introduction

The provision of clean, and sustainable, energy supplies to satisfy our ever-growing needs is one of the most critical challenges facing mankind at the beginning of the twenty-first century. It is becoming increasingly clear that the traditional ways in which we have satisfied our large, and growing, appetite for energy to heat our homes, power our industries, and fuel our transportation systems, are no longer sustainable. That this is so is partly due to the increasing evidence that emissions from fossil fuel usage are resulting in global climate change, as well as being responsible for local air pollution. It is also due to the realization that we are rapidly depleting the world's stock of fossil fuels, and replacement resources are getting more and more difficult to find and produce. The problem is made even more acute by the huge and rapidly growing appetite for energy in the developing world, where many countries are experiencing extremely high economic growth rates, leading to equally high demands for new energy supplies. In China, for example, total energy demand has been growing at an annual average rate of 4% in recent years, while in India it has been growing at 6%, compared with just under 2% in the rest of the world.

Global climate change, in particular the prospect for global warming, has put the spotlight on our large appetite for fossil fuels. Although there is considerable debate on the extent of the problem, there is no doubt that the atmospheric concentration of CO_2, one of the key "greenhouse gases," is increasing quite rapidly, and that this is likely due to mankind's activities on earth, or "anthropogenic" causes. The utilization of any fossil fuel results in the production of large quantities of CO_2, and most scientific evidence points to this as the main cause of increasing concentration levels in the atmosphere, and of small, but important increases in global average temperatures. Studies by the United Nations Intergovernmental Panel on Climate Change

(IPCC) have shown that the atmospheric concentration of CO_2 has risen from a level of around 280 ppm (parts per million) in pre-industrial times to nearly 370 ppm today, with most of the increase occurring in the last 200 years. The average global temperature over this same period appears to have risen by about 1 °C, with most of this occurring in the last 100 years or so. Computer modeling of the atmosphere by IPCC scientists, using a range of scenarios for future energy use, have suggested that over the next 100 years the concentration of CO_2 in the atmosphere may increase to a level between 540 ppm and 970 ppm, with a resultant rise in the global average temperature at the low end of 1.4 °C to a level of 5.8 °C at the high end. While mankind may be able to adapt easily to the relatively small changes in the global climate which would result from the lower estimate of temperature rise, at the higher end there would likely be significant and widespread changes, including a significant rise in sea-level around the world due to melting of polar ice caps and expansion of the warmer water in the ocean. At the extreme end there would also likely be increased desertification, particularly in low-latitude regions, and an increase in the volatility of global weather patterns. Of course, the widespread use of fossil fuels also results in significant local effects, in the form of increased levels of air pollution, primarily in large urban areas and centers of industrial concentration where the emission of oxides of nitrogen, unburned hydrocarbons and carbon monoxide lead to "smog" formation. These localized effects can result in serious health effects, as well as reduced visibility for the local population.

When energy use in any economic sector is examined in detail, the end-use can always be traced back to one (or more) of only three primary sources of energy: fossil fuels, renewable energy, or nuclear power. In order to understand the full implication of changes to our present pattern of energy utilization, however, it is necessary to consider the effects of any proposed changes on the complete energy system from primary energy source through to the final end-use. This is sometimes referred to as a "well-to-wheels" approach, in a reference to the complete energy supply and end-use pattern associated with providing fossil-fuel energy to motor vehicles. The same kind of assessment can be used to study any energy system, however, by considering the "energy conversion chain," which links primary energy sources to energy "carriers" like refined petroleum products and electricity, through to its ultimate end-use in the industrial, commercial, residential, or transportation sectors. This approach, which is outlined in more detail in the next chapter, is used throughout the book to provide an analysis of all the steps required in converting a primary energy source into its final end-use form. In this way all of the energy losses, and pollutant emissions, inherent in each of the conversion steps are taken into account so that a complete assessment of the overall energy system may be obtained. The need to establish a more sustainable global energy supply, without the threat of irreversible climate change, or the health risks associated with local air pollution, has led to many suggestions for improving current energy use patterns. Often, however, solutions that are proposed to address only one aspect of the complete energy conversion chain do not address in a practical way the need to establish a truly sustainable energy production and utilization system. This, as we shall see in later chapters, appears to be true for the so-called "hydrogen economy" which promises to be "carbon-free" at the point of end-use, but may not be so attractive if the complete energy conversion chain is analyzed in detail from primary source to end-use. By analyzing the complete energy conversion chain for any proposed changes to current energy use patterns, we can more readily see the overall degree of "sustainability" that such changes might provide.

The growing global demand for energy in all of its forms is naturally putting pressure on the declining supplies of traditional fossil fuels, particularly crude oil and natural gas. The large multinational energy companies that search for, and produce, crude oil and natural gas report that greater effort (and greater expense) is required to maintain traditional "reserves to production" levels. These companies have worked hard to keep the ratio of reserves to production (R/P) for crude oil at about 40 years, and for natural gas at about 70 years. However, in recent years few major new production fields have been found, and the exploration effort and cost required to maintain these ratios has been significantly increased. Ultimately, of course, supplies of oil and natural gas will be depleted to such an extent, or the cost of production will become so high, that alternative energy sources will need to be developed. In some regions of the world new production from non-traditional petroleum supplies, such as heavy oil deposits and oil-sands, are being developed to produce "synthetic" oil, and will be able to extend the supply of traditional crude oil. Coal is available in much greater quantities than either crude oil or natural gas, and the reserves to production ratio is much higher, currently on the order of 200 years. This ratio is sufficiently large to preclude widespread exploration for new coal reserves, although they are no doubt available. The challenges, however, of using coal in an environmentally acceptable manner, and for applications other than large-scale generation of electricity, are such that coal remains under-utilized.

Increasing concern about the long-term availability of crude oil and natural gas, and about the emission of greenhouse gases and pollutants from fossil-fuels, has led to increased interest in the use of coal to produce both gaseous and liquid fuels. Historically, coal was used to manufacture "producer gas" before the widespread availability of natural gas, and processes have also been developed to convert coal into synthetic forms of gasoline and diesel fuel. At the present time the commercial production of liquid fuels from coal is limited to South Africa, but other coal-producing countries are also now examining this as a possible option to replace liquid fuels derived from crude oil. Of course the greater utilization of coal in this way, or for the production of synthetic natural gas, would result in increased emission of greenhouse gases and other pollutants. As a result, there is also increasing research and development being conducted on so-called "carbon capture and storage," or "carbon sequestration" techniques. There are several proposed methods for separating the CO_2 which is released when coal is burned, or converted into synthetic liquid or gaseous fuels, and to store, or "sequester," this in some way so that it doesn't enter the atmosphere as a greenhouse gas. Proposals to date are at an early stage, particularly for the difficult CO_2 separation step, but there have been several pilot studies to establish the long-term storage of CO_2 in depleted oil and gas reservoirs. Other studies of the feasibility of storing large quantities of CO_2 in the deep ocean are also under way, but these are at a much earlier stage of development. If such carbon capture and long-term storage processes can be proven to be technically feasible and cost-effective, they could provide a way to expand the use of the very large coal reserves around the world, without undue concern about production of greenhouse gases.

At the present time our primary energy sources are dominated by non-renewable fossil fuels, with nearly 80% of global energy demand supplied from crude oil, natural gas, and coal. A more sustainable pattern of energy supply and end-use for the future will inevitably lead to the need for greater utilization of renewable energy sources, such as solar, wind, and biomass energy as well as geothermal and nuclear energy which many people consider to be sustainable, at least for the foreseeable future. Many assessments have shown that there is certainly enough primary energy available from renewable sources to supply all of our energy needs. Most renewable energy sources, however, have a much lower "energy density" than we are used to, which means that large land areas, or large pieces of equipment, and sometimes both, are required to replace fossil fuel use to any significant extent. This, in turn, means that the energy produced at end-use from renewable sources tends to be more expensive than energy from fossil fuels, even though the primary energy is "free." This is beginning to change in some cases, however, as fossil fuel prices continue to increase, and the cost of some renewable energy supplies, such as wind-power, drops due to improved technology and economies of scale. Other concerns with renewable energy arise due to their intermittent nature, however, and with the impact of large-scale installations, particularly in areas of outstanding natural beauty, or where there are ecological concerns.

Some observers are proposing the widespread expansion of nuclear power as one way to ensure that we have sufficient sources of clean, low-carbon, electricity for many generations to come. Although nuclear power currently accounts for nearly 7% of global primary energy supplies, there has been little enthusiasm for expansion of nuclear capacity in recent years. The lack of public enthusiasm for nuclear power appears to be primarily the result of higher costs of nuclear electricity production than was originally foreseen, as well as concerns over nuclear safety, waste disposal, and the possibility of nuclear arms proliferation. The nuclear industry has demonstrated, however, that nuclear plants can be operated with a high degree of safety and reliability, and has been developing new modular types of reactor designs which should be much more cost-effective than original designs, many of which date from the 1950s and 1960s. New nuclear plants are being built in countries with very high energy demand growth rates, like China and India, and electric utilities in the developed world are also starting to re-think their position on building new nuclear facilities. There will no doubt be a vigorous debate in many countries before widespread expansion of nuclear power is adopted, but it is one of the few sources of large-scale zero-carbon electricity that can be used to substantially reduce the production of greenhouse gases. The need for such facilities may increase if applications which have traditionally used fossil fuels, such as transportation, begin a switch to electricity as the energy carrier of choice, necessitating a major expansion of electricity generation capacity.

Transportation accounts for just over one-quarter of global energy demand, and is one of the most challenging energy use sectors from the point of view of reducing its dependence on fossil fuels, and reducing the emission of greenhouse gases and other pollutants. This is because the fuel of choice for transport applications is overwhelmingly gasoline or diesel fuel, due to the ease with which it can be stored on board vehicles, and the ubiquitous nature of the internal combustion engine which has been highly developed for over 100 years for this application. Although proposals have been made to capture and store CO_2 released during the combustion of fossil fuels in stationary applications, this is not a viable solution for moving vehicles of any kind. Hydrogen has been proposed as an ideal replacement for fossil fuels in the transportation sector, either as a fuel for the internal combustion engines now universally used, or to generate electricity from fuel cells on-board the vehicle. The use of hydrogen in either of these ways would result in near-zero emissions from the vehicle, of either greenhouse gases or other pollutants, and has been cited as an important step in developing the "hydrogen economy." If one looks at the complete energy conversion chain, however, it is clear that hydrogen is only the energy carrier in this case, and the primary energy source will necessarily come from either fossil fuels, or from renewable or nuclear sources, using electricity as an intermediate energy carrier. The use of renewable or nuclear energy as a primary source would result in zero emissions for the complete energy cycle, but the overall energy conversion efficiency would be very low, requiring a large expansion of the electricity-generating network. An alternative solution, with a much higher overall energy efficiency and lower cost, may be the successful development of "grid-connected," or "plug-in" hybrid electric vehicles, which use batteries charged from the grid to provide all of the motive power for short journeys, and a small engine to recharge the batteries if a longer range was required. In a later chapter we will examine these alternative transportation energy scenarios using the energy conversion chain approach.

The "energy problem," that is, the provision of a sustainable and non-polluting energy supply to meet all of our domestic, commercial, and industrial energy needs, is a complex and long-term challenge for society. Fortunately, man is by nature a problem-solving species, and there are many possible solutions in which future energy supplies can be made sustainable for future generations. The search for these solutions is, however, by its very nature a "multidisciplinary" activity, and involves many aspects of science, engineering, economics, and social science. The development of these solutions also tends to be very long-term, on the order of 10, 20, or even 50 years, and therefore far beyond the time-frame in which most politicians and decision-makers think. We must, therefore, develop new long-term methods of strategic thinking and planning, and make sure that some of the best minds, with a wide range of skills and abilities, are given the tools to do the job. This book summarizes the current state of the art in balancing energy demand and supply, and tries to provide some insight into just a few of the many possible scenarios to build a truly sustainable, long-term, energy future. No one individual can provide a "recipe" for energy sustainability, but by working together across a wide range of disciplines, we can make real progress towards providing a safe, clean, and secure energy supply for many generations to come.

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The energy conversion chain

Every time we use energy, whether it's to heat our home, or fuel our car, we are converting one form of energy into another form, or into useful work. In the case of home heating, we are taking the chemical energy available in natural gas, or fuel oil, and converting that into thermal energy, or "heat," by burning it in a furnace. Or, when we drive our car, we are using the engine to convert the chemical energy in the gasoline into mechanical work to power the wheels. These are just two examples of the "Energy Conversion Chain" which is always at work when we use energy in our homes, offices, and factories, or on the road. In each case we can visualize the complete energy conversion chain which tracks a source of "primary energy" and its conversion into the final end-use form, such as space heating or mechanical work. Whenever we use energy we should be aware of the fact that there is a complete conversion chain at work, and not just focus on the final end-use. Unfortunately, many proposals to change the ways in which we supply and use energy take only a partial view of the energy conversion chain, and do not consider the effects, or the costs, that the proposed changes would have on the complete energy supply system. In this chapter we will discuss the energy conversion process in more detail, and show that some proposed "new sources" of energy are not sources at all, and that all energy must come from only a very few "primary" sources of energy.

A schematic of the global "energy conversion chain" is shown in Figure 2.1. Taking a big-picture view, this chain starts with just three "primary" energy sources, and ends with only a few end-use applications such as commercial and residential building heating, transportation, and industrial processes. Taking this view, our need for energy, which can always be placed broadly into one of the four end-use sectors shown on the far right in Figure 2.1, anchors the "downstream" end of

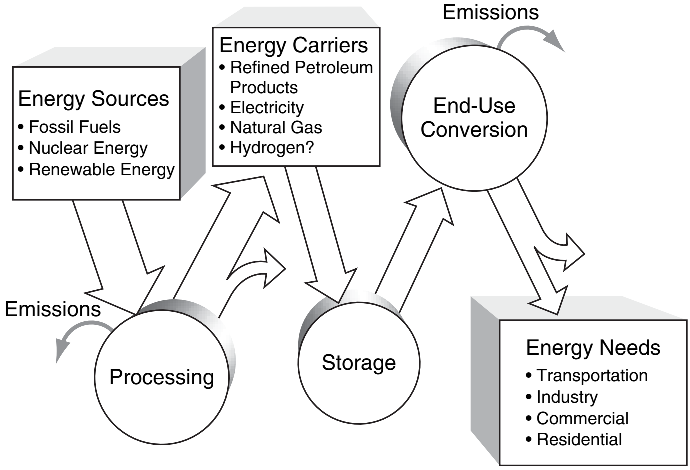

Figure 2.1 The energy conversion chain.

the conversion chain. This energy need is always supplied, ultimately, from one of the primary sources of energy listed on the far left-hand side of the diagram. In between the primary source and the ultimate end-use are a number of steps in which the primary source is converted into other forms of energy, or is stored for use at a later time. To take a familiar example, in order to drive our car, we make use of a fossil fuel, crude oil, as the primary energy source. Before this source provides the motive power we need, however, the crude oil is first "processed" by being converted into gasoline in an oil refinery, shown in the second step in Figure 2.1. The result of this processing step is the production of a secondary form of energy, or what is usually called an energy "carrier." Also, in this step there is usually some loss of energy availability in the processing step, as indicated by the branched arrow joining the processing block to the energy carrier block. There are, again, relatively few energy carriers, as shown in the third step of the diagram. Broadly speaking, these are refined petroleum products (gasoline in our car example), electricity, natural gas, and potentially, hydrogen. Once the primary source has been converted into the carrier of choice, it is usually stored, ready for later use in the final energy conversion step. In our automobile case, the gasoline is stored in the fuel tank of the vehicle, ready for use by the engine. When we start the engine, and drive away, the final step in the energy conversion chain is undertaken. This is the final end-use conversion step in which the chemical energy stored in the gasoline is converted into mechanical work by the engine