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Introduction, Brief History, and Chosen Approach

ABSTRACT

Because energy is essential to provide the basic needs of humanity, namely food, clean fresh water, fuel for transportation, the generation of electricity, and the production of heat, it is at the core of economic and social activity; and because energy is consumed by people, estimates of the consumption of energy during the 21st century need to be based on projections of the size, composition, and mode and amount of energy use of the human population of the world. Estimates of the possible supply of energy are based on the availability of the presently known sources: principally oil, natural gas, coal, and hydroelectric and nuclear power. The development of these estimates is the objective of this study. They support the conclusion that, although the global distribution of energy sources is obviously uneven, during the 21st century, there will be sufficient sources to adequately satisfy the demand for energy of a human population whose growth rate shows signs of starting to level off.

INTRODUCTION

The ascent of mankind, from its appearance on Earth to its present condition, has depended on the availability of food, clean fresh water, certain materials, and energy. These are not independent factors; they are interrelated in many ways, and the circumstances of their availability and efficacy of their use have established important milestones in the progress of humanity. Each and every one of these factors is essential for the prosperity and growth of every country and every region of the world; sustaining and enhancing our quality of life depend on them. To speculate about the future of the human family and to attempt to predict the circumstances under which it will live or perish, we must consider whether these essentials of human life will be available in the future in the quantities necessary to maintain a growing world population.

Although the global distribution of energy sources is obviously uneven, there will probably be adequate energy resources for a world population whose growth rate shows signs of starting to level off. The inevitable price fluctuations and transportation problems will mean periodic shortages in some areas of the globe. Continuing technological progress in many fields, from petrochemistry and electronics to more efficient energy transformation and use, will stretch the available resources while lessening negative impacts on the environment. Much depends on the ability of the world's political leaders to fashion realistic long-range policies while continuing to support the scientists and technical specialists who work toward cleaner energy sources at reasonable cost.

A BRIEF HISTORY

The availability and use of energy has had a fundamental influence throughout the history of mankind. The ''discovery'' and control of fire completely changed people's everyday life. It allowed them to keep warm, to drive off predators, to cook, to dry and harden wood, and to heat and split bones and gave them access to

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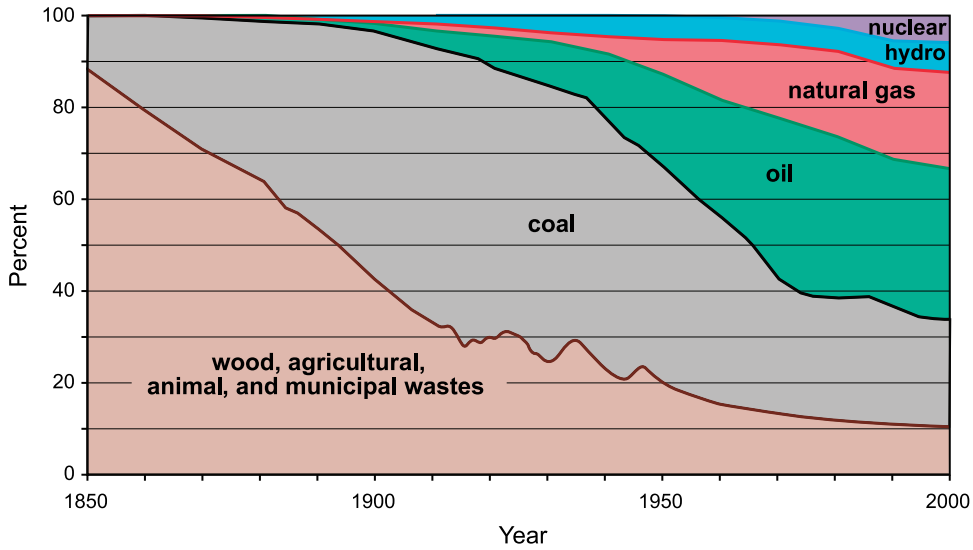

Figure 1. World primary energy sources (generalized after Nakicenovic et al., 1998).

an entirely new class of materials: the metals. Similar changes were brought by the subsequent use of the wind, running water, coal, the steam engine, oil and natural gas, and nuclear power. Each new source of energy provided new benefits and physical comforts. Energy is at the core of economic and social activity. The conditions governing supply, transportation, distribution, and consumption of energy affect all individuals everywhere in the industrialized countries as well as in the Third World. An adequate supply of energy is essential for the achievement of political, social, and economic stability and world peace, a matter of life or death for all humanity.

Energy sources are needed to fight hunger and poverty. Tractors, other agriculture equipment, trucks, trains, and cargo ships that increase the efficiency and mechanization of agriculture and make possible the transportation and distribution of food all need energy to run. The availability of energy therefore will be critical to ensure enough food for the world's growing population. Similarly, availability of a source of energy will determine the eventual feasibility of desalinating sea water as clean fresh water becomes insufficient for the needs of an increasing world population. Fossil fuels (oil and coal) are used in the production of plastics, which have replaced some metals and other materials in innumerable products; and energy is necessary to produce the materials crucial in an advanced civilization.

In discussing the consumption and sources of supply of energy in the 21st century, it is essential to keep in mind that energy is used, in order of importance,

- to fuel land, water, and air transport (cars, trucks, tractors, trains, ships, and airplanes)
- to generate electricity
- to produce heat

Before the Industrial Revolution, during the last half of the 18th century, the main sources of energy to provide mankind with heat, light, and work were wood, agricultural residues, and animal wastes (what have been called the ''traditional renewables'') and, to a small extent, wind and running water.

The introduction of the steam engine during the Industrial Revolution opened a new chapter in the use of energy and brought a considerable increase in the production and use of coal. During the second half of the 19th century and the first two decades of the 20th century, coal and the traditional renewables supplied more than 90% of the energy consumed in the world. By the end of the 19th century, coal had replaced the traditional renewables as the principal energy source over much of the world (Figure 1).

The beginning of the 20th century witnessed the introduction of two revolutionary innovations in energy use: electricity and the internal combustion engine. Electricity provided new and safer sources of light, heat, and work; the internal combustion engine completely transformed transportation. Other new sources of energy were put into use: oil, hydropower, and eventually, natural gas (see Nakicenovic et al., 1998, p. 11–14).

Crude oil, ''discovered'' in 1859 in the United States, progressively replaced coal during the 20th century as the principal source of energy, and during the middle part of the century, 60–70% of world energy demand was supplied by coal and oil (Figure 1). Most of this demand was for transportation fuels and for the generation of electricity, the demand for which increased rapidly during the 20th century. The main fuels for generating electricity during the early and middle parts of the 20th century were coal, hydropower, and oil. Demand for natural gas increased during

the second half of the 20th century, particularly as a cleaner fuel for the generation of electricity.

At the start of the 21st century, more than 80% of the demand for energy is supplied by oil, coal, and natural gas; they provide all the fuels for transport and 65% of the primary energy for the generation of electricity. Traditional renewables are still used, particularly in many developing countries, and hydropower and nuclear power provide about 35% of the input for the generation of electricity, but only about 10% of the total energy supply.

Other sources of energy, namely geothermal, solar (photovoltaic), and wind, make only a minute contribution to the total supply of energy in the early years of the 21st century. In considering their potential contribution during the rest of this century, we must keep in mind that solar and wind power, as well as hydropower and nuclear power, will be used mainly in the generation of electricity. Geothermal power can be and has been used as a source of heat in addition to its contribution to electricity generation; wind can be used to pump water and grind grain, and solar power is also used directly to heat water. However, the enormous demand for land, water, and air transportation fuels can only be supplied at this time (and for a long time in the future) by the fossil fuels: oil, natural gas, and coal.

The quantity of energy economically available during the 21st century will determine, to a considerable extent, how people live and what their standard of living will be. What will the future bring? As the human population of the world continues to increase and as people aspire to a higher standard of living, will energy sources be available to supply the growing demand? What sources of energy will supply the demand?

The present study tries to answer these questions.

ANALYTICAL APPROACH

To estimate the rates of energy consumption during the 21st century, I experimented with several possible approaches. I finally came to the conclusion that the most direct and best approach was to first compile the past trends of human population size and rates of growth and of consumption of energy. These trends could then be combined to obtain the past trends of consumption of energy per capita, not only for the whole world, but also for specific countries, groups of countries, and regions of the world. These trends could then be combined as needed and extrapolated into the 21st century.

The next most promising approach would have been to attempt to establish for these countries or groups of countries the historical trends of energy consumption per unit of economic activity, as expressed by the gross domestic product (GDP) or some other economic indicator— what has been called ''energy intensity'' (the amount of primary energy needed per unit of economic output). Estimates of the consumption of energy in the 21st century would then be based on the extrapolations of these trends of energy intensity.

The first approach proved to be more direct and preferable. To compile historical statistics on population and on energy consumption (two fairly objective pieces of information) and to compute past trends of energy consumption per capita on the basis of this information was reasonably easy and involved only two variables. Statistics on economic activity, on the other hand, proved much more difficult to obtain and were found to be considerably less well documented and commonly inconsistent, particularly in the case of the developing countries. As stated by Nakicenovic et al. (1998, p. 16), ''A major difficulty in comparing GDPs across countries is the need to translate everything into a common currency. Most often, this is done using market exchange rates, with the United States dollar as the common currency. Problems arise for several reasons. First, not all economies have a free market for foreign currency exchange. Second, the use of market exchange rates implicitly assumes that domestic prices are comparable with international prices. This is not the case for most developing countries, where prices for food and basic services, for example, are substantially below international levels. Third, many transactions are not accounted for in the formal economy, especially in less developed economies.'' In addition, many economists have come to doubt that there is a necessary direct relationship between GDP and energy consumption, and statistics show that this certainly seems to be the case. Finally, to attempt to use trends of economic activity would involve three variables: population, consumption of energy, and economic activity, making the process considerably more complicated.

Economic indicators (conservation and efficiency in the use of energy, cost of production and transportation of energy and its effect on the price of energy, and possible economic improvements resulting from new and better technology) were, of course, used in projecting the consumption of energy into the 21st century.

Following the chosen approach, the results of this study will be presented in five sections.

The first section deals with the historical trends of the size and growth rates of human population and of energy consumption and energy consumption per capita since the middle of the 20th century. It is critical

for the purpose of this study to know how many people have lived on Earth during the 20th century, how this population has been distributed in the various regions of the world, and what the trends of population growth were. The volumes of energy consumption and the levels of energy consumption per capita in the various regions provide essential historical data. Without that, it would be futile to try to estimate the multiple aspects of energy consumption in the 21st century.

The second section attempts to extrapolate the historical population and energy consumption trends into the 21st century.

The third section deals with the sources that have supplied energy in the past and that most likely will supply it in the future.

The fourth section deals with the generation and consumption of electricity historically and in projections for the future.

The fifth and final section of the study discusses five scenarios of estimated energy consumption during the 21st century and the possible sources of energy that may supply it. These five forecasts are based on the historical data discussed in the previous four sections; the key to predicting the future is understanding the past. For each scenario, the choices of basic information, assumptions, and predictions of possible future developments will be specified, documented, and discussed.

The first, third, and fourth sections are reasonably objective; the second and fifth necessarily involve numerous assumptions and a considerable level of uncertainty. The predictions and estimates of future developments and events range from fairly well-documented inferences to guesses, some of relatively minor significance, others critical to the results of the study.

Multiple projections within ranges believed to be realistic have been made in some cases: population growth, increase in the efficiency of energy use, ultimate recovery of some energy sources, and others. Obviously, assumptions, predictions, and estimates had to be attempted to generate a picture of the consumption and possible sources of energy in the 21st century, the objective of this study. Like gemstones, predictions need not be perfect to be valuable.

Readers are, of course, free to disagree with these assumptions, predictions, and estimates. However, they will have available the historical statistical data assembled in this study, on the basis of which they can make their own assumptions and derive their own predictions of the probable consumption and sources of energy in the 21st century.

The five forecasts of supply and use of energy during the 21st century do not include energy provided by wood, charcoal, and agricultural, animal, or other wastes, important as they may have been and still are in some regions of the world (Figure 1). It has been said that as late as about 1940, more energy was obtained worldwide from agricultural wastes than from hydrocarbon fuels, and that in 1959, farm wastes contributed between 10 and 15% of world energy requirements or three times that provided by wood. This may or may not be true. These sources of energy are the most poorly documented, and their consumption is very difficult to estimate. The percentage of the total world energy consumption supplied by wood, charcoal, and the various types of wastes, as shown in Figure 1, is highly conjectural. In the developed countries, both wood and farm wastes have progressively been replaced by more convenient sources of energy, but in many developing countries, wood, charcoal, and agricultural wastes still provide an important percentage of the energy requirements.

It has been mentioned earlier, but it may be worthwhile to state again, that the overall energy picture for the 21st century presented in this study is generally optimistic for three reasons:

- There will be plenty of energy sources to supply the demand, although their uneven geographic distribution will, in some cases, result in long-distance transport and price fluctuations, which may restrict at certain times their availability and affordability in certain countries and regions of the world.
- The growth rate of the world's population is decreasing and may, perhaps, nearly reach stability toward the end of the 21st century.
- Advances in present technologies will make possible a better, more efficient, and environmentally more benign supply and use of energy.

The demand for energy by the world's population, for the most part, will be satisfied. However, this optimistic outlook should not breed overconfidence. The future supply of energy is perhaps the most urgent question facing the world, and it is possible that a misguided choice of energy policies will create problems of many kinds, including critical environmental problems. Energy policies will need early and careful consideration and action.