Future Energy: Opportunities and Challenges

Part III. Energy Demand

Chapter 14. Population and Energy Demand

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Future Energy:
Opportunities and Challenges

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14
Population and Energy Demand

The Main Points

- **World population will be a major factor in determining future energy needs (maybe THE major factor).**
- **Traditional population growth is exponential in nature.**
- **The population growth rate is currently slowing.**
- **World population is expected to grow from 6.8 billion (2009) to over 9 billion by the mid-twenty-first century.**
- **Most of the future population growth will be in developing countries.**
- **The preponderance of the increased population will expect to have more energy.**

14.1 Introduction

World population has been growing exponentially for many years. Much of this growth has been–and is continuing–in developing countries, where the population expects to increase its standard of living and to have the energy required for this increase. The energy issue for the future is intimately related to population and demographics.

It is clear that population growth cannot continue indefinitely. World resource limitations will eventually limit population. The resource base includes exhaustible resources and renewable resources. A sustainable world population depends on the capacity of renewable resources to replace exhaustible resources as they are depleted, coupled with some acceptable level of per capita consumption.

Through the years, attempts have been made to assess the maximum sustainable population of the world. Many analysts have estimated the maximum sustainable world population. Their results are generally wrong. Some of their estimates are even lower than the 2009 world population of around 6.8 billion.

Stabilizing population at some level above the current level may not be good enough. Actual population reductions may be necessary to achieve sustainability. Availability of all of the resources needed to sustain increased populations will be an issue, but food availability is the most fundamental resource needed for survival. The so-called "Green Revolution" that started in the mid-twentieth century provided greatly increased agricultural production, but this was achieved with fertilizers and pesticides that were produced from fossil hydrocarbons. Energy for irrigation and farm machinery also comes from fossil hydrocarbons. The question is, "What will happen to agricultural production and the number of people that can be sustained when fossil hydrocarbons become scarce or unavailable?"

14.2 Population History

The world and U.S. population histories are shown in Figures 14.1 and 14.2.[1] 2009 populations were around 6.8 billion for the world and 306 million for the U.S. Both world and U.S. populations currently exhibit exponential growth.

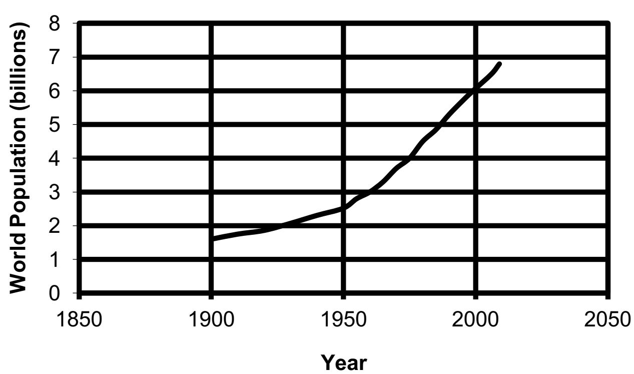

Figure 14-1. World Population History

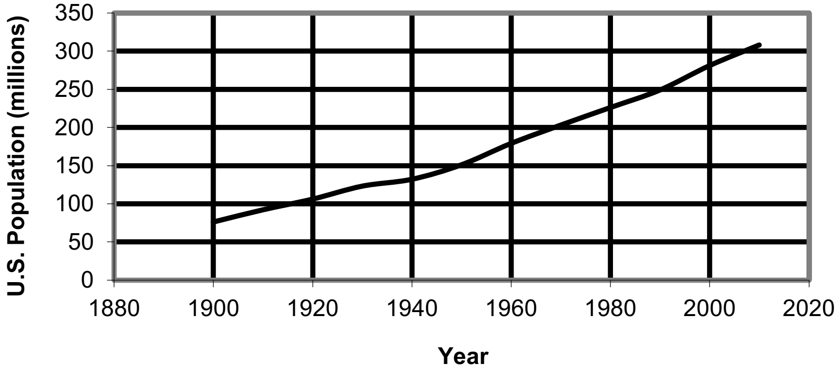

Figure 14-2. U.S. Population History

14.3 Exponential Population Growth

Exponential population growth is represented mathematically by:

$$dP/dt = (b\text{-}d)P \tag{14-1}$$

where

P	=	population
t	=	time
dP/dt	=	the rate of change of population
b	=	birth rate
d	=	death rate

The solution to Equation 14-1 is:

$$P = P_0 \exp((b\text{-}d)t) \tag{14-2}$$

where:

P_0 = population at a selected starting time ($t = 0$)

It can be shown that the time required to double a population that is growing exponentially is given by:

$$T_d = 0.693/(b\text{-}d) \tag{14-3}$$

where:

T_d = time required to double the population

The quantity (b-d) is called the rate of natural increase. For the world, the birth rate in the early twenty-first century is about 21 births per thousand people ($b = 0.021$), and the death rate is about nine deaths per thousand people ($d = 0.009$). The doubling time for world population (assuming constant values of b and d) is 60 years. For the U.S., the birth rate is about 14 births per thousand people, and the death rate is about eight, giving a doubling time of 116 years.

14.4 The Demographic Transition and Population Stabilization

Slowing of population growth occurs with a decreasing birth rate and/or an increasing death rate. Statistics show the worldwide death rate has been decreasing. This decrease is due to better sanitation, better health care, and better nutrition. Simultaneously, the birth rate has been decreasing throughout most of the world. Many factors account for this decrease, but societal and economic forces are the basis for most of these factors. The shift from high birth rates and high death rates to an era of low birth rates and low death rates is called the Demographic Transition.

Figure 14-3 shows a plausible, but hypothetical, path to population stabilization. The population curve has the S-shaped (sigmoid) behavior seen in Chapter 4 and Appendix F in estimating future fossil hydrocarbon production and consumption.

One is tempted to turn to logistic function modeling, as was used successfully to forecast U.S. oil production (see Section 4.2.6 and Appendix F).

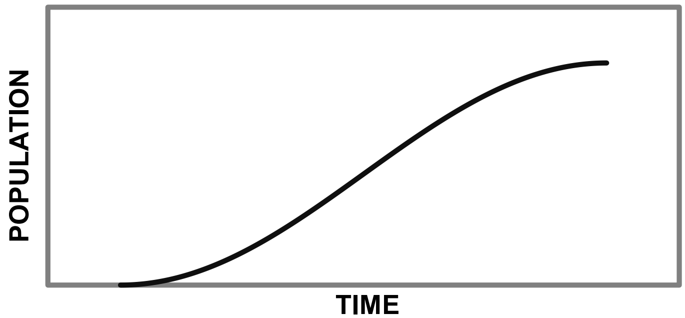

Figure 14-3. A Hypothetical Path to Population Stabilization

However, predicting future population involves complications. For example, how would projections change if we should find that growth rates had been increased by the temporary availability of resources such as oil? A plausible outcome is that the population that is sustainable without the availability of these resources is smaller than what would have been possible with continued availability. In this case, population would peak and then decline to a resource-constrained level. Figure 14-4 shows a hypothetical population curve for such a scenario. Other complications include the possibility of wars, pandemics, and famines that would result in decreased populations and technological advances that would enable larger sustainable populations. The conclusion is population forecasting is even more uncertain than resource forecasting.

14.5 Total Fertility Rates

Another way to assess the factors that influence population growth is with total fertility rates. If there were no deaths among women before the end of child-bearing age, and male and female populations were equal, then replacing the existing population would require a total fertility rate of exactly 2.0 children per woman. The total fertility rate required for replacing the existing population under actual conditions is called the replacement rate and is currently around 2.1 for developed countries and between 2.5 and 3.3 for developing countries, where early mortalities are more frequent. Values of

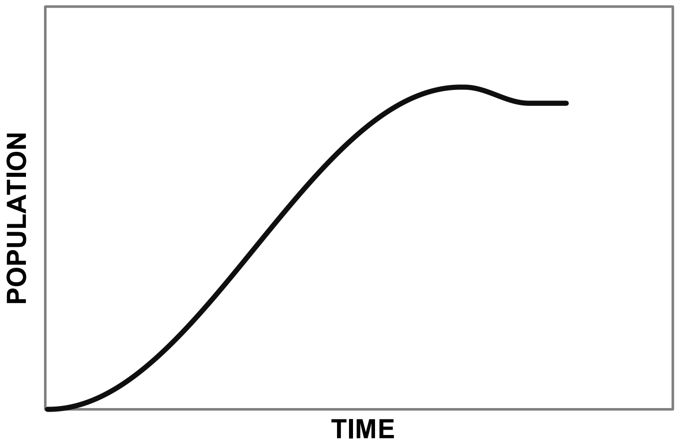

Figure 14-4. A Hypothetical Path Following a Period of Temporary Abundance

total fertility rate below the replacement rate are referred to as sub-replacement rates.

The total fertility rate in the U.S. dropped from around four in 1900 to around two in the early twenty-first century. The world total fertility rate is around 2.7 and is decreasing. These decreases are cause for optimism that the world population will stabilize at a sustainable level. Some developed countries are already experiencing population decreases. Of course, this does not happen without concomitant problems, one of which is funding for pensions for older citizens through taxes on working citizens.

14.6 Future Population Estimates

The U.S. Census Bureau has estimated future population levels[2]. The estimates are that world population will increase from its 2009 level of 6.8 billion to around 8 billion in 2025 and 9.5 billion in 2050. Other estimates generally fall around 9 billion for 2050. Interestingly, while the estimate for the U.S. is to increase to 357 million in 2025 and 439 million in 2050, the estimate for western Europe is to increase from around 400 million to 406 million in 2025, then decrease to 387 million in 2050.

14.7 Energy Implications

Energy requirements are the product of the number of people and the energy required per person. Demographers provide population estimates as presented above. The energy required per future world citizen can only be provided by educated guesswork.

One approach is to assume everyone will demand as much energy as is currently consumed by U.S. citizens. 306 million U.S. citizens currently use about 100 Quads (about 330 million BTU per person) per year. If the world population reaches 9 billion in 2050, and each person requires 330 million BTU per year, the world energy demand would be about 3,000 Quads per year, or about six times the current world energy consumption. One might argue that assuming that everyone will become as energy hungry as modern Americans is absurd because world citizens will choose to practice greater conservation, efficiency, and simplicity because of cultural differences or because of energy supply difficulties. On the other hand, one might argue that future citizens will need at least as much energy as Americans currently use because of the need for more energy for activities such as growing food on less-productive land and extracting mineral resources from increasingly lean deposits. These increases could cancel out reductions in energy demand achieved through increased conservation, efficiency, and simplicity.

It is instructive to assess the energy resources required to produce 3,000 Quads per year. In order to get a feel for the quantities required, consider the facilities needed to produce 3,000 Quads totally from each energy production option. Of course, the energy production serving future populations will be derived from a mix of sources, but the calculation illustrates the scope of the effort needed if everyone were to reach current U.S. levels of consumption. Here are the numbers, along with some comparisons:

- Crude oil: around 500 billion barrels per year (the remaining world reserve estimates range from 1,000 to 2,000 billion barrels)

- Coal: around 120 billion tons per year (the U.S. currently consumes slightly more than 1 billion tons per year)

- Land to grow biomass (60% conversion to biofuel efficiency): more than 30 billion acres (the continental U.S. land area is 1.9 billion acres)

- 1,000 MWe nuclear power plants (90% availability and 40% thermal to electrical efficiency*): around 45,000 plants (the U.S. now has around 100 plants)

- 2.5 MWE wind machines (30% availability): around 50 million machines**

- Land for 30% efficient photovoltaic electrical systems: around 200 million acres**

(*Note: The total world energy requirement of 3,000 Quads per year is primary energy. An advanced 1,000 MWe nuclear plant produces about 2,500 thermal megawatts.)

(**Note: For wind, hydropower and photovoltaics, each directly produced electrical watt is equivalent to about 2.5 watts of thermal energy consumed in a thermal plant.)

The assessment presented above serves only to illustrate the magnitude of the problem of satisfying future energy appetites. However, these numbers permit you to make your own assumptions and to assess the consequences of those assumptions. For example, if you assume that world per capita energy consumption in 2050 will be one-fourth of current U.S. per capita consumption and also assume coal will provide one-fourth of that energy, then the estimated annual coal consumption is 120 billion tons × 0.25 × 0.25 = 7.5 billion tons, or 7.5 times current U.S. consumption.

14.8 The Bottom Line

World population will grow in the future, and world energy demand will grow even faster than population growth as more people want more energy to support better lifestyles. Satisfying these future energy demands will be difficult because of their magnitude and because of the depletion of traditional energy resources. The total energy requirements will be reduced somewhat if birth rates continue to decrease, but wise energy policy is to expect and prepare for large increases in population and in energy requirements in the future.

References

1. Population Reference Bureau "2007 World Population Data Sheet" at http://www.prb.org.

2. U.S. Census Bureau web site at http://www.census.gov.

Exercises

14-1. The death rate of the world population was around nine deaths per 1,000 people in 2000. It was dropping at around 10 percent per year. Why was it dropping? What change do you expect to see in the rate of decline in the death rate? Why?

14-2. A country's population is composed of two ethnic groups that do not intermarry. The population of group A is 90 percent of the total population and is decreasing at 1 percent per year. The population of group B is 10 percent of the total population and is increasing at 2 percent per year. If current rates of change persist, how long will it be before each group has the same population?

14-3. The children's riddle of the French lily pond is as follows: Lilies growing on the surface double every year. Fifty years after lilies started growing in the pond, they cover half of the surface. How long will it take to cover the whole surface?

14-4. Estimate the number of 5 MWe wind turbines that will be needed in 2050 if the world per capita energy consumption is one-fourth of current U.S. per capita consumption and these wind turbines provide 10 percent of that energy.