1.6: Sustainable Energy- Away from the Sun and Back Again

As discussed in more detail in Chapter 15, the key to sustainability is abundant, environmentally safe energy. The evolution of humankind's utilization of energy is illustrated in Figure 1.6.1. Until very recently in the history of humankind we have depended upon the sun to meet our energy needs. The sun has kept most of the land mass of Earth at a temperature that enables human life to exist. Solar radiation has provided the energy for photosynthesis to convert atmospheric carbon dioxide to plant biomass providing humans with food, fiber, and wood employed for dwelling construction and fuel. Animals feeding on this biomass provided meat for food and hides and wool that humans used for clothing. Eventually humans developed means of indirectly using solar energy. This was especially true of wind driven by solar heating of air masses and used to propel sailing vessels and eventually to power windmills employed for power. The solar-powered hydrologic cycle provided flowing water, the energy of which was harnessed by water wheels. Virtually all the necessities of life came from utilization of solar energy.

The Brief Era of Fossil Fuels

Dating from around 1800, humankind began to exploit fossil fuels for their energy needs. Initially, coal was burned for heating and to power newly developed steam engines for mechanical energy used in manufacturing and steam locomotives. After about 1900 petroleum developed rapidly as a source of fuel and, with the development of the internal combustion engine, became the energy source of choice for transportation needs. Somewhat later natural gas developed as an energy source. The result was a massive shift from solar and biomass energy sources to fossil fuels. Utilization of fossil carbon-based materials resulted in a revolution that went far beyond energy utilization. One important example was the invention by Carl Bosch and Fritz Haber in Germany in the early 1900s, of a process for converting atmospheric elemental nitrogen from air to ammonia, NH_3 by the reaction of N_2 with H_2. This high-pressure, high-temperature process required large amounts of fossil fuel to provide energy and to react with steam to produce elemental hydrogen. The discovery of synthetic nitrogen fixation enabled the production of huge quantities of relatively inexpensive nitrogen fertilizer and the resulting increase in agricultural production may well have saved Europe, with a rapidly developing population at the time, from widespread starvation. (It also enabled the facile synthesis of great quantities of nitrogen-based explosives that killed millions of people in World War I and subsequent conflicts.) Fossil fuel, which has been described as "fossilized sunshine,"[7] resulted in an era of unprecedented material prosperity and an increase in human population from around 1 billion to over 6 billion.

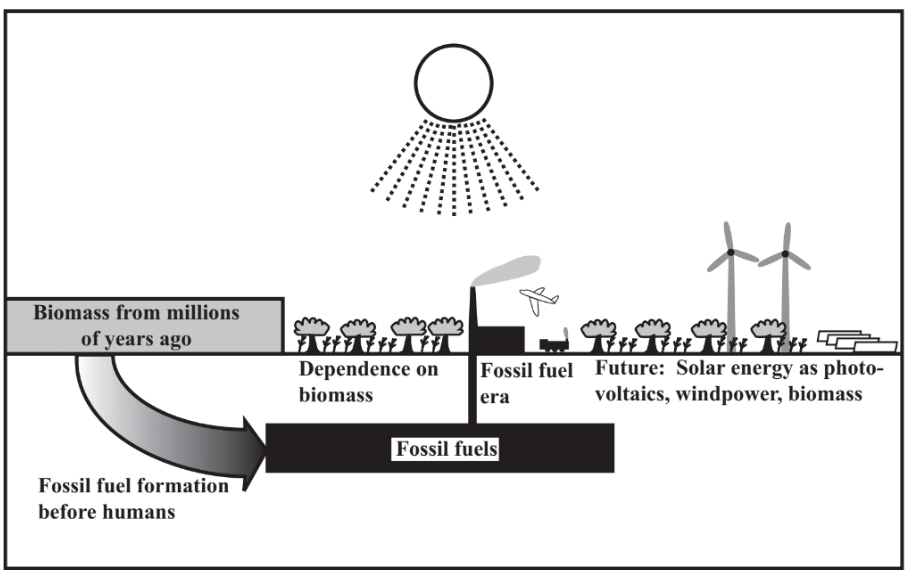

Figure 1.6.1, Evolution of the use of energy from solar and biomass sources through the brief, but spectacular, era of fossil fuels and on to renewable solar-based sources

By the year 2000 it had become obvious that the era of fossil fuels was not sustainable. One reason is that fossil fuel is a depleting resource that cannot last indefinitely as the major source of energy for the industrial society to which it has led. Approximately half of the world's total petroleum resource has already been consumed so that petroleum will continue to become more scarce and expensive and can last for only a few more decades as the dominant fuel and organic chemicals raw material. Coal is much more abundant, but its utilization leads to the second reason that the era of fossil fuels must end because it is the major source of anthropogenic atmospheric carbon dioxide, greatly increased levels of which will almost certainly lead to global warming and massive climate change. Natural gas (methane, CH_4) is an ideal, clean-burning fossil fuel that produces the least amount of carbon dioxide per unit energy generated. Rapidly expanding new discoveries of natural gas largely from previously inaccessible tight shale formations means that it can serve as a "bridging fuel" for several decades until other sources can be developed. Nuclear energy, properly used with nuclear fuel reprocessing, can take on a greater share of energy production, especially for base load electricity generation. But clearly drastic shifts must occur in the ways in which energy is obtained and used.

Back to the Sun

With the closing of the brief but spectacular era of fossil hydrocarbons, the story of humankind and its relationship to Planet Earth is becoming one of "from the sun to fossil fuels and back again" as humankind returns to the sun as the dominant source of energy and photosynthetic energy to convert atmospheric carbon dioxide to biomass raw materials. In addition to direct uses for solar heating and for photovoltaic power generation, there is enormous potential to use the sun for the production of energy and material. Arguably the fastest-growing energy source in the world is wind-generated electricity. The wind is produced when the sun heats masses of air causing the air to expand. Once the dominant source of energy and materials, biomass produced by solar-powered photosynthesis is beginning to live up to its potential as a source of feedstocks to replace petroleum in petrochemicals manufacture and of energy in synthetic fuels (see Chapter 14,"Chapter 14 Feeding the Anthrosphere: Utilizing Renewable and Biological Materials" and Chapter 15, "Sustainable Energy: The Essential Basis of Sustainable Systems"). Biomass is still evolving as a practical source of liquid fuels. The two main ones of these are fermentation to produce ethanol and synthesis of biodiesel fuel made from plant lipid oils. Unfortunately, although ethanol made from sugar derived from sugar cane that grows prolifically in some areas such as Brazil is an economical gasoline substitute, the net energy gain from ethanol derived from cornstarch relies on the grain, the most valuable part of the plant otherwise used for food and animal feed; the net energy gain is marginal. The economics of producing synthetic biodiesel fuel from sources such as soybeans may be somewhat better. However, production of this fuel from oil palm trees in countries such as Malaysia is resulting in destruction of rain forests and diversion of palm oil from the food supply.

Practical means do exist to utilize biomass for energy and materials without seriously disrupting the food supply. Arguably the best way to do that is to thermochemically convert biomass to synthesis gas, a mixture of CO and H_2 that can be combined chemically by long-established synthetic routes to produce methane, larger-molecule hydrocarbons, alcohols and other products (see Chapter 15). The main pathway for so doing is to utilize biomass from renewable non-food biosources, which include crop byproducts (wheat straw, rice straw, cornstalks produced in surplus during the production of grain) and dedicated crops among which are highly productive hybrid poplar trees and sawgrass. Microscopic algae are especially promising as a biomass source because of their much higher productivity than terrestrial plants, their ability to grow in brackish(somewhat saline) water in containments in desert areas, and their ability to utilize sewage as a nutrient source. When biomass is used to produce synthesis gas, the essential nutrients, especially potassium and phosphorus, can be reclaimed from the biomass residues and used as fertilizer material to promote the growth of additional biomass.

Future scientific discoveries and technological advances will play key roles in the achievement of energy sustainability. Three areas in which Nobel-level breakthroughs are needed in the achievement of energy sustainability were expressed in a February 2009 interview by Dr.Steven Chu, a Nobel Prize winning physicist who had just been appointed Secretary of Energy inU.S. President Barack Obama's new administration. The first of these is in solar power in which the efficiency of solar energy capture and conversion to electricity needed to improve several-fold. A second area of need is for improved electric batteries to store electrical energy generated by renewable means and to enable practical driving ranges in electric vehicles. A third area in need of a quantum leap is for improved crops capable of converting solar energy to chemical energy in biomass by photosynthesis at much higher efficiencies than the current levels of less than 1%achieved by many crops. In this case the potential for improvement is enormous because most plants convert less than 1% of the solar energy falling on them to chemical energy through photosynthesis. Through genetic engineering, it is likely that this efficiency could be improved several-fold leading to vastly increased generation of biomass. Clearly, the achievement of sustainability employing high-level scientific developments will be an exciting development in decades to come