Chapter 1
Energy: An Overview

1.1 Introduction

World energy pundits have long proclaimed that the fossil fuels in the Earth's crust are limited and will be exhausted some day. This argument is similar to the accepted pronouncements of cosmologists that "the entropy of the Universe is increasing towards a maximum" or that "the sun will one day burn itself out." The world energy crisis of 1973 was precipitated when OPEC curtailed oil production and fixed their own price for oil for the first time, and within a year, the price of oil went from $2/bbl in early 1973 to more than $11/bbl by the spring 1974. This was aggravated by the increase in oil imports to the USA, which ceased to be self-sufficient in oil in the late 1960s. By 1990, the USA imported 47% of its crude oil, compared to 73% in 1973. In 2008, the USA bought 65% of its crude oil abroad, and the cost of imported oil and refined oil products was the single largest contributor—48%—to the country's more than $700 billion trade deficit. By 1998, the average price of crude oil had fallen to less than $12/bbl (a mere $16/bbl in 2008 dollars), and the oil industry's stocks were one of the worst performing investments of the 1990s. Not until the early years of the new millennium, when oil prices began to rise again, did attention return to energy supply. During the latter half of 2003, the price of crude oil reached $25/bbl–$30/bbl, and during 2004, it came close to, and briefly even rose above, $40/bbl. The upward trend continued in 2005 and for the first 8 months of 2006, and the media came to comment routinely on record high prices. According to Dr. Vaclav Smil's study of myths and realities of energy supply, no records were broken once two key price corrections—adjusting for the intervening inflation and taking into account lower oil intensity of Western economies—were made. Until the early summer 2008, these doubly adjusted oil prices remained well below the records set during the early 1980s.

In August 2006, the weighted mean price of all traded oil peaked at more than $71/bbl; it then fell by 15% within a month and closed the year at about $56/bbl. But during 2007, it again rose steadily. By November 2006, it reached almost $100/bbl in trading on the New York Mercantile Exchange (NYMEX; see http://www.oilnergy.com/1onymex.htm and http://www.eia.gov/emeu/international/oilprice.html), and during the first half of 2008, that price rose by half, reaching a high of $147.27/bbl on July 11, 2008. As always, prices for the basket of OPEC oils, including mostly heavier and more sulfurous crudes, remained lower (see www.opec.org and http://en.wikipedia.org/wiki/Brent_Crude). But just after setting a record, oil prices fell by more than 20%, to about $115/bbl. By November 12, 2008, the price had fallen below $50/bbl, and a year later, it was around $75/bbl, a rise largely caused by the falling value of the US dollar.

The present world price for oil is about $100–110/bbl in 2011 and it is expected to eventually increase again. In the long term, world liquids consumption increases after 2014 and rise to more than $130 per barrel by 2035 (IEA Outlook 2010, p. 23).

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Table 1.1 GDP (PPP) and GDP (MER) top in the world 2009

GDP (PPP) top in the world 2009			GDP (MER) top in the world 2009		
Country	PPP current US$	World (%)	Country	GDP current US$	World (%)
USA	14,256	20.42	USA	14.256	24.61
China	8,765	12.56	Japan	5,068	8.75
Japan	4,159	5.96	China	4,909	8.47
India	3,526	5.05	Germany	3,353	5.79
Germany	2,806	4.02	France	2,676	4.62
UK	2,139	3.06	UK	2,184	3.77
Russia	2,110	3.02	Italy	2,118	3.66
France	2,108	3.02	Brazil	1,574	2.72
Brazil	2,013	2.88	Spain	1,464	2.53
Italy	1,740	2.49	Canada	1,336	2.13
Mexico	1,466	2.10	India	1,236	2.13
Korea	1,364	1.95	Russia	1,229	2.12
Spain	1,361	1.95	Australia	997	1.72
Canada	1,281	1.84	Mexico	875	1.51
Indonesia	962	1.38	Korea	833	1.44
World	*69,809*		*World*	*59,937*	

The global economic recession that began in 2008 and continued into 2009 had a profound impact on world income (as measured by gross domestic product GDP) and energy use. According to Table 1.1, world energy consumption increased by 49%, or 1.4% per year, from 495 quadrillion Btu in 2007 and is expected to need 739 quadrillion Btu in 2035 (IEA Outlook 2010, p. 9). The price of oil will depend on demand as well as the financial needs of the oil producers. The successful development of alternate energy sources, e.g., fusion, could bring the price down. Since energy is an integral part of every function and product from food (which requires fertilizer) to plastics which are petroleum based, to steel or other metals which require energy for extraction, beneficiation, reduction, and fabrication, worldwide inflation can be directly attributed to the rising price of oil.

The International Energy Agency (IEA) has estimated that world increasing demand for energy will require a total investment of $20 trillion (value in 2005 dollars) by 2030 out of which about $11 trillion would be needed in the global electricity sector alone. Worldwide, the race is on to increase exploitation of existing oil fields and to find new ones. Capital expenditure in the oil industry amounts to just one-fifth of the total energy investment.

Projected oil development programs in North America required a total investment of $856 billion over 2005. In order to restore Iraqi oil production to the 1990 level, some $5 billion was needed over the following 6 years, and, in a rapid growth scenario, production could reach 5.4 million barrels per day by 2030 at a cost of $54 billion. China will need a total of $7 trillion investments, which is 18% of the total investment. The IEA states that total investment of $20 trillion is required by the global oil and gas industry to keep pace with the anticipated demand over the next 30 years, of which about $700 billion is needed to support the Middle East oil sector. Oil from the Persian Gulf region will play an increasingly important role in the world economy.

Global investments in Russia’s energy sector are projected to exceed $195 billion by 2030. Peak investment was in 2010 for prospecting new oil fields and gas reserves, maintaining old ones and improving the infrastructure for transporting oil. According to the IEA, the total level of investment in oil transportation will increase sixfold by 2030. Russia is poised to become one of the leading exporters of oil and gas by 2030, gaining an important niche in many markets, including Asia (see Figs. 1.1 and 1.2).

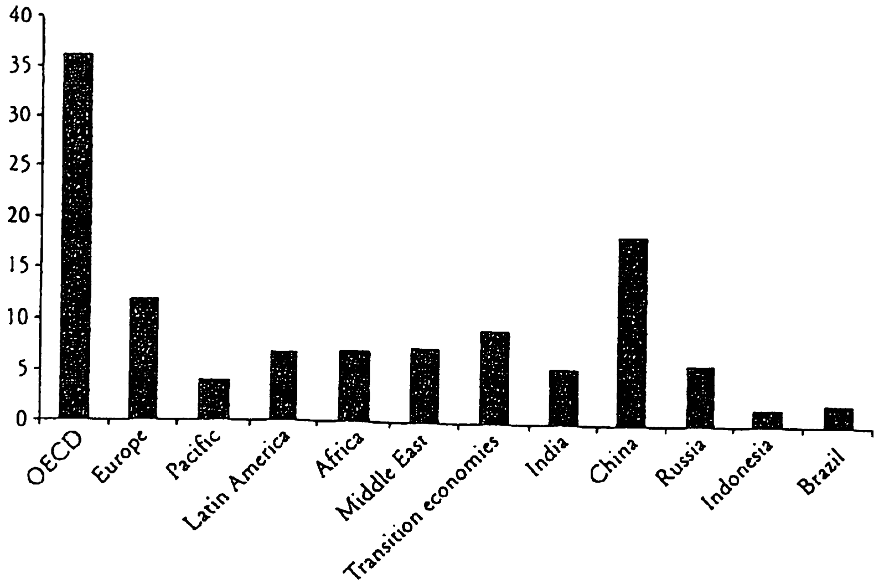

Fig. 1.1 Share of energy investment in different countries and groups, 2005–2030

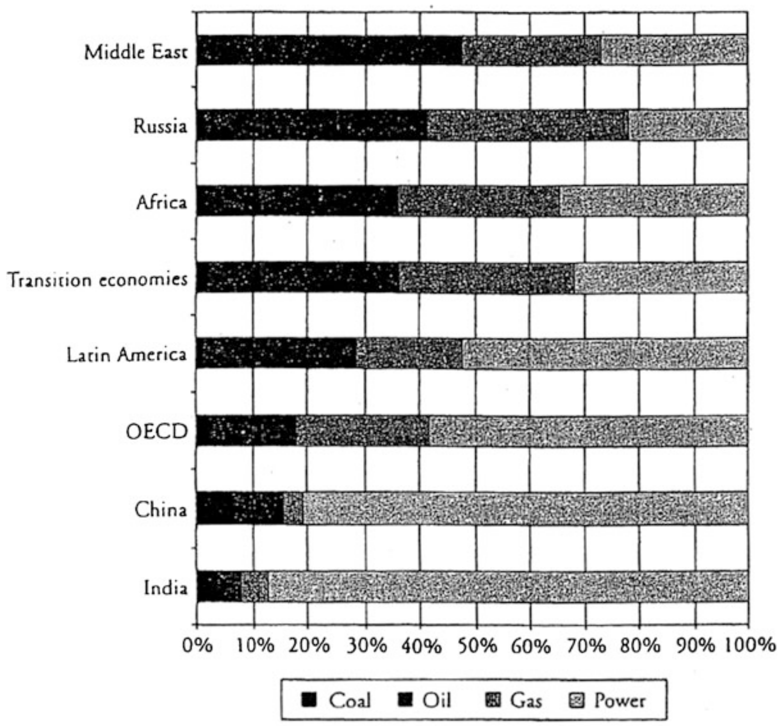

Fig. 1.2 The changing patterns of fuel share in energy investment requirements, 2005–2030 (Source: IEA 2006a)

Worldwide electricity demand will be increased to 5,100 GW electricity generating capacity by 2030 and about half of that needs to be built in Asia. Europe will need to invest about $1.7 trillion on power plants, transmission, and distribution to meet increasing demand for electricity and maintain the current capacity. Germany alone anticipates a new capacity around 40,000 MW in electricity

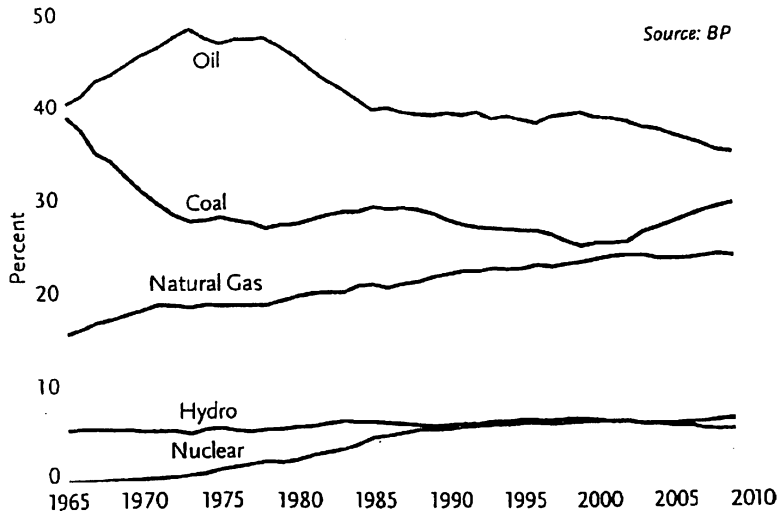

Fig. 1.3 The changing patterns of world energy consumption as a percentage of total usage, 1965–2009 (Source: BP)

production, which corresponds roughly to 60 large-scale power plants (IEA 2006). Developing countries will account for over half of the total investment over the next 20 years, or \$10.5 trillion, with transition economies accounting for \$1.85 trillion. Brazil's energy sector will need investments of \$250 billion to meet the country's electricity demand in the next 20 years. More than \$1 trillion will need to be spent on China's transmission and distribution networks—an amount equivalent to 2.1% of China's annual GDP. India will need an investment close to \$100 billion in electric and oil sectors.

An illustration of the importance of energy to the world economy is shown in Fig. 1.3, where the changing patterns of world energy consumption as a percentage of total usage are plotted from 1965 to 2009. Comparison of the global per capita energy consumption and its patterns in major regions is shown in Fig. 1.4. In general, the higher the GNP[1] of a country, the larger is its per capita energy consumption. Energy is essential to progress and there is no substitute for energy. Society's use of energy has continuously increased, but sources have invariably changed with time.

It is interesting to note that the per capita use of commercial energy for the UK and the USA has been essentially constant for 100 years whereas that for Germany, Russia, and Japan showed an exponential growth (doubling time of 12 years) toward the constant US/UK values (see Tables 1.1 and 1.2). The world's population grew up fast from 2.5 billion people (1950) to 5 billion people (1987), 6 billion people (1997), and 6.8 billion people (2009). The world's population will be grown up about 9.1 billion people by 2050. The effect of the world's population growth on energy usage is obvious.

Energy can conveniently be classified into renewable and nonrenewable sources as shown in Fig. 1.5. Such a division is quite arbitrary and is based on a timescale which distinguishes hundreds of years from millions.

According to IEA Outlook 2010 in January 1, 2010, the world's total proved natural gas reserves were estimated at 6,609 trillion cubic feet. As of January 1, 2010, proved world oil reserves were estimated at 12 billion barrels (see Table A-1 in Appendix for the conversion of energy units and Tables 1.3, 1.4, and 1.5). The USA reported 22.5 billion barrels of proved reserves in 1998, proved reserves of 19.1 billion barrels were reported in 2009—a decrease of only 3.4 billion barrels despite the cumulative 24.2 billion barrels of liquids supplied from the US reserves between 1998 and 2009 (IEA Outlook 2010, p. 37).

[1] The gross domestic (national) product (GDP or GNP) is the sum total of the market value of goods and services produced per annum for final consumption, capital investment, or for government use.

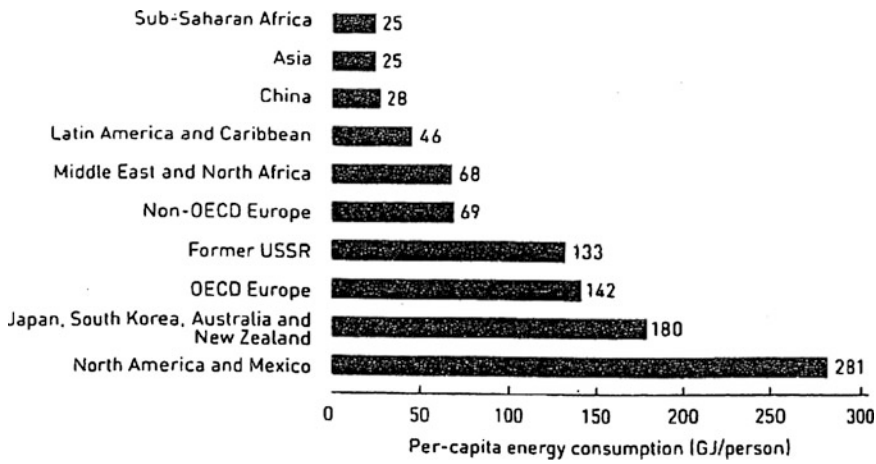

Fig. 1.4 Comparison of per capita energy consumption in major regions

Table 1.2 Comparison of the economic performance and per capita use of commercial energy in various countries

	USA	China	EU	Japan	India	Russia	Brazil
Economic size relative to the USA, current dollars, and market exchange rates 2009, %	100	33	113	35	9	9	10
GDP per capita relative to US, current exchange rates 2009, %	100	8	67	85	2	19	17
GDP per capita relative to the USA, PPP exchange rates 2009, %	100	14	66	71	6	32	23
Real GDP growth, 1999–2009 p.a. average, %	2.5	9.9	1.9	1.1	6.3	1.6	2.5
Population 2007, proportion of the USA	1.00	4.37	1.65	0.42	3.73	0.47	0.63
Share of world merchandise exports, 2008, excluding intra-EU exports, %	10.6	11.8	20.4	6.5	1.5	3.9	1.6
Trade to GDP ratio, 2004–2006 excluding intra-EU trade for EU, %	25.9	69.0	20.2	28.8	41.8	55.8	26.4
Share of world carbon dioxide emissions from energy consumption, 2007, %	20.1	21.0	15.7	4.2	4.7	5.6	1.3
Share of world military spending in US$, 2009, %	43.0	6.6	11.0	3.3	2.4	3.5	1.7
Deployed and other nuclear warheads, 2010	9,600	240	525	0	60–80	12,000	0

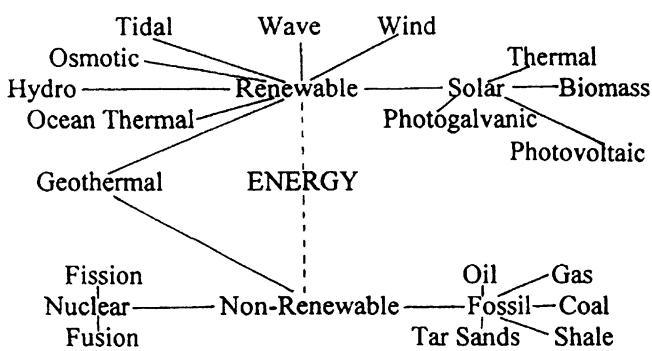

Fig. 1.5 A classification of energy sources

Table 1.3 World reserves of fossil fuels (IEA 2006)

Area	Natural gas, trillion cubic feet (2007)	Natural gas, quads (1998)	Oil, billion barrels (2007)	Oil, quads (1998)	Coal, million short tons (2005)	Coal, quads (1998)
North America	283.6	297	212.5	395	272,569	7,900
Latin America	240.7	221	102.7	430	17,941	660
Western Europe	180.3	166	15.8	110	50,781	2,755
East Europe, CIS	2,014.8	1,950	98.9	355	249,117	8,000
Africa	484.4	350	114.0	425	54,680	1,870
Middle East	2,556.0	1,723	739.2	3,770	1,528	5
Australia, Far East	419.5	430	33.4	290	283,807	8,910
Total	6,189.4	5,137	1,316.7	5,775	930,423	30,100

Table 1.4 World consumption of energy by sources in 1986, 1995, 1997, and 2006 (quads, IEA 2006)

	1986	%	1995	%	1997	%	2006	%
Oil	126.6	40.4	141.1	38.9	148.7	39.3	171.7	36.3
Coal	86.3	27.5	77.5	21.4	92.8	24.6	127.5	27
Natural gas	62.3	19.9	93.1	25.7	83.9	22.2	108.0	22.8
Hydroelectric energy	21.3	6.8	25.7	7.2	26.6	7.1	29.7	6.2
Nuclear energy	16.3	5.2	23.2	6.4	24.0	6.3	27.7	5.9
Renewable sources	0.7	0.2	1.6	0.4	1.8	0.5	4.7	1.0
Total	313.5	100	362.2	100	377.8	100	472.3	100

Table 1.5 World oil reserves by country as of January 1, 2010 (bbl—billion barrels)

Saudi Arabia	259.9 bbl/19.20%
Canada	175.2 bbl/12.94%
Iran	137.6 bbl/10.16%
Iraq	115.0 bbl/8.50%
Kuwait	101.5 bbl/7.50%
Venezuela	99.4 bbl/7.34%
United Arab Emirates	97.8 bbl/7.22%
Russia	60.0 bbl/4.43%
Libya	44.3 bbl/3.27%
Nigeria	37.2 bbl/2.75%
Kazakhstan	30.0 bbl/2.22%
Qatar	25.4 bbl/1.88%
China	20.4 bbl/1.51%
USA	19.2 bbl/1.42%
Brazil	12.8 bbl/0.95%
Algeria	12.2 bbl/0.90%
Mexico	10.4 bbl/0.77%
Angola	9.5 bbl/0.70%
Azerbaijan	7.0 bbl/0.52%
Norway	6.7 bbl/0.49%
Rest of world	72.2 bbl/5.33%
World total	1,353.7 bbl/100.00%

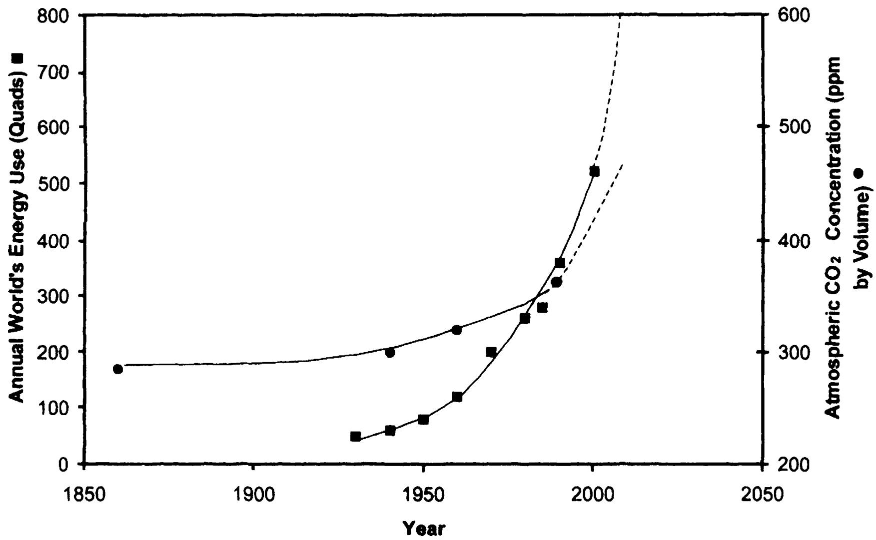

Fig. 1.6 The concentration of carbon dioxide in the Earth's atmosphere as a function of time

According to the *Oil & Gas Journal*, 56% of the world's proved oil reserves are located in the Middle East. Just below 80% of the world's proved reserves are concentrated in eight countries, of which only Canada (with oil sands included) and Russia are not OPEC members. Oil and gas production has still been slowly rising with oil production expected to peak in 2035. Gas production is expected to peak by 2050 and so will last only slightly longer, assuming that more oil and gas resources are made available. Coal is the major fossil fuel on Earth and consists of over 75% of the available energy (see Tables 1.3 and 1.4 and Fig. 1.2). Present world energy consumption is given in Table 1.4 and Fig. 1.4.

Conservative considerations of our energy consumption predict that coal will supply 1/4–1/3 of the world's energy requirements by the year 2050. Its use can be relied upon as an energy source for about another 200 years; however, other considerations (such as the greenhouse effect and acid rain) may restrict the uncontrolled use of fossil fuel in general and coal in particular.

The increase in use of fossil fuel during the past few decades has resulted in a steady increase in the CO_2 concentration in the atmosphere. This is shown in Fig. 1.6. In 1850, the concentration of CO_2 was about 200 ppm, and by the year 2025, the estimated concentration will be about double present values (350 ppm) if fossil fuels are burned at the present rate of 5 Gton of C/year. By the year 2025, the world's energy demands will have increased to over 800 Quads from 472 Quads in 2006 and 250 Quads in 1980, respectively. If a large fraction of this energy is fossil fuel, i.e., coal, then the annual increase in the concentration of CO_2 in the atmosphere is calculated to be greater than 10 ppm.

The CO_2 in the atmosphere is believed to have an adverse effect on the world's climate balance. The atmosphere allows the solar visible and near ultraviolet rays to penetrate to the Earth where they are absorbed and degraded into thermal energy, emitting infrared radiation which is partially absorbed by the CO_2, water vapor, and other gases such as CH_4 in the atmosphere (see Fig. 1.7).

There is at present a thermal balance between the constant energy reaching the Earth and the energy lost by radiation. The increase in CO_2 in the atmosphere causes an increase in the absorption of the radiated infrared from the Earth (black body radiation) and a rise in the thermal energy or temperature of the atmosphere. This is called the *greenhouse effect*. Temperature effects are difficult to calculate and estimates of temperature changes vary considerably, although most agree that a few degrees rise in the atmospheric temperature (e.g., 3°C by the year 2025) could create deserts out of the prairies and convert the temperate zones into tropics, melt the polar ice caps, and flood coastal areas. For example,

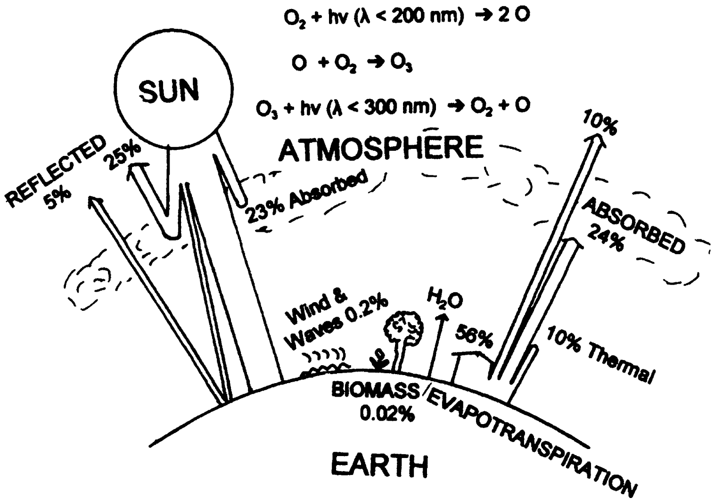

Fig. 1.7 The greenhouse effect—a schematic representation

for a 1°C rise in the Earth's temperature, the yield of wheat would be expected to drop by 20%, though rice yields might rise by 10%. If the average temperature of the oceans increased by 1°C, the expansion would cause a rise in sea level of about 60 cm (assuming no melting of glacier ice).

One uncertain factor in the modeling and predictions is that there is a lack in a material balance for CO_2, i.e., some CO_2 is unaccounted for indicating that some CO_2 sinks (i.e., systems which hold or consumed CO_2) have not been identified. The oceans and forests (biomass growth) consume most of the CO_2, and it is possible that these sinks for CO_2 may become saturated or on the other hand some new sinks may become available. With such uncertainties, it is obvious that reliable predictions cannot be made. However, the climate changes which will occur as the CO_2 concentration increases are real and a threat to world survival. Recent measurements by satellites of the temperature of the upper atmosphere over a 10-year period have indicated no overall increase in temperature. This measurement has yet to be confirmed.

Coal is considered the "ugly duckling" of fossil fuel as it contains many impurities which are released into the atmosphere when it is burned. An important impurity is sulfur which introduces SO_2 and SO_3 into the atmosphere, resulting in acid rain that can actually change the pH of lakes sufficiently to destroy the aquatic life. The acid rain is also responsible for the destruction of the forests in Europe and the eastern parts of Canada and the USA. The clean conversion of coal to other fuels may circumvent the pollution problems, but would not overcome the greenhouse effect since CO_2 ultimately enters the atmosphere.

Thus, the depletion of fossil fuels may not be soon enough and tremendous efforts are being made in the search for viable economic alternatives such as nuclear energy or renewable energy such as solar, wind, tidal, and others (Table 1.6).

1.2 Renewable Energy Sources

Ultimate sources of renewable energy are the Earth, which gives rise to geothermal energy, the Moon, which is responsible for tidal power, and the Sun, which is the final cause of all other hydro, wind, wave, thermal, and solar photodevices. A brief discussion of each source is essential for an overall appreciation of the difficulties we are facing and possible solutions to our energy requirements.

Table 1.6 World natural gas reserves by country as of January 1, 2010 (trillion cubic feet)

World	6,609 trillion cubic feet 100.0%
Top 20 countries	6,003 trillion cubic feet 90.8%
Russia	1,680 trillion cubic feet 25.4%
Iran	1,046 trillion cubic feet 15.8%
Qatar	899 trillion cubic feet 13.6%
Turkmenistan	265 trillion cubic feet 4.0%
Saudi Arabia	263 trillion cubic feet 4.0%
USA	245 trillion cubic feet 3.7%
United Arab Emirates	210 trillion cubic feet 3.2%
Nigeria	185 trillion cubic feet 2.8%
Venezuela	176 trillion cubic feet 2.7%
Algeria	159 trillion cubic feet 2.4%
Iraq	112 trillion cubic feet 1.7%
Australia	110 trillion cubic feet 1.7%
China	107 trillion cubic feet 1.6%
Indonesia	106 trillion cubic feet 1.6%
Kazakhstan	85 trillion cubic feet 1.3%
Malaysia	83 trillion cubic feet 1.3%
Norway	82 trillion cubic feet 1.2%
Uzbekistan	65 trillion cubic feet 1.0%
Kuwait	63 trillion cubic feet 1.0%
Canada	62 trillion cubic feet 0.9%
Rest of world	606 trillion cubic feet 9.2%

1.3 Geothermal

Thermal energy from within the Earth's crust is classified as geothermal energy. At depths greater than 10 km, the temperature of the magma is above 1,000°C and is a potential source not yet fully exploited. The temperature of the Earth's core is about 4,000°C. Drilling to depths of 7.5 km is presently possible and may someday reach 15–20 km. The surface source of thermal energy is due to the decay of natural radioactive elements and to the frictional dissipation of energy due to the movement of plate tectonics. The heat is usually transmitted to subsurface water which is often transformed into steam that can force water to the surface. Old Faithful at Yellowstone National Park, WY, USA, is an example of a geyser erupting 50 m every hour for 5 min (see Fig. 1.8).

The International Geothermal Association (IGA) has reported that 10,715 MW of geothermal power in 24 countries is online, which is expected to generate 67,246 GWh of electricity in 2010. This represents a 20% increase in geothermal power online capacity since 2005. IGA projects will grow to 18,500 MW by 2015, due to the large number of projects presently under consideration, often in areas previously assumed to have little exploitable resource. In 2010, the USA led the world in geothermal electricity production with 3,086 MW of installed capacity from 77 power plants; the largest group of geothermal power plants in the world is located at the Geysers a geothermal field in California. The Philippines follows the USA as the second highest producer of geothermal power in the world, with 1,904 MW of capacity online; geothermal power makes up approximately 18% of the country's electricity generation. Last January 2011, Al Gore said in The Climate Project Asia Pacific Summit that Indonesia could become a super power country in electricity production from geothermal energy. Geothermal energy is exploited near San Francisco where a 565-MW power plant is run on geothermal steam, and 15 MW of thermal energy from hot water reservoirs is used for heating and industrial heat processes. At present, there are five geothermal plants in operation in Mexico with a total output of more than 500 MW. Similar uses of geothermal energy have been developed in Italy, Japan, Iceland, USSR, and New Zealand, and it is rapidly being exploited in many other parts of the world.

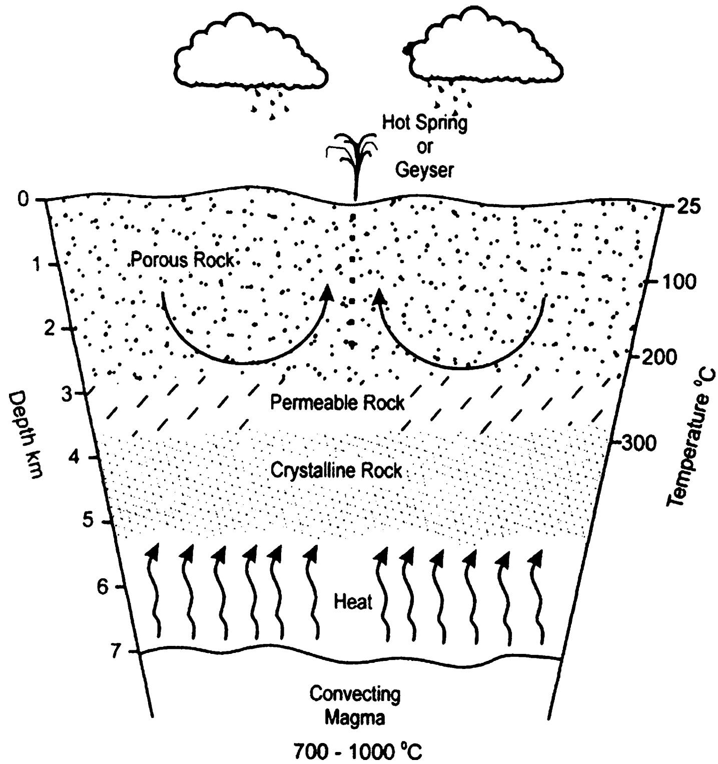

Fig. 1.8 A schematic representation of geothermal energy

It has been estimated that the geothermal energy in the outer 10 km of the Earth is approximately 10^{23} kJ or about 2,000 times the thermal energy of the total world coal resources. However, only a small fraction of this energy would be feasible for commercial utilization. Estimates of geothermal energy presently in use and converted into electrical power is about 2×10^3 MW. The greater use of geothermal energy could help save much of our energy needs and would reduce the rate of increase of CO_2 in the atmosphere.

1.4 Tidal Power

Tidal power is believed to have been used by the Anglo Saxons in about 1050. Tidal power is a remarkable source of hydroelectrical energy. The French Ranee River power plant in the Gulf of St. Malo in Brittany consists of 24 power units, each of 10 MW. A dam equipped with special reversible turbines allows the power to be generated by the tidal flow in both directions.

Several tidal projects have been in the planning stages for many years and include the Bay of Fundy (Canada-USA), the Severn Barrage (Great Britain), and San Jose Gulf (Argentina). Though tidal power is reliable, it is not continuous, and some energy storage system would make it much more practical. However, as the price of fossil fuels rises, the economics of tidal power becomes more favorable.

1.5 Solar Energy

The Sun is approximately 4.6×10^9 years old and will continue in its present state for another 5×10^9 years. The Sun produces about 4×10^{23} kJ/s of radiant energy, of which about 5×10^{21} kJ/year reaches the outer atmosphere of the Earth. This is about 15,000 times more than man's present use of energy on Earth. We are fortunate however that only a small fraction of this energy actually reaches the Earth's surface (see Fig. 1.7). About 30% is reflected back into space from clouds, ice, and snow; about 23% is absorbed by O_2, O_3, H_2O, and upper atmosphere gases and dust; and about 47% is absorbed at or near the Earth's surface and is responsible for heating and supporting life on Earth. Of the energy absorbed by the Earth, about 56% is used to evaporate water from the sea and plants (evapotranspiration). Another 10% is dissipated as sensible heat flux. The remainder is radiated back into space, about 10% into the upper atmosphere and about 24% is absorbed by our atmosphere. A small but important fraction of the Sun's energy, about 0.2%, is consumed in producing winds and ocean waves. An even smaller fraction, 0.02%, is absorbed by plants in the process of photosynthesis of which about 0.5% of the fixed carbon is consumed as nutrient energy by the Earth's 6×10^9 people. The variation in solar intensity reaching the Earth due to its elliptical orbit about the Sun is only 3.3%. The production of fixed carbon by photosynthesis is about ten times present world consumption of energy by human society. Thus, solar energy is sufficient for man's present and future needs on Earth. The main difficulty is in the collection and storage of this energy.

Solar energy can be utilized directly in flat bed collectors for heating and hot water or concentrated by parabolic mirrors to generate temperatures over 2,000°C. The thermal storage of solar energy is best accomplished with materials of high heat capacity such as rocks, water, or salts such as Glauber's salt, which undergo phase changes, e.g.,

$$Na_2SO_4 \bullet 10H_2O_{(s)} \rightarrow Na_2SO_{4(s)} + 10H_2O_{(1)} \quad \Delta H = 81.5 \text{ kJ/mol of salt} \tag{1.1}$$

(The transition temperature for Glauber's salt is 32.383°C).

Solar energy can also be directly converted into electrical energy by photovoltaic and photogalvanic cells or transformed into gaseous fuels such as hydrogen by the photoelectrolysis or photocatalytic (solar) decomposition of water.

The Sun consists of about 80% hydrogen, 20% helium, and about 1% carbon, nitrogen, and oxygen. The fusion of hydrogen into helium, which accounts for the energy liberated, can occur several ways. Two probable mechanisms are:

The Bethe mechanism: (1939)	Q (MeV)
$^{12}C+^{1}H \rightarrow ^{13}N+\gamma$	1.94
$^{13}N \rightarrow ^{13}C+c^{+}+\nu$ ($t_{1/2}$ = 9.9 min)	1.20
$^{13}C+^{1}H \rightarrow ^{14}N+\gamma$	7.55
$^{14}N+^{1}H \rightarrow ^{15}O+\gamma$	7.29
$^{15}O \rightarrow ^{15}N+c^{+}+\nu$ ($t_{1/2}$ = 2.2 min)	1.74
$^{15}N+^{1}H \rightarrow ^{12}C+^{4}He$	4.96
$4^{1}H \rightarrow ^{4}He+2e^{+}+2\nu$	24.68
$2e^{+}+2e^{-} \rightarrow 2\gamma$ (+2 × 1.02)	2.04
Total energy	26.72

The Salpeter mechanism: (1953)	Q (MeV)
$^{1}H+^{1}H \rightarrow ^{2}H+e^{+}+\nu$	0.42
$^{2}H+^{1}H \rightarrow ^{3}He+\gamma$	5.49
$^{3}He+^{3}He \rightarrow ^{4}He+2^{1}H$	12.86
$4^{1}H \rightarrow ^{4}He+2e^{+}+2\nu$	24.68

Both reactions occur, though the Bethe mechanism requires a higher temperature and therefore predominates in the central regions of large stars.

The solar constant is 2.0 cal/cm^2 min or 1,370 W/m^2 above the Earth's atmosphere and about 1.1 kW/m^2 normal to the Sun's beam at the equator. At other latitudes, this value is reduced due to the filtering effect of the longer atmospheric path.

Ideal sites for solar energy collection are desert areas such as one in northern Chile which has low rainfall (1 mm/year) and 364 days/year of bright sunshine. The Chile site (160 $\times$ 450 km^2) receives about 5 $\times$ 10^{17} kJ/year (1 kJ/m^2/h $\times$ 60 min/h $\times$ 8 h/day $\times$ 365 day/year $\times$ 72,000 km^2 $\times$ 10^{6}m^2/km^2). This is about a third of the world's use of energy in 1995. Thus, theoretically, the desert areas or nonarid lands could be used to supply the world with all its energy requirements, and there is no doubt that before the next century has passed solar energy will probably dominate a large portion of the world's energy sources.

Figure 1.5 shows the subclassification of solar energy into thermal, biomass, photovoltaic, and photogalvanic. The most familiar aspect of solar energy is the formation of biomass or the conversion of carbon dioxide, water, and sunlight into cellulose or food, fuel, and fiber. Thus, wood was man's major fuel about 200 years ago to be displaced by coal, the modified plants of previous geological ages. Wood is a renewable energy source but it is not replenished quickly enough to be an important fuel today. A cord of wood is 128 ft^3 (8′ $\times$ 4′ $\times$ 4′) of stacked firewood. It is not recognized as a legal measure. A cord contains about 72 ft^3 of solid wood or about 4,300 lb to which must be added about 700 lb of bark or a total of about 5,000 lb, varying with the wood and its moisture content. The thermal energy of wood is from 8,000 to 9,000 Btu/lb. It has been argued that biomass used for fuel is not practicable because it displaces land which could be used for agriculture—a most essential requirement of man whose nutritional demands are continuously increasing. This objection is not valid if the desert is used, as in the case of the Jojoba bean which produces oil that has remarkable properties, including a cure for baldness, lubrication, and fuel.

Plants which produce hydrocarbons directly are well known—the best example is the rubber tree which produces an aqueous emulsion of latex—a polymer of isoprene (mol. wt. 2 $\times$ 10^6 D) (see Fig. 1.9). The annual harvest of rubber in Malaysia was 200 lb/acre/year before World War II, but by improving plant breeding and agricultural practices, the production has increased to ten times this value.

Melvin Calvin, Nobel Prize winner in Chemistry in 1961 for his work on the mechanism of photosynthesis, has been one of the principal workers in the search for plants which produce more suitable hydrocarbons, e.g., a latex with a mol. wt. of 2,000 Da which can be used as a substitute for oil. One plant he has studied, Euphorbia *(E. lathyris)* yields, on semiarid land, an emulsion which can be converted into oil at about 15 bbl/acre. Another tree, Copaiba, from the Amazon Basin, produces oil (not an aqueous emulsion) directly from a hole drilled in the trunk about l m from the ground. The yield is approximately 25 L in 2–3 h every 6 months. This oil is a C_{1S} terpene (tri-isoprene) which has been used in a diesel truck (directly from tree to tank) without processing.

Recent studies have shown that oils extracted from plants such as peanuts, sunflowers, maize, soya beans, olives, palm, corn, rapeseed and which are commonly classed as vegetable oils in the food industry can be used as a renewable fuel. These oils are composed primarily of triglycerides of long chain fatty acids. When used directly as a diesel fuel, they tend to be too viscous, clog the jet orifices, and deposit carbon and gum in the engine. Some improvement is obtained by diluting the oil with alcohol or regular diesel fuel or by converting the triglycerides into the methyl or ethyl esters. This is done in two steps: (1) hydrolysis and (2) esterification. The methyl or ethyl ester produced is more volatile and less viscous but is still too expensive to burn as a fuel.

The energy ratio for biomass energy, i.e., the energy yield/consumed energy for growth and processing, is variable and usually between 3 and 10. Plant breeding and genetic engineering should greatly improve this ratio.

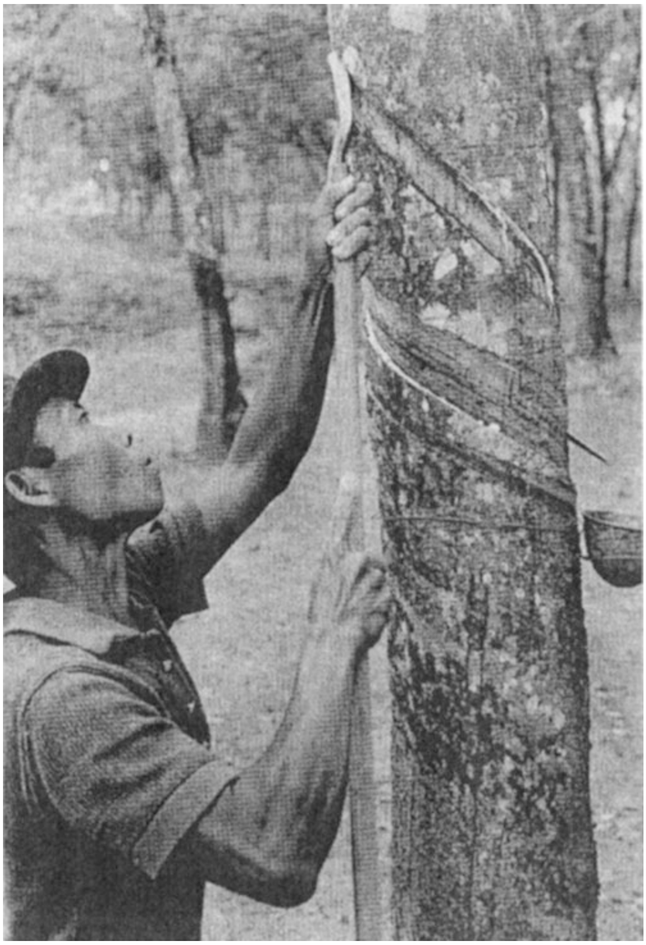

Fig. 1.9 A tapper at Goodyear's Dolok Merangir rubber plantation on the Indonesian island of Sumatra uses an extension knife to draw latex from a rubber tree. The bark of a rubber tree is cut up part of the year and down the rest to allow the tree to replenish itself. The rubber is sold by Goodyear to other manufacturers for making such diverse products as surgical gloves, balloons, overshoes, and carpet backing (Courtesy of Goodyear, Akron, OH)

Grain, sugarcane, and other crops containing carbohydrates can be harvested for the starch and sugar which can be fermented to ethyl alcohol. The residue which is depleted in carbohydrates but richer in protein is still a valuable feed stock.

Thus, the Energy Farm, where a regular crop can be utilized as a fuel, is obviously a requirement if stored solar energy is to replace dwindling fossil fuels.

1.6 Photovoltaic Cells

The direct conversion of solar energy into electrical energy is accomplished by certain solid substances, usually semiconductors (see Chap. 18), which absorb visible and near ultraviolet (UV) light, and by means of charge separation within the solid lattice a voltage is established. This generates a current during the continuous exposure of the cell to sunlight. Typical solar cells are made of silicon, gallium arsenide, cadmium sulfide, or cadmium selenide. The main hindrance to

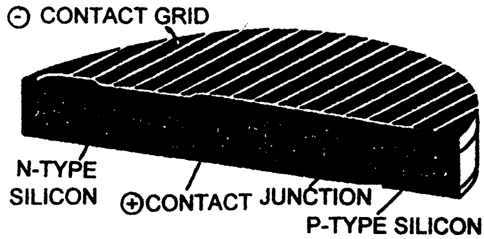

Fig. 1.10 Part of a typical solar cell 100 mm in diameter

widespread use of solar cells is their high cost, which is at present about $400/m^2 of amorphous silicon (13% efficient). A price of $50/m^2 would make such solar cell economic and practical. The reduction in cost to some composite cells of CdS/Cu_2S has been reported. Even lower costs may be expected as a result of the major efforts being made to develop inexpensive methods of forming the polycrystalline or amorphous materials by electroplating, chemical vapor deposition, spray painting, and other processes to dispense with the expensive single crystal wafers normally used. A typical photovoltaic cell is shown in Fig. 1.10.

A 6 × 9-m2 panel of solar cells operating at 10% efficiency with a peak output capacity of 5 kW at midday would yield an average of 1 kW over the year—more than the electrical energy requirements of an average home if electrical storage was utilized to supply energy for cloudy and rainy days and during the night. More recently, a solar powered airplane crossed the English Channel using photovoltaic cells to power an electrical motor. This clearly demonstrates the potential power of solar energy.

1.7 Photogalvanic Cells

Cells in which the solar radiation initiates a photochemical reaction, which can revert to its original components via a redox reaction to generate an electrochemical voltage, are called *photogalvanic cells*. This is to be distinguished from a solar rechargeable battery where light decomposes the electrolyte which can be stored and recombined to form electrical energy via an electrochemical cell, e.g.,

$$\begin{aligned} FeBr_3 + hv &\rightarrow FeBr_2 + 1/2Br_2 \\ FeBr_2 + I/2Br_2 &\rightarrow FeBr_3 \ \xi^\circ = 0.316 \text{ V} \end{aligned} \tag{1.2}$$

Photogalvanic cells usually consist of electrodes which are semiconductors and a solution which can undergo a redox reaction. The band gap of the semiconductor must match the energy of the redox reaction before the cell can function. Light absorbed by the electrodes promotes electrons from the valence band to the conduction band where they migrate to the surface (in n-type semiconductors) where reaction with the electrolyte can occur. This is shown in Fig. 1.11 for the system in which two photochemically active semiconductor electrodes are used, one in which the *p*-type oxidizes Fe(II) to Fe(III):

$$Fe^{2+} \rightarrow Fe^{3+} + e^- \tag{1.3}$$

The reverse reaction occurs at the other n-type electrode. Many such cells have been prepared but the efficiency is very low due to the limited surface area of the electrodes. More recently, porous transparent semiconductor electrodes have been made which can increase efficiency by some orders of magnitudes and it remains to be seen if these systems are stable over long periods. Such cells when shorted can be used for the photoelectrolysis of water or the production of hydrogen, but more will be said about this later.

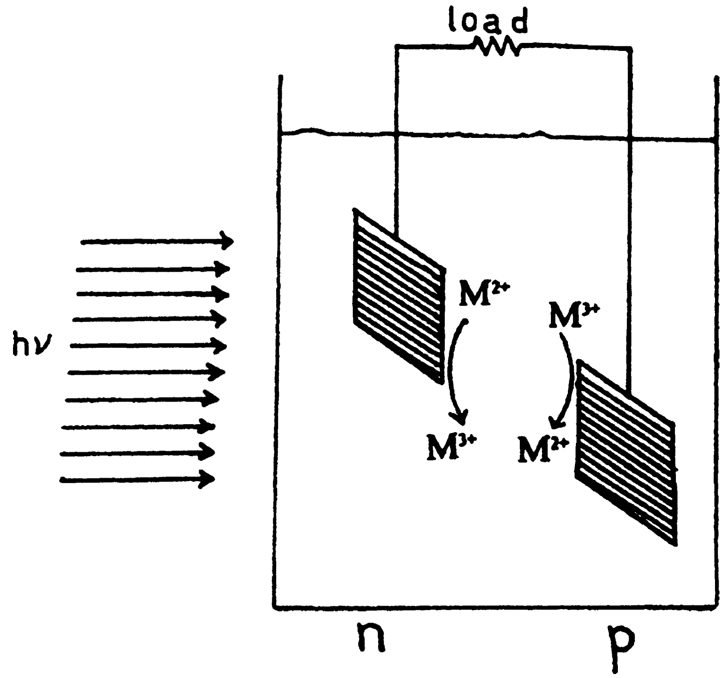

Fig. 1.11 A photogalvanic cell using n-type and p-type semiconductor electrodes and a regenerating redox system ($M^{3+} \rightleftarrows M^{2+} + e$) to carry the current

1.8 Wind Energy

Wind first powered sailing ships in Egypt about 2500 B.C. and windmills in Persia about 650 A.D. The use of windmills for the grinding of grain was well established in the Low Countries (Holland and Belgium) by 1430 where they are still used to this day.

The maximum power available from a horizontal axis windmill is given by

$$P_{\max} = \tfrac{1}{2}\rho A V^3 \tag{1.4}$$

where ρ = density of air, A = cross-sectional area of the windmill disk, and V = air velocity.

However, to maintain a continuous air flow past the windmill implies that the extractable power, P_{ext}, must be less than $P_{\max}$ and it can be shown that $P_{\text{ext}} = (16/27)P_{\max}$ or 59.3% is the optimum extractable power available and usually 70% of this value is realized practically. The energy which is usually extracted by an electrical generator or turbine can be stored in a bank of batteries for future use. Several very large windmills have been built to generate electrical energy, but costs are still too high to make them commonplace. The vertical axis windmill is much simpler than the horizontal axis type, but large units have not as yet been tested.

Wind farms have been successfully operating in California where many small windmills are located on exposed terrain. The continuous wind at about 17 miles/h is sufficient to make the generation of electrical energy a viable project. Many of the largest operational onshore wind farms are located in the USA. As of November 2010, the Roscoe Wind Farm is the largest onshore wind farm in the world at 781.5 MW, followed by the Horse Hollow Wind Energy Center (735.5 MW). Also, the largest wind farm under construction is the 800 MW Alta Wind Energy Center in the USA. As of November 2010, the Tranet Offshore Wind Project in the UK is the largest offshore wind farm in the world at 300 MW, followed by Horns Rev II (209 MW) in Denmark. The largest proposed project is the 20,000 MW Gansu Wind Farm in China.

1.9 Hydropower

Hydropower relies on the conversion of potential energy into kinetic energy which is used to turn an electrical generator and turbines. The development of highly efficient turbines has increased the output of power stations and allowed for their installation in many new areas. The main disadvantage in hydropower is that the transmission of electrical energy over long distances results in losses which effectively place a limit on such distances. Also, it is not convenient, because of environmental factors, to store the potential energy or the electrical energy. Several methods have been used, such as storing water behind a dam, pumping the water into another reservoir, compressing air in a large cavern, or electrolyzing water and transporting the hydrogen in a pipeline. This latter alternative has an interesting by-product, namely, heavy water which is essential for the CANDU nuclear reactor. During the electrolysis of water, the lighter isotope ^{1}H is liberated as H_2 more readily than the heavier ^{2}H or deuterium D_2 gas. Hence, the heavy water accumulates in the electrolyte and can eventually be purified by distillation.

The Yenisey River in Siberia passes north through the City of Krasnoyarsk. Two hydro dams on the Yenisey River each produce 6,000 MW which is primarily used in the electrolytic production of aluminum from imported bauxite ore. Such power source can also be used to make hydrogen and other electrochemical products.

1.10 Ocean Thermal

The oceans cover over 70% of the Earth's surface and are continually absorbing solar radiation. The penetration of the solar energy is only 3% at 100 m. This results in a temperature gradient which can be used to generate electrical energy. A variety of schemes have been proposed, and some experimental units have been tested as early as 1929 off Cuba and more recently near Hawaii. The main disadvantages to Ocean Thermal Energy Conversion (OTEC) or Solar Sea Power Plants (SSPP) are (1) the need to operate turbines with a very low temperature gradient of about 15–20°C, (2) the corrosive nature of seawater, and (3) the usually large distances from shore that the plant has to be located. The Carnot thermodynamic efficiency[2] of the heat engine is only about 3%, but by using ammonia or a low boiling organic compound as the boiler fluid, it is possible to approach maximum conversion efficiency.

It is possible to magnify the solar thermal gradient by using nonconvecting solar ponds. Much of the recent development work has been done by Tabor in Israel where Dead Sea brine is used to establish a density gradient in a pond approximately 1 m deep. The bottom of the pond is dark and absorbs the solar energy, heating the denser lower layer. With temperature differences of more than 50°C, it is possible to achieve a Carnot efficiency of over 13%. A schematic diagram of a solar pond is shown in Fig. 1.12 with an estimate of the operating parameters shown in Table 1.7. The diffusion of

[2] The Carnot efficiency is the theoretical maximum efficiency by which a heat engine can do work when operating between two temperatures. The greater the difference in temperatures, the greater is the efficiency by which heat can be converted into work.

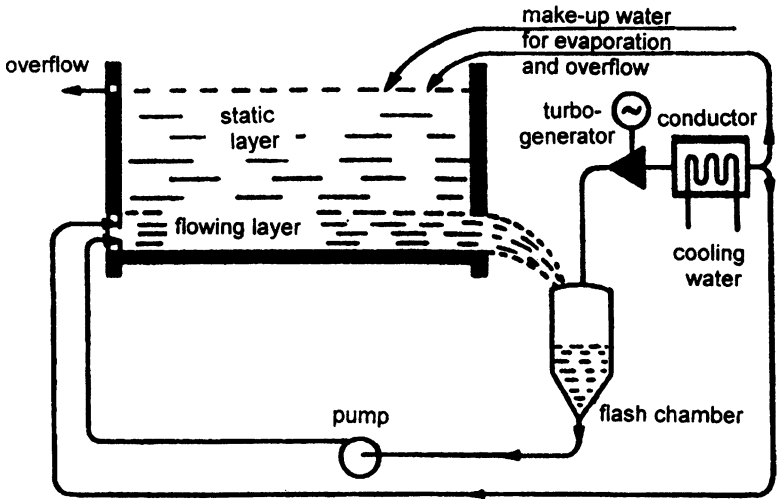

Fig. 1.12 Schematic representation of the "falling pond" method of extracting heat from the bottom of a pond (From Tabor H (1980) Non-convecting solar ponds. Phil Trans R Soc Lond A295:428 with permission)

Table 1.7 Estimated annual yield of a solar pond

Area	1 km^2
1. Insulation	2,000 GWh(t)
2. Pond heat yield	400 GWh(t)
3. Equivalent fuel oil	43,000 t
Power yield	33 GWh(e)
Source temperature	87°C
Sink temperature	30°C
H-X drops	10° total
Carnot effect	13.2%
Turbine factor	0.6
Overall thermal energy	ca. 8%
Equivalent cont. power	0.4 MW
(58% load factor)	4.7×10^4 m^3

salt tends to destroy the density gradient and hence will allow convection to upset the temperature gradient. To maintain the density gradient, salt-free water is added to the surface and salt-enriched water is fed into the bottom layer. The flash chamber can also yield desalinated water as a by-product as indicated in Fig. 1.12 and Table 1.7. The electrical energy is obtained from a Rankine cycle turbine which was developed for such solar energy conversion and which runs on an organic vapor.

The problems associated with solar ponds involve: (1) Surface mixing due to winds which tend to create convecting zones near the surface. This can be reduced by adding a floating netting grid to the surface. A floating plastic sheet cannot be used because it acts as a collector of dust and becomes opaque in a few days. (2) Ecological factors must be considered since brine may be slowly lost through the bottom of the pond to the aquifer. Hence, the location of the pond in flat sterile land is preferred.

Solar ponds are presently being tested in Israel where plans are in progress for a large unit located at the Dead Sea.

1.11 Wave Energy

Wave energy has been described as liquid solar energy since it originates from the Sun, which causes wind, which in turn forms waves. Wave energy has enormous potential and presents a tremendous challenge to the engineer. Its presence on the high seas is almost continuous. It has been estimated that the power available along a kilometer of shore can be over 20 MW. Several devices have been tested and usually operate air turbines which generate electricity. The power takeoff and mooring are still problems to be solved. An example of a simple wave energy device is shown in Fig. 1.13. A one-way flap allows a head of water to be stored over 5–100 waves. When the full head is reached, the water is released and allowed to drive the turbine as it empties.

As a renewable energy source, wave power is an untapped source which could help alleviate the rising cost of energy and its continued development must be encouraged.

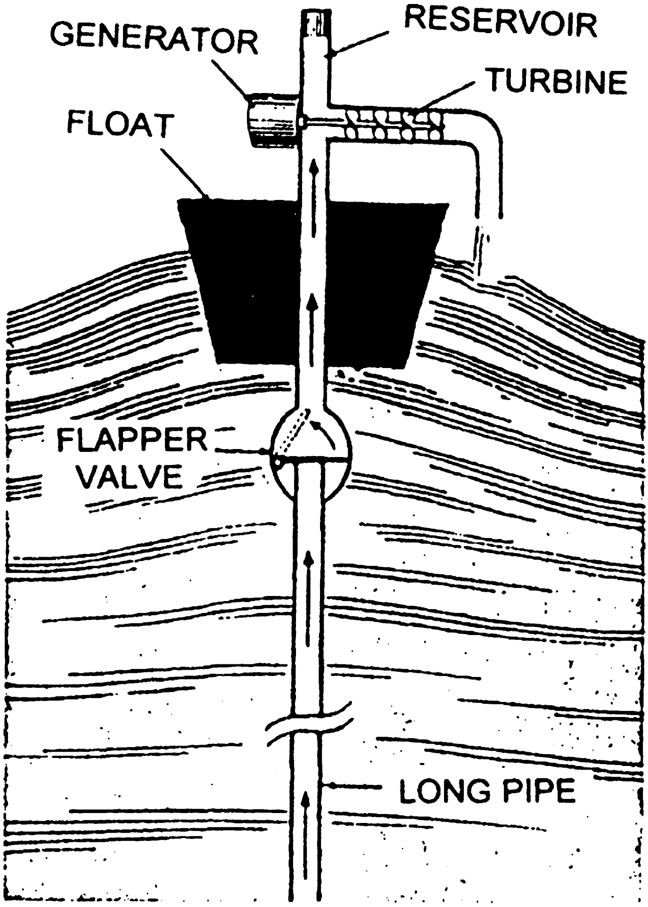

Fig. 1.13 Wave-powered generators convert the kinetic energy of waves into electricity. The Scripps wave pump amplifies the effective height of a wave by trapping water in a reservoir on each downward plunge of the buoy. Water in the long standpipe surges through a one-way flapper valve as it oscillates out of phase with the up-and-down motion of the waves. When enough water is collected after about eight to ten waves, it is released to spin the turbine-generator

1.12 Osmotic Power

As a river empties into the sea, it is possible to extract hydro power by converting gravitational potential energy into kinetic energy—mechanical energy and electrical energy. At the same time, the difference in salt concentration between the river and the sea results in a difference in chemical potential or free energy (ΔG) which can be exploited by means of the osmotic pressure.

The osmotic pressure of a solution is the pressure exerted by the solution on a semipermeable membrane which separates the solution from pure solvent. The semipermeable membrane allows only the solvent to pass freely through it while opposing the transport of solute. This is illustrated in Fig. 1.14. The solvent tends to dilute the solution and passes through the membrane until equilibrium is established, at which point a pressure differential, *it*, exists between solution and solvent. This pressure differential is called the *osmotic pressure*.

At equilibrium, the osmotic pressure, π, of a solution relative to the pure solvent is given by a relation which resembles the Ideal Gas Law $(PV - nRT)$ where

$$nV - nRT \quad \text{or} \quad n = (n/V)RT = CRT \tag{1.5}$$

where V = volume of solution, R = ideal gas constant (0.0821 L atm/°K mol), C = concentration of solute (molar mass/liter), n = mols of dissolved solute, ions, etc., and T = absolute temperature (273° + 10°) = 283 K.

The average molar concentration of salt in seawater is about 0.5 M and since it may be assumed that the salt is primarily NaCl, then the total molar concentration of solute is 1.0 M (i.e., 0.5 M Na^+ + 0.5 M Cl^-). Hence,

$$\pi = 1.0\ \text{mol/L} \times 0.0821\ \text{L, atm/K, mol} \times 283\ \text{K} - 23\ \text{atm}$$

This osmotic pressure represents a hydrostatic head of water of about 700 ft (30 ft/atm × 23 atm) or over 200 m. A schematic diagram of osmotic power is illustrated in Fig. 1.15 where seawater is pumped into a pressure chamber at a constant rate depending on the flow of the river. The river passes through the membrane, diluting the seawater and creating the hydrostatic head which can then turn a water wheel and generate electricity. The membrane area must be enormous to accommodate the

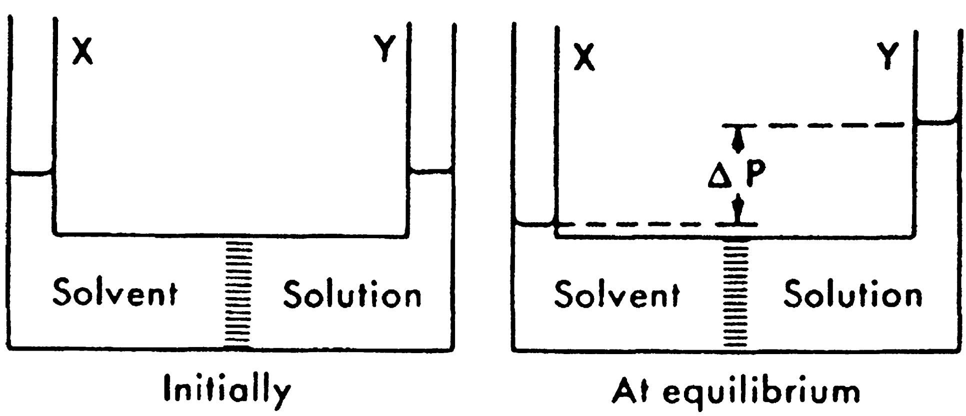

Fig. 1.14 The development of osmotic pressure is illustrated by the difference between an initial state and the final equilibrium state. Solvent, but not solute, passes through the semipermeable membrane, tending to dilute the solution and thereby allowing a differential pressure ΔP to develop. At equilibrium, the differential hydrostatic pressure is equal to the osmotic pressure

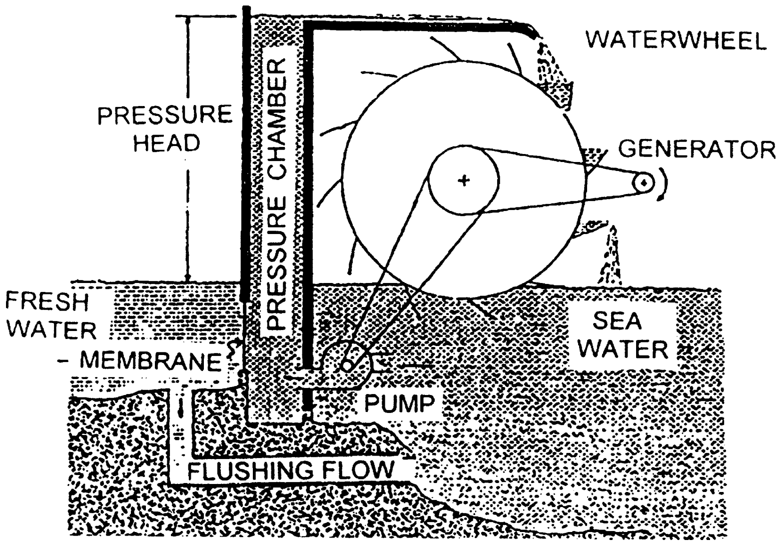

Fig. 1.15 Diagram of an osmotic salination energy converter to extract power from the natural flow of freshwater into the sea

Table 1.8 Potential power due to salinity gradients

Source	Flow rate (m^3/s)	Power (W)
π = 23 atm		
Amazon River (Brazil)	2×10^5	4.4×10^{11}
La Plata-Parana River (Argentina)	8×10^4	1.7×10^{11}
Congo River (Congo/Angola)	5.7×10^4	1.2×10^{11}
Yangtze River (China)	2.2×10^4	4.8×10^{10}
Ganges River (Bangladesh)	2×10^4	4.4×10^{10}
Mississippi River (USA)	1.8×10^4	4.0×10^{10}
US waste water to oceans	500	1.1×10^9
Global runoff	1.1×10^6	2.6×10^{12}
κ = 500 atm		
Salt Lake		5.6×10^9
Dead Sea		1.8×10^9

permeability of the river. An estimate of power output is 0.5 MW/m^3 of input flow resulting in an amortized cost of about 5 cents/kWh. Lower costs are expected if the salt concentration gradient is higher, e.g., seawater ($\pi = 23$ atm) emptying into the Dead Sea ($n = 500$ atm) to produce electrical power from the gravitational as well as the chemical potential. The potential power from various rivers is listed in Table 1.8.

Only with the developments in membrane technology as a result of work in reverse osmosis will osmotic power become a significant factor in world energy supply.

It has been estimated by the Scripps Institution of Oceanography that world power needs in the year 2000 will be about 33 million megawatts (33 TW). The seas can provide all this and more: wave energy 2.5 TW, tidal power 2.7 TW, current power 5 TW, osmotic power 1,400 TW, OTEC 40,000 TW. The Weitzman Institute of Science has studied this topic and has shown that with a suitable membrane, it would be a feasible source of energy.

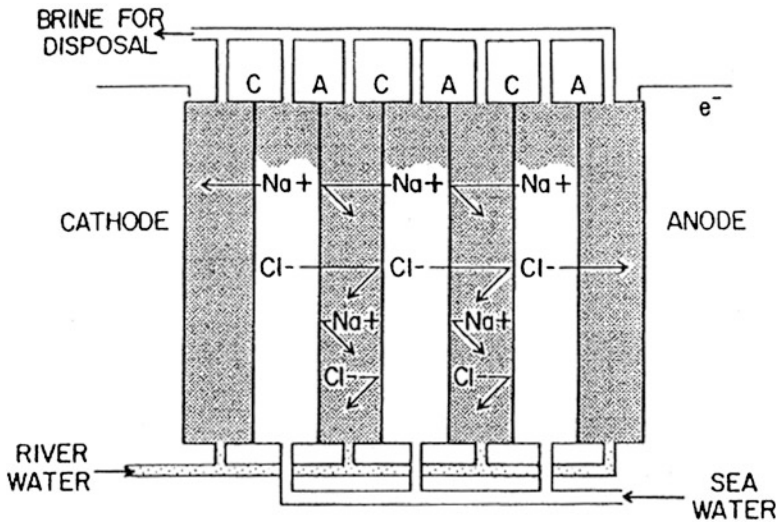

Fig. 1.16 The conversion of chemical potential into electrical energy by reverse electrodialysis

With such optimistic projections and present-day technology, it may soon be possible to rely on our renewable energy resources with confidence and assurance so long as we continue to minimize the environmental effects (Fig. 1.16).

Exercises

1. Using Internet, compare GDP per capita (PPP, 2012) for the following countries: Australia, Brazil, Canada, China, Finland, Germany, New Zeeland, Norway, Japan, Russia, South Korea, the UK, and the USA. Give the source.
2. Explain why geothermal energy is classed as both a renewable and nonrenewable energy source. Do you agree with this explanation?
3. Complete Table 1.3 with references to uranium available as a nuclear fuel, 860 Quads from the Earth and 10^5 Q from seawater.
4. It has been argued that the CO_2 absorption band in the atmosphere is almost saturated and if more CO_2 is produced there will be no additional absorption. Explain why this is incorrect.
5. From Figs. 1.7 and 1.8, it would appear that water is more important than CO_2 in governing the greenhouse effect. Comment on this.
6. Explain why burning wood and burning coal are not equivalent as far as the greenhouse effect is concerned.
7. The normal energy requirements of a house in Winnipeg in winter is 1 million Btu/day or 10^6 kJ/day. (a) What weight of Glauber's salt would be required to store solar energy for 1 month of winter use? (b) If the optimum conditions for using the Glauber's salt are a 35% by weight (Na_2SO_4) solution in water, what volume of solution would be required? (Note: Density of GS solution is 1.29 g/mL.)
8. Canada produces over 700 million pounds of vegetable oils per annum. If this were to replace all Canadian petroleum oil used, how long would it last?
9. If a typical home has 1,200 ft^2 of floor space and a sloping A-type roof at 45°–60° for optimum solar collection, the roof area facing the Sun would be approximately 850 ft^2. Calculate the energy per day available as heat and as electricity via photovoltaic cells (assume 5% efficiency) for both summer and winter.

10. What would be the rise in sea level if the average temperature of the oceans increased by 1°C at 20°C. The density of water at 20°C is 0.99823 g/mL, and at 21°C, the value is 0.99802 g/mL. Assume no ice melts and that the ocean area does not increase. The average depth of the ocean is 3,865 m.
11. Reverse electrodialysis is a method of extracting electrical energy directly from the flow of a fresh water river into the sea (salt water). Ion-exchange membranes are used to separate the flow of fresh and salt water. Draw a diagram of the system and explain how it works. See Fig.1.16 in Chap. 1 or Fig. 15.7 in Chap. 15.

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