Chapter 1

Energy and the Environment

Learning outcomes

• Demonstrate the various forms of energy: mechanical, electrical, chemical and nuclear	Knowledge and understanding
• Evaluate the amount of energy for various types	Analysis
• Solve problems associated with energy conversion	Problem solving
• Distinguish between: potential and kinetic energy, electrostatic and electromagnetic energy, chemical and thermal energy, energy from nuclear fission and nuclear fusion	Knowledge and understanding
• Calculate the calorific value of fuels	Analysis
• Calculate the combustion products of fuels	Analysis
• Examine future world energy scenarios	Reflections
• Practise further tutorial problems	Problem solving

Energy Audits: A Workbook for Energy Management in Buildings, First Edition.
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1.1 Introduction

It is necessary to appreciate that energy will be needed to modify the state of any working environment and keep the conditions comfortable, whether by providing warm or cool air.

Heating the air is a simple process of increasing its thermal energy and consequently raising its temperature. Heating of air can be achieved either by direct or indirect means: examples such as coal and gas fires represent the direct forms of heating normally used in domestic situations; electrical resistance heating elements provide an example of an indirect method because electricity is produced elsewhere. Hot water radiators are also used to provide indirect heating of indoor air.

Similarly, the process of cooling air, or reducing its thermal energy, is energy driven.

Both cooling and heating require a further process. After being treated (i.e. heated or cooled), the air has to be delivered to the space where it is needed, and hence an electric fan is usually used to push the air from the apparatus out into the room.

The following sections will discuss the various forms of energy, and how energy can be converted from one form to another form which is convenient for heating, cooling, etc.

This chapter will demonstrate the environmental impact of using different fuels to provide energy for heating or electricity.

1.2 Forms of energy

We associate energy with devices whose inputs are fuel based, such as electrical current, coal, oil or natural gas, and whose outputs involve movement, heat or light.

The unit of energy is the Joule (J). The rate of producing energy is called *power*, and this has the unit Joules per second (Js^{-1}) or the Watt (W).

There are five forms of energy:

- mechanical energy;
- electrical energy;
- chemical energy;
- nuclear energy;
- thermal energy.

1.2.1 Mechanical energy

This type of energy is associated with the ability to perform physical work. There are two forms in which this energy is found; namely *potential energy* and *kinetic energy*.

Potential energy

This is energy contained in a body due to its height above its surroundings. An example is the gravitational energy of the water behind a dam.

Potential energy = mass × acceleration due to gravity (9.81) × height above datum

Or

$$E_p = m \times g \times h \qquad [1.1]$$

The energy produced by one kilogram of water falling from a height of 100 m above ground is an example of potential energy, and can be calculated as follows:

Potential energy = mass × acceleration due to gravity × height above datum

$$E_p = 1 \times 9.81 \times 100 = 981\ \text{J/kg}$$

Kinetic energy

Kinetic energy is related to the movement of a particular body. Examples of kinetic energy are the flywheel effect and the energy of water flowing in a stream.

Kinetic energy = ½ mass × velocity squared

Or

$$E_k = \tfrac{1}{2} \times m \times v^2 \qquad [1.2]$$

The water in a river flowing at a velocity of 2 m/s has a kinetic energy of:

Kinetic energy = ½ mass × velocity squared = $\tfrac{1}{2} \times 1 \times (2)^2 = 2$ J/kg

1.2.2 Electrical energy

This type of energy, as the name implies, is associated with the electrons of materials. Electrical energy exists in two forms: *electrostatic energy* and *electromagnetic energy*.

Electrostatic energy

This type of electrical energy is produced by the accumulation of charge on the plates of a capacitor. Charles Coulomb first described electric field strengths in the 1780s. He found that for point charges, the electrical force varies directly with the product of the charges; the greater the charges, the stronger the field. And the field varies inversely with the square of the distance between the charges. This means that the greater the distance, the weaker the force becomes. The formula for electrostatic force, F, is given by:

$$F = k\,(q_1 \times q_2)/d^2 \qquad [1.3]$$

where q_1 and q_2 are the charges and d is the distance between the charges. k is the proportionality constant, which depends on the material separating the charges.

Electromagnetic energy

This type of energy is produced with a combination of magnetic and electric forces. It exists as a continuous spectrum of radiation. The most useful type of electromagnetic energy comes in the form of solar radiation transmitted by the sun, which forms the basis of all terrestrial life.

1.2.3 Chemical energy

This is associated with the release of thermal energy due to a chemical reaction between certain substances and oxygen. Burning wood, coal or gas, for example, is the main source of energy we use in heating and cooking.

Calculation of chemical energy

The energy liberated from the combustion of a given mass of fuel with a known calorific value in a combustion chamber of known efficiency is given by:

$$\text{Chemical energy} = \text{mass of fuel} \times \text{calorific value} \times \text{efficiency of combustion} \qquad [1.4]$$

Typical coal has an energy value of 26 MJ/kg (refer to Table 1.3), which implies that during the combustion of one kilogram of coal, there will be a release of 26 mega joules of thermal energy.

The energy contained in the food we consume is another example of chemical energy.

Analyses of thermal energy liberated from stored chemical energy during the combustion of coal, oil and natural gas will be discussed later in this chapter.

1.2.4 Nuclear energy

This energy is stored in the nucleus of matter, and is released as a result of interactions within the atomic nucleus.

There are three nuclear reactions: *radioactive decay*, *fission* and *fusion*.

Radioactive decay

Here, one unstable nucleus (radioisotope) decays into a more stable configuration, resulting in the release of matter and energy.

Fission

A heavy nucleus absorbs a neutron, splitting it into two or more nuclei and thereby releasing energy. Uranium U235 has the ability to produce 70×10^9 J/kg.

Einstein proposed the following equation to calculate the energy produced from nuclear fission (i.e. the conversion of matter (m) into energy (E) is related to the speed of light (C)):

$$E = mC^2 \qquad [1.5]$$

This reaction forms the basis for current nuclear power generation plants.

Fusion

Two light nuclei combine to produce a more stable configuration and this is accompanied by the release of energy. A heavy water (Deuterium) fusion reaction may produce energy at the rate of 0.35×10^{12} J/kg.

This reaction is yet to be used to produce electricity on a commercial basis.

1.2.5 Thermal energy

Thermal energy is associated with intermolecular vibration, resulting in heat and a temperature rise above that of the surroundings. Thermal energy is calculated for two different regimes.

When the substance is in a pure phase, say if it is a liquid, gas or solid, then:

$$\text{Thermal energy} = \text{mass} \times \text{specific heat capacity} \times \text{temperature difference} \qquad [1.6]$$

During a change of phase, such as evaporation or condensation, it can be calculated by:

$$\text{Thermal energy} = \text{mass} \times \text{latent heat} \qquad [1.6a]$$

However, if there is a change of phase, say during the condensation of water vapour into liquid, there is an additional amount of heat released while the temperature remains constant during the change of phase. For 1kg of water to be heated at ambient pressure from 20 to 120°C, the requirement is:

$$\text{Thermal energy} = \text{heating water } (20\text{–}100)^\circ\text{C} + \text{evaporation at } 100^\circ\text{C} + \text{super-heating vapour } (100\text{–}120)^\circ\text{C}$$

$$\text{Thermal energy} = 1 \times 4.219 \times (100\text{–}20) + 1 \times 2256.7 + 1 \times 2.01 \times (120\text{–}100)$$
$$= 337.52 + 2256.7 + 40.2$$
$$= 2634.42\,\text{kJ}$$

Note that the specific heat capacity for water at 1 atmosphere is:

For liquid state $Cp_f = 4.219\,\text{kJ/kg}$
For vapour state $Cp_g = 2.010\,\text{kJ/kg}$

The latent heat of evaporation is 2256.7 kJ/kg

1.3 Energy conversion

It is important to understand that losses are encountered when energy is transformed during the various conversions into the final form for a given application. For example, consider a power station using coal as a fuel; the following conversions take place.

Coal is mined, extracted and transported to the site. It is then turned into a fine powder and is fed to the combustion system. Energy is liberated by the combustion of coal (chemical to thermal); in other words, not all coal is burnt completely. The thermal energy of the combustion gases is used to raise steam (thermal to thermal); some thermal energy is lost as the exhaust gases leaving the boiler have a temperature above that of the ambient air outside the boiler. High pressure and temperature steam turns the steam turbine (thermal to mechanical). Not all of the energy of the steam is converted into rotational energy, as the steam leaving the turbine has a temperature well above the ambient. The steam turbine drives the electrical generator (mechanical to electrical). Some losses are dissipated through the mechanical connections between the turbine and the electrical generator. Electricity is used by customers for lighting/heating or to operate electrical devices such as radios, televisions, etc. Electrical devices are designed to operate in an optimum condition; the efficiency of the operation will vary depending on its use, age and maintenance.

The energy input to a coal-fired power station (Figure 1.1) can be analysed in a simple way by considering the energy flow diagram; it may look like this:

100 units of energy are stored in the coal fuel
95 units are converted into thermal energy entering the boiler
70 units are absorbed by the water converting into steam
45 units are converted into mechanical energy at the steam turbine rotor
38 units are converted into electrical energy in the electrical generator
30 units go up to waste through the chimney stack.

It is very important to state that, although the initial part of the system above does not indicate any penalties associated with the fuel preparation, this

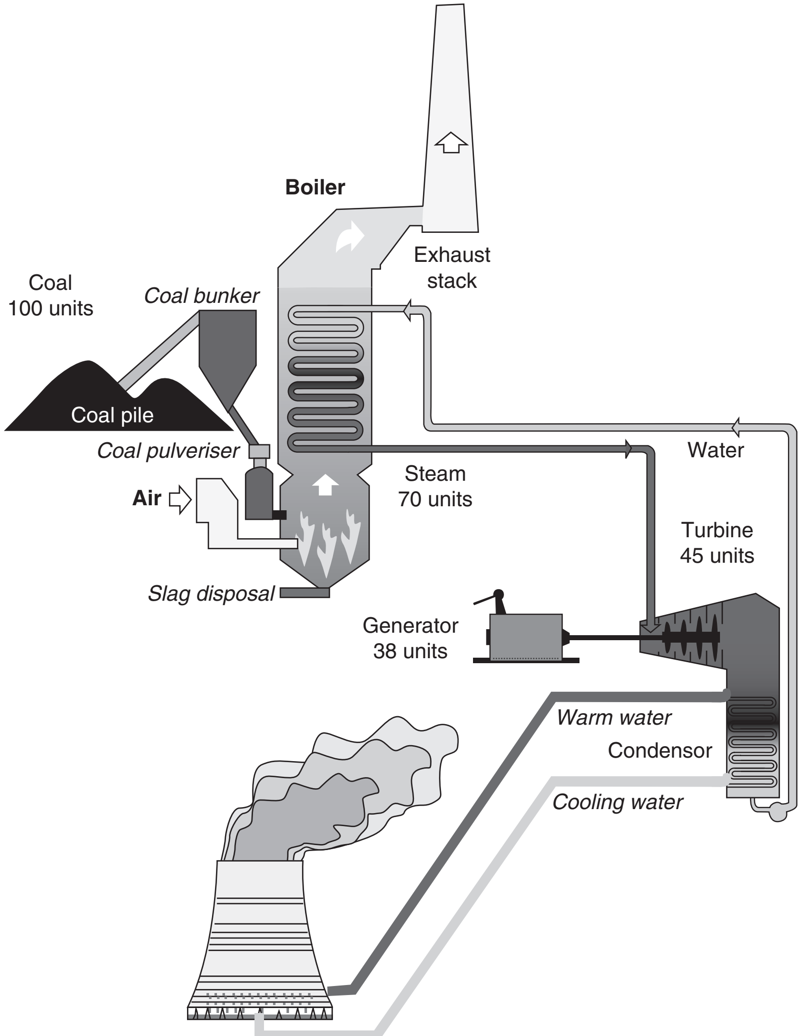

Figure 1.1 Energy conversions in a typical coal-fired power plant (numbers quoted represent the units of energy; dark grey represents warm water and pale grey represents cooling water).

aspect is of particular importance, especially when the fuel is imported. Transportation of fuel implicitly lowers its heating value, an important consideration; the use of local fuel has another added advantage in that it eliminates any fuel security risks.

Most of the devices in common use have the ability to convert energy from one form to another. Table 1.1 shows the 25 possibilities of energy transfer (the symbol x indicates an unrealised link at the present time).

Table 1.1 Energy conversion matrix.

From\To	Mechanical	Electrical	Thermal	Chemical	Nuclear
Mechanical	Gear Nutcracker Push mower	Electric generator	Friction	x	x
Electrical	Electric motor	Light bulb	Electric fire	Electrolysis	Particle accelerator
Thermal	Steam turbine	Thermo-couple	Heat exchanger	x	Fusion reactor
Chemical	Jet engine Rocket	Battery Fuel cell	Car engine Boiler	Intermediate reaction	x
Nuclear	x	x	Nuclear reactor	x	x

1.4 The burning question

Although man discovered fire a very long time ago, the fuel for cooking, heating and light relied on burning just wood. By the 4th century AD, the Romans sent an entire fleet of ships to bring wood from France and North Africa.

It was not until the 17th century that coal was discovered, and this was used extensively during and after the Industrial Revolution in Europe.

In the 19th century, oil was discovered and this has been used extensively by the industrialised world ever since. There have been times when the West has enjoyed cheap oil prices due to competition between oil-producing countries; however, a major shock was felt as a result of the 1973 war between Arab nations and Israel and the subsequent tripling of oil prices.

For all combustion processes, the fuel must contain one or more of the elements (carbon, hydrogen and sulphur). When they react with oxygen, these produce thermal energy – the amount is called its *calorific value*.

Combustion of carbon:

$$C + O_2 \longrightarrow CO_2 + \text{energy}$$

Carbon has an energy content of 32 793 kJ/kg

Combustion of hydrogen:

$$H_2 + 2O_2 \longrightarrow 2H_2O + \text{energy}$$

Hydrogen has an energy content of 142 920 kJ/kg

Combustion of sulphur:

$$S + O_2 \longrightarrow SO_2 + \text{energy}$$

Sulphur has an energy content of 9300 kJ/kg

Table 1.2 Enthalpy 'heat' of combustion of elementary fuel matter.

		Molecular weight	Heat of combustion	
Substance	**Formula**	**kg/kmol**	**kJ/kmol**	**kJ/kg**
Carbon	C (s)	12.001	393 520	32 793
Hydrogen	H_2 (g)	2.016	285 840	142 920
Sulphur	S (s)	32	297 600	9 300
Water vapour	H_2O (g)	18.016	40 620	2256.7

Table 1.2 shows the heat of combustion of these three prime elements for fuels, as they form all combustible products known to mankind. Although the main fuels are coal, oil and natural gas, there are other sources which can be substituted in some cases, such as dry wood, agricultural waste and general household waste.

In the next three subsections, three typical fuels will be analysed, and a method of calculating their respective calorific values and the associated combustion products will be shown.

1.4.1 Combustion of coal

Typical coal in the UK has the following composition (percentage by weight):

Carbon	64.4
Hydrogen	4.4
Oxygen	4.4
Nitrogen	0.9
Sulphur	10
Ash	15
Total	100%

The heat released from burning one kilogram of coal can thus be estimated as the sum of the energy released (Table 1.2) from the proportions given above of carbon, hydrogen and sulphur contained in coal. Hence, the calorific value of coal is calculated as follows:

Part due to combustion of carbon	$+32\,793 \times 0.644 = 21\,119$
Part due to combustion of hydrogen	$+142\,920 \times 0.044 = 6288$
Part due to combustion of sulphur	$+9300 \times 0.1 = 930$
Part lost in combustion of water content	$-2256.7 \times 0.044 - 9 = -893.6$

Calorific value of coal $21\,119 + 6288 + 930 - 893.6 = 27\,444$ kJ/kg

This value is obtained on the assumption of 100% efficient and complete combustion.

Emissions:
Production of CO_2 from coal $= 0.644 \times (44/12) = 2.36$ kg CO_2/kg coal
Production of CO_2 per kWh $= 2.36 \times 3600/27\,444 = 0.309$ kg/kWh

Production of CO_2 per GJ energy = 2.36 × 10^6/27 444 = 86.043 kg/GJ
Production of SO_2 from coal = 0.009 × (64/32) = 0.018 kg SO_2/kg coal

1.4.2 Combustion of oil

Typical oil in the UK has the following composition (percentage by weight):

Carbon	86
Hydrogen	12
Sulphur	2
Total	100%

The heat released from burning one kilogram of oil can thus be estimated as the sum of the energy released (Table 1.2) from the proportions given above of carbon, hydrogen and sulphur contained in oil. Hence, the calorific value of oil is calculated as follows:

Part due to combustion of carbon	+32 793 × 0.86
Part due to combustion of hydrogen	+142 920 × 0.12
Part due to combustion of sulphur	+9300 × 0.02
Part lost in combustion of water content	–2256.7 × (0.12 × 9)
Calorific value of oil	= 28 202 + 17 150 + 186 – 2437
	= 43 101 kJ/kg

Emissions:
Production of CO_2 from oil = 0.86 × (44/12) = 3.153 kg CO_2/kg oil
Production of CO_2 per kWh = 3.153 × 3600/43 101 = 0.263 kg/kWh
Production of CO_2 per GJ energy = 3.153 × 10^6/43 101 = 73.161 kg/GJ
Production of SO_2 from oil = 0.02 × (64/32) = 0.040 kg SO_2/kg oil

1.4.3 Combustion of natural gas

Typical natural gas in the UK has the following composition (percentage by weight):

Carbon	75
Hydrogen	25
Sulphur	0
Total	100%

The heat released from burning one kilogram of natural gas can thus be estimated as the sum of the energy released (Table 1.2) from the proportions given above of carbon and hydrogen contained in natural gas. Hence, the calorific value of natural gas is calculated as follows:

Part due to combustion of carbon	$+32\,793 \times 0.75$
Part due to combustion of hydrogen	$+142\,920 \times 0.25$
Part lost in combustion of water content	$-2256.7 \times (0.25 \times 9)$
Calorific value of natural gas	$= 24\,595 + 35\,730 - 5077$
	$= 55\,248$ kJ/kg

Emissions:
Production of CO_2 from natural gas $= 0.75 \times (44/12) = 2.75$ kg CO_2/kg gas
Production of CO_2 per kWh $= 2.75 \times 3600/55\,248 = 0.179$ kg/kWh
Production of CO_2 per GJ energy $= 2.75 \times 10^6/55\,248 = 49.776$ kg/GJ
Production of SO_2 from natural gas = ZERO

1.5 Environmental impact from fossil fuels

Coal, oil and natural gas have their relative merits in terms of availability, price and thermal performance. Table 1.3 is based on the calculations carried out in the previous sections and presents a comparison of the heat capacity and CO_2 and SO_2 production of the three fossil fuels. The fourth column is of particular importance in comparing all three fuels; it represents the quantity of carbon dioxide emitted for every unit of energy produced.

Coal produces the highest amount of carbon dioxide for a given output of energy, then oil, then natural gas, which produces nearly half the emissions of coal and a third less than oil.

The results displayed in Table 1.3 for the production of CO_2 mass per unit energy compare well with data published by the UK government. The values found in this chapter are slightly lower than those quoted in the Action on Energy publication; the reason for this is that the calculations shown in this chapter are only concerned with the combustion process itself; these calculations do not take into account the effect of the lifecycle of the fuel, such as the energy used to transport and process the fuel, nor do they include distribution losses.

Table 1.3 Environmental impacts of fossil fuels.

Fuel	Calorific value MJ/kg	CO_2 kg/kg fuel	CO_2 /Energy kg/MJ	CO_2 /Energy kg/MJ*	SO_2 kg/kg fuel
Coal	26	2.361	0.091	0.093	0.018
Oil	42	3.153	0.075	0.079	0.040
Natural gas	55	2.750	0.050	0.055	0

*Source: Action on Energy Publication No. EEB006.

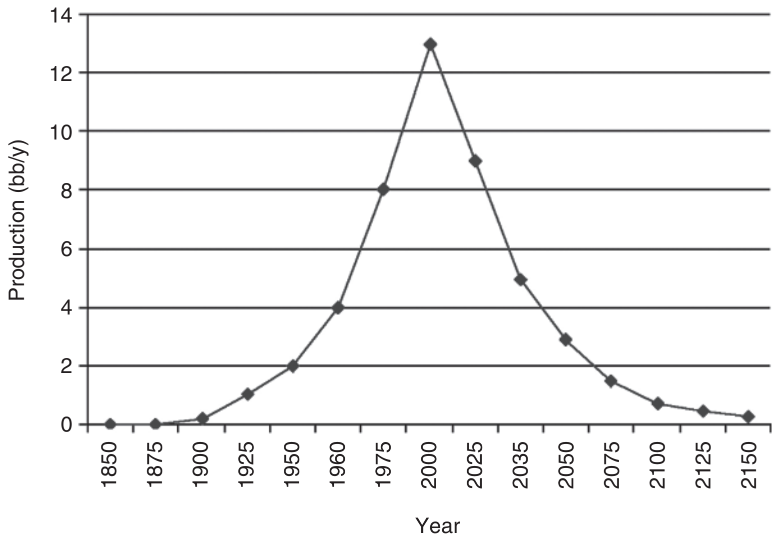

Figure 1.2 The first wake-up call by Hubbert.

1.6 Energy worldwide

The consumption of energy by humankind has evolved over the ages. It began with the invention of fire; man relied on wood burning to cook and to provide warmth and light for millions of years. As civilisation evolved, the needs for energy became greater and other sources were sought. In the long search, man discovered coal. Over the years, coal provided a much greater resource for energy, encouraging man to push its use into further applications.

A major leap in the 19th century was achieved by the discovery of oil in the Middle East. This unfortunate discovery eventually led to two major international wars as the leading industrial nations attempted to dominate the world market and to secure the energy supply for their huge manufacturing industries.

The oil crisis due to the Arab–Israeli war in 1973 resulted in the tripling of oil prices. This was a major shock for nonproducing countries, particularly in Europe, as it put tremendous strain on the energy consumer's budget.

The discovery of oil pushed the competition for manufacturing beyond the industrialised countries' own borders. This competition for shares in the export market put enormous pressure on the reserves of fossil fuel. Hubbert put out a caution when he published his famous curve in 1956 (Figure 1.2). It is clear that the oil reserves of the world are being consumed unsustainably and that they will be exhausted within this century. Humans have to find a new source or sources of energy to replace oil.

However, on the positive side, the depletion of oil can be considered a major advantage to humankind and the environment, in that it will force consumers to reduce their excessive consumption of energy, it will help man to review manufacturing processes and attempt to increase energy efficiency, and it has

Table 1.4 World's energy consumption: past, present and future.

Year	Coal EJ	Oil EJ	Natural gas EJ	Renewable energy EJ	TOTAL EJ	Population millions	Energy kW/capita
1860	3.8	0	0	0	3.8	1000	3.8
1900	20.8	0.8	0.3	0	21.9	1700	12.8
1920	35.8	3.8	0.9	0	40.5	1900	21.3
1940	42.1	11.2	3.1	0	56.4	2000	28.2
1960	60.0	40.2	17.9	10	128.1	2400	53.4
1972	66	115	46	26	253	2500	101.2
1985	115	216	77	33	441	3884	113.5
2000	170	195	143	56	564	5780	97.6
2020	259	106	125	100	590	8846	66.7

probably already pushed governments to search for newer sources of energy. Substantial funds are being allocated to research into renewable resources such as hydropower, wind turbines and solar energy.

Energy consumption worldwide has continued to rise. It is estimated that in 1900, the world consumption was around 22 EJ and by 1960 it had risen to 128 EJ; this reached 564 EJ in 2000 (Table 1.4).

The continued increase in the global population and the associated increase in manufacturing to cater for our greater dependence on energy-driven devices and the culture of multi-car ownership have put even greater importance on energy. It is interesting to note that the energy consumption for individuals increased by tenfold over the course of the 20th century. This is further proof that our use is becoming excessive and that we are much more dependent on energy than we have ever been before.

1.7 Energy and the future

The planet's fossil fuel resource is finite; the production of oil since 1900 is estimated to have reached its peak, and the expected drop in oil reserves will commence shortly. The current rate of consumption is unsustainable; it has taken the Earth millions of years to form these fossil fuels, and it seems that we are about to consume them all in a matter of 200–300 years (see Figure 1.3 and Table 1.5).

The issue is not so much one of 'running out', but more a case of not having enough to keep our current exuberant wasting of energy running. It is a matter of responsibility and obligation to keep some reserves for generations to come.

The second critical issue is that as energy becomes scarce, there will be wars over it. The world has already witnessed major wars in the Middle East. The situation will deteriorate as the fuel supply is reduced.

The shift from fossil fuels to alternative sources is not going to be easy, it is going to take time and much effort and sacrifice in order to adjust.

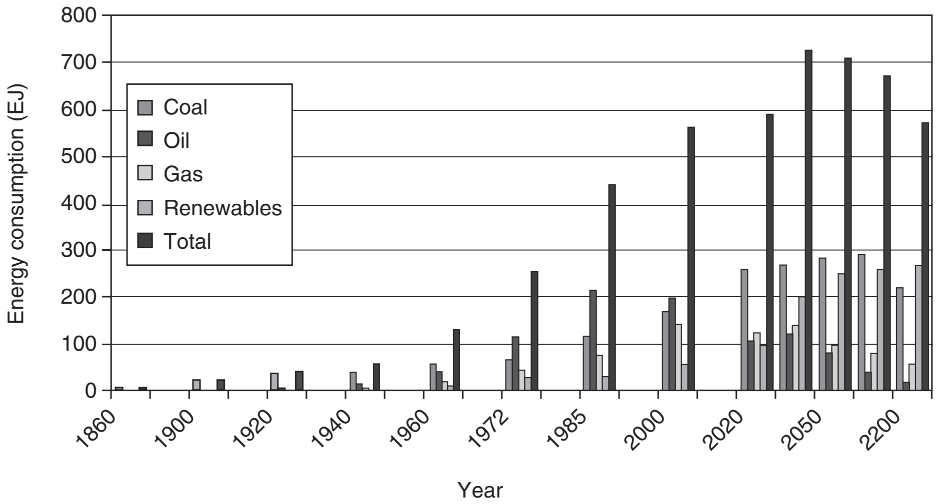

Figure 1.3 World's energy consumption, past and forecast.

Table 1.5 Estimated energy reserves of the world.

Source	Quantity	Form
Earth's daily receipt of solar energy	14.9×10^{21} J	Thermal/ Electromagnetic
Hydropower	3×10^{12} J/s	Mechanical
Tidal power	6.7×10^{10} J/s	Mechanical
Geothermal	0.4×10^{21} J	Thermal
Natural gas	11×10^{21} J	Chemical
Petroleum	11.7×10^{21} J	Chemical
Coal	200×10^{21} J	Chemical
Uranium	1800×10^{21} J	Nuclear fission
Deuterium	$6\,000\,000 \times 10^{21}$ J	Nuclear fusion

As affordable oil is necessary to power any serious attempt at a switchover to alternative sources of energy, extreme prices will severely hinder – if not completely cripple – the ability of society to cope. The economic fallout from high prices will almost certainly produce geopolitical tensions (i.e. war), thereby further hampering the development of large-scale alternative sources of energy. Worse still, in a global environment characterised by massive energy wars, the bulk of the world's financial capital is likely to be disproportionately invested in weapons technologies over alternative energy technologies.

In 1905 Albert Einstein put forward his equivalence theory, and in 1938 Otto Hahn discovered nuclear fission; however, it was not until 1957 that the first nuclear electricity generation was achieved in the USA. Today, France produces 80% of its electricity from nuclear energy.

It is well known by now that although nuclear fission is a valuable source of energy, it has long-term hazards during the production period and the burden of long-term storage of waste after use and the decommissioning of the power plant at the end of its productive life. There has to be a solution in order to avoid such crises; the way forward involves two possibilities.

1.7.1 The dream scenario

A fusion reaction is the process by which large quantities of heat are generated by fusing the nuclei of hydrogen or helium isotopes, which may be derived from seawater. The temperatures and pressures needed to sustain fusion make it a very difficult process to control. In theory, this process has the potential to supply vast quantities of energy with relatively little pollution. Many countries are supporting fusion research; however, inadequate research on quantity and quality has meant no real progress thus far.

If, by extreme good fortune, someone is able to realise nuclear fusion on a realistic scale, it is estimated that this form of energy will sustain life on Earth for millions of years to come. However, realising this goal may be similar, at the moment at least, to someone planning to go to heaven!

1.7.2 The renewable scenario

Renewable energy sources include solar, wind, hydro, geothermal and biomass. All have been realised to a limited degree so far.

This is a more realistic solution for the near future. Renewable energy is freely available and it is pollution-free, but at the present time it does not compete on economic terms with cheap fuels such as coal, oil and gas. This is because, so far, the technology of harnessing renewable energy is relatively inefficient. However, considerable international effort has been coordinated to increase the use of renewable energy in order to reduce global warming caused by the combustion of fossil fuels.

1.8 Worked examples

Worked example 1.1

Determine the 'free' energy of water contained in a lake if the lake size is 2000 m^3 and its water level is 300 m above the axis of a water turbine.

Determine the velocity of the water in the supply pipe at the turbine inlet if losses due to friction in the pipe represent the equivalent of 50 m energy head.

Solution:

The potential energy of the water behind the dam is calculated using Equation [1.1]:

Potential energy = $m\ g\ h$
Mass of water = volume of the lake × density of water
= 2000 × 1000 = 2 × 10^6 kg
Potential energy, PE = 2 × 10^6 × 9.81 × 300
= 5.886 × 10^9 J

Potential energy is converted into kinetic energy at the turbine inlet, less the energy consumed in overcoming friction, hence:

Potential energy ($m\ g\ h$) = kinetic energy ($\frac{1}{2}\ m \times v^2$)

Hence

$$v = \sqrt{2gh} = \sqrt{2 \times 9.81 \times 250}$$
$$= 70 \text{ m/s}$$

Note that the effective head used is 300 – 50 = 250 m to allow for losses.

Worked example 1.2

A car engine consumes 0.2 litres of fuel every minute; the petrol has a heating value of 42 000k J/kg and a density of 800 kg/m^3. If only 30% of the fuel is converted into useful mechanical energy, determine the power of the car. Discuss the fate of the wasted energy.

Solution:

Mass of fuel used = volume × density
= (0.2/1000) × 800
= 0.16 kg/minute
= 0.0026 kg/s

The chemical energy liberated from burning the fuel is calculated using Equation [1.3]:

Useful energy = mass × calorific value × combustion efficiency
= 0.0026 × 42 000 000 × 0.30
= 33 600 J/s (W)
= 33.6 kW

This is the part utilised to move the car. The remaining energy content of fuel has been wasted as:

- thermal energy carried away by the exhaust gases;
- thermal energy carried away by the engine cooling system;
- mechanical energy wasted as friction in various places;
- other minor forms such as sound and light generated by excessive friction between the tyres and the road.

Worked example 1.3

Using Einstein's mass-energy equation ($E = mC^2$)

(a) Determine the energy produced when one milligram of a fissionable material undergoes a nuclear chain reaction.
(b) What is the power rating of such a power plant if the consumption of Uranium is 1kg per day?

Assume the speed of light $C = 3 \times 10^8$ m/s

Solution:

(a) Using Einstein's famous mass-energy equation, the energy liberated from nuclear fission is calculated as follows:

$$E = mC^2$$
$$= 10^{-6} \times (3 \times 10^8)^2$$
$$= 90 \times 10^9 \text{ J}$$

Note that the mass has to be in units of kilograms, and the speed of light in metres per second.

(b) The number of seconds in a day = 24 × 3600 = 86 400 seconds

$$\text{Power} = E/\text{time} = mC^2/\text{time}$$
$$= 1.0 \times (3 \times 10^8)^2/86\,400$$
$$= 1.04 \times 10^9 \text{ kW}$$

Worked example 1.4

(a) Calculate the thermal energy needed to raise the temperature of 20 litres of water from 20 to 50°C.
(b) If the above process is completed in 4 minutes, what is the power of the heater used?

Assume that, for water, 1 litre weighs 1kg and specific heat capacity Cp = 4200 J/kgK.

Solution:

(a) Using Equation [1.5] to calculate the heat (thermal energy) required to raise the temperature of water:

$$\begin{aligned}\text{Thermal energy} &= \text{mass} \times \text{specific heat} \times \text{temperature difference}\\ &= 20 \times 4200 \times (50\text{–}20)\\ &= 2\,520\,000\,\text{J}\end{aligned}$$

Note that 20 litres of water has a mass of 20 kg.

(b) By definition, power is the rate of energy consumed, hence:

$$\begin{aligned}\text{Power} &= \text{energy/time}\\ &= 2\,520\,000/(4 \times 60)\\ &= 10\,500\text{W or } 10.5\,\text{kW}\end{aligned}$$

Worked example 1.5

Describe the energy conversion in each of the following units:

- a motor car;
- a battery;
- a gas boiler;
- an electric fire.

Solution:

Take, for example, the first part. The motor car converts fuel (chemical energy) into torque (mechanical energy). The other cases are shown in Worked example 1.5, Table 1.

Worked example 1.5, Table 1

Unit	Input	Output
Motor car	Chemical	Mechanical
Battery	Chemical	Electrical
Boiler	Chemical	Thermal
Electric fire	Electric	Thermal

1.9 Tutorial problems

1.1 Describe the energy conversion in each of the following units

- an aeroplane;
- a push mower;
- a radio.

Ans. (chem/mech; mech/mech; elec/mech)

1.2 Calculate the thermal energy needed to raise the temperature of 40 litres of water from 10 to 40°C. If the process is completed in 5 minutes, what is the power of the heater? Assume, for water, 1 litre weighs 1 kg; Cp = 4200 J/kgK.
Ans. (5040 kJ, 16.8 kW)

1.3 Using Einstein's mass-energy equation ($E = mC^2$) determine the energy produced when a one-metre long bar of Uranium of 25 mm diameter (density 8400 kg/m^3) undergoes a nuclear chain reaction. Assume the speed of light, $C = 3 \times 10^8$ m/s.
Ans. (3.71×10^{17} J)

1.4 A car engine consumes 0.2 litres of fuel every minute; the petrol has a heating value of 45 MJ/kg and a density of 800 kg/m^3. If only one third of the fuel is converted into useful mechanical energy, determine the power of the car.
Discuss the fate of the wasted energy.
Ans. (40 kW)

1.5 Determine the potential energy of water contained in a lake if the lake size is 200 m^3 and its water level is 30 m above the axis of a water turbine. Determine the velocity of the water at the turbine inlet if losses due to friction in the pipe represent the equivalent of 5m energy head.
Ans. (58.86 MJ, 22 m/s)

1.6 Coal has the following composition by weight:

Carbon	50%
Hydrogen	10%
Sulphur	20%
Incombustibles	20%

Determine the calorific value of this fuel assuming that the enthalpy of evaporation for the following is:

Carbon	32 793 kJ/kg;
Hydrogen	142 920 kJ/kg
Sulphur	9300k J/kg
Water vapour	–2256.7 kJ/kg

Ans. (30.5 MJ/kg)

1.10 Case Study: Future energy for the world

The purpose of this case study is to examine current world energy consumption and investigate various strategies for securing a sustainable energy supply. In Case Study 1.10, Table 1, the world energy consumption for the year 2007 (taken from the BP statistics website) is used as a starting point. The idea behind this exercise is to examine a few possibilities in which some of the more polluting fuels are replaced by cleaner fuels, and to debate the merits of each proposal.

Case Study 1.10, Table 1 World energy consumption data 2007.

	World consumption		CO_2	Total CO_2	% CO_2
Type of fuel	mtoe*	GJ	kg/GJ	million tons	%
Oil	3939	1.6E+11	79	13 029	41.15
Coal	3194	1.3E+11	93	12 437	39.28
Nat gas	2658	1.1E+11	55	6121	19.33
Biomass	1000	4.2E+10	1	42	0.13
Hydro	179	7.5E+09	1	7	0.02
Nuclear	622	2.6E+10	1	26	0.08
Total	11 592	4.9E+11		31 661	100

*mtoe = million tonne oil equivalent.

Note that for hydro and nuclear plants, the CO_2 figures correspond to construction of the plant and manufacture of components.

Now let's propose some schemes for reducing the total emission, discussing the merits of each proposal.

1.10.1 Scheme 1 – Reduce emissions of CO_2 – Replace coal by natural gas

The relevant information for this scheme is shown in Case Study 1.10, Table 2.

Case Study 1.10, Table 2 Reducing emissions by replacing coal by natural gas.

	World consumption		CO_2	Total CO_2	% CO_2
Type of fuel	mtoe	GJ	kg/GJ	kg	%
Oil	3939	1.6E+11	79	1.3E+13	49.02
Coal	0	0.0E+00	93	0.0E+00	0
Nat gas	5852	2.5E+11	55	1.3E+13	50.7
Biomass	1000	4.2E+10	1	4.2E+10	0.16
Hydro	179	7.5E+09	1	7.5E+09	0.03
Nuclear	622	2.6E+10	1	2.6E+10	0.1
Total	11 592	4.9E+11		2.7E+13	100

Reduction in $CO_2 = 16.05\%$
Merits of the proposal:
For: it provides a 16% reduction in CO_2
Against: expensive solution; finite resource.

1.10.2 Scheme 2 – Reduce emissions of CO_2 – Replace coal by biomass

The relevant information for this scheme is shown in Case Study 1.10, Table 3.

Case Study 1.10, Table 3 Reducing emissions by replacing coal by biomass.

	World consumption		CO_2	Total CO_2	% CO_2
Type of fuel	mtoe	GJ	kg/GJ	kg	%
Oil	3939	1.6E+11	79	1.3E+13	67.3
Coal	0	0.0E+00	93	0.0E+00	0
Nat gas	2658	1.1E+11	55	6.1E+12	31.62
Biomass	4194	1.8E+11	1	1.8E+11	0.91
Hydro	179	7.5E+09	1	7.5E+09	0.04
Nuclear	622	2.6E+10	1	2.6E+10	0.13
Total	11 592	4.9E+11		1.9E+13	100

Reduction in $CO_2 = 38\%$
Merits of the proposal:
For: it provides a 38% reduction in CO_2
Against: impractical solution as it needs a huge area of plantation. Furthermore, it will affect the land use for food.

1.10.3 Scheme 3 – Reduce emissions of CO_2 – Replace coal by nuclear

The relevant information for this scheme is shown in Case Study 1.10, Table 4.

Case Study 1.10, Table 4 Reducing emissions by replacing coal by nuclear.

	World consumption		CO_2	Total CO_2	% CO_2
Type of fuel	mtoe	GJ	kg/GJ	kg	%
Oil	3939	1.6E+11	79	1.3E+13	67.3
Coal		0.0E+00	93	0.0E+00	0
Nat gas	2658	1.1E+11	55	6.1E+12	31.62
Biomass	1000	4.2E+10	1	4.2E+10	0.22
Hydro	179	7.5E+09	1	7.5E+09	0.04
Nuclear	3816	1.6E+11	1	1.6E+11	0.83
Total	11 592	4.9E+11		1.9E+13	100

Reduction in CO_2 = 38%
Similar reduction to biomass, but at what environmental cost?

1.10.4 Other possibilities

There is also the possibility of using a combination of renewable energy sources, such as hydro, wind energy, solar energy and biomass.