So apart from improving the energy efficiency of the buildings and appliances in the industrial sector, where the approaches are similar to those in the domestic and services sectors, there are other measures that apply specifically to industry. In particular, these include 'cascading' of energy uses, where 'waste' heat from a high-temperature process is used to provide energy for lower temperature processes; and the use of high-efficiency electric motors, pumps, fans and drive systems, with accurate matching of motors to the tasks they are required to perform, and accurate sizing of pipes and their associated pumps.

Dematerialization

The measures that can be adopted by industry also include reductions in the material content of products, for example in car bodies or drinks cans, where thinner metals can be used without any reduction in the required strength; or the substitution of less energy-intensive materials, as in the use of plastics instead of steel for car bumpers.

These measures are one form of what has been termed 'dematerialization' – a reduction in the material-intensity (and hence the energy-intensity) of production.

Another form of dematerialization involves changes that are more social than technological. It occurs when the structure of a country's entire economy shifts towards less energy- and materials-intensive activities. For example, in the UK the steel industry today accounts for a much smaller share of the country's gross domestic product (GDP) than it did 20 years ago. By contrast, the UK services sector now constitutes a much bigger fraction of GDP than two decades ago. Since the service sector usually requires less energy than the steel industry for every pound's worth of production, Britain's overall energy demands have been less than they would otherwise have been. However, if the steel that was formerly manufactured in Britain is now manufactured abroad but still imported to the UK in similar quantities, all that has happened is that the energy input, with its associated CO_2 emissions and their implications for global warming, has been transferred to another country.

The transport sector

Motor vehicles (cars, vans, buses, trucks, motor cycles) dominate the transport sector in developed countries. But this sector also encompasses many other modes of transport, including rail, air and shipping, and non-motorized transport forms such as cycling and walking.

As can be seen from Figure 1.49, the various forms of transport vary enormously in their energy requirements per passenger-kilometre travelled. Cycling and walking, of course, require no fuel input apart from food.

In most developed countries there has been an enormous increase in transportation, measured in passenger-kilometres travelled annually, over the past few decades (Figure 1.50). Most of this has involved motorized transport, mainly fuelled by oil, and so energy use has also increased greatly, as have the associated CO_2 emissions.

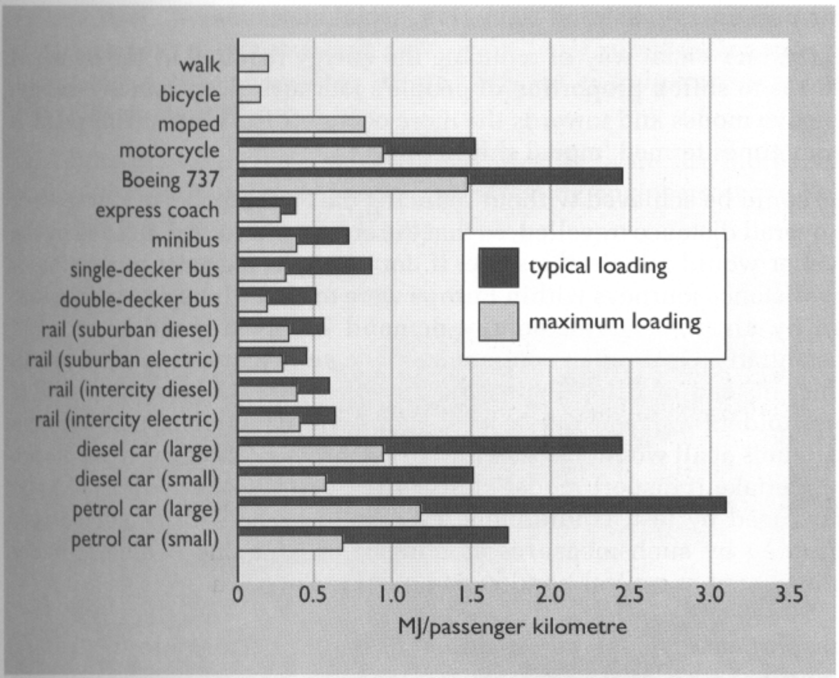

Figure 1.49 Energy efficiency of different modes of transport in the UK (source: Hughes, 1993)

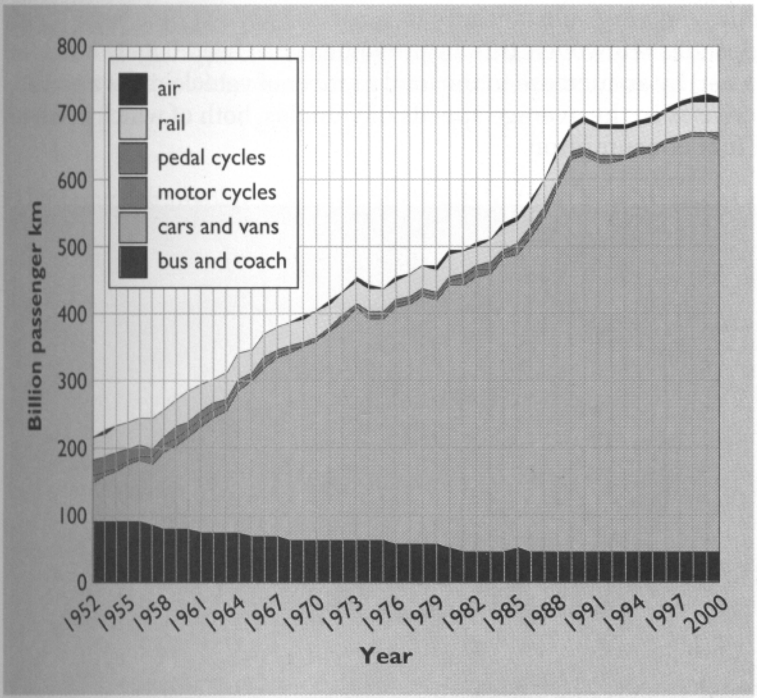

Figure 1.50 Annual passenger-kilometres travelled in the UK, 1952–2000, by transport mode. Note: air travel data refers to internal flights only (source: DTLR, 2001)

Transport energy demand reduction: social measures

Clearly, one social way of reducing the energy required by the transport sector is to shift a proportion of people's journeys away from the energy-intensive modes and towards the more energy-frugal modes. This process is sometimes termed 'modal shift'.

This could be achieved without reducing the total number of journeys, or the overall distance travelled, so that the amenity or service enjoyed by the traveller would remain the same. If, for example, a greater proportion of long-distance journeys within Europe were made by inter-city train rather than by air, the overall energy demand involved could be reduced substantially. Or if urban commuters made more journeys to work by rail or bus instead of using their cars, the effects would be similar. And if householders walked to their local shops instead of taking their cars, no fossil fuels at all would be used for those journeys. Of course, if people are to undertake transport modal shifts of these kinds, they will need to be encouraged by fast, comfortable, efficient services – or penalized into switching by such measures as congestion charging, which is being implemented in central London and other major cities.

Transport energy demand reduction: technological measures

In addition to such social measures, there are numerous technological options for improving the energy-efficiency of transport energy use. Improving vehicle fuel economy is one obvious measure, and the average fuel economy (in miles per gallon, or litres per 100 km) of vehicles has indeed improved very substantially in most developed countries over the past few decades. However, this improvement has been largely offset (in the UK at least) by an increase in the total number of vehicle-miles travelled, and by increases in the average speeds of vehicles, both of which result in increased fuel consumption.

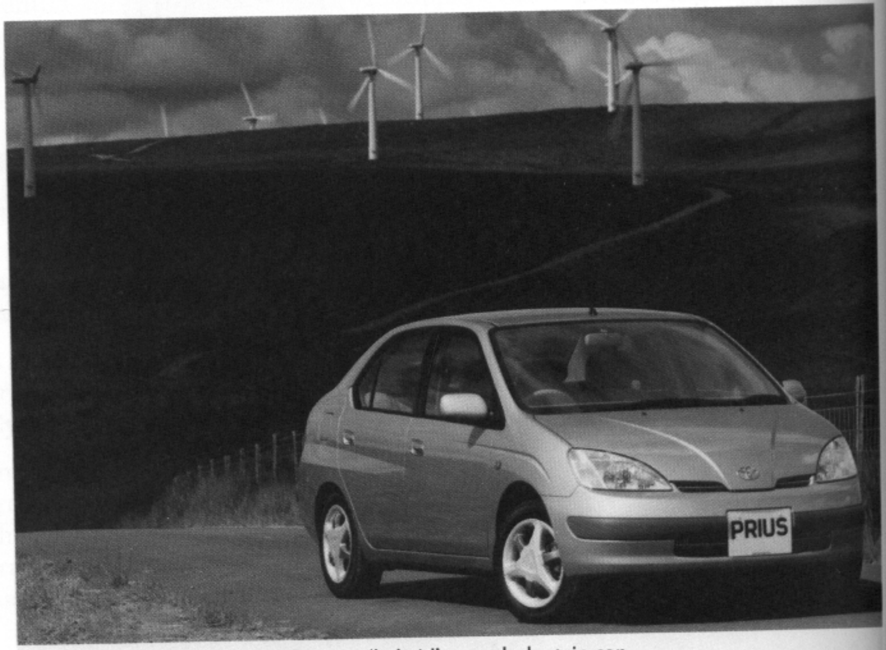

Figure 1.51 The Toyota Prius, a 'hybrid' petrol-electric car

Nevertheless, manufacturers continue to introduce new models with steadily improving fuel economy, partially spurred by legislation requiring them to do so. New approaches include 'hybrid' petrol-electric cars such as the Toyota Prius (Figure 1.51).

In addition to such incremental improvements, there are also more radical possibilities, such as the 'hypercar', proposed by engineers at the Rocky Mountain Institute in the USA (Figure 1.52).

Figure 1.52 The 'Hypercar', designed by engineers at the Rocky Mountain Institute, Colorado, USA, would be streamlined and made of strong but ultra-light, composite materials

This approach involves the use of strong but ultra-lightweight composite materials such as carbon fibre or Kevlar, combined with a highly streamlined body shell. The drive system is would either be of the 'hybrid' type, consisting of a small gasoline-fuelled engine augmented by electric motors and a small battery store; or a more advanced system employing a fuel cell powered by hydrogen. Fuel cells are rather like conventional batteries, except that they are continuously re-charged by supplying fuel – usually hydrogen gas – that reacts electrolytically with oxygen from the atmosphere to produce an electric current. In the hypercar, the fuel cell would generate electricity for electric motors that provide power to the wheels. The hydrogen fuel would either be stored in tanks in its pure form, or generated on-board by 're-forming' fossil fuels. The oxygen would come from the surrounding atmosphere. Hypercars, their proponents claim, could achieve between three and five time the fuel economy of current models, with emissions levels approaching zero in the case of the hydrogen-fuel cell version.

Hypercars may still be some way off, but major manufacturers such as Daimler-Chrysler and Ford have recognized the need to make dramatic reductions in vehicle CO_2 emissions in the long term, and are investing many hundreds of millions of dollars in the production of fuel-celled vehicles (Figure 1.53).

Figure 1.53 This Mercedes A-Class car is powered by a fuel cell running on hydrogen. The manufacturers, Daimler-Chrysler, and other car-makers such as Ford and General Motors, have announced plans to introduce similar cars on the market around 2004

The rebound effect

When individuals or organizations implement energy efficiency improvements, they usually save money as well as saving energy. However, if the money saved is then spent on higher standards of service, or additional energy-consuming activities that would not have otherwise been undertaken, then some or all of the energy savings may be eliminated. This tendency is sometimes known as the 'rebound effect'. For example, if householders install improved insulation or a more efficient heating boiler, they should in principle reduce their heating bills. However, if they instead maintain their homes at a higher temperature than before, or heat them for longer periods, the savings may be wholly or partly negated. Alternatively, they may decide to spend the money saved through lower heating bills by taking a holiday involving air travel. Since air travel is quite energy-intensive (see Figure 1.49) once again the energy savings will be offset by increased consumption, albeit of a different kind.

In devising national policies to encourage energy efficiency improvement, Governments need to take the rebound effect into consideration. In some cases, it may mean that the energy savings actually achieved when energy efficiency measures are implemented are less than expected. Another policy implication is that citizens should be given incentives to spend any savings they make when they implement energy efficiency measures in ways that are energy-frugal rather than energy-intensive.

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1.6 Energy in a sustainable future

In this chapter we have briefly introduced three key approaches to improving the sustainability of human energy use in the future:

- 'Cleaning-up' fossil and nuclear technologies
- Switching to renewable energy sources
- Using energy more efficiently

(a) 'Cleaning-up' fossil and nuclear technologies

This means mitigating some of the adverse 'environmental' consequences of fossil and nuclear fuel use through the introduction of new, 'clean' technologies that should substantially reduce pollution emissions and health hazards. These include 'supply-side' measures to improve the efficiency with which fossil fuels are converted into electricity in power stations; cleaner and more efficient combustion methods; the increasing use of 'waste' heat in combined heat-and-power schemes; and 'end of pipe' technologies to intercept and store pollutants before they enter the environment. This approach also includes 'carbon sequestration' [Box 1.3] and 'fuel switching' – shifting our energy use towards less-polluting fuels, for example from coal to natural gas. It may also be possible to 'clean up' nuclear power by adopting more advanced technologies that are safer and entail the emission of fewer radioactive substances over the entire nuclear fuel cycle.

(b) Switching to renewable energy sources

The use of renewable energy usually involves environmental impacts of some kind, but these are normally lower than those of fossil or nuclear sources.

Approaches (a) and (b) are essentially 'supply-side' measures – applied at the supply end of the long chain that leads from primary energy production to useful energy consumption.

(c) Using energy more efficiently.

This, as we have seen, involves a mixture of social and technological options, applied at the demand-side of the energy chain.

How might these three approaches to improving the future sustainability of our energy systems be combined in future? What are the various possibilities, and what are the main factors that will determine the ultimate outcomes?

Changing patterns of energy use

Before considering the feasibility, and the plausibility, of radical changes in patterns of energy production and consumption, of the kind that will be needed during first half of the twenty-first century if we are to progress towards sustainability, it is useful to recall the profound changes that have already occurred in our energy systems during the latter half of the twentieth century.

BOX 1.3 **Carbon sequestration**

One way of mitigating climate change that could be important is called 'carbon sequestration'. To sequester means to 'put away', and sequestration of carbon essentially involves finding ways of removing the carbon generated by fossil fuel burning and storing it so that it cannot find its way back into the atmosphere.

One way of sequestering carbon is to plant additional trees which 'soak up' CO_2 from the atmosphere while they are growing. However, whilst this could provide a partial response to the problem of rising CO_2 levels, the sheer magnitude of world emissions is now so great that sequestration in forests alone is probably impractical. It has been estimated that to sequester in trees the carbon produced by world fossil fuel combustion over the next 50 years would require the afforestation of an area the size of Europe from the Atlantic to the Urals. (RCEP 2000). Also, when these trees eventually decayed and died, they would emit a similar quantity of CO_2 to that which they absorbed during growth, so it would be necessary to replace the old trees with new ones on a indefinite basis.

However wood fuel from fast-growing plantations, managed sustainably, could be harvested and used as a substitute for fossil fuels, instead of simply being allowed to grow to maturity and then decay. This would offset the carbon emissions that would otherwise have been generated by burning the fossil fuels.

Another approach to sequestering CO_2 is to extract it after combustion in, for example, a power station and store it in some suitable location. It appears to be technically possible to transport by pipeline large quantities of post-combustion CO_2 and store it indefinitely in disused oil or gas wells or in saline aquifers beneath the sea bed (Figure 1.54). Further research is required to confirm the feasibility, security, safety and economic viability of such techniques. They would only be a realistic option in the case of power stations or similar large installations: it would hardly be practicable to apply this approach to emissions from vehicles or homes.

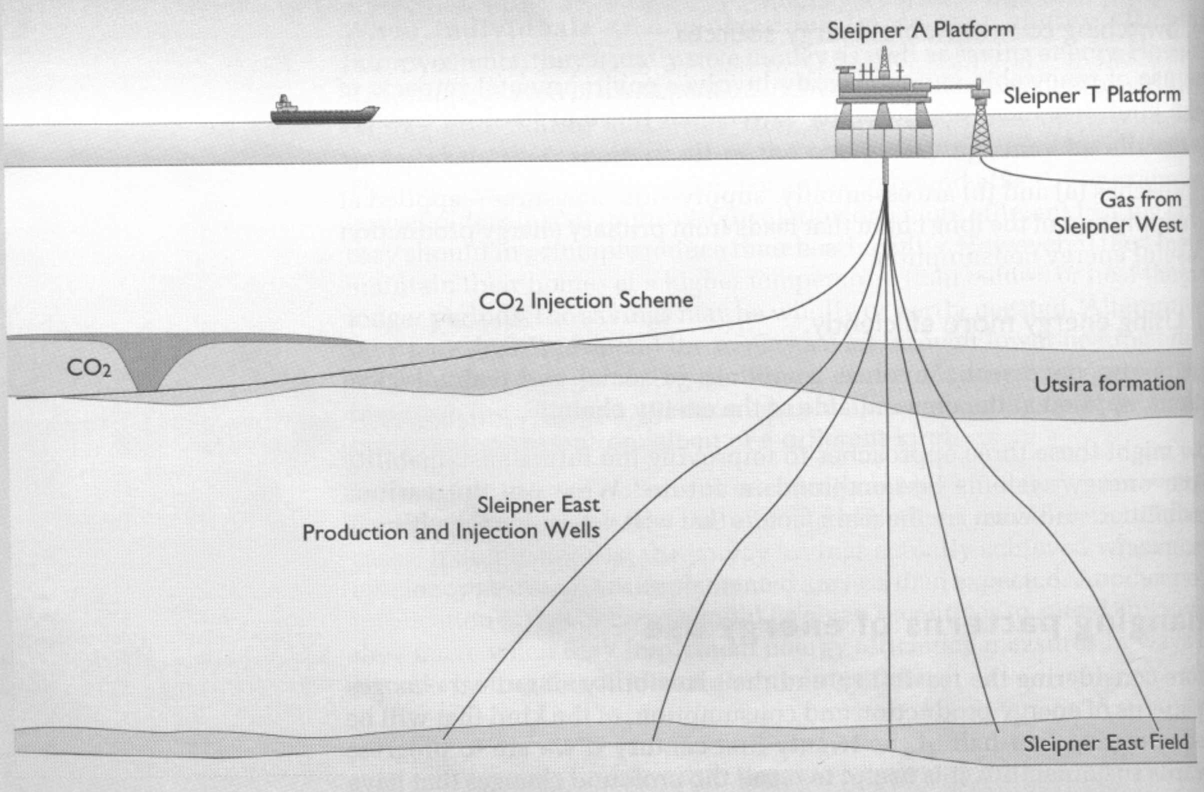


Figure 1.54 Norwegian Statoil's Sleipner field project. Gas from this field has a very high CO_2 content. Excess CO_2 is pumped into a saline aquifer, the Utsira formation, about 800 m below the sea bed. A million tonnes per year of CO_2 are 'sequestered' in this way

In Britain just after World War II most homes and other buildings were heated by coal. Most electricity generation was coal-fired, and most rail transport was propelled by coal-burning steam engines. Coal combustion caused major pollution problems, including the notorious London 'smogs' which in most winters caused the premature deaths of hundreds (and occasionally thousands) of people until the introduction of the Clean Air Act in 1956.

Coal miners perished in their dozens, and sometimes hundreds, in mining accidents every year, and many others died slowly of lung diseases caused by inhaling coal dust. Open coal fires in most houses were so inefficient that, despite consuming large quantities of energy, they only heated a few rooms effectively whilst the rest remained cold.

Motor cars were still owned only by a minority and air travel was confined to a small elite. Most people travelled by bus, train, cycle or on foot. Journeys were relatively few, compared with today, and usually over quite short distances.

Since the late 1940s, the UK's energy systems have been transformed. Natural gas, which burns much more cleanly and efficiently, was introduced very rapidly to British homes and buildings from the 1970s, after its discovery beneath the North Sea, and has now replaced coal as the main heating fuel for buildings. Most homes now have gas-fired central heating systems which ensure that the whole house is maintained at a comfortable temperature.

Coal is still used for electricity generation, but flue gas desulphurization and electrostatic precipitators now greatly reduce emissions of sulphur dioxide and particulates. In new power stations, coal is increasingly being replaced by gas, which can be burned very cleanly and efficiently using combined cycle gas turbines. Nuclear power, since its modest beginnings at Calder Hall in 1956, now contributes around one-quarter of UK electricity.

Cars are now owned by the majority, air travel overseas has become a mass market, railways are powered mainly by electricity, and travel overall, measured in passenger-kilometres, has tripled since the 1950s (Figure 1.50). Britain is currently a net exporter of oil, thanks to its large North Sea reserves, whereas before the 1970s all its oil was imported.

The dramatic changes that have occurred in Britain's energy systems during the past 50 years have, broadly, been paralleled in most 'developed' countries over the same period. Examples of changing patterns of energy use in other EU countries are given in Chapters 2 and 3.

Given the scale and profundity of the changes over the past half-century, it does not seem unrealistic to suggest that equally-profound changes could well occur over the next 50 to 100 years, as we attempt to improve the sustainability of our energy systems, nationally and globally.

Long-term energy scenarios

To begin to understand the range of long-term future possibilities, let us look briefly at two major studies of future sustainable energy options, the first addressing the UK situation, the second taking a world perspective.

The Royal Commission on Environmental Pollution scenarios

The UK's Royal Commission on Environmental Pollution produced its 22nd report *Energy: the Changing Climate* in June 2000. The commission examined what changes would be needed in Britain's energy systems if, as suggested by the various reports of the Intergovernmental Panel on Climate Change (IPCC, 2001), it should prove necessary to reduce the country's emissions of greenhouse gases by about 60% by 2050.

The Commission investigated the various possibilities very thoroughly and summarized them in four 'scenarios' for 2050. Scenarios are not predictions of what *will* happen, but plausible outlines of what *could* happen, under given conditions. In all four scenarios, the overall contribution from fossil fuels is reduced to approximately 40% of current consumption, consistent with the 60% reduction in fossil fuel use required to achieve a 60% cut in CO_2 emissions.

The RCEP scenarios are summarized in Box 1.4. They demonstrate that it would be feasible for the UK to progress towards much greater sustainability (in terms of reducing CO_2 emissions) in its energy systems over the next 50 years. They also show that there are a number of ways in which this could be achieved.

The actual outcome over coming decades will depend on the extent to which we change our lifestyles and our technologies in order to conserve energy; how effective we are in generating and using it more efficiently; how rapidly we choose to develop and deploy renewable energy sources; how large a role we choose to give to nuclear power; and whether or not we decide to implement carbon sequestration and other technologies for 'cleaning-up' fossil fuels.

The World Energy Council scenarios

What are the possibilities for radical changes in our energy systems when viewed from a world perspective? There have been numerous studies of the various future options for the world's energy systems. One of the most recent and most comprehensive was produced in 1998 by the International Institute for Applied Systems Analysis (IIASA) and the World Energy Council (WEC), a version of which was published in 2000 as part of the United Nations' *World Energy Assessment* (United Nations Development Programme, 2000). IIASA is a leading 'think tank' based in Austria, whilst the WEC is a body that represents the world's main energy producers and utilities. For simplicity, we shall refer to their scenarios here as the World Energy Council (WEC) Scenarios.

There are six WEC scenarios in all, and these have been grouped into three 'cases', A, B and C. Case B includes only one scenario, termed 'Middle Course'. Case A consists of three 'High Growth' scenarios, and case C includes two 'Ecologically-Driven' scenarios.

Each scenario incorporates different assumptions about rates of economic growth and the distribution of that growth between rich and poor countries; about the choices that are made between different energy technologies and the rapidity with which they are developed; and regarding the extent to which ecological imperatives are given priority in coming decades. They

BOX 1.4 Four energy scenarios for the UK in 2050

Four scenarios were constructed to illustrate the options available for balancing demand and supply for energy in the middle of the twenty-first century if the UK has to reduce carbon dioxide emissions from the burning of fossil fuels by 60%.

Scenario 1: no increase on 1998 demand, combination of renewables and either nuclear power stations or large fossil fuel power stations at which carbon dioxide is recovered and disposed of.

Scenario 2: demand reductions, renewables (no nuclear power stations or routine use of large fossil fuel power stations).

Scenario 3: demand reductions, combination of renewables and either nuclear power stations or large fossil fuel power stations at which carbon dioxide is recovered and disposed of.

Scenario 4: very large demand reductions, renewables (no nuclear power stations or routine use of large fossil fuel power stations).

The key parameters for these four scenarios are as follows:

	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Percentage reduction in 1997 carbon dioxide emissions	57	60	60	60
DEMAND (percent *reduction* from 1998 final consumption)				
low-grade heat	0	50	50	66
high-grade heat	0	25	25	33
electricity	0	25	25	33
transport	0	25	25	33
Total	0	36	36	47
SUPPLY (GW) (annual average rate)				
fossil fuels	106	106	106	106
intermittent renewables	34	26	16	16
other renewables	19	19	9	4
baseload stations (either nuclear or fossil fuel with carbon dioxide recovery)	52	0	19	0

Source: Royal Commission on Environmental Pollution, 2000

all assume that world population will increase from its current (2000) level of around 6.1 billion to 10.1 billion by 2050 and 11.7 billion by 2100. (More recent UN projections, however, suggest that these figures may be overestimates, with 9 billion as the new median population estimate for 2050 (United Nations, 2001). Other recent research also suggests that world population is likely to peak before the end of the twenty-first century and then begin to decline. (Lutz *et al.*, 2001)).

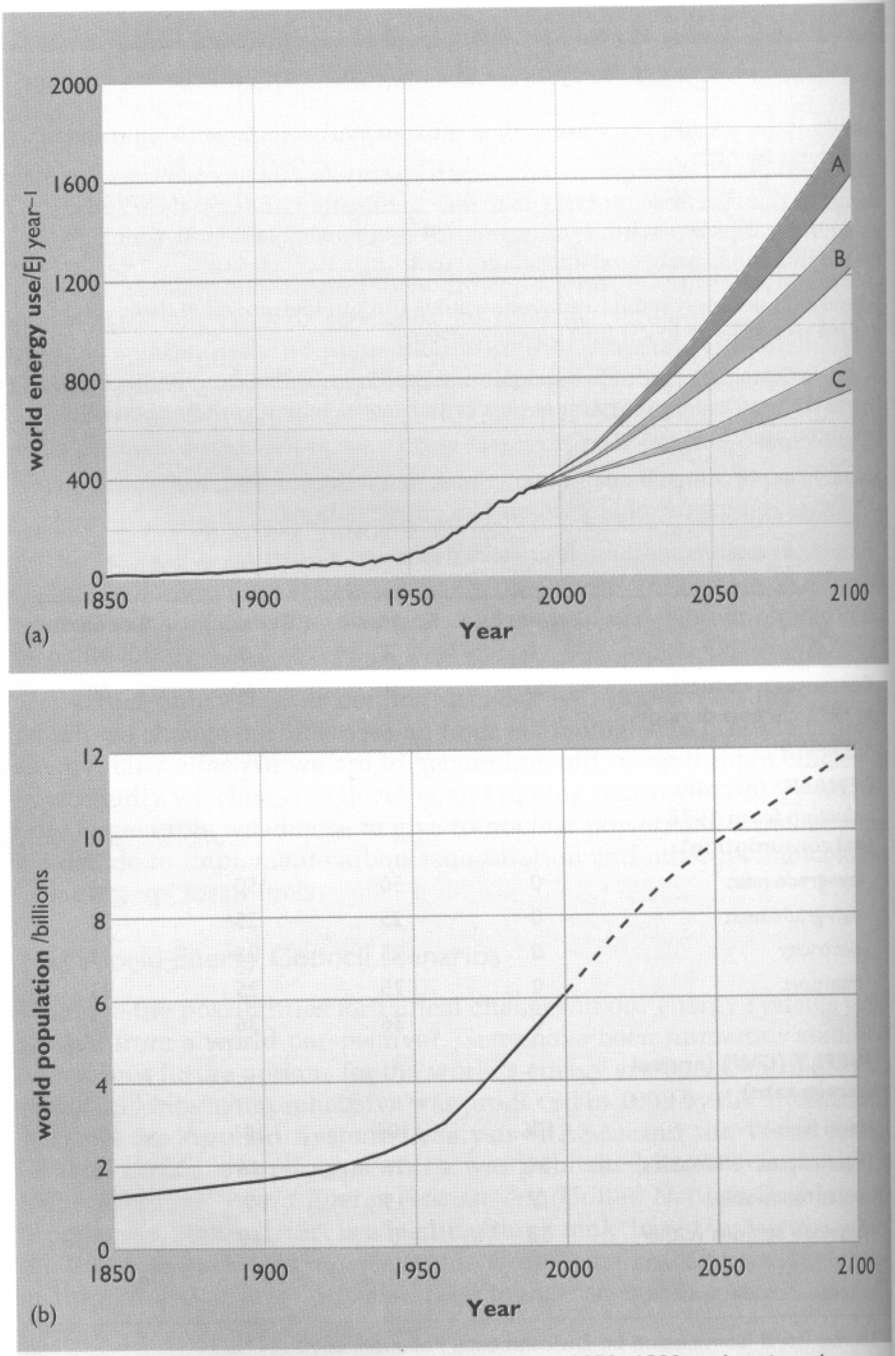


Figure 1.55 (a) Global primary energy requirements, 1850–1990, and projected requirements 1990–2100 in the three World Energy Council scenario 'cases', A, B and C. World energy use here includes commercially-traded energy only;
(b) World population, 1850–2000 and projected population, 2000–2100 (see text)
(source: United Nations Development Programme, 2000)

The results of these assumptions are shown in Figure 1.55 which also shows world population growth from 1850 to 2000 alongside the various scenario projections to 2100.

In all three High Growth scenarios, the world's economy expands very rapidly, at an annual average rate of 2.5% per annum – significantly faster than the historic growth rate of about 2% per year. In all of them, primary energy intensity (the amount of primary energy required to produce a dollar's worth of output in the economy) reduces quite rapidly, reflecting a fairly strong commitment to energy efficiency measures and/or dematerialization. The three scenarios differ mainly in their choices of energy supply technologies. One is based on ample supplies of oil and gas; another envisages a return to coal; and the third has an emphasis on non-fossil sources, mainly renewables with some nuclear. By 2100, the High Growth scenarios all envisage world primary energy consumption rising to over 1800 exajoules, more than four times the 2000 level.

In the single Middle Course scenario, economic growth is lower than in the High Growth scenarios, averaging around 2.1% per annum, close to the historic average rate. Primary energy intensity improves rather more slowly, reflecting a slightly lower world-wide emphasis on energy efficiency improvement. Energy supplies come from a wide variety of fossil, nuclear and renewable sources, and by 2100 total primary energy consumption has reached more than 1400 EJ, over three times the 2000 level.

In the two Ecologically-Driven scenarios, world economic growth is 2.2% per annum, slightly higher than in Middle Course, but there is a very high emphasis on improving energy efficiency, reflected in substantially lower primary energy intensity figures. Both scenarios feature a strong development of renewables, alongside a continued use of oil, coal and natural gas. In one scenario, nuclear energy is phased out by 2100 whereas in the other some nuclear power is retained. Overall primary energy consumption increases to some 880 EJ by 2100, just over twice the 2000 level.

The WEC authors conclude that, judged in terms of their sustainability, one of the High Growth scenarios (the third) includes many elements favouring sustainable development, though the other two High Growth scenarios do not. The Middle Course scenario, however, falls short of fulfilling most of the conditions for sustainable development.

The Ecologically-driven scenarios, unsurprisingly, are much more compatible with sustainable development criteria, although one of them requires a more radical departure from current policies since it envisages a phasing-out of nuclear energy.

The overall message of the WEC scenarios, examining possible solutions at a world scale, is similar to that of the RCEP scenarios for Britain: that progress to much greater sustainability in our energy systems is feasible over the next 50–100 years; that there are a number of different paths to sustainability; and that some paths are probably better than others.

The WEC scenarios, and a number of other similar studies, will be examined in more detail in the companion volume, *Renewable Energy*.

Meanwhile, in this volume we now turn away from this general overview to examine in more detail our current energy systems and their sustainability, starting with a look at our primary energy sources.

References

Anon (2002) 'The Windicator', *Windpower Monthly,* January, p. 50.

Blake, William (1994) *The Marriage of Heaven and Hell*, Dover Publications.

Boyle, G. (1996, 2003) *Renewable Energy*, Oxford, Oxford University Press in association with the Open University.

BP (2002) *BP Statistical Review of World Energy* [online], BP. Available at http://www.bp.com/centres/energy2002/index.asp [accessed 12 July 2002].

Campbell, C. J., and Laherrere, J. H (1998) 'The End of Cheap Oil', *Scientific American*, March, pp. 60–65.

Department of Trade and Industry (2001) *Digest of UK Energy Statistics*, 2000.

Department of Transport, Local Government and Regions (DTLR) (2001) *Transport Statistics, Great Britain* (27th edn), The Stationery Office, Table 9.1, p. 161.

Hughes, P. (1993) *Personal Transport and the Greenhouse Effect: a Strategy for Sustainability,* London, Earthscan.

Intergovernmental Panel on Climate Change (2001) *Climate Change 2001: the Scientific Assessment*, Cambridge University Press.

International Energy Agency (2000) *Key World Energy Statistics from the IEA*, Paris, International Energy Agency.

Lutz, W., Sanderson, W., and Scherbov, S. (2001) 'The End of World Population Growth' *Nature* 412, 543–545, August.

Royal Commission on Environmental Pollution (2000) *Energy: the Changing Climate*, London, Stationery Office.

Smil, V. (2000) 'Energy in the Twentieth Century: Resources, conversions, costs, uses, and consequences', *Annual Review of Energy and the Environment,* vol. 25, pp.21–51.

Smith, K. R., Uma, R., Kishore, V. V. N., Zhang, J., Joshi, V., and Khalil, M. A. K. (2000) 'Greenhouse Implications of Household Stoves: An Analysis for India' *Annual Review of Energy and the Environment*, vol. 25, pp. 741-763.

United Nations (2001) *World Population Prospects; the 2000 Revision,* UN Population Division, Department of Economic and Social Affairs, 18 pp.

United Nations Development Programme (2000) *World Energy Assessment,* New York, United Nations.

United Nations: World Commission on Environment and Development (1987) *Our Common Future* (the Brundtland Report), Oxford, Oxford University Press.

Chapter 2

Primary Energy

by Janet Ramage and Bob Everett

2.1 World primary energy consumption

> 'The world is consuming primary energy at a rate of about 13.4 terawatts.'

This statement raises a number of questions.

- What is primary energy?
- How does the world *consume* energy?
- What are 13.4 terawatts, and how are they related to the world annual consumption of 10 100 Mtoe quoted in Chapter 1?
- How do we *know* the world's energy consumption? What are the sources of energy data, and how reliable are they?

The first part of this chapter addresses these essential questions about the nature and basis of our knowledge of the world's use of energy. We will then be in a position to look at the situation in more detail. The chapter continues with accounts of the changing contributions to world primary energy over the past century or so, and the varying patterns of energy consumption and energy production across the different regions of the world. To illustrate these contrasts, it concludes with some details of the recent energy history of a few selected countries.

What is primary energy?

Essentially, **primary energy** is the total energy 'content' of the original resource. Our main present resources are the fossil fuels (coal, oil and natural gas) and the biofuels such as wood, straw, dried dung, etc. (The energy content of the food we eat is not customarily included in the count.) To these we can add the energy provided by nuclear power stations and by hydroelectric or geothermal plant and other 'renewables' such as solar or wind power.

The rather arbitrary nature of the definition becomes evident if we consider solar energy. When special systems such as solar panels or photovoltaic cells are used, their output may be included in the primary energy total, but the daily contribution of solar energy in warming and illuminating our buildings does not normally appear in national or international statistics. Section 2.3 below discusses in more detail the methods used to assess and compare the various contributions to primary energy production or consumption.

What is energy consumption?

One of the most fundamental scientific laws states that energy is conserved. The total quantity stays constant. You cannot create energy or destroy it. If you have ten units of energy at the start, you have ten units of energy – somewhere – at the finish. In this sense, we never consume energy.

It is however a matter of great practical importance that energy can take many different forms, and what we *can* do – and have done at least since our ancestors first used fire – is to devise means of converting from one form to another. When we talk of consuming energy this is what we mean: converting from the chemical energy stored in fuels such as wood, coal, oil or gas, from the energy stored in atomic nuclei, from the gravitational energy of water in a high reservoir, the kinetic energy of moving water or the wind, and the radiated energy of sunlight, into heat or electrical energy or light or the kinetic energy of a moving vehicle. We'll discuss all these forms of energy later, but the first important point is this: *Consumption is conversion.*

BOX 2.1 **'Conservation of energy'**

Why should I switch off lights to conserve energy, when there is a law which states that energy is always conserved?

The question is of course mischievous, deliberately confusing two different meanings of 'conserve'. It is however important to appreciate that phrases such as 'conservation of energy' do have these two meanings, both of which are common in discussions of our uses of energy. The scientific law is fundamental. It underlies all our reasoning, even when it is not specifically stated. In the other sense of the term, when we are told to 'conserve energy' by switching off unnecessary lights, we are really being asked to conserve *energy resources* – in this case, the fuel consumed in power stations. Fortunately the context usually makes it clear which meaning is intended, and in practice the two senses of the word rarely lead to problems.

'Energy arithmetic'

Any serious discussion of energy must be quantitative:

> 'My car uses very little petrol.'

In driving a thousand miles, or standing in the garage? Compared with Saudi Arabian oil exports or with a bicycle?

The trivial example illustrates two requirements. In order to compare quantities we must be able to measure them, i.e. we need *units* (litres, or gallons, or tonnes); and then we must know which type of quantity we are discussing (litres per kilometre, litres per year or just litres).

In 1960 the scientific world reached agreement on a single consistent set of units: the Système Internationale d'Unités. The SI system uses three main base units: the metre, the kilogram and the second, and the units for many other quantities are derived from these. Some of the derived units, such as *metres per second* for speed, reveal their base units immediately, whilst for others the combination of base units has been replaced by a specific name. The name of the SI unit for energy is the **joule**, abbreviated J, and you'll find more details of this and other SI units in Appendix A. In everyday terms, one joule is a rather small quantity of energy – roughly the amount needed to toss a medium-sized apple just one metre vertically upwards.

One of the happier consequences of the energy debates of the past few decades has been a growing appreciation of the advantages of using this universal unit for all amounts of energy. Nevertheless, if you open a book or technical paper, you can still find yourself in a rather less tidy world. Quantities of energy are quoted in tonnes (or tons) of oil or coal, cubic metres of gas, kilowatt-hours, terawatt-years, therms, calories and Calories, and if we are to follow the real world debate, we must come to terms with these. Accordingly, one aim in this chapter is to introduce the art of 'energy arithmetic' – of converting between different ways of specifying quantities of energy.

The need to use extremely large numbers can also lead to problems. Most of us can visualize a dozen objects, perhaps even a hundred, but who can picture 13 400 000 000 000? We cannot avoid such very large numbers, but they can be made more manageable by using special names, or more compact ways of writing them. Appendix A explains these methods in detail, and Table 2.1 is a short summary of the prefix names used in this chapter.

Table 2.1 Prefixes

symbol	prefix	multiply by[1,2]
k	kilo-	one thousand
M	mega-	one million
G	giga-	one billion (one thousand million)
T	tera-	one trillion (one million million)
P	peta-	one quadrillion (one billion million)
E	exa-	one quintillion (one billion billion, or one million million million)

[1] Note that each multiplier is one thousand times the previous one.

[2] The multipliers beyond one million have the now usual USA meanings: one billion is one thousand million and not one million million as in the older British usage.

Watts

A terawatt is one million million watts – but what is a watt? The important point is that a watt is not a unit of energy, but a *rate* at which energy is being transformed or converted from one form to another. Technically a watt is a unit of **power**, of energy per second:

- One **watt** is by definition one joule per second.

Thus a 600 W heater is converting electrical energy into heat at a rate of 600 joules in each second. And we, the population of the world, with our 13.4 TW rate of consumption, are converting 13.4 million million joules of primary energy every second into the forms of energy we want (and a great deal of waste heat).

Kilowatt-hours

The kilowatt-hour (kWh) is a unit of *energy*.

- One **kilowatt-hour** is the amount of energy converted in one hour at a rate of one kilowatt.

The heater in a 3 kW clothes dryer, for instance, used for 40 minutes (two-thirds of an hour), converts 2 kWh of electrical energy into heat energy.

Like any quantity of energy, a kilowatt-hour must of course be equal to a certain number of joules. The reasoning in Box 2.2 shows that one kilowatt-hour is 3.6 megajoules.

It is important to appreciate that the kilowatt-hour and the watt are *gener* units for energy and power respectively. Although many of us meet the first in the context of electricity, they are equally applicable to the energ you use and the power you develop in running up a flight of stairs.

BOX 2.2 kW and kWh

We note that 1 kW is 1000 watts (Table 2.1), and that there are 3600 seconds in an hour.

Power

1 watt = 1 joule per second

1 kilowatt = 1000 joules per second

1 kilowatt = 3 600 000 joules per hour

Energy

1 kilowatt-hour = 3 600 000 joules

1 kWh = 3.6 MJ

BOX 2.3 Per capita consumption

It can be useful to convert very large numbers into more manageable quantities. Instead of total world energy consumption, we might consider the average consumption per person.

The world rate of primary energy consumption is 13.4 TW, which is 13.4 million million watts, and the world population is about 6100 million people. The average *per capita* rate of consumption is therefore

$$13\,400\,000 \div 6100 = 2197 \text{ watts.}$$

On average, therefore, we are each consuming primary energy at a steady rate of about 2.2 kW.

There are 24 hours in a day, so the daily consumption per person is

$$2.2 \text{ kW} \times 24 \text{ hours} = 53 \text{ kWh.}$$

On average, therefore, we each consume just over 50 kWh of primary energy every day.

Remembering that 1 kWh is 3.6 MJ, this becomes about 190 MJ, which is the energy content of a little over five litres of oil – about one and a quarter UK gallons.

So the average person – man, woman and child – uses the energy equivalent of just over a gallon of oil a day. This must of course supply *all* our energy needs: food production and a water supply, the provision of housing, heat for cooking and to keep us warm, clothing and manufactured goods, transport of people and freight, communications and entertainment, and the medical, educational and other services that we expect.

2.2 Quantities of energy

The publication of national or international energy data was largely a development of the second half of the twentieth century, but records of dealings in *commodities* are as old as trade itself. During the eighteenth and nineteenth centuries, coal became an extremely important commodity for developing countries such as Britain. As it was also the dominant energy source, the data on coal production and consumption came to serve as national energy data for much of the period. When new energy sources such as oil began to appear, it was natural to assess their contributions in terms of the quantity of coal they could replace, and Britain continued to do this into the 1980s, expressing all national energy data in *tonnes of coal equivalent*.

Meanwhile, some of the most accessible international energy data were being assembled and published by the major oil companies, and not surprisingly their favoured unit for energy was the *tonne of oil equivalent*. In the UK, where oil has been the major fuel since 1970, the national statistics now tend also to use tonnes of oil equivalent.

Units based on oil

When oil is burned, whether in a furnace or an internal combustion engine, its chemical energy is converted into heat energy. One **tonne of oil equivalent (toe)** is simply the heat energy released in the complete combustion of 1000 kg of oil. This varies between crude oils from different sources, but a commonly used world average is 41.88 GJ (41 880 MJ). When the data do not justify this precision, 42 GJ is a useful approximation. World annual primary energy consumption then becomes 10 100 Mtoe (Box 2.4).

Figure 2.1 Filling barrels at a Pennsylvania oil well in 1870

This of course includes all forms of energy, so the actual world oil consumption of 3500 million tonnes a year accounts for just over a third of the total.

Another measure of quantity of oil and correspondingly of energy is the *barrel*. This odd unit, alien in a world of pipelines and super tankers, comes from the size of the barrels used to carry oil from the world's first drilled well in Pennsylvania in the 1860s. One barrel is 42 US gallons or 35 Imperial (British) gallons – about 160 litres.

How is a barrel of oil related to a tonne of oil? A barrel is a certain *volume*, whereas a tonne is of course a *mass*, and crude oils from different sources have different densities, so more barrels would be needed to hold one tonne of a 'light' crude than for a 'heavier' one. The solution has again been to adopt a world average: 7.33 barrels to the tonne. Using this we find that the energy content of one barrel is approximately 5.71 GJ, and this is one **barrel of oil equivalent (boe)**. The oil industry commonly expresses data in **million barrels daily (Mbd)**. In 2000, for instance, world oil consumption was 73.9 Mbd, and world total primary energy was equivalent to 203 Mbd (Box 2.4).

Finally, we have the everyday units for the fuel used in our vehicles: the litre and the gallon. Petrol (gasoline) has a slightly higher energy content *per tonne* than crude oil – about 44 GJ. But it has an appreciably lower density, and in terms of volume, the energy content is about 150 MJ per Imperial gallon, or 33 MJ per litre, compared with nearly 36 MJ per litre for crude oil.

BOX 2.4 World energy in Mtoe, Mbd and TW

In terms of the accepted SI unit for energy, world annual primary energy consumption for the year 2000 was **424 EJ** (exajoules).

We have also expressed this rate of consumption as 10 100 Mtoe per year, 13.4 TW and 203 Mbd. This box shows the energy arithmetic that relates all these figures.

Millions of tonnes of oil equivalent

The value given in the text for a tonne of oil equivalent is 42 GJ.

1 Mtoe is therefore 42 million GJ.

424 EJ is the same as 424 000 million GJ

World consumption in Mtoe is therefore

$424\,000 \div 42 = \mathbf{10\,100\ Mtoe}$

Millions of barrels of oil daily

There are 365 days in a year, so the daily primary energy is

$424 \div 365 = 1.16$ EJ.

The value given in the text for a barrel of oil equivalent is 5.71 GJ.

1 Mboe is therefore 5.71 million GJ.

1.16 EJ is the same as 1160 million GJ.

World consumption in Mbd is therefore

$1160 \div 5.71 = \mathbf{203\ Mbd}$.

Terawatts

The conversion from exajoules a year to terawatts starts with the definition of the watt:

1 watt is 1 joule per second …

which is 3600 joules per hour …

or $24 \times 3600 = 86\,400$ joules per day …

or $365 \times 86\,400 = 31\,536\,000$ joules per year …

which is 31.5 MJ per year.

1 terawatt (TW) is one million million watts …

which is 31.5 million million MJ per year …

or 31.5 EJ per year.

World consumption in TW is therefore

$424 \div 31.5 = \mathbf{13.4\ TW}$.

Units based on coal

One **tonne of coal equivalent** (**tce**) is the heat energy released in burning one metric tonne of coal (Box 2.5). Coal is a much more variable material than crude oil, and world-wide its energy per tonne ranges from less than 20 GJ to over 30 GJ. The figure of 28 GJ per tonne is often adopted in energy statistics, and is the one used in this book unless otherwise specified.

BOX 2.5 Tonnes, tons and short tons

As mentioned above, national or even international energy data do not yet appear in one agreed set of units, and whilst the approved SI units for mass are the kilogram and its multiples such as the metric tonne (1000 kg), you will still find other 'tons' in use. This box describes the relationships.

1. The **tonne**, or metric tonne, is 1000 kg and is equal to about 2205 lb (pounds).
2. The **ton**, a unit in the pre-metric system of weights and measures of the UK and many other countries, is still widely used. The hundredweight (cwt) is an intermediate unit, equal to one-twentieth of a ton. One ton is 2240 lb – about 1.6% more than a tonne.
3. The **short ton** is still found occasionally as the unit for quantity of coal or wood in some countries. One short ton is 2000 lb – about 10% less than a tonne.

Figure 2.2 Filling a London coal cellar. Coal was delivered in hundredweight sacks, and the 'coal holes', often with attractive iron covers, can still be identified in many eighteenth- or nineteenth-century streets

The BTU and related units

Before the general adoption of the joule, the *British thermal unit* (BTU) and its multiples were in common use, in the English-speaking world in particular.

- One **BTU** is the heat energy needed to warm one pound of water by one degree Fahrenheit and is equal to 1055 joules. Multiples of the BTU include the therm (100 000 BTU) and the quad.
- One **quad** is a quadrillion British thermal units (see Table 2.1) and is equal to 1.055 EJ.

These units are still used, notably in the USA where the common unit for energy quantities on the national scale is the quad. As can be seen, the BTU and the quad are slightly larger than the kilojoule and exajoule respectively.

The calorie and related units

In most of Europe, and many other countries, the common unit for heat in the past was the calorie.

- One **calorie** is the heat energy needed to warm one gram of water by one degree Celsius and is equal to 4.19 joules.

  For many purposes the **kilocalorie**, written kcal or Calorie (with capital C), has proved more convenient, and it remains familiar as the unit for the energy content of food.

This gives us yet another way of looking at our energy consumption. Nutritionists tell us that the *food energy* needed to support an adult is about 2000 Calories a day, which is a little over 8 MJ. In Box 2.3 we saw that world average daily primary energy consumption per person is about 190 MJ. It appears therefore that the energy we each use in non-food forms is, on average, more than twenty times the amount we each need to feed ourselves. As we shall see, this is by no means universally the case.

2.3 Interpreting the data

There remains a final question about world primary energy, or indeed any energy data. How do we know? Before venturing further into the sources of energy, we should perhaps discuss the sources of *data*. Where do the figures come from? The first answer is that we find them in official statistics, technical journals and similar publications. However, one shouldn't believe everything one reads in books (or anything in newspapers) and care is always needed in interpreting published figures, for reasons which we can characterize under three headings: *definitions*, *conversions* and *conventions*.

Definitions

World data usually start as national statistics, and with some 200 countries it is hardly surprising that the terminology doesn't always match at the seams. Does 'production' include energy used by the producer? Does 'consumption' include energy used for transmission of energy? Unless we know the answers to such questions, how are we to interpret the statement that 75.102% of Britain's coal in 2000 was used for electricity generation? In the absence of pages of explanation, it is surely better to say, 'About 75% …', or even, 'Roughly three-quarters …'.

A further mismatch appears in comparing figures for *production* and *consumption*. One would hope that any difference would be accounted for by changes in stocks, but when production data necessarily come from producers and consumption data from consumers this is by no means always the case. Recent world data, for instance, include 15.8 million tonnes of 'unidentified' crude oil exports. Some of it may be on the high seas – in ships, one hopes – but the figures again illustrate the problem.

Conversions

We have seen several examples of conversion between different energy units, but have not bothered too much about the nature of these relationships. On inspection we find that the term *equivalent* has been used in a number of different ways.

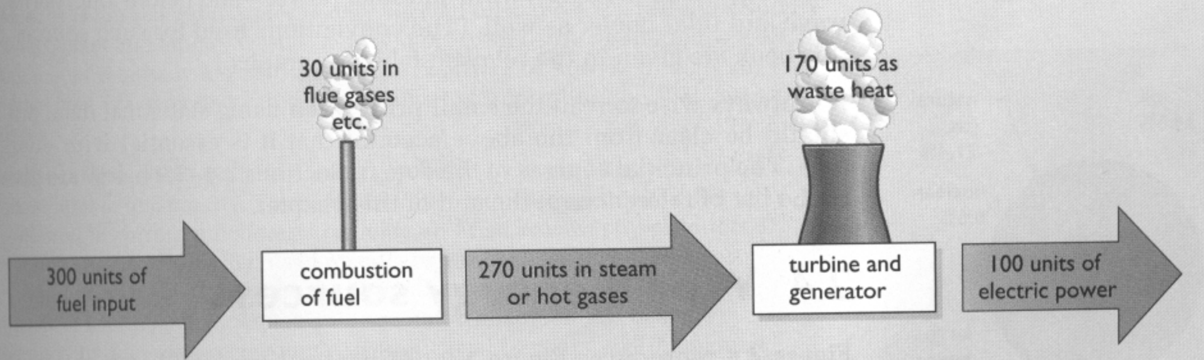
First there are cases where the conversion between units is *exact*. One watt is exactly one joule per second because that is how it is defined; and 1 kWh is therefore exactly 3.6 MJ. Then there are relationships which although not exact are known very precisely and may be regarded as *universal*. The conversions between joules, British thermal units and Calories are examples.

When we come to quantities such as the heat content of a fuel, matters are not quite so simple. The heat content of a particular specimen of oil can be measured to great accuracy under laboratory conditions, and with similar care we might measure the solar energy reaching a particular roof in the course of a particular day. But it is hardly practicable to use these methods for the total output during the lifetime of an entire oil well or solar panel. In the real world it becomes essential to use *average* values. The problem is that not everyone uses the same average. If your tonne of oil equivalent and daily solar energy are not the same as mine, our discussion is likely to end in confusion. Once more, the rule is to make sure we know what the figures mean before using them.

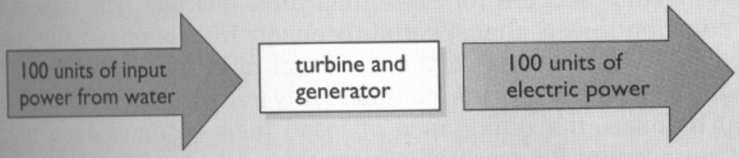
Conventions

Finally, there is the rather different question of the output from power stations. The difficulty is not in measuring it, as most national data include the annual kilowatt-hours produced, and conversion of these to joules is no problem. The question is whether this output should count as 'primary energy'? Shouldn't that be the *input*? Unfortunately there are difficulties with this. Recording the input of coal, oil or gas is relatively straightforward, but measuring the total 'water energy' entering a country's hydroelectric plants in a year, or the total wind energy sweeping across its wind turbines, is not practicable. And nuclear plants, whose input is the result of a complex series of processes, pose a similar problem.

Figure 2.3 shows the essential facts for the world's main types of power station. In most **thermal power stations**, where heat from the fuel produces steam or hot gases to drive the turbine, about two-thirds of the energy input



(a) The convention for thermal power stations. The data represent the generally accepted conventions. See later chapters for the actual inputs and outputs of the different types of plant.



(b) The convention for hydroelectric plants. Note that there will always be some losses in practice, but they will be much less than for thermal plants.

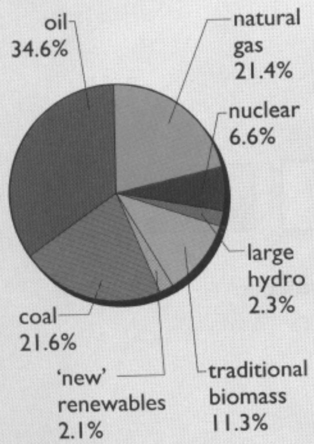
Figure 2.3 Primary energy conventions for electric power becomes waste heat. This is not the case for hydroelectric plants, where the output is only a little less than the input. These facts have led to a fairly straightforward convention for the main types of power station.

- The **notional primary energy** input for all main types except hydroelectric is taken to be the electrical output divided by 0.33 (roughly the same as multiplying it by 3).
- The primary energy input for hydroelectric plants is taken to be equal to the electrical output.

This dual convention has become dominant and is now used by bodies such as the United Nations Department of Economic and Social Affairs and the International Energy Agency (IEA) of the OECD, in the annual BP Statistical Review of World Energy and in UK energy statistics. It is therefore the method adopted in this book, and all data have been converted in accordance with the above rules unless we specify otherwise. A consequence of this is that when using the data or looking at diagrams such as Figure 2.4 below, it is important to bear in mind, for instance, that although the world primary contribution from nuclear power is shown as three times that of hydroelectricity, the annual *electrical outputs* from the two are in fact nearly the same.

Other conventions than this one are unfortunately still in use, or have been until recently. In the past, for instance, the UK used to multiply *all* power station outputs by about 3, including hydroelectricity. Some countries still do this, including France (but with the output divided by 0.386 rather than by 0.33). In contrast, some countries and international organisations treat nuclear power in the same way as hydroelectricity – using the electrical output as the primary energy contribution, with no multiplier. And further questions arise with the growing contributions from renewable sources such as geothermal energy, wind and solar power – and before long, perhaps wave and tidal power as well. (The conventions used for such sources in this book are given in the relevant tables or graphs.)

It is always wise to read the small print when using statistical data, but it should be clear from the above account that it is essential with energy data. The principal sources of the data in Sections 2.4–2.9 below are given in the list of references at the end of this chapter.



Total: 424 EJ or 10 100 Mtoe per year, or an average rate of 13.4 TW

Figure 2.4 World primary energy by source, 2000

2.4 World energy sources

Figure 2.4 reproduces Figure 1.9 of Chapter 1, and Table 2.2 shows the data in more detail. The picture is clear enough. We see a situation in the year 2000 where oil contributes more than a third of all our energy and the fossil fuels together account for more than three-quarters. The largest of the other contributions is almost certainly energy from biomass, although for the reasons outlined in Box 2.6, its exact magnitude is difficult to establish. If we consider only the 'commercially traded' sources, excluding traditional biomass, the dominance of fossil fuels becomes even more striking. They account for nearly ninety percent of the world's total traded energy.

Table 2.2 World primary energy, 2000

Energy source	**Quantity in customary units**	**Energy in EJ**	**Percentage contribution**	
			to total energy	**to commercial energy only**
Fossil fuels				
oil	3504 million tonnes	146.7	34.6%	39.1%
natural gas	2407 billion cubic metres	90.7	21.4%	24.1%
coal	3125 million tonnes	91.6	21.6%	24.4%
Fossil fuels total		**329.0**	**77.6%**	**87.6%**
Electric power				
nuclear electricity	2590 billion kWh[1]	28.0[2]	6.6%	7.5%
large hydro	2670 billion kWh[1]	9.6[2]	2.3%	2.6%
Other renewables				
traditional biomass[3]		48.0	11.3%	
'new' renewables[4]		9.0	2.1%	2.4%

1 Actual power station output.

2 See Conventions, above.

3 See Box 2.6.

4 About 7 EJ from 'new' bioenergy, 1.6 EJ of geothermal heat and the remainder from wind, small-scale hydro and solar power.

(Principal sources: BP, 2001; UN, 2000)

BOX 2.6 Bioenergy

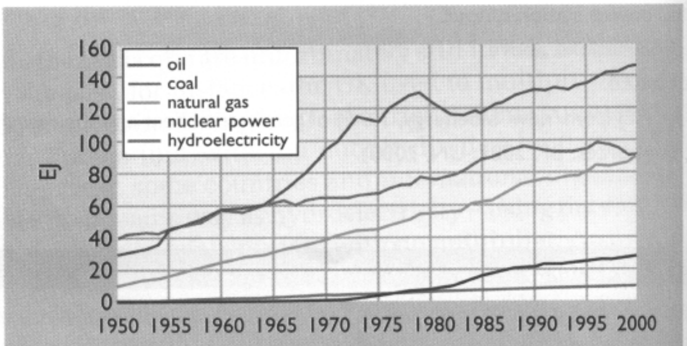
Bioenergy is the general term for energy derived from biomass: materials such as wood, plant and animal wastes, etc., which – unlike the fossil fuels – were living matter relatively recently. Such materials may be burned directly to produce heat or power, but can also be converted into solid, liquid or gaseous **biofuels**.

Estimates of the contribution of biomass to world primary energy are subject to considerable uncertainty. The fuels are often 'non-commercial' – they may be gathered in surrounding forests or fields, or arise as waste by-products of other activities, and are often used on site, or bartered for other goods or services. In other words, they are not formally traded, so the economists' methods of keeping track of quantities are not available. It has become customary to refer to these resources as traditional biomass, distinguishing them from 'new' bioenergy sources such as purpose-grown wood or other 'energy crops', forestry wastes and municipal solid waste. These are often commercially traded and can be treated in the same way as other 'new' renewables such as wind power or solar PV.

In recent years, detailed studies have suggested total bioenergy contributions ranging from 10% to 15% of world primary energy (Hall *et al.*, 1993; WEC, 1998; IEA, 1998). 'New' bioenergy – in the world context mainly urban waste used as fuel for power stations – currently contributes about 7 EJ, and the 48 EJ shown in Table 2.2 for traditional biomass brings the total bioenergy contribution to 55 EJ, or a little less than 13% of total primary energy.

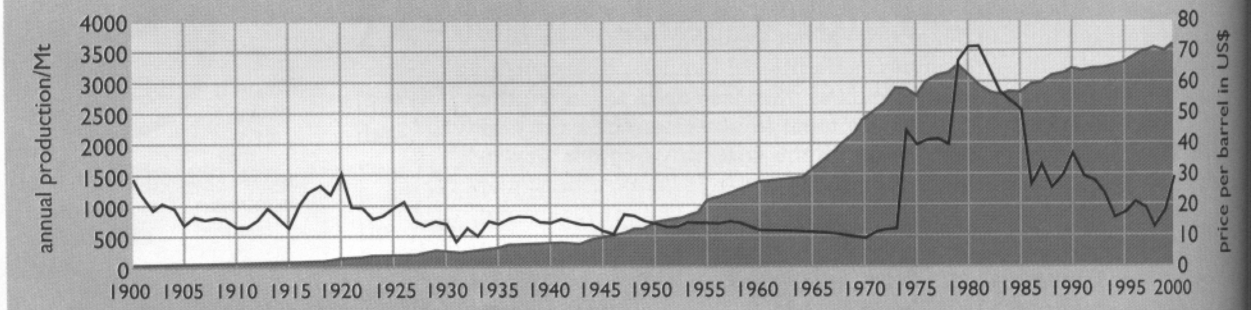
Figure 2.5 reveals how consumption of these non-renewable and carbo dioxide-producing energy sources increased during the second half of th twentieth century. The dramatic growth in the use of oil is even mor obvious over the longer period shown in Figure 2.6, although its most rapi rate of rise occurs between 1965 and 1973, with an average increase o nearly 8% a year. Had this rate been maintained, as seemed likely in th early 1970s, the annual output required by the end of the century woul have exceeded *20 billion* tonnes, or about six times the actual output i 2000. It is no surprise that sudden doubts about future supplies led t panic and disarray. The crises of the 1970s, with oil prices doubling i 1973 and rising steeply again at the end of the decade, followed by economi recession in the early 1980s, did eventually bring the growth in oi consumption to a halt – but only after some delay, and only temporarily The mid-eighties saw a return to annual increases, and despite all the crises the world has consumed more oil since 1985 than in the whole of histor before that date.

Natural gas production, with its steady, almost linear growth, stands i marked contrast, and its history is very different. In 1950, use was almos



Note: Only the main commercially-traded energy sources are shown.

Figure 2.5 World annual primary energy consumption by source, 1950–2000. (source: Times, 1980; BP, various issues)



Note: Past prices have been adjusted for inflation, to give the equivalent prices in dollars of the year 2000.

Figure 2.6 World oil production and the price of oil, 1900–2000. (source: Ramage, 1997) confined to the USA, and as late as 1970, North America was still responsible for two-thirds of world production (and consumption). But new sources elsewhere, already being developed in the 1960s, account for much of the rise of the next thirty years. By the year 2000, the output from Russia and other countries of the former Soviet Union was only a little less than that of North America, each providing about a third of the total. (The gas fields of the North Sea, the Middle East and the Far East supplied almost all the remainder.) Natural gas, as the 'cleanest' of the fossil fuels, has become the energy source of choice for heating and power generation; but the increasing reliance of a number of Western European countries on gas delivered by pipeline from Russia and her neighbours is starting to raise strategic concerns.

Coal, the dominant fuel for two centuries, fell to second place in the 1950s, and despite a slight rise at the very end of the twentieth century, seems destined to fall to third place during the early years of the twenty-first. Nevertheless, it is worth noting that world coal consumption more than doubled in the fifty-year period of Figure 2.5. Moreover, as we shall see later, coal can be a source of synthetic liquid fuels as substitutes for petroleum, and future oil crises might yet bring a reversal in the fortunes of this least desirable fossil fuel, as happened briefly in the 1980s.

As Table 2.2 shows, nuclear and large-scale hydroelectric plants each contribute some 2600 billion kilowatt-hours of electrical output a year. Both have experienced reductions in their rates of growth in recent decades, and in both cases environmental concerns have been in part responsible.

More detailed discussions of the primary energy sources, the histories of their use and accounts of the associated technologies appear in later chapters, or for the renewable resources, in the companion volume to this book, *Renewable Energy* (Boyle, 1996).

International comparisons

13.4 TW divided equally between all the inhabitants of the world gives each of us, as we have seen (Box 2.3), a little over 2 kW of continuous primary power.

It will have been no surprise to learn in Chapter 1 that world energy is not distributed in uniform shares, and the further comparisons in Table 2.3 surely provide food for thought. A seventh of the world's population is currently consuming nearly half the world's primary energy. The average daily energy used by an individual in the world's wealthiest two dozen countries is over six times that in the rest of the world. It is a salutary thought that to bring the remaining hundred or more countries even to the present European level of per capita energy provision would require world primary energy production to rise to almost *twice* the current level. And it is worth noting in this context that the energy data in the table include the contribution from traditional biomass, usually an important component of total energy in the less developed countries. It follows that for these countries to reach European levels in the use of 'modern' energy sources would require an even greater increase – and of course a corresponding increase in the environmental consequences of the use of these resources.

The average citizen of the USA earns nearly thirty times as much as the average Bangladeshi and consumes over sixty times as much energy each day. These are extremes, but comparison of *per capita energy consumption* and *per capita income* does show a not unexpected correlation. However, we should be wary of the easy conclusion that rising living standards necessarily mean the consumption of ever more energy each year. As we'll see in later chapters, many of our energy systems have improved in

Table 2.3 International comparisons, 2000

	Percentage of world total ...			Comparison with world average per capita ...	
	population	energy produced[1]	energy consumed[1]	primary energy consumption as a multiple of world average	Gross Domestic Product[2] as a multiple of world average
Wealthiest countries[3]	14%	35%	48%	3.3	3.7
Rest of world	86%	65%	52%	0.6	0.5
Selected regions					
USA + Canada	5%	21%	26%	5.0	4.6
Western Europe	15%	11%	16%	2.3	3.1
Middle East	2%	12%	3%	1.3	0.9
Africa	13%	8%	5%	0.4	0.3
Selected countries[4]					
USA	4.6%	17.2%	23.5%	5.0	4.7
China	21.4%	10.5%	10.8%	0.5	0.5
Russian Federation	2.3%	9.4%	6.0%	2.5	1.1
Japan	2.1%	1.0%	5.1%	2.4	3.6
India	16.5%	4.3%	5.0%	0.3	0.3
France	0.9%	1.3%	2.7%	2.8	3.5
Canada	0.5%	3.6%	2.4%	4.7	3.9
United Kingdom	1.0%	2.8%	2.3%	2.3	3.2
Brazil	2.8%	1.3%	1.8%	0.6	1.0
Australia	0.3%	2.1%	1.1%	3.4	3.8
Poland	0.6%	0.8%	0.9%	1.5	1.4
Greece	0.2%	0.1%	0.3%	1.5	2.1
Switzerland	0.1%	0.1%	0.3%	2.2	4.0
Bangladesh	2.2%	0.1%	0.2%	0.1	0.2
Denmark	0.1%	0.3%	0.2%	2.3	3.8
Kenya	0.5%	0.1%	0.1%	0.3	0.1

[1] Annual primary energy, including bioenergy contributions.

[2] The **Gross Domestic Product** (**GDP**) of a country is the total annual production of the nation's economic system, i.e. the value of everything the country produces in a year. The data used here are adjusted to take into account the local purchasing power of the GDP per person in each country. Many goods are normally cheaper in the poorest countries, so the contrasts would be even greater if normal exchange rates were used to convert to US dollars.

[3] USA and Canada, Western Europe, Australia and New Zealand, Japan

[4] In descending order of total primary energy consumption.

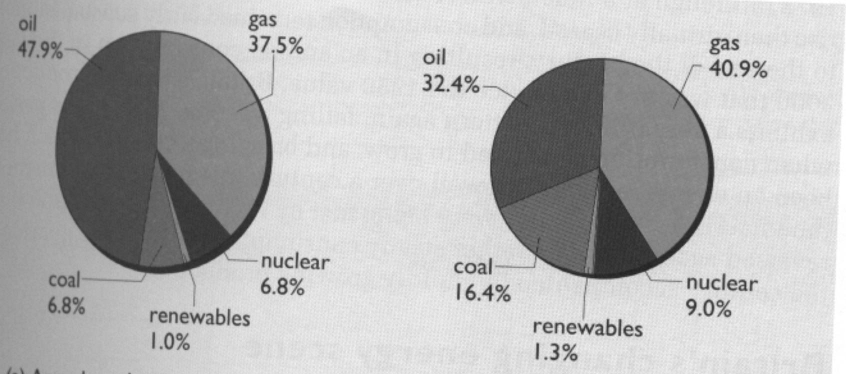
(Sources: BP, 2001; Gazetteer, 2001; IEA, 2001; UN, 2000) efficiency by large factors over the years – supplying the same quantity of heat, light or driving power for a much smaller energy input. Unfortunately, the response has at times been an increased demand for the output, leading in some cases to an *increase* in the total demand for energy.

In the remainder of this chapter we compare the primary energy production and consumption data for a few of the countries in Table 2.3, to see the detail behind some of the differences. For the world as a whole, total annual primary energy production and consumption differ so slightly that we have implicitly taken them to be equal, but this is by no means true for individual countries. The difference between energy consumption and indigenous production determines of course whether a country is a net energy importer or exporter, a matter of considerable economic and strategic importance. The recent histories of our chosen countries provide some interesting contrasts, and we'll look briefly at each in turn.

2.5 Primary energy in the UK

The main contributions to primary energy production and consumption for the UK in the year 2000 are shown in Figure 2.7. The 'renewables' category includes biofuels, hydroelectricity, wind and solar energy (see also Table 2.4 below). The captions show the energy totals, expressed in some of the units introduced above, and Figure 2.7(b) includes per capita consumption data.

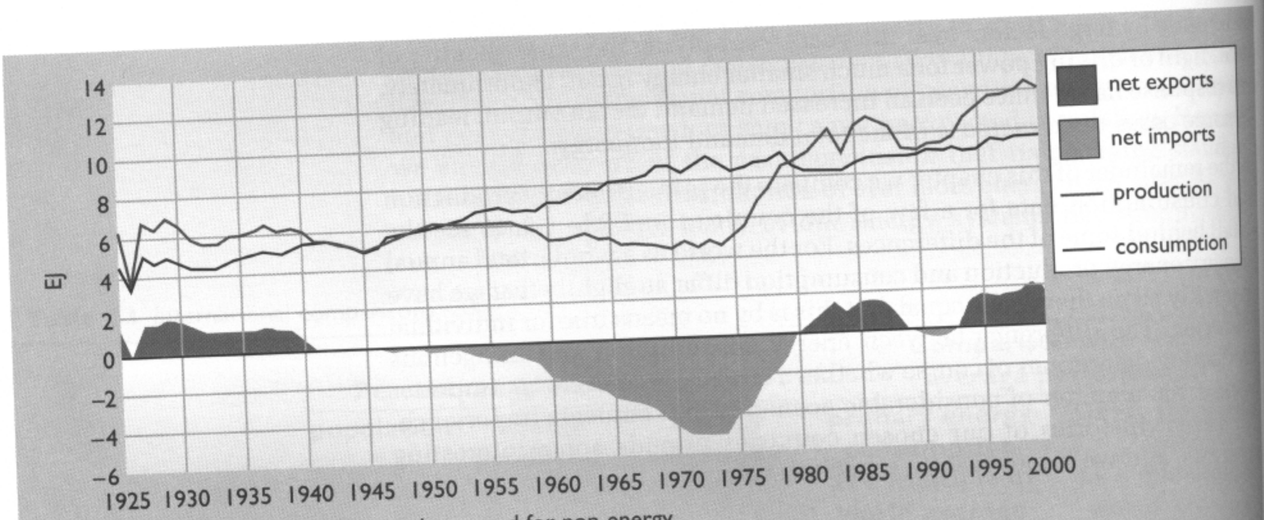
When we compare Figure 2.7 with the corresponding world data (Figure 2.4) the most striking difference is in the role of natural gas, which accounts for two-fifths of UK consumption – nearly twice its proportion for the world as a whole. The histories of primary energy production and consumption



(a) Annual production
Total production: 12.1 EJ or 289 Mtoe per year, or an average continuous rate of 380 GW.

(b) Annual consumption
Total consumption: 9.7 EJ or 232 Mtoe per year, or an average continuous rate of 310 GW. Per capita consumption: 165 GJ per year, or an average continuous rate of 5.2 kW per person.

Figure 2.7 UK: Primary energy production and consumption, 2000. (source: BP, 2001; DTI, 2001.)



Note: Net imports include petroleum used for non-energy purposes, as raw material in the petrochemicals industry.

Figure 2.8 UK annual primary energy production and consumption and net exports and imports, 1925–2000

reveal further significant differences, particularly over the past fifty years. As Figure 1.8(a) showed, world total primary energy consumption experienced an almost continuous rise throughout the twentieth century, pausing only briefly during oil crises or periods of recession, and leading to an annual consumption in the year 2000 that was nearly five times that of 1950.

The UK pattern of primary energy consumption was rather different (Figure 2.8), particularly over the second half of the century. There was a fairly steady increase from the end of World War II until the first oil crisis in 1973, although at a much slower rate than for the world as a whole. This rise then virtually ceased, and consumption remained fairly constant almost to the end of the century, resulting in an annual consumption in the year 2000 that was not even twice the 1950 value. Britain's energy *production* exhibits a very different pattern again, falling by some 25% over a period when consumption continued to grow, and bringing a country which had been an energy exporter for well over a century to a position where more than half her energy needs were being met by imports. The situation then reversed again, with the rather steady consumption of the final quarter of the century accompanied by rapidly growing production.

Britain's changing energy scene

To see the background to these fluctuating fortunes we need to look at the data for individual energy sources (Figure 2.9). Until the 1950s, Britain was not merely a coal-producing country but a coal-*based* country, with almost all primary energy production and over ninety percent of consumption coming from coal. Coal fuelled the railways, the power stations and industrial machinery, and together with the 'town gas' that was derived from coal, met almost all the country's heating needs. But this was about to change. Coal production, which had started to rise again after the war years began its long decline. Meanwhile, as in other industrialized countries, oil consumption in the UK was growing rapidly, with an average annual increase of over 10% a year from 1950 to 1970 (Figure 2.9(b)). These two factors are sufficient to account for the transformation during the 1950s from net energy exporter to net importer, a state that was to continue for more than thirty years.

However, the late 1960s already saw the start of yet another change, with the first contributions from Britain's North Sea gas fields. In the early years, from 1967 to 1972, output more than doubled each year – a remarkable annual average growth rate of over 100%. Consumption rose in step as the change from town gas to natural gas spread across the nation. Coal was of course the main energy source being displaced, but coal production was dropping in parallel with the falling demand. In consequence, the overall effect of Britain's natural gas resource on energy imports was very slight in these early years, and it was only with the discovery of yet another new resource that the trend eventually reversed.

The story of the exploration and subsequent development of North Sea oil will be told later, but its immediate consequences for the UK can be seen in Figure 2.9. The first significant deliveries came in 1976, and within three years oil had outstripped coal in its contribution to primary energy production. (As a proportion of primary *consumption,* oil – imported – had overtaken coal in the late 1960s.) By 1980 Britain was self-sufficient in oil, and despite the continuing fall in coal output, was about to become

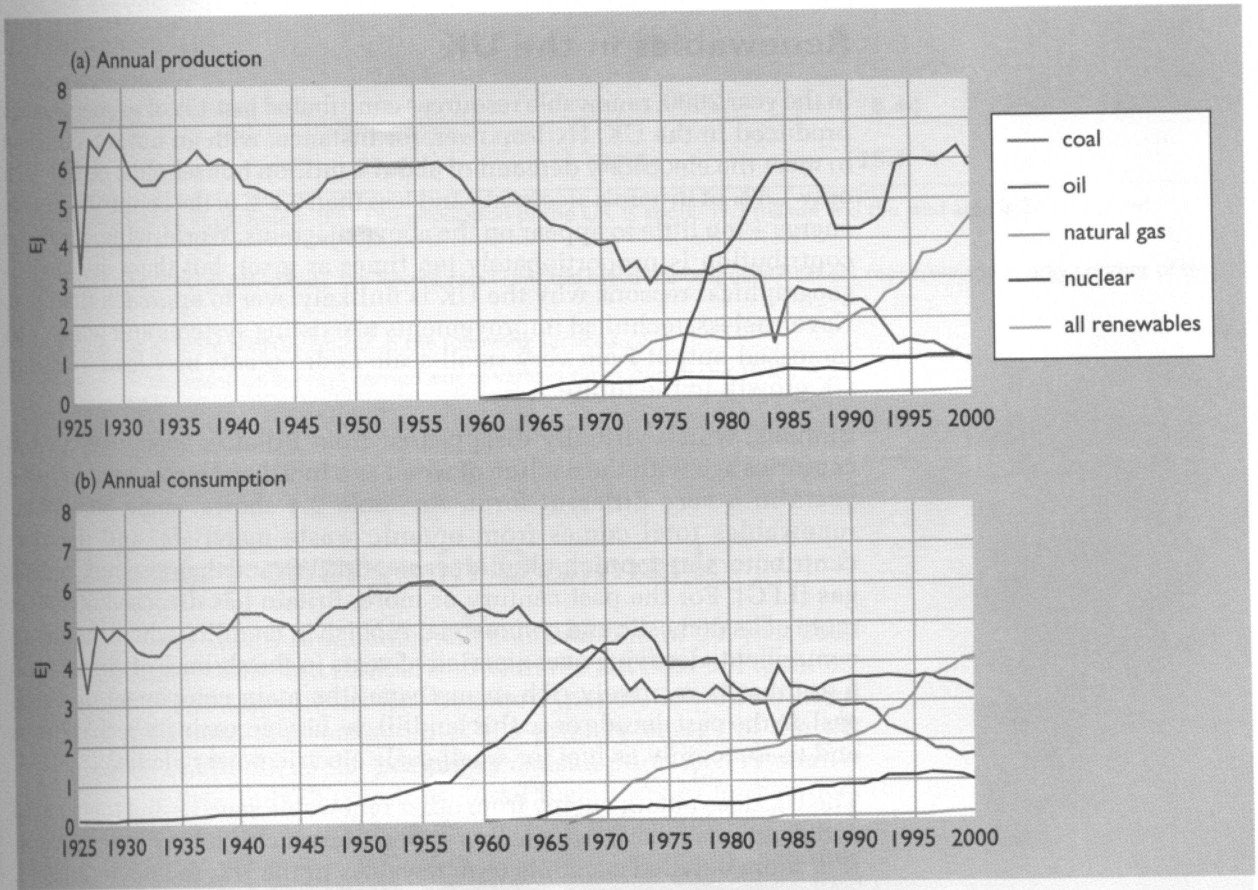


Figure 2.9 UK: Primary energy by source, 1925–2000

again a net energy exporter. A brief reversal occurred when oil production fell by a third following the steep drop in world oil price in the early 1980s (see Figure 2.6 above), but by the turn of the century output reached its highest level ever, and as we have seen, oil accounted for almost half the nation's primary energy production.

The period of rapidly increasing oil output saw a levelling-off in gas production, and with completion of the national change from town gas, a much slower annual rate of rise in consumption. But then came the 'dash for gas' of the 1990s, as the electricity generating industry started to take advantage of the technical and financial merits of gas turbine plants. This development and its environmental and other consequences are treated in more detail in later chapters.

Nuclear power is the only other energy source to make a significant contribution to UK primary energy. Growth at a rather modest 3% average annual rate over the last quarter of the twentieth century brought its contribution, on the 'notional primary input' basis, to almost exactly that of coal in the year 2000. Whether or not the slight fall at the end of the century will continue in the coming decades remains a current issue at the time of writing.

Later chapters treat the history of Britain's energy industries in more detail and discuss the social, economic and technical factors that have determined the changes described here.

Renewables in the UK

In the year 2000, renewable resources contributed just 1% of primary energy produced in the UK. Hydropower, for instance, with an output sufficient to meet the electricity demand of about a million households, contributed only 1.5% of Britain's electricity and less than 0.2% of the country's primary energy – too little to appear on the above diagrams. World-wide, the hydro contribution is proportionately ten times as great, but there are obvious geographical reasons why the UK is unlikely ever to approach that level. Nevertheless, technical improvements to existing systems and possibly an increased output from very small-scale hydro plants may lead to modest UK growth in the future.

Biofuels, which virtually disappeared from Britain's energy supply two centuries ago with the decline of wood as a fuel, have reappeared in recent years in a very different form. As Table 2.4 shows, some 80% of the renewables total comes from organic waste materials, and the main contributors are **municipal solid wastes (MSW)**, and their product, **landfill gas (LFG)**. For the past century or more, Britain has disposed of 90% or more of its domestic and commercial rubbish in landfills, where the organic component, decaying over a period of years in the absence of air, produces a gas that is relatively rich in methane (the main component of natural gas). In the past decade or so this landfill gas has increasingly been collected and used, mainly as fuel for small-scale electric power plants.

The UK does obtain energy from other renewable sources, but their annual contributions remain too small to appear separately on the diagrams above. (For more detailed accounts of renewables in the UK, see Boyle, 1996.)

Table 2.4 UK: renewable energy contributions to primary energy, 2000

Energy source	Used to generate electricity[1]	Used to generate heat	Totals by source	Percentage of all renewables
HYDROELECTRICITY				
large scale	17.5			
small scale	0.86			
Hydro total			**18.4**	14.7%
BIOFUELS				
MSW combustion	23.4	3.20		
landfill gas	30.0	0.57		
sewage sludge	5.03	1.72		
wood wastes[3]		20.7		
straw[3]		3.00		
other wastes	13.1	2.01		
Biofuels total			**102.8**	82.2%
WIND	3.4		**3.4**	2.72%
GEOTHERMAL[2,3]		0.03	**0.03**	0.03%
SOLAR ENERGY[2]				
solar heating[3]		0.44		
photovoltaics	0.004			
Solar total			**0.44**	0.35%
TOTALS	**93.4**	**31.6**	**125.1**	

Data: All energies are in petajoules (PJ). The population of the UK is about 59.2 million and the land area is 245 thousand square kilometres.

1 For hydro, wind and photovoltaics the figures represent the electrical output. All others represent the energy content of the fuels.

2 Brief accounts of these sources appear in the following sections.

3 Approximate data based on surveys carried out at various times during the 1990s.

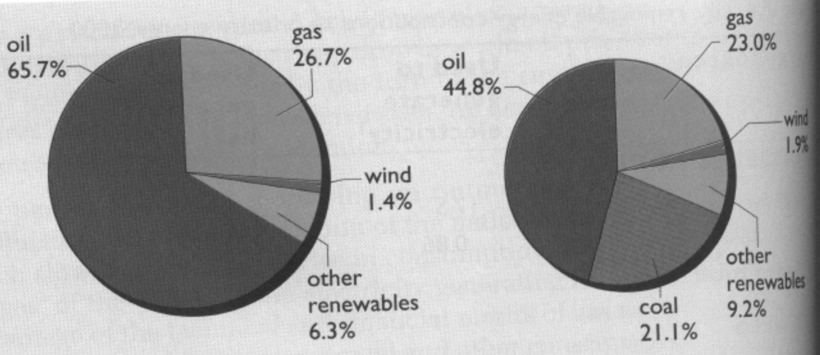
(Source: DTI, 2001)

2.6 Primary energy in Denmark

Denmark's primary energy production and consumption in the year 2000 are shown in Figure 2.10, and comparison with the UK data in Figure 2.7 reveals some interesting similarities. Denmark (population 5.3 million) consumes slightly less than one-tenth of the primary energy of the UK (population 59.2 million), so the *per capita* consumption is very similar for the two countries. In both countries, fossil fuels account for just over 92% of the primary energy produced and 89% of the energy consumed. And as the diagrams show, both countries produce more energy than they consume (see also Box 2.7 overleaf).

BOX 2.7 Self-sufficiency

A useful measure of the extent to which a country depends on energy imports is its degree of **self-sufficiency**. This is defined as the total primary energy production divided by the total primary energy consumption, expressed as a percentage. A self-sufficiency greater than 100% obviously implies that the country has an energy surplus and is therefore likely to be a net exporter. This is the case for both Denmark, with a self-sufficiency of 138%, and the UK with 123%. It is important, however, to note that self-sufficiency in an individual energy resource such as oil can be even more important than overall self-sufficiency.



(a) Annual production
Total production: 1.16 EJ or 27.8 Mtoe per year, or an average rate of 37 GW.

(b) Annual consumption
Total consumption: 0.84 EJ or 20 Mtoe per year, or an average rate of 27 GW.
Per capita consumption: 158 GJ per year, or an average rate of 5.0 kW.

Figure 2.10 Denmark: primary energy production and consumption, 2000

A significant difference between the two countries in the year 2000 is th nature of the non-fossil fuel contribution to energy production (a consumption). In the UK, as we have seen, most of this is from nucle power, with renewables contributing only 1% of total primary energ Denmark, in contrast, has no nuclear contribution and renewables accou for nearly 8% of total production, with wind alone providing a great percentage than all renewables in the UK.

When we compare the recent histories of the two countries (Figures 2 and 2.11), other major differences appear, and Figures 2.9(a) and 2.12 reveal the details behind the contrast. In 1960, Britain was reaching t end of a long period of energy self-sufficiency sustained by her coal expor Denmark in 1960 had virtually no primary energy resources. A limit amount of lignite (a low quality form of coal; see Chapter 5) was the o fossil fuel, and the country had been almost totally dependent on impor fuel throughout modern times. By 1970, the continuing need for impor coal together with a steep rise in oil consumption (Figure 2.12(b)) w bringing her to a serious position strategically and economically. T

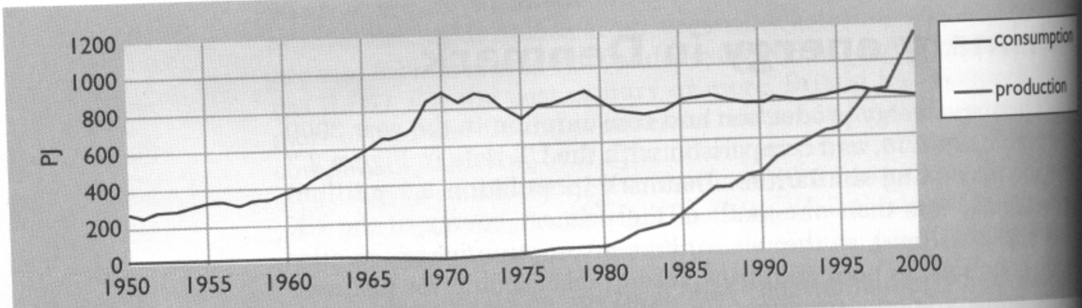
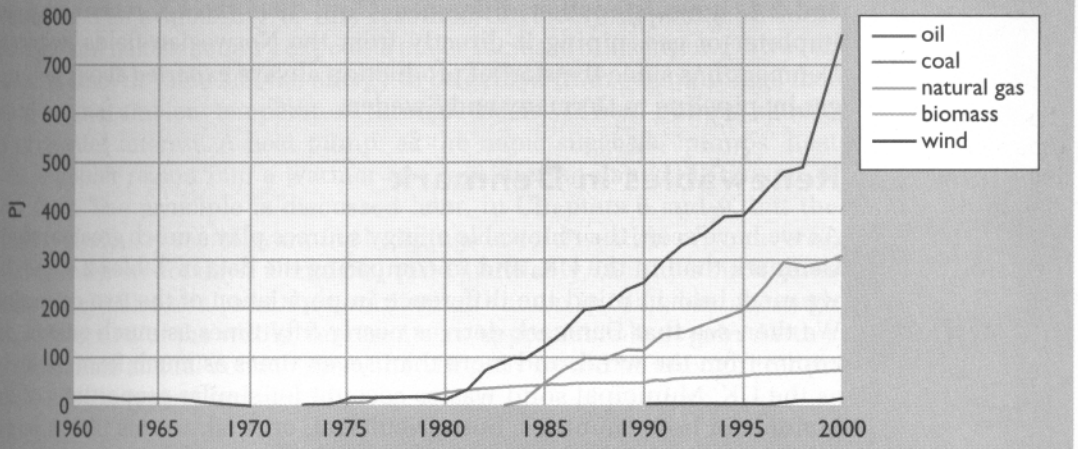


Figure 2.11 Denmark: Annual primary energy production and consumption, 1960–2000

(a) Annual production



(b) Annual consumption

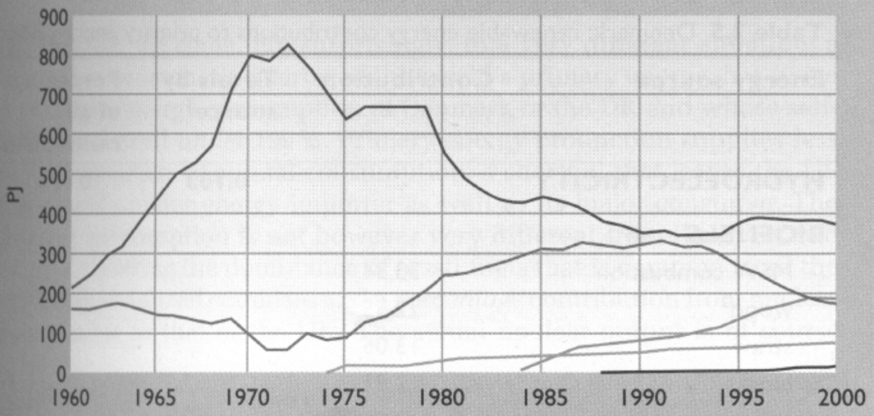


Figure 2.12 Denmark: Primary energy by source, 1960–2000

measures taken by successive Danish governments to ameliorate this situation are discussed in the next chapter, but their main result can be seen in the graphs: a total primary energy consumption in 2000 that is slightly *less* than in 1970, and a remarkable reduction in oil consumption to less than half its peak value. As Figure 2.12 shows, initially this was achieved in part by increased consumption of imported coal, but the final decade of the century saw domestic production of oil and gas making an appreciable contribution, and in 1997 Denmark became self-sufficient in energy for the first time in modern history.

The details appear in Figure 2.12(a). In the late 1970s – at a time when the largest contribution to domestic energy production was 20–30 PJ from renewables – the development of oil in Denmark's sector of the North Sea began. By 1985, output was growing at an average annual rate of over 12%, and with consumption still falling, Denmark became self-sufficient in oil in 1993. In the year 2000, as much oil was exported as was consumed internally.

Denmark's development of her natural gas resource came about five years after the oil – a reversal of the UK sequence. Closer study of Figures 2.9 and 2.12 reveals another difference. Until 1995 the UK remained a net importer of gas, piping it directly from the Norwegian fields, whereas Denmark has since the start of production always *exported* about half her gas by pipeline to Germany and Sweden.

Renewables in Denmark

As we have seen, the renewable energy sources play a much greater role in Denmark than in the UK, and in comparing the data in Tables 2.4 and 2.5 we must bear in mind the difference in population of the two countries. We then see that Denmark derives nearly fifty times as much energy *per capita* from the wind, and more than seven times as much from biofuels as the UK. Municipal solid wastes account for similar proportions of the biofuels in both countries, but agricultural, or rural, wastes play a larger role in Denmark.

Table 2.5 Denmark: renewable energy contributions to primary energy, 2000

Energy source	Contribution	Totals by source[1]	Percentage of all renewables
HYDROELECTRICITY		**0.103**	0.12%
BIOFUELS			
MSW combustion	30.34		
wood[2]	22.55		
straw	13.05		
biogas	2.91		
other wastes	0.05		
Biofuels total		**68.91**	77.4%
WIND		**15.99**	17.96%
GEOTHERMAL[3]		**0.06**	0.07%
SOLAR		**0.33**	0.37%
HEAT PUMPS[3]		**3.66**	4.11%
TOTAL		**89.00**	

Data: All energies are in petajoules (PJ). The population of Denmark is about 5.3 million and the land area is 43 thousand square kilometres.

[1] For hydro and wind the figures represent the electrical output. All others represent the energy content of the fuels.

[2] Comprises wood chips and pellets, wood sold as 'firewood' and wood wastes. (Imports in the form of chips and pellets increase the consumption of wood to about 5 PJ more than the production shown here.)

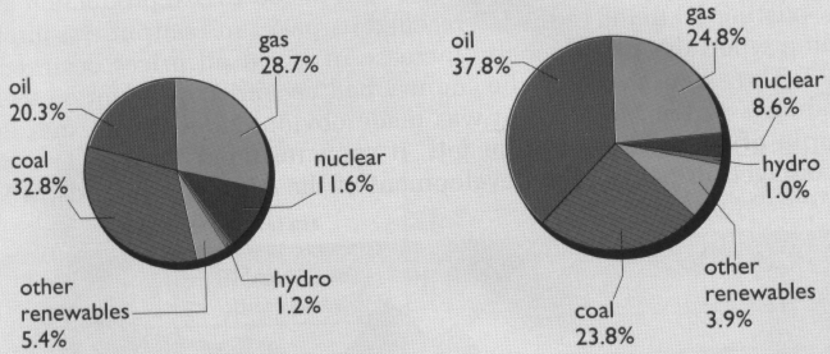
[3] Additional heat energy extracted from the ground or water (see the main text).

(Source: DEA, 2001)

Geothermal energy, heat drawn from regions below the Earth's surface, contributes a tiny fraction of the renewables total in both Britain and Denmark. The availability of this resource obviously depends on local geology, and neither country expects a major increase in its input. However, the final item in Table 2.5, the energy to be gained from surroundings that are at normal ambient temperature through the use of *heat pumps*, should be of greater interest. A heat pump, as the name suggests, 'pumps' heat from a cooler region into a warmer one, against the natural direction of heat flow. The principle is discussed later, in Chapters 6 and 9, but the result is obviously useful, warming buildings in cold weather or, in reverse, cooling them on hot days. Denmark, quite justifiably, includes such gains in the renewables total, and the contribution shown in the table, although a small fraction of the whole, represents an appreciable heat gain. With a proportionate annual contribution, the UK gain would be enough to heat half a million typical houses.

2.7 Primary energy in the USA

With the USA we come, not surprisingly, to a very different situation: a country that consumes a quarter of the world's primary energy, has twice the per capita energy consumption of Denmark or the UK and whose self-sufficiency is well *under* 100%. Primary energy production supplies less than three-quarters of annual consumption, a shortfall that leaves the US as the world's major energy importer as well as its major consumer. The pattern of consumption is not however very different from the other two countries, showing the dominance of fossil fuels that is common to all the world's industrialized countries and a *percentage* contribution from nuclear power similar to that of the UK. The actual nuclear output is of course



(a) Annual production
Total: 72.9 EJ or 1740 Mtoe per year,
or an average continuous rate of 2.31 TW.

(b) Annual consumption
Total: 99.3 EJ or 2370 Mtoe per year,
or an average continuous rate
of 3.15 TW.
Per capita consumption: 350 GJ
per year, or an average rate of 11 kW.

Figure 2.13 USA: Primary energy production and consumption, 2000