Biofuels: The Back Story

John A. Bryant and John Love

College of Life and Environmental Sciences, University of Exeter, Exeter, UK

Summary

This chapter looks at the history of the use of fossil and non-fossil fuels and of environmental energy sources from the earliest phases of human society right up to the present day. Factors, especially climate change, which affect the use of particular fuels are discussed. The chapter ends with an overview of biofuels, thus setting the scene for the rest of the book.

1.1 Introduction

The earliest recorded use of the word biofuel was in 1970 when it was defined as 'a fuel (such as wood or ethanol) composed of or produced from biological raw materials.' Use of the term gradually became more frequent but it is only in last 15 years or so that it has entered into everyday speech. The definition has also widened: the Oxford Dictionary On-line now simply states 'a fuel derived immediately from living matter.' This clearly covers much more than wood and ethanol; the range will be apparent from the chapters in this book. The purpose of this chapter is to provide the context for, and to discuss the reasons behind, this increased interest in biofuels. It is an unfolding story of human ingenuity and inventiveness in the search for sources of light and heat and of energy for industry, transport, commerce and domestic appliances. It is a fascinating story that sets the scene for the rest of the book.

1.2 Some History

1.2.1 Wood and Charcoal

Although the first recorded use of the word was relatively recent, the use of biofuels actually goes back much further. Biological materials have been used as energy
sources throughout human existence; indeed it is likely that the Neanderthals had discovered fire and the use of wood as a fuel. On a small local scale, burning of wood as a fuel may be regarded as having a very small ‘ecological footprint’, especially since, reflecting our modern concerns, it releases only recently fixed CO$_2$ into the atmosphere.

Pyrolysis of wood in the absence of air produces charcoal, a form of carbon that burns at a higher temperature than wood and can thus be used in metal smelting. The use of charcoal as a fuel dates back at least 6,000 years (and probably longer). Initially it was confined to Egypt and what is now known as the Middle East. Its use soon spread across Europe so that by the Middle Ages, charcoal production was very widespread and resulted in extensive deforestation over large areas. It thus had an ecological/environmental impact that today we would regard at least as undesirable.

With the invention of a method for making coke from coal (i.e. a fossil fuel), charcoal production declined dramatically, especially from 1900 onwards (although one of us can remember seeing charcoal burners in woods in Surrey in the middle years of the 20th century). Today the use of charcoal as a fuel$^1$ in developed countries is largely confined to domestic barbecues. However, across the world, wood and charcoal are still the mostly widely used fuels. This includes the use of wood-burning stoves in people’s homes and wood-burning power stations, often regarded as environmentally friendly because, as noted before, it is recently fixed CO$_2$ that is released. This CO$_2$ release may be further mitigated by the planting of replacement trees in managed forestry systems. However, there is no universal agreement on this; some think that growing wood just for burning is not wise when the wood could have so many other uses$^2$. Furthermore, in many parts of the world where emissions are less stringently controlled, burning of wood often causes serious smoke pollution and damaging effects on human health.

1.2.2 Dung as Fuel

Evidence for use of dried animal dung as fuel dates back about 9,000 years to Neolithic communities in which cattle, sheep, goats and pigs had been domesticated. It is still used today in many less-developed countries. There is also evidence for use by Native Americans of dung from wild bison in the prairies where wood fuel was very scarce or non-existent. There is undoubtedly today support for increased use of dung as fuel, both in what we might call traditional or semi-traditional methods and by anaerobic digestion (see Chapter 3).

1.2.3 Oils and Fats

The use of natural oils for lighting dates back to about 15,000 years. Most ancient oil lamps ran on plant oils. Thus the lamps referred to in the Old and New Testaments of the Bible and in the Qur’an were fuelled with olive oil. Both plant and animal oils were also used for lighting in ancient Egypt, dating back to about 3000 BC: rushlights, precursors to candles, were made by dipping rolled-up papyrus into oil or into melted

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$^1$ Powdered charcoal has several non-fuel uses, including absorption of gases and purification of liquids.

$^2$ http://www.usewoodwisely.co.uk/
beeswax or melted animal fat. The Romans are generally credited with invention of the true candle containing a wick that ran through the length of a cylinder of bees’ wax (other solid animal fats may also be used).

Another animal-based biofuel is whale oil, which was used for lighting from the 17th until the second half of the 19th century, when it was finally displaced by kerosene and by coal gas (see also Sections 1.3.2 and 1.3.3). It was noted that ‘sperm oil’ (from the head of the sperm whale) gave a much cleaner and less odoriferous flame than whale blubber oil and this was one of the factors that led to intensive hunting of sperm whales in the 18th and 19th centuries. Thus, in the period between 1770 and 1775, the northeastern United States produced about 7.16 million litres of sperm oil per year. At least 6,400 sperm whales would have been killed annually to supply this amount of oil. Hunting at this intensity continued until the second half of the 19th century and of course was not confined to US-based whaling fleets. It is estimated that the world population of sperm whales declined by about 235,000 in the 18th century alone and it seems very likely that they would have been hunted to extinction had petroleum oil and oil-based products not displaced sperm oil as fuels of choice.

1.2.4 Peat

The last traditional biological fuel we wish to consider is peat. This occurs in the wetter areas of the world, covering between 2% and 3% of the global land area, and consists of compressed and partly rotted remains of plants, especially *Sphagnum* moss. It may thus be regarded as being part way to forming lignite, a form of coal. Peat is cut from the bog in slices, known in Ireland and Scotland as turves (singular *turf*), which are left to dry before being burned as fuel. One of the problems with peat is that it takes a long time to form, growing at a mean rate of 1 mm/year in a typical peat wetland. It is thus regarded as a semi-renewable fuel. However, in many areas, the rate of exploitation far exceeds the rate of re-growth, resulting in denudation of the peat bog and increased run-off of water, leading to flooding.

Peat is a less efficient fuel than coal and natural gas, which means that per unit of energy, peat releases twice as much CO₂ as natural gas and 15% more than coal. This difference is only partly mitigated by the slow renewal of peat fuel (as mentioned above). Large-scale peat fires, sometimes initiated by lightning strikes and sometimes by illegal ‘slash and burn’ activities, in addition to releasing large amounts of CO₂ into the air, also cause very extensive particulate pollution. One of us was working in Singapore during the notorious 1997 Southeast Asia haze, caused by illegal burning of forest trees and subsequent out-of-control peat fires in Indonesia. Visibility was very poor, the air smelt of smoke and we were advised not to exercise outside. Right across the region there were deleterious effects on human and animal health. Similar hazes have occurred several times since 1997, as exemplified in Figure 1.1.

Peat may be regarded as being on its way to becoming a fossil fuel. However, the true fossil fuels are coal (including lignite), oil and natural gas. We thus move on to discuss the history of their use.

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3 See also Hoare P (2008).
1.3 Fossil Fuels

1.3.1 Coal

On Caerphilly Common, between Cardiff and Caerphilly in South Wales, are some shallow depressions and some small mounds. These are the remains of bell pits and their associated spoil tips, providing evidence of coal mining in the area dating from the 14th century. However, use of coal as a fuel for heating, cooking and even smelting metals actually goes back several thousand years. Its use was recorded in China at around 1000 BC and in Ancient Greece at around 350 BC. In Britain, surface or outcrop coal has been used since the Bronze Age (2000–3000 BC). In Roman times, houses and baths were heated by burning coal and a brazier of coal was kept permanently alight in the Temple of Minerva in Aquae Sulis (now known as Bath). The Romans also used coal for smelting iron.

However, it was not until the end of the 18th century that coal mining became really organised. Those simple bell pits at Caerphilly Common were tapping into the enormous South Wales coalfield and it was coal mined from this field that fuelled the Industrial Revolution in that part of Britain. Indeed, the Industrial Revolution led to a large increase in the demand for coal, which was mined in nearly all of the countries in which industry was increasing. Coal mining in the UK has nearly ended now, not because stocks have run out but because it has become uneconomical to mine it. Nevertheless, coal is still mined in many other countries and known global reserves will last for centuries, even taking into account the acceleration in use in countries like India.
and especially China. Consumption of coal currently runs at nearly $8 \times 10^9$ tonnes per year, with China being responsible for just over 50% of that total. Combustion of that amount of coal, assuming that it is all carbon, releases $22.88 \times 10^9$ tonnes of CO$_2$ into the atmosphere.

### 1.3.2 Petroleum Oil

As with coal, the use of petroleum oil as a fuel goes back much further than we might suppose. Oil, pitch and asphalt were all known in Babylon and Persia about 4,000 years ago and were used for lighting, heating and in building work. The first recorded drilling for oil occurred in China in the 4th century AD and oil was first distilled to make lighter products such as kerosene in Persia in the 9th century. From there the practice of distillation spread through the Arab world and eventually reached Spain, via Morocco, in the 12th century. Deposits of oil and/or asphalt were also known from many locations in Europe, including France, Greece and Romania and some of these have been worked until the second half of the 20th century. The first recorded oil refinery was built in Russia in 1745, producing kerosene, mainly for lighting of churches, monasteries and the homes of aristocrats. Oil and associated products were also known from the New World. In 1595, Sir Walter Raleigh described the asphalt lake in Trinidad and from the beginning of the 17th century onwards, oil springs and other types of oil deposits were discovered in many places in North America, including the now-notorious tar sands in Canada.

It was a Scotsman, James Young, who is often credited with starting the modern oil and petrol industry. In 1847, he refined petroleum that was seeping from a coal seam in a mine in Derbyshire (in the English Midlands) and obtained both a light oil suitable for lighting (as in the earlier Russian refinery) and a heavier oil suitable for lubrication. Within a few years he had also shown that oil could be obtained by a simple chemical treatment of coal and in 1851 set up a factory at Bathgate (in Scotland) for refining oil from coal. So, from around that time there was a flurry of activity of establishing oil wells and refineries in known oil fields all over the world. In the 1860s, the most productive refinery was in Baku$^4$, then in Russia but now in Azerbaijan, which produced 90% of the oil being used in the world, and this despite the rapid growth of the industry in North America.

However, it was the internal combustion engine that catalysed our modern dependence on oil. The first such engines, built around the middle of the 19th century, used mixtures of various flammable gasses as fuels. Later in the same century, engines were invented that used refined oil (gasoline/petrol) or heavier oil (‘diesel’) as fuel. These were ideal fuels for the cars and other motor vehicles that were being developed in Europe and North America. The growth in car production and ownership since the early 20th century has been phenomenal and continues apace as countries like India, China and Brazil undergo rapid economic growth. At the beginning of 2014, the global daily use of oil was 14 billion ($14 \times 10^9$) litres and transport accounted for 25% of global CO$_2$ emissions (see Section 1.4).

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$^4$ Thus Edmund de Waal, in his chronicle of the very wealthy Russian-Jewish Ephrussi dynasty, *The Hare with Amber Eyes*, writes of ‘new possibilities in oil in Baku and gold near Lake Baikal’ (p. 31).
1.3.3 Natural Gas

In the late 19th century and for over half of the 20th century, much of the gas used as fuel in Europe, including Britain and North America, was coal gas produced by the destructive distillation of coal or as a by-product of producing coke. However, the existence of another fossil fuel, natural gas, had been known since about 500 BC in China, where it was even transported in pipes made from large bamboo canes. The world’s first industrial-scale extraction plant was built in 1825 at Fredonia on the shores of Lake Erie in New York State but for many years, natural gas was known mainly from flaring-off of the gas associated with oil deposits. Nevertheless, commercial and industrial use of natural gas increased from around the middle of the 20th century, so that the fuel now makes a major contribution to the world’s energy budget. At the time of writing, global consumption of natural gas is about 3.4 trillion \((3.4 \times 10^{12})\) litres per year; at this rate of consumption we have about 250 years-worth of known recoverable reserves.

A significant proportion of the known reserves are in the form of shale gas, which is released by a procedure known as hydraulic fracturing (‘fracking’). For some, this is a controversial procedure and it has been claimed to pollute ground waters and even cause earthquakes\(^5\). Thus, at the time of writing, the very word ‘fracking’ elicits a fierce and angry response from some groups of environmental campaigners who, in the UK and the USA, have attempted to block new fracking sites, even though some fracking ‘wells’ have been running safely for several years. Indeed, fracking has been practised in the USA since 1940 and in the UK since about 1982\(^6\). On a more positive note, natural gas is the ‘cleanest’ of the fossil fuels. The output of \(\text{CO}_2\) per unit of energy is 29% less than with oil and 44% less than with coal (see Section 1.4). Indeed, in 2013, output of \(\text{CO}_2\) in the USA was at its lowest for 20 years, despite increased energy production. Some of this is attributable to increased use of solar and wind power (see Section 1.4), but the major part of the reduction is due to increased use of shale gas with a concomitant reduction in the use of oil and coal. Furthermore, burning natural gas releases much lower amounts of sulphur dioxide and nitric oxides than either oil or coal.

1.4 Fossil Fuels and Carbon Dioxide

1.4.1 The Club of Rome

In 1972, the Club of Rome, a global ‘think-tank’, founded in 1968 and describing itself as ‘a group of world citizens, sharing a common concern for the future of humanity’ published *Limits to Growth*. This dealt with the difficulties of sustaining economic and social development in a world of finite resources. Amongst several pessimistic scenarios was a prediction that at some point in the early years of the 21st century, the ability to extract oil would not keep up with demand. This

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\(^{5}\) Actually, in some rock formations, fracking can cause very minor, harmless earthquakes: see Royal Society/Royal Academy of Engineering (2012).

\(^{6}\) Fracking has been widely used in the off-shore oil and gas fields in the North Sea since the 1970s.
prediction has become known as ‘peak oil’. Now, we need to say that a subsequent report, *Mankind at the Turning Point* written by Eduard Pestel and Mihajlo Mesarovic, published in 1974 and based on a very much wider analysis than *Limits to Growth*, presented a more optimistic prognosis. In particular, it noted that many of the factors affecting the future of humankind on our planet are within human control. Thus it was suggested that with appropriate use of science, technology, architecture and so on, environmental and economic disasters are preventable or avoidable. But there was one major factor that did not enter the reckoning in either of these reports, and that was global climate change.

1.4.2 Climate Change

It may well be that, at least in terms of fuel availability, the Club of Rome was too pessimistic. The concept of peak oil has remained with us over the years, but the actual year in which this will occur has crept slowly backwards. The trend in oil extraction continues upwards and some commentators are now suggesting that peak oil will be never be reached. However, since the world’s oil deposits are in fact finite, peak oil will certainly be reached at some time, albeit many years into the future. Even then, the very extensive known reserves of coal mean that oil production from coal (as described earlier) will continue to be possible for very many years. Oil shortage on its own then will not drive a reduction in oil usage. It is climate change that is now the main driver for reduction in the use of all fossil fuels.

We need to be clear that without ‘greenhouse gases’ the Earth would be a giant snowball. These gases, especially water vapour, CO₂ and methane (CH₄), prevent some of the Sun’s heat energy from being lost into space, thus warming the Earth’s surface and making life as we know it possible. However, since the start of the Industrial Revolution, the concentration and balance of the greenhouse gases has changed. Every year, the CO₂ concentration in the atmosphere peaks in May, and in May 2013, it reached 400 ppm. Not only does that represent an increase of 42% on the pre-industrial baseline of 280 ppm, but it is also the highest concentration that the Earth’s atmosphere has contained for at least 800,000 years and possibly since the Pliocene era, over 3 million years ago. This increase in the atmospheric concentration of CO₂ is attributed to the hugely increased rate of burning of fossil fuels in the industrial era. Fuels that took millions of years to be laid down are being burned in a tiny fraction of that time.

As we have already noted, CO₂ is a greenhouse gas and it was as long ago as 1938 that a paper was published that drew attention to the likely warming effects of the increasing concentration of CO₂.

Awareness of the problem slowly grew; by the 1970s, meteorologists and atmospheric physicists were concerned about global warming, a concern that had spread to the wider scientific community by the early 1980s. The World Climate Research Programme was set up in 1979, followed in 1988 by the establishment of the Intergovernmental Panel on Climate Change (IPCC). In a series of reports starting in 1990,
the IPCC has shown with increasing clarity and certainty that the increased atmospheric CO₂ concentration is caused by human activity and that this is causing global warming.

So, how much warming might we expect? As discussed by Robert Kunzig of the *National Geographic* magazine, when the atmospheric concentration of CO₂ was at 400 ppm in the Pliocene era, the Earth was two to three degrees (C) warmer than it is now, in the late stages of a long ‘greenhouse epoch.’ Horses and camels lived in the high Arctic and sea levels were around 10 m higher, at a level that would flood many major cities around the world today. That does not mean that temperatures will rise this much in the current era; several other factors also affect the Earth’s temperature. Nevertheless, it does seem very likely that there will a further increase on top of the currently experienced (as of early 2015), mean global temperature that is 0.7°C higher than the pre-industrial mean.

There has been much discussion about how much CO₂ and therefore how great an average temperature rise can be accommodated. Comparison with earlier geological eras is not necessarily helpful. First, because, as already noted, CO₂ concentration is not the only driver of temperature and second, because we are now living in an era in which over 7 billion humans inhabit the planet. Furthermore, based on geological and geochemical evidence, there has been no period in which CO₂ concentration has risen so rapidly. Some climate scientists are now discussing the possibility of tipping points, points at which either the temperature or the CO₂ concentration or both, lead to an event which then accelerates the change. Such possible events include the melting of permafrost, leading to release of large amounts of previously trapped methane, which is 20 times more effective a greenhouse gas than CO₂.

Because of all these uncertainties there has been a strong and widely supported suggestion that we should attempt to reduce the atmospheric CO₂ to 350 ppm, the value that was last seen in about 1988. At this concentration, the global temperature is likely to stabilise at about 0.5°C above the previous running mean, provided that no serious tipping points have occurred. A target of 350 ppm will be very difficult to hit. Even if we stopped burning fossil fuels today, it will take about 500 years for the CO₂ concentration to drop far enough. In the face of such difficulties, there is an international effort (supported by national governments with varying degrees of enthusiasm) to limit the temperature rise to 2°C (probably equivalent to a CO₂ concentration of about 450 ppm). Even this target is not easy; furthermore, even if it is achieved, there will still be a good deal of disruption across the globe, not least because of changing weather patterns and rising sea levels. Indeed, the March 2014 report of the IPCC presents a gloomy picture. We are already seeing the effects of ‘irreversible’ changes in the climate, with increased frequency of extreme weather events, flooding, ecological problems and reductions in crop yield.

One final comment is needed. In the geological history of the Earth, temperatures have at times been significantly higher than they are now or even than they are projected to be. The planet survived. So, when we hear people talking about saving the planet, what is mainly meant, as we see from the recent IPCC reports, is maintaining the planet in a state where it can continue to support the human population (and, if there is an interest in the environment for its own sake, also to support the current range of living organisms).
1.5 Alternative Energy Sources

1.5.1 Introduction

If the rise in mean global temperature is to be kept to 2°C or lower, it will take a good deal of hard work on an integrated global scale. Fossil fuels currently provide about 83% of the world’s energy (but only 66% in the USA) and this proportion needs to drop very dramatically. Even if the proportion drops, it is predicted that the world’s energy demands will have increased by around 50% between 2010 and 2035, with largest increases being seen in China and India. A decreased proportion may still mean a larger amount. So, where fossil fuels continue to be used, carbon-capture techniques, currently in their ‘technological infancy’, will need to be deployed.

One obvious way to reduce the use of fossil fuels is to turn to alternative energy sources. Thus, the European Union, in its 2009 Renewable Energy Directive, determined that the Union should obtain 20% of its energy from renewable sources. This includes both fuels for combustion and means of generating electricity.

1.5.2 Environmental Energy Sources

By ‘environmental’ we mean using the ‘forces of nature’ to generate energy for human use. Actually, utilisation of some forms of environmental energy dates back many centuries. Windmills for example, have been used to grind cereal grains for at least 1,500 years and possibly longer; their first use in Europe dates back to the late 12th century. Use of wind to propel boats goes back much further, probably to about 3000 BC in ancient Egypt; by 500 BC, two-masted cargo ships were regularly plying the Mediterranean trade routes.

By the end of the 19th century, windmills were in wide use in northern Europe, exemplified by Denmark where there are 2,500 windmills, mostly used in mills and for pumping. Up to 6 million were installed on farms in the mid-west of the USA, where their main use was to power irrigation pumps.

Water wheels (or water mills), with applications in irrigation and as a power source, were used by the Greeks (and were later copied by the Romans) as far back as the 3rd century BC. They were certainly known in Europe by the 6th century AD and at the time when William the Conqueror’s assistants compiled the Doomsday Book, there were at least 6,000 water mills, including tide mills, in England alone. Overall, in pre-industrial Europe, water mills outnumbered windmills by at least two to one.

In more modern times, the water wheel was mostly replaced in the Industrial Revolution by the water turbine and in the 19th century, water power began to be used both in small local hydro-electric plants and in more large-scale generation of electricity in hydro-electric power stations. An example of the former was at Lynmouth in North Devon, southwest England. The small hydro-electric plant, built in 1890, harnessed the power of the River Lyn which flowed rapidly from Exmoor, a high rainfall area. It remained working until 1952, at which time it was destroyed by severe floods.

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10 Indeed, in the 1st century AD, the Greek engineer, Heron of Alexander built a device that used wind power to drive simple machinery, including a pipe organ.
Increased use of hydro-power has continued right through to the 21st century; in the USA for example, hydro-electric power generation contributes to about 7% of the energy budget. However, large-scale hydro-electric power generation has its downside in that the trapping of water behind a dam causes loss of land and in many cases, displacement of people.

Some water wheels are still in operation in several countries and increasing numbers of organisations with access to appropriate water courses are installing modern water turbines. Thus, at a conference centre in North Devon, southwest England, a water turbine provides an average of 30% of the electricity used at the centre (Figure 1.2). In the same area, several villages have built or are planning to build their own hydro-electric stations. Across the globe, small-scale hydro-electric generation accounts for about 20% of the total hydro-electric output.

There has also been a renewal of interest in the power of the tides: the first modern tidal power station was built on the estuary of the Rance (between St Malo and Dinard in Brittany, northwest France) and opened in 1966. For several years, ‘La Rance’ remained the sole example of tidal power generation and even when other tidal power stations began to be built, the Rance power station remained the largest (with a capacity of 240 MW) until it was ‘overtaken’ by Sihwa Lake tidal power station (254 MW) in South Korea. None of the other six tidal power stations in the world (as at the end of 2013) has a generating capacity greater than 3.2 MW, although several very large ones are planned for South Korea and Russia. In fact, there are many sites over the world where the tidal range would merit construction of a tidal power station. However, this would destroy the inter-tidal zone which in many places, for example in South Wales and in southwest England, are important wild-life habitats – an example of clashing environmental ethics priorities.

There is also extensive interest in harnessing the power of waves but as yet, much of the work on this is only at the experimental stage. The world’s first commercial wave-power plant, commissioned in 2000, was a very small one, situated on the shore of Islay, an island off the west coast of Scotland and generating only 0.5 MW. Since then only four other wave-driven power plants have been built (as in early 2014), the largest of which, in Orkney, Scotland, generates 2.4 MW. Experimental rigs are working in several places in Europe and North America and it is likely that more commercial wave-power plants will be built in the next ten years.

As with water power, the use of wind as a power source has also had a renaissance in modern times. Once again, a Scotsman was a key pioneer in this: in 1887, Professor James Blyth built a windmill that charged accumulators (effectively large rechargeable batteries), which then supplied the electricity to light his holiday cottage. This cottage, at Marykirk in eastern Scotland, was the first house in the world to use electricity generated by wind power. Windmills for electricity generation were also built in the USA in the later years of the 19th century, but it was in Denmark that the most rapid progress was made. In 1895, the Danish scientist Paul la Cour modified an earlier-designed wind turbine to produce enough electricity to light a whole village. From then, wind turbines were built all over Denmark as part of a programme to decentralise the generation of electricity; the largest of these turbines generated 25 kW. The rest of the world quickly
Figure 1.2 (a) Hydro-electric generating station at Lee Abbey Conference Centre, Devon. Even a small station like this can generate a significant proportion of the electricity used by up to 120 delegates plus 80 resident members of the community. This picture shows the turbine house and tail race through which the water is exiting. (b) Self-cleaning Coanda screen at the head of the high pressure inlet pipe in the Lee Abbey system. (c) The generator in the turbine house at the Lee Abbey conference centre. Thanks to Lee Abbey, Devon, for supplying these photos.
followed with the use of wind turbines to generate electricity in places distant from any centralised supply. This included remote regions of the USA, Australia, parts of Africa and even Antarctica.

The first wind turbine of the modern type that we are now familiar with was built at Yalta in Russia in 1931 and ran for about ten years. This generated 100 kW but an experimental rig, set up in 1941 in Vermont, USA was capable of generating 1.25 MW; however, it only ran for 1,100 hours before a blade collapsed. Meanwhile, developments continued in Denmark; in 1957, Johannes Juul built and installed a 200 kW wind turbine that fed alternating current directly into the grid. The turbine incorporated a number of technical innovations which were adopted by other manufacturers as wind power became more widely used. The term ‘Danish design’ is still used in the industry.

However, it was the oil price crisis of 1973 that provided a strong impetus for the exploitation of alternative energy sources in general and of wind power in particular. Even though oil prices declined again in the 1980s, other concerns such as energy security and climate change continued to drive the development of the use of renewable energy. The visual impact of this will be familiar to our readers. There are large turbines installed in windy places all over the world, sometimes individually or in small groups, but often in large arrays known as wind-farms (Figure 1.3) Some of these installations are at sea (‘off-shore’), including the recently opened London Array located off the Kent coast. The maximum power output achieved so far by an individual turbine (early 2014) is 8 MW, although most turbines generate between

Figure 1.3 Wind Farm at Bears’ Down, Cornwall, UK. Photograph by Ron Stutt; reproduced under the Creative Commons Attribution ShareAlike Licence.

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12 The famous Gedser wind turbine.
2 and 5 MW. The largest wind farm in the world, the Alta Wind Energy Centre in California, has a total generating capacity of 1,320 MW (1.32 GW).

At the time of writing, the use of wind power across the world is growing by 30% per year. Focusing on the UK as a specific example, overall mean power generation rose 35-fold between 2000 and 2013 (300 MW to 10.5 GW). At the end of 2013, wind power generated about 6% of the electricity used in the UK. However, in windy periods, that percentage can be much higher. For example, in December 2013, wind power generated approximately 10% of the UK's electricity demand. In the week beginning 26 December, 13% of Britain's total electricity needs were met by wind power, with a record of 17% being set on 21 December. In 2016, for a limited time, Scotland was able to generate all its electricity requirement using renewable sources. It is figures like these that add weight to the view that the UK is one of the most favourable countries in Europe for wind power.

More off-shore and land-based wind farms are either under construction or are being planned. However, it is here that we meet another of those environmental ethical tensions. It is stating the obvious that wind turbines are most efficient in windy places, but many of those windy places are in areas of wilderness and/or rugged natural beauty. In a small country like the UK, there are few areas of wilderness and thus they are very precious. For this reason, some environmental campaigners, while remaining very concerned about climate change, actually oppose many of the plans to build more land-based wind farms.

This brings us to the last of the major environmental energy sources, the Sun. While the UK may be the most favourable place in Europe for wind power, the same cannot be said about sunshine. Despite this, modern methods for capturing the Sun's energy mean that the UK can generate considerable amounts of energy by this route and of course this is even more so for the sunnier regions of the world, including southern Europe.

Like other forms of environmental energy, use of the Sun's power first occurred many centuries ago. Mirrors and lenses were used to concentrate the Sun's rays to start fires (including the lighting of lamps) as long ago as the 7th century BC; in ancient Greece, the Olympic torch was lit in this way. There is even a legend, actually not verified, that Archimedes set fire to Roman ships by using mirrors to focus the Sun's rays. The Romans themselves were among the first to use glass in windows, which allowed them to exploit passive solar gain in the heating of bath houses. In the UK, glass became widely used in homes in the 16th and 17th centuries and passive solar gain was (and still is today) used to heat orangeries and greenhouses (hence the term 'greenhouse effect').

The more technological approaches to using solar power did not begin until the late 19th century. The first solar powered water heater was installed in the USA in 1896 and the technology slowly gained in popularity from the 1920s onwards. In both the USA and across the 'developed' world, there was an increase in uptake from the 1960s onwards and especially after the oil crisis of 1973. Modern systems have very efficient heat exchangers and provide hot water both for the tapped supply and for central heating. Solar water heating systems are especially popular in China,

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13 It was indeed a very windy week; across the UK, thousands of trees were blown down, including over 200 in the National Trust’s estate at Killerton in Devon, UK (and two in the garden of one of the present authors)!
which currently accounts for over 80% of the world’s new solar heating installations. The huge array at Kramer Junction in California (built in 1986) is also essentially a hot water system: mirrors focus the Sun’s rays onto the heat exchangers, leading to the production of steam. This is used to drive turbines which generate electricity.

However, the most rapid recent growth in the use of solar power has been in the more direct generation of electricity. In 1839, a very young Edmund Becquerel (who would later share a Nobel Prize with Pierre and Marie Curie for the discovery of radioactivity) demonstrated the photovoltaic (PV) effect: illumination of some but not all metals causes the generation of an electric current. Einstein later called this the photoelectric effect and worked out the theoretical basis for its occurrence. Increasing awareness of the types of material that exhibited the effect and continuing sophistication and therefore efficiency of the experimental devices employing the effect, eventually led to its use in generating electricity on a practical scale. Since 1958, satellites have been powered by PV cells; in the 1960s, some small hand-held devices were powered by PV cells (now commonplace in things like calculators) and by the 1970s larger pieces of equipment and machines could be solar powered. The first applications in providing electricity for buildings were also in the 1970s.

By the 1980s, it became apparent that PV technology has enormous potential for widespread generation of electricity. It had proved its worth in pilot studies on all the world’s continents. In 1981, a solar-powered plane, piloted by Paul McCready, flew across the English Channel; in 1982, a one-MW PV power station was opened in California and in the same year, Hans Holstrup drove a solar-powered car across Australia. Since then, there has been immense progress in developing ever lighter arrays, in increasing the energy conversion efficiencies and increasing the efficiency at lower light intensities. There are PV power stations all over the world, the largest two of which (as in early 2014) are both in California; each generates 500 MW. A 700 MW array is under construction in Arizona, USA. There has also been, in the 21st century, increasing uptake by domestic users. In the UK and in some other countries, this has doubtless been accelerated by the ‘feed-in’ tariffs: electricity in excess of the consumer’s use is fed back into the grid, attracting a payment to the consumer. Thus, in the UK, it is becoming common for farmers to cover a whole field with an array of large PV panels (Figure 1.4).

By the end of 2013, installed capacity of PV arrays, from small domestic roof panels to vast solar parks, exceeded 100 GW, of which the UK contributed about 2.5 GW, but these numbers are growing daily. This increased uptake, combined with the greater conversion efficiency of modern PV materials and their ability to utilise lower light intensities, means that the generating capacity from PV installations is growing faster than the generating capacities of either wind or water power, although in terms of actual totals, PV remains in third place. However, the potential for use of solar power is huge and we have barely scratched the surface of what is possible.

While water, wind and sun are undoubtedly the major sources of environmental energy, we must also mention geothermal energy using the heat from the Earth. This may involve a direct use of hot springs and hot water in underground aquifers, as happens for example in Iceland, New Zealand and many other countries where such supplies are readily available. However, geothermal energy (which may include dry sources such as ‘hot rocks’) is increasingly used to generate electricity, first done
on a commercial scale in Italy in 1911\textsuperscript{14} and eventually, from 1958 onwards, in New Zealand and then in several other countries. By 2013, total generating capacity across the globe was 10.7 GW, with five countries – El Salvador, Kenya, The Philippines, Iceland and Costa Rica generating more than 15% of their electricity from this source.

Finally, there are ground-source heat pumps. Technically, the source of energy is not geothermal because pumps exploit the more or less stable temperatures (with some variation according to latitude) a few metres below the soil surface, temperatures that arise from the Sun heating the Earth’s surface. Temperatures at a few metres depth are usually higher than ambient in winter and lower in summer, meaning that the heat pumps may be used for summer cooling as well as winter heating. There are at least 2 million installed over the world and in Finland all new houses built since 2006 have had ground-source heat pumps installed.

\subsection*{1.5.3 Nuclear Power}

Another major energy source is nuclear fission. It is not technically a renewable energy source in that fuel supplies are finite (but far from being exhausted), but it is a ‘clean’ energy source in that it does not use fossil fuels and does not release CO\textsubscript{2} into the atmosphere. In the Second World War, nuclear fission had been used in the bombs that destroyed Nagasaki and Hiroshima, but after the war there was a strong motivation to use ‘atoms for peace’ (as in President Eisenhower’s speech to the United Nations in

\footnote{\textsuperscript{14} Following an experiment in 1904, in which geothermally generated electricity powered four light bulbs.}
The world’s first commercial nuclear power station, at Windscale (now known as Sellafield) in the UK, was commissioned in 1956 and from then, use of nuclear power increased rapidly across the industrial nations until the mid-1980s. However, there had always been some opposition, first because of the accumulation of very long-lived radioactive waste for which there has been (and still is) no universally acceptable solution. Second, there have always been background concerns about safety and these fears had been exacerbated by an accident at Three Mile Island in Pennsylvania, USA in 1979. Anxiety was then further stoked up by a major accident at Chernobyl, Ukraine in April 1986. From that time there was a major slowdown in the building of new nuclear power stations. However, there were some exceptions. In the UK, the Sizewell B power station was built in the late 1980s. France in particular continued to invest in nuclear power and by early 2014, obtained 75% of its electricity from its 58 nuclear power stations. This compares to an average of about 12% across the rest of the world. A further 15% of France’s electricity comes from hydro-power (including tidal – see earlier), which means that per unit of electricity generated, France has by far the lowest CO₂ output. It also produces the cheapest electricity in Europe and thus can export to other nations, including the UK.

In the 21st century, with the increased awareness of climate change, there has been a revival of interest in nuclear power, at least as a supplement to the growing use of renewable energy sources. Indeed, the French model tells us that a combination of nuclear and environmental energy can be very effective in lowering CO₂ emissions. Thus, France continues to build nuclear power stations, about 25 new stations are under construction in China and in the UK a power station is under construction at Hinkley Point. In the USA, which is actually the world’s largest producer of electricity from nuclear power (30% of the global total; 19% of its own electricity), there had been a long pause since the Three Mile Island accident. However, by early 2014, five new nuclear power stations were under construction and licences had been granted for six more.

Against this increased activity in nuclear power generation we need to set reactions to the disaster at Fukushima in Japan. On 11 March 2011, there was a huge earthquake off the coast of Japan. The Fukushima-Daiichi power station had been built to withstand earthquakes and indeed it did so. What it did not withstand was the enormous tsunami that followed the earthquake. The power station was badly damaged and three of the six reactors went into meltdown\textsuperscript{15}. It was a very serious accident and catalysed extensive opposition to nuclear power, both amongst the public and at government level in several countries. Although it did not halt the planning of the new power stations that are now being built in France, the UK and the USA, the nuclear power industry was brought to a sharp halt in other countries. In Japan itself, all the other 48 nuclear power plants were shut down in September 2013 and some remained shut down to April 2014. Since these nuclear power stations previously provided 30% of Japan’s electricity, this has made a major ‘dent’ in supplies. In Germany, all of the old-style nuclear power plants were rapidly shut down and all of the newer ones will be shut down by 2022. Plans to build new nuclear power stations were halted in Bahrain, Kuwait, Malaysia and the Philippines while in

\textsuperscript{15} For further details, see archive at http://fukushimaupdate.com/
China, plans were put temporarily on hold but were re-instated in mid-2012. Since nuclear power is regarded as having a role to play in reducing CO₂ emissions (as has clearly happened in France), these negative responses make the adoption of renewable energy sources even more urgent.

1.5.4 Hydrogen

Although each of the foregoing energy sources has a role to play in reducing the use of fossil fuels, none directly produces fuel for combustion. It is here that we encounter the largest difficulty in reducing our reliance on fossil fuels. For example, as stated earlier in this chapter, in Spring 2014, the global use of petroleum oil was 14 billion litres per day. Much of this is used to fuel transport of various types. Now it is true that some transport systems use other sources of power such as nuclear power (as in submarines) and electricity, as with many trains and trams and, increasingly, some cars. Despite this, we will need combustible fuels for many years to come. Hydrogen gas has been seen by some as playing a significant role in dealing with this problem. It is certainly true that hydrogen is a renewable fuel: it is made mainly from water and turns back to water when burned; it is thus a very clean fuel. It is also true that vehicles can be adapted to use it either in a fuel cell to produce electricity or in an internal combustion engine (as with conventional fuels).

The first hydrogen-fuelled vehicles were made in Germany in the late 19th century and by the start of the Second World War, thousands of hydrogen-fuelled lorries and buses (and some submarines) were in use in that country. Today, Germany is still a world leader in hydrogen-fuel technology and, combined with its expertise in automotive innovation, may yet produce hydrogen-powered vehicles for the mass market. Hydrogen and hydrogen fuel cells were amongst the propulsion systems used in space rockets from the 1960s onwards and the US Navy developed some fuel-cell-driven submarines. However, it took the oil crisis of 1973 to generate a wider interest in the potential for the domestic market. The first vehicles to use hydrogen fuel cells were built in the 1990s, although the technology had been invented in the 1830s and 1840s in Switzerland and England, and from that time there has been parallel development in Europe, Japan, Canada, Australia and the USA of both hydrogen-fuelled vehicles and fuel-cell-driven vehicles.

In 1998, Iceland announced that it was working towards a hydrogen economy, freeing the country from dependence on fossil fuels by 2040. The first hydrogen-fuelled buses were introduced in 2003 and the first cars in 2007 (admittedly not many); there is also one passenger ferry that uses hydrogen. Although the project is behind schedule, it is understood to still be part of government policy. Indeed, Iceland is an ideal country for such a policy. Producing hydrogen, either by release from organic compounds or more usually by the electrolysis of water, uses energy and by the laws of thermodynamics, less energy is obtained by burning the fuel than went into producing it. It is thus Iceland’s valuable resources of renewable energy – geothermal, hydroelectric and wind – that make this feasible. In a similar way, hydrogen production in the USA generally uses electricity generated by solar or wind power.

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16 Ireland (2014).
17 Sir William Grove is known as the Father of the Fuel Cell.
1.6 Biofuels

And so we return to the theme with which we started the chapter. As we noted, ‘traditional’ biofuels have been in use for many centuries. We have also seen that there is now a worldwide imperative to move away from fossil fuels; biofuels clearly have a place in the mix of alternative energy sources. However, for all the excellence of many alternative energy sources, there is still a major shortfall in availability of combustible fuels that may be used for direct propulsion of, for example, planes and road vehicles, in contrast to indirect, in which fuel combustion is used to generate electricity. It is a major task to meet this need and biofuels will certainly have a role but it will not be easy. We have already mentioned the amount of oil that is consumed daily, but Tim Ireland illustrates the problem even more vividly: imagine a line of cars, say 500 m long. Based on productivity of biofuel crops, it would take an area of 500 m × 8 km to produce enough fuel for them. Thinking specifically of the UK, devoting all the available arable land that is currently used for conventional crops to biofuels, would provide only a tiny fraction of the nation’s liquid fuel needs.

It is with these problems in mind that we start to look at the modern era in biofuel generation. This was initiated by two very different technologies, namely the use of ethyl alcohol as fuel and the generation of methane by anaerobic digestion. Use of alcohol as a fuel, either on its own, or mixed with petrol (gasoline), has occurred on a small scale since the end of the 19th century. However, it entered the modern era in Brazil in the early 1970s, where a decision was made to use sugar from the extensive sugar-cane plantations to make alcohol. In 1976, it was made compulsory for petrol to contain between 10 and 22% by volume of anhydrous alcohol; in 2003, the range was tightened up to 20–25%. For several years, Brazil was the world’s biggest producer and biggest exporter of fuel-alcohol, although they have recently been overtaken in both areas by the USA. Between them, Brazil and the USA produce about 85% of the world’s fuel alcohol, but it is in Brazil where alcohol makes a very significant contribution to the fuel economy. Further benefit is obtained from the waste sugar-cane material (bagasse), which is used to generate heat or power, the latter contributing to the 85% of electricity generated from renewable resources.

There is more on alcohol production in Chapters 5 and 8. For the present though, we now briefly consider anaerobic digestion. It has been known since at least the 17th century that rotting biological material produces a flammable gas, and the identification of the gas as methane arising from microbial metabolism was made in the 19th century. By the end of that century, the city of Exeter in the UK had installed a series of septic tanks that utilised anaerobic methanogenic bacteria to treat its waste water; the methane was burned to provide heating and lighting at the treatment works. A true anaerobic digester was built in India in 1897, using human waste as fuel to generate methane to light a leprosy hospital. These two types of application were developed across the world in a piecemeal fashion until the 1970s when two factors, the oil-price crisis of 1973 and, in many developed countries, tighter pollution controls, catalysed further research and development on ‘biogas’ generation. Today, anaerobic digesters are a relatively common sight at sewage treatment works and in places where biological waste is generated (see front cover). These may include farms of various types, breweries and food-processing factories (see Chapter 3). Some digesters are set up as central facilities where output from several
farms, or waste food from schools, restaurants and supermarkets, can be digested. In most cases, the methane is used to drive electricity generators but some motor vehicles have been modified to run on methane, thereby helping in a small way with the transport fuels problem mentioned above.

Focusing specifically on liquid fuels, one more type is classed as first generation, namely fuel from plant lipids, that is, biodiesel. Like ethanol derived from fermentation of sucrose, it is mainly produced from crops that are normally used for food production. This raises the food vs fuel issue, which is discussed in several chapters in this book. What we need to see say here is that even if, in a country such as the UK, all the land currently used for growth of food crops was used instead for biofuel production, we would still be a very long way from being able to fulfil our liquid fuel requirements. As will become apparent in reading the rest of this book, progress is already being made on ‘second-generation’ and ‘third-generation’ fuels, with a look forward even to the fourth generation. So read on!

**Selected References and Suggestions for Further Reading**


