John Lowry

Avoiding Carbon Apocalypse Through Alternative Energy

Life After Fossil Fuels

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Preface

We have reached the point where the carbon emissions released from combusting fossil fuels are causing global warming. Almost 95% of scientific experts are in agreement that this is a real problem.

Global warming gives rise to a myriad of problems, chief among which is sea level rise, which will cause widespread flooding. Global warming is also likely to affect food production, to affect the spread of diseases and to endanger wildlife.

After the Paris conference held at the end of 2015, a number of countries worldwide agreed to limit the average increase in temperature to 2 °C, although how they will achieve this is not yet totally clear.

Existing technology has developed to the point where we could free ourselves from combusting fossil fuels for the generation of energy, as well as for transport. Not only will this allow us to stop releasing carbon dioxide, one of the chief causes of global warming, but it also looks as though this option could make more economic sense than using fossil fuels for power generation and transport.

This book explains the various available sustainable technologies and alternative transport systems. It examines the economics of sustainable power production and shows how the new technology can be implemented and in what timescale. This book shows how carbon dioxide released due to combustion of fossil fuels can be eliminated entirely, rather than simply reduced.

Bishopstone, UK John Lowry

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Chapter 1
Introduction

1.1 What Is Meant by the Carbon Apocalypse?

By carbon apocalypse, we mean a situation in which very serious damage and destruction occurs as a result of the release of carbon dioxide. This is largely brought about by combusting fossil fuels to make electric power and to fuel transport. This is now considered to bring about global warming, which has several consequences including catastrophic sea level rise.

There are also longer-term consequences that will be caused by the eventual depletion of fossil fuels.

1.2 Rationale for This Book

It is essential that we deal with the consequences of global warming which the majority of scientists have predicted.

This book outlines a serious plan for freeing the world from using fossil fuels totally, not just limiting their use or limiting the temperature rise caused by carbon release to 2 °C (we have already reached 1.5 °C). The plan outlined will provide a better solution than that of many of today's technologies. The suggested solutions are based on current technology and not on future technologies that will doubtless arrive one day but cannot produce a solution now. Overall, the technologies outlined will provide a less expensive solution to the issue of energising and running the planet, so the usual excuse for doing nothing, namely 'it is too expensive', does not apply.

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1.3 Global Warming

Models produced by NASA, among others, predict that as the world consumes ever more fossil fuel, greenhouse gas concentrations will continue to rise, and the Earth's average surface temperature will rise with them. Based on a range of plausible emission scenarios, **average surface temperatures could rise between 2 °C and 6 °C by the end of the 21st century and this is likely to be catastrophic** (Fig. 1.1).

The mean surface temperature has already risen by nearly 1.2 °C and this rise is accelerating.

This book outlines a serious plan for freeing the world from using fossil fuels totally, not just limiting their use or the temperature rise caused by carbon release to 1.5°C. The plan outlined will produce a better technical and economic solution than many of today's technologies have provided. The solutions outlined are based on technology which is already developed and not on future technologies which will doubtless arrive one day but cannot produce solutions now. The technologies outlined provide a less expensive solution to energizing and running the planet, so the usual excuse for doing nothing—***it is too expensive***—does not apply.

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Global warming refers to the rise of the earth's temperature and is considered to be predominantly caused by the combustion of fossil fuels. There is some controversy as to whether this is the case; however, multiple studies published in

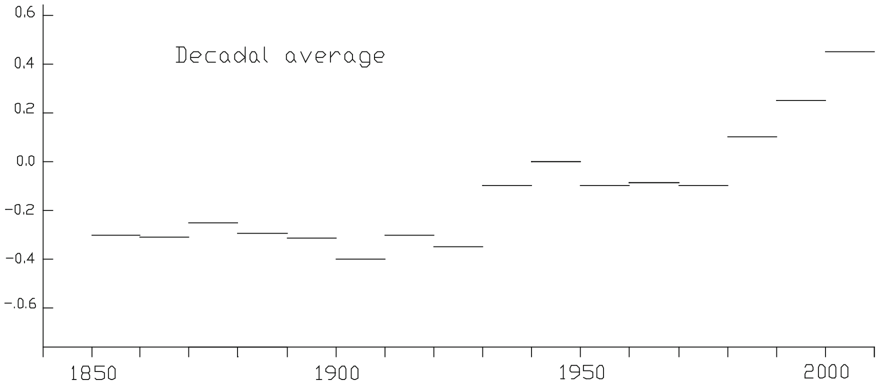

Fig. 1.1 Approximate decadal average temperature rise since 1850. *Source* Courtesy of IPCC http://treealerts.org/wp-content/uploads/2013/09/ipcc-warming-graph.jpg

peer-reviewed scientific journals show that 97% or more of actively publishing climate scientists agree. The planet is warming, from the North Pole to the South Pole, and everywhere in between. Globally, the mercury is already up by 1.3 °C, and even more in sensitive polar regions. The effects of rising temperatures are happening now and are likely to get worse.

The consequences of global warming are potentially extremely serious and could result in destruction that is unprecedented in the earth's recorded history.

The average global temperature is predicted to rise by around 2 °C this century, which will cause the sea to rise due to thermal expansion of seawater and the melting of glaciers and small ice caps. Over the 21st century, the IPCC (Intergovernmental Panel on Climate Change) predicts that that global mean sea level could rise by 52–98 cm. The IPCC's projections are conservative, and may underestimate future sea level rise. Other estimates for the same period suggest that global mean sea level could rise by 0.2–2.0 m (0.7–6.6 ft), relative to mean sea level in 1992.

The melting of small glaciers on the Antarctic Peninsula and its margins would itself increase sea levels by around 0.5 m. Potentially, at the extreme, according to the Third Assessment report of the IPCC, when entirely melted the ice contained within the Greenland ice sheet would increase sea level by 7.2 m (24 ft). This is a fraction of the ice contained within the Antarctic ice sheet, which, if it entirely melted, would produce 61.1 m (200 ft) of sea level change. Together, this would both total a sea level rise of 68.3 m (224 ft).

The ice sheet, consisting of layers of compressed snow from more than 100,000 years, contains in its ice today's most valuable record of past climates. In the past decades, scientists have drilled ice up to 4 km (2.5 miles) deep. Scientists have, using those ice cores, obtained information on (proxies for) temperature, ocean volume, precipitation, chemistry and gas composition of the lower atmosphere, volcanic eruptions, solar variability, sea-surface productivity, desert extent and forest fire greater than in any other natural recorder of climate, such as tree rings or sediment layers.

Positioned in the Artic, the Greenland ice sheet is especially vulnerable to climate change. The melting Greenland ice sheet is illustrated in Fig. 1.2.

Many scientists who study the ice melt in Greenland consider that a 2 or 3 °C temperature rise would result in a complete melting of Greenland's ice. Positioned in the Arctic, the Greenland ice sheet is particularly vulnerable to climate change. Eventually, the snow became the Greenland ice sheet, a blanket of ice so huge that it covered 650,000 square miles and reaching in places a thickness of 10,000 ft in places.

If the ice sheets on Greenland and Antarctica were to collapse and melt entirely, the result would be a sea–level rise of 61 m (200 ft) No scientist believes that all this ice will melt into the oceans immediately; however, this is a significant enough warming for the world to take preventative action. During the last year, however, a small contingent of researchers have begun to consider whether sea level–rise projections, increased by the recent activity of collapsing glaciers on the periphery of the ice sheets, point toward a potential catastrophe. It would not take 61 m

Fig. 1.2 Meltwater in Greenland. Scientists using NASA data released new insights into the hidden plumbing of melt water flowing through the Greenland Ice Sheet as well as the most detailed picture ever of how the ice sheet moves toward the sea. *Source* NASA/Michael Studinger https://www.nasa.gov/sites/default/files/thumbnails/image/agu_greenland1.jpg

(200 ft) to drown London, New Orleans or New York. A mere 1.5–3 m (5 or 10 ft) of sea level rise and a few powerful storm surges would probably suffice).

The Arctic climate is now believed to be rapidly warming and much larger Arctic shrinkage changes are projected. The Greenland Ice Sheet has also experienced record melting in recent years (in relation to the years since detailed records were kept) and is likely to contribute substantially to sea level rise as well as to possible changes in ocean circulation in the future if this is proven to be true or sustained. The area of the sheet that experiences melting has been argued to have increased by about 16% between 1979 (when measurements started) and 2002 (most recent data). The area of melting in 2002 broke all previous records.

The **Antarctic ice sheet** is one of the two polar ice caps of the Earth. It covers about 98% of the Antarctic continent and is the largest single mass of ice on Earth. It covers an area of almost 14 million square kilometres (5.4 million square miles) and contains 26.5 million cubic kilometres (6.4 cubic miles) of ice. That is, approximately 61% of all fresh water on the Earth is held in the Antarctic ice sheet, an amount equivalent to about 58 m of sea level rise. In East Antarctica, the ice

Fig. 1.3 Ross Ice Shelf in 1997. The Ross Ice Shelf, the largest ice shelf of Antarctica, approximately the size of France and up to several hundred metres high. *Source* https://en.wikipedia.org/wiki/Ross_Ice_Shelf#/media/File:Ross_Ice_Shelf_1997.jpg)

sheet rests on a major land mass, but in West Antarctica the bed can extend to more than 2500 m below sea level. Much of the land in this area would be seabed if the ice sheet were not there.

A picture of the massive Ross Ice Shelf in Antarctica is shown in Fig. 1.3.

A satellite image of Antarctica is shown in Fig. 1.5

It is estimated that Antarctica, if fully melted, would contribute more than 60 m of sea level rise, and Greenland would contribute more than 7 m. Small glaciers and ice caps on the margins of Greenland and the Antarctic Peninsula might contribute about 0.5 m. While the latter figure is much smaller than for Antarctica or Greenland, it could occur relatively quickly (within the coming century), whereas the melting of Greenland would be slow (perhaps 1500 years to fully deglaciate at the fastest likely rate) and Antarctica would be even slower. However, this calculation does not account for the possibility that as meltwater flows under and lubricates the larger ice sheets; they could begin to move much more rapidly towards the sea.

Together, the Antarctic and Greenland ice sheets contain more than 99% of the freshwater ice on Earth. The Antarctic Ice Sheet extends almost 14 million square kilometres (5.4 million square miles), which is roughly the area of the USA and Mexico combined. The Antarctic Ice Sheet contains 30 million cubic kilometres (7.2 million cubic miles) of ice. The Greenland Ice Sheet extends about 1.7 million square kilometres (656,000 square miles), covering most of the island of Greenland, three times the size of the state of Texas.

Fig. 1.4 Antarctica. *Source* https://en.wikipedia.org/wiki/Antarctic#/media/File:Antarctica_6400px_from_Blue_Marble.jpg

Severe problems that will eventually occur in many of the world's major cities may leave some of the world's cities looking like those illustrated in Figs. 1.3, 1.4 and 1.5, with a 2–4 °C rise in temperatures.

Figures 1.5, 1.6, 1.7 and 1.8 have been included to illustrate a point and it is doubtless that climate deniers will say that this is ridiculous. When it considered that the Artic and Antarctic ice sheets contain in excess of 30 million cubic kilometres of ice, of which 3% would need to melt to produce catastrophe, perhaps these figures are not so ridiculous.

Whilst this will not happen in the next few days, the eventual effects will still be devastating. It may be feasible for richer countries to move their cities to higher ground or to build suitable defenses but the millions of inhabitants who live on the coast in poorer countries may not be so lucky. Low lying islands such as the Maldives and the Philippines, for example, could disappear completely.

Fig. 1.5 London after a 4 °C rise in global temperature. Picture acknowledgement Climate Central http://sealevel.climatecentral.org

Fig. 1.6 Washington after a 4 °C rise in global temperature. Picture acknowledgement Climate Central http://sealevel.climatecentral.org

Fig. 1.7 Mumbai after a 2 °C rise in temperature. Picture acknowledgement Climate Central http://sealevel.climatecentral.org

Fig. 1.8 Sydney after a 4 °C rise in temperature. Picture acknowledgement Climate Central http://sealevel.climatecentral.org

Fig. 1.9 Malé, the capital of the Maldives

Malé, the capital of the Maldives, is shown in Fig. 1.9. It can be seen that only a small rise in sea level would cause devastation.

The Cayman islands are another series of low lying islands that are at risk. Grand Cayman is an important financial center. Other financial centers that are likely to suffer damage due to sea level rise include London, New York, Washington and Tokyo. All of these are face eventual danger from rising sea levels. Apart from everything else, global warning could cripple the world's financial system.

If the sea rises by 1 m, 10 million people on the coast of Pakistan would become displaced, causing a major refugee crisis.

In addition to the melting of ice and the rising sea levels, other effects of global warming are likely to be equally problematic. These include greater threats from extreme weather events, such as increased precipitation (rain and snowfall); hurricanes and other storms, which are likely to become stronger; and floods and droughts, which will become more common leading to reduced availability of fresh water. Some diseases will spread, such as malaria, which is carried by mosquitoes. Ecosystems will change: some species will move farther north or become more successful; others will not be able to move and could become extinct.

Bearing in mind that the vast majority of informed scientific opinion believes that global warming is true, it would seem rash to ignore this. Clearly, it is not a good time to be complacent.

1.4 World Opinion

Political opinion around the world supports concerns about global warming and this culminated in the 2015 United Nations Climate Change Conference held in Paris, France, from 30 November to 12 December 2015. The outcome of the conference was that the 195 participating countries agreed by consensus to reduce their carbon output "as soon as possible" and to do their best to keep global warming "to well below 2 °C".

Governments agreed:

- A long-term goal of keeping the increase in global average temperature to **well below 2 °C** above pre-industrial levels;
- To aim to limit the increase to **1.5 °C**, since this would significantly reduce risks and the impacts of climate change;
- On the need for **global emissions to peak as soon as possible**, recognising that this will take longer for developing countries;
- To undertake **rapid reductions thereafter**, in accordance with the best available science.

Before and during the Paris conference, countries submitted comprehensive **national climate action plans** (INDCs). These are not yet enough to keep global warming below 2 °C, but the agreement traces the way to achieving this target.

This agreement is a step in the right direction and at least we have reached the point where there is international agreement that there is a real problem that we need to address. Many consider that it does not go far enough and it is not clear exactly how "the world intends to set about achieving this".

Models produced by NASA predict that as the world consumes ever more fossil fuel, greenhouse gas concentrations will continue to rise and Earth's average surface temperature will rise with them. Based on a range of plausible emission scenarios, average surface temperatures could rise between 2 and 6 °C by the end of the 21st century, which is likely to be catastrophic.

1.5 Fossil Fuel Depletion

Although the primary reason for freeing the world from fossil fuels is to prevent the consequences of global warming, a strong secondary reason is to for preserve fossil fuels thus preventing fossil fuel depletion, which will eventually become inevitable should we continue to burn fossil fuels at present rates.

Planning and implementing technology has a lead time and, as such, a clear idea of the alternatives is necessary. We cannot leave it to the last minute to free ourselves from the reliance on fossil fuels and only then adopt a solution.

Whether or not you agree with the consequences of global warming caused by the burning of fossil fuels, the question of whether we need to produce essential power and energy without fossil fuels is, to an extent, academic, since at present usage rates fossil fuels will eventually become depleted in the fullness of time. In addition, it is shown in this book that it will become less expensive to produce energy by alternative energy. As a result, it is likely to become economically attractive to produce electricity from sustainable sources.

Preventative action is needed to address concerns about global warming. In addition, fossil fuels are finite and need to be preserved.

Nobody knows precisely how much of the world's fossil fuel remains in the ground and, unsurprisingly, estimates vary. Data indicating proved reserves for most countries have, for many years, consisted of very conservative numbers, and, in part, this is still the case. In the UK, for example, proved oil reserves have always been about half the 'proved-plus-probable' (i.e., the 'most-likely') value for oil reserves that are held in oil industry databases. However, on top of these proved-plus-probable reserves (i.e., oil already discovered, and still not yet produced), one has to add the quantity of oil-yet-to-find (now relatively small for the UK, but reasonably large globally) and, on top of this again, the extra amount of oil that will come in the future from the application of 'enhance oil recovery' (EOR) techniques, especially those that will be encouraged by a higher oil price.

So, the total amount of even conventional oil in the world expected to be producible under current technology and oil price is much larger than the proved reserves indicate. The US EIA, for example, estimates globally that there is about 95 years' worth of conventional oil yet to be produced; the EIA data given below estimates about 100 years' worth of conventional oil.

Conventional oil and conventional gas production typically reaches its resource-limited maximum when only about half the total producible quantity of the resource has been produced—the so-called 'mid-point' peak in production—i.e. the production peak occurs when large quantities of reserves still remain.

For coal, the data seem to be even worse, as is the difference between proved reserves and the total likely to be available for production. A common figure is that globally there are 1000 years' worth of potentially recoverable coal supplies remaining.

The predicted effects of global warming are truly horrific, and, with scientific opinion broadly agreeing with these predictions, it is difficult to see that we have any other option other than to act and to act quickly, regardless of much fossil fuel may eventually be available.

Whilst preventing carbon release seems to be the most urgent consideration and should be the primary task addressed, there is also a strong case for the world to use methods of energy production from sources other than fossil fuels, which are a finite resource that is running out (even if it is not known precisely when).

It is hoped that this book will propose a course of action and show that we need not revert to previous technologies but rather that it is possible to establish a superior technology that avoids the consequences of global warming, is less polluting, cheaper and helps to create a better world.

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Chapter 2
Energy Produced and Carbon Released from Fossil Fuels and the Amount of Alternative Energy Required as a Replacement

2.1 Use and Production of Power and Energy from Fossil Fuels

Before we embark on discussing future energy supply, it is important to understand how we use and produce power and energy at present.

For power generation, fossil fuels are normally burnt and used to run internal or external combustion engines to drive electric generators. Much transport is either electric or uses internal combustion engines using oil based fuels.

To produce heat, fossil fuels are usually burnt in a furnace or fires.

Figure 2.1 shows the generation of energy from fossil fuels in the USA.

An approximate breakdown of the use of energy used by different forms of transport is illustrated in Fig. 2.2. This is based on figures for worldwide emissions.

2.2 Transport

The majority of road vehicles that rely on fossil fuels use the familiar internal combustion engine and these require petrol or diesel stored in tanks. Non-electric trains were traditionally powered by steam engines, whereas modern trains use fossil fuels (normally diesel). Modern aeroplanes also use internal combustion engines, such as jet engines, gas turbines or spark ignition engines. Ships normally use combustion engines as well. All combustion engines have thermal efficiencies considerably less than 100%, i.e. they only convert a fraction of the heat energy stored in the fuel to mechanical or electrical power. Typical automotive combustion engines have thermal efficiencies of, on average, under 20% for petrol engines and under 25% for diesel engines. The rest of the energy in the fuel is converted to heat, which is released into the atmosphere together with the products of combustion.

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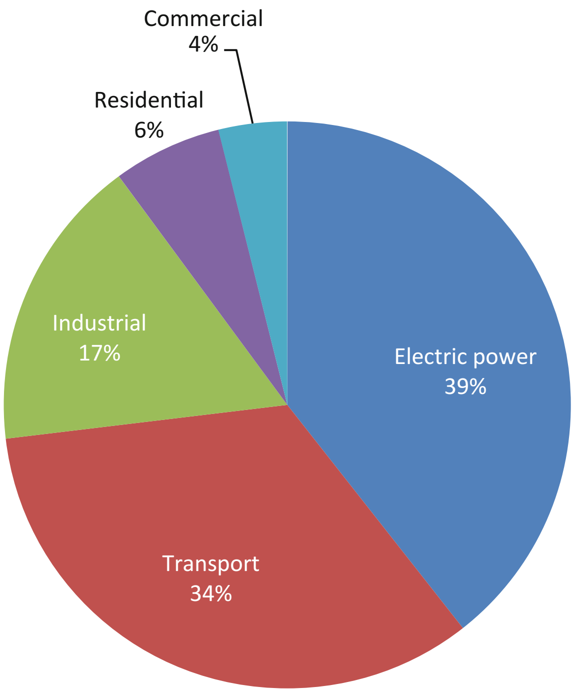

Fig. 2.1 Electricity generated from fossil fuels in the USA in 2005 (*Source* John Lowry)

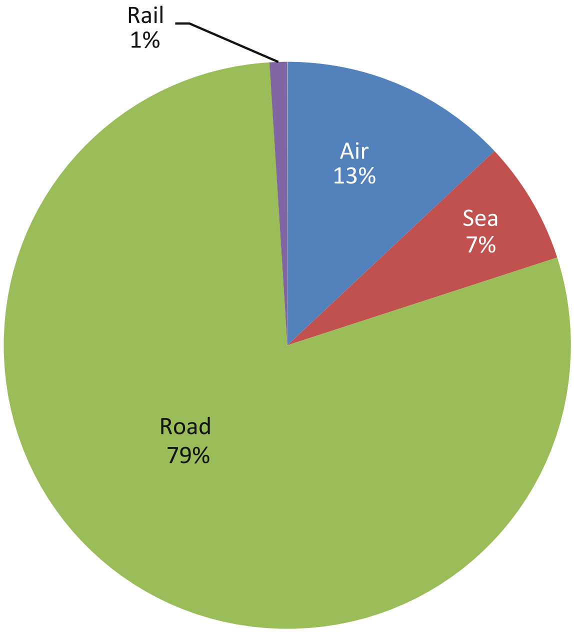

Fig. 2.2 Breakdown of how fossil fuels are used in transport worldwide (*Source* John Lowry)

2.3 Electricity Generation

Electricity generation relies on internal or external combustion engines to drive electric generators. A breakdown of energy sources used in electricity generation for the USA is shown in Fig. 2.3, where it can be seen that the vast majority (68%) comes from fossil fuels, namely coal and natural gas. A small amount of electricity is generated by oil.

Once electricity leaves the power station as AC electricity, its voltage is stepped up by a transformer and it is then transmitted by high voltage AC transmission lines. When it nears its destination, the voltage is stepped down again and transmitted to the end user. The transmission and distribution efficiency varies from place to place and country to country. Normally, the efficiency of transmission (the power transmitted to customer/power fed into network) is better than 90%. Typical losses in the USA are believed to be 6–8%.

An electrical grid is a complex device and probably represents the largest machine used on earth. A general layout of an electric grid is illustrated in Fig. 2.4. The voltages and depictions of electrical lines are typical for Germany and other European systems.

As seen in Fig. 2.3, the majority of electricity is generated from coal, which involves burning the coal in a furnace or boiler unit to raise steam, which is put through a turbine connected to a generator.

The efficiency of older coal power stations is around 25% (electrical energy generated/energy in the coal burnt). The average efficiency for a coal-powered power station is currently 28%, although modern power stations can achieve efficiencies of 45%. Combined cycle power stations can achieve efficiencies as high as 60%. The heat is normally discarded by cooling towers; however, it can be used in district heating schemes, which can boost overall efficiency.

Modern fossil fuel heating units are well known and still frequently used. Modern gas boilers have efficiencies of slightly below 100%. As fuel prices

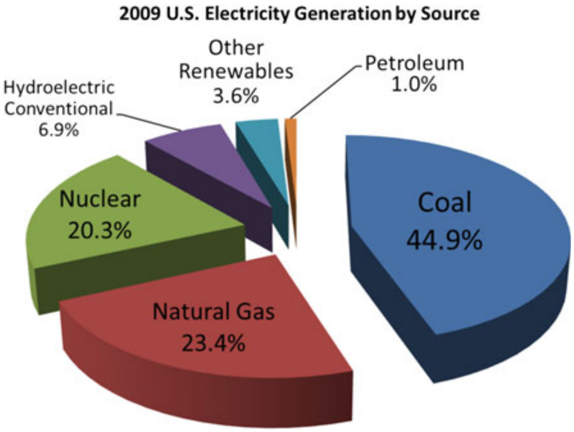

Fig. 2.3 Sources for electricity generation in the USA in 2009 (*Source* John Lowry)

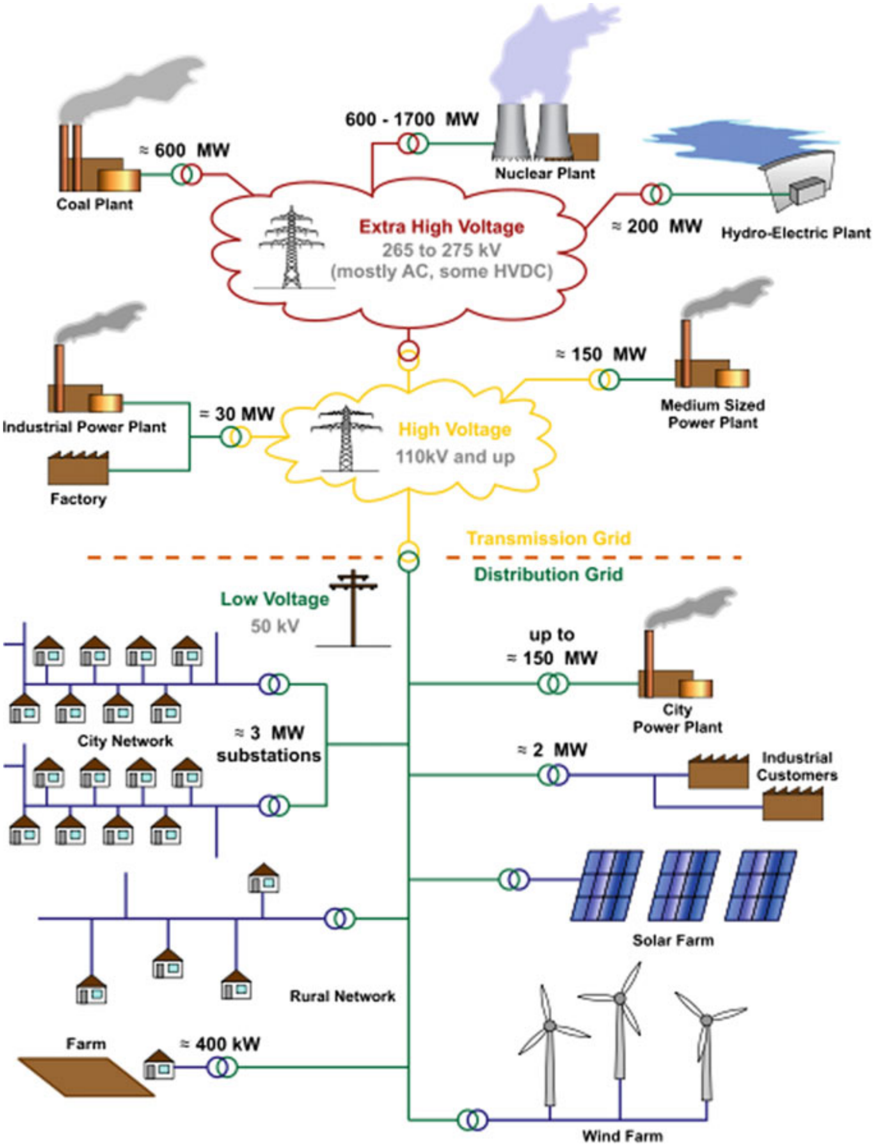

Fig. 2.4 General layout of electricity networks, typically seen in some European Union countries (*Source* http://en.wikipedia.org/wiki/Electrical_grid)

increase, one option is to use heat pumps. Although heat pumps use electricity, they pump heat from a cold source such as a river or from the atmosphere to the area that needs heating. They typically have a coefficient of performance of 300% or greater.

A modern steam turbine generator set is shown in Fig. 2.5 and a coal fired power plant in Utah, USA is shown in Fig. 2.6.

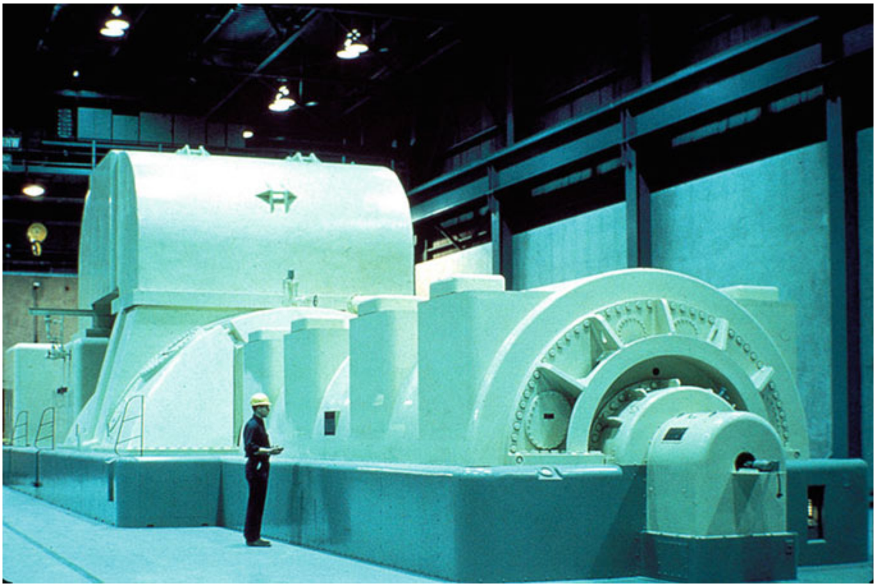

Fig. 2.5 A modern steam-driven turbine generator (*Source NRC*)

Fig. 2.6 A coal-fired power plant in Utah, USA (*Source* http://en.wikipedia.org/wiki/Fossil-fuel_power_station)

Fig. 2.7 Gas turbine generator (*Source* http://en.wikipedia.org/wiki/Electricity_generation#Turbines)

Power from natural gas is normally obtained from gas turbine generator plants (Fig. 2.7).

It is sometimes convenient to use oil to generate electricity and a large oil engine generator unit is illustrated in Fig. 2.8. Such oil engine generators are still frequently used in developing countries.

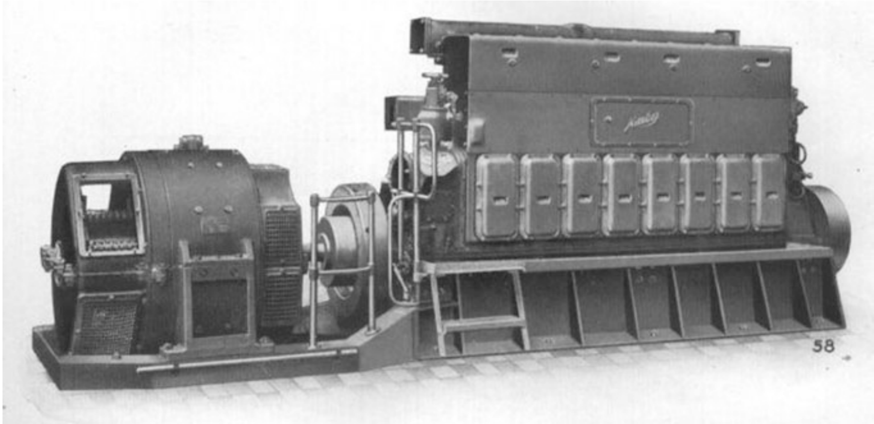

Fig. 2.8 Mirlees 1320 engine from 1934 (Reproduced with kind permission from The Anson Engine Museum)

In order to run global energy sources without oil and other fossil fuels, all of the energy generated from these sources must be replaced with energy generated from non-fossil fuel sources.

In the next section, we examine the actual amounts of energy that are generated throughout the world from fossil fuels.

2.4 How Much Alternative Energy Do We Need to Replace This?

The total world consumption of fossil fuels for 2008 amounted to around 10,000 million tonnes of oil equivalent, or approximately 116,000 TWh (terawatt hours) of energy in the fuel, i.e. the calorific value of energy in the fuel that can be converted to heat, assuming 100% efficiency (Fig. 2.9). Further details are given in Appendix A. Fossil fuel consumption is likely to rise by 2% every year, i.e. doubling the consumption in 35 years.

Oil is used to make a variety of products and approximately 70% of oil is burnt to produce power—mainly for transport. It is estimated that 90% of coal and gas is used for power generation.

This brings the total energy contained in the fossil fuels burnt for energy to 31,971 TWh in oil; 28,526 TWh in gas; and 34,574 TWh in coal; with a grand total of 95,071 TWh of calorific value contained within all fossil fuels burnt. This is illustrated in Fig. 2.9.

Fossil fuels are converted into power by heat engines, which have efficiencies well below 100%. Internal combustion engines in cars, for example, have typical average thermal efficiencies of 20%. The average efficiency of coal-burning power stations is currently 28% (although modern stations can achieve 45%), gas turbine generators on average produce 40% and burning fossil fuels in furnaces for heating has thermal efficiencies of 90% or higher on average. However, the amount of fossil fuel used for heating is relatively small. The vast majority of the energy values in

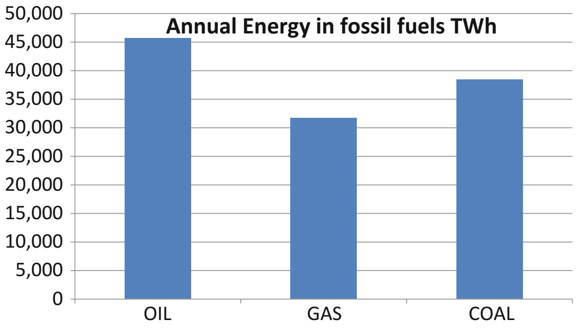

Fig. 2.9 Worldwide annual consumption of fossil fuels used to make power in 2008 (*Source* John Lowry)

fossil fuels is wasted as heat unless some of the heat can be recovered, as is the case for combined heat and power (CHP). Using the above efficiencies, the output energy obtained from the power station or from the wheels of vehicles will be:

6394 TWh per annum from oil.
12,837 TWh per annum from gas.
9681 TWh per annum from coal.

This brings the total delivered energy to 28,912 TWh per annum from fossil fuels. This is the total energy per annum that alternative energy will need to deliver at output, i.e. the wheels of transport systems or the output from power stations.

To put this into perspective, this is the equivalent of 6884 nuclear power stations. The Fort Calhoun plant in Nebraska, USA has one reactor and the smallest generating capacity of 479 MW would produce around 4.2 TWh per annum if working at 100% load factor. We would therefore need 6884 nuclear power stations of this size to supply the world's energy needs that are currently supplied by fossil fuels. A square kilometre of solar photovoltaic panels with an average efficiency of 10% would supply 359 MWh of electricity (0.000359 TWh). Therefore, to supply 28,912 TWh of electricity requires 8053 km^2 of solar photovoltaics or 1000 solar photovoltaic power stations with a photovoltaic area of 8 km^2 (a square of under 3 km by 3 km) located in desert regions similar to the Sahara. There are over 30 deserts in the world.

A more detailed set of data for calorific value of fossil fuel usage is shown in the Appendix.

It is normally possible to make energy savings of between 5 and 10%, without any huge cost implications. This has not been included in the above analysis, but, in a more complex study, people should be aware of this. For example, a change to LED lighting results in considerable energy saving. Energy saving can also result from better architecture that makes greater use of passive solar heating, and from better insulation, which cuts down on energy used for heating and cooling from air conditioning systems.

Where small photovoltaic panels are used for lighting, more energy efficient lighting will reduce the size and cost of the photovoltaics and the batteries, and may therefore reduce overall cost.

There are areas that are known to use less energy, such as the use of heat pumps for heating. Heat pumps, as their name implies, pump heat from a cold source such as a river, or from the atmosphere to the area that needs heating. As a result, they have a coefficient of performance of 3–4 times, equivalent to an efficiency of 300–400%. They therefore use a third to a quarter of the energy of heating sources that rely on combustion.

Another factor that must be taken into account is the energy expended to produce the energy from different sources known as energy return on investment (EROI). This is basically the total energy created by a product such as photovoltaics, divided by the energy used in their manufacture.

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Chapter 3
Electrical Super Grids

Sustainable and alternative energy have some disadvantages compared with fossil fuel power generation. Renewable energy is often readily available in one place, but needed in another. As a simple example, wind energy may be abundantly available from offshore wind farms in the North Sea and simultaneously needed during times of low wind in Spain. High solar energy may be produced in the Sahara at times when more northerly climates may not be able to produce much solar energy, such as in mid-winter. It is hard to store energy in meaningful quantities using today's technology. Many forms of sustainable energy, such as solar and wind, are not capable of providing an increase in power to match an increase in demand, as would be the case for a gas-powered turbine driving a generator, for example. Therefore, some degree of rethink is required if we are to rely totally on alternative energy. Hydropower and tidal power are more flexible. Nuclear has a high base load and electricity is often wasted, as it is hard to regulate nuclear power stations to match demands.

What is needed is a global energy network, or a super-grid, that would allow electricity to be passed around the world. This would make non-fossil fuel energy generation more viable, allowing us to make much of our electricity from renewable and nuclear sources. The idea was firsts mooted in the 1970s by Richard Buckminster Fuller. With the development of high voltage direct current transmission, which allows very efficient transmission of electricity, the electrical super-grid is now possible. A high voltage DC transmission line is illustrated in Fig. 3.1.

A high voltage DC transmission system has already been started in Europe and is illustrated in Fig. 3.2 Many of these links and proposed links will transfer power from renewable sources such as hydro and wind. High voltage DC transmission is probably the only way of connecting the diverse electrical systems used in different countries.

This can be expanded into a wider system for Europe and North Africa.

This can be expanded into a worldwide super-grid as originally proposed by Buckminster Fuller and is illustrated in Fig. 3.3.

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Fig. 3.1 Pylons of the Baltic Cable HVDC in Sweden (*Source* http://en.wikipedia.org/wiki/High-voltage_direct_current)

Some parameters for a high voltage DC transmission system are shown in Table 3.1.

Costs vary widely depending on the specifics of the project, such as power rating, circuit length, overhead versus underwater route, land costs, and AC network improvements required at either terminal. A detailed evaluation of DC versus AC cost may be required where there is no clear technical advantage to DC alone and only economics drives the selection.

Some real examples of installed high voltage DC transmission systems are discussed below.

For an 8 GW 40 km link laid under the English Channel, the following are the approximate primary equipment costs for a 2000 MW 500 kV bipolar conventional HVDC link (excluding way-leaving, on-shore reinforcement works, consenting, engineering, insurance, etc.):

- Converter stations: approximately GBP 110 M (around USD 173.7 M)
- Subsea cable + installation: approximately GBP 1 M/km (around USD 1.6 M/km)

So for an 8 GW capacity between England and France in four links, little is left over from GBP 750 M for the installed works. Another GBP 200–300 M for the other works can be added, depending on the additional on-shore works required.

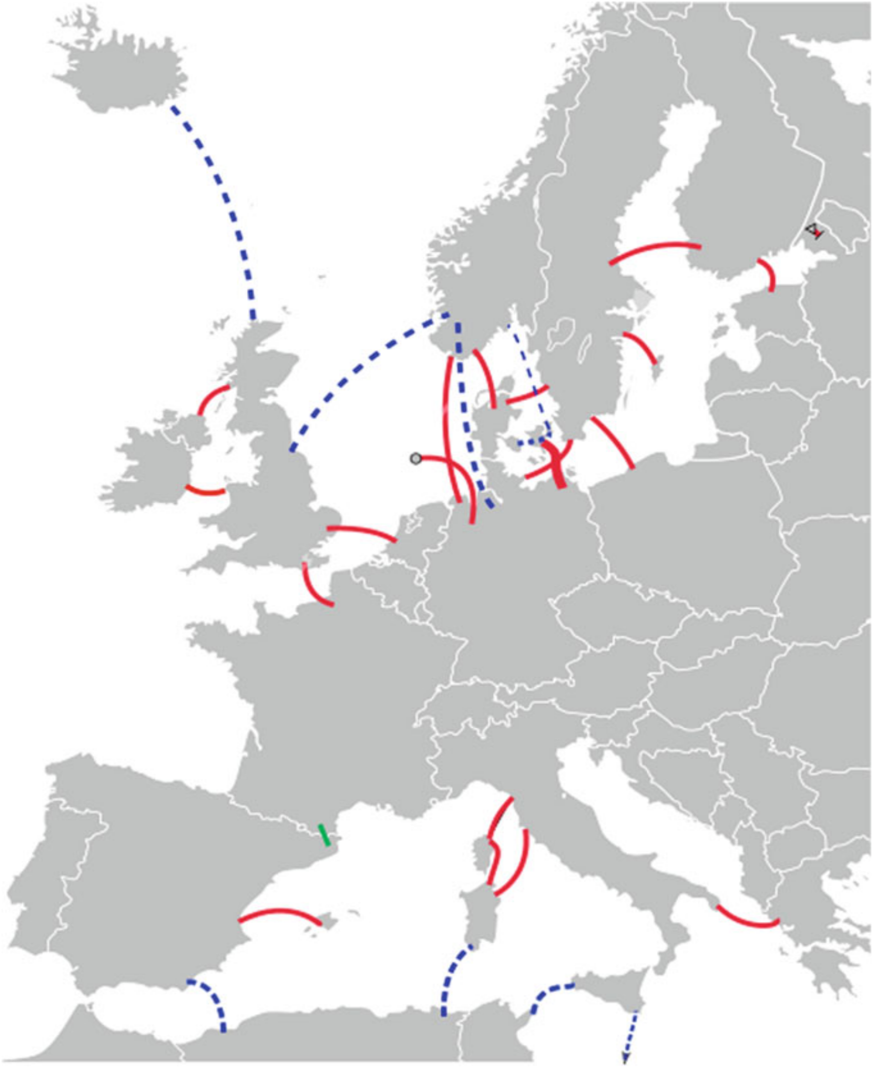

Fig. 3.2 Early high voltage DC connections. Solid lines show existing links and those under construction dashed and lines show proposed links (*Source* http://en.wikipedia.org/wiki/High-voltage_direct_current)

In April 2010, a 2000 MW 64 km high voltage DC line between Spain and France was announced at a cost of EUR 700 M, which includes the cost of a tunnel through the Pyrenees.

A worldwide super-grid network is a considerable undertaking and this will not be created in a few years. Very considerable planning is needed to find appropriate routes that travel through politically stable countries. A worldwide super-grid is

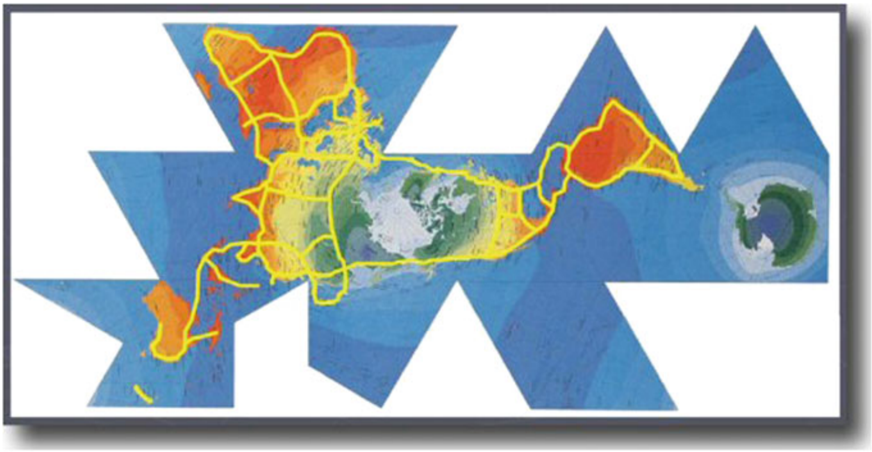

Fig. 3.3 The worldwide super-grid is shown on a dymaxion, or Fuller map projection, looking down on the earth from above the North Pole. *Source* http://www.terrawatts.com,™ The Fuller Projection Map design is a trademark of the Buckminster Fuller Institute. ©1938, 1967 & 1992. All rights reserved, www.bfi.org

Table 3.1 Some parameters of high voltage DC transmission

Operating voltage	800	kV
Line loss overhead cables	2.5	% per 1000 km
Line loss submarine cables	3.25	% per 1000 km
Terminal loss	0.7	% per station
Overhead line cost	450	M EUR/1000 km
Sea cable cost	2500	M EUR/1000 km
Terminal cost	350	M EUR

essential if widespread use of non-fossil fuel power systems that do not release carbon dioxide are to become viable.

The circumference of the world at the equator is approximately 40,000 km. Therefore, a cable route running halfway around the circumference of the planet will be approximately 20,000 km. Using the losses in Table 3.1, the losses are 2.5% per 1000 km for land cable and 3.25% for submarine cables. Therefore, to transmit electricity halfway around the world (i.e., 20,000 km), the losses would be around 40%. Allowing for the fact that the cable is not going to be perfectly straight and some of the route would require submarine cables, an overall loss of 50% is taken as a first approximation.

Using today's prices, it would seem uneconomical to generate power by fossil fuels and then lose half of it due to transmission inefficiencies would seem to be unacceptable. However, as is shown later in the book, the predicted price for photovoltaic electricity is extremely low, possibly as low as USD 0.04/ kWh by 2025; as low as half of the cost of fossil fuel energy within the next 10 years. It is predicted to be as low as USD 0.02/ kWh by 2050, which is nearly one quarter the price of electricity from fossil fuels.

It would therefore not only be acceptable to suffer transmission losses of 50% but would become economically sensible. This makes a strong case for an electrical super grid and, for the first time, it would be economical to light northern European cities during hours of darkness with electricity from photovoltaics from as far away Australia where it would be daylight.

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Chapter 4
Alternative, Sustainable and Nuclear Energy

4.1 Solar Power

Solar energy is an abundant source of sustainable energy. The cost of converting solar energy to electricity continues to fall, making it a strong prospect for a future power source that could generate much of the energy currently generated from burning fossil fuels. Not only could solar power provide enough energy to replace that supplied by fossil fuels, but it could also provide enough energy for the earth's total requirements many times over.

Solar energy is abundant and available worldwide. Every year, the sun irradiates the land with 0.22 billion TWh. Only a fraction of this would be needed to satisfy the world's energy needs, currently supplied by fossil fuels. Put differently, in under an hour, the amount of solar energy reaching the earth could power the planet for one year. In 2008, the earth used around 116,000 TWh of fossil fuel energy, a fraction of a percent of the solar energy available.

Clearly, there are adequate amounts of solar energy available now and for the future. The problems related to using solar energy in the past have been the cost and availability of the technology necessary to capture solar power. The amount of solar radiation varies both with the time of day and with the weather, and rarely matches the requirements of users. However, there has been a quiet revolution in the cost, and as super-grids become developed, the electricity can be transmitted from places with high solar radiation to the location where it is required. A super-grid could, in theory, transfer solar electricity from places where it is day to those where it is night.

The two well-established ways of turning solar radiation into electricity are by photovoltaic panels (Fig. 4.1), which turn solar radiation into DC electricity, and solar thermal power systems, whereby solar radiation is turned into heat and is used to run steam turbines or other heat engines.

The cost of photovoltaic panels has fallen consistently since the 1980s. Photovoltaic prices have fallen from USD 76.67 per watt in 1977 to an estimated USD 0.3 per watt in 2015, for crystalline silicon solar cells. This is seen as evidence

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Fig. 4.1 The first solar 40 MW photovoltaic array installed in Waldpolenz, Germany (Photo courtesy of JUWI Group)

supporting Swanson's law, an observation similar to the famous Moore's law, which states that solar cell prices fall 20% for every doubling of industry capacity that occurs. The cost is predicted to continue to fall to a lower value.

The cost of energy generated by solar photovoltaic power has already reached cost parity with electric grid costs when using solar photovoltaics in sunny parts of southern Europe, and is predicted to reach parity with less sunny places, such as the UK and Germany, soon. It is estimated that the average cost of solar power in the USA has fallen below the current average retail electricity price of USD 0.12 per kWh.

The efficiency of solar photovoltaics has risen over the last few years, as shown in Fig. 4.2.

This shows that maximum efficiency has risen to just below 40% and that the efficiency of multicrystalline photovoltaic calls is just above 20%. And that the efficiency of monocrystalline photovoltaic cells has risen to 26%.

Solar radiation in itself has a low energy density in terms of energy per square metre, and in countries such as the UK where land per head of population is in relatively short supply, sufficient land will not be available to generate enough energy to replace the energy generated from fossil fuels. However, there are vast areas of land such as the Sahara Desert in North Africa, which have plenty of land and plenty of solar radiation. Power generated from solar plants in the desert could be transmitted back to countries in Europe via the super-grid. For night time use in Europe, the energy would need to be transmitted from further afield.

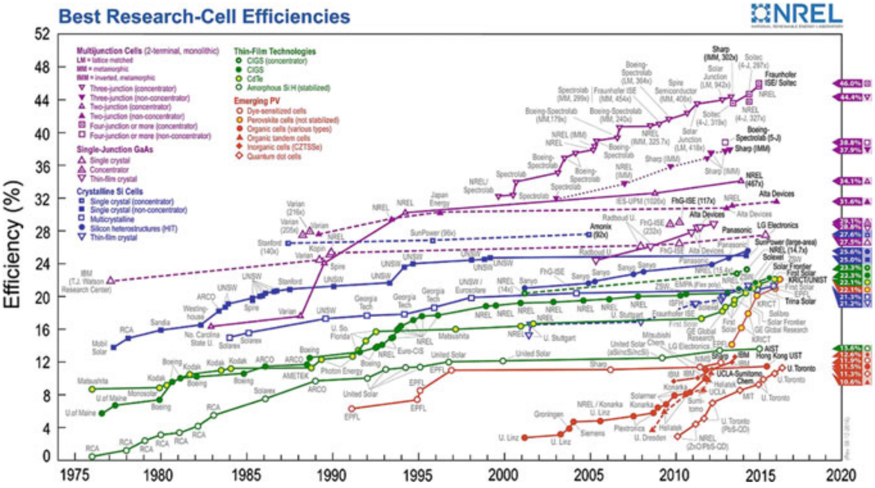

Fig. 4.2 Showing the rise of photovoltaic efficiency between 1992 and 2014. https://en.wikipedia.org/wiki/Solar_cell_efficiency

In the Sahara, the average sunshine radiation on a horizontal surface is 273 W/m^2. Solar photovoltaic panels have an efficiency of about 15% (electrical energy generated/solar energy). Therefore, in the Sahara, one square metre of panel will produce an average of 41 W and 359 kWh per annum. The UK, for example, uses 2461 TWh of fossil fuels. In order to generate this much power, a photovoltaic panel the size of 2284 km^2 would be required. The Sahara is 9.3 million square kilometres, meaning the photovoltaic panels would occupy 0.025% of the total area. This is little more in proportion to a small rug on a football pitch. If the solar panels are tracked to face the sun at all times, nearly 600 kWh per square metre per annum of electricity would be obtained every year.

As a simple example, consider solar photovoltaics costing USD 300 installed per peak kilowatt, i.e. the photovoltaics will produce 1 kW with a solar radiation level of 1 kW per square metre. In practice, a much lower radiation figure will be achieved and in the solar radiation averaged across 8769 h in a year in locations such as the Sahara will be 273 W per square metre. The annual electricity produced by photovoltaics rated for 1 kW peak will therefore be 2390 kWh per annum. Spread over a life of 20 years and ignoring interest, this photovoltaic panel will cost USD 50 per year and produce electricity at a cost of 2.1 cents per kWh. This figure needs to be increased to account for 10% loss in performance over the life of the photovoltaics and a further 20% to account for inefficiencies in inverters and transmission. This still brings the cost of electricity to less than USD 0.03 per kWh —an attractive figure.

Electricity from solar power stations in desert areas would need to be transmitted back to areas where the power was needed using the super-grids discussed earlier. The cost of high voltage transmission lines is a relatively small part compared with the cost of the solar panels.

By using super-grids with stations distributed around the globe and connected by high voltage, high efficiency electric transmission lines, solar power would provide solar electricity throughout the day and the night.

Solar power stations are not of course limited to the Sahara. The best location is in the "sun belt", located roughly between the 40th parallels north and south of the equator, between southern Spain and South Africa, for example. This vast area of the earth's surface would include parts of Spain, France, Italy, the USA, India and Australia.

Large solar power stations do not detract from rooftop solar photovoltaic electricity generation, although this will not provide sufficient energy to replace the energy currently produced by fossil fuels.

There are no insurmountable technical problems with solar photovoltaic power stations or indeed with solar thermal power stations. Bearing in mind the almost limitless availability of solar radiation and that the cost of solar will fall continuously—whereas the capital cost of virtually every other power source is likely to increase—solar power is an extremely attractive option for the future.

Photovoltaic-generated electricity has the advantage that power can be generated in virtually any size of plant from small systems in villages to large power stations. It has the disadvantage compared with modern gas stations that you get whatever energy is generated; you cannot simply turn up the power to match demand.

Solar photovoltaics are now a cheap and competitive form of electricity generation. For example, in Germany, a relatively northern location, the cost of generating electricity has already fallen below 40 ct/kWh. Solar photovoltaic electricity is becoming the cheapest form of electricity in many parts of the world and by 2025 is expected to provide electricity in many regions of the world for 4–6 ct/kWh by 2025 and 2–4 ct/kWh by 2050, or possibly even cheaper. Figures in 2015 have been quoted for both 9 ct/kWh and under 7 ct/kWh in Australia, and under 7 ct/kWh in India, the Middle East and north Africa. In 2025, these figures are likely to be around 7 ct/kWh in Australia and 5 ct/kWh in India, the Middle East and North Africa. As demand grows, by 2050, these are predicted to fall below 6 ct/kWh in North America, 5 ct/kWh in Australia and below 4 ct/kWh in India, the Middle East and North Africa.

An alternative to photovoltaics are solar thermal systems. These work by concentrating direct solar radiation onto an absorber where energy is retained as heat. This heat is used to drive a heat engine such as a Stirling engine or a Rankin cycle system such as a steam engine. An early example of solar thermal power according to legend is when Archimedes planned to burn the Roman fleet by concentrating the sun's rays onto the invading Roman fleet and repel them from Syracuse. In 1973, a Greek scientist, Dr Ioannis Sakkas, curious about whether Archimedes could really have destroyed the Roman fleet in 212 BC, lined up nearly 60 Greek sailors, each holding an oblong mirror tipped to catch the sun's rays and directed them at a tar-covered plywood silhouette 160 feet away. The ship caught fire after a few minutes; however, historians continue to doubt the Archimedes story.

In 1866, August Mouchout used a parabolic trough to produce steam for the first solar steam engine. The first patent for a solar collector was obtained by Alessandro

Fig. 4.3 Array of parabolic troughs at the National Solar Energy Centre in Israel (*Source* http://en.wikipedia.org/wiki/Parabolic_trough)

Battaglia in Genoa, Italy, in 1886. A modern solar trough design is illustrated in Fig. 4.3. A fluid is passed through the receiver tube located at the focus to collect the heat. The parabolic dish is rotated so that it faces the sun at all times. The receiver may be enclosed in a glass vacuum chamber, which can significantly reduce convective heat loss.

Professor Giovanni Francia (1911–1980) designed and built the first concentrated-solar plant in Sant'Ilario, near Genoa, Italy in 1968. This plant had the architecture of today's concentrated solar plants with a solar receiver in the centre of a field of solar collectors. The plant was able to produce 1 MW with superheated steam at 100 bar and 500 °C. The 10 MW Solar One power tower was developed in Southern California in 1981, and the 354 MW SEGS built in 1984 is still the largest solar power plant in the world. A solar tower concentrating system in Spain is illustrated in Fig. 4.4.

The US National Renewable Energy Laboratory has estimated that, by 2020, electricity could be produced from power towers for 5.47 cents per kWh. Companies such as ESolar are continuing to develop cheap, low maintenance, mass producible heliostat components that will reduce costs in the near future. ESolar's design uses large numbers of small mirrors (1.14 m^2), which reduce costs for installing mounting systems such as concrete, steel, drilling and cranes. It is hoped that future developments will reduce costs further.

Fig. 4.4 Crescent Dunes Solar, December 2014. https://commons.wikimedia.org/wiki/File:Crescent_Dunes_Solar_December_2014.JPG#/media/File:Crescent_Dunes_Solar_December_2014.JPG

Solar thermal power lacks the simplicity of photovoltaics and is likely to be superseded by it as costs reduce.

At very good sites, today's solar thermal power plants can generate electricity in the range of USD 0.1635 per kWh (EUR 0.15 per kWh), and series production could bring down these costs below EUR 0.10 per kWh. Unlike photovoltaics, this price is unlikely to fall in the future.

http://www.volker-quaschning.de/articles/fundamentals2/index_e.php.

4.2 Wind Energy

Wind energy is probably the oldest form of sustainable power and traditional wind mills are well known. For electricity generation, modern aero-generators incorporate high-speed aerodynamic propeller type blades in their design. Potentially, five times the world's total requirement for energy could be generated from wind. Currently, it is around 3%.

At present, electricity generation from the wind increases by an average of 40% per annum and it is likely to go on expanding at this rate. In the early 1980s, the largest commercially available wind turbine was 50 kW. By the end of the 20th century, 1.7 MW machines were commercially available. The total wind power installed in Europe is 20,447 MW and in the British Isles it is 655 MW. This equates to around 60 TWh per annum in Europe and around 2 TWh in Britain. To produce this amount of energy by burning oil at a power station with an overall efficiency of 0.33 would require 18 million tonnes of oil in Europe and 600,000 tonnes of oil in Britain compared with 41 million tonnes of oil used for road transport in Britain. Wind energy currently available in Britain could possibly provide 1.5% of the energy needed for transport if it were used to charge electric vehicles. Whilst this is a relatively low figure, the UK is currently only capturing 0.5% of the wind energy available. The top 10 wind-producing countries in 2010 are listed in Table 4.1.

Table 4.1 Energy produced by wind in 2010 for 10 leading countries

Country	Wind power production (TWh)	World total (%)
United States	95.2	27.6
China	55.5	15.9
Spain	43.7	12.7
Germany	36.5	10.6
India	20.6	6.0
United Kingdom	10.2	3.0
France	9.7	2.8
Portugal	9.1	2.6
Italy	8.4	2.5
Canada	8.0	2.3
(Rest of world)	(48.5)	(14.1)
World total	344.8 TWh	100%

Source A more recent development has been offshore wind farms (Fig. 4.5). Offshore wind farms have the advantage that wind speed is higher and more consistent. In addition, there are fewer objections to their aesthetics; however, power has to be transferred ashore by submarine cables

Fig. 4.5 Offshore wind turbines near Copenhagen, Denmark (*Source* http://en.wikipedia.org/wiki/Offshore_wind_power)

Doubling the amount of wind power produced in 2010, i.e. generating a further 345 TWh, would be used for replacing 1% of the energy produced from fossil fuels. One estimate is that we could produce 40 times more energy from wind than we do at present, replacing nearly 40% of the energy that we currently derive from fossil fuels. If wind energy was fully exploited, it could provide sufficient energy to replace that produced by fossil fuels.

The cost of wind-generated electricity in the UK is 94 GBP/MWh and the cost of offshore wind is 157–186 GBP/MWh. In the USA, the cost for onshore electricity varies from 66 to 82 USD/MWh whereas onshore wind varies from 170 to 270 USD/MWh.

4.3 Water Energy

4.3.1 Hydroelectricity

Hydroelectricity is electricity generated from water falling from a height. The potential energy of the falling water is converted into electrical energy by water turbines. It is the most widely used form of renewable energy, accounting for 16% of global electricity generation—3427 TWh of electricity production in 2010[1]—and is expected to increase by about 3.1% each year for the next 25 years.

Hydropower has been used successfully for several thousand years, initially in the form of water wheels to drive mills. In large hydro energy schemes, a valley is dammed and a lake formed. Outlet pipes from the dam direct water through a water turbine. The water flow is controlled to give power on demand.

A surprisingly high proportion of the world's electricity generation is obtained from hydro power. In the UK, 2% of power is obtained in this way, compared with Canada where the figure is 60%. In total, approximately 16% of the world's electricity is renewable, with hydroelectricity accounting for 21% of renewable sources and 3.4% of total energy sources. Since much of the potential sites for hydroelectricity production have been exploited, it is unlikely that considerably more can be generated to replace fossil fuels. Hydropower accounted for 16% of global electricity consumption, and 3427 TWh of electricity production in 2010, which continues the rapid rate of increase observed between 2003 and 2009.

Worldwide, in 2010, the installed capacity of hydroelectric schemes was 1010 GW, with a further 92 GW under construction. Many of the more accessible hydro resources have already been developed, but there is some room for further development. The Hoover Dam (in the USA) alone provides 2080 MW of electricity (Fig. 4.6).

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[1] https://en.wikipedia.org/wiki/Hydroelectricity#cite_note-wi2012-1.

Fig. 4.6 The Hoover Dam in the USA is a large conventional dammed-hydro facility, with an installed capacity of 2080 MW (*Source* http://en.wikipedia.org/wiki/Hoover_Dam)

The cost of hydropower is relatively low, making it a competitive source of renewable electricity. The average cost of electricity from a hydro plant larger than 10 megawatts is USD 0.3–0.5 per kWh.

There are disadvantages to hydropower, in particular: disruption to the environment. Hydropower has the advantage that power can be switched on and off to match demand. However, there have been some very serious accidents associated with hydropower.

Hydropower accounts for 74% of total renewable electricity generation. The International Energy Agency (IEA), an inter-governmental energy advisory organization, wants to see the output of hydroelectricity doubled globally by 2050. As mentioned, 16% of the world's electricity is generated by hydropower, but the current capacity could be tripled if all available resources were harnessed to generate approximately 15,000 TWh a year. Just this year, the global output of hydroelectricity reached 1000 GW for the first time ever, and policy support for taking advantage of untapped hydropower capacity continues to grow. The worldwide estimate for the total possible production of hydroelectricity is about 14,000 TWh, which is five times greater than the potential hydroelectricity being exploited today.

The cost of hyro-electricity in the USA varies from USD 69.3–107.2 (average: USD 83.5) per MWh.

A variation on hydropower is pumped storage, in which pumped storage hydroelectricity (PSH or PHES) is a type of hydroelectric energy storage used by electric power systems for load balancing. This method stores energy in the form of the gravitational potential energy of water, pumped from a lower elevation reservoir to a higher elevation. Low-cost off-peak electric power is used to run the pumps. During periods of high electrical demand, the stored water is released through turbines to produce electric power. Although the losses of the pumping process makes the plant a net consumer of energy overall, the system increases revenue by selling more electricity during periods of peak demand, when electricity prices are highest. It is also ideal for maximising the use of alternative energies such as solar and wind, where energy is concentrated depending on sun or wind conditions.

The only available technology for storing large amounts of electrical energy is hydropower pumped storage. A pumped storage station costs in excess of USD 1000/kW and the overall losses are about 25%. Most pumped storage stations store sufficient water for 6–10 h of operation. The ideal operating head is between 500 and 700 m (1500–2200 ft). In order to build a pumped storage station, you need to find in one place, a source of water, a hill at least 400 m high, and topography suitable for building a large pond at the top of the hill and another large pond at the bottom of the hill.

World experience is that hydro projects cost about USD 2000–4000 per kW. As of 5th April 2010, the Electricity Storage Association gave costs for pumped hydro power ranging from of USD 500 per kW to USD 1500 per kW.

4.4 Tidal Energy

Tidal energy on a small scale has been used for centuries on the coasts of Britain and France. Proposals for a major barrage in Britain were published as early as 1849, but probably the best known tidal scheme is the Rance tidal power station in France. In this scheme, the tidal energy is captured by a dam in the estuary and by forcing the tidal waters through axial flow turbines. The scheme (Fig. 4.6) uses 24 turbines and has an installed capacity of 240 MW. It produces about 600 GWh of electricity per year. In November 1996, the **La Rance tidal power plant** celebrated 30 years of active service during which time **16 billion kWh** of electricity were generated without major incident or mechanical breakdown. The initial capital cost of the power plant (620 million Francs) has long since been recovered, and the cost of electricity production is now **below EUR 0.02** per kWh. http://www.reuk.co.uk/La-Rance-Tidal-Power-Plant.htm.

A similar scheme to put a tidal barrage across the River Severn in the UK has been in existence for a long time. A barrage at Weston Super Mare would produce

2 GW continuously and, alternatively, a dam further east would produce double this amount (36.5 TWh of electricity per annum). However, the government has decided not to press ahead with the River Severn barrage.

More recently, the government has decided to go ahead with tidal lagoons such as the Swansea Bay lagoon. Tidal lagoon projects could produce cheaper electricity than offshore wind and some could be competitive in price with nuclear energy. One study into the three proposed lagoons predicts the costs as GBP 168 per MWh; GBP 130 per MWh; and GBP 92 per MWh for lagoons 1, 2 and 3, respectively. The levelised cost for the first three lagoons is £100/MWh.

It has been decided to press ahead with the Swansea bay lagoon.

As concerns about future energy supplies grow, highly adventurous schemes should start to be considered. Using the Irish Sea, for example, a north and south barrage could produce 58,814 MW, assuming 20% of the energy captured was turned to power. This equates to an annual energy of 515 TWh, nearly 60% of the requirement of the UK and Ireland combined, the equivalent of 78 150 MW nuclear power plants with a potential cost of GBP 360 trillion.

There are other advantages as the dams could be used for rail links from Scotland and Wales. As with other forms of energy, the use of super-grids will be of benefit.

There are of course environmental concerns that accompany the development of tidal barriers and these must always be kept in mind, but if humanity is to enjoy a full supply of energy when we stop using fossil fuels, ambitious projects will be needed.

The concept of damming the Irish Sea would be an enormous undertaking but, in itself, it could provide around 1.76% of the energy generated by fossil fuels.

The Rance tidal station cost E 620 million and it should supply 600 GWh of energy for 46 years, which brings the cost of electricity to 22.5 ES per MWh.

4.4.1 Marine Currents

A considerable amount of energy can be captured from undersea currents—certainly this is the opinion of companies working in the field, such as Atlantis (formerly Marine Current Turbines Ltd.)

Npw (Fig. 4.7). The company plan to install 300 MW in the next decade. This source alone could provide 20–30% of the UK's electricity needs. A total of 48 TWh per year could be produced from 106 sites around Europe, with majority in the UK. The marine currents are potentially more predictable than wind and solar (Fig. 4.8).

Marine currents could provide 150 TWh of electricity globally. At present, the cost of electricity produced is around GBP 280–300 per MWh. But it is early days yet.

Fig. 4.7 Aerial view of the Rance Tidal Barrier and generating station (*Source* http://en.wikipedia.org/wiki/Rance_Tidal_Power_Station)

Fig. 4.8 Commercial marine turbine with its rotors raised (Reproduced with kind permission Marine Current Turbines Ltd)

4.4.2 Wave Power

Another method of obtaining sustainable energy is harnessing wave power. There are several systems under trial but, as yet, none have been commercialised. Nonetheless, this is another interesting possibility for providing a sustainable energy supply in the future.

4.5 Obtaining Energy from Waste

Energy can be obtained from agricultural residues and waste, either by burning them directly in power stations or by converting them into fuels such as ethanol. The number of waste tyres throughout the world is staggering—there are 300 million scrap tyres per year produced in the USA alone—and these can be converted to energy in a furnace or pyrolysed to make more oil-based fuels.

Another option is to ferment waste such as discarded food in large bio-digesters (see Fig. 7.2).

There are also considerable wastes that occur throughout the world including agricultural residues. Agriculture residues can include straw, rice husk and peanut shells. There are about 100 million tonnes of agricultural waste produced annually in the USA.

4.6 Geothermal Energy

Based on current geologic knowledge and technology, the Geothermal Energy Association (GEA) estimates that only 6.5% of total global potential has been tapped so far, while the IPCC reported geothermal power potential to be in the range of 35 GW to 2 TW. Countries generating more than 15% of their electricity from geothermal sources include El Salvador, Kenya, the Philippines, Iceland and Costa Rica.

Estimates of the electricity-generating potential of geothermal energy vary from 35 to 2000 GW. This is not sufficient to replace fossil fuel-generated electricity, but it could certainly make a useful contribution. A recent report concludes that 20% of the UK's electricity could be produced by deep geothermal energy.

"If we can drill and recover just a fraction of the geothermal heat that exists, there will be enough to supply the entire planet with energy—energy that is clean and safe," says Are Lund, senior researcher at SINTEF Materials and Chemistry.

Geothermal energy is produced by taking heat from underground rocks and running this through a heat engine and generator to produce electricity. Normally, water is pumped underground via a pipe and returns to the surface via a second pipe. Provided that too much heat is not taken away from the rocks, this method is

Fig. 4.9 Larderello Geothermal Station in Italy (*Source* http://en.wikipedia.org/wiki/Geothermal_electricity)

sustainable. Such energy is only usable in a few locations, Italy being one. Interestingly, they are actively working on conversion of this energy to chemical energy in the form of hydrogen, for use in fuel cells. The Lardello Geothermal Power Plant (Fig. 4.9) produces 4800 GWh of electricity per annum—10% of the world's current geothermal supply.

The cost of geothermal energy lies between USD 43.8–52.1 (average: USD 47.8) per MWh.

4.7 Nuclear Power

(http://www.world-nuclear.org/info/current-and-future-generation/nuclear-power-in-the-world-today/-good%20article)

Despite the controversy surrounding it, nuclear fission has demonstrated that it can provide considerable quantities of electrical power and give off very little carbon release. Currently, over 10% of the world's electricity is generated by nuclear fission. It is well established, and France, for example, uses nuclear fission as its main source of electricity generation.

Nuclear reactors work in a similar way to other power plants, but instead of using coal or gas to generate heat, they use nuclear fission reactions. Heat from the nuclear reactions converts water into steam, which drives turbines that produce electricity.

Nuclear fission has been developed as a power source since the end of the Second World War. There has been considerable debate about the safety of the power and the safety of disposing of nuclear waste. The argument continues but it has been overshadowed by the debate about harm caused by global warming resulting from CO_2 release.

From the late 1940s and early 1950s, work on nuclear power proceeded in the USA, United Kingdom, Canada and the USSR. Electricity was generated for the first time by a nuclear reactor on 20 December 1951, at the experimental station near Arco, Idaho; it initially produced about 100 kW. The first light bulbs ever lit by nuclear electricity are illustrated in Fig. 4.10.

On 27 June 1954, the USSR's Obninsk nuclear power plant became the world's first to generate electricity, producing around 5 MW of electric power. The world's first commercial nuclear power station, Calder Hall at Windscale, England, was opened in 1956 with an initial capacity of 50 MW (later 200 MW) and was the world's first nuclear power station to produce electricity in commercial quantities (see Fig. 4.11).

The first commercial nuclear generator to become operational in the USA was the Shippingport reactor in Pennsylvania in December 1957 (Fig. 4.12).

Fig. 4.10 The first light bulbs ever lit by electricity generated by nuclear power (*Source* http://en.wikipedia.org/wiki/Nuclear_power)

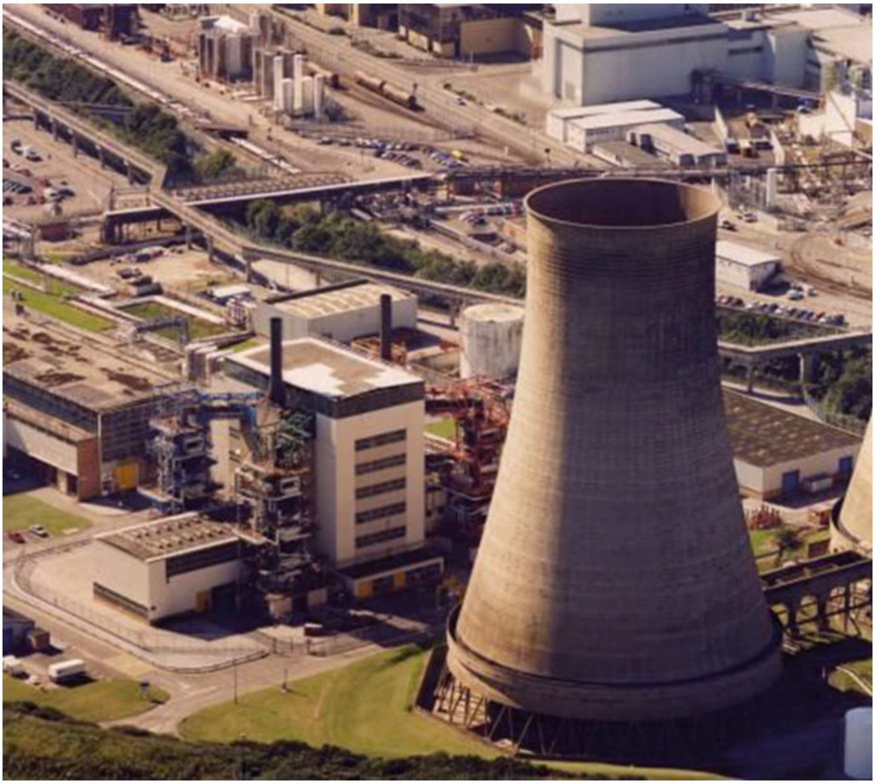

Fig. 4.11 Calder Hall nuclear power station in the United Kingdom (*Source* http://en.wikipedia.org/wiki/Nuclear_power)

Breeder reactors use U-238 as a fuel; there is 140 times as much of it as there is of U-235, which is used in traditional nuclear power. Enough U-238 can be converted to plutonium so that after a fuel cycle there is more fissionable material than there was in the original fuel rods in the reactor, hence the term ‘breeder reactor’. France has built two of them, the USA has a small one, the British built one, the Russians built one and the Japanese are building one. Superphénix, the world’s largest fast breeder reactor (FBR) on the Rhone River at Creys-Malville in France, close to the border with Switzerland, is illustrated in Fig. 4.13. This 1200 MW power station entered service in 1984, and, as of 2006, remains the largest FBR built. It was shut down in 1998 due to the left-wing government’s political commitment to competitive market forces.

The capital costs are at least 25% more than water-cooled reactors and may need to wait until uranium gets more expensive for large-scale deployment. This is unlikely to be soon because large uranium reserves have been discovered in recent years, which has stymied their deployment and lent some credence to calls for their abandonment. This situation is likely to remain until the demand for uranium

Fig. 4.12 The Shippingport Atomic Power Station, Pennsylvania, USA (*Source* http://en.wikipedia.org/wiki/Nuclear_power)

exceeds the supply. In addition, safety issues are cited as a concern with fast reactors that use a sodium coolant; a leak could lead to a sodium fire. Finally, since plutonium breeding reactors produce plutonium from U-238, they could pose potential proliferation risks.

Installed nuclear capacity initially rose relatively quickly, rising from less than 1 GW in 1960 to 100 GW in the late 1970s, and 300 GW in the late 1980s. Since the late 1980s, worldwide capacity has risen much more slowly, reaching 366 GW in 2005. Between around 1970 and 1990, more than 50 GW of capacity was under construction (peaking at over 150 GW in the late 1970s and early 1980s). In 2005, around 25 GW of new capacity was planned. More than two-thirds of all nuclear plants ordered after January 1970 were eventually cancelled. A total of 63 nuclear units were cancelled in the USA between 1975 and 1980.

During the 1970s and 1980s, rising economic costs (related to extended construction times largely due to regulatory changes and pressure-group litigation) and falling fossil fuel prices made new nuclear power plants less attractive.

The 1973 oil crisis caused countries such as France and Japan, which had relied more heavily on oil for electricity generation, to invest in nuclear power. Today, nuclear power supplies about 80 and 30% of the electricity in those countries, respectively.

Fig. 4.13 Superphénix, France, the world's largest fast breeder reactor. © Yann (*Source* http://en.wikipedia.org/wiki/Breeder_reactor)

Nuclear plants produce huge amounts of energy from small amounts of fuel and release negligible carbon emissions. Nuclear power plants provide about 6% of the world's energy and over 10% of the world's electricity. France has demonstrated that it is possible to run a country's power system largely without fossil fuels with the exception of their road transport system, which still uses oil.

It is important to note that capital costs quoted by reactor vendors or those that are general and not site-specific will usually be just for engineering, procurement and construction (EPC) costs. This is because an owner's costs will vary hugely, most of all according to whether a plant is on a greenfield site or at an established site, perhaps replacing an old plant. Mid-2008 vendor figures for overnight costs (excluding owner's costs) for some plants[2] have been quoted as about USD 3000 per kW. There are also decommissioning costs, which have been estimated at 9–15% of capital costs.

Fuel costs for nuclear plants are a minor proportion of the total generating costs, though capital costs for nuclear plants are greater than those for coal-fired plants and much greater than those for gas-fired plants. There are also running costs, and the cost of decommissioning nuclear power is considered cost-competitive with most other forms of electricity generation.

The cost of advanced nuclear energy in the USA is between USD 91.8–101 (average: USD 95.2) per MWh. The cost of new nuclear in the UK is USD 118.4–155.4 per MWh (GBP 80–105 per MWh). The guaranteed strike price for Hinkley

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[2] GE-Hitachi ESBWR, Hitachi ABWR and Westinghouse AP1000.

point C in 2023 is GBP 92.5 per MWh. This will fall to GBP 89.5 per MWh if the EDF Group goes ahead with plans to develop a new nuclear power station at Sizewell in Suffolk, UK.

The safety of nuclear power stations is a highly controversial issue and is certainly being addressed. Reactors that do not rely on external power systems are being introduced.

Pebble bed reactors are considered to overcome many of the safety problems associated with nuclear fission reactors and these may form the basis for future nuclear reactors. In these reactors, the fuel takes the form of uranium bits scattered among graphite pebbles. Helium is used as the coolant and it cannot become radioactive, like the water in water-cooled plants does.

Whilst it is probably impossible to make nuclear plants totally safe, there is also a cost to continuing to burn our supplies of fossil fuel, particularly if the danger of global warming due to carbon dioxide release continues at this pace.

4.8 Nuclear Fusion

Research into nuclear fusion is ongoing. Nuclear fusion is the process that takes place in a hydrogen bomb and in the sun. To create useful fusion power, we need to be able to control this process in a power station. There has been some success in

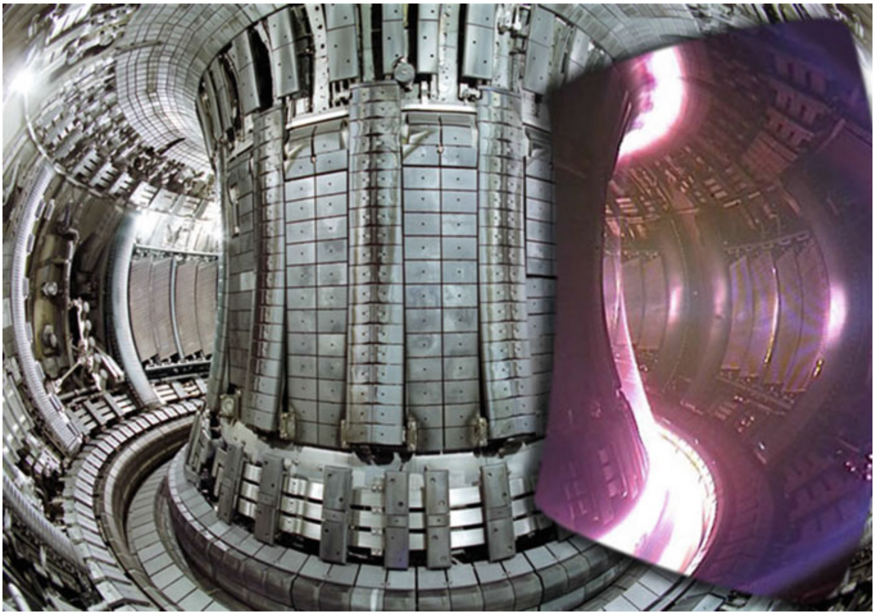

Fig. 4.14 Internal view of the JET tokamak superimposed with an image of a plasma taken with a visible spectrum video camera (*Source* http://en.wikipedia.org/wiki/File:JointEuropeanTorus_internal.jpg)

Fig. 4.15 Ignition of a hydrogen bomb (*Source* http://en.wikipedia.org/wiki/Nuclear_fusion)

achieving fusion power; for example, the Joint European Torus (JET) (Fig. 4.14). New international group ITER will continue the research and it has been proposed that the construction of DEMO should begin, the first reactor demonstrating sustained net energy-producing fusion on a commercial scale in 2024. Certainly, if we could produce economic fusion power on a commercial scale, many of our energy problems would be solved.

The only man-made fusion device to achieve ignition to date is the hydrogen bomb (Fig. 4.15).

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Chapter 5
Hydrogen and Other Synthesised Fuels

It is quite possible to manufacture fuels from other sources without the use of fossil fuels. The main contenders are hydrogen, biofuels and synthesised fuels. Since the aim of this book is to investigate energy from non-fossil fuels, traditional methods of producing fuels such as hydrogen from fossil fuels must be ruled, out and any fuel should be manufactured using a non-fossil fuel source such as nuclear, wind, tidal or solar. Using fossil fuel energy rather defeats the object of eliminating fossil fuels and will contribute to carbon release.

5.1 Biofuels

Biomass fuels consist of a wide range of fuels that use sunshine to grow the fuel. Use of biofuels is by no means a new idea. Wood has been burnt to create steam to run steam engines since the time of James Watt, and Rudolf Diesel ran his engine on peanut oil in 1893. Ethanol, an alcohol normally made by fermenting sugar or starch, has been used as a fuel in Brazil for over 60 years.

Cars, ships, aeroplanes and trains can all be run successfully on biofuels using conventional combustion engines. Development of biofuels is an option that could be pursued to provide transport systems that would no longer rely on fossil fuels.

The problem with growing crops for biofuels on land that would otherwise be used for agriculture is not whether the crops can be used successfully, but whether growing crops for biofuels will detract from essential food production. To put this into perspective, to supply the global aviation industry at current levels of consumption would require some 274.8 million acres of cropland, about 425,000 square miles—roughly the area of Texas, Oklahoma, Kansas and Iowa combined!

A range of fuels including biodiesel, bio-gasoline and methane can be made from algae (see Fig. 5.1) grown on land that is not suitable for agriculture. These fuels can be grown with minimal impact on fresh water resources as they can be produced using seawater and waste water and are relatively harmless to the environment. They

J. Lowry, *Avoiding Carbon Apocalypse Through Alternative Energy*,
DOI 10.1007/978-3-319-52195-4_5

Fig. 5.1 An example of Soladiesel (biodiesel) from solazyme, a company that uses microalgae to make transportation fuels (*Source* http://en.wikipedia.org/wiki/Solazyme)

are claimed to yield between 10–100 times more fuel per unit area compared with other biofuel crops.

The US Department of Energy estimates that if algae fuel replaced all the petroleum fuel in the USA, it would require 15,000 square miles (39,000 km^2), which is only 0.42% of the US land area. This is less than one-seventh of the area of corn harvested in the USA in 2000. However, these claims remain unrealised commercially. According to the head of the Algae Biomass Organisation, algae fuel can reach price parity with oil in 2018 if it is granted production tax credits.

If algae-derived biodiesel were to replace the annual global production of 1.1 billion tons of conventional diesel then a land mass of 57.3 million ha would be required, which is highly favourable compared with the requirements of other biofuels.

Rising jet fuel prices are putting severe pressure on airlines, creating an incentive for algal jet fuel research. The International Air Transport Association, for example, supports research, development and deployment of algal fuels. Trials have been carried out with aviation biofuel by Air New Zealand, Lufthansa and Virgin Airlines.

In February 2010, the Defence Advanced Research Projects Agency announced that the US military was about to begin large-scale production of oil from algal ponds into jet fuel. After extraction at a cost of USD 2 per gallon, the oil will be refined at less than USD 3 per gallon. A larger-scale refining operation producing 50 million gallons a year was expected to go into production in 2013, with the possibility of lower per gallon costs so that algae-based fuel would be competitive with fossil fuels. The projects, run by the companies SAIC and General Atomics, are expected to produce 1000 gallons of oil per acre per year from algal ponds.

Whilst algae-based fuels show considerable promise, the production of commercial fuels is yet to be realised.

Algae can produce up to 300 times more oil per acre than conventional crops such as rapeseed, palm or soybeans. Unlike yearly crops, as algae have a harvesting cycle of 1–10 days, it is possible to have several harvests in a very short period. Algae, which can grow 20–30 times faster than food crops, can also be grown on land that is not suitable for other established crops, for instance arid land, land with excessively saline soil and drought-stricken land. This minimises the issue of utilising land that could otherwise be used for the cultivation of food crops. Algae farms can also be set up on marginal lands, such as in desert areas, where the groundwater is saline; it is not necessary to utilise fresh water.

Biogas is a gas produced by the biological breakdown of organic material in the absence of oxygen (i.e., anaerobic digestion). Organic waste such as dead plant and animal material, animal faeces, and kitchen waste can be converted into biogas. Biogas comprises primarily methane and carbon dioxide. The gases methane, hydrogen and carbon monoxide (CO) can be combusted or oxidised. This energy release allows biogas to be used as a fuel in any country for any heating purpose, such as cooking. It can also be used in anaerobic digesters where it is typically used in a gas engine to convert the energy in the gas into electricity and heat. Biogas can also be compressed and used to power motor vehicles. In the UK, for example, biogas is estimated to have the potential to replace around 17% of vehicle fuel. Biogas can also be cleaned and upgraded to natural gas standards, where it becomes bio-methane. A biogas plant is shown in Fig. 5.2.

Fig. 5.2 Biogas production plant in rural Germany (*Source* http://en.wikipedia.org/wiki/Biogas)

5.2 Hydrogen as a Fuel

Hydogen has potential advantages as a fuel. It can be produced locally simply by electrolysing water and the products of combustion in both internal combustion engines and fuel cells in water. It has a high specific energy of 33.3 kWh/kg, whereas petrol has a specific energy of 12.3 kWh/kg. Unfortunately, whilst it contains a lot of energy per kilogram, it also takes up a lot of volume compared with oil-based fuels such as petrol and kerosene. For the same energy content, hydrogen has a mass of 0.35 that of petrol. Hydrogen has a high energy density, meaning that ai a large volume is required to store hydrogen fuel.

Hydrogen has successfully been stored in pressurised tanks (Fig. 5.3) for supplying fuel cell vehicles, or it can be stored as liquid hydrogen at low temperature.

The composition of the tanks is shown in Fig. 5.4. The FCX's 350 bar tanks are constructed in three layers. The two tanks provide the FCX with 157 l of fuel capacity. The time to refuel the vehicle is three minutes.

The exact weight of the Honda FCX tank is not known, but it is possible to store hydrogen at 30 bar pressure in a 145 l capacity tank weighing 45 kg. The mass of hydrogen stored in this tank would be 4.43 kg. This means that a tank approximately 10 times the mass of hydrogen would be needed to store hydrogen at 340 bar pressure. If a pressure of 680 bar were used, a slightly better tank mass to hydrogen mass of 8.2 would be achieved.

Even stored as cryogenic liquid, hydrogen has a very low energy density of 2330 kWh/m^3. A fuel tank of liquid hydrogen will need to be 3.89 times the volume of a petrol tank containing petrol with the same energy content. Storing hydrogen as a pressurised gas is intrinsically simple but when pressurised to 300 bars, the hydrogen tank will need to be 10 times the volume of the equivalent petrol tank.

Fig. 5.3 Two 350 bar high-pressure hydrogen tanks from the Honda FCX Clarity (*Source* http://world.honda.com/FuelCell/FCX/tank/)

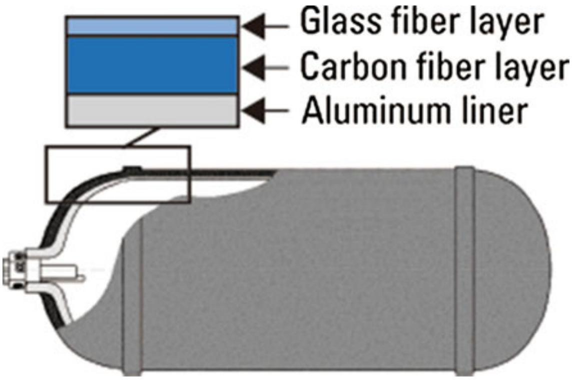

Fig. 5.4 Composition of high pressure hydrogen tanks (*Source* http://world.honda.com/FuelCell/FCX/tank/)

In order to manufacture hydrogen without using fossil fuels, it would be necessary to electrolyse water into hydrogen and oxygen, using electricity from a non-fossil fuel source.

A British company, ITM of Sheffield, manufactures modular electrolysers (Fig. 5.5). This system provides flexibility and allows for easy expansion. The units currently have a system efficiency of 70% but they hope to improve this to 85% in the future.

ITM electrolysers deliver hydrogen at 15 bar, which is consistent with existing propane storage technology, metal hydride storage systems and hydrogen compressors. ITM have experience of generating hydrogen directly at 75 bar, which offers a route for bypassing the need for external compression and reduces the complexity of a downstream high pressure plant.

There are also energy implications in storing hydrogen, whether as a pressurised gas or by cooling the hydrogen to a liquid form. Cryogenically cooling hydrogen can take as much energy as is stored in the hydrogen. Hydrogen can be used either in fuel cells or as a fuel in internal combustion engines. One of the advantages of hydrogen is that it can be used in fuel cells that have very high efficiency, and therefore less hydrogen is required than the petrol equivalent driving an internal combustion engine.

Hydrogen can be stored in gas storage facilities and then reused either in gas turbines or in fuel cells to generate power. Fuel cells typically have efficiencies of up to 60% and the efficiency of gas turbine generators is, at best, around 58%. Hydrogen can also be stored and used in gas pipes and underground caverns, salt domes and oil and gas fields. The storage of large quantities of liquid hydrogen underground can function as grid energy storage. The round-trip efficiency is approximately 40% (vs. 75–80% for pumped hydro), and the cost is slightly higher than for pumped hydro. Large quantities of gaseous hydrogen have been stored in underground caverns by ICI for many years without any difficulties.

Hydrogen can also be distributed using natural gas pipelines, although care must be taken to ensure that there are no leaks. Hydrogen can be stored in natural sites where natural gas is stored, such as salt caverns. Large salt deposits occur in many

Fig. 5.5 ITM modular electrolysis units (reproduced with kind permission of ITM)

locations around the UK—reserves in the Northwest have supplied a large chemicals sector for many years—and salt caverns, which can be made by dissolving away a void within the salt stratum, using techniques originally developed for salt-mining by ICI, have the right sort of volume and strength to store a significant amount of pressurised hydrogen safely.

Of course, whenever hydrogen is mentioned, safety concerns are close behind: the gas is, after all, flammable, explosive and difficult to contain because of the very small dimensions of hydrogen molecules. ‘We’re looking carefully at security,’ the caverns would be formed so that they are still surrounded by thick, strong deposits of crystalline salt, which can contain hydrogen safely. ‘If these facilities were onshore, they’d be in highly industrialised areas, away from anywhere residential, but they’d be more likely to be offshore.’

5.3 Synthesised Fuel

An alternative, better option is to combine hydrogen with carbon dioxide taken from the atmosphere to create more conventional fuels, such as methane or kerosene. It is quite possible to produce fuels from carbon dioxide; in other words, reversing the process of combustion. The energy to create fuels would need to be taken from a non-fossil fuel source. These fuels could then be used directly in conventional ways without having to change considerable infrastructure. Up to 15% hydrogen can already be assed to gas mains and this could be combined with synthesised methane. This could be used directly in stationary gas turbine generators; for example, to make essential backup power.

A firm known as Air Fuel Synthesis Ltd is working on developing commercial units to produce a fuel similar to petrol and they are developing a plant that will produce a kerosene substitute for use in conventional jet engines. Studies from Air Fuel Synthesis indicate that 3 kWh of electrical energy is needed to produce 1 kWh of jet fuel. The plant producing 1 ton per day of fuel is shown in Fig. 5.6 and a sample of synthesised fuel is shown in Fig. 5.7.

An advantage of synthesised fuel over hydrogen is that synthesised fuel can be run in conventional road vehicles and aircrafts without any major modification; hydrogen requires either pressurised fuel tanks or cryogenically cooled fuel tanks. However, the advantage of hydrogen is that it can be used in fuel cells, which convert the hydrogen into energy directly. Hydrogen has a higher specific energy than synthesised fuel but will have a lower energy density, hence the requirement of larger tanks. Once the extra mass of storing hydrogen is taken into account, the advantage of hydrogen's high specific energy is likely to be lost. However, where hydrogen can use the existing infrastructure for storage and transmission, and where hydrogen can be used directly to produce instant power on demand, hydrogen has clear advantages. Hydrogen can also be used in fuel cell cars, which are now appearing on the market.

Audi is building a plant that will use solar and wind power to make methane from water and carbon dioxide. The plant, which will use technology developed by Stuttgart, Germany-based SolarFuel, is scheduled to start operation later this year. It will produce enough methane to power 1500 of Audi's new natural-gas vehicles, which also go on sale this year. In a video it is suggested that the price may be EUR 1–1.50/l.

Fig. 5.6 Air fuel synthesis plant for producing 1 ton per day of fuel (reproduced with kind permission of Air Fuel Synthesis Ltd)

Fig. 5.7 Synthesised fuel (reproduced with kind permission of Air Fuel Synthesis Ltd)

In northern Germany, Audi has an e-gas facility under construction together with system builder, SolarFuel. It will be the world's first facility to convert renewable electricity and CO_2 into a synthetic natural gas that can be fed into the natural gas network on an industrial scale.

The facility gets electricity from windmills nearby to produce hydrogen (from water) by electrolysis and obtains its CO_2 from a biogas plant, which is not using energy crop plants, but organic waste. By compressing with CO_2 from the atmosphere, a process called methanation, another renewable energy source is created: synthesised renewable methane, or Audi e-gas.

- Using European electricity prices, the energy cost of e-diesel at the refinery gate would be of the order EUR 1.8/l—excluding manpower, capex, profit, distribution costs and taxes. Adding in the latter might easily take the price to EUR 3/l, which much higher than Audi's estimate of EUR 1–1.5/l. This compares with a refinery gate price for FF diesel in the order EUR 0.65/l. E-diesel may cost 2.7–4.5 times as much as traditional diesel.
- The energy return on energy invested (ERoEI) for the process is at best 0.5. For every kWh of e-diesel produced, about 2 kWh s of electricity are consumed. E-diesel is an energy sink or energy conversion where at least 50% of the energy is lost along the way.
- To convert Europe to running on e-diesel would require a 12-fold increase in todays "new renewable" infrastructure and would result in a doubling of the energy consumed in the transport sector.

Economics

- The cost calculation below simply converts the energy used into euros and cents using an industrial electricity price of EUR 0.09 per kWh for Germany [1].
- CO_2 separation = 800 kWh * EUR 0.09 = EUR 72 per ton
- Hydrogen production = 17,044 kWh * EUR 0.09 = EUR 1534 per ton
- Thermal energy for conversion = 5600 kWh * EUR 0.09 = EUR 504 per ton
- Total = 23,444 kWh per ton * EUR 0.09 = EUR 2110 per ton
- 1 ton = 308 US gallons = 1165 l [2]
- 23,444 * EUR 0.09 = EUR 2110 per ton = EUR 6.85 per gallon or EUR 1.81/l (Germany)
- This is a bit higher than the EUR 1–1.5/l claimed by Audi. At face value, with diesel retailing at EUR 1.24/l in Germany [3], this price of EUR 1.81/l does not seem to be a game killer. But here's the rub. For a start, here mean price of electricity is used, made cheap in Germany by burning coal. Arguably a significantly higher price for electricity should be used, since the input price should be for wind or solar power that are well above the average. Furthermore, this calculation is for the energy cost alone and excludes manpower, capex, profit and distribution costs. Adding in all those other costs, it is not difficult to imagine the real cost of e-diesel coming in at over EUR 3/l. And then there is tax.
- The price paid for diesel at the pump in Europe is enormously distorted by taxes. The refinery gate price for diesel in Europe is in the order EUR 0.66 [4]. Hence, e-diesel is at least 2.7 times as expensive, perhaps as much as 4.5 times more costly than conventional diesel. And that is a game killer, especially since it is unlikely that governments will be able to levy taxes on the CO_2 neutral fuel.

The current cost of fossil fuel diesel is around EUR 0.76/l and aviation fuel around EUR 0.40/l.

The carbon-neutral fuels used in Germany and Iceland will be used for distributed storage and renewable energy, minimising problems of wind and solar intermittency, and enabling transmission of wind, water, and solar power through existing natural gas pipelines. Such renewable fuels could alleviate the costs and dependency issues associated with imported fossil fuels without requiring either electrification of the vehicle fleet or conversion to hydrogen or other fuels, enabling continued compatible and affordable vehicles. A 250 kW methane synthesis plant was constructed by the Center for Solar Energy and Hydrogen Research (ZSW) in Germany and began operating in 2010. It is being upgraded to 10 mW, scheduled for completion in Autumn, 2012.

Whilst these plants are now on a relatively small scale, the development of ideas will increase the efficiency and reduce the cost.

Several notable research organisations from academia through to industry (ETH Zürich, Bauhaus Luftfahrt, Deutsches Zentrum für Luft- und Raumfahrt (DLR), ARTTIC and Shell Global Solutions) have explored a thermochemical pathway driven by concentrated solar energy. A new solar reactor technology has been pioneered to produce liquid hydrocarbon fuels suitable for more sustainable transportation.

“Increasing environmental and supply security issues are leading the aviation sector to seek alternative fuels which can be used interchangeably with today’s jet fuel, so-called drop-in solutions,” states Dr. Andreas Sizmann, the project coordinator at Bauhaus Luftfahrt. “With this first-ever proof-of-concept for ‘solar’ kerosene, the SOLAR-JET project has made a major step towards truly sustainable fuels with virtually unlimited feedstocks in the future.”

The SOLAR-JET project demonstrated an innovative process technology using concentrated sunlight to convert carbon dioxide and water to a so-called synthesis gas (syngas). This is accomplished by means of a redox cycle with metal oxide-based materials at high temperatures. The syngas, a mixture of hydrogen and carbon monoxide, is finally converted into kerosene by using commercial Fischer-Tropsch technology. http://www.sciencedaily.com/releases/2014/05/140503184918.htm.

“The solar reactor technology features enhanced radiative heat transfer and fast reaction kinetics, which are crucial for maximising the solar-to-fuel energy conversion efficiency,” said Professor Aldo Steinfeld, who is leading the fundamental research and development of the solar reactor at ETH Zürich.

Although the solar-driven redox cycle for syngas production is still at an early stage of development, the processing of syngas to kerosene is already being deployed by companies, including Shell, on a global scale. This combined approach has the potential to provide a secure, sustainable and scalable supply of renewable aviation fuel and more generally for transport applications. Moreover, Fischer-Tropsch derived kerosene is already approved for commercial aviation.

“This is potentially a very interesting novel pathway to liquid hydrocarbon fuels using focused solar power,” said Professor Hans Geerlings at Shell. “Although the individual steps of the process have previously been demonstrated at various scales, no attempt had been made previously to integrate the end-to-end system. We look forward to working with the project partners to drive forward research and development in the next phase of the project on such an ambitious emerging technology."

SOLAR-JET (Solar chemical reactor demonstration and Optimization for Long-term Availability of Renewable JET fuel) was launched in June 2011 and is receiving financial support from the European Union within the 7th Framework Programme for a duration of four years. In a first step, the technical feasibility of producing solar kerosene was proven. In the next phase of the project, the partners will optimise the solar reactor and assess the techno-economic potential of industrial scale implementation. The outcomes of SOLAR-JET will put Europe at the forefront of research, innovation and production of sustainable fuels directly from concentrated solar energy.

On nuclear powered aircraft carriers, the US. Navy estimates that 100 mW of electricity can produce 41,000 gallons of jet fuel per day and shipboard production from nuclear power would cost about USD 6 per gallon. While that was about twice the petroleum fuel cost in 2010, it is expected to be much less than the market price in less than five years time if recent trends continue. Moreover, since the delivery of fuel to a carrier battle group costs about USD 8 per gallon, shipboard production is already much less expensive. Today, jet fuel costs USD 1.7 per gallon.

So a team at the Naval Research Laboratories headed by Heather Willauer has jumped many technical hurdles over a period of 12 years to devise a technique that can use carbon dioxide/hydrogen from seawater and electricity from small modular nuclear reactors found aboard some navy ships to synthesise both F-76 diesel and JP-5 jet fuel.

The process begins by temporarily lowering the pH of the seawater to a value of 4.5 and removing 92% of the carbon dioxide (CO_2). The CO_2, along with elemental hydrogen from electrolysis, runs through a specialised catalyst that synthesises longer hydrocarbon chains. This creates a fuel that actually exceeds current specifications for the navy. Although it takes about 23,000 gallons of water (which is the volume of a large home swimming pool) to produce 1 gallon of JP-5 jet fuel, using available technology, we can potentially manufacture 41,000 gallons per day from a single ship carrying a 100 mW reactor. This means that we could supply the entire navy fleet with roughly 5 vessels carrying these systems, and they do not necessarily need to be devoted fuel manufacturing vessels (i.e. nuclear aircraft carriers). A cost analysis for the navy reactors puts the price of delivered fuel using this new fuel synthesis system at approximately USD 2.90, which is much friendlier than the current price of around USD 7.00+. With higher-temperature fourth generation reactor designs, this price would go substantially down, due to the fact that water disassociates at high operating temperatures of these reactors thus making electrolysis unnecessary.

Fuels synthesised from hydrogen produced by the electrolysis of water and carbon dioxide taken from the atmosphere are currently more expensive than traditional oil and gas. The cost is going to fall with large commercial plants and the use of solar energy and this will enable both conventional aircraft gas turbine generator systems to rapidly respond to demand whilst producing no carbon dioxide.

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Chapter 6
Energy Storage

6.1 The Need for Energy Storage

One of the advantages of using fossil fuels for power generation is the ability to respond rapidly to energy demand. Some alternative energy sources can also produce power on demand and others cannot. Hydropower can produce power on demand, as can geothermal energy.

Production of photovoltaic energy is limited to 4–5 h either side of noon at the latitude concerned; it also depends to an extent on solar insolation. This is illustrated in Fig. 6.1, which refers to a clear day.

Wind power varies with prevailing conditions. Tidal energy varies depending on the tides, which vary from day to day midnight.

Solar power also depends on local weather. Therefore, having several solar power stations in the solar belt and connected by electrical super grids would be an advantage and would minimise this reliance.

Nuclear power stations provide massive amounts of energy at a constant rate. This can only be controlled to a limited extent. As a result, they are used largely to supply base load electricity and demand matched for daytime use usually does not match nighttime use.

Tidal energy is greatest twice a day, once at high tide and once at low tide. Wind energy varies both on a day to day and a month to month basis.

Variation in energy demand for a typical day is shown in Fig. 6.2. Demand throughout the world will, on the whole, be similar, i.e., starting at a relatively low level at night and then ramping up to a higher level as the day progresses. There will of course be fluctuations that occur to meet instant demands. Any electrical power system supply has to be able to match demand.

This shows that much of the electricity demand is in fact for continuous 24/7 supply (the base load), while some is for a lesser amount of predictable supply for about three quarters of the day, and less still is for variable peaks in demand for up to half of the time. Some of the overnight demand is for domestic hot water systems

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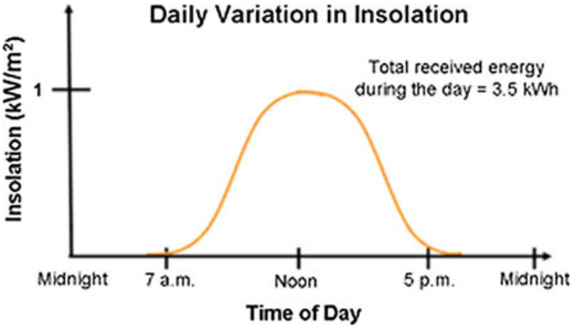

Fig. 6.1 Variation of solar power during a clear day

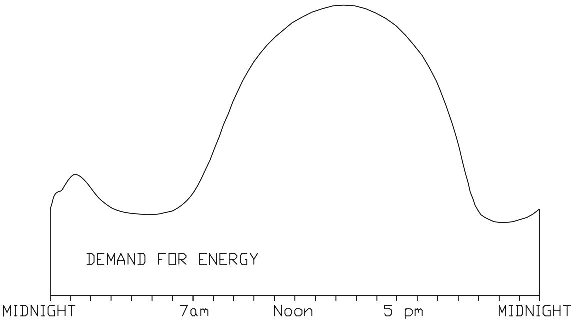

Fig. 6.2 Typical energy demand throughout the day

on cheap tariffs. With overnight charging of electric vehicles, it is easy to see how the base-load proportion would grow.

Most electricity demand is for continuous, reliable supply that has traditionally been provided by base load electricity generation. Some is for shorter-term (e.g., peak load) requirements on a broadly predictable basis. Hence, if renewable sources are linked to a grid, the question of back-up capacity arises for a stand-alone system, and energy storage is an important issue.

Although low-cost alternative energy is available from alternative energy sources, the times at which such energy is available does not always match demand during times of demand. Therefore, some form of energy storage is essential.

There are a variety of ways in which demand can be matched to energy available. Firstly, demand can be matched to price. For example, electric vehicles may be charged at any time throughout the day. If the price of electricity is cheaper when there is plenty of electricity available, people will charge their cars at the time that enables them to obtain the best price. Computers can be programmed to charge the vehicles at these times. Many industries could arrange peak loads to coincide with times of surplus electricity. Hydro-electricity has the ability to boost electricity supply to match demand.

The current methods of generating electricity have largely evolved to allow supply to match demand and the current system uses gas turbine generators, which can be brought into use very quickly. In this way, there is normally a base load that is supplied by a power station, such as a coal or nuclear power station, which cannot be switched on and off quickly, and this electricity supply is augmented by other generators such as gas turbines, which can be brought in quickly to meet extra demand.

Another method of operating a grid is to provide a high base load to meet maximum demand. It could also supply peripherals, such as factories that synthesise fuels or electrolyse water to make hydrogen, those that pump water for pumped storage systems and could also power other items such as desalination plants. These peripherals could be turned off at times of maximum demand and then turned back on at times of low demand. In this way, all energy generated would be used and peak demand would be met. This could be a better way of running a worldwide grid based on sustainable and alternative energy.

As mentioned, low-cost solar electricity is typically available for around 5 h either side of noon at the latitude concerned, and therefore storage for at least 24 h would be effective. However, variations in wind energy occur over a longer period.

West Denmark (the main peninsula part) has the highest concentration of wind turbines on the planet, with 1.74 per 1000 people. There are 4700 turbines totalling 2315, 1800 MWe of which has priority dispatch and power must be taken by the grid when it is producing. The total system capacity is 6850 MWe and the maximum load during 2002 was 3700 MWe, hence a huge 81% margin. In 2002, 3.38 billion kWh were produced from the wind, a load factor of 16.8%. The peak wind output was 1813 MWe on 23 January, which was well short of the total capacity, and there were 54 days when the wind output supplied less than 1% of demand. On two occasions, in March and April, wind supplied more than total demand for a few hours. In February 2003, during a cold calm week, there was virtually no wind output. Too much wind is also a problem—at over 20 m/s, output drops; and at over 25 m/s, turbines are feathered. Generally, a 1 m/s wind change causes a 320 MWe power change for the whole system.

As mentioned, for solar power, there is a strong case for storing electricity for a period of at least 24 h. For wind, a longer storage period would be necessary.

There are three main ways in which energy can be stored effectively. Firstly, electric batteries; secondly, pumped storage; and thirdly, producing synthesised fuel or hydrogen and restoring this as energy on demand.

6.2 Rechargeable Electric Batteries

The first rechargeable electric battery was invented in 1859 by Gaston Plante. The individual cells from which the battery is made consist of a lead anode and a lead dioxide cathode immersed in sulphuric acid. Both electrodes react with the acid to produce lead sulphate. The reaction at the lead anode releases electrons whilst the reaction at the lead dioxide consumes them, thus producing a current. These chemical reactions can be reversed by passing a reverse current through the battery, thereby recharging it. There were several attempts to build improved rechargeable

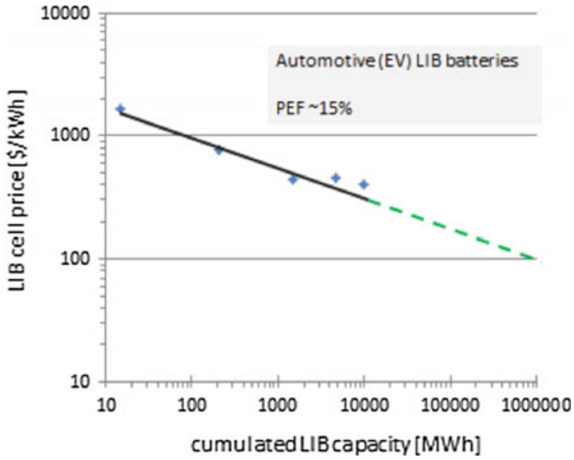

Fig. 6.4 Predicted fall in battery prices

batteries—including Thomas Edison's nickel iron battery—but, for storage purposes, the lead acid battery dominated throughout most of the twentieth century.

Electric cars and taxis were used in the early twentieth century but were replaced in popularity by internal combustion engine vehicles. Ironically, this opened up a huge market for batteries used to drive the starters of internal combustion engine cars. Until the onset of lighter lithium batteries, the lead acid batteries with their specific energy of 20–35 Wh per kg were really too heavy to make a successful electric vehicle. As lithium batteries with higher specific energies were developed towards the end of the twentieth century, commercial electric vehicles became a possibility and several suitable designs became available on the market in early twenty first century.

Electric batteries continue to develop, both in terms of higher specific energy and lower capital cost. Currently, electric batteries are relatively expensive, costing about USD 200 MWh but the price is predicted to fall by 2030 as the number produced increases.

The simplest way of storing electricity is in batteries, which, at present, is rather expensive. Battery costs, like the cost of photovoltaics, are due to fall to USD 60 per MWh by 2030. The predicted fall in battery prices is illustrated in Fig. 6.4. One prediction puts the price possibly as low as USD 0.05 per kWh by 2030.

6.3 Pumped Hydro Storage

A variation on hydropower is pumped storage, in which pumped storage hydroelectricity (PSH or PHES) is a type of hydroelectric energy storage used by electric power systems for load balancing. The method stores energy in the form of the gravitational potential energy of water, pumped from a lower elevation reservoir to a higher elevation. Low-cost off-peak electric power is used to run the pumps. During periods of high electrical demand, the stored water is released through turbines to produce electric power. Although the losses of the pumping process makes the plant a net consumer of energy overall, the system increases revenue by selling more electricity during periods of peak demand, when electricity prices are highest. It is also ideal for maximising the use of alternative energies, such as solar and wind, where energy is concentrated depending on sun or wind conditions.

A pumped storage station costs in excess of USD 1000 per kW and the overall losses are about 25%. Most pumped storage stations store sufficient water for 6–10 h of operation. The ideal operating head is between 500–700 m (1500–2200 ft). To build a pumped storage station, you need to find, in one place, a source of water, a hill at least 400 m high and topography suitable for building a large pond at the top of the hill and another large pond at the bottom of the hill. Pumped hydropower storage is relatively expensive but it is efficient, at typically 75–80%.

Hydropower installations can have a useful life of over 100 years and many such plants are in existence worldwide. However, many places in the world do not have convenient hill and mountains to build pumped storage systems.

One example of hydropower storage is the La Muela pumped storage scheme. With over 2000 MW of power generating 5000 GWh (5,000,000 MWh) of energy per year, it is Europe's largest pumped storage scheme. The scheme cost EUR 22 billion 12 years ago. This pumped storage scheme stores energy produced by wind power at peak periods, in order to provide energy during lulls. Another scheme is the Sir Adam Beck generating complex at Niagara Falls, Canada, which is illustrated in Fig. 6.5 is the, which includes a large pumped-storage hydroelectricity reservoir.

Fig. 6.5 Sir Adam Beck generating complex acknowledgement Ontario power generation. *Source* https://en.wikipedia.org/wiki/Wind_power

6.4 Storing Energy Through Hydrogen and Generating Power Through Gas Turbines

Creating and storing hydrogen by alternative energy was discussed in the previous chapter. This can then be turned to electrical power on demand by using conventional gas turbine generators.

In the extreme, approximately 200,00 TWh of storage may be needed for around 6 h. 200 TWh, which equates to a value of 714,286 m^3 of gas storage. Much of the infrastructure for storing gas already exists or can be modified to store gas. In addition, existing gas turbine generating sets need slight modification to run on hydrogen. Worldwide, working gas capacity totalled 399 billion cu m (bcm).

The advantage of using gas turbines is that they can be used to rapidly respond to power demands. In addition, they are used in commercial power stations and therefore the technology is well understood. Conventional gas turbines, as illustrated in Fig. 6.6, can run on hydrogen.

Another advantage of storing hydrogen and using it for power is that it can be stored for relatively long periods, allowing countries to build up reserves. This is useful in times of energy shortage, for example, during natural disaster.

It is hoped that much of the infrastructure used for storing gas and used with existing gas turbine generators, currently used with fossil fuel gas can be adopted.

Gas turbines can be particularly efficient—up to at least 60%—when waste heat from the turbine is recovered by a heat recovery steam generator in order to power a conventional steam turbine in a combined cycle configuration. The desired efficiency of the electrolysis of water to make hydrogen is 85%. Therefore, the efficiency of electricity generation is, at best, going to be around 50%. This means that 2 MWh of hydrogen will be needed for every 1 MWh of electricity generated.

A simpler gas turbine without heat recovery will have a thermal efficiency of up to 40%, so using the gas turbine without heat recovery will give an overall efficiency of 34%. In this case, 3 MWh of hydrogen will be needed for every 1 MWh of electricity generated.

Large gas turbines cost in the region of USD 100 per kW and have a life of 10,000–20,000 h. Discounted over the life and doubling for maintenance, this will add a further USD 0.02 plus the cost of the hydrogen which will require 2–3 units of hydrogen in for every unit in kWh of electricity generated.

A typical gas turbine is illustrated in Fig. 6.6.

An alternative would be to use diesel engines to produce power from hydrogen. Large diesel engines can have thermal efficiencies in excess of 50%.

Storage of energy using hydrogen electrolysed from alternative energy and turned back to electrical power using gas turbines has several advantages. Suitable hills and mountains are not required, nor is the building of capitally expensive structures. In addition, a lot of the existing infrastructure, including storage and gas turbine generators, which are currently used for fossil fuels, can be adapted for use with hydrogen made from alternative energy sources.

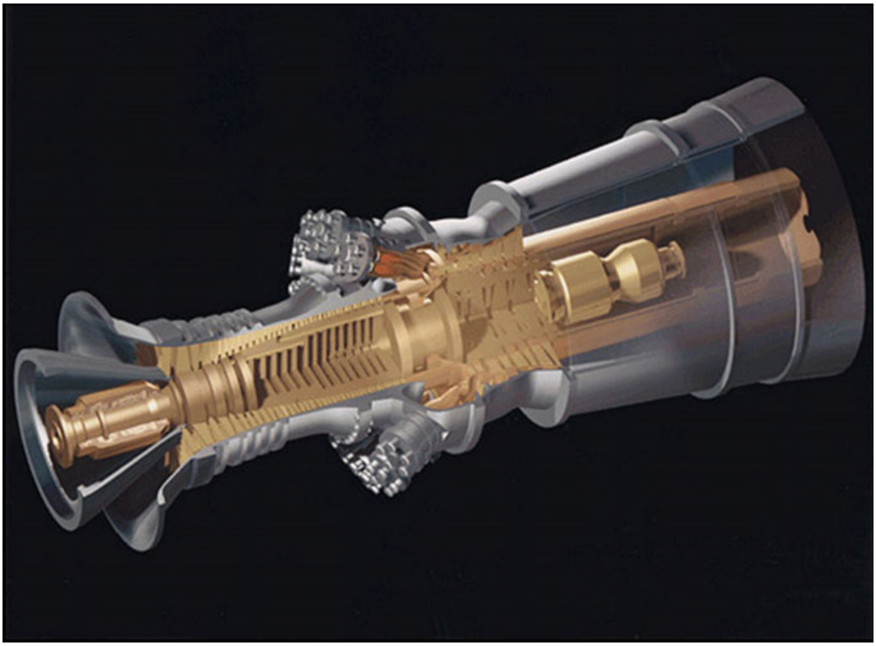

Fig. 6.6 GE H series power generation gas turbine: in combined cycle configuration, this 480-MW unit has a rated thermal efficiency of 60%

In the extreme, approximately 20,000 TWh of storage may be needed for around 6 h. 200 TWh, which equates to a value of 714,286 m^3 of gas storage. Much of the infrastructure for storing gas already exists or can be modified to store gas. In addition, existing gas turbine generating sets need slight modification to run on hydrogen. Worldwide, working gas capacity totalled 399 billion cu m (bcm).

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Chapter 7
Economics

There are three major economic factors to consider in the cost of using non fossil fuel energy sources to energise the world. The first is the cost of generating energy from non-fossil fuel sources; the second is the cost of doing nothing; and the third is the cost of adapting the world's infrastructure to enable the use of alternative energy.

7.1 The Cost of Generating Energy from Non-fossil Fuel Sources

A critical feature of changing to non-fossil fuel energy sources will be the cost of generating power from alternative sources. Fortunately, considerable work has been done on the cost of generating power from both conventional and alternative sources now and in the future.

A cost comparison between various sources of energy in USD per MWh is shown in Fig. 7.1. The cost of electricity generated by conventional fossil fuels coal and gas is also included.

The comparison shows that the current cost of generating electricity by photovoltaics, onshore wind, hydropower and large tidal plants, and geothermal is below the cost of fossil fuel-fired power stations in some countries.

The cost of photovoltaic electricity has fallen consistently over the years and will continue to fall. This depends on production quantities and is known as Swanson's Law and this is shown graphically in Fig. 7.2.

In 2025, photovoltaic electricity is projected to cost cost between USD 0.032–0.083 per kWh in the USA (USD 32–83 per MWh), average: 5.75 ct/kWh; between 3.4 and 7.1 ct/kWh in Australia (USD 34–71 per MWh), average: USD 0.0525 per kWh; and between USD 0.033 and 0.054 per kWh in India, the Middle East and North Africa (USD 33–54 per MWh) average: USD 0.0425 per kWh. This averages

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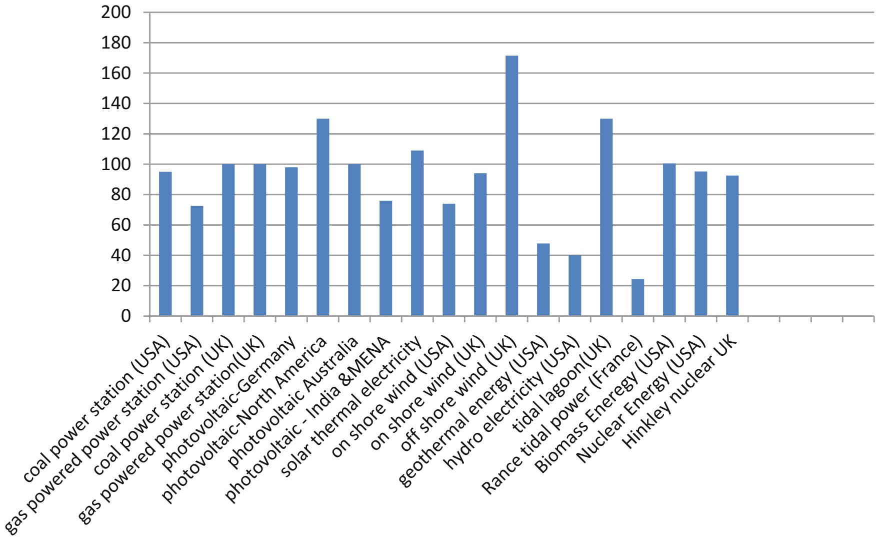

Fig. 7.1 Cost comparison of electricity generation in 2015

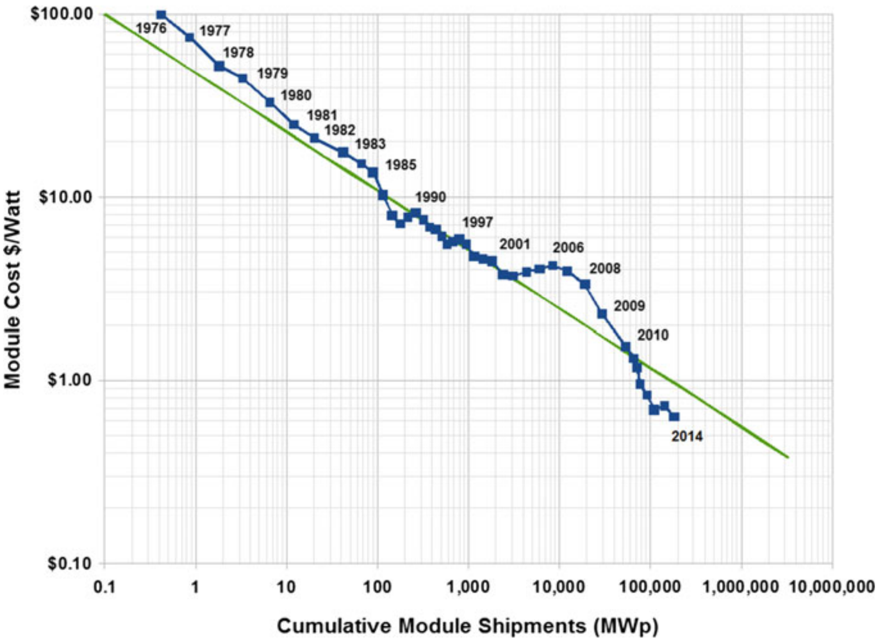

Fig. 7.2 The effect of Swanson's law (https://commons.wikimedia.org/wiki/File:Swansons-law.png)

out at around USD 50 per MWh, which is nearly two thirds the price of electricity from fossil fuels (Fig. 7.3).

The cost of photovoltaic electricity will continue to fall and the predicted costs in 2015 are shown graphically in Fig. 7.4. This shows that the cost of photovoltaic electricity will cost between USD 15 and 58 per MWh in the USA, average: USD 3.65 per MWh; between USD 16–49 per MWh in Australia, average: USD 3.25 per MWh; and between USD 16–37 per MWh in India, the Middle East and North Africa, average: USD 2.64 MWh.

The predicted cost of photovoltaic electricity in 2050 of USD 15 per MWh is less than a third of cheapest electricity generated from fossil fuels in 2016, and this is expected to happen within 34 years!

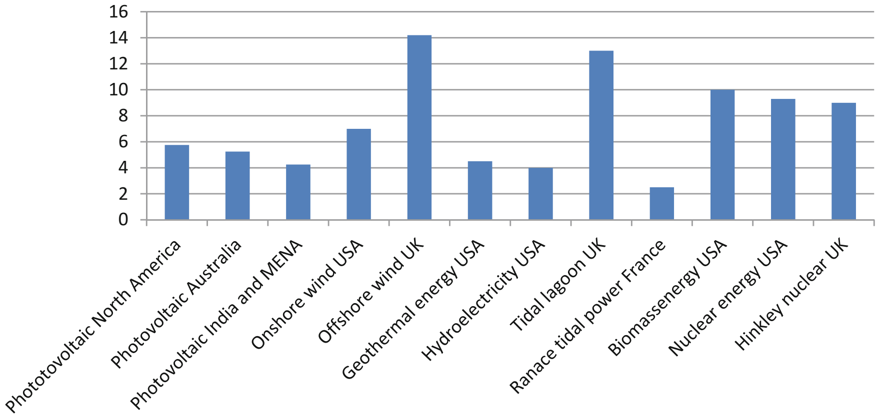

Fig. 7.3 Predicted cost of electricity in 2025 in US cents per kWh

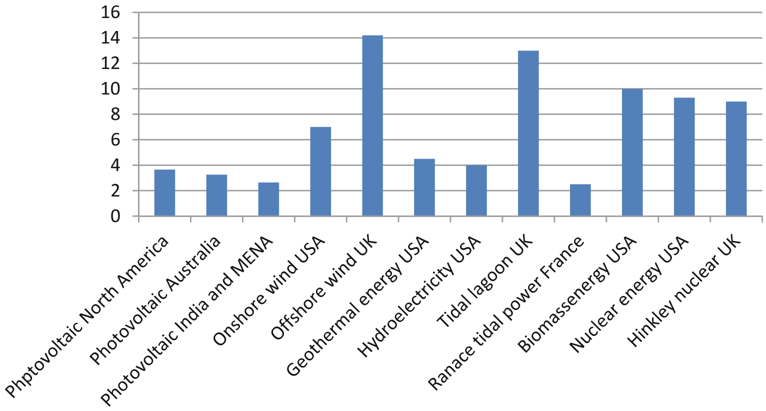

Fig. 7.4 Predicted cost of electricity in 2050 in US cents per kWh

There are other forms of alternative energy that will still be cheaper the fossil fuel electricity today and these include onshore wind, geothermal electricity, hydroelectricity and some tidal power.

Clearly, there are other technologies for which considerable money is being spent on development, particularly offshore wind, and it is hoped that these will come down in price in the future. A figure of GBP 100 per MWh (USD 147 per MWh) for wind energy is one current target price, although this will not be as low as the cost of photovoltaics. Tidal lagoons is another area where the cost is likely to be reduced once the initial development costs are recovered. The cheapest cost at present is GBP 130 per MWh (USD 190 per MWh).

Clearly, non fossil fuel-generated electricity is often now competitive with coal- and gas-generated electricity and much electricity may start to become be considerably cheaper in the coming years.

These diverse power sources have to be combined into a system that will meet our needs. This is discussed further in Chap. 12.

7.2 The Cost of Storage

It was seen in Chap. 6 **that the most practical methods of energy storage are**: firstly, electric batteries; secondly, pumped storage; and thirdly, producing synthesised fuel or hydrogen and restoring this as energy on demand.

The first method is currently expensive, although the cost is predicted to fall dramatically by 2030. The second method requires hills and mountains to make it work but has a high efficiency of around 80%. The third method is the most promising for general use. The cost of storage varies between two and three times the amount of energy (average: 2.5) needed to electrolyse the water, plus around USD 0.02 per kWh to cover the capital cost over the lifetime of the gas turbine generator and its maintenance. It is assumed that usually the hydrogen will be stored in storage that has previously been used for fossil fuel gas.

7.3 The Cost of Doing Nothing

The cost of not taking action, i.e. doing nothing, is likely to be an important factor in the economics of both global warming and exhausting fossil fuels.

The total economic and insured costs of catastrophic weather events from 1989 to 2013 as recorded by the Munich Re insurance company have gone up since 1980. The figures for 2005, approximately USD 200 billion for insured losses, show the financial impact of Hurricane Katrina in the USA.

There is no complete proof that Hurricane Katrina was caused by global warming. Katrina will be recorded as the most destructive storm in terms of economic losses. It certainly serves as an example of how high economic losses caused by catastrophic weather events can be. Estimates from the insurance industry, as of late August 2006, had reached approximately USD 60 billion in insured losses (including flood damage) from Katrina. The storm could cost the Gulf Coast states as much as an estimated USD 125 billion when, and if, a final toll is ever tallied, according to NOAA, parent organisation to the National Weather Service.

The storm may not have been caused by global warming, but there is a school of thought that we are experiencing more storms with higher wind speeds, and that these storms will be more destructive, last longer and cause landfall more frequently than in the past. Because this phenomenon is strongly associated with sea surface temperatures, it seems reasonable to suggest that there is a strong probability that the increase in storm intensity and climate change are linked.

Damage caused by Hurricane Katrina pales into insignificance compared with the damage that rising sea levels is predicted to be cause to major cities, as illustrated in Figs. 1.4, 1.5, 1.6 and 1.7 in Chap. 1.

There is a school of thought that if the vast majority of informed scientists are right about global warming, eventually lawyers may bring successful prosecutions against people who may be held responsible for damage, such as the oil companies. Bearing in mind that the risks of damage to life and property are substantial, and that alternative energy sources may be cheaper anyway, it would seem wise to pursue alternative energy solutions.

The Pacific Island State of Palau recently announced that it will seek an Advisory Opinion from the International Court of Justice asking whether countries have a responsibility to avoid producing emissions causing climate change damage elsewhere.

Many Pacific Islands are extremely vulnerable to the impacts of climate change and sea level rise is predicted to eventually make some islands uninhabitable. For instance, the highest point on the island nation of Tuvalu is just 4.6 m above sea level.

In 2002, Tuvalu threatened to sue Australia and the USA over the impacts of climate change. To date, Tuvalu has not brought about the threatened litigation.

Instead, Tuvalu, Palau and other Pacific Islands have focused their efforts on the international climate negotiations, because the Kyoto Protocol runs out in 2012.

But their attempts (and those of other States) to secure a new international agreement with strong cuts to greenhouse gas emissions have been unsuccessful.

In Miami (AFP), a lawsuit over climate change filed by 21 young Americans has gained the attention of the fossil fuel industry, which is joining the US government to oppose the plaintiffs' demands for sharper pollution cuts.

The plaintiffs, aged 8–19, include the granddaughter of renowned climate scientist James Hansen, formerly of NASA, and a well-known advocate of reducing the greenhouse gases that are causing the planet to heat up.

The plaintiffs want the government to commit to significantly reducing carbon dioxide emissions and implement "a science-based climate recovery plan" that protects the Earth for future generations, according to the Oregon-based group, Our Children's Trust.

In this, the 115th Romanes lecture, at Oxford University Dr. Steven Chu, who shared the 1997 Nobel Prize in Physics, likened possible litigation to litigation over smoking where there was a considerable delay between the event and it becoming clear that smoking caused harm. He explored how we can use science, technology and public policy to mitigate the risks and make sustainable energy the most attractive, low-cost option. The future potential litigation over global warming is likely to be interesting.

7.4 The Cost of Adapting Infrastructure for Energy Produced by Alternative Means

The infrastructure for using this electricity will need to be implemented. That is, a system that will allow the full infrastructure including transport, agricultural machinery, aeroplanes and ships will be necessary to make use of the new energy.

Supplying electric trains, trams and trolley buses with electricity from alternative energy will not be a problem. Vehicles that have previously run from fossil fuels will have to be designed to be able to use the new energy. Either the energy will need to be adapted to run using the energy from alternative sources. In the case of motor vehicles, aeroplanes and ships, either the energy will need to be adapted to a form such as synthesised kerosene that the vehicles can use, or the vehicles will need to be redesigned in a form where they can run from the new fossil fuel-free energy. A simple example would be a battery-run electric car that can simply recharge from fossil fuel-free electricity, or even a nuclear ship. This may not always be possible and aeroplanes may need to be redesigned to cope with the alternative energy. Where another form of transport could be used, such as high-speed trains over land routes, passengers would need to be encouraged to switch from aeroplanes to this form of transport. In this case, passengers may be encouraged by the facts that high-speed trains use one fourteenth of the energy of a jet, are much quicker to load and unload and are potentially considerably more comfortable. Again, cost may be a deciding factor, or, in the case of using an automated trackway for cars, speed may of travel and the ability of the vehicle to park itself may be influencing factors.

The infrastructure for using this electricity will need to be implemented. Electric trains, which are highly energy-efficient already use electricity directly. Bearing in mind that high-speed trains use one fourteenth of the energy of jet airliners, their use should be encouraged to replace air travel over short and medium journeys over land.

Either battery electric vehicles or fuel cell electric vehicles should largely replace internal combustion engines for road transport. Although there are an increasing number of electric vehicles that are now available, much of the infrastructure for their use, including available public charging points and hydrogen filling stations, is not yet in place. These facilities need to be put in place urgently. Alternatively, automated transport systems in which electric vehicles can use a track where they will be driven under automated control need to be developed rapidly.

Where air travel is essential, conventional aeroplanes should use fuel synthesised from water and carbon dioxide obtained from the atmosphere. Ships should also use synthesised fuel. Widespread use of air transport using hydrogen is considered to be on the whole impractical, and synthesised fuel is considered to be preferable.

Agricultural and other heavy plant machines should utilise hydrogen or synthesised fuels.

7.5 The Price of Fossil Fuels

From an economic point of view, the cost of oil and other fossil fuels will be an important factor. At the time of writing this, the price of fossil fuels is low but, as will be seen later in the book. There is still an economic argument for switching to alternative energy.

The price of oil is unlikely to remain low. Partly because unless a reasonable return on investment for exploration can be gained, oil and other companies are likely to cut back on exploration, and partly because too many people have a vested interest in obtaining a reasonable price for oil.

It is therefore expected that the price of oil will rise and this will make an even stronger case for the adoption of appropriate forms of alternative energy.

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Chapter 8
Land Transport Without Fossil Fuels

8.1 Land Transport

Different forms of transport use widely different amounts of energy and it is important to understand this when comparing one form to another. It also enables us to judge whether one form of transport can be substituted for a more economical form or one that can use electricity directly from an alternative energy source.

Some transport statistics for Japan (Fig. 8.1) show that the car uses the most energy per unit, with the bullet train, or Shinkansen, using the least.

Comparing various modes of transport is difficult since a lot depends on the percentage occupancy of the mode concerned. Assuming 100% occupancy, the Boeing jet uses the most energy by far, with the two types of trains using a much lower amount, as illustrated on Fig. 8.2.

Clearly, public transport is considerably more energy-efficient than motor cars, air and sea transport. Even buses, which are not as energy efficient as rail transport, use just over one quarter of the energy than cars do.

It should be noted that the conventional electric train at 100 mph uses 4% of the energy of the Boeing 747 and the high-speed train uses 7.4% of the energy of the Boeing 747. The electric train, at 100 mph, uses 7.5% of the energy of the fully loaded car and the high-speed train uses 16% of the energy of a fully loaded car. Some caution is needed when using these figures as the efficiency of converting fuel into energy is used for the calculation of the Boeing 747 and for the car, whereas the high-speed train figure is calculated for the output from the power station. Nevertheless, both conventional trains at 100 mph and the high-speed train are considerably more energy-efficient in terms of kWh per person per km than both the aeroplane and the car.

J. Lowry, *Avoiding Carbon Apocalypse Through Alternative Energy*,
DOI 10.1007/978-3-319-52195-4_8

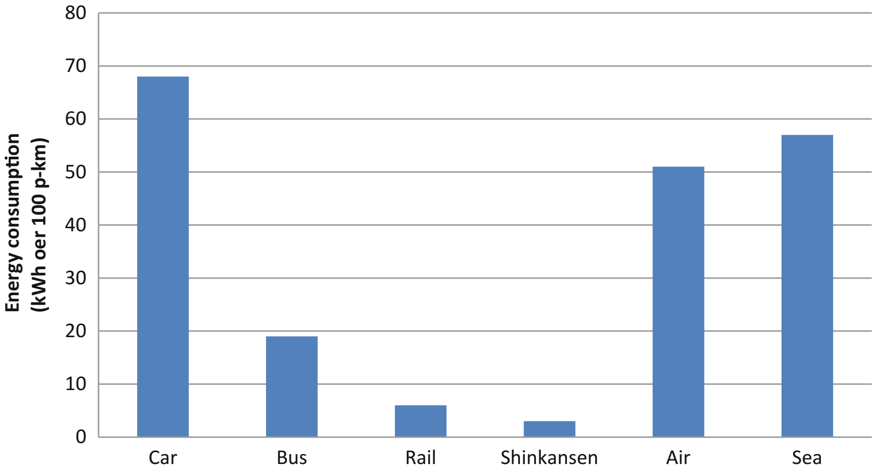

Fig. 8.1 Overall transport efficiencies in Japan in 1999 (compiled from figures in *Sustainable Energy Without the Hot Air*) (*Source* John Lowry)

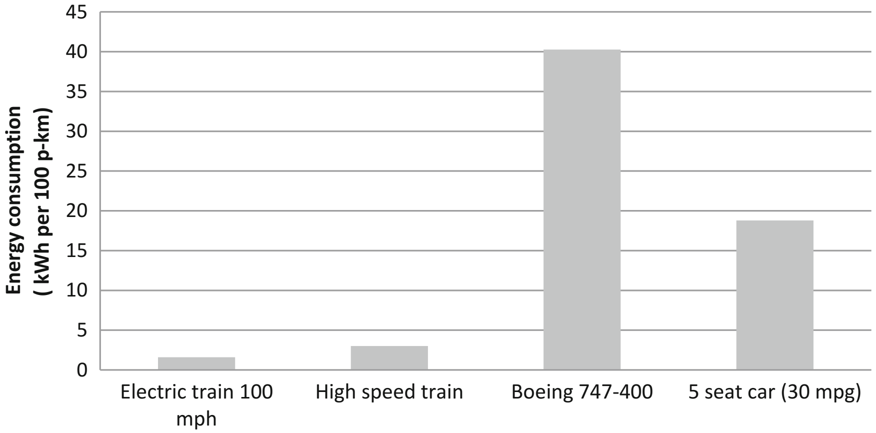

Fig. 8.2 Comparison of different forms of transport with 100% occupancy (compiled from *Sustainable Energy Without the Hot Air*) (*Source* John Lowry)

8.1.1 Trains

Electric trains are well developed and the impressive energy figures compared with airliners and cars show how attractive trains are in energy terms. Trains have the advantage over road vehicles in that they can take energy directly from the electric grid provided that the rail line is electrified. In addition to energy saving considerations, train companies prefer electric trains to combustion engine trains as they are more reliable, lighter and require far less maintenance.

Fig. 8.3 Line-up of Shinkansen trains in Japan, October 2009 (*Source* http://en.wikipedia.org/wiki/Shinkansen)

Electric trains continue to develop and high-speed trains over land are already competitive with aircraft over land for short and medium distances. High-speed trains started with the development of the Shinkansen, or bullet train, in Japan, illustrated in Fig. 8.3. Modern high-speed trains in Japan reach speeds of 300 km/h. The current system carries 151 million passengers per year and runs up to 13 trains per hour with a capacity of 1323 seats.

Not only do high-speed trains save a considerable amount of energy, but they are also profitable. In Japan, they have brought the country closer together, allowing people to move from city to city quickly, which has in itself brought about considerable benefits to business and to the country in general.

High-speed trains are used successfully in other countries such as France and China. The French hold the current speed record for a conventional train; a French TGV (*Train à Grande Vitesse*) reaches a speed of 574.8 km/h (357.2 mph).

High-speed trains could benefit countries such as the USA, which relies heavily on air transport. This would allow high-speed transport from city centre to city centre without the problems of high energy use and the pollution associated with air travel.

The world record for a non-conventional manned train is held by the experimental Japanese JR-Maglev, which achieved 581 km/h (361 mph) on a magnetic levitation track. Maglev trains (Fig. 8.4) do not use wheels but run on a special track on which the train is magnetically levitated and moved forward by linear electric motors. The trains are theoretically capable of very high speeds.

Fig. 8.4 Maglev in Shanghai (*Source* https://en.wikipedia.org/wiki/High-speed_rail_in_China#/media/File:Picture-4.jpg)

High-speed electric trains are an important development as not only are they energy-efficient, consuming a fraction of the energy of airliners, but also they are starting to reach speeds where they can become competitive with air transport for inter-city transport overland, particularly where new tracks are used. Initially, this is true on shorter routes but speeds are increasing all the time. Trains have added advantages in that they can travel to and from city centres, whereas aeroplanes have to land at airports often placed at considerable distances from the city centre. Plus, trains are quicker to load and unload than aeroplanes. In countries such as France where electricity is largely generated by nuclear power, electric trains do not rely on fossil fuels and produce no carbon emissions.

8.2 Road Transport

8.2.1 Battery Electric Vehicles and Light Vans

Developing road transport that can be free from fossil fuels is considerably more complex than for electric trains, which can be connected to the electric grid by supply lines using electricity generated from fossil fuel-free sources—as is the case in France. Until recently, there were no effective road vehicles that could be considered suitable for transporting passengers and goods at reasonable speeds over reasonable distances.

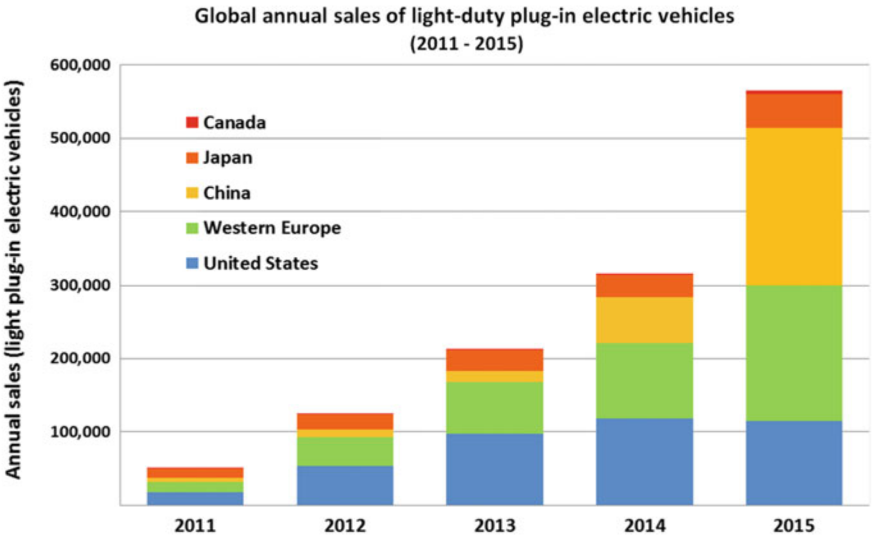

Fig. 8.5 Annual sales of light-duty plug-in electric vehicles in the world's top markets (*Source* https://en.wikipedia.org/wiki/Electric_car_use_by_country#cite_note-Global2011_2015-5between%202011%20and%202015)

Perhaps the biggest change in electric vehicles in the last few years has been the development of the lithium battery, which has a reasonable specific energy and a more reasonable charge time than previous batteries.

Adoption of electric vehicles started slowly but continues to develop. Figure 8.5 illustrates the growth of electric vehicles between 2011 and 2015.

Several countries including Norway, the Netherlands and India are looking into requiring all new cars to be fully electric, starting in 2025 in the case of the Netherlands and Norway and by 2030 in the case of India. Whilst this has not yet been enshrined in law, it is a good indicator of the way in which people are thinking.

Developments have ultimately led to a series of commercial vehicles such as the Tesla Roadster (Fig. 8.6), which is a battery electric vehicle (BEV) produced by Tesla Motors in the USA. The Roadster is the first production automobile to use a lithium ion battery and the first production BEV (all-electric) to travel more than 200 miles (320 km) per charge.

More recently, manufacturers such as Nissan, Mitsubishi and Renault are quantity producing commercial electric vehicles such as the Nisan Leaf (see 8.11). The Nissan Leaf is a five-door hatchback using a 24 kWh lithium ion battery driving a synchronous motor. It has a typical range of 100 miles and can be rapidly charged to 80% of the battery capacity in half an hour.

Nissan are also marketing a van and a seven-seater minibus.

Renault have produced a range of electric vehicles such as the new Renault Kangoo van (Fig. 8.7) and the Renault Zoe, a small five-seat, four-door car with a

Fig. 8.6 The Tesla Roadster

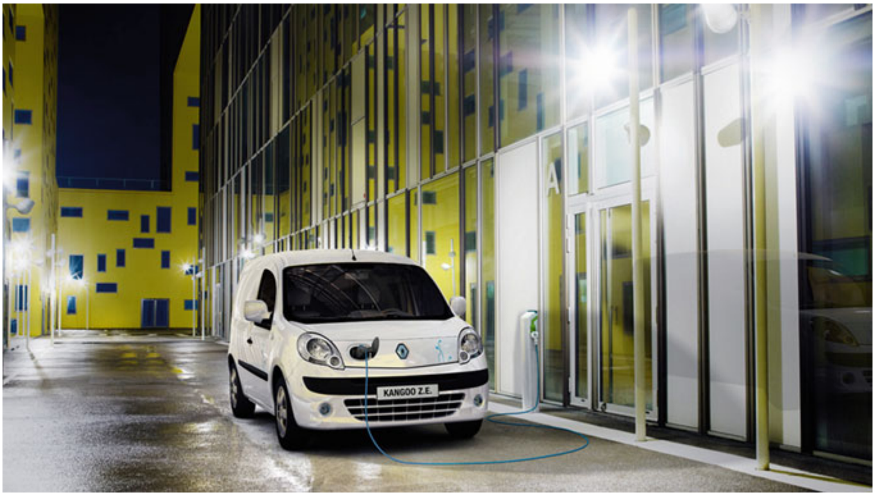

Fig. 8.7 Renault Kangoo electric. Renault has decided to sell the car whilst the batteries need to be leased, which may be a system that appeals more to the public (reproduced with kind permission of Renault)

Fig. 8.8 Renault Zoe (*Source* NRMA New Cars)

range of 135 miles, which can be fast-charged in 35 min (Fig. 8.8). Plus, with government subsidies in the UK, electric vehicles look economically attractive compared with their internal combustion counterparts. Ranges are increasing all the time and charge times are reducing.

In 2012, Tesla introduced the Tesla S, a pure electric four-door sedan that can seat five adults as well as two children (Fig. 8.9). It can have a range of 160 miles, 230 miles or 300 miles depending on the battery pack option. It therefore will easily cover 96% of journeys. Effectively, with the biggest 300 mile battery pack, it will compete well with internal combustion engine vehicles. It can be rapidly charged in half an hour.

Fig. 8.9 The Tesla S (*Source* http://www.teslamotors.com/blog/alpha-hits-road)

The Model S is expected to have swappable batteries and is intended to compete with more luxurious cars such as the Mercedes E series, the Audi A6 and the BMW 5 series. The car has a 0–60 mph (97 km/h) time of 5.5 s. The body panels and chassis will be primarily aluminium.

Tesla delivered 50,580 vehicles last year. Most of those were its Model S saloon, which overtook the Nissan Leaf to become the world's most popular selling pure-electric vehicle.

Tesla has announced it Model 3 electric car. The price and range of this five-seater should make the vehicle appeal to new types of customers and could boost interest in other electric vehicles.

Chief executive Elon Musk said his goal was to produce about 500,000 vehicles a year once production reaches full speed. In total, 180,000 vehicles have already been pre-ordered. The basic model will start at USD 35,000 (GBP 4423) and have a range of at least 215 miles (346 km) per charge.

For the first time, drivers will have access to an affordable electric vehicle at a reasonable price that also gives a reasonable range. With the development of a reasonable recharging infrastructure the Model 3 will be acceptable to a majority of drivers and such vehicles will be an acceptable replacement for internal combustion engine vehicles.

The first deliveries of the vehicle are scheduled to start in late 2017, and it can be ordered in advance in dozens of countries, including the UK, Ireland, Brazil, India, China and New Zealand. The vehicle is illustrated in Fig. 8.10.

The release of the Tesla Model 3 will also encourage other manufacturers to come up with competitive designs that sell at prices that are competitive with internal combustion engine vehicle and have a range of over 200 miles.

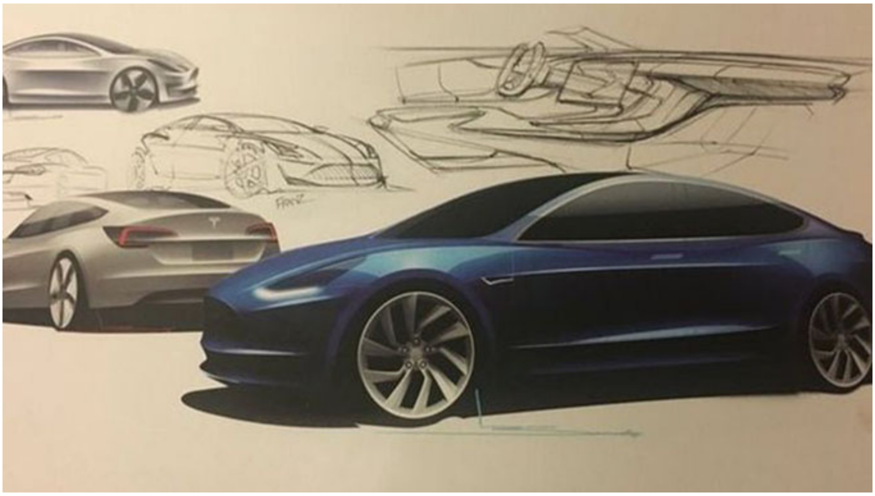

Fig. 8.10 The Model 3 Tesla electric car

Fig. 8.11 The Nissan Leaf

Another way to improve the range of electric vehicles is with the use of rechargeable hybrid vehicles, originally invented by Ferdinand Porsche (Fig. 8.10). A hybrid vehicle can use two forms of energy, such as a battery and an internal combustion engine.

The new Nissan LEAF 30 kWh, shown in Fig. 8.11, can travel up to 155 miles per full charge, based on the New European Driving Cycle (NEDC).

Nissan also sell a light van and a seven-seater minibus, shown in Fig. 8.12.

There has been much criticism in the motoring press about the limited range of vehicles of this type. As such, it is worth taking a look at typical lengths of motor

Fig. 8.12 NV200 Combi 7 seater

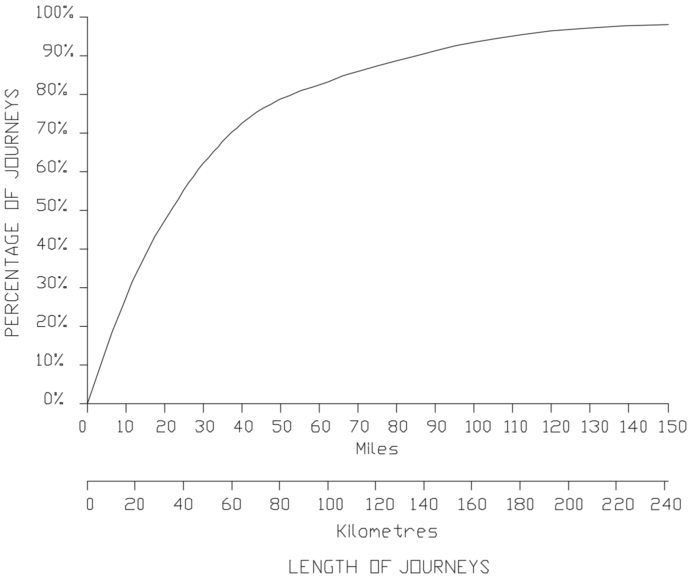

Fig. 8.13 Typical journey lengths in the USA (adapted from data from http://www.hybridconsortium.org/dot_data.html) (*Source* John Lowry)

Table 8.1 Frequency of car journey lengths in the UK

Percentage of journeys (%)	6	16	33	22	17	4	1	1
Length of journeys (miles)	<1	1–2	2–5	5–10	10–25	25–50	50–100	<100

Derived from http://webarchive.nationalarchives.gov.uk/20100514175047/http:/www.dft.gov.uk/adobepdf/162469/221412/221531/223955/32274311/NTS2008.pdf
Source John Lowry

journeys. Figure 8.13 shows typical journey lengths in the USA where it can be seen that around 90% of journeys are less than 100 miles. The frequency of different car journey lengths in the UK is shown in Table 8.1, which shows that journey lengths, not surprisingly, are considerably shorter—98% of journeys are less than 50 miles.

The US Department of Transport's Nationwide Personal Transportation Survey data contradict the popular notion of long daily commutes for most Americans. In actuality, of those personal automobiles on the road, 42% travel less than 15 miles each day, approximately 50% drive about 25 miles a day, and approximately 80% drive 50 miles a day or less. More surprising is that these data show that less than 5% travel 100 miles or more daily.

Lithium batteries continue to develop rapidly and future batteries are likely to have considerably higher specific energy so that the future equivalent of the Nissan Leaf may have a much greater range.

8.2.2 Hybrid Electric Vehicles

One method to increase the range of battery electric vehicles is to use hybrid electric vehicles. This is an idea that dates back to 1900. In hybrid vehicles, range can be extended by another power source, such as an internal combustion engine. If the vehicle is not to use fossil fuels, a fuel must be used such as biofuel or synthesised fuel. A Lohner Porche, designed and driven by Dr. Ferdinand Porsche, is shown in Fig. 8.14.

Recently, General Motors have released the Volt, a rechargeable hybrid (Fig. 8.15). This can complete many of its journeys using electricity, relying on the internal combustion engine as a range extender for longer journeys. The Volt is a four-door saloon with a range of 35 miles when running on the rechargeable lithium ion batteries but with an overall range of 379 miles from one petrol tank.

The new Toyota Prius (Fig. 8.16) is a rechargeable hybrid with a range of 16 miles when using the batteries alone.

When driving on batteries alone, the current range of rechargeable hybrid vehicles is too short to make considerable inroads into the reduction of fossil fuels. However, the range will increase in the future.

A crude analysis based on Fig. 8.8 would indicate that in the USA, the Chevrolet Volt would save 63% and the Prius would save 35% of the fuel that an internal combustion engine vehicle would have used. A hybrid vehicle in the USA with an electric-only range of 50 miles would save 80% of the equivalent fuel; with a range of 75 miles, would save 90%; and with a range of 100 miles, would save 97%. All

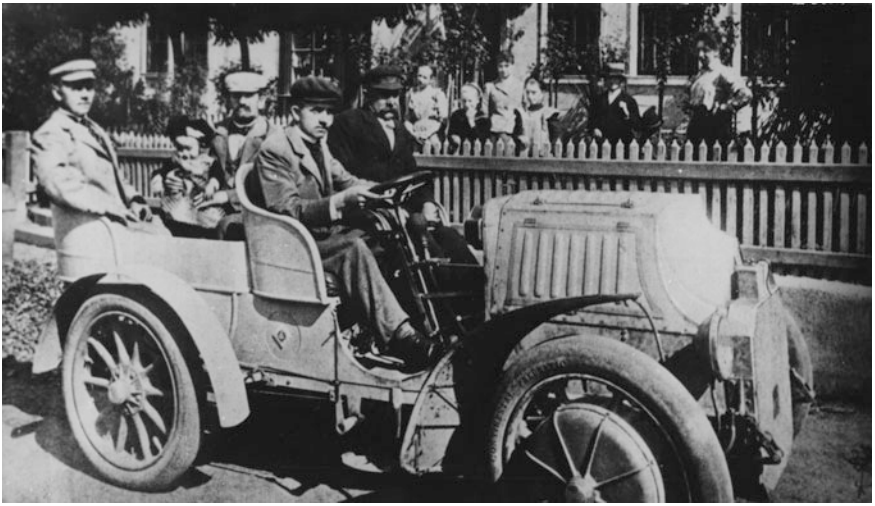

Fig. 8.14 The Lohner Porsche was the first electric hybrid vehicle, designed and driven by Dr. Ferdinand Porsche (*Source* Beaulieu Motor Museum)

Fig. 8.15 The Chevrolet Volt (reproduced with kind permission of Chevrolet)

Fig. 8.16 Rechargeable Toyota Prius (reproduced with kind permission of Toyota)

that would be needed to make this a fossil fuel-free vehicle would be to use a non-fossil fuel, such as a synthesised fuel. In the UK, with its lower average journey lengths, a hybrid vehicle with an electric-only range of 25 miles would use only 6% of the fuel used by an equivalent internal combustion engine vehicle. This would reduce still further to 2% if the electric-only range was increased to 50 miles.

8.2.3 Fuel Cell Vehicles

A fuel cell vehicle (FCV) or fuel cell electric vehicle (FCEV) is an alternative to battery electric vehicles. It is a type of vehicle that uses a fuel cell to power its on-board electric motor. Fuel cells in vehicles create electricity to power an electric motor, generally using oxygen from the air and hydrogen. Normally, the hydrogen is stored in a pressurised container, as discussed in Chap. 5.

Fuel cells have in the past been prohibitively expensive but recently the cost has been reduced and it is hoped with high volume production, the cost can be brought down to USD 40 per kW by 2020 and ultimately to USD 30 per kW.

By 2010, advancements in fuel cell technology had reduced the size, weight and cost of fuel cell electric vehicles.[1] In 2010, the U.S. Department of Energy (DOE) estimated that the cost of automobile fuel cells had fallen 80% since 2002 and that such fuel cells could potentially be manufactured for USD 51 per kW, assuming high-volume manufacturing cost savings. Fuel cell electric vehicles have been produced with "a driving range of more than 250 miles between refueling". They can be refueled in less than 5 min (see Footnote 1). Deployed fuel cell buses have a 40% higher fuel economy than diesel buses. EERE's Fuel Cell Technologies Program claims that, as of 2011, fuel cells achieved a 42–53% fuel cell electric vehicle efficiency at full power, and a durability of over 75,000 miles with less than 10% voltage degradation—double that achieved in 2006. In 2012, Lux Research, Inc. issued a report that concluded that "Capital cost… will limit adoption to a mere 5.9 GW" by 2030, providing "a nearly insurmountable barrier to adoption, except in niche applications". Lux's analysis concluded that by 2030, PEM stationary fuel cell applications will reach USD 1 billion, while the vehicle market, including fuel cell forklifts, will reach a total of USD 2 billion.

Fuel cell vehicles have the advantage over batteries that they can give much longer ranges. Recently, Honda introduced the FCX Clarity (Fig. 8.17), which runs on hydrogen. This is currently available as a lease to customers in the USA and is not yet available for general sale. The Honda FCX has an impressive range of 270 miles and has a top speed of 100 mph.

The hydrogen is stored at pressure in a tank (see Fig. 7.2) containing 4.1 kg of hydrogen at 5000 psi (340 bar).

Recently, two fuel cell vehicles have become available commercially. The first is the Toyota Mirai, which is a hydrogen-powered production car that is commercially available. The second is the Hyundai ix35 Fuel Cell vehicle. The Toyota Mirai is illustrated in Fig. 8.18 and the Hyundai ix35 Fuel cell vehicle in Fig. 8.19.

There are a range of larger fuel cell vehicles that have been trialed (Fig. 8.20).

There are also demonstration models of buses; in total, there are over 100 fuel cell buses deployed around the world today. Most of these buses are produced by UTC Power, Toyota, Ballard, Hydrogenics, and Proton Motor. UTC buses have already accumulated over 970,000 km (600,000 miles) of driving. Fuel cell buses have a 30–141% higher fuel economy than diesel buses and natural gas buses. Fuel cell buses have been deployed around the world including in Whistler Canada; San Francisco, USA; Hamburg, Germany; Shanghai, China; London, England; São

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[1] https://en.wikipedia.org/wiki/Fuel_cell_vehicle#cite_note-progressreport-81.

Fig. 8.17 Honda FCX Clarity (*Source* http://en.wikipedia.org/wiki/Honda_FCX_Clarity)

Fig. 8.18 The Toyota Mirai (*Source* https://upload.wikimedia.org/wikipedia/commons/f/f3/Toyota_Mirai_in_Warsaw%2C_Poland_Nov_2015_IMG_0123.JPG)

Paulo, Brazil; as well as several others. The fuel cell bus club is a global cooperative effort in trialling fuel cell buses. Notable Projects Include:

- 12 Fuel cell buses are being deployed in the Oakland and San Francisco Bay area of California.
- Daimler AG with 36 experimental buses powered by Ballard Power Systems fuel cells completed a successful 3-year trial, in 11 cities, in January 2007.

Fig. 8.19 Hyundai ix35 Fuel Cell vehicle

Fig. 8.20 Mercedes-Benz fuel cell bus (photograph reproduced by kind permission of Ballard Power Systems)

Fig. 8.21 An elevated view of London's first hydrogen fuel cell bus showing the six roof-mounted hydrogen fuel tanks (*Source* http://en.wikipedia.org/wiki/Fuel_cell_bus)

- A fleet of Thor buses with UTC Power fuel cells was deployed in California, operated by SunLine Transit Agency.

The first Brazilian hydrogen fuel cell bus prototype in Brazil was deployed in Sao Paulo. The bus was manufactured in Caxis do Sul and the hydrogen fuel will be produced in Brazil from water through electrolysis. London's first fuel cell bus is shown in Fig. 8.21.

Another way of boosting the range of electric vehicles is to arrange for electric pickups on the road. Trams and trolley buses widely used this technology in the early twentieth century.

8.2.4 Autonomous Cars

An autonomous car (driverless car, self-driving car, robotic car) is a vehicle that is capable of sensing its environment and navigating without human input. These self-driving cars have attracted a lot of publicity recently and are basically electric cars under computer control. They will not in themselves save any more fossil fuel

Fig. 8.22 Google's driverless car (*Source* https://en.wikipedia.org/wiki/Google_self-driving_car#/media/File:Google_driverless_car_at_intersection.gk.jpg)

than electric cars do; however, combined with road rail systems discussed later in this chapter, they could.

A google driverless car is illustrated in Fig. 8.22.

8.2.5 *Electric Bikes*

The proliferation of electric bikes and electric motor bikes is another important area that is developing rapidly.

E-bikes have exploded in popularity in China, for example, where they can provide a quick, low cost method of getting around. This is illustrated in Fig. 8.23. A firm marketing electric bikes in the UK claim electric bicycles using cycle lanes is the quickest way to get around London. Judging by the speed of London traffic, I am inclined to believe them.

There is an important place for bicycle tracks in cities and towns that allow bicycles and electric bikes to move through the city in safety and comfort. As the use of electric vehicles grows, the cities will become less polluted and bicycle tracks will be a pleasant way to move around the city.

Bicycle routes should become an essential part of town and city transport. As fossil fuel transport powered by alternative energy, pollution will be largely eliminated, making bicycles and e-bikes a very pleasant way of moving around towns and cities (Fig. 8.24).

Fig. 8.23 Electric bicycles in China (*Source* http://www.electric-bicycle-guide.com/chinese-electric-bike.html)

Fig. 8.24 Former railroad line transformed into bicycle path between Metelen and Steinfurt, in Germany

Fig. 8.25 Zero DS (motorcycle)

8.2.6 *Electric Motorbikes*

There are now several electric motor bikes available commercially, such as the **Zero DS** Electric Motorcycle, which illustrated in Fig. 8.25 as an example of a modern battery electric vehicle.

There are several experimental prototypes using fuel cell technology. ENV, developed by Intelligent Energy, is a hydrogen fuel cell prototype. The motorcycle has a range of 100 miles (160 km) and can reach a top speed of 50 mph (80 km/h). Suzuki has also developed a concept hydrogen fuel cell scooter based on the Suzuki Burgman. Yamaha has created a hydrogen fuel cell prototype called FC-AQEL, which is considered equivalent to a 125cc vehicle. Honda has also developed a hydrogen fuel cell scooter.

The Suzuki Burgman, an electric motor scooter, is illustrated in Fig. 8.26.

Fig. 8.26 A fuel cell motorbike (*Source* https://commons.wikimedia.org/wiki/File:Zero_Z-Force.jpg)

8.2.7 Trams and Trolley Buses

Trams were an ideal form of city transport as they could use electricity generated from any source and their use of steel wheels running on tracks had low rolling resistance, which made them potentially highly energy efficient. An example of a double decker tram in London (Hanwell to Brentford) in 1910 is illustrated in Fig. 8.27.

With the advent of internal combustion engines running on cheap oil, trams and trolley buses were largely abandoned, which, viewed from today's perspective, seems akin to an act of vandalism. Trams and trolley buses using modern technology are now making a comeback (Fig. 8.15). Trolley buses have the advantage over trams in that rails do not need to be installed, but wheels using tyres have a higher rolling resistance and they are not quite as energy efficient.

Trolley buses represent another old idea which is being brought back to provide a modern carbon-free transport solution.

Figure 8.28 shows a modern Cristalis trolleybus in Lyon, France. A bus/train from the Manchester Metrolink is illustrated in Fig. 8.29.

A modern bus/train system is used in Manchester (Fig. 8.29).

Fig. 8.27 A double deck London (Hanwell to Brentford) tram in 1910 (*Source* http://en.wikipedia.org/wiki/Tram)

Fig. 8.28 A modern Cristalis trolleybus in Lyon, France (*Source* http://en.wikipedia.org/wiki/Trolleybus)

Fig. 8.29 A bus/train from the Manchester Metrolink (*Source* http://en.wikipedia.org/wiki/Manchester_Metrolink)

8.2.8 Road Rail Systems

The idea of a road rail system in which vehicles can travel on roads either as conventional vehicles or on a special track has several advantages. It would combine the benefit of a road vehicle with its free ranging travel with train systems where vehicles can travel for considerable distances without hold ups in relative safety and comfort. Such a system would enable electric vehicles on the track to be under automatic control and to take electrical energy from the track.

By picking up electricity as vehicles progress along the track, battery electric vehicles could travel for many miles without being curtailed by the limited range and cost of current battery technology.

A road rail system is proposed in which electric vehicles, energised by either electric batteries or fuel cells could be used. The vehicles would run on their own tyres but would be automatically controlled whilst on the track. The tyres would be low-drag tyres using minimum energy but would be suitable for ordinary use as well as the track.

The track would consist of special lanes located on motorways and major roads. Only authorised vehicles would be able to use the electric track. Computer control would not only ensure that only authorised vehicles would be allowed on the track, but also that the vehicles were correctly maintained and that the tyre pressures were correct before entry was permitted.

The vehicles would be supplied with electricity, either by electric pick-up from supply rails, possibly using the tyres as conductors, or using inductive pick-up rails. These systems would be designed to avoid the unpleasant flashing that is common on underground electric trains.

Whilst on the track, the electric motors would take their electricity from the electric supply line and, at the same time, on-board rechargeable batteries would be topped up, allowing vehicles using the system to leave with charged batteries.

Another advantage is that because the vehicles have on-board batteries, the system would not need to supply electricity at all points along the route and complex electric power pick-up systems at junctions could be avoided.

The track system could be designed to take a variety of vehicles from cars and light vans to larger commercial vehicles. The vehicles would not necessarily have access to all parts of the trackway. For example, it may be permissible to open up parts of the trackway to all vehicles up to 2.6 m wide and of limited weight but to only allow cars and light vans to use the system to travel through cities. Thus, cars and light vans with a maximum vehicle width of 1.8 m, a height of under 1.8 m and a maximum vehicle mass of 2.5 tonnes may be allowed to use lighter trackways, whereas heavier and wider vehicles would have to progress through cities on conventional roads.

In addition, the times at which vehicles could use the system could be controlled by the time of day. It may be desirable, for example, to limit the use of heavy commercial vehicles to times of day when traffic was light, or at nighttime.

In this way, lighter vehicles could use a trackway with a maximum width of around 2 m allowing a smaller lighter trackway to be threaded through towns and cities. Lorries wishing to travel through towns and cities would have to use conventional road possibly at night.

The system is considered to be particularly suitable for use on motorways as well as intercity use. On the motorway, the central lanes would be devoted entirely to the system, as illustrated in Fig. 8.30. Internal combustion vehicles would be banned from using the system. Once on the track, vehicles would be automatically controlled including steering, speed and spacing. The whole system would be controlled by a central computer. Smaller computers would look after local controls, such as speed and braking distances.

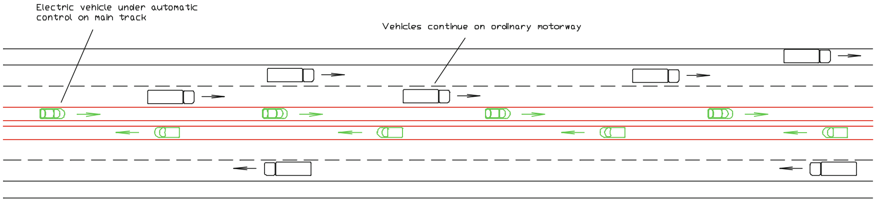

Fig. 8.30 Aerial view showing automated track (*Source* John Lowry)

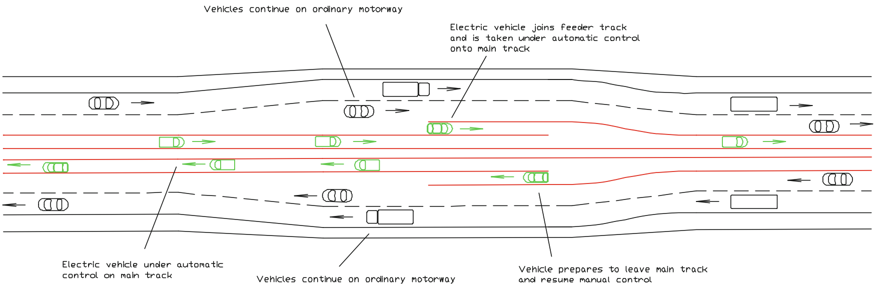

Fig. 8.31 Vehicles would join and leave the track using feeder and exit lanes (*Source* John Lowry)

Vehicles wishing to join the system would drive into the feeder lanes and be taken under automatic control and join the main track, as illustrated in Fig. 8.31. The feeder lanes would be considerably longer than indicated in the diagram. Conventional vehicles would continue driving on the motorway as normal.

Vehicles could leave the system at appropriate places. The computer would guide the vehicles into exit lanes where the driver would resume manual control and simply return to the normal traffic using their own on-board batteries.

Most parts of the UK lie well within 100 miles of a motorway, a distance that would be covered by the battery. As such, the system would allow electric vehicles to travel throughout the UK. The system could also be used on trunk roads outside the motorway network.

The intracity system would allow vehicles to travel rapidly within a city. Because the system is compact and relatively light, it could be fed through the city with relative ease without causing major disruption. Vehicles could leave the system at appropriate places returning to manual control and simply return to the normal traffic using their own on-board batteries.

Vehicles being automatically controlled whilst on the system would confer several advantages. Greater packing density in terms of number of vehicles per mile would result, since braking distances would be kept to a minimum and lane widths could be minimised. Alternatively, the vehicles could be bunched into road trains. The system would be inherently safer than vehicles under manual control, so overall speed could be increased. Vehicles wishing to leave the system would be returned to the normal motorway where they would resume manual control. On busy junctions, a flyover system such as the one illustrated in Fig. 8.32 could be used.

Computer checks would prevent vehicles that have not been serviced regularly from using the system. Run-flat tyres would be used to prevent vehicles becoming inoperable whilst on the system and when tyre pressure fell below predetermined levels, vehicles would be forced to leave at the next junction.

In cities, it would be relatively easy to provide an appropriate track for the vehicles, so the system would allow vehicles to travel relatively quickly.

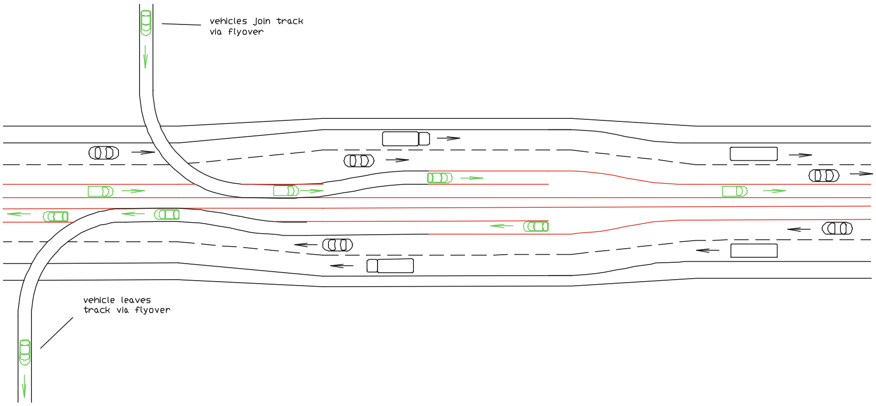

Fig. 8.32 Vehicles join and leave the track via flyovers (*Source* John Lowry)

There are no insurmountable technical problems that would prevent an electric road rail system from being successfully developed. The system would allow drivers and passengers to travel considerable distances between towns and cities in comfort whilst allowing them the flexibility of conventional motor vehicles on leaving the system. The system would allow relatively rapid intercity travel, avoiding traffic jams and tediously slow journeys, and would also minimise road accidents.

8.2.9 Agriculture and Plant Without Fossil Fuels

Agriculture is the most important sector that must be addressed if our fossil fuels run out. If oil is in short supply or unavailable we would, for example, be able to make journeys by public transport rather than driving in our cars. However, if agriculture cannot be run without fossil fuels, mass starvation would result.

Agriculture depends largely on oil to drive modern agricultural machinery such as tractors and combine harvesters. Fossil fuels are also consumed when transporting food to its desired market and energy is required for mills and other food processing, as well as for irrigation and for crop drying. The latter could, on the whole, be powered from electricity.

At busy periods, such as during harvesting, energy is required more or less continuously, often in remote places, and this has to be borne in mind in whatever solution is chosen for running agricultural machinery without fossil fuels. For example, battery-powered machinery may not be an acceptable solution in many cases because there is not necessarily an electric supply available, and stopping to recharge batteries is time consuming.

Fig. 8.33 New Holland fuel cell tractor (*Source* https://commons.wikimedia.org/wiki/File:New_Holland_NH2_hydrogen_tractor_at_Agritechnica_2009)

The amount of fossil fuel needed for agriculture varies depending on the source, but, based on emissions, the USA uses around 14% of the fossil fuels needed by the whole country.

Huge combine harvesters are now needed to bring in the harvest.

Using modern technology, New Holland has produced the world's first fuel cell tractor in Turin, Italy (Fig. 8.33). The tractor's fuel cell generates 106 hp, and its hydrogen tank can hold enough to power the tractor for 1.5–2 h.

Electric tractors run from hydrogen-powered fuel cells would be one option for agricultural machinery. Hydrogen would need to be stored in suitable containers for refuelling but, in principle, this could be made to work.

A more immediate solution would be to use synthesised fuel produced using non-fossil fuel electricity, as outlined in Chap. 5.

There are examples of electric heavy plant such as the Komatsu 860-ik.

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Chapter 9

Air and Sea Transport Without Fossil Fuels

9.1 Aircraft Not Dependent on Fossil Fuels

Air transport is possibly the hardest form of transport to run using non-fossil fuel energy sources. Land transport can be run from electricity by storing it in rechargeable batteries or pressurised containers of hydrogen or, as is the case with trains, electricity can be supplied via supply cables or rails. Nuclear-powered aircraft, if practical, are likely to be considered an unacceptable risk.

It is possible to energise aircraft via transmission sources that beam up energy from the ground in microwaves; this has been done several times for small aircraft, such as models. A Nasa aircraft is shown in Fig. 9.1. At the present time, this can only be done for short distances unless the transmitter follows the aircraft. It is not yet practical for full-sized passenger transport.

Some aeroplanes and virtually all spacecraft can and do run on liquid hydrogen quite successfully. As discussed in Chap. 5, hydrogen can be produced by the electrolysis of water and liquid hydrogen can be stored as fuel. Liquid hydrogen, despite its high specific energy, has a low energy density and requires bulky fuel tanks. High pressure tanks are relatively heavy, weighing around 10 times the weight of hydrogen stored. This is not so important in electric vehicles such as the Honda FCX, but lightness is of vital importance in aircraft. Cryogenic storage of hydrogen is potentially lighter; however, liquefying hydrogen requires energy and the efficiency of production and cryogenic storage is 30–49%, meaning that two to three times the energy is required to end up with liquid hydrogen in the fuel tanks. Producing hydrogen by electrolysis and storing it in pressurised containers is better and efficiencies of 80% can be obtained. Conventional planes can be modified to run on hydrogen and since the beginning of the 1990s, Germany's Dasa have been working on hydrogen propulsion system's within the framework of the German-powered Dornier 328JET. Dornier studied building a 328 demonstrator powered by hydrogen. The liquid hydrogen fuel would have been stored in two external tanks under the wings and outboard of the engines. In addition, the

J. Lowry, *Avoiding Carbon Apocalypse Through Alternative Energy*,
DOI 10.1007/978-3-319-52195-4_9

Fig. 9.1 An artist's impression of the Airbus 310 cryoplane (*Source* http://www.kennislink.nl/publicaties/eerste-vliegtuig-op-waterstof)

Russians developed the Tupolev Tu-155, a hydrogen-fuelled aircraft, which first flew on 15 April 1988. It used hydrogen as fuel initially and the aircraft used cryogenics to store fuel in a fuel tank located in the rear compartment. The Tu-155 used Kuznetsov NK-88 engines. During test flights, 14 world records were established for hydrogen-powered aircraft.

The storage of hydrogen for aviation in reality is limited largely to cryogenic storage (at 22 °K) as the storage tanks need to be as compact and as light possible. To put hydrogen storage into perspective, a Boeing 732-100 has a fuel capacity of 17.9 m^3 and a range of 2850 km. The equivalent fuel tank for liquid hydrogen would have a capacity of 4.04 times the volume, i.e. 72.3 m^3.

The existing fuel tank contains 17.9 m^3 of kerosene, which could be contained inside a sphere of internal diameter of 3.25 ms. The equivalent liquid hydrogen tank would require a cylinder of 3.25 ms diameter fitted with hemispherical ends with an overall length of 9.8 m—34% of the length of the fuselage. Alternatively, the hydrogen could be stored as two 5.5 m long cylinders of 3.25 m diameter, with hemispherical ends mounted under each wing. It is unlikely that the fuel tanks for liquid hydrogen could be fitted in the wing structure, as is often the case with kerosene fuel tanks.

The weight of the kerosene would be 14 tonnes and the liquid hydrogen would be 5 tonnes, nearly 9 tonnes lighter. Despite this, because of the low energy density of hydrogen, tanks would take up more volume. Incorporating hydrogen tanks in simple terms would result in less room for passengers or freight, and using external tanks would result in increased drag.

The hydrogen would need to be stored in insulated flasks. It is debateable whether these would need to be Dewar flasks as the liquid hydrogen would simply cool as it evaporated and the resulting hydrogen could be fed to the engines to produce power. The hydrogen tanks could be cooled from external sources whilst the plane was on the ground. Insulation may be required to prevent passengers getting frost bite, which would not improve business.

Various ideas for hydrogen-fuelled aircraft have been put forward by Boeing and others. An artist's impression of the hydrogen-powered version of the A310 Airbus is shown in Fig. 9.3 using liquid hydrogen tanks located above the passengers. This would result in a bulky aircraft with increased drag.

In this picture, the hydrogen is stored above the passengers. Another arrangement for storing hydrogen is to locate the fuel tanks behind the passengers.

Whilst engines can be modified to run on hydrogen, storing hydrogen in fuel tanks presents some real problems. Sufficient hydrogen cannot easily be stored in pressurised containers, which are heavy, so it has to be stored as a liquid in cryogenic form at 22 °K. Whilst hydrogen-fuelled aircraft undoubtedly would work, considerable redesign of current aircraft would be needed to allow for this.

For conventional aircraft, it would be much simpler to use synthesised fuel as described in Chap. 5. It appears that a similar amount of energy is needed to synthesise fuels such as a kerosene substitute for aircraft as is needed to electrolyse and store hydrogen cryogenically. There are huge advantages of synthesised fuels in that existing aircraft designs can be used, whereas very considerable design and development work is needed to produce a new generation of aircraft fuelled by hydrogen. The military may also respond better to synthesised fuels rather than hydrogen for fuelling their aircraft.

On the fringes of current aviation technology aircraft, we have the A2. A team of British engineers developed the cleaner and supersonic passenger aircraft, code-named A2, which can fly five times faster than the speed of sound. The A2 will use liquid hydrogen as a fuel. Without refuelling, this aircraft will be able to fly up to 12,430 miles or 20,000 km. A sketch of the proposed A2 aircraft taking off is shown in Fig. 9.2 and one of the aircraft in the upper atmosphere is shown in Fig. 9.3.

The A2 will carry up to 300 passengers 20,000 km and use 198 tonnes fuel, i.e.: 0.033 tonne/passenger/1000 km.

The Boeing 747 carries 524 passengers 9800 miles and uses 178 tonne fuel i.e.: 0.1 tonne/passenger/1000 miles 035 tonne/passenger/1000 km.

http://www.reactionengines.co.uk/lapcat.html

The specification for the aircraft is as follows:

Capacity: 300 passengers
Length: 143 m (469 ft)
Wingspan: 41 m (area: 900 m^2)
Max take-off weight: 400,000 kg
*Fuel capacity: 198 tonnes liquid hydrogen
Cruise speed: Mach 5.2 (6400 km/h)
Range: 12,430 miles (20,000 km)

Fig. 9.2 Proposed A2 aircraft (*Source* http://en.wikipedia.org/wiki/Reaction_Engines_A2)

Fig. 9.3 Sketch of A2 aircraft in the upper atmosphere (*Source* http://en.wikipedia.org/wiki/Reaction_Engines_A2)

Specific fuel consumption: 0.86 lbf/lb h at Mach 5, 0.375 lbf/lb h at Mach 0.9
Lift to drag ratio: 11.0 at 5.9 km, Mach 0.9, 5.9 at 25 km Mach 5
Noise: 101 dBa at 450 m lateral

There have been a range of experimental electric aircraft such as The SkySpark (Fig. 9.4), which is a joint project of engineering company DigiSky and the Polytechnic University of Turin. The two-seat Pioneer Alpi 300 has a 75 kW (101 hp) brushless electric motor powered by lithium polymer batteries. The aircraft achieved a world record of 250 km/h (155 mph) for a human-carrying electric aircraft on 12 June 2009.

There have been other hydrogen aircraft. Boeing has demonstrated a manned hydrogen fuel cell airplane (Fig. 9.4). This light aircraft used both a lithium ion battery pack and PEM hydrogen fuel cell.

There have been some proposals to develop electrically powered aircraft such as the VoltAir concept, which could be flying in 25 years. However, whilst it will be interesting to watch the development of such concepts, they are unlikely to come to fruition within the next 25 years.

There have been several hydrogen-powered small aircraft produced such as the Boeing shown in Fig. 9.5. Boeing is not known to have any plans for using fuel cell aircraft commercially. Potentially, fuel cells and an electric motor have a higher efficiency than an internal combustion engine. Storage for the hydrogen would need to be made light enough for use in aircraft.

The Boeing Company has unveiled the hydrogen-powered internal combustion engined Phantom Eye unmanned airborne system (Fig. 9.6), a demonstrator that will stay aloft at 65,000 feet for up to four days, and eventually 10 days. Boeing also states that the Phantom Eye demonstrator will be able to carry a 450-pound payload and have a cruising speed of 150 knots. The Phantom Eye demonstrator has a 150-foot (46 m) wingspan. It has no armament and has been built for "persistent intelligence and surveillance" rather than combat.

Fig. 9.4 SkySpark in flight, 2009 (*Source* http://en.wikipedia.org/wiki/Electric_aircraft)

Fig. 9.5 Boeing's hydrogen-powered light aircraft (*Source* http://en.wikipedia.org/wiki/Hydrogen-powered_aircraft)

Fig. 9.6 Phantom Eye taking off from launch trolley (*Source* http://phys.ofdrg/news/2012-06-phantom-eye-liquid-hydrogen-powered-unmanned.html) (Reproduced with kind permission of Boeing)

Each of the two propulsion systems consists of modified Ford 2.3 l engines, reduction gearbox, and four-blade propeller. The engines were originally designed for use with some models of the petrol-burning Ford Fusion car. To be able to run in the oxygen starved atmosphere at 65,000 ft, the engines feature a multiple turbocharger system that compresses that available low density air and reduces the radiated infrared heat signature to increase its stealth properties.

The engines, which provide 150 horsepower at sea level, have been tuned to be able to run on hydrogen. The Boeing marketing department states that this will make the aircraft economical and "green" to run, since the only by-product will be water.

Phantom Eye is the first of its kind and could open up a whole new market in collecting data and communications. The capabilities inherent in Phantom Eye's design will offer game-changing opportunities for military, civil and commercial customers. According to Boeing, "The hydrogen propulsion system will be the key to Phantom Eye's success. It is very efficient and offers great fuel economy, and its only by product is water, so it's also a 'green' aircraft." Rather than using fuel cells, the hydrogen is used in piston engines.

Solar powered aircraft such as the Helios (Fig. 9.7) have been used for both manned and unmanned aircraft. As with fuel cell and battery aircraft, it is very early days in their development but the technology is interesting and it could lead somewhere.

A manned solar-powered plane, the Solar Impulse (Fig. 9.8), made its test flight in 2009.

Fig. 9.7 Helios electric-powered UAV (*Source* http://en.wikipedia.org/wiki/Electric_aircraft)

Fig. 9.8 The Swiss-engineered Solar Impulse HB during its first test flight on 3 December 2009 (*Source* http://en.wikipedia.org/wiki/Solar_Impulse)

The first leg of the trip was 2500 km (1550 miles) from Switzerland to Morocco in May, and the second leg was from Spain to Morocco. Pilot Bertrand Piccard landed the Solar Impulse in Rabat 19 h after taking off from Madrid. The project eventually hopes to achieve the first circumnavigation of the Earth by a piloted fixed-wing solar aircraft in 2014.

Made of carbon fibre, the plane is the size of an Airbus A340 but only weighs as much as an average family car. The plane was powered by 12,000 solar cells turning four electric motors. The plane has the following specifications:

Crew: 1
Length: 21.85 m (71.7 ft)
Wingspan: 63.4 m (208 ft)
Height: 6.40 m (21.0 ft)
Wing area: 11,628 photovoltaic cells: 200 m^2 (2200 sq ft)
Loaded weight: 1600 kg (3500 lb)
Max take-off weight: 2000 kg (4400 lb)
Engine: 4 electric motors, powered by lithium ion batteries (450 kg), providing 7.5 kW (10 hp) each
Take-off speed: 35 km/h (22 mph)
Cruise speed: 70 km/h (43 mph)
Endurance: 36 h (projected)
Ceiling: 8500 m (27,900 ft) with a maximum altitude of 12,000 m (39,000 ft)

On August 13, 2001, the Helios Prototype piloted remotely by Greg Kendall, reached an altitude of 96,863 ft (29,524 m), a world record for sustained horizontal flight by a winged aircraft. The altitude reached was more than 11,000 ft (3400 m) —or more than 2 miles (3.2 km)—above the previous altitude record for a sustained flight by a winged aircraft. In addition, the aircraft spent more than 40 min above 96,000 ft (29,000 m).

On June 26, 2003, the Helios Prototype broke up and fell into the Pacific Ocean about ten miles (16 km) west of the Hawaiian Island Kauai during a remotely piloted systems checkout flight in preparation for an endurance test scheduled for the following month.

Although solar aircraft are currently not going to contribute to carbon reduction, it is worth reflecting on how far developments of conventional aircraft have come in 25 years following Orville Wright's initial flight. Within this period, heavy bombers were used in warfare, airlines were introduced and planes successfully crossed the Atlantic.

Another form of development of electric flight for the future is being carried out by Airbus.

Recently an Airbus test pilot, Didier Esteyne, flew a small two-seat electrically powered aircraft called the E-Fan across the English Channel in July. Airbus is apparently planning to put the E-Fan into production as a pilot-training aircraft. It will go on sale towards the end of 2017 to be followed by a four-seat version.

ASA is testing a DEP wing mounted above a truck and driven at high speed across a dry lake bed at Edwards Air Force Base in California. The wing uses 18 small, electric propellers strung along its leading edge. Electric motors make the concept, called distributed electric propulsion (DEP), feasible. The advantage of distributing power is that it can be used to increase the airflow over the wings and thus allow an aircraft to fly more efficiently.

The next step is a project called Sceptor, which is due to begin test flights in 2017. This involves replacing the wing on a conventional four-seater light aircraft —in this case, a twin-engined Italian-built Tecnam P2006T—with a DEP wing containing a dozen or so electrically driven propellers, as illustrated in Fig. 9.13.

Sceptor's line of small propellers will increase the aircraft's lift at lower speeds, allowing it to take off and land on shorter runways. It also means the wing could be made more slender, perhaps only a third of the width of the wing on a conventional aircraft, thus saving weight and fuel costs. Typically, the wing on a light aircraft is relatively large to prevent it from stalling (which happens at low airspeeds, when the wing cannot provide sufficient lift). But large wings are not very efficient when an aircraft is cruising because they create a lot of drag. Sceptor's wing will be optimised for cruise, yet still provide enough lift to help prevent stalling on take-off or landing.

Airbus is not alone in thinking about making much bigger electric and hybrid aircraft to carry passengers. Just as in cars, electrical propulsion offers a number of advantages over piston and jet engines. Modern, digitally controlled electric motors supply lots of torque, a rotational force that is as good at turning propellers and fan blades as it is wheels. Electric power is also quiet, clean and highly reliable, with fewer engine parts to wear or break.

Batteries alone will not currently provide sufficient for a passenger aircraft range but the concept could be potentially useful. Electric propulsion provides the opportunity to build radically different aircraft, such as concept of the Airbus E-Thrust.

The idea is that instead of hanging big and heavy jet engines below the wing, a greater number of small and lighter electrically driven fans or propellers could instead be incorporated into other areas of an aircraft. Doing this with lots of small conventional engines would be complicated and would add a lot of weight. However, electric motors make the concept, called DEP, feasible. The advantage of distributing power is that it can be used to increase the airflow over the wings and thus allow an aircraft to fly more efficiently. “DEP enables a fundamental shift in aircraft design”.

The wing will also be capable of other tricks. The speed of each electric propeller can be controlled independently, which provides the ability to change the pattern of airflow over the wing to cope with rapidly changing flying conditions, such as wind gusts. When cruising, the propellers closer to the fuselage could be folded back, leaving those on the wing tips to do the work.

Airbus’s E-Thrust concept is further from the runway. A collaborative project with Rolls-Royce—a British manufacturer of jet engines—and other research groups, the aircraft, or something like it, is projected to enter service around 2050. By then, the European Union expects the aviation industry to have cut fuel consumption, emissions and noise from passenger aircraft by at least 20–30%, relative to today’s state-of-the-art designs.

The goal of the E-Thrust is to meet such targets and be able to carry around 90 passengers on flights of two hours or more, and still have a generous safety margin from its batteries. However, this will require a breakthrough in the technology for storing electricity—which might well happen over the next few decades. The concept also uses distributed propulsion, but with a twist because it is hybrid.

A traditional jet engine sits in the tail of the E-Thrust. It also has three electrically driven fans on each wing. On take-off, the jet and all six electric fans will be used to provide maximum lift. When the aircraft reaches its cruise altitude, the jet can be throttled back but is powerful enough both to power the fans and to top up the batteries. During descent, both the jet and the fans will be turned off. As the aircraft glides, the oncoming air will turn the fans so that they work like wind turbines to top up the battery some more. The fans will be used to land, with the jet ticking over ready to provide additional thrust should the aircraft need to go around again.

One advantage of the hybrid system is that it provides a massive boost to a jet aircraft’s “bypass” ratio. This is a measure of the amount of air that flows around the hot core of a jet engine compared with that which goes through it to provide oxygen in the combustion chamber. The jet engines on early passenger aircraft had a low bypass ratio, producing a lot of their thrust from the fast-moving air blasting out of the rear of the core. This made them noisy and fuel-hungry. As the blast leaves the core, it turns a turbine, which via a shaft turns a fan at the front of the engine to draw in more air. By making the fan larger, it has been possible to move a bigger volume of slower-moving air (the bypass) around the outside of the core. This is more efficient and much quieter. It is also the reason why jet engines have got fatter over the years.

Modern jets have a bypass ratio of up to 12:1 compared with about 5:1 or less in the 1970s. However making the fans larger is becoming more difficult as they take up more and more room under the wing. In addition, bigger engines need stronger wings, which adds to an aircraft's weight. The hybrid set up in the E-Thrust neatly gets around these problems because only the jet engine in the tail has a fuel-burning core. This means all of the air flowing through the six electrically driven fans contribute to its "effective" bypass ratio of 20:1 or more. This would make the aircraft extremely fuel-efficient and very quiet.

Another efficiency comes from the distributed engines "ingesting" what is called the boundary layer of air flowing over the wing. This is a very thin layer of air close to the surface of the wing. It is slowed down by friction as molecules of air touch the wing's surface. The boundary layer passing over the raised upper surface of the aerofoil shape of a wing (which provides a wing with its lift) can become turbulent, which helps produce the wake that a jet aircraft leaves behind. By positioning the E-Thrust's electric fans above the wing to intercept the boundary-layer air, the fans can accelerate it, which reduces drag from the wake.

Technical advances in two areas are needed for the E-Thrust to fly. Besides better batteries, the other advancement needed is superconductivity, a phenomenon that removes electrical resistance when certain materials are cooled below a critical temperature. Reducing resistance allows construction of electrical and motor systems that are light and powerful enough to fly the aircraft. This has been done on a small scale, in equipment such as hospital scanners.

By overcoming technical difficulties, the aircraft design will overcome problems and the electric aircraft will progress.

Currently, the best bet for using fossil fuel free aircraft is firstly to divert all routes that do not contain long sea crossings to rail transport, which would save considerable amounts of fossil fuel energy. Where flying is essential for long distance travel, conventional aircraft using synthesised kerosene as fuel should be used.

Eventually, some design concepts that are still on the drawing board (or CAD system) will eventually come to fruition. In the meantime, we have the two concepts above, which should free us in the short term from fossil fuels.

9.2 Ships Not Dependent on Fossil Fuels

Sea transport for freight is relatively efficient but still produces 3% of global emissions due to its use of fossil fuels.

Nuclear energy is one alternative for shipping and has been well tested. Nuclear submarines, for example, are used by many of the world's leading navies and have covered vast distances successfully for over half a century.

Nuclear cargo and passenger ships have been used successfully in trials. The NS Savannah (Fig. 9.9) was the first nuclear-powered cargo-passenger ship, built in the late 1950s at a cost of USD 46.9 million, including a USD 28.3 million nuclear

Fig. 9.9 The nuclear-powered ship NS Savannah passing under the Golden Gate Bridge in California (*Source* http://en.wikipedia.org/wiki/NS_Savannah)

reactor and fuel core, funded by US government agencies as a demonstration project for the potential of nuclear energy. Launched on 21 July 1959, she was in service between 1962 and 1972. The NS Savannah is one of only four nuclear-powered cargo ships ever built. These were considered to be technically successful but they were not economically competitive with fossil fuel-powered ships. However, as oil gets scarcer and the cost rises, the economics are likely to change.

The NS Savannah was a demonstration of the technical feasibility of nuclear propulsion for merchant ships and was not expected to be commercially competitive. She was designed to be visually impressive, looking more like a luxury yacht than a bulk cargo vessel, and was equipped with 30 air-conditioned staterooms (each with an en-suite bathroom), a dining facility for 100 passengers, a lounge that could double as a movie theatre, a veranda, a swimming pool and a library. By many measures, the ship was a success. She performed well at sea, her safety record was impressive, her fuel economy was unsurpassed, and her gleaming white paint was never smudged by exhaust smoke. Even her cargo handling equipment was designed to look good. From 1965 to 1971, the Maritime Administration leased NS Savannah to American Export-Isbrandtsen Lines for revenue cargo service.

Another successful nuclear-powered cargo ship is the German-built Otto Hahn (Fig. 9.10). This ship ran on nuclear power for over 10 years. In 1972, after four years of operation, her reactor was refuelled. She had covered some 250,000 nautical miles (463,000 km) on 22 kg of uranium. The nuclear power plant was eventually replaced with a conventional power plant, as oil was then cheap and was considered to be more cost effective.

Nuclear-powered ships that can run independently of fossil fuels are a possible contender for future transport. There are likely to be severe political implications for the use of nuclear-powered ships and it is likely that countries with nuclear capabilities will wish to control its use in shipping. In addition, there are likely to be safety concerns in the event of nuclear ships sinking. Nevertheless, nuclear propulsion is a valid option for sea travel without fossil fuels, but a change in attitude from the public to nuclear is needed for it to become acceptable.

Other possibilities for shipping include wind power, hydrogen and synthesised fuels. The problem with hydrogen is that considerable quantities of cryogenic hydrogen would have to be kept for long periods, over which time there would be considerable evaporation, making hydrogen-powered sea shipping an unlikely

Fig. 9.10 Otto Hahn nuclear-powered cargo ship in Hamburg harbour, 9 June 1970 (*Source* http://en.wikipedia.org/wiki/Otto_Hahn_(ship))

possibility although it is quite possible for inland waterways, as are battery electric boats. Synthesised fuels are a possible contender for use at sea and many of the comments on synthesised fuels for aircraft discussed earlier in the chapter are relevant.

Boats used on inland waterways have a wider variety of possible solutions. A fuel cell boat, the Hydra, with a 6.5 kW power output is illustrated in Fig. 9.11.

Iceland has committed to converting its vast fishing fleet to fuel cells to provide auxiliary power by 2015 and, eventually, to provide primary power in its boats. Amsterdam recently introduced its first fuel cell powered boat to ferry people around the city's famous and beautiful canals. An interesting development is the solar-powered boat. In May 2012, the Tûranor PlanetSolar (Fig. 9.12) became the first solar electric vehicle to circumnavigate the globe.

The boat is covered in over 500 m^2 of solar panels rated 93 kW, which in turn connect to one of the two electric motors in each hull. Its hull is capable of hosting 200 persons, and the shape of the boat means that it is be able to reach speeds of up to 14 knots (16 mph). The boat's hull is 31 m long and has been designed to be used as a luxury yacht after its record attempt is finished.

Wind has powered sea transport for several thousand years. There have been recent attempts to reintroduce wind power to help power commercial shipping. An example is the B9 cargo ship (Fig. 9.13). Ireland-based B9 Shipping has started work on a full-scale demonstration vessel as part of its goal to design the modern world's first 100% fossil fuel-free cargo sailing ship. Unlike most conventional large cargo vessels, which are powered by bunker fuel, B9 Shipping's cargo ship would employ a Dyna-rig sail propulsion system combined with an off-the-shelf Rolls-Royce engine powered by liquid biomethane derived from municipal waste.

Fig. 9.11 The world's first certified fuel cell boat (Hydra), in Leipzig, Germany (*Source* http://en.wikipedia.org/wiki/Fuel_cell)

Fig. 9.12 Tûranor PlanetSolar, the world's largest solar-powered boat (*Source* http://en.wikipedia.org/wiki/Solar_vehicle)

Fig. 9.13 B9 Shipping's sailing cargo ships would feature a Dyna-rig sail system (Reproduced with kind permission of B9 shipping/HYD)

The company understand that such a ship would become economical when the price of oil rises above USD 180 per barrel. In the long term, nuclear-powered transport would also provide a solution to the issue of running sea transport without fossil fuels, as would the use of synthesised fuels, which are likely to be more attractive politically. A return to sail using modern technology is a possibility. Possibly, a combination of wind power and engines using synthesised fuel could be a solution.

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Chapter 10
Do We Have the Resources?

It is worth taking a brief look at whether the world has sufficient resources to provide an energy system that is not based on fossil fuels. Clearly, there is no point in replacing fossil fuels with a non-fossil fuel based energy system if it uses materials with insufficient reserves to last. Where necessary, it is worth having alternatives in mind when one particular material is likely to become depleted.

On the energy front, there is no obvious problem with material availability.

According to the Nuclear Energy Agency (NEA), identified uranium resources total 5.5 million metric tons, and an additional 10.5 million metric tons remain undiscovered—totalling a roughly 230-year supply at today's consumption rate. Further exploration and improvements in extraction technology are likely to at least double this estimate over time.

World distribution of uranium is shown in Fig. 10.1 and production is shown in Fig. 10.2. An open cast uranium mine in Namibia is illustrated in Fig. 10.3.

Two technologies could greatly extend the uranium supply itself. Neither is economical now, but both could be in the future if the price of uranium increases substantially. First, the extraction of uranium from seawater would make 4.5 billion metric tons of uranium available, a 60,000-year supply at present rates of consumption. Second, fuel-recycling fast-breeder reactors, which generate more fuel than they consume, would use less than 1% of the uranium needed for current LWRs. Breeder reactors could match today's nuclear output for 30,000 years using only the NEA-estimated supplies.

There is no problem either with the availability of resources for silicon cells. Silicon is the second most common material in the Earth's crust and is commonly available in sand, for example. Polycrystalline silicon used to produce silicon monocrystals is shown in Fig. 10.4.

Availability of materials to make batteries for motor vehicles is a possible problem, particularly lithium. There are nearly 1 billion automobiles in the world and to equip them all with a 10 kWh lithium ion battery would consume over 35% of the world's producible lithium salt reserves. According to a 2011 study conducted at Lawrence Berkeley National Laboratory and the University of

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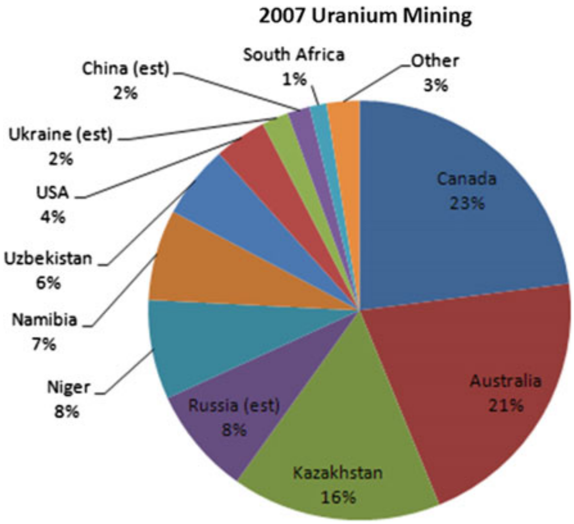

Fig. 10.1 Uranium mining in 2007, by nation (*Source* http://en.wikipedia.org/wiki/Uranium_mining)

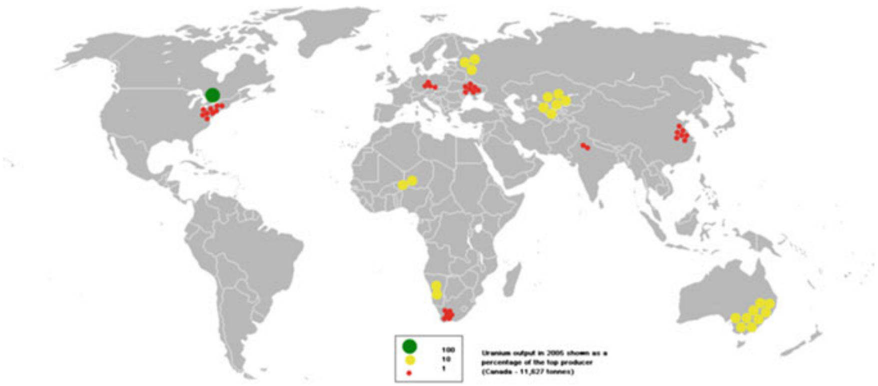

Fig. 10.2 World uranium production in 2005 (*Source* http://upload.wikimedia.org/wikipedia/commons/1/1a/Uranium_production_world.PNG)

California Berkeley, the currently estimated reserve base of lithium should not be a limiting factor for large-scale battery production for electric vehicles, as the study estimated that about 1 billion 40 kWh lithium-based batteries could be built with current land-based reserves. Another 2011 study by researchers from the University of Michigan and Ford Motor Company found that there are sufficient lithium resources to support global demand until 2100, including the lithium required for the potential widespread use of electric vehicles. In addition, lithium is recyclable.

Fig. 10.3 Rössing open pit uranium mine, Namibia (*Source* http://en.wikipedia.org/wiki/Uranium_mining)

Fig. 10.4 Polycrystalline silicon used to produce silicon monocrystals (*Source* http://en.wikipedia.org/wiki/Polycrystalline_silicon)

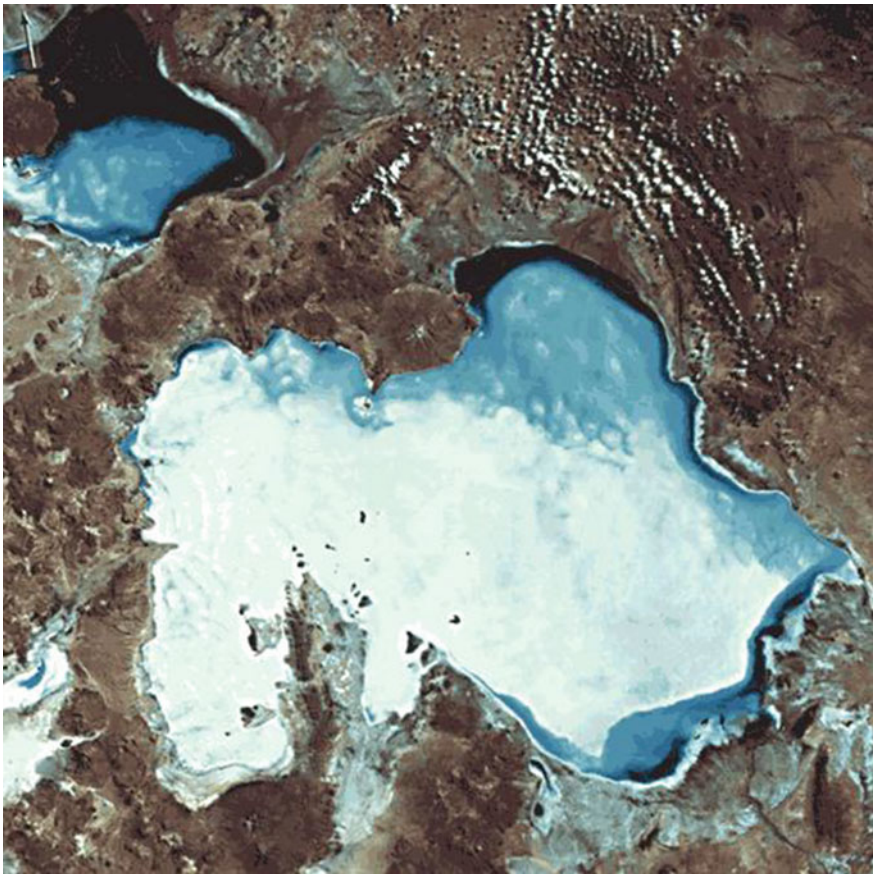

Fig. 10.5 NASA satellite image of the salt flats in Uyuni, Bolivia (*Source* http://upload.wikimedia.org/wikipedia/commons/5/53/Uyuni_landsat.JPG)

The above analysis is based on current lithium reserves, based on land reserves of 10–20 million tonnes.

A satellite image of the salt flats in Bolivia is illustrated in Fig. 10.5. Bolivia has an estimated 5.4 million tonnes of lithium. Apart from in salt flats, lithium occurs in spodumene, a lithium aluminium inosilicate.

There are 230 billion tonnes of lithium in the sea—over 10,000 times that of the land reserves. South Korea is building a plant to extract lithium from seawater and, by 2014, this plant is predicted to extract 33 tonnes of lithium per year. In total, it is expected to produce 20,000–100,000 tonnes of lithium from the plant. Such plants can be replicated.

There are also other types of batteries. For example, if NaNiCl (sodium nickel chloride) batteries were used, 12% of the world's nickel reserves would be required; if zinc batteries were used, 3% of the world's zinc reserves would be needed.

Fig. 10.6 Neodymium magnet with nickel plate mostly removed (*Source* http://upload.wikimedia.org/wikipedia/commons/d/de/Neodymium_magnet_-_19-11-2010.JPG)

Hydrogen is a common element and although hydrogen fuel cells use a platinum catalyst that is rare and expensive, the platinum element can be recycled.

There are other rechargeable batteries such as zinc air and aluminium air batteries, which have suitable specific energies. In the case of aluminium air batteries, it should be noted that aluminium is a common element.

Modern DC motors rely on rare earth magnets, i.e. magnets made from alloys of rare earth elements. There are two types: neodymium magnets and samarium-cobalt magnets. The term "rare earth" can be misleading as these metals are not particularly rare or precious; they are about as abundant as tin or lead, so the environmental impact is not as harsh as it sounds. Neodymium magnets (Fig. 10.6), invented in the 1980s, are the strongest and most affordable type of rare earth magnet. They are made of an alloy of neodymium, iron and boron. Neodymium magnets are used in numerous applications requiring strong, compact, permanent magnets, such as electric motors.

Samarium, used in samarium-cobalt ($SmCo_5$) magnets, is the 40th most abundant element in the Earth's crust, making it more common than tin, whereas neodymium is almost as abundant as copper. Effective electric motors for automobiles do not have to use any rare earth metals and it must be borne in mind that realistic alternatives do exist anyway.

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Chapter 11
Energising the World Using Non-fossil Fuel Sources

It was seen in Chap. 3 that each year the world uses fossil fuels containing an energy content (calorific value) of around 10,000 million tonnes of oil equivalent, i.e. with an energy content of approximately 116,000 TWh.

Due to the inefficiencies of heat engines, the actual energy that would be needed to replace fossil fuel energy would just less than 30,000 TWh. That is, the energy from alternative energy sources at the outlet from power stations and the output energy from transport such as wheel energy in the case of trains or motor vehicles.

This amount of energy could be supplied by 6884 nuclear power stations with output of 479 MW or by 1000 photovoltaic power stations with a collector area of 8 km^2, located in desert areas with solar radiation similar to the Sahara.

The amount of energy produced would not, on its own, be able to match demand at all periods throughout the day. Typical energy demand throughout the day is shown in Fig. 11.1. The output showing the same amount of energy from a solar power station is shown in Fig. 11.2 and the same amount of energy for a nuclear power station is shown in Fig. 11.3.

In fact, although both systems could each generate enough energy, they would not fulfil the requirements for electricity generation throughout the day. Nuclear power stations produce a constant base load for 24 h, whereas solar photovoltaic power station produce all of the energy for several hours either side of noon at the latitude where it is generated.

Typical energy from a nuclear power station delivering the same amount of power is more likely to look like that illustrated in Fig. 11.3.

When the energy supplied by a solar power station is superimposed on the demand curve, it can be seen in Fig. 11.4 that although the solar power station produces the same amount of energy, at around noon the excess energy is produced, as shown in area 1; and at night there is a lack of energy, as shown in area 2.

In the case of a nuclear power station, as shown in Fig. 11.5, a similar pattern exists when the demand curve is superimposed on the curve for the same amount of energy supplied from a nuclear power station. There would be times when surplus

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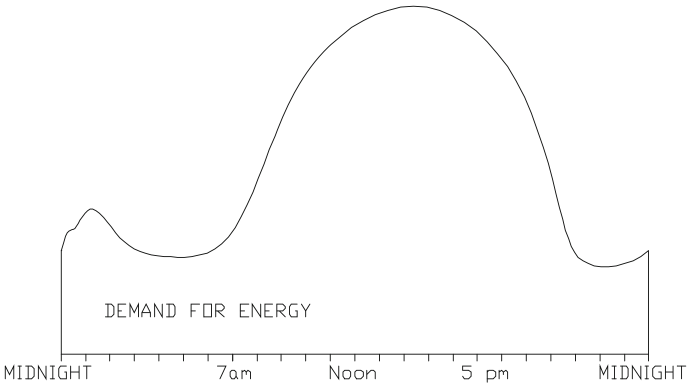

Fig. 11.1 Possible energy demand during the day

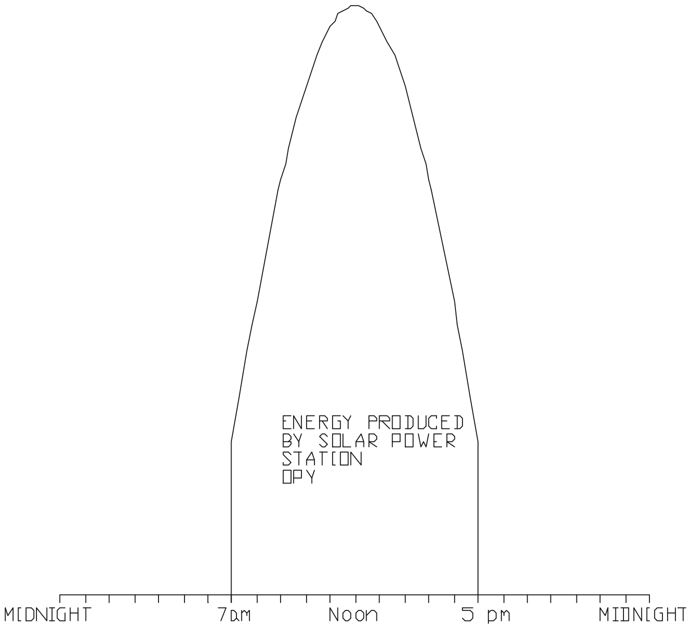

Fig. 11.2 Energy supplied by solar photovoltaic power station during the day

energy was available early and late in the day, and there would be times when there was a lack of energy occurs around noon.

When the demand curve is superimposed on the same amount of energy (half supplied from solar photovoltaic and half supplied by nuclear), the results are illustrated in Fig. 11.6 where it can be seen that the times of surplus and time in which there was a lack of energy could be minimised.

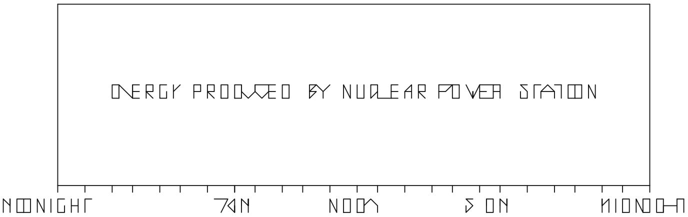

Fig. 11.3 Nuclear power supplied over 24 h

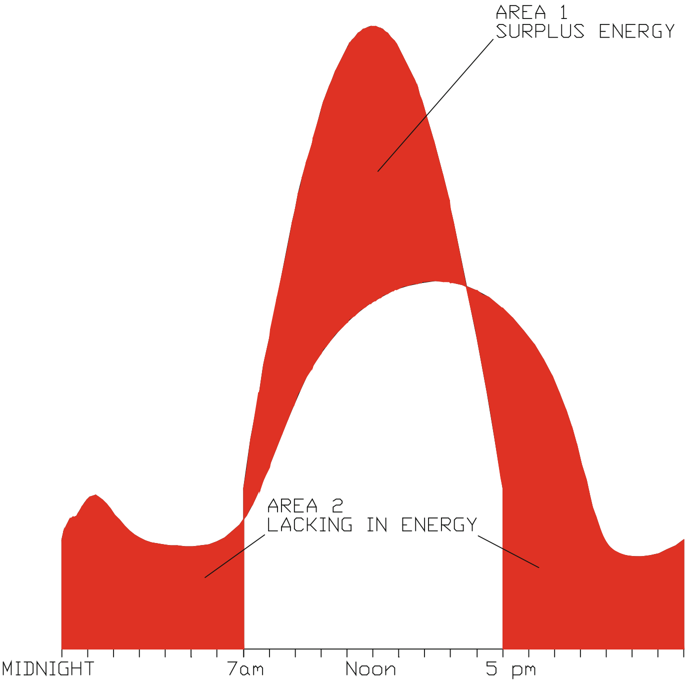

Fig. 11.4 Energy from a photovoltaic power station superimposed on the demand curve for the same amount of energy

If several alternative sources of energy were to be used, the peaks and troughs in energy availability could be minimised. This is a complex statistical problem and involves combining energy systems from different sources with varying supply patterns, such as nuclear, with a relatively constant base load; solar energy, which peaks either side of noon; wind energy, which peaks on different days; tidal energy, which peaks at high and low tides at different times every day; as well as hydro energy; biomass energy; geothermal energy; and energy from waste, which can be adjusted to meet demand.

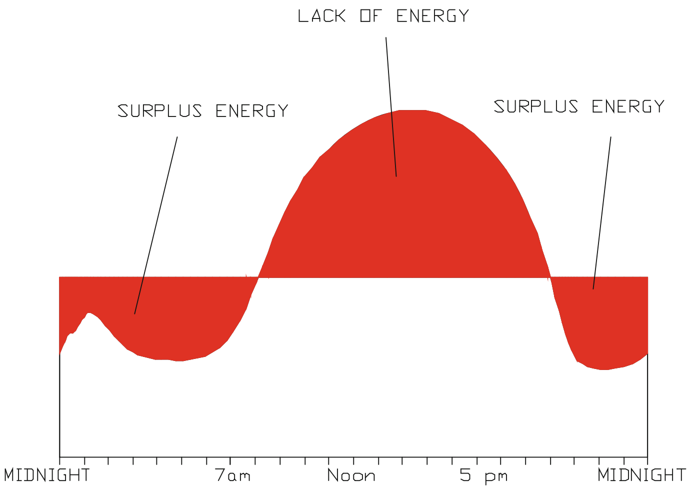

Fig. 11.5 Energy from a nuclear power station superimposed on the demand curve for the same amount of energy

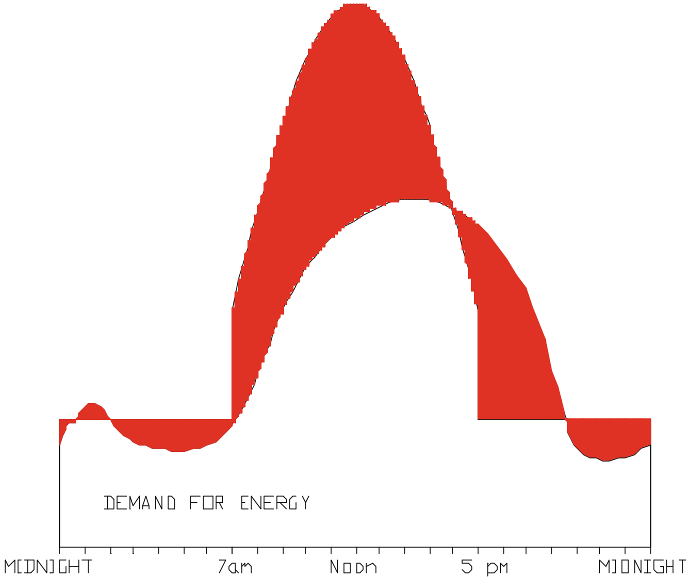

Fig. 11.6 Energy from combined solar and nuclear used together superimposed on demand curve for the same amount of energy

Whilst it is desirable to minimise periods of surplus and lack of energy, where this is unavoidable, excessive energy should be stored and used at periods of shortage.

Fossil fuel-powered generators are able to produce power on demand as are some alternative power sources, such as hydro and geothermal; whereas other sources of power, such as solar, wind and tidal, are not able to produce power on demand.

Where, as is likely, we use a world energy system that produces excessive energy, we will need to find a use for the surplus power, such as water desalination or producing synthetic fuels, or to encourage people where possible to use the energy at times when it is available. A simple example of the latter would be to make surplus energy inexpensive and to encourage the charging of electric cars or storage heaters at these times. Alternatively, we could store the energy for future use.

There are three main forms of energy storage as where discussed in previous chapters. These are pumped hydro storage, producing hydrogen by electrolysis and electric battery storage.

At present producing hydrogen by electrolysing water, storing it where we has previously stored gas and then when required turning this back into electricity by means of gas turbine generator sets is perhaps the most attractive method. Previously the cost it was seen that 2 kWh of energy in the hydrogen were required to produce 1 kWh of electricity plus a further $0.22 for the cost of the turbos generator discounted over its life time.

Battery storage was discussed in Chap. 6 and is currently expensive but is predicted to cost USD 0.05 per kWh by 2035.

A suitable mix of alternative energies together with predicted annual cost is shown in Table 11.1, together with predicted generation costs for 2025 and 2050. These alternative energies include photovoltaic, hydro, geothermal, wind, tidal,

Table 11.1 Projected annual cost of alternative energy in 2025

	Annual electricity (TWh)	Cost (USD per MWh)	Annual cost (billion $)
Annual cost of alternative energy in 2025			
Photovoltaic	12,000	50.0	600,000
Hydro	1500	40.0	60,000
Geothermal	3000	47.8	143,400
Wind (onshore)	3000	94.0	282,000
Wind (offshore)	3000	140.0	420,000
Traditional tidal	3000	24.5	73,500
Tidal lagoons	1500	130.0	195,000
Biomass waste	1500	100.0	150,000
Nuclear	500	92.5	46,250
Marine	1000	150.0	150,000
Total	30,000		2,120,150
Annual cost of fossil fuel electricity			
Fossil fuel	30,000	100	3,000,000
	Percentage cost of alternative electricity compared with fossil fuel energy		**71%**

biomass, waste, marine current and nuclear. The present day cost of fossil fuel electricity is included for comparative purposes.

This is not the definitive list but shows how a typical energy mix may look. Considerable work is needed to arrange the final combination of fossil free energy systems.

It can be seen in Table 11.1 that, by 2025, the cost of the alternative energies is predicted to be competitive with the cost of fossil fuel energy today, which is likely to increase. In the table, it is predicted to be 71% of the cost by 2025. Table 11.2 shows the predicted cost of alternative energies in 2050. It can be seen that the cost of alternative energies will have fallen to 63% of the cost of electricity produced by fossil fuels. The cost does not include energy storage.

In Tables 11.3 and 11.4, the four lowest-cost alternative energy systems i.e. photovoltaic, hydro geothermal and traditional tidal energy, are compared. Initially, the costs are shown without storage and it can be seen that the predicted cost of these alternative energies is projected to be 71% of the cost of fossil fuels in 2025 and 62% in 2050. The cost of storing 50% of the energy gained from photovoltaics and used for electrolysed hydrogen, which is stored and turned back into energy using gas turbine generators, is included. It is shown in Tables 11.3 and 11.4 that even with storage, the cost is still below the cost of fossil fuel-generated electricity: 81% of the cost of fossil fuels in 2025 and 70% in 2050.

Table 11.2 Projected annual cost of alternative energy in 2050

	Annual electricity (TWh)	Cost (USD per MWh)	Annual cost (billion USD)
Photovoltaic	12,000	30.0	360,000
Hydro	1500	40.0	60,000
Geothermal	3000	47.8	143,400
Wind (onshore)	3000	94.0	282,000
Wind (offshore)	3000	140.0	420,000
Traditional tidal	3000	24.5	73,500
Tidal lagoons	1500	130.0	195,000
Biomass waste	1500	100.0	150,000
Nuclear	500	92.5	46,250
Marine	1000	150.0	150,000
Total	30,000		1,880,150
Annual cost of fossil fuel electricity			
Fossil fuel	30,000	100	3,000,000
	Percentage cost of alternative electricity compared with fossil fuel energy		**63%**

Table 11.3 Cost of alternative energy in 2025 with and without storage versus cost of fossil fuels

2025			
	Annual electricity (TWh)	Cost (USD per MWh)	Annual cost (billion USD)
Photovoltaic	22,500	50	1,012,500
Hydro	1500	40	60,000
Geothermal	3000	47.8	143,400
Traditional tidal	3000	24.5	73,500
Total	**30,000**		1,289,400
Cost of fossil fuel (USD)			3,000,000
Percentage cost of fossil fuel			43.0
Additional hydrogen for storage	**16,875**	50	843,750
Cost of generator		22	371,250
Total for storage			1,130,625
Cost of electricity with 16,875 TWh storage			2,420,025
Cost of 30,000 TWh of fossil fuel electricity (USD)			3,000,000
Cost of fossil fuel electricity			80.7%

Table 11.4 Cost of alternative energy in 2050 with and without storage versus fossil fuels

2050			
	Annual electricity (TWh)	Cost (USD per MWh)	Annual cost (billion USD)
Photovoltaic	22,500	30	675,000
Hydro	1500	40	60,000
Geothermal	3000	47.8	143,400
Traditional tidal	3000	24.5	73,500
			951,900
Total	**30,000**		
Cost of fossil fuel			3,000,000.0
Percentage cost of fossil fuel			31.73%
Additional hydrogen for storage	**16,875**	50	843,750
Cost of generator		22	371,250
Total for storage			1,130,625
Cost of electricity with 16,875 TWh storage			2,082,525
Cost of 30,000 TWh of fossil fuel electricity			
Percentage of cost of fossil fuel electricity			69.4%

The results are striking as this indicates that the amount of energy that we use from fossil fuels could be produced for less by alternative energy sources from 2025 onwards, as shown in Fig. 11.1. Even better results are obtained when we combine the four cheapest forms of alternative energy i.e. photovoltaics hydro, geothermal and traditional tidal, as shown in Table 11.2, even when storage is accounted for.

Whilst the analysis has deliberately been kept simple, there are clear potential economic advantages in adopting alternative energy. The economic case for using alternative energies, which do not release carbon dioxide has been made without the cost of global warming being included and this is likely to be substantial.

It is interesting that the case for using alternative energies can be made on economic grounds alone.

Solar photovoltaics have a high EROI (energy return on energy invested). In fact, any extra energy required in the production of photovoltaics, for example, will be paid for in the purchase price, and so no allowance needs to be made on economic grounds.

Typically, photovoltaics require a generous fraction amount of the energy produced during their life in production. Whilst this does not in theory alter the costing, sufficient alternative energy must be put in place to allow for this.

To avoid the argument that this is biased, there are a couple of factors that will further sway the case in favour of alternative energy. Firstly, by using electrical super grids that are relatively inexpensive per unit of energy as well as better planning, it should be possible to cut down on energy storage. Secondly, no adjustment for EROI for fossil fuel energy has been allowed. Whilst this is admittedly smaller than that for photovoltaics, it will nevertheless push the cost of fossil fuel energy and nuclear energy upward.

It is likely in practice that a combination of the best ideas from all these schemes would be used. Use of low-cost photovoltaic energy and other forms of low-cost alternative energy will definitely be included. Storage of energy including hydrogen manufactured by electrolysing water and used to generate electricity using the hydrogen in gas turbine generators. Pumped storage and electric battery storage will also be used, particularly, in the latter case, when the cost starts to drop.

Combining the use of an electrical super-grid with storage would ensure that adequate energy could be kept back for times of emergency, allowing a considerable supply of energy to be held in reserve.

Looking at these figures objectively, it is hard to see that we have any other option, bearing in mind the predicted dire consequences of global warming, future depletion of fossil fuels and the fact that a potential alternative energy mix is cheaper.

We need to design and implement an alternative energy-based generation system that does not use fossil fuels without further delay.

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Chapter 12
Final Infrastructure

12.1 Proposed Infrastructure

In order to free the world from burning fossil fuels for power and transport, a great deal of new infrastructure will need to be planned and put in place. The outline of the world system, which will need to be planned in detail and implemented, is described below.

12.2 The Sustainable Energy Generation System

The energy generation system will consist of a mixture of the likely sustainable energy systems as discussed in Chap. 11, where it was shown that it is possible to build an energy system that does not need fossil fuels and that, in the near future, from 2025 onwards, this will be the most economical way of producing world energy. The costs will continue to fall as we approach 2050 and beyond.

Any future energy generation will utilise systems that produce the most economic energy and, as this is likely to be a system based on alternative energy, carbon dioxide release and associated global warming should no longer be an issue, provided that we act quickly.

In Chap. 11, various combinations of power sources were discussed, together with the associated economics. The most important change that is taking place is our ability to manufacture relatively cheap photovoltaics. The predicted prices from 2025 will ensure that photovoltaics are likely to form a major part of any future energy generation system. There are other forms of cheap sustainable energy systems including geothermal, hydro and traditional tidal power. These are all likely to play a major part in future energy generation.

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12.3 Electrical Super Grids

All alternative energy systems provide electrical power, which is a convenient way of transmitting power through national grids. Large power stations that need to transmit large amounts of electricity over long distances—for example, from the Sahara to Europe, or across Africa—will need to utilise high DC voltage transmission lines, which are highly efficient. Apart from this, much of the present infrastructure does not have to be changed.

12.4 Energy Storage

There will, however, need to be some change in energy storage infrastructure in order to allow the alternative energy to be used to maximum benefit. These changes will consist of storage schemes, such as hydrogen storage, which can use existing facilities that are currently used for gas. The gas will use gas turbine generators for electricity production. Eventually, electric batteries should be used, provided the price falls as predicted.

12.5 Transport

Much of sustainable and nuclear energy delivers electric power and most transport, with the exception of electric trains, use fossil fuels such as petroleum and diesel oil. Electric trains will require no changes as they will be able to run as before, simply taking electricity from the grid. However, aeroplanes and ships will either need to be redesigned or, more likely, the electrical energy will need to be converted into fuels such as synthetic kerosene made using fossil free energy. An alternative would be to encourage the use of transport that could use electricity. High-speed trains such as the Japanese Shinkansen (Bullet train) and the maglev trains are starting to compete with aeroplanes for overland transport. They use a fraction of the energy of aeroplanes and their use should be encouraged to cut down on air transport.

Changes will be required in the transport sector to allow vehicles to run on electricity or to use fuels derived from electricity. Options include battery electric vehicles using electricity from the grid; or fuel cell vehicles using hydrogen made by electrolysing water; or electric vehicles, which can run for part of their journeys on automated trackways and can be charged whilst on the track. Electric vehicles may be the preferred option as they eliminate tail pipe emissions and associated local pollution.

At the moment, with government subsidies, electric vehicles are starting to become cost competitive. With zero road tax and untaxed electricity on the energy compared with petrol and diesel, it can be as cheap to run electric vehicles. With the predicted fall in prices of batteries and fuel cell vehicles, the governments will be able to remove the subsidies and tax the electricity used for transport. Once this has been done, vehicles will continue to be economically competitive with vehicles running on petrol and diesel.

Where battery electric vehicles or hydrogen fuel cell vehicles are adopted, major changes in the general infrastructure are needed. At present, acceptable designs are starting to come onto the market; however, there is precious little infrastructure for recharging battery vehicles or to charge hydrogen tanks. For example, in the United Kingdom, although there are some reasonable hydrogen vehicles on the market, only a handful of hydrogen dispensers for refilling tanks exist. These facilities need to be put in place urgently. In all of these cases, vehicle design and manufacturing will need to be modified. Whilst synthetic fuel could be used in conventional vehicles, their efficiency would be much lower than any of the above vehicles, so this is considered to be undesirable. Nuclear-powered ships are another possibility but it is doubtful that this would be politically acceptable.

Changes to the infrastructure will be required, where it is decided to adopt trams and trolley buses, which run directly from electricity, thus saving fossil fuels required by most buses.

There will be some major changes to the present infrastructure, such as putting in high speed rail lines and establishing electric trackways. As discussed earlier, where possible, air travel should be substituted for high-speed and other train transport for overland routes. Electric trains and high-speed trains use a fraction of the energy that aeroplanes do. One advantage of this is that additional airports could be avoided in countries such as the UK, where there is considerable argument regarding where and if a third London airport is required. This requires a major change in established behaviour, but trains give the advantage of improved comfort and quicker loading and unloading.

Automated transport systems in which electric vehicles can use a track where they will be driven under automated control need to be developed rapidly. These do not need to take up additional space in most cases as the trackways can be incorporated into existing motorways and main roads. Whilst the automated trackways will save on energy and space, they will be quicker than travel on motorways and trunk roads; they will also be less prone to traffic jams.

Trackways for cycles and electric bicycles should be included in towns and cities. Not only will these save energy but they are also considered to be the fastest way to travel through many modern cities, which are often jammed with motor traffic. In addition, correctly designed cycle ways will make travelling through cities, which will now start to become pollution free, both pleasant and safe.

12.6 Agricultural Machinery and Heavy Plant

Agricultural and other heavy plant machines should utilise hydrogen or synthesised fuels. This would give them the versatility that they obtained from fossil fuels but would allow them to use fuels that are carbon neutral.

12.7 Other Benefits of Energy and Transport Free from Fossil Fuels

Pollution from fossil fuel exhausts causes a host of problems that should be minimised with their replacement. These problems result in pollution and the associated health problems. Not only is pollution unpleasant, but it can also be directly attributed to several lung and heart diseases and the associated deaths. One study found that in 2010, 3.2 million people died prematurely from air pollution, particularly the sooty kind that spews from the exhaust pipes of cars and trucks. In addition, many of those deaths were in Asia, where a boom in car use has choked the streets of India and China's fast-expanding cities with smog. In the USA, there is mounting evidence that diesel exhaust poses major health hazards; reducing diesel pollution has become a public priority.

Diesel-powered vehicles and equipment account for nearly half of all nitrogen oxides (NOx) and more than two-thirds of all particulate matter (PM) emissions from US transportation sources.

Particulate matter or soot is created during the incomplete combustion of diesel fuel. Its composition often includes hundreds of chemical elements, including sulfates, ammonium, nitrates, elemental carbon, condensed organic compounds, and even carcinogenic compounds and heavy metals such as arsenic, selenium, cadmium and zinc. Though just a fraction of the width of a human hair, particulate matter varies in size from coarse particulates (less than 10 μm in diameter) to fine particulates (less than 2.5 μm) to ultrafine particulates (less than 0.1 μm). Ultrafine particulates, which are small enough to penetrate the cells of the lungs, make up 80–95% of diesel soot pollution.

Particulate matter irritates the eyes, nose, throat, and lungs, contributing to respiratory and cardiovascular illnesses and even premature death. Although everyone is susceptible to diesel soot pollution, children, the elderly, and individuals with preexisting respiratory conditions are the most vulnerable. Researchers estimate that, nationwide, tens of thousands of people die prematurely each year as a result of particulate pollution. Diesel engines contribute to the problem by releasing particulates directly into the air and by emitting nitrogen oxides and sulfur oxides, which transform into "secondary" particulates in the atmosphere.

Diesel emissions of nitrogen oxides contribute to the formation of ground level ozone, which irritates the respiratory system, causing coughing, choking, and reduced lung capacity. Ground level ozone pollution, formed when nitrogen oxides and hydrocarbon emissions combine in the presence of sunlight, presents a hazard for both healthy adults and individuals suffering from respiratory problems. Urban ozone pollution has been linked to increased hospital admissions for respiratory problems such as asthma, even at levels below the federal standards for ozone.

Diesel exhaust has been classified as a potential human carcinogen by the U.S. Environmental Protection Agency (EPA) and the International Agency for Research on Cancer. Exposure to high levels of diesel exhaust has been shown to cause lung tumors in rats, and studies of humans routinely exposed to diesel fumes indicate a greater risk of lung cancer. For example, occupational health studies of railroad, dock, trucking, and bus garage workers exposed to high levels of diesel exhaust over many years consistently demonstrate a 20–50% increase in the risk of lung cancer or mortality.

12.8 Deaths from Road Transport

Although road deaths are not a direct consequence of the use of fossil fuels, new transport systems such as the automated transport system should minimise the number of accidents causing deaths, which currently stand at over 1 million per annum worldwide.

The above figures are a staggering statistic both for deaths from pollution and from accidents, with over 3 million deaths from pollution and over 1 million deaths caused through accident, in addition to millions suffering through ill health and countless millions from accidents. If these deaths and injuries had happened in aircraft, the statistics would be unacceptable and the aircraft would be banned from flying. We accept these horrendous figures for land vehicles simply because they have evolved over time and have become commonplace.

This new infrastructure both for energy generation and for transport would be better than the old one. We are not envisaging a return to 18th century transport using horses and carts and crude sailing ships, but to a more sophisticated, safer and more cost-effective system.

To summarise, a worldwide system running without creating energy from fossil fuels would not only release no carbon, with all the dangers of associated global warming, but would also be better in many ways and cheaper than the present system. It would also allow fossil fuels to be conserved for making essential products in the future.

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Chapter 13
Avoiding the Carbon Apocalypse

We have reached a point in time where global warming caused by the release of carbon dioxide, is going to cause major problems. At the same time, reserves of fossil fuels are starting to run out.

There is no need for this to happen since we do in fact have the resources to move away from combusting fossil fuels for electricity generation and transport.

Far from being unaffordable, in a relatively short space of time—in under a decade—alternative energy is likely to become more economical than fossil fuel energy. This book shows how this can be done.

The resulting power generation system will not only be economical but will also result in a cleaner, better planet and will have additional advantages that may not be immediately obvious.

The world accepts that action needs to be taken; this was reflected in the conference in Paris, from 30 November to 11 December, 2015.

At the Paris conference, countries agreed to aim to limit the increase in the global average temperature to 1.5 °C, with a long-term goal of keeping the increase in global average temperature to well below 2 °C above pre-industrial levels. There was also agreement on the need for global emissions to peak as soon as possible, with recognition that this will take longer for developing countries. It was also agreed to undertake rapid reductions in accordance with the best available science.

Before and during the Paris conference, countries submitted comprehensive national climate action plans. These are not yet enough to keep global warming to below 2 °C, so it can be concluded that politicians are not yet exactly certain how they are planning to achieve this target.

The spirit of the agreement is sound and it is generally accepted that failure to act will, among other problems, result in widespread flooding due to sea level rises caused by global warming.

Not only do the ideas proposed in this book show how the temperature rise due to carbon dioxide release can be kept below 2 °C, but it also shows how carbon dioxide release from power generation and transport can be totally eliminated.

J. Lowry, *Avoiding Carbon Apocalypse Through Alternative Energy*,
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There are other advantages of moving away from fossil fuels. For example, combusting fossil fuels produces pollution and over 3 million people annually worldwide die prematurely from air pollution such as sooty pollution, which spews from the exhaust pipes of cars. Approximately 200,000 early deaths are caused annually from exhaust pollution in the USA alone.

The ideas outlined in this book outline a cleaner, healthier world in which power can be generated without carbon dioxide release and at a lower cost than fossil fuel-generated power. In addition, it can be generated without pollution and the associated health hazards.

This book shows how a combinations of alternative energies, including some hydrogen storage, could be combined to generate energy economically and how transport can be adapted to make use of this power.

In order to avoid the carbon apocalypse and the resulting world catastrophe, we need to start planning and implementing alternative power and energy generation systems now before it is too late. This book shows how a combination of alternative energies, including some hydrogen storage, could be combined to generate energy economically, and how transport can be adapted to make use of this power.

We do not have, any longer, the luxury of continuing to wait for new technical developments that may or may not happen. The alternative energy systems are starting to become economical and will clearly be economical throughout the world by 2025.

We need action now!

Appendix

The amount of fossil fuel as well as the amount of nuclear and hydro power used worldwide for different countries (in 2008) is shown in Table 1. To enable like to be compared with like, the values have been converted to TWh (http://www.guardian.co.uk/environment/datablog/2009/sep/02/oil-reserves).

See Table 2.

Table 1 Consumption of fossil fuels in 2008 (in TWh)

Country/region	Oil	Natural gas	Coal	Total
Canada	1186.0	1046.5	383.7	2616.3
USA	10,284.9	6984.9	6569.8	23,839.5
UK	915.1	982.6	411.6	2309.3
Eire	104.7	52.3	16.3	173.3
UK + Eire	1019.8	1034.9	427.9	2482.6
France	1072.1	462.8	138.4	1673.3
Germany	1375.6	858.1	940.7	3174.4
Total Europe and Asia	11,108.1	11,972.1	6077.9	29,158.1
Russia	1516.3	4397.7	1177.9	7091.9
Australia	494.2	246.5	596.5	1337.2
New Zealand	84.9	39.5	24.4	148.8
South Africa	305.8	0.0	1195.3	1501.2
Total world	45,673.3	31,698.8	38,415.1	115,787.2

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Table 2 The energy produced from engines and power stations, assuming a thermal efficiency of 0.25 (in 2008) (in TWh)

Country/region	Oil	Natural gas	Coal	Total
Canada	297	262	96	654
USA	2571	1746	1642	5960
UK	229	246	103	577
Eire	26	13	4	43
UK + Eire	255	259	107	621
France	268	116	35	418
Germany	344	215	235	794
Total Europe and Asia	2777	2993	1519	7290
Russia	379	1099	294	1773
Australia	124	62	149	334
New Zealand	21	10	6	37
South Africa	76	0	299	375
Total world	11,418	7925	9604	28,947

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