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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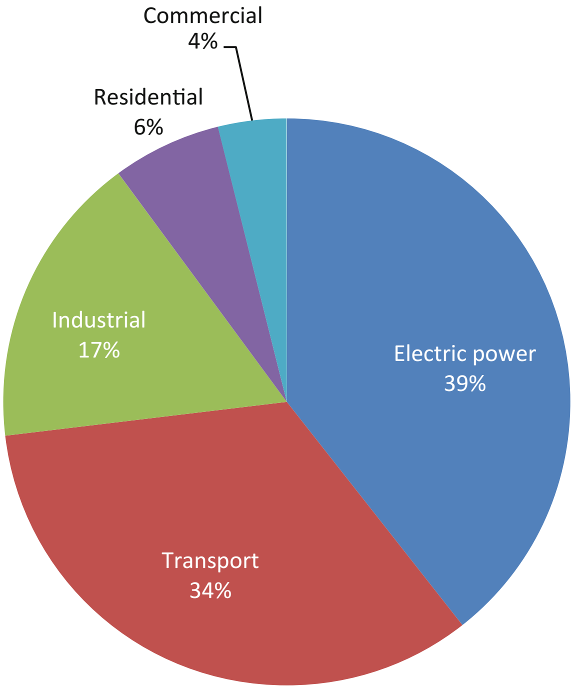

Fig. 2.1 Electricity generated from fossil fuels in the USA in 2005 (*Source* John Lowry)

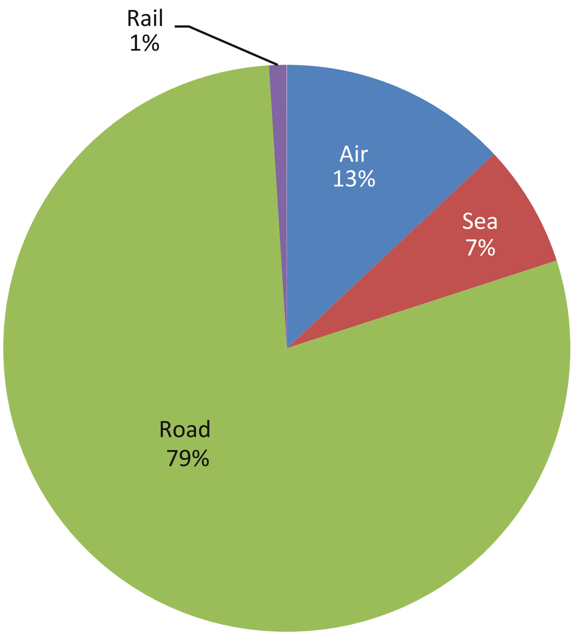

Fig. 2.2 Breakdown of how fossil fuels are used in transport worldwide (*Source* John Lowry)

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

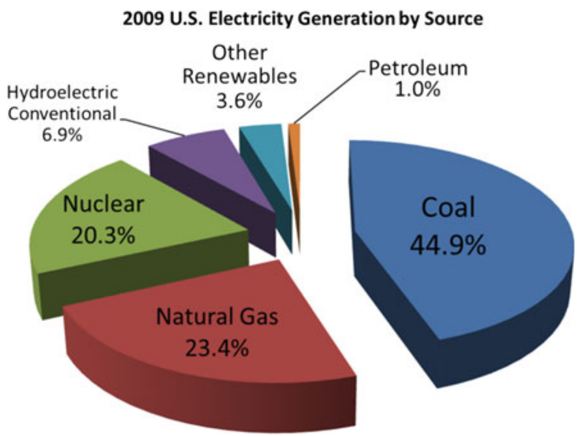

Fig. 2.3 Sources for electricity generation in the USA in 2009 (*Source* John Lowry)

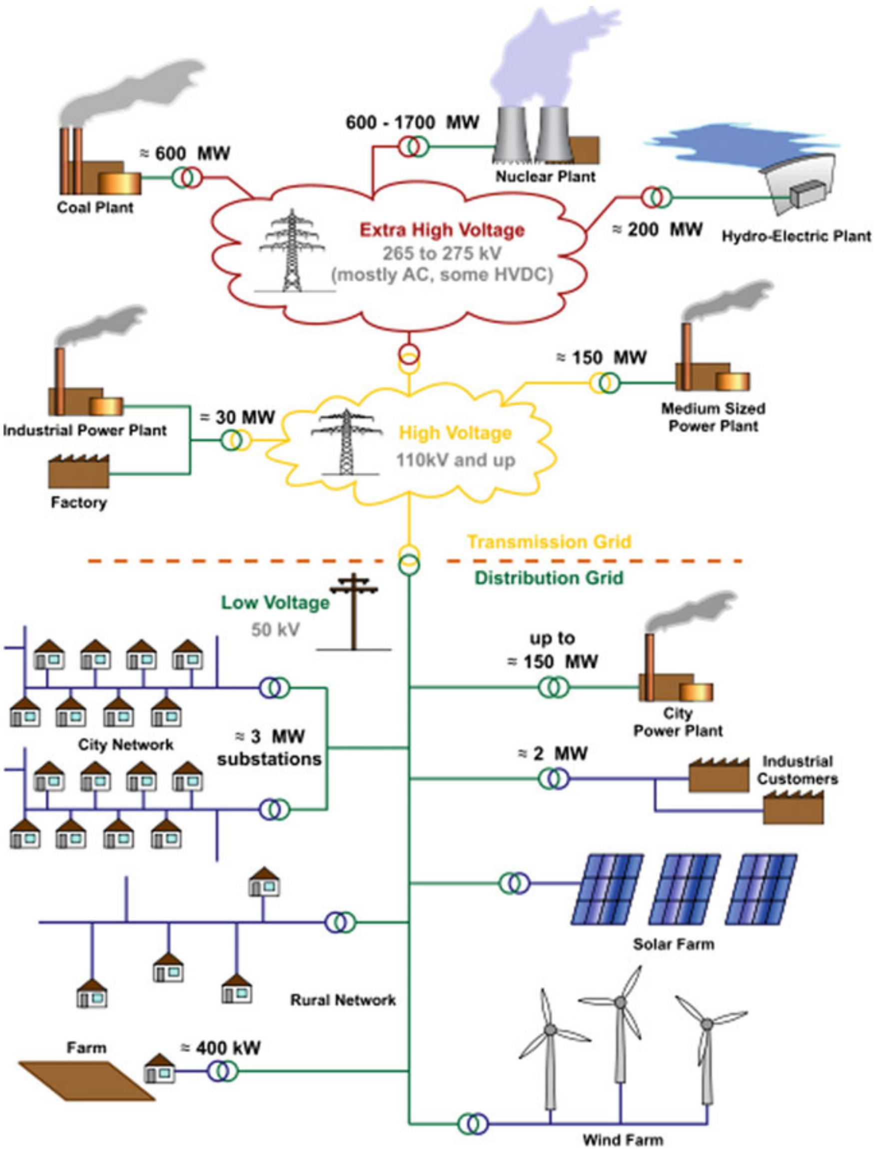

Fig. 2.4 General layout of electricity networks, typically seen in some European Union countries (*Source* http://en.wikipedia.org/wiki/Electrical_grid)

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.

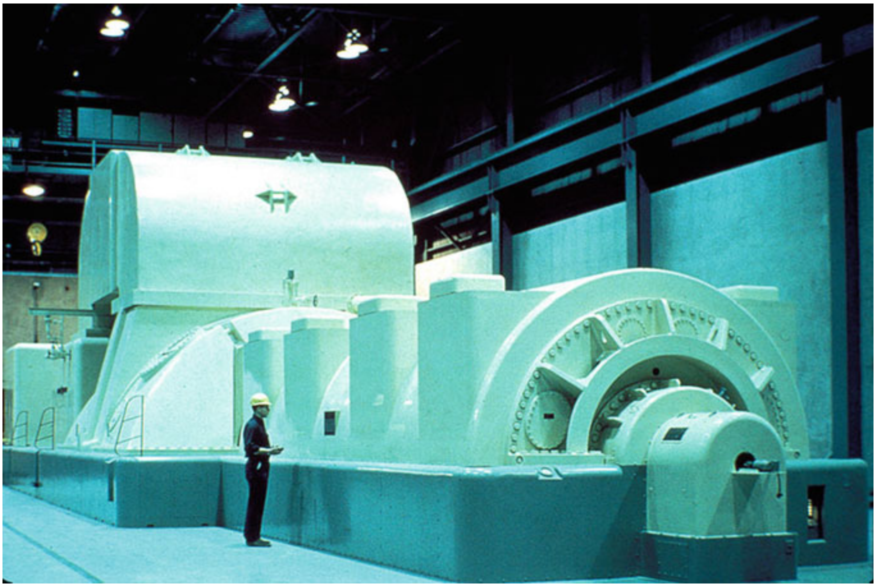

Fig. 2.5 A modern steam-driven turbine generator (*Source NRC*)

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.

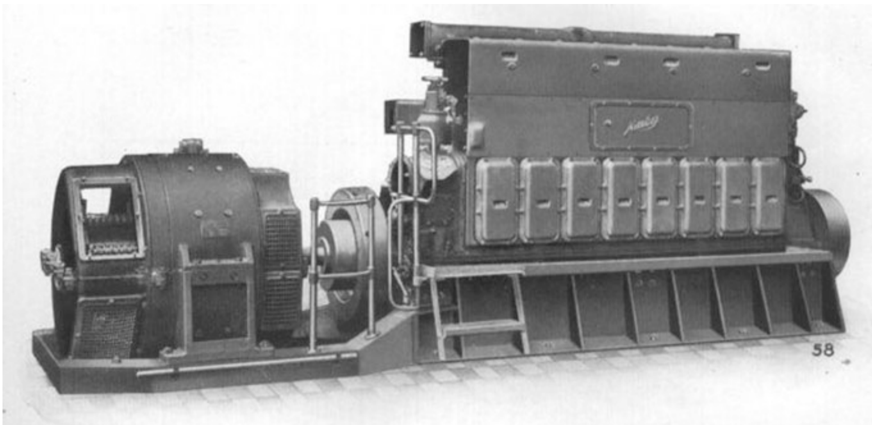

Fig. 2.8 Mirlees 1320 engine from 1934 (Reproduced with kind permission from The Anson Engine Museum)

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

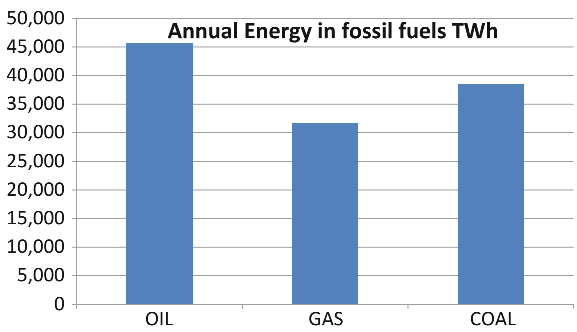

Fig. 2.9 Worldwide annual consumption of fossil fuels used to make power in 2008 (*Source* John Lowry)

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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http://alternativeenergy.procon.org/view.resource.php?resourceID=001797. 70% of the oil used in the US is for transport
http://alternativeenergy.procon.org/view.resource.php?resourceID=001797
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