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Power Generation for Transport – Particularly for Zero Emissions

13.1 Introduction

As IC vehicles are replaced by electric vehicles increasing amounts of oil will be saved. However, the energy for the new EVs will have to be produced in addition to electricity used for existing purposes. This will require a considerable increase in electricity generation and this will have to be planned for. Decisions will have to be made whether electricity for transport will come from carbon-free generation or whether the standard mix of energy currently used will be adhered to.

An estimate of the amount of electrical energy which would be required throughout the world is given in Table 13.1. If power for transport from fossil fuels is to be replaced, substantial investment in new forms of power for transport, be it nuclear or alternative energy, will be required.

Initial use of EVs will probably need no great changes to electricity supply. EVs will be able to recharge at times of low demand thus smoothing our demand patterns. If EVs become widely used, extra generating capacity will clearly be needed. Oil is a finite resource and will eventually become exhausted or, more likely, will become so expensive that the demand will reduce substantially. EVs may well eventually become the replacement, in which case it can be seen from Table 13.1 that eventually approximately 450 GW of generating capacity will be needed. This would be a mix of alternative power and nuclear power if carbon emissions are to be avoided. If total replacement of IC vehicles with EVs happens and if the electricity is generated by sources which do not release carbon, in excess of 5000 million tonnes per annum of CO_2 will no longer be released.

Electric Vehicle Technology Explained, Second Edition. James Larminie and John Lowry.

Table 13.1 Worldwide energy used for transport

Country	Predicted electricity required (GW)	Predicted electricity energy (TWh per annum)
UK	16	144
France	13	120
Europe	115	1051
USA	179	1636
Worldwide	447	4083

13.2 Power Generation using Fossil Fuels

Power generation using fossil fuels remains one of the major methods of electricity generation. Fossil fuels which are used include coal, peat, gas and oil. The efficiency of generation has improved dramatically. Old-style coal stations, for example, have been replaced with more modern coal-burning power stations with nearly twice the efficiency.

The average global efficiency of coal-fired plants is currently 28% compared with 45% for the most efficient plants. A programme of updating existing coal-fired plants to improve their efficiency, coupled with the newer and more efficient plant being built, will generate significant CO_2 reductions. The 400 MW_e Unit 3 at Nordjylland Power Station, a coal-fired power plant in Denmark, is at present the world's most efficient coal-fired power station and has achieved efficiencies of 50%.

Combined cycles use two or more heat engines in tandem. Combined cycle power stations have achieved efficiencies of more than 60% (electrical energy generated/energy in the fuel). In general service combined cycle efficiencies are over 50%; larger units have peak steady-state efficiencies of 55–59%. Research using a 1370 °C turbine inlet temperature has led to even more efficient combined cycles and 60% efficiency has been reached.

Large diesel engines have achieved efficiencies (energy generated/energy in the fuel) of 50%.

Despite these advances fossil fuel power stations will never achieve thermal efficiencies higher than 100%. However efficient they become, their use will always result in CO_2 emissions. With current worries about global warming due to carbon emissions, considerable efforts are being made to replace fossil fuel power stations with generating methods which do not release CO_2.

13.3 Alternative and Sustainable Energy

13.3.1 Solar Energy

Solar energy is probably the only alternative source which could generate the amount of energy needed to replace the energy used for transport which is currently generated from oil.

Solar energy is abundant and available worldwide. Every year, the sun irradiates the land masses on earth with the equivalent of 19 000 billion tons of oil equivalent or 0.22 billion TWh. Only a fraction (9 billion tons of oil equivalent), 105 000 TWh, would satisfy the world's current energy requirements. Put differently, in 20 minutes the amount of solar energy falling on the earth could power the planet for 1 year. The earth currently uses 1.75 billion tons of oil equivalent for transport, under 0.01% of the solar energy available. Capturing and using this abundant solar energy is another matter.

The average sunshine radiation on a horizontal surface varies from around 87 $\mathrm{W\,m^{-2}}$ in Alaska to 273 $\mathrm{W\,m^{-2}}$ in the Sahara.

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

The cost of solar photovoltaics has now fallen to the point where placing it on roofs and connecting the output to the electricity grid have started to become economic. However, rooftop solar will only produce a fraction of the power which may be needed for future electric transport.

Cheaper solar photovoltaic panels have an efficiency of about 10% (electrical energy generated/solar energy); expensive ones perform at 20% efficiency. The lower efficiency panels are more likely to be mass produced and we will therefore assume that these will be widely used.

An alternative to using local solar panels such as rooftop systems is to place solar power systems such as photovoltaics in sunnier regions of the earth, such as deserts, and to transmit the electricity to areas where it is required using high-voltage transmission lines. A solar power station using photovoltaics is shown in Figure 13.1. One advantage of placing solar power stations in desert areas is that they will not use up land which is otherwise used for agriculture.

Using 10% efficiency and the solar energy as 273 $\mathrm{W\,m^{-2}}$ in the Sahara, to produce sufficient energy for world electric transport, that is 4083 TWh, would require an area of

Figure 13.1 A 14 MW power plant installed in 2007 in Nevada, USA (Source: U.S. Air Force, http://en.wikipedia.org/wiki/Renewable_energy)

photovoltaic panels of 1700 km^2, that is a square 42 km × 42 km. The area of the Sahara is over 9 000 000 km^2, so less than 0.04% of it is needed.

Electricity from solar power stations in desert areas would need to be transmitted back to areas where the power was required using the high-voltage DC lines, which were discussed in Chapter 5. The cost of high-voltage transmission lines is a relatively small part compared with the cost of the solar panels. EVs could be charged at times of day when solar electricity is abundant.

An attractive option is to use a series of solar farms distributed around the globe and connected by high-voltage, high-efficiency electric transmission lines. Global distribution would provide solar electricity throughout the day and night.

The cost of photovoltaic panels has fallen consistently since the 1980s, which has largely been predicted. The cost is still predicted to fall considerably lower and some predictions put this at US$1500 by 2020, as low as $500 per peak kilowatt by 2030 and $300 per peak kilowatt by 2050. The cost of energy generated by solar photovoltaic power has already reached 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 Britain and Germany by 2020.

There are no insurmountable technical problems with solar photovoltaic power stations or indeed with solar thermal power stations. By 2020, with the predicted price of photovoltaics of US$1500 per peak kilowatt, power stations located in desert regions such as the Sahara would be able to produce electrical energy at competitive prices when compared with coal-powered and nuclear power stations. Bearing in mind that the peak cost of photovoltaics is likely to continue to fall, the future of solar power looks extremely promising. There would need to be political agreements with countries in which the solar power stations would be placed. The political problems may be greater than the technical problems.

13.3.2 Wind Energy

Wind energy, as with solar, is a rapidly developing technology. Growth of wind energy production has averaged 40% per annum and 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 twentieth century 1.7 MW machines were commercially available. The total wind power installed in Europe is 20 447 MW and in the British Isles 655 MW. This equates to around 60 000 000 MWh per annum in Europe and around 2 000 000 MWh 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 41 000 000 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 EVs. While this is a relatively low figure the UK is only capturing 0.5% of the wind energy available. It would therefore be possible, in theory at least, to provide most if not all of the energy needed for transport by wind energy if required.

Large wind farms can now be found all over the world, many producing up to 40 MW of electrical power. An example of a large (750 kW) wind turbine is shown in Figure 13.2. This is from the wind farm in El Perello, Spain, ‘Parc Eolic de Colladeres’. This park has

Figure 13.2 A 750 kW wind turbine from the 'Parc Eolic de Colladeres', Spain

54 large turbines giving a total maximum power of 36.63 MW. These typically produce 97.5 million kWh per annum. Again, if this energy were produced in a conventional fossil-fuel-burning power station of efficiency 33% it would require 30 000 tonnes of oil.

While wind energy will undoubtedly make a contribution to alternative energy, it is unlikely that it will supply anything near the total amount that will eventually become needed.

13.3.3 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.

Hydro energy has been used successfully for several thousand years, initially in the form of water wheels to drive mills. In large hydro schemes a valley in a hill or mountain 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.

The surprisingly high figure of 6% of world electricity generation is currently obtained from hydro power. In Britain 2% of power is obtained, compared with Canada where the figure is 60%. In total approximately 16% of the world's electricity is renewable, with hydroelectricity accounts for 21% of renewable sources and 3.4% of total energy sources.

In 2010 the installed capacity of hydroelectric schemes worldwide was 1010 GW, with a further 92 GW under construction. Many of the more accessible hydro resources have already been developed. There is some room for further development but a lot of hydro resources have already been developed.

The Gordon Dam in Tasmania is one of many large hydro facilities, with an installed capacity of 430 MW. It is illustrated in Figure 13.3.

13.3.4 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. Probably

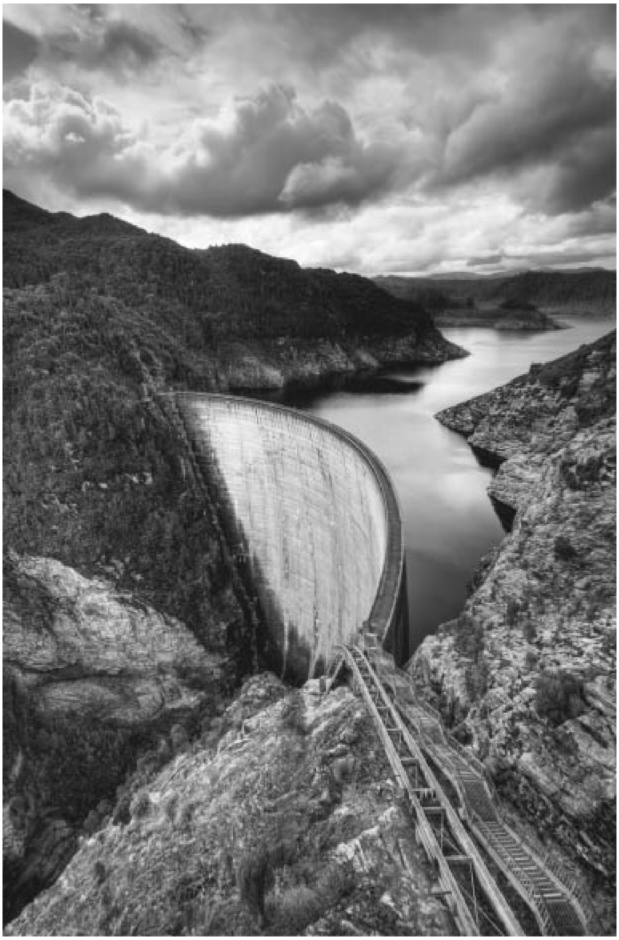

Figure 13.3 The Gordon Dam in Tasmania is one of many large hydro facilities, with an installed capacity of 430 MW (Source: http://en.wikipedia.org/wiki/Gordon_Dam)

Figure 13.4 Aerial view of the Rance Tidal Barrier and generating station (Source: http://en.wikipedia.org/wiki/Rance_Tidal_Power_Station)

the best known tidal scheme is the Rance Power Station in France. In this scheme the tidal energy is captured by damming the estuary and forcing the tidal waters through axial flow turbines. The scheme which is illustrated in Figure 13.4 uses 24 turbines and has an installed capacity of 240 MW. It produces about 600 GWh of electricity per year.

A proposed scheme to put a tidal barrage across the Severn in England 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, that is 36.5 TWh of electricity per annum, 15% of the requirement for electric transport in Britain. An artist's impression of the Severn Barrage is shown in Figure 13.5.

Figure 13.5 Artist's impression of proposed Severn Barrage (Source: http://en.wikipedia.org/wiki/Severn_Barrage)

Tidal barrages on their own will not provide sufficient electricity for transport; however, they could add a reasonable amount of electricity. There is scope for further development of tidal electricity generation in Britain and in other parts of the world. There are of course environmental concerns which accompany the development of tidal barriers and these must always be kept in mind.

13.3.5 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 Marine Current Turbines Ltd. The company plans to install 300 MW in the next decade. This source alone could provide 20–30% of Britain's electricity needs, and 48 TWh per annum could be produced from 106 sites around Europe, the majority being in Britain. This could, if used for transport, provide 20% of the electricity estimated to be required for electric transport. Marine currents are more predictable than wind and solar. A Marine Current Turbine with its rotors raised is shown in Figure 13.6.

13.3.6 Wave Energy

Another method of obtaining sustainable energy is by tapping the power in the waves. There are several systems under trial but as yet none have been commercialised.

Figure 13.6 SeaFlow with its rotors raised (Source: http://en.wikipedia.org/wiki/Marine_Current_Turbines)

Nevertheless this is another interesting possibility for providing sustainable energy supply in the future.

13.3.7 Biomass Energy

Biofuels consist of a wide range of fuels derived from biomass. Use of biofuels is by no means a new idea. Wood has been burnt for raising 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, aircraft and trains can all be run successfully on biofuels using conventional combustion engines. Development of biofuels is an option which could be pursued to provide transport systems which did not rely on fossil fuels.

The problem with widespread use of biofuels is not whether they can be used successfully, but whether growing crops for biofuels will detract from essential food production.

To supply the global aviation industry at current levels of consumption would require some 274.8 million acres of cropland, that is 1.11 million square kilometres or about 424 700 square miles, roughly the area of Texas, Oklahoma, Kansas and Iowa combined.

Clearly the use of biofuels would detract from food production and there is little argument for using biofuels as a major replacement for fossil fuels.

13.3.8 Obtaining Energy from Waste

Energy can be obtained from agricultural residues and waste either by burning them directly in power stations or by converting to fuels such as ethanol. Although a useful potential source of energy, there is insufficient waste to make this a major source of energy for transport.

13.3.9 Geothermal Energy

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 too much heat is not taken away when the rocks become chilled, this method is sustainable. Such energy is usable only in a few locations, Iceland being a case in point (Figure 13.7). Interestingly, active work is being undertaken on converting this energy to chemical energy in the form of hydrogen, for use in fuel cells.

Geothermal energy is another useful source of energy, but again this is unlikely to make a major contribution to energy for transport.

13.4 Nuclear Energy

13.4.1 Nuclear Fission

Nuclear fission has been developed as a power source since the Second World War ended in 1945. Of the world's electricity, 13–14% is currently generated by nuclear fission. It

Figure 13.7 The Nesjavrllir geothermal power plant in Iceland (Source: http://en.wikipedia.org/wiki/Nesjavellir_Geothermal_Power_Station)

is well established and France, for example, uses nuclear fission as its main source of electricity generation. Nuclear fusion gives off no carbon release.

There has been considerable debate about safety 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.

Pebble bed reactors are considered to overcome many of the safety problems which are 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.

Nuclear fission certainly has the potential to generate enough electricity to power future electric transport. Western powers try to prevent the use of nuclear fission in countries where they fear nuclear weapons may be developed from the nuclear waste.

13.4.2 Nuclear Fusion

Research into nuclear fusion is ongoing. An example of nuclear fusion is the process which takes place in a hydrogen bomb and also 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 achieving fusion power, for example the Joint European Torus (JET). A new international group, ITER, will continue the research and it has been proposed to begin construction of DEMO, 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.

13.5 In Conclusion

It is quite possible to produce electricity for transport and other uses by methods which do not cause carbon emissions or which deplete fossil fuels any further. In all probability such methods will include a mix of nuclear fission power stations and a range of alternative energy sources. Solar energy is likely to be the main alternative energy but a mix of solar, wind, tidal and undersea currents among others are likely to feature strongly. In the future nuclear fusion power stations may also develop to contribute to future power generation.

Further Reading

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