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Introduction

Electric vehicles are becoming increasingly important as not only do they reduce noise and pollution, but also they can be used to reduce the dependence of transport on oil – providing that the power is generated from fuels other than oil. Electric vehicles can also be used to reduce carbon emissions. Production of zero release of carbon dioxide requires that the energy for electric vehicles is produced from non-fossil-fuel sources such as nuclear and alternative energy.

The worst scenario is that we have only 40 years supply of oil left at current usage rates. In practice, of course, increasing scarcity will result in huge price rises and eventually the use of oil and other fossil fuels will not be economically viable, hence oil will be conserved as usage will decrease. Oil can also be produced from other fossil fuels such as coal. Traditionally oil produced in this way was considered to be around 10% more expensive, but with current oil prices production from coal is starting to become economic. Coal is more abundant than oil and there is in excess of 100 years of coal left, though it is still a finite resource.

Increasing worries about global warming continue. Global warming is blamed on the release of carbon dioxide when fossil fuels are burnt and it is believed to give rise to a myriad of problems including climate change and rising sea levels which could destroy many of the world's coastal cities.

Electric trains are well developed and are widely used whereas road transport has only just reached the point where vehicle manufacturers are starting to produce electric cars in quantity. Whereas small electric vehicles used in niche markets, such as electric bicycles, invalid carriages and golf buggies, are widely used, electric road vehicles are not. Electric road vehicles have not enjoyed the enormous success of internal combustion (IC) engine vehicles, which normally have much longer ranges and are very easy to refuel.

It is important that the principles behind the design of electric vehicles and the relevant technological and environmental issues are thoroughly understood; these issues will be pursued in the following chapters.

1.1 A Brief History

1.1.1 Early Days

Electric motors developed following Michael Faraday's work in 1821. The first commutator-type direct current electric motor capable of turning machinery was invented by the British scientist William Sturgeon in 1832.

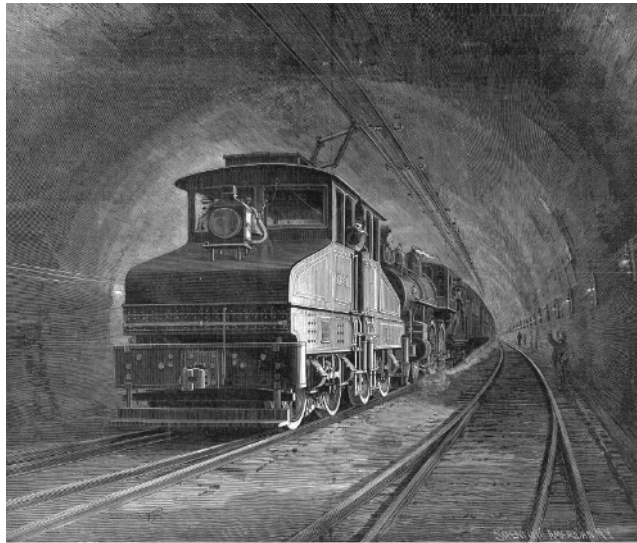
The first known electric locomotive was built in 1837 by the chemist Robert Davidson, and was powered by non-rechargeable batteries. Davidson later built a larger locomotive which was exhibited at the Royal Scottish Society of Arts Exhibition in 1841. The first use of electrification on a main line was on a 4 mile (6.4 km) stretch of the Baltimore Belt Line in the USA in 1895. Figure 1.1 shows the locomotive.

Electric trams or trolley cars were first experimentally installed in St Petersburg, Russia, in 1880. The first regular electric tram service, the Gross-Lichterfelde Tramway, went into service in Lichterfelde, a suburb of Berlin, Germany, and was produced by Siemens & Halske AG, in May 1881.

The first electric street tramway in Britain, the Blackpool Tramway, was opened on 29 September 1885. By the start of the First World War trams were used in many cities throughout the world. Figure 1.2 shows a tram in London in 1910.

The trolleybus dates back to 29 April 1882, when Dr Ernst Werner ran his bus in a Berlin suburb. In 1901 the world's first passenger-carrying trolleybus operated at Bielathal, near Dresden, in Germany. In Britain, trolleybuses were first put into service in Leeds and Bradford in 1911.

Half a century was to elapse after the first electric vehicles before batteries had developed sufficiently to be used in commercial free-ranging electric vehicles. An early electric vehicle, a Baker Runabout, made in the USA and imported into Germany by the founder



THE NEW ELECTRIC LOCOMOTIVE OF THE BALTIMORE AND OHIO RAILROAD COMPANY

Figure 1.1 Electric locomotive, 1895 (Source: http://en.wikipedia.org/wiki/Electric_locomotive)



Figure 1.2 Double-decker tram in London, 1910 (Source: <http://en.wikipedia.org/wiki/Tram>)



Figure 1.3 Baker Runabout in 1893 (Reproduced with permission from Varta)

of Varta Batteries, is illustrated in Figure 1.3. Figure 1.4 shows the first car to exceed the ‘mile a minute’ speed (60 mph; 97 kph) when the Belgian racing diver Camille Jenatzy, driving the electric vehicle known as ‘La Jamais Contente’,¹ set a new land speed record of 106 kph (65.9 mph) making this the first car to exceed 100 kph.

By the end of the nineteenth century, with mass production of rechargeable batteries, electric vehicles became fairly widely used.

Private cars, though rare, were quite likely to be electric, as were other vehicles such as taxis. An electric New York taxi from about 1901 with Lilly Langtree, the actress and mistress of Edward VII, alongside, is illustrated in Figure 1.5.

¹ ‘Ever striving’ would be a better translation of this name, rather than the literal ‘never happy’.

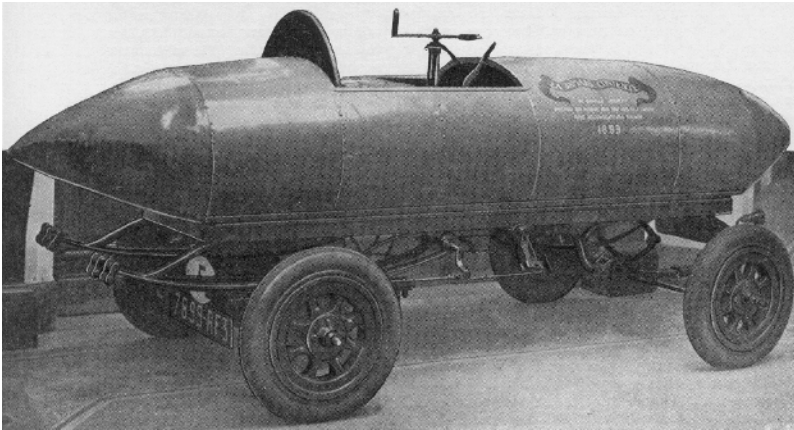


Figure 1.4 Camille Jenatton's 'La Jamais Contente'. This electric car held the world land speed record in 1899, and was the first vehicle to exceed both 60 mph and 100 kph

At the start of the twentieth century, electric road vehicles must have looked a strong contender for future road transport. Indeed, if performance was required, the electric cars were preferred to their IC or steam-powered rivals.

The electric vehicle was relatively reliable and started instantly, whereas IC engine vehicles were at the time unreliable, smelly and needed to be manually cranked to start. The other main contender, the steam engine vehicle, needed lighting and the thermal efficiency of the engine was relatively low.

By the 1920s several hundred thousand electric vehicles had been produced for use as cars, vans, taxis, delivery vehicles and buses. However, despite the promise of these early electric vehicles, once cheap oil was widely available and the self-starter for the IC engine (invented in 1911) had arrived, the IC engine proved a more attractive option for powering vehicles. Ironically, the main market for rechargeable batteries has since been for starting IC engines.

The reasons for the greater success to date of IC engine vehicles are easily understood when one compares the specific energy of petroleum fuel with that of batteries. The specific energy² of fuels for IC engines varies, but is around 9000 Wh kg^{-1} , whereas the specific energy of a lead acid battery is around 30 Wh kg^{-1} . Once the efficiency of the IC engine, gearbox and transmission (typically around 20%) for a petrol engine is accounted for, this means that 1800 Wh kg^{-1} of useful energy (at the gearbox shaft) can be obtained from petrol. With an electric motor efficiency of 90% only 27 Wh kg^{-1} of useful energy (at the motor shaft) can be obtained from a lead acid battery. To illustrate the point further, 4.51 (1 gal)³ of petrol with a mass of around 4 kg will give a typical motor car a range of 50 km. To store the same amount of useful electrical energy requires a lead acid battery with a mass of about 270 kg. To double the energy storage and hence the range

² 'Specific energy' means the energy stored per kilogram. The normal SI unit is joule per kilogram (J kg^{-1}). However, this unit is too small in this context, and so the watt-hour per kilogram (Wh kg^{-1}) is used instead, where $1 \text{ Wh} = 3600 \text{ J}$.

³ The British gallon is 4.51. In the USA a gallon is 3.81.



Figure 1.5 New York taxi cab in about 1901, a battery electric vehicle (The lady in the picture is Lily Langtree, actress and mistress of King Edward VIII)

of the petrol engine vehicle requires storage for a further 45l of fuel with a mass of around 4 kg only, whereas to do the same with a lead acid battery vehicle requires an additional battery mass of about 270 kg. This is illustrated in Figure 1.6. In practice this will not double the electric vehicle range, as a considerable amount of the extra energy is needed to accelerate and decelerate the 270 kg of battery and to carry it up hills. Some of this energy may be regained through regenerative braking, a system where the motor acts as a generator, braking the vehicle and converting the kinetic energy of the vehicle to electrical energy, which is returned to battery storage, from where it can be reused. In practice, when the efficiency of generation, control, battery storage and passing the electricity back through the motor and controller is accounted for, less than a third of the energy is likely to be recovered. As a result regenerative braking tends to be used as much as a convenient way of braking heavy vehicles, which electric cars normally are, as for energy efficiency. For lead acid batteries to have the effective energy capacity of 45l (10 gal) of petrol, a staggering 2.7 tonnes of batteries would be needed!

Another major problem that arises with batteries is the time it takes to recharge them. Even when adequate electrical power is available, there is a minimum time, normally several hours, required to recharge a lead acid battery – whereas 45l of petrol can be put into a vehicle in approximately 1 minute. The recharge time of some of the new batteries has been reduced to under 1 hour, but this is still considerably longer than it takes to fill a tank with petrol.

Yet another limiting parameter with electric vehicles is that batteries are expensive, so any battery electric vehicle is likely not only to have a limited range, but also to be

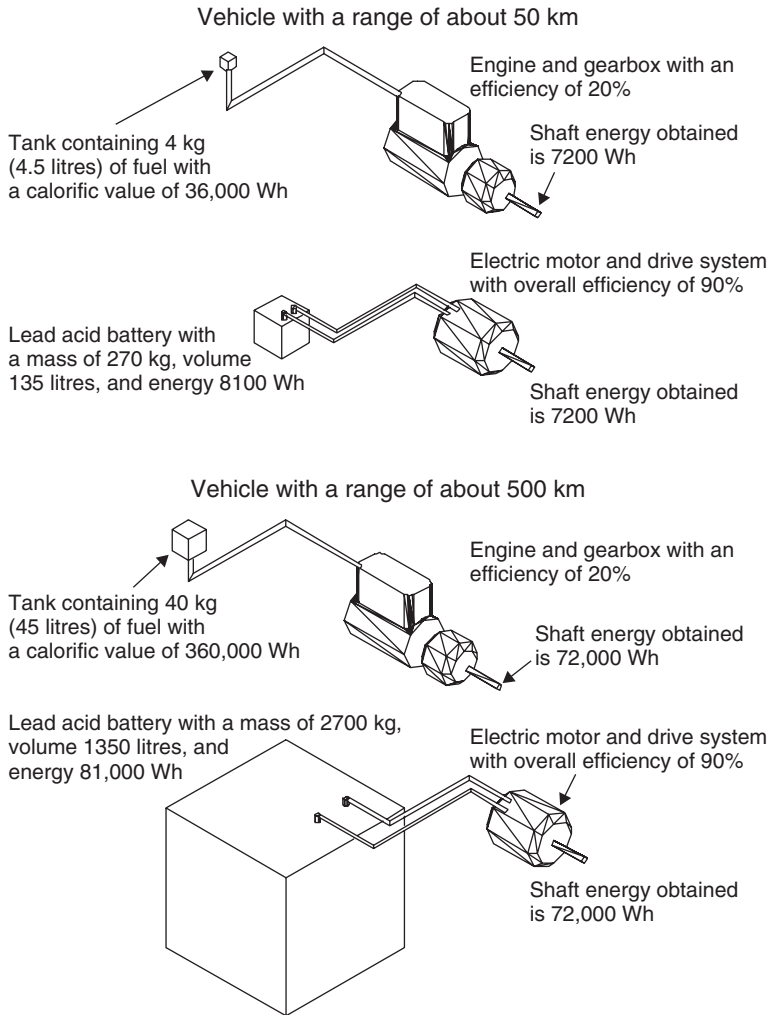


Figure 1.6 Comparison of energy from petrol and lead acid battery

more expensive than an IC engine vehicle of similar size and build quality. For example, the 2.7 tonnes of lead acid batteries which gives the same effective energy storage as 451 (10 gal) of petrol would cost around £8000 at today's prices. The batteries also have a limited life, typically 5 years, which means that a further large investment is needed periodically to renew the batteries.

When one takes these factors into consideration the reasons for the predominance of IC engine vehicles for most of the twentieth century become clear.

Early on in the development of electric vehicles, the concept of the hybrid vehicle, in which an IC engine driving a generator is used in conjunction with one or more electric

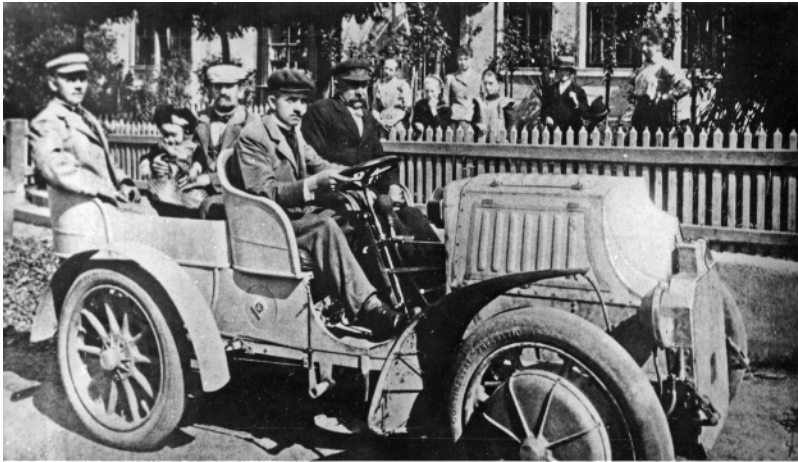


Figure 1.7 The Lohner Porshe, the first electric hybrid vehicle designed and driven by Dr Ferdinand Porsche (Reproduced with permission from the Beaulieu Motor Museum)

motors, was introduced. In 1900, Ferdinand Porsche developed a hybrid vehicle, which is shown in Figure 1.7. This vehicle could run with electricity either from the battery or from the 2.5 hp Daimler engine.

1.1.2 The Middle of the Twentieth Century

Electric trains developed steadily through the twentieth century using both DC and AC systems. Electric trains are the preferred option of railway companies as they require less maintenance, both of the locomotive and the track.

With abundant supplies of cheap oil and mass-produced IC engine vehicles the use of trams and trolleybuses became less economically viable and on the whole fell into disuse.

Electric road vehicles never achieved the success of electric trains, which could take energy from supply rails or overhead lines and did not rely on batteries. There have always been uses for electric vehicles since the early part of the twentieth century, although in the main electric vehicles did not compare favourably with road vehicles at this time. Electric vehicles have certain advantages over those with IC engines, mainly that they produce no exhaust emissions in their immediate environment, and, secondly, that they are inherently quiet. This makes the electric vehicle ideal for environments such as warehouses, inside buildings and on golf courses where pollution and noise will not be tolerated.

One popular application of battery/electric drives is for mobility devices for the elderly and physically handicapped; indeed, in Europe and the USA this type of vehicle is one of the most common types of electric vehicle. It can be driven on pavements, into shops and in many buildings. Normally a range of 4 miles (6.4 km) is quite sufficient but longer ranges are possible.



Figure 1.8 Lineup of Shinkansen trains in Japan, October 2009 (Source: <http://en.wikipedia.org/wiki/Shinkansen>)

Electric vehicles also retain their efficiencies in start–stop driving, when an IC engine becomes very inefficient and polluting. This made electric vehicles attractive for use as delivery vehicles such as the famous British ‘milk float’. In some countries this has been helped by the fact that leaving unattended vehicles with the engine running, for example when taking something to the door of a house, is illegal!

1.1.3 Developments towards the End of the Twentieth Century and the Early Twenty-First Century

Electric trains, having become well established in the middle of the twentieth century, have continued to develop further. Great emphasis has been placed on high-speed trains, starting with the development of the Shinkansen or bullet train in Japan. A modern Shinkansen is illustrated in Figure 1.8. The Tōkaidō Shinkansen began service in 1964 travelling from Tokyo to Osaka, a distance of 515.4 km, in 4 hours. Modern high-speed trains in Japan reach speeds of 300 kph. The current system carries 151 million passengers per year and runs up to 13 trains per hour of 1323-seat capacity.

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*) reached a speed of 574.8 kph (357.2 mph).

The world record for a non-conventional crewed train is held by the experimental Japanese JR-Maglev, having achieved 581 kph (361 mph) on a magnetic levitation track. Maglev trains do not use wheels but run on this special track. The train is magnetically levitated and moved forward by linear electric motors. The trains are theoretically capable of very high speeds. A JR-Maglev train on its test track at Yamanashi, Japan, is illustrated in Figure 1.9.



Figure 1.9 JR-Maglev on test track at Yamanashi, Japan, in November 2005 (Source: <http://en.wikipedia.org/wiki/JR%E2%80%9393Maglev>)

The overall speed of trains is often limited by the track and ideally new track should be laid with gentle bends and no delays due to level crossings. High-speed electric trains are an important development as they are starting to reach speeds where they can become competitive with aircraft for intercity 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 from city centre to city centre whereas aircraft have to land at airports often placed at considerable distances from the city centre. Trains are quicker to load and unload than aircraft. Most importantly, high-speed trains use a fraction of the energy of aircraft. 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.

Modern trams have made a comeback in several cities. A tram from the Manchester tram and light railway is shown in Figure 1.10.

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. This has ultimately led to a series of commercial vehicles such as the Tesla sports car illustrated in Figure 1.11. More recently manufacturers such as Nissan, Mitsubishi and Renault are producing in quantity commercial electric vehicles such as the Nissan Leaf and the Mitsubishi MiEV illustrated in Figures 1.12 and 1.13.



Figure 1.10 Tram on the Manchester Metrolink (Source: http://en.wikipedia.org/wiki/Manchester_Metrolink)



Figure 1.11 The Tesla Roadster (Source: <http://www.teslamotors.com/roadster/gallery>)



Figure 1.12 The Nissan Leaf (Source: http://en.wikipedia.org/wiki/Nissan_Leaf)



Figure 1.13 The Mitsubishi i-MiEV (Source: <http://www.mitsubishi-cars.co.uk/imiev/models.aspx>)

Electric vans and buses continue to be used and these have benefited from the new lithium batteries.

There has also been a resurgence in hybrids starting with those which cannot be recharged from the mains, such as the Toyota Prius illustrated in Figure 1.14. Non-rechargeable hybrids, while efficient, still rely entirely on oil. As a result they cannot make use of mains electricity, which can be generated from a wide range of sources. Recently General Motors has released the Volt, a rechargeable hybrid, illustrated in Figure 1.15. This can complete many of its journeys using electricity, relying on the IC engine as a range extender for longer journeys.



Figure 1.14 The Toyota Prius (Pictures reproduced by kind permission of Toyota)



Figure 1.15 The Chevrolet Volt (Source: http://en.wikipedia.org/wiki/Chevrolet_Volt)

Fuel cell vehicles were believed to show considerable promise and a lot of work was carried out on the development of prototype fuel cell vehicles. Fuel cells normally run on hydrogen, which needs to be stored on the vehicle. Fuel cell vehicles have an advantage over batteries in that they can give much longer ranges. Recently Honda has introduced the FCX Clarity, which runs on hydrogen and is illustrated in Figure 1.16. This is currently leased to customers in the USA and is not yet available for general sale. A fuel cell bus is illustrated in Figure 1.17.

Electric bicycles such as that illustrated in Figure 1.18 have become increasingly popular throughout the world. For example, in the 1990s China witnessed the world's most spectacular growth in two-wheeled electric vehicles and annual sales of bicycles and



Figure 1.16 Honda FCX Clarity (Source: http://en.wikipedia.org/wiki/Honda_FCX_Clarity)



Figure 1.17 Citaro fuel-cell-powered bus, one of a fleet that entered service in 2003 (Photograph reproduced by kind permission of Ballard Power Systems)

scooters grew from 56 000 in 1998 to over 21 million in 2008, compared with 9.4 million automobiles in 2008.

1.2 Electric Vehicles and the Environment

Electric vehicles are normally associated with benefits to the environment and saving energy. These benefits include reducing local pollution from the vehicles themselves,



Figure 1.18 Electric bicycles are among the most widely used electric vehicles

reducing dependence on oil and other fossil fuels and reduction of carbon emissions. When considering the introduction of electric vehicles a thorough understanding of the effects on the environment is needed.

1.2.1 Energy Saving and Overall Reduction of Carbon Emissions

Where use of electric vehicles replaces a less energy efficient source of transport considerable energy saving can accrue. A good example is replacing air travel with transport by electric train, which uses a fraction of the energy per passenger mile. Encouraging car users to use electric trams would be another example.

Replacing IC vehicles with electric vehicles saves energy, provided that the electricity is produced by an efficient grid system using modern power stations. It will also further reduce carbon emissions when a proportion of the electricity is generated by nuclear or alternative energy sources which do not release carbon. In Britain nuclear energy provides around 20% of the electricity and a further 10% is generated by alternative energy such as wind and hydro. In France 90% of its electricity generation does not release carbon. In 2003, for example, approximately 75% of France's electricity was generated by nuclear power and a further 15% by hydro. Only 10% was generated by fossil fuel power stations.

1.2.2 Reducing Local Pollution

There are increasing concerns about pollution from vehicles, particularly in towns and cities, and electric vehicles can and do make towns and cities more pleasant to live in. These vehicles reduce emissions of carbon dioxide and also the local emission of exhaust fumes.

Environmental issues may well be the deciding factor in the adoption of electric vehicles for town and city use. Leaded petrol has already been banned and there have been attempts in some cities to force the introduction of zero-emission vehicles. The state of California has encouraged motor vehicle manufacturers to produce electric vehicles with its Low Emission Vehicle Program. The fairly complex nature of the regulations in this state has led to very interesting developments in fuel cell, battery and hybrid electric vehicles.

Not only do electric vehicles charged from modern grid systems reduce the overall amount of energy used, but also they do away with tail pipe emissions from IC vehicles. Much of the emission problem is transferred to the power stations, where it can be handled responsibly.

1.2.3 Reducing Dependence on Oil

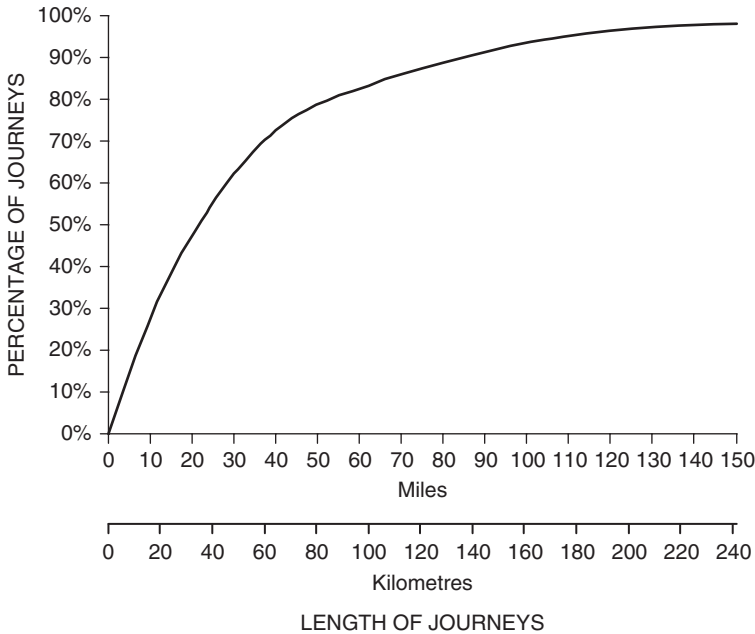
Oil is a finite resource which is becoming evermore expensive to produce. Many of the major wells from which we take oil are near exhaustion and we will need to take oil from wells which are more difficult and hence more expensive to exploit or alternatively we will need to make oil from other fossil fuels such as coal. These factors will dramatically affect the cost of petrol and diesel at the pumps and this may well be a significant factor in making more widespread use of electric vehicles.

1.3 Usage Patterns for Electric Road Vehicles

The range and recharging times of battery electric vehicles are extremely important and the new ranges of electric vehicles, such as the Nissan Leaf, have attracted criticism from the motoring press, much of it unfair. Electric vehicles are unlikely in the near future to achieve the range and rapid refuelling of IC vehicles.

It is important to consider the pattern of use of vehicles when considering the issue of range. Figure 1.19 shows typical journey lengths in the USA. The results show that 50% of all journeys are less than 25 miles (40 km), 75% are around 40 miles (64 km) and around 94% of journeys are less than 100 miles (161 km). The new generation of mass-produced electric vehicles such as the Nissan Leaf and the Mitsubishi MiEV have ranges of around 100 miles and this fits in well with these findings. Many drivers will have journey patterns which mean that most of their journeys can be carried out on a single charge. The refuelable hybrid, the Chevrolet Volt, has a range of around 40 miles before it needs to resort to the IC engine, and therefore would be able to complete 75% of journeys on a single charge alone.

Trains, trolleybuses and trams do not have limitations on range problem in the sense that they can travel wherever there are supply lines. Neither do they need recharging or refuelling.



The DOT (NPTS) data contradicts 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 this data shows that less than 5% travel 100 miles or more daily.”
http://www.hybridconsortium.org/dot_data.html

Figure 1.19 Typical journey lengths in the USA. The US Department of Transportation (DOT) Nationwide Personal Transportation Service (NPTS) data contradicts 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 this data shows that less than 5% travel 100 miles or more daily (Source: http://www.hybridconsortium.org/dot_data.html)

The time taken to charge battery electric vehicles is a major issue. Vehicles can normally be charged overnight from a 13 A plug and be charged to most of their capacity quickly if higher powered chargers are used. This still takes the best part of an hour and manufacturers recommend that this is not done more than once daily. The infrastructure for charging electric vehicles mid journey and for return journeys will need to be put into place.

Clearly there is a pattern of use for which electric vehicles are appropriate. Vehicles which need to travel regularly on long journeys could be either fuel cell vehicles or hybrid vehicles which have longer ranges.

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