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Efficiencies and Carbon Release Comparison

11.1 Introduction

The term efficiency is only useful when it is used for comparing like with like. The term is widely and often erroneously used. As a simple example, one may often hear statements such as a battery electric vehicle is four times as efficient as a petrol IC engine vehicle. But what does this actually mean? Assuming it means that in terms of electrical energy supplied to the battery vehicle/energy delivered by the wheels is four times higher than energy in the petrol/delivered to the wheels then the statement may be reasonable. In fact the efficiency of the EV (road energy/electrical energy supplied to the vehicle) may well be around 80%. The efficiency of the IC engine vehicle (road energy/petrol energy) may well be 20%. Hence the efficiency of the EV may well be four times that of the IC vehicle (road energy/energy supplied). Again, what does this mean? It may be useful as part of a calculation if you are trying to compare energy costs, provided you have the cost of electricity and the cost of petrol. It certainly does not help if you are trying to compare the efficiency of converting fossil fuel energy into road energy unless you know the efficiency of converting fossil fuel at the power station. Typically the efficiency of converting coal to electricity and transmitting it to end users may be around 25%. Hence the overall efficiency of the EV (road energy/energy in the fossil fuel at the power station) is the same in both cases.

The efficiency of older coal power stations is around 25% (electrical energy generated/energy in the coal burnt). The current average efficiency for a coal-powered power stations is 28%; modern power stations can achieve efficiencies of 45%. Combined cycle power stations can achieve efficiencies as high as 60% (electrical energy generated/energy in the fuel burnt).

Again let us compare a petrol engine car with an EV using electricity from a solar power station. Typical efficiencies of the solar power station (road energy/solar energy) will be around 10%. This means that the overall efficiency of the EV supplied with solar electricity is 2.5% (road energy/energy at source) compared with the efficiency of the IC vehicle (road energy/energy at source, i.e. in the petrol) which will still be 25%.

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

The IC vehicle is now 10 times as efficient as the EV supplied with solar power. Basically this is a meaningless statement. The EV will result in zero carbon emissions whereas the IC engine vehicle will; the cost of using the EV powered from solar energy may of course be considerably higher than the petrol vehicle. This will be dealt with in the next chapter.

Efficiencies can be useful, for comparing like with like. For example, when comparing electric motor A with electric motor B the efficiencies will give a good comparison of the energy efficiencies.

Efficiencies involved in calculations, however, are also extremely useful. They may, for example, be used in cost calculation or in calculations of carbon dioxide savings. Efficiencies should always be well defined.

11.2 Definition of Efficiency

Energy efficiency is simply the ratio of the energy output to the energy input expressed as a percentage or alternatively as a decimal. The latter is especially useful as the efficiencies in a chain of items can be multiplied to give an overall efficiency. Hence if a power station has an efficiency of 0.3 (electrical energy output from power station/chemical energy in the fuel) and is supplying electricity through transmission lines which have an efficiency of 0.9% (energy at end of the line/energy input to the line) and this drives an electric motor which has an efficiency of 0.8 (shaft energy from the motor/electrical energy supplied to the motor) then the overall efficiency of the combined system (shaft energy from the motor/chemical energy in the fuel) will be $0.3 \times 0.9 \times 0.8 = 0.216$ or 21.6%.

11.3 Carbon Dioxide Emission and Chemical Energy in Fuel

Carbon dioxide emission as well as specific energy content are normally shown in tabular form such as in Table 11.1. This is based on the Carbon Trust release. The figure for CO_2/kWh is based on an average and efforts are made to reduce this all the time. Table 11.2 shows the CO_2 release for generation in different countries.

Using these figures it is now fairly easy to compare the amount of CO_2 generated by EVs and IC engine cars. For example, a Nissan Leaf will travel 100 miles (160 km) using

Table 11.1 Carbon dioxide release

Energy source	Units	Kilograms of CO_2 equivalent per unit
Natural gas	kWh	0.185 23
Gas oil	kWh	0.275 33
	l	3.021 20
Fuel oil	kWh	0.265 92
	t	3219.7
Diesel	kWh	20.253 01
	l	2.672
Petrol	kWh	0.241 76
	l	2.322

Table 11.2 Carbon dioxide release per kilowatt hour of generated electricity

Country	Carbon release (kg kWh^{-1})
Japan	0.381
USA	0.59
Germany	0.5
UK	0.44
Canada	0.21
France	0.07

a battery of 24 kWh. Allowing an efficiency of 90% for charging efficiency (electrical energy stored/electrical energy supplied). The vehicle will require 26.7 kWh of electricity. Hence the CO_2 released in the UK will be $26.7 \times 0.44 = 11.75$ kg. In France where the CO_2 release is currently $0.07\,\text{kg kWh}^{-1}$ the amount of CO_2 released would be 1.87 kg.

A diesel car with an economy of 40 mpg or 8.9 l per mile travelling 100 miles will use 2.5 gal or 11.25 l of diesel. Using the figures in Table 11.1, it will release $11.25 \times 2.672 = 30\,\text{kg}\,CO_2$.

This shows a marked advantage for EVs using mains electricity – it will cause approximately half of the CO_2 release compared with the diesel car. The figure for CO_2 release per kilowatt-hour of electricity is an average which varies all of the time. It includes nuclear power, which currently supplies around 20% of UK electricity, and alternative energy, which supplies around 10% at present and is due to increase to 20% by 2020. In France where much of the electricity is generated by nuclear and alternative energy sources the figure will be much lower.

The CO_2 release from a hydrogen fuel cell vehicle can also be calculated. The Honda FCX fuel cell vehicle which runs on hydrogen has a fuel consumption of 60 miles per kilogram of hydrogen. Therefore to travel 100 miles it will use 1.67 kg of hydrogen. Hydrogen has a specific energy of $33.3\,\text{kWh kg}^{-1}$ and therefore the energy in the hydrogen will be 55.6 kWh. Assuming the hydrogen to be reformed from natural gas with an efficiency of 70%, and the efficiency of compressing the fuel into the tank is 90%, the energy in the natural gas from which the hydrogen was reformed will be $55.6/0.9/0.7 = 88.2$ kWh. From Table 11.1 this will cause a CO_2 release of 0.185 23 kg of CO_2 per kilowatt-hour in the natural gas, that is 16.3 kg. This compares with the diesel car mentioned above, which will release 30 kg of CO_2 to travel 100 miles. The fuel cell car releases 54% of the CO_2 compared with the CO_2 release from the diesel engined car. (Honda claims 60% in its literature.)

If instead of reforming the hydrogen from natural gas we electrolyse this from water with an efficiency of 70%, we will need 88.2 kWh of electricity. Again from Table 11.2, the CO_2 release in the UK will be $0.545\,22 \times 88.2 = 38.8$ kg of CO_2. In France where the CO_2 released per kilowatt-hour of electricity generated is 0.07, the CO_2 released would be 6.2 kg. If the hydrogen is produced from energy sources which do not release CO_2, such as nuclear of alternative energy, there will be virtually no carbon releases.

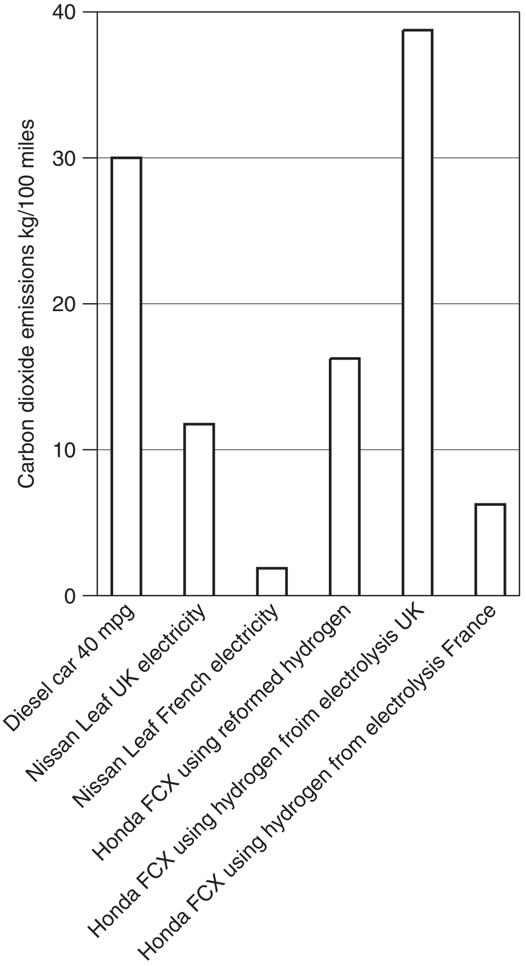

Figure 11.1 Carbon dioxide released for different EVs travelling 100 miles or 160 km

The above outline analysis is fairly simple but nevertheless we are able to draw some very interesting conclusions from it. These are summarised below and in Figure 11.1.

1. A battery car (e.g. the Nissan Leaf) charged in the UK will cause 14.5 kg of CO_2 to be released for a journey of 100 miles or 160 km.
2. For the same journey in France where the CO_2 emissions per kilowatt-hour of electricity are much lower, the release of CO_2 would be 1.9 kg.
3. A diesel engine car for the same journey would release 30 kg of CO_2.
4. A hydrogen fuel cell car using hydrogen reformed from natural gas would release 16.3 kg of CO_2.
5. A hydrogen fuel cell car using hydrogen electrolysed from water using mains electricity would release 48.1 kg of CO_2 in the UK and 6.2 kg in France.

The conclusions are clear. Firstly, EVs are more carbon friendly than IC engine vehicles. This is clearly influenced by the type of electricity generation used. This is markedly better for EVs used in France, for example, where CO_2 release per kilowatt-hour of electricity generated is markedly lower than that in the UK due to the predominance of non-CO_2-releasing electricity generation. Secondly, the hydrogen fuel cell vehicle using reformed hydrogen gives considerably better CO_2 release than the diesel car – almost a 50% saving. Thirdly, the hydrogen fuel cell is not as carbon friendly as the battery EV when using mains electricity to obtain hydrogen from electrolysing water. At present in the UK the hydrogen fuel cell using reformed hydrogen is on a par with the battery EV. As the amount of CO_2 released per kilowatt-hour of electricity decreases when more carbon-neutral electricity generation is used, the battery EV will show a marked advantage over the fuel cell vehicle.