Transport energy and emissions: urban public transport

Book Section

TRANSPORT ENERGY AND EMISSIONS: URBAN PUBLIC TRANSPORT

Dr. Stephen Potter
Department of Design and Innovation
Faculty of Technology
The Open University,
Walton Hall,
Milton Keynes MK7 6AA
Great Britain

URBAN PUBLIC TRANSPORT AND ENERGY USE

In recent years transport's use of energy has risen strongly. Forty years ago, in most developed economies, transport's proportion of total energy use was between 15% and 20%. Today it is around 35% of all energy consumption and is still rising (Potter, 1997, 2000). Urban public transport accounts for very little of this growth in energy use, or of transport's overall energy consumption. In Great Britain, of all fuel used for transport, 18% was consumed by air travel, 2% by railways, 2% by water transport, 2% by buses and 76% by private road transport – cars and lorries (DETR, 2000). The situation is similar in other developed economies. The rise in transport's use of energy has primarily come about by the increased use of the private car for personal transport and the road lorry for freight.

This does not mean that the energy and emissions from urban public transport is not an important issue. As urban policies increasingly seek to transfer travel from the private car to public transport, questions arise about the impact this might have on overall emissions. Studies of transport energy and emissions from passenger transport often concentrate upon individual vehicles, but this is only a part of the vehicle/transport system generating the total amount of energy used and pollutants emitted. This total is a product of a number of factors. As well as the energy used per vehicle, key variables are how well occupied and utilised a vehicle is, patterns of use and the overall volume of travel undertaken (Potter, 2001). Outside of this vehicle/transport system there are also indirect effects, such as long distance commuter rail contributing to metropolitan decentralisation and so increasing car use and dependency. An awareness of such wider system effects helps to explain why energy and emissions improvements to individual vehicles have been accompanied by a substantial increase in energy use and emissions from the transport sector. This article explores the nature of energy use and emissions from urban public transport and indicates some of the strategic issues involved. It starts by examining energy and emissions from public transport vehicles themselves and then extends the system boundary to encompass public transport systems, how they are developed for transport and environmental policies and then indirect effects upon wider travel patterns and behaviour.

MEASURING VEHICLE ENERGY AND EMISSIONS

Life cycle analysis studies of the environmental impacts of road vehicles (for example, Teufel et al., 1993, OECD, 1993) have indicated that that the fuel used in running vehicles represents 80 – 90% of total life cycle energy use. The production and processing of materials, vehicle manufacture, maintenance and disposal stages of the life cycle are relatively insignificant compared to the energy consumed and emissions generated when vehicles are in use. The OECD study, for example, calculated CO_2 emissions from an ‘average petrol car’ and showed that only 9% was from vehicle manufacturing, with 76% from the fuel at point of use and a further 15% from emissions and losses in the fuel supply system. These life cycle studies were of cars, which are utilised less intensively and have a shorter life than public transport vehicles. Thus is probable that an even higher proportion of the energy and emission impacts of buses, trams and trains are in their use phase.

However, when considering energy and emissions from vehicle operations, it is important to use data on fuel life cycle (or primary energy) consumption. As noted in the OECD study, energy use and emissions in the fuel supply system are important for vehicles powered by internal combustion engines. It is even more so for public transport modes using electricity, where there can be 60% losses in electricity generation. This particularly applies to CO_2 emissions, which are a function of the amount of fossil fuel used. For local urban air quality, emissions at the point of use (delivered energy) become more important.

AIR QUALITY EMISSIONS

Diesel or electricity predominantly powers urban public transport vehicles. Buses and many trains are diesel powered, whereas electrification is widespread for urban railway lines and is standard for metro and tram systems. Diesel used to be thought of as a rather ‘dirty’ fuel, but in recent years there have been considerable improvements to both fuel formulations (e.g. low sulphur ‘city’ diesel) and to engine design and exhaust after treatments. For electricity, emissions are transferred to power stations, which may use a variety of fuels.

It is useful to separate emissions from urban public transport into those that affect urban air quality and those that contribute to global climate change. For diesel-powered buses and trains, the key emissions that affect air quality are:

- Carbon Monoxide (CO) – a highly toxic gas that can impair brain function and, in sufficient concentrations, kill. Transport is the major source of CO, although 90% comes from cars.
- Nitrogen Oxides (NOx) – these cause respiratory problems and contribute to low-level ozone formation and acid rain. Transport produces about half of NOx emissions. Diesel vehicles (Buses, lorries and diesel cars) are an important source.
- Hydrocarbons (HC) – include known carcinogens.
- Particulate matter (PM) – About half of all particulates come from diesel vehicles. These aggravate respiratory diseases and smaller particles (PM10s – particles of less than 10 um in diameter) may be carcinogenic.

In all cases, urban public transport vehicles are only a minority source, although in certain specific locations, such as where buses operate in otherwise pedestrianised streets, bus depots, or near large stations served by diesel trains, emissions from public transport vehicles can be important.

Electric vehicles produce no significant emissions in their operations on urban streets, but power stations do in generating the electricity these vehicles use. Fossil fuel (particularly coal and oil) power stations are a major source of Sulphur Dioxide (SO_2) and NOx. These emissions also have regional air quality impacts as they play a key role in producing acid rain. Natural gas fuelled power stations do not emit any SO_2 as it is removed before the gas is distributed. Nuclear power stations produce no emissions that affect urban air quality (and tend to be located well away from urban areas), but have other important environmental and health issues including toxic waste disposal and accident risk. Hydro-electricity and other renewable energy sources produce no emissions affecting local air quality, but again there are other environmental impacts (e.g. the environmental and eco-system effects of large dams).

Carpenter (1994), in his examination of the environmental impact of railways, compiled information from a number of UK and German sources on emissions by a several types of public transport vehicle. Table 1 summarises the 'typical emissions' for urban public transport modes.

Table 1: Typical emissions (grams per passenger kilometre) from urban public transport

Mode	**NOx**	**SO_2**	**CO**	**HC**
Buses	0.8	0.1	1.0	0.1
Diesel Rail	1.0	0.2	0.1	0.1
Electric Rail	0.4	1.1	0.1	0.002
Tram/Metro	0.2	-	0.01	-
Cars	2.1	-	11.0	-

Summarised from Carpenter (1994) Table 8.2, p 171.

As the issue of modal transfer between car and urban public transport is important, Carpenter's 'typical' figure for cars is also included. Per passenger kilometre, NOx and CO emissions are substantially lower for urban public transport modes than travelling by car. Electric rail (via power stations) does have high SO_2 emissions, but this is counterbalanced by very low emissions of other pollutants.

The information in Table 1 is from the early/mid 1990s, and since then, governments throughout the world have introduced increasingly stringent regulations to cut emissions from new diesel and petrol vehicles. Typical of these are the European Commission 'Euro' road vehicle standards. The diesel Euro I standard was introduced in 1992, followed by Euro II in 1996 and Euro III in 2000. Euro IV and V standards are due to be introduced in 2005 and 2008 respectively (Table 2). The reduction in emissions required under these standards has been significant. By 2000, permitted particulate emissions had been cut to a quarter of their 1992 levels and NOx cut by a third. Further significant improvements will come with Euro IV and V for 2005 and 2008, which will require both cleaner fuel formulations and exhaust gas after treatment, such as particulate traps and 'deNOx' catalysts.

Table 2 EU Emission standards for heavy duty diesel engines (grams per kWh)

Standard	**Date**	**CO**	**HC**	**NOx**	**PM**
Euro I	1992 (>85kW)	4.5	1.1	8.0	0.36
Euro II	1996	4.0	1.1	7.0	0.25
	1998	4.0	1.1	7.0	0.15
Euro III	2000	2.1	0.66	5.0	0.10
Euro IV	2005	1.5	0.46	3.5	0.02
Euro V	2008	1.5	0.46	2.0	0.02

Adapted from Ford, 2002

However, as Ford (2002) notes in his review of diesel train engines, in Europe these standards apply only to road vehicles. So, although buses have to meet the increasingly stringent Euro standards, trains do not. This is not the situation in the United States, where the Environmental Protection Agency has introduced NOx and particulate limits for diesel trains. However, in Europe, local urban diesel multiple-unit trains are powered by a variant of diesel engines designed for lorries and buses. As these meet the Euro emission standards then the trains they power will also have lower emissions.

The situation is not quite as simple as automotive emission standards automatically cleaning up urban passenger diesel trains. The operating regime of trains is different to that of buses and lorries, and engine adjustments to improve the fuel economy of train engines will increase NOx emissions to above the Euro limits. The International Union of Railways (UIC), in conjunction with rail operators and suppliers has been developing a new set of emission limits for rail traction diesels. The figures for smaller engines (used in urban diesel multiple-unit trains) are shown in Table 3. Due to the different operating regime and test cycles, these are not directly comparable to the road vehicle Euro standards. The considerable reduction in NOx is of note, as this is a crucial local air pollutant from diesel engines.

Table 3: Proposed UIC diesel engine emissions (grams per kWh)

Date	NOx	HC	CO	PM
Until 31.12.02	12	0.8	3.0	n/a
1.1.03-31.12.07	9.9	0.8	3.0	0.25
From 1.01.08	4.5	0.5	2.0	0.15

Adapted from Ford, 2002

CLIMATE CHANGE EMISSIONS

The principal gas contributing to climate change is Carbon Dioxide (CO_2). As noted above, gasses and particulates affecting local air quality can be addressed by technologies that reduce or eliminate them at source, although improvements may be countered by an increase in the amount of travel. Emissions of CO_2 are not amenable to such technical fixes, as they are simply a function of the carbon content of fossil fuels. Diesel fuel averages 2.7 kg CO_2 per litre, with petrol a little lower at 2.4 kg CO_2 per litre. Liquefied petroleum and natural gas have a lower carbon content (with natural gas having 0.18 kg CO_2/kWh). The carbon content of fuels is somewhat modified by the technology of diesel, petrol and gas engines having inherently different efficiencies. The diesel engine is more efficient than the petrol engine, with gas engines less efficient than either diesel or petrol engines.

A number of studies (Carpenter, 1994, Wood, 1995, Potter, 2000 and Roy, Potter and Yarrow, 2002) have sought to compile information on the amount of energy and CO_2 emissions arising from the operations of various transport modes. Table 4 is a compilation from these sources for a range of urban public transport vehicles. These figures are for fuel life cycle (as discussed above) allowing for the different engine efficiencies and fuel production systems and the carbon content of the fuels concerned. Clearly, the energy use depends very much upon the individual designs of vehicles and their operating regimes, and the above studies do note variations. It should be emphasised that in Table 4 only contains information on urban public transport vehicles. Larger and faster inter-city trains, for example, have higher energy use and CO_2 emissions.

The figures used are largely based on UK data. The information for buses was provided by a number of urban bus companies and that for railways by London suburban rail operators. The light rail figures were provided for the modern tram operations in Manchester and the metro/underground figure is for the London Underground. The data has been cross-checked with other UK and European energy and CO_2 emission estimates (CEC, 1992, Climate Care, 2000 and Bestfootfoward, 2000). For other developed countries, the energy use and CO_2 emissions for buses and diesel trains are likely to be similar. For electric trains, light rail and metros, the energy use is also likely to be broadly similar to these UK figures, but CO_2 emissions will vary according to the primary fuel mix of the power stations. The UK mix of gas, coal and nuclear generation was estimated to produce 480 grams of CO_2 /kWh.[1]

[1] Modern coal power stations produce about 950 grams of CO_2 per kWh of electricity generated and gas combined cycle stations about 450 grams of CO_2 per kWh of electricity generated (Everett and Alexander, 2000). The UK average also includes oil, hydo and nuclear generation.

Table 4 Fuel life cycle energy consumption and CO_2 emissions for urban transport modes

Mode	*Seats*	*MJ per vehicle kilometre*	*Kilograms CO_2 per vehicle kilometre*	*MJ per seat kilometre*	*Grams CO_2 per seat kilometre*
Urban Electric Train	300	117	11.7	0.39	39
Urban Diesel Train	146	74	8.8	0.50	60
Light Rail	265	47	10.1	0.18	38
Metro/Underground	555	122	26.0	0.22	46
Single Deck Bus	49	14.2	1.6	0.29	33
Double Deck Bus	74	16.2	1.9	0.22	26
Minibus	20	7.1	0.8	0.36	40
Medium-sized Car	5	3.5	0.39	0.70	78

Based upon Carpenter (1994), Potter (2000) and Roy, Potter and Yarrow (2002)

Because of the considerable variation in the size of public transport vehicles, a valid comparison can only be made if a standard unit is used. Hence Table 3 uses the unit of energy and emissions per passenger seat kilometre to provide comparable figures. In general, the slower forms of public transport using lighter vehicles use less energy and produce the least CO_2 emissions. The Metro/Underground figure is surprisingly high. There are two reasons for this. One is that it involves an older system and vehicles than the other vehicles for which data were gathered. There is also a problem with urban transport vehicles designed to accommodate standing as well as seated passengers, which particularly affects metro services like the London Underground. Dividing energy and CO_2 emissions by seats thus gives the impression that such vehicles are less efficient than they actually are. For urban and transport policy comparisons, figures for a medium-sized car are also included. This shows that, per seat kilometre, public transport uses a third or less the energy and CO_2 emissions of a car.

The ‘per seat kilometre’ measure in Table 4 provides a valid comparison between different public transport modes, but in actual practice there is a further variable that crucially affects the actual emissions per passenger kilometre. This is how well occupied a vehicle is. If there is only the driver in a private car, then he or she will be consuming 3.5MJ per passenger kilometre compared to around 0.2 – 0.3MJ for a fully loaded bus or train. In such a situation, driving a car consumes ten times the energy than were the same trip made by public transport. In Britain, peak-hour car occupancy averages 1.17 persons (Potter 2000) while trains and buses are near fully-loaded (with standing in addition to seated passengers), so in such circumstances such a ratio of energy use is likely to be achieved.

In the off-peak the situation is different. For shopping, leisure and holiday trips, car occupancy is in the range of 2 – 3 persons (50-60%) and off peak loadings of public transport are down to 40% or less, despite lower frequencies. Taking vehicle occupancy/loadings into account makes it more difficult to produce a comparison between modes, as occupancy varies between systems, time and is affected by demography and even culture. Table 5 involves a reworking the data from Table 4, with adjustments from other data sources (principally Carpenter, 1994). This involves making assumptions (based on operational experience) for the sort of average loadings that are experienced in peak and off-peak trips. Even at peak times, trains and buses are not fully occupied for the whole of a trip. A train may well have a crush loading of 130% (or more) as it arrives at a city-centre terminus, and metro systems often have more people standing than sitting (a 200%+ loading based on seats). However, only a proportion of those passengers were on board when the train started its journey, and counter-peak services will be running at much lower levels of occupancy.

Table 5 Peak and off-peak fuel life cycle energy consumption and CO_2 emissions for urban transport

Mode	*MJ per seat kilometre*	*Grams CO_2 per seat kilometre*	*Assumed peak period occupancy (%)*	*MJ per passenger km - Peak Travel*	*Grams CO_2 per passenger km - Peak Travel*	*Assumed off-peak period occupancy (%)*	*MJ per passenger km – Off-Peak Travel*	*Grams CO_2 per passenger km – Off Peak Travel*
Urban Electric Train	0.39	39	60	0.65	65	25	1.56	156
Urban Diesel Train	0.50	60	60	0.83	98	25	2.00	240
Light Rail	0.18	38	70	0.25	54	40	0.45	95
Metro	0.22	46	70	0.31	66	40	0.55	115
Single Deck bus	0.29	33	50	0.58	66	20	1.45	165
Double Deck bus	0.22	26	50	0.44	52	20	1.10	130
Minibus	0.36	40	70	0.51	57	20	1.80	200
Medium-sized Car	0.70	78	23	3.04	339	40	1.75	195

Based upon Carpenter (1994) Potter (2000) and Roy, Potter and Yarrow (2002)

Although some of the figures in Table 4 are reported to two decimal places, this should not be taken as a precise level of accuracy. The data sources used contained some variation, although the relative energy use and emissions between modes was in proportion. The information in Table 4 represents the best comparable figures from these various sources. The main point is that once occupancy is taken into account, it makes a considerable change to the overall picture. For peak period travel, the ratio of energy and emissions from public transport compared to the car drops from that of 1:10 using the seat kilometre measure to about 1:7. For off-peak the ratio drops even further. It is only around 2:1 and for some types of public transport, the average energy used is higher for public transport than for car (although in general CO_2 emissions remain lower for public transport).

This has important implications. It shows that the biggest environmental gain in modal shift from car to public transport is achieved where and when cars are poorly occupied. Once the occupancy level of public transport drops, its energy and emissions performance worsens dramatically. However, the use of average figures in these tables disguises an important fact. If car trips are transferred to off-peak public transport, this is usually accommodated by increasing loads on existing services, so no additional energy and emissions are involved. Indeed, improving public transport occupancy levels by modal transfer from cars will yield very positive energy and emission reduction results. It is important to take into account if a policy measure will affect occupancy levels.

With careful interpretation and use, such figures can be used to evaluate the energy and CO_2 emissions of alternative public transport systems or for policy development. For example, in a recent project for the British government exploring the modal shift impacts of personal tax concessions on public transport commuting, an estimate was made of the amount of CO_2 reduced by alternative policy options (Potter et al 2001 p 65). This estimated that, given the average UK car fuel consumption of 9 litres per 100km, and the average commuting distance by car, each single car occupancy commuting trip produces about 1.3 tonnes of CO_2 emissions per annum. Were a tax instrument introduced that resulted in car commuters shifting to public transport, it was assumed that, being at peak load times, additional services would have to be provided. The net reduction in CO_2 emissions from cars would therefore be counterbalanced by rises from the new public transport services. Using similar data to that in Tables 4 and 5 above, it was estimated that public transport in peak hours used less than 20% of the energy consumed by a single occupancy car. Thus for every peak hour car trip diverted to public transport, the *net* CO_2 saved would be 80% of the *gross* cut in CO_2 from the car, amounting to a cut of just over 1 tonne per annum for every single car occupancy trip diverted to public transport.

IMPROVING ENERGY AND EMISSIONS FROM PUBLIC TRANSPORT

Overall, both road and rail urban public transport has a good energy efficiency performance, but can this be further improved? Fuel economy has for long been of commercial importance in public transport operations and improvements have been continually achieved. However there are trends that have counterbalanced this. In particular higher speeds for trains and the inclusion of air conditioning and other power-hungry on-board equipment means that fuel consumption has recently increased, rather than decreased. This has had a larger effect on inter-urban trains and road coaches rather than urban public transport services, which tend to be slower and where air conditioning is less frequently used. However some factors, like achieving high acceleration for local stopping services, have pushed up energy use for urban trains as well.

For buses, despite the diesel bus's relatively good environmental credentials, the public often perceive diesel buses as polluting. Wood (1996) suggests that:

> "a bus perceived to be clean (as well as *being* clean) is more likely to attract passengers from cars and thus contribute to a general environmental improvement. Of course, the cleaner buses actually are, then the greater their environmental advantages over cars. Furthermore, low-emission buses will make bus stations and other centres of their activity (such as Oxford Street) more pleasant places."

Wood 1996, p3

The latter point is not insignificant. For example, shop owners in city-centre streets are becoming antagonistic to bus operations on pollution grounds, particularly in otherwise pedestrianised streets.

As already noted, increasingly stringent Euro and UIC standards are cutting diesel emissions, but the transport agenda contains more than the cleanup of existing fuels and engines. For private cars, 'alternative fuels' to petrol and diesel have attracted considerable attention. These have included liquefied petroleum gas (LPG), compressed natural gas (CNG), biofuels like ethanol and methanol, battery electric vehicles and (in the longer term) hydrogen fuel cells. For public transport, electric traction is far from being new or innovative. Electric-powered trains, trams and metros are established and commonplace. Electricity is by no means a new or alternative fuel for these applications. .

For buses, however, diesel is starting to be challenged by a number of new fuels. Battery-electric traction is not suitable for vehicles above the size of a mini-bus, and increasingly appears not to be viable except in small niche applications. A number of USA cities use small fleets of heavily subsidised battery electric mini-buses for city centre shuttles. They have also been tried in Europe. Florence and Rome use Italian-built 27 seater electric minibuses for city centre services, which have received substantial EU subsidies. Overall the experience of battery electric buses in not encouraging. The operating regime is too demanding, the range too short and recharging a lengthy process. For example, the first UK electric bus scheme started in Oxford in 1993 connecting the city centre with the railway station. Each bus needed an 11hour overnight charge and a 15 minutes boost each hour before commencing the 4km route. Electric minibuses have been more successful for specialist transport services for the elderly and disabled (e.g. in Camden in north London, see Potter, 1999), but they have been dropped even in this less operationally demanding role.

For other alternative fuels, their application to buses has been considerably more positive. Generally it is easier to apply fuels like LPG, CNG and even hydrogen to public transport than to private cars. Fuelling infrastructure is a major problem for alternative fuels, but with fuelling for public transport vehicles concentrated at train or bus depots, this is relatively easily accommodated. The predictable requirements and limited infrastructure needs mean that bus operations are a good sector for a new technology's initial application. Owen (1996) notes that buses are the lead market for new fuels followed by vans, taxis and 'city cars' (second cars used for local trips). Indeed, in countries such as New Zealand and Italy, where natural gas has been an important fuel for many years, CNG buses are commonplace. They have been introduced for simple economic reasons and are an established part of the public transport fleet.

Alternative fuels for buses are largely being promoted because of reductions in pollutants affecting air quality – particularly NOx and particulates produced by diesel powered buses. LPG and CNG powered buses can meet the ever-tightening air emission standards with less need for complex exhaust aftertreatment. Tests on a Volvo CNG bus achieved NOx emissions of 2.5 g/kWh, CO of 0.28, HC of 0.53 and 0.1 g/kWh of particulate matter. However, recent research by the Californian Air Resources Board (California EPA, 2002) suggests there is little to choose between state-of-the art diesel and CNG technologies. Overall it appears that CNG and LPG initially had an advantage over diesel for air quality emissions, but in the last ten years, the application of new fuel formulations and cleanup technologies to diesel traction may actually see off the newcomers.

In terms of CO_2 emissions, alternative fuels also present a mixed picture. Research by the OECD (1995) and ETSU (1996) has documented the life cycle emissions of CO_2 from a variety of alternative fuels. The benchmark is diesel, producing 210 g km^{-1}. Compared to this, CNG produces 238 g km^{-1}, methanol from natural gas 254 g km^{-1} and ethanol from maize 247 g km^{-1}. So all of these alternative fuels produce more CO_2 than diesel. LPG is about the same as diesel with the only fuels that represent a significant improvement being methanol from wood (89 g km^{-1}), ethanol from wood (59 g km^{-1}) and liquid hydrogen (62 g km^{-1}). The biofuels from wood do not involve a large amount of energy in growing and manufacturing processes, but the main constraint is one of limited supply.

Rather than switching fuels, a more effective approach would be to use fuels more efficiently. This can apply to both the vehicle and the transport system. Rail electrification is an example of a system approach. Until recently the energy losses in electricity production were roughly similar to the energy losses from a diesel engine. However the use of gas combined cycle power stations together with regenerative braking returning current to the power supply system, means that electrification can cut CO_2 emissions.

At the level of the vehicle, although there have been incremental improvements to diesel engines, it is the use of hybrid engines that offers the largest improvement in fuel consumption. Hybrids involve two types of engine used on one vehicle, the idea being that the use of an energy buffer (e.g. a battery) enables the main power unit to be operated close to maximum efficiency. For example an electric engine will be used under conditions of partial load or high acceleration, which is when internal combustion engines are at their least efficient. The load is evened out on the internal combustion engine, which thus runs at a better efficiency, cutting fuel consumption and emissions. The internal combustion engine also charges the electric engine's batteries, meaning that only a relatively small battery capacity is needed. There are two types of hybrid – a 'parallel hybrid' where, as above, traction is switched between engines, and a 'series hybrid' where an internal combustion engine runs constantly to charge batteries to power an electric motor.

Hybrid cars are now available. For example, the Toyota Prius was launched in Japan in 1997 and on the European/USA markets in 2000). This 5-seater family saloon petrol/electric parallel hybrid returns an impressive test fuel consumption of 3.6 litres/100km, roughly half that of a comparable petrol only car. But, as Lane (2002) notes, hybrid buses have been given less priority and are still at the development stage. They are expected to be commercially available by 2005 (Atkin and Storey 1998, DTI 2000). One advanced example of a hybrid is the *Volvo Environmental Concept Bus*. This is a gas turbine/electric hybrid, which can run on ethanol or a variety of other cleaner fuels.

In the long term, hydrogen fuel cells are viewed as the ideal clean transport fuel/engine system. A fuel cell involves chemical energy conversion whereby the combination of hydrogen and oxygen produces electricity with water as the only waste product. Vehicles would have hydrogen tanks supplying the fuel cell, with the electricity generated on board being used to power electric drive motors. With an on board 'reformer' other fuels can be used, but this results in a loss of efficiency and the production of some emissions. A fuel cell uses hydrogen more efficiently than in an internal combustion engine, so, as noted above, CO_2 emissions can be cut by about two-thirds compared to diesel traction (with all the emissions being at the hydrogen production plant away from urban areas). The method of manufacturing the hydrogen, as with electricity, is crucial in achieving this improvement.

There has been rapid progress in the trial automotive use of fuel cells in recent years. As detailed by Lane (2002), DaimlerChrysler built a demonstration fuel cell *Nebus* in 1997, and a small fleet of these buses saw service in Germany, Chicago and Vancouver. This was followed in 2000 with a demonstration of the Zebus (Zero Emissions Bus) in California as part of the California Fuel Cell Partnership Programme. A major European fuel cell bus project is planned for 2002-05 with 27 DamilerChrysler 'Citaro' buses used in nine cities, including London, Reykjavik (linked to the hydrogen being produced with geothermal energy), Stockholm, Amsterdam and Hamburg. The intention is that this project will lead to commercial fuel cell bus production. There seems to be no interest in applying fuel cell technology to railways, where it would appear to have potential to deliver the benefits of electrification without the cost of electrifying lines.

Overall, the basic technology of public transport vehicles has altered remarkably little in the last 50 years. Within this regime, in the last decade, significant improvements have been achieved that have cut the emission of pollutants. Fuel efficiency has been historically good compared to car travel, but here the improvements within the traditional regime have been incremental. New technologies and fuels have come to challenge the diesel bus, but it now looks like they offer no real energy efficiency or emission improvements over advanced diesel technologies. A diesel-electric hybrid looks the most promising option for the immediate future. In the long-term hydrogen fuel cells represent a significantly cleaner technological regime for urban public transport.

ENERGY AND EMISSIONS AT THE SYSTEMS LEVEL

Reference has already been made in this article to policies to reduce energy use and emissions from the passenger transport system by transferring trips from car to public transport. Public transport, when well utilised, is an inherently more energy efficient system, and electric traction emits fewer pollutants than diesel or petrol. However it is necessary to conclude this article with a warning that the design of an urban public transport system as a whole, and not just the vehicles within it, can have major implications for energy use and emissions.

This is particularly so if a public transport development generates travel without diverting many trips from the more environmentally-damaging modes of car and air, or attracts trips from more environmentally benign modes such cycling, walking (or not needing to travel at all). Simply generating more public transport trips will be environmentally degrading in the same way that more car trips are environmentally degrading. However, in policy development little discernment is made about the way in which urban public transport expands and develops. There appears to be an assumption that any growth in public transport must be environmentally beneficial. For example, Adrian Shooter, Managing Director of the Chiltern Railways said in the early days of rail privatisation in Britain that:

> *"There are opportunities for saving costs, but these are limited; there are bigger opportunities for increasing revenue. As fares are regulated, the surest way to increase revenue is to increase the number of passengers travelling. There is thus a neat alignment of objectives: action taken in the pursuit of profit"… " is compatible with the socio-political objective of getting more people to travel by train and thereby easing road congestion."*
>
> *Shooter, 1997*

The juxtaposition of policy aims and commercial interests is not as perfect as Shooter suggests. How expansion occurs is crucial to the net environmental impacts. It is generally more profitable for railways to expand long distance leisure and business markets rather than short distance urban services. Short distance urban commuting is also an expensive and loss-making market, even though it may be a priority for urban and environmental policy.

The example of the type of markets that make and lose money relates to the neglected issue of the role of trip lengthening in generating increased emissions and energy use from personal transport. Travel survey statistics (Potter 1997) show that people are not undertaking any more trips, or devoting much more time to travel than they did 25 years ago. The main factor behind the growth in travel is that we are undertaking longer trips, made possible by greater car use, new roads and faster railways. Thus, even if travel is diverted to more environmentally benign modes, it is possible for travel growth to overwhelm energy efficiency. Long distance, high-speed, rail commuting is environmentally damaging. This is part of the trip lengthening problem and yet is often portrayed as environmentally beneficial. Long distance high-speed rail reinforces, if not stimulates, metropolitan decentralisation. People relocate from cities and suburbs, where their trips are relatively short and walking and public transport viable, to dispersed, city fringe and rural settlements, which are highly travel intensive and where most of that travel has to be by car. Commuting constitutes fewer than 20% of all trips. A fast rail service may result in the work journey being be by public transport, but if it is doubled in length, emissions and fuel use will be high. Add to that increased car travel and longer trips for the 80% of all other travel that takes place, then long distance, fast rail services can only be seen as worsening energy consumption and emissions from transport.

Potter and Roy (1996) have documented examples of the tendency towards such environmentally-damaging rail developments in the UK, and note similar trends even in the environmentally-conscious Netherlands (Potter and Roy, 1996). Here, new rail infrastructure was provided as part of the National Environmental Policy Plan, but Dutch Railways, being required to behave in a more commercial manner, used the new capacity to develop long-distance commercially lucrative flows and not short-distance commuter services to effect a shift from car use. The former is more profitable, but far less environmentally relevant.

CONCLUSIONS

Exploring the energy and emissions from public transport is not a straightforward as it may at first seem. There is a lot more to this issue than just documenting the amount of fuel used by a bus or train, and the various emissions that emerge from the exhaust pipe. Vehicle performance is very important. In general public transport vehicles have a good energy and emissions record, and new technologies have yielded further improvements, with plenty of further potential yet to come. Some surprises are emerging, like the unexpected matching by diesel of the environmental performance of alternative fuels. It looks like the diesel bus (probably as a diesel-electric hybrid) may well be our mainstay until the fuel cell bus becomes a practical and commercial reality.

But as a wider system boundary is adopted, the energy and emissions picture becomes less clear. Low loadings at some times and in some places are an almost inevitable part of a comprehensive urban public transport system. These crucially reduce energy efficiency and raise emissions per passenger carried. Once the system boundary is extended to cover the transport system as a whole, then more disturbing features emerge. Public transport developments advocated as helpings to address transport's environmental impacts may actually worsen them. A more integrated understanding is needed as urban public transport's energy use and emissions can only be fully understood at this highest systems level. And at this level all transport is using unsustainable amounts of energy and generating unacceptable emissions, even if some are not as bad as others.

REFERENCES

Atkin, G. and J. Storey (1998) *Electric Vehicles, prospects for battery, fuel cell and hybrid powered vehicles*, Financial Times Report, London.

Best Foot Forward (2000) http://www.bestfootforward.com

California Environmental Protection Agency (2002) *Diesel and CNG bus emissions*, News Release 02-20, www.arb.ca.gov/newsel/nr041802.htm

Carpenter, T. G. (1994): *The Environmental Impact of Railways,* John Wiley.

Climate Care (2000) http://www.co2.org

Commission for the European Communities (1992) *Green Paper: The Impact of transport on the environment: a community strategy for 'sustainable mobility'*. CEC Office for Official Publications, Luxembourg.

Department of the Environment, Transport and the Regions (2000) *Transport Statistics Great Britain*, The Stationery Office London

Department of Trade and Industry (DTI) (2000) *The Report of the Alternative Fuels Group of the Cleaner Vehicle Task Force Report,* DTI, Automotive Directorate, The Stationery Office, London (www.roads.detr.gov.uk/cvtf/index.htm)

Everett, R. and G. Alexander (2000) Energy File Part 1: Energy and its use, *T172 Working with our environment: technology for a sustainable future.* The Open University, Milton Keynes

ETSU Energy Technology Support Unit (1996): *Alternative Road Transport Fuels; A Preliminary Life-cycle Study for the UK* - Stationary Office, London

Ford, R. (2002) Diesel engines *Modern Railways*, June, pp 68-69.

Lane, B. (2002) *Optimising implementation strategies for fuel cell powered road transport systems in the United Kingdom.* PhD Thesis, The Open University, Milton Keynes.

Owen, D. (1996): Plugging in to EVs, *Electric and Hybrid Vehicle Technology '96*, pp 188-190

OECD (Organisation for Economic Co-operation and Development (1993) *Cars and Climate Change*, Paris: OECD.

OECD (Organisation for Economic Co-operation and Development) (1995) *Motor Vehicle Pollution: reduction strategies beyond 2010,* OECD, Paris

Potter, S. and R. Roy, (1996): *The Environmental Implications of Rail Privatisation* Report to the ESRC, The Open Universirty, Milton Keynes

Potter, S. (1997) *Vital Travel Statistics*, Landor, London

Potter, S. (1999) Managing the design of an innovative green transport project. *The Design Journal,* Volume 2, Issue 3, pp 51-60

Potter, S. (2000) Travelling Light, Theme 2 of *T172 Working with our environment: technology for a sustainable future.* The Open University, Milton Keynes

Potter, S. (2001) Cutting CO_2 Emissions from Personal Transport: a consumption systems approach. *7th European Roundtable on Cleaner Production, Institute for Industrial and Environmental Economics*, Lund University, Sweden

Potter, S., M. Enoch, T. Rye and C. Black (2001*) The Potential for Further Changes to the Personal Taxation Regime to Encourage Modal Shift,* Final Report to the Department of the Environment, Transport and the Regions, June, http://www.dtlr.gov.uk/itwp/modalshift/index.htm

Roy, R., S. Potter and K.Yarrow (2002) *Towards sustainable higher education: phase 1 final report*, Design Innovation Group, The Open University, Milton Keynes

Shooter, A. (1997) Chiltern Railways goes for growth, *Modern Railways*, February, pp 81-85

Teufel, D. *et al*., (1993) *Öko-Billanzen von Fahrzeugen*, Heidelberg: Umwelt und Prognose Institut

Wood, C. (1995) *Energy use by different passenger modes*, Transplan, Norwich

Wood, C. (1996): Golden Fuels or Fuel's Gold? *CILT Journal,* Centre for Independent Transport Research in London, Vol. 11/12, September pp 3-17