Public Transport

HIGHLIGHTS

■ **TECHNOLOGY STATUS –** This brief covers buses and coaches, trolleybuses, trams and light rail. Heavy intercity rail is coverd by ETSAP T11 (Rail Transport). Public transport is substantially more energy efficient than private vehicle use. Figures for OECD Europe show light duty vehicles (LDVs) typically consume 1.9MJ per passenger kilometre (p-km) compared to buses at 0.8MJ/p-km and rail at 0.3MJ/p-km [1]. The vast majority of buses and coaches are diesel powered. These have benefitted from general improvements in combustion engine efficiencies over recent years. In some countries there are significant numbers of natural gas powered buses operating. Hybrid-electric buses are in commercial production and in service in many cities across North America [2], China and Europe and there are also a few examples of small full-electric buses in service. Trials of hydrogen fuel cell buses have been conducted for a number of years but have yet to demonstrate overall energy savings. Electric trolleybuses - buses with overhead power lines - have low energy consumption (typically 0.2 - 0.6MJ/seat-km) and have a long history of use but form only a small percentage of the total bus fleet. Personal Rapid Transit systems (driverless electric vehicles which operate on a track or guideway) can also achieve low energy consumption (around 0.55MJ/seat-km) but are a relatively new concept and the first examples are just entering service. Light-rail, trams and metro systems are well established in many countries and offer significantly lower energy consumption than road-based public transport (0.18 - 0.28MJ/seat-km) due to the lower rolling resistance of steel wheels on rails, better aerodynamics and lack of congestion.

■ **PERFORMANCE AND COSTS –** Aside from general improvements in the efficiency of heavy duty diesel engines there are a number of technologies which can be applied to buses and coaches. Hybrid electric systems with stop/start operation offer 20 - 40% energy savings for typical bus usage patterns. The capital cost of hybrid buses is currently 40% higher than the cost of conventional diesel buses. However, as production volumes increase, the cost is expected to come down. The use of biomethane and bio-synthetic gas in converted engines can achieve at least a 60% reduction in CO_2 as well as local pollutants reductions. Retail prices are currently 20 - 25% higher but would be expected to reduce as production volumes increase. Battery electric buses offer up to 70% lower energy consumption in comparison to diesels, however current costs for comparable performance are prohibitive. As battery technology improves and costs come down their use is likely to increase. The primary opportunity for energy saving in light-rail, tram and metro systems comes from reducing weight. As with any transport powered by grid sourced electricity, the largest potential for carbon reduction comes from de-carbonising electricity generation.

■ **POTENTIAL AND BARRIERS –** To reduce overall transport energy use there is a need to encourage a shift from private vehicles to public transport. Public transport offers some of the best opportunities for the application of new more efficient and lower carbon technologies. The high vehicle utilisation rates and long service lifetimesmake payback periods much shorter than for private vehicles. Rail based systems offer the highest efficiencies but face barriers of high initial capital cost and the required land take in dense urban environments. For road based public transport, electric drivetrains appear to offer the greatest efficiency potential. For battery-electric vehicles, barriers are the high costs, modest battery lifetime and range limitations. For hydrogen fuel-cell vehicles, key barriers are high costs, lack of hydrogen storage and refuelling infrastructure and concerns over whole life-cycle energy requirements.

TECHNOLOGY STATUS – Public transport plays a central role in transport systems, particularly in countries in which private vehicle ownership is not widespread. Bus travel accounted for 6% of world transport sector final energy use in 2007 with rail (both light and heavy) accounting for a further 3% [1]. Public transport is generally significantly more energy efficient than private vehicle use, with bus and rail travel accounting for 18% of passenger-kilometres (p-km) in OECD Europe but only 5% of energy consumption [1].

■ **Buses & Coaches** – Buses are heavy duty vehicles primarily used for scheduled intra-urban, inter-urban and rural public transportation. Bus services are typically characterised by having shorter routes with high frequency stops, but in the developing world are frequently used for longer range transportation as well. In city use, average speeds can be as low as 7km/h but are more typically 10 - 17km/h. Depending on their design and intended purpose, buses typically seat anywhere between 20 and 150 passengers, although some designs can seat 300. From available data it appears that buses carry more passengers than urban rail systems in the vast majority of cities [3]. About 85% of bus sales are diesel-engine powered with the majority of the remainer being gasoline and a small number using compressed natural gas (CNG) [3]. In common with other heavy duty vehicles, such as goods vehicles, there is a range of energy saving technologies open to bus manufacturers. The most appropriate technologies to apply will depend on the drive cycle on which the vehicle operates. Buses are mostly found in an urban context and so operate on a predominantly low speed, transient (accelerating and decelerating) drive cycle and so benefit more from measures such as weight reduction and energy recovery technologies. They also tend to have centralised refuelling facilities so are an attractive contender for alternative fuels. Coaches, on the other hand, typically operate between urban centres on a predominantly high speed, steady

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state drive cycle and so benefit more from aerodynamic measures.

Conventional powertrain improvements offer the most accessible near-term improvements in efficiency and reductions in energy consumption for buses [3]. ETSAP T02 (Advanced Automotive Diesel Engines) covers the current status of diesel technologies [4]. Many of these technologies - including common rail injection, turbo-compounding, and twin turbocharging - are applied to the large capacity diesel engines commonly found in buses and coaches. These are described in ETSAP T11 (Heavy Trucks). However further combustion system improvements are only expected to achieve 1 - 2% reductions in fuel consumption [5].

Stop-start system technologies which allow the internal combustion engine to be automatically stopped and re-started are also well suited to the heavy urban traffic conditions encountered on many bus routes.

Hybrid vehicles, which run on two or more power sources, commonly use a combination of an internal combustion engine and electric motors, but there are other options such as hydraulic and kinetic flywheel hybrids. Compressed air hybrids also exist for heavy goods vehicles (HGVs). Depending on the architecture, hybrid systems can recover some of the energy normally lost during braking. Brake energy can be stored in different ways (see ETSAP T11 – Heavy Trucks). **Hybrid-electric buses** are in use in 46 transit authorities across America and Canada, including a fleet of over 200 in Seattle in 2005 [2]. Results from tests there showed a 27% improvement in fuel economy for the hybrid models compared to the otherwise identical diesel buses [6]. Series-hybrid designs in use in both San Francisco and Vancouver have a smaller than usual diesel engine which charges a battery to provide power to an electric motor drivetrain. The battery is also able to store recovered brake energy. In San Francisco, in comparison to the previous conventional diesel buses, these hybrids have reduced particulate matter (soot) by 95%, oxides of nitrogen (NOx) by about 40% and greenhouse gas emissions by 30% [7]. London has a fleet of 100 hybrid buses which consists of series, parallel and parallel blended hybrids. The fleet size is planned to increase to 300 by 2011 and Transport for London quote a minimum 30% reduction in fuel use and CO_2 emissions in comparison to diesel equivalents [8] (savings of up to 40% are also often quoted). **Hydraulic hybrid buses** have been trialed in Beijing [9]. It is worth noting that kinetic flywheel storage is ideally suited to buses and can be retro-fitted saving around 20% of emissions during urban stop-start operation [10].

Plug-in hybrid electric vehicles (PHEV) use electrical energy stored in batteries which can be recharged directly by plugging into a power supply. The resultant "well to wheel" CO_2 emissions will be dependent on the nature of the power stations used to source the electricity. In most countries this will result in an overall reduction in CO_2 emissions in comparison with a conventional diesel powertrain, and will increase if the electricity supply is de-carbonised. For light duty cars and vans the expectation is that they would run on electric motor power alone for the majority of the time, recharging between trips and using an internal combustion engine to extend their range for longer journeys. However urban buses may be in use for 12 - 18 hours at a time, covering up to 400km, without the opportunity to recharge [3]. This problem could be resolved by providing recharging facilities which can be accessed while moving, such as overhead electric lines [3]. While electric only operation eliminates tailpipe emissions and improves local air quality, unless electric only operation is possible for a substantial proportion of the time, the additional cost and weight of the battery storage system (resulting in higher fuel energy consumption in non-electric operation) may outweigh the benefits.

Full electric buses can be either autonomous (with some form of electricity storage on board) or non-autonomous (for instance, trolleybuses). They do not emit exhaust emissions, giving substantial local air quality benefits. As with plug-in hybrid electric vehicles, any overall reduction in CO_2 emissions will be dependent on the CO_2 intensity of the electricity supply used to charge the batteries.

Battery electric vehicles depend solely on an electric motor powered by batteries for their motive power. The battery pack can be charged from mains electricity or dedicated charging points or can be "swapped out" and replaced with a freshly charged pack. Due to the limited range of commercial battery technologies, battery-electric buses have primarily been used on shorter, lower speed routes such as shuttle services [2]. However a small battery electric bus designed and made in Italy is currently in service on urban bus routes in Italy, France, Spain, Portugal, Germany, England and Canada [11]. Small (6.7m long) electric buses are also in service in several places in America, including Santa Barbara, Miami and Chattanooga [2], A 26 seat battery electric bus has been operating in Adelaide since 2008. It is described as the world's first **solar electric** bus as a solar PV generator has been installed on the bus station's roof to offset the energy required for battery recharging [12]. In 2009, an electric bus was launched with a claimed range of 500km [13] and in 2010 a 12m long, 6 tonne electric bus was reported to be going into production in China [14].

Ultracapacitors can also be used to store electricity. While they have very limited storage capacity in comparison to batteries, they can be recharged very quickly. A fleet of over 100 pure electric ultracapacitor buses is running in Shanghai. Once the ultracapacitor is fully charged (taking 5 minutes) the bus has a range of

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3 miles but the ultracapacitors can be recharged, typically for 30 seconds, via short overhead catenaries at bus stops [15]. Since the ultracapacitors are lighter than a battery pack the bus is claimed to use less electricity than an equivalent battery electric bus, although the design incorporates a back-up battery with a 50 mile range and has a total weight of 13 tonnes. The maker also claims 40% lower electricity use than trolleybuses [16]. Ultracapacitors have also been used in diesel and gasoline hybrid buses with over 80 in service in America.[2]

Trolleybuses are similar to trams but instead of operating on rails they have conventional rubber bus tyres. Unlike conventional buses they are powered electrically from overhead cables and so are confined to defined routes through a town or city. Trolleybuses are currently used in about 340 cities or metropolitan areas today with the largest system being in Moscow [17]. Trolleybuses are particularly suited to hilly areas as electric motors provide full torque when starting off and rubber tyres provide much better traction than trams' steel wheels on rails. They are also cheaper and quieter than tram systems. **Hybrid trolleybuses** with an auxiliary power unit (APU) built in to allow 'off-wire' running are now becoming common. This overcomes the major disadvantage of not being able to re-route services in the event of disruption to the normal route.

Hydrogen fuel cell buses have been trialed in a number of cities worldwide. A fuel cell converts chemical energy from hydrogen into electrical energy which can power an electric motor. There are no exhaust emissions other than water vapour but the impact on overall CO_2 emissions will be dependent on the production and distribution of the hydrogen. Fuel cell buses have been demonstrated in a number of European cities as part of the Clean Urban Transport for Europe (CUTE) project using 27 buses in 9 cities. However the energy consumption figures reported in the CUTE project (0.7 - 1.3MJ/seat-km) have been higher than typical diesel buses. There are also issues with hydrogen fuel cell vehicles due to the current high costs of fuel cell technology and the lack of hydrogen distribution networks. These are discussed in ETSAP T11 (Heavy Trucks) and ETSAP T07 (Automotive Hydrogen Technology).

Compressed natural gas (CNG) can be used as a fuel either in a dedicated ICE or a diesel dual-fuel ICE, with the potential to reduce pollutant emissions and fuel costs [3]. For details on CNG engine technology, see ETSAP T11 (Heavy Trucks) and ETSAP T03 (LPG/Natural Gas Internal Combustion Engines). Urban buses are one of the most common applications for CNG engines. It is estimated that there were 400,000 CNG buses worldwide in 2010, with China, Ukraine, India and the USA having the highest numbers [18]. In Europe, Russia has by far the highest number at about 8,000 [19], but for the EU27 CNG buses represent just 0.8% of the total fleet according to European statistics [20]. As well as air quality improvements and CO_2 reductions, the buses are generally quieter than their diesel equivalents. The environmental benefits of CNG engines can be further improved by blending or replacing natural gas with **biomethane** or **bio-synthetic gas**, resulting in a reduction in life-cycle CO_2 emissions. Liquid biofuels can also be blended or switched with diesel fuel in conventional ICEs with little or no design changes needed. In Sweden, ethanol fuel is being used in a hybrid bus trial until 2011 and ethanol ED95 fuel has been successfully used in diesel buses with modified engines in Sweden, the UK and Italy [21]. For more information on Biofuels, see IEA ETE02 (Biofuel Production) and IEA's Biofuels for Transport report.

Other technologies, systems and transport modes to increase efficiency and reduce emissions of CO_2 and exhaust gases from buses are discussed below:For **diesel engines**, technologies such as diesel particulate filters (DPF), exhaust gas recirculation (EGR) and selective catalytic reduction (SCR) are used to meet exhaust emissions limits. More stringent Euro 6 legislation is expected to require all three of these technologies with a consequent initial increase in fuel consumption of about 3%. However this increase is expected to reduce to close to zero within about three years due to technological improvements [22]. **Auxiliary loads** such as coolant and oil pumps, air conditioning, cooling fans and power assisted steering all increase fuel consumption by increasing the load on the engine. Savings of between 0.7 - 4% can be made through improved design. More detail is given in ETSAP T11 (Heavy Trucks). **Weight reduction** will be particularly appropriate for buses due to their stop-start duty cycle in which energy is repeatedly expended to accelerate the mass of the vehicle. However, long distance buses and coaches will also benefit. Note that vehicle weight reduction measures will reduce the benefits obtained from brake energy recovery systems. **Drag reduction** is most important for vehicles that spend significant amounts of their time at higher speeds such as long distance buses and coaches. While long distance buses and coaches are generally more aerodynamically designed than heavy goods vehicles, worthwhile improvements should still be possible and are likely to have a relatively short payback period from fuel savings. For more information, see ETSAP T08 (Weight and Drag Reduction – Automotive).

Bus Rapid Transit (BRT) is a transport system which utilizes conventional diesel buses, but which also makes use of elements of light rail operations, including dedicated road space which enables a faster and more predictable service and platforms raised to the level of the bus's floor pan which reduces passenger loading time. BRT does not require costly engineering works for tracks or electrification infrastructure but BRT stations are typically more substantial than conventional bus

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stops. Probably the best known BRT system can be found in Curitiba in Brazil, but initiatives are now being planned or implemented in over 40 cities [3].

Personal Rapid Transit (PRT) consists of driverless electric vehicles which operate on a track or guideway. They are generally either rubber tyred and supported or are suspended. They operate on a defined track,and system users do not share the vehicle and so do not stop for other people to get on and off. The system's automated nature means that additional vehicles can be routed to stations during periods of high demand and when demand is low, vehicles can be parked at stations ready to be picked up when demand returns, ensuring that load factors are kept high, increasing energy efficency per passenger. The concept of personal rapid transport has existed since the 1960s but it is only in the last few years that the first systems have started to appear. Part of the reason for this gestation period has been the need for sophisticated automated vehicle control systems. The ULTra (Urban Light Transport) PRT system has successfully completed final trials in London's Heathrow airport, linking the long stay car parks with the new Terminal 5 [23]. A PRT network is also being deployed at Masdar City in Abu Dhabi [24].

■ **Light Rail, Metro, Trams –** Rail based public transport is generally more energy efficient than road based systems. Data from 2007 for OECD Europe suggest rail has a stock average energy intensity of 0.3 MJ/p-km versus buses at 0.8 MJ/p-km [1]. This is due to a number of reasons:

a) Steel wheels on rails have a much lower rolling resistance compared to rubber tyres on tarmac;
b) The aerodynamic benefit of longer train shapes;
c) The lack of congestion-induced stop/start in rail systems.

In addition there is some evidence that where there are sufficient passenger numbers, light rail based public transport is more effective at achieving modal switch away from private car use than buses, leading to higher loading factors [25]. The various types of rail based public transport are discussed below. Heavy rail for intercity travel is discussed in ETSAP T13 (Rail Transport).

Light rail is typically used to bring people from suburban areas into cities as well as to move people quickly and efficiently within an urban environment. Compared with heavy rail, light rail usually transports lower volumes of passengers over shorter distances and at lower speeds, but this is coupled with more frequent services and shorter distances between stops. Light rail tends to employ electrically powered multi-carriage trains, operating off overhead power supplies. Light rail services can operate on separate track (sometimes shared with heavy rail) or can be found in city centres, sharing road space with cars, buses and trucks or a combination of the two. **Metro systems**, also known as subways, are not considered to be light rail as the volumes of passengers transported and the operational speeds tend to be substantially higher. Metro trains are driven on electric motors and can operate on both above and underground tracks which usually interlink to form an interconnected network. Notable examples include the London Underground, Tokyo Subway (Tokyo Metro and Toei Subway), Moscow Metro and New York City Subway. **Trams** (sometimes known as streetcars or trolleycars), are electric public transport vehicles that operate on rails with at least part of their route on shared public streets. Trams tend to operate as single vehicles, but can also be found as multi vehicle trains. Trams are particularly popular in European cities, but are also found in cities in the USA, Latin America, Australasia and Japan.

A single metro line has a typical maximum capacity of about 50,000 passengers an hour, although some modern systems can be higher for instance the Hong Kong West Rail has been designed to allow for up to 100,000 passengers an hour [26]. Light rail and trams have a maximum capacity of about 20,000 passengers an hour [27]. By comparison buses generally carry fewer than 2000 passengers an hour, however bus rapid transit systems can achieve figures of 10,000 - 20,000 [28] and the Transmilenio in Bogota is reported to have a maximum capacity of 41,000 passengers per hour [29].

Light rail, metro and tram systems are normally powered by electricity and the energy saving technologies open to them tend to be more restricted than for other vehicles.

Reducing the weight and aerodynamic drag of rail based electrically powered transport offers perhaps the greatest opportunities for reducing energy consumption [30]. Additional benefits include reduced wear of both braking systems and track. For urban light rail with comparatively low speeds, reduction of aerodynamic drag offers relatively little benefit.

PERFORMANCE AND COSTS

■ **Buses & Coaches** – Buses accounted for 6% (133 Mtoe) of global transport sector final energy use in 2007[3]. The vast majority of this was mineral diesel fuel. The variation in energy and CO_2 intensity of buses across key geographical regions is shown in Figure 1. A typical diesel bus will use about 55 litres/100km of fuel [31] which translates to about 21MJ/km or about 0.4MJ/seat-km.

For conventional diesel engines, optimisation of the combustion system (for instance higher pressure fuel injection and high capability air/EGR systems) is expected only to deliver 1 - 2% fuel consumption and CO_2 emissions reductions [32]. The primary focus of these technologies is to meet more stringent NO_x legislation. Euro 5 legislation requires NO_x levels of 2.0g/kWh, Euro 6 (effective 2013) requires 0.4g/kWh

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[33]. Expected costs are €120-600/vehicle for Euro 5 legislation and €1200-1675/vehicle for Euro 6 [32].

Stop-start systems are estimated to achieve up to 30% reductions in CO_2 emissions versus a conventional diesel with an average of 4% for buses [22]. Stop-start technology on buses in London has been reported to achieve 15% reductions in carbon emissions [34]. Costing for a stand-alone system for buses and coaches is unavailable, but a system is listed as an option for a 3.5 tonne van at about €650 [32].

Hybrid buses can achieve 20 - 40% energy savings for typical bus usage patterns (urban, stop-start routes) but for longer haul coach journeys this figure drops to 4 - 10% [22]. The additional cost of a hybrid system can add up to 40% to the cost of a bus [35]. However this cost can be compensated by improved fuel consumption, extended brake life, reduced maintenance and lower engine wear depending on the exact system employed. The new double-decker diesel hybrid bus design for London claims a fuel consumption of 28 l/100km, while having 62 seats, giving 0.17 MJ/seat-km [36].

Electric buses can achieve up to a 70% energy reduction in comparison to a conventional diesel bus [22]. The Tecnobus Gulliver, a midi-sized electric bus, uses 1.62 MJ/km [37]. The maximum number of passengers carried in the latest version is 31, giving 0.05 MJ/passenger-km, and the vehicle is fitted with 9 passenger seats, implying 0.18 MJ/seat-km [11]. Costs will be very dependent on the battery technology and available range. Again, vehicle purchase costs will be offset against likely lower running costs for a full electric drivetrain given the much lower energy usage and reduced maintenance requirements.

The 41-seat **ultracapacitor** bus operating in Shanghai since 2006 has achieved an energy consumption of 3.36 MJ/km [15], equating to 0.08 MJ/seat-km. Technology costs are not known. Figures available for the energy use of **trolleybuses** indicate that they are generally more efficient than diesel buses. In Landskrona, Sweden they are recorded as achieving 6.5 MJ/km (29 seats and a maximum passenger capacity of 70 giving figures of 0.22 MJ/seat-km and 0.09 MJ/passenger-km at full capacity) [38]. Figures from the US Department of Transportation for five different trolleybus systems give a range of 0.23 - 0.62 MJ/seat-km [39].

Hydrogen fuel cells have much higher theoretical thermal efficiencies than internal combustion engines, and are expected to achieve up to four times the efficiency of conventional internal combustion engines [40].However, energy consumption figures for prototype **hydrogen fuel cell buses** so far have been higher than typical diesel buses. Results from the CUTE, ECTOS and STEP programmes have shown fuel consumption figures equivalent to 21 - 38 MJ/km [41]. The buses

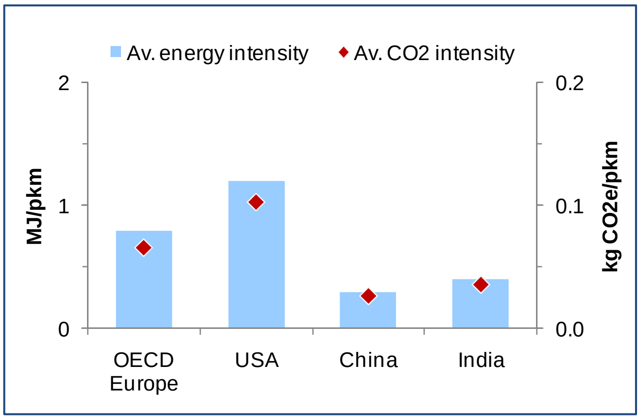

Figure 1 – Energy and CO_2 intensity of buses [1]

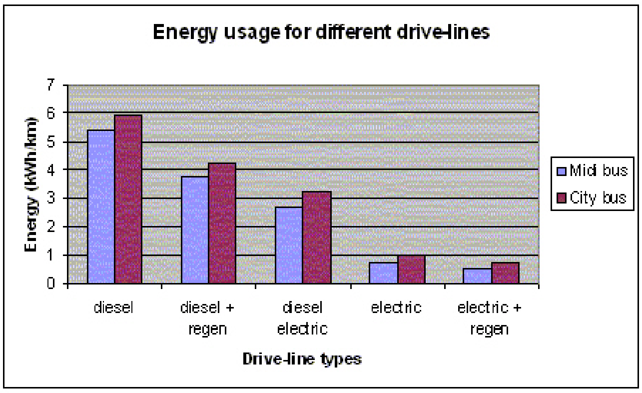

Figure 2 – UK bus energy useage for different powertrains [24]

used had 30 seats so this translates to 0.7 - 1.3MJ/seat-km. The CUTE project report gives several reasons for this: the buses used were conversions and not optimised for efficiency; temperatures below 0°C and above 18°C noticeably increase fuel consumption due to the need for cabin heating (up to 16% increase) and air conditioning; and the fuel cell used required a minimum current to be produced at all times, meaning fuel was used even when coasting downhill [42]. Fuel cells offer the best efficiency improvements over internal combustion engines at light loads but fuel cell vehicles can have higher parasitic losses and can be heavier, somewhat offsetting these benefits [40]. Assessment of the overall lifecycle impacts of hydrogen powered buses in Western Australia concluded that the fuel cell system consumed approximately three times the energy of the diesel system (primarily from fuel production and bus operation), but noted that there is ‘significant room for improvement’ [43]. Fuel cell technology is currently expensive as it is not in series production. The estimated cost of the fuel cell prototype buses used in the CUTE programme was around €1.3 million - more than 4 times (one million Euros more than) the price of the diesel version.

Heavy duty spark ignition CNG engines are estimated to achieve about a 10 - 15% tailpipe CO_2 reduction in comparison to a Euro 5 emissions level diesel engine [32]. A further 0 - 5% reduction is expected due to changes to meet future more stringent NO_x emissions requirements [32]. Low production volumes mean spark ignition CNG engines currently retail at about 20 - 25% higher than an equivalent diesel engine although the piece cost is estimated to be about 10 - 15% lower [32].

Dual fuel diesel-CNG engines can achieve higher (10 - 20%) reductions in tailpipe CO_2 emissions since they retain the base diesel engine's high compression ratio [22]. Full integration with the engine management system maximises the benefits, though these benefits are also dependant on both the availability of the CNG fuel and the specific drive cycle. Costs are currently higher than for a standard diesel engine as the technology is a retrofit option. Manufacturer information suggest current cost is about £24,000 per vehicle [44]. However fuel cost savings result in 18 - 24 month payback periods depending on fuel costs and annual mileages. Studies indicate that running on **biomethane** results in at least a 60% reduction in CO_2 in comparison to a standard diesel engine and the technology is likely to add around £25,000 - £35,000 to the cost of a vehicle [32].

A study commissioned by the International Aluminium Institute found that **weight savings** on a city bus would save 6.2 MJ per 100km for every 100kg weight reduction (6.2 MJ/(100km*100kg). In comparison, the figure for a long distance bus was calculated as 1.6 MJ/(100km*100kg) [45]. Over a typical lifetime of operation, these figures were calculated to represent primary energy savings of 62 GJ/100kg and 20 GJ/100kg respectively (see Figure 3).

Weight saving costs will be dependent on material choice. A strong focus on weight saving throughout the vehicle design process is likely to be the most cost-effective approach. Tests conducted on heavy goods vehicles indicate that **drag reduction** through the use of teardrop shaped box van trailers achieved CO_2 reductions of up to 24% on constant speed testing [32]. It is likely that applying a similar approach to the profile of long-distance coaches would yield similar results. **Platooning** (driving vehicles in close proximity nose to tail to create 'a train') can further help reduce aerodynamic drag. The concept has been studied primarily for cars at motorway speeds where it has been found to reduce CO_2 emissions by about 20% [32]. However, it could also be applied to long distance buses and coaches mixed with heavy goods vehicles (HGVs). The technology requires vehicles to be fitted with additional sensors, adaptive cruise control and lane departure warning systems.

■ **Light Rail, Metro, Trams –** At 3% of total transport sector final energy use, the entire rail sector represents half the energy use of the bus sector [3].Light rail, metro and trams will account for only a small proportion of this total. These systems are inherently energy efficient in comparison to road transport due to their low rolling resistance. For more information seeESTAP T13 (Rail Transport).

Weight reduction is a powerful way to reduce light rail energy consumption. On subways and urban trains 100kg weight reduction results in 4.3 MJ of energy saving per 100km. This translates to lifetime energy savings of 130 GJ, amongst the highest of the transport modes considered in Figure 3. This is due to the frequent stop/start operation and substantially longer service life (3 million kilometres) in comparison to road transport.

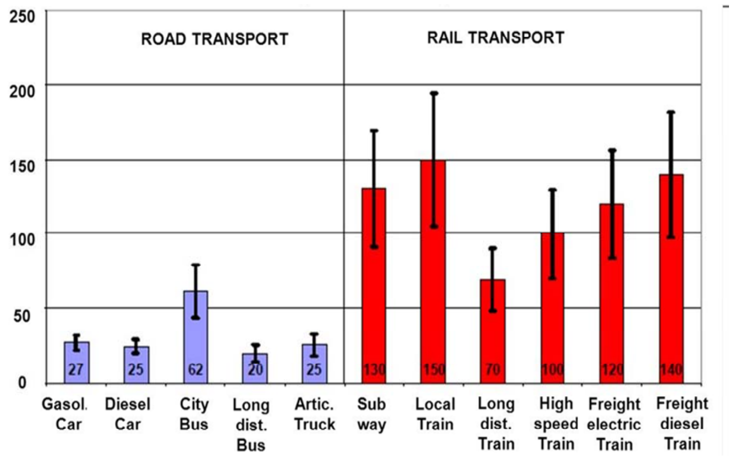

Figure 3 – Lifetime primary energy savings from light-weighting [GJ/100kg], with sensitivity to uncertainty of basic data (IFEU 2003)

POTENTIAL AND BARRIERS – Looking to the future, in order to reduce overall energy consumption there is a need to encourage modal shift to public transport both in Europe and developing countries such as India and China [3]. In urban areas this may have additional benefits in reducing congestion, pollution and air quality problems.

Public transport offers some of the best opportunities for the application of new, more efficient and lower carbon technologies. The high vehicle utilisation rates and long service lifetimes make payback periods much shorter than for private vehicles.

The greatest potential for improvements in the longer term appear to come from shifting from road-based to rail-based public transport where possible and by shifting from internal combustion to electric drivetrains in combination with decarbonisation of the electricity supply. Where internal combustion engines continue to be used, biomethane from biogas or bio-synthetic gas appears to offer the greatest carbon reduction opportunities. It should be noted that **ultra-light rail systems** are being proposed with onboard propulsion systems which may be powered by a variety of options including biomethane, negating the need for electrification, overhead wires and track insulation [46]. In the shorter term, the most potential appears to be offered by the introduction of stop-start and hybrid

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technologies to buses possibly in conjunction with bus rapid transit systems.

The first Personal Rapid Transit (PRT) systems are being built and are expected to have very low energy consumption of 0.55 MJ per passenger kilometre [47].

Primary barriers to these changes are the high initial capital cost of new rail based urban public transport and the required land take. For battery powered vehicles, the high costs and concerns over battery life may also present barriers. The need for new electric recharging infrastructure is a significantly lower barrier than for other modes due to fixed/known routes and centralised depots for refuelling. For fuel cells the high costs, issues regarding lack of hydrogen storage and re-fuelling infrastructure, and concerns over whole lifecycle energy requirements are the key barriers.

Table 1 – Summary Table: Key Data and Figures for Baseline Bus

Baseline vehicle: Diesel ICE Bus	
Energy Input	Diesel
Base Energy Consumption (l/100km)	50-55
Base Energy Consumption (MJ/seat-km) [31]	0.4 (0.22 [a] - 0.54) [b]
Technical Lifetime, (years) [31]	15
Capital Cost, overnight, Euro/unit	€300,000
O&M cost, Euro/year	N/A

a) Figure for double decker bus [48]; b) Based on 21.6 MJ/km (6 kWh/km [31]) vehicle energy consumption and assuming 40 seats.

Table 2 –Summary of Energy Reduction Options for Buses

Description	**Energy reduction potential (%)**		**Additional Cost**	**Payback period**
	Low	**High**		
Conv. powertrain improvements	1	2	€120-1675	Required to meet forthcoming emission standards
Stop-start system [22]	0	30	N/A	N/A
Hybrid system [22]	20	30	+40% [35]	Medium
Full electric [22]	0	70	N/A	N/A
Hydrogen fuel cell [49]	0	60	+300-600% [32]	Long
Weight saving [45]	Approx. 6 J/100kmx100kg		N/A	N/A
Drag reduction [32]	0	24	N/A	N/A

Table 3 – Summary Table: Key Data and Figures for Baseline Light Rail

Baseline vehicle: Electric Multiple Unit			
	Light Rail [39]	**Metro** [39]	**PRT** [47]
Energy Input	Electricity	Electricity	Electricity
Base Energy Consumption (kWh/seat-km)	0.08 (0.04- 0.22) [a]	0.07 (0.04-0.15) [b]	0.15 [c]
Base Energy Consumption (MJ/seat-km)	0.28 (0.15 - 0.80) [a]	0.24 (0.14-0.56) [b]	0.55 [c]
Technical Lifetime, (years)	30-35	30-35	N/A
Capital Cost, overnight, Euro/unit	Varies	Varies	N/A
O&M cost, Euro/year	Varies	Varies	N/A

a) Based on figures from US Department of Transportation – average of 29 US light rail systems [39]; b) Based on figures from US Department of Transportation – average of 14 US Metro heavy rail systems [39]; c) Figures from ULTra PRT system website FAQ [47]

The primary technology for energy reduction for light rail systems is weight reduction which results in approximately 4MJ/100km energy saving for every 100kg of weight reduction [45].

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