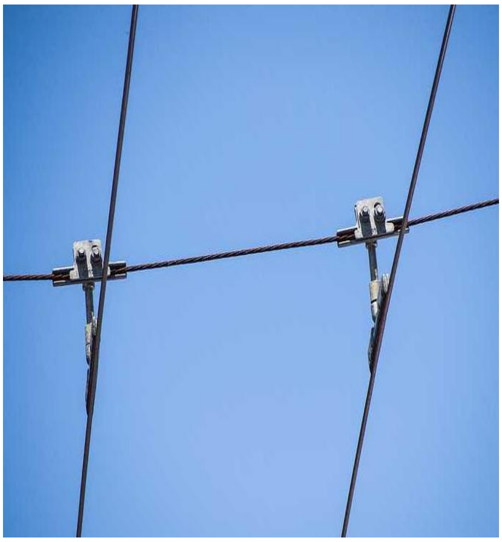
Clean Buses – Experiences with Fuel and Technology Options

February 2014



1. Aims of the Report 3
1.1. Trials and demonstrations 4
1.2. Adapting existing diesel vehicles 4
2. Factors influencing fuel/technology selection 5
2.1. Subsidies, tax incentives, funds etc. 5
2.2. Total cost of ownership/life cycle cost 5
2.3. Prioritisation of air pollution or CO_2 emissions 6
2.4. Availability of fuel and refuelling infrastructure 6
2.5. Topography, route and climate 6
2.6. Scope of replacement activities 6
2.7. Whole Fleet 7
3. Alternative fuel/technology overview – pros and cons 7
MARKET READY FUELS AND TECHNOLOGIES 10
4. Gas fuels 10
4.1. CNG 10
4.2. Other gas technologies 13
5. Biofuels 15
5.1. Biomethane 16
5.2. Biodiesel (FAME) 18
5.3. Paraffinic diesel (HVO and BTL) 20
5.4. Bioethanol (E95) 22
6. Trolleybuses 23
7. Hybrids 26
7.1. Diesel-hybrids 27
LESS MATURE TECHNOLOGIES 30
7.2. CNG- and Ethanol-electric hybrids 30
7.3. Plug-in Hybrids 31
8. Fully Electric Buses 33
9. Hydrogen fuel buses 36
10. Buses with standard combustion engines 39
11. Contributors 41

1. Aims of the Report

According to a UITP report published in 2011[1], buses account for 50-60% of the total public transport offer in Europe, and 95% use diesel fuels. However, a wide range of alternative fuels and technologies, at different levels of technical and market maturity are now available for bus operators. If CO_2 emission and local pollution targets are to be met it is clear that alternative vehicle solutions must be found.

When purchasing buses, public authorities and operators of public transport services are obliged to follow the conditions laid out in the Clean Vehicles Directive (2009/33/EC), by taking into account energy consumption, CO_2 emissions, and other harmful emissions (NO_x, NMHC and particulates). In addition, all new bus models sold on the market since 1 January 2014 must meet the stringent Euro VI standards for harmful emissions. More information on implementing the Directive, and relevant European legislation can be found on the Clean Fleets website – www.clean-fleets.eu.

This Report has been produced by the Clean Fleets project consortium (see end of document for list of partners), and aims to document some of the experiences of European local authorities and public transport operators in operating buses running on alternative fuels and technologies.

The report is based on:

- Existing reports on different fuel/technology options (see references throughout)
- Interviews with public authorities/fleet operators (see list of contributors at end – just names and organisations)
- Comments and direct input from other experts in the field (see list of contributors at end just names and organisations)

The report is aimed at providing a review of potential fuels and technologies available for buses, including relevant strengths and weaknesses, as a reference document for local authorities and public transport operators.

Technological and market developments in the alternative vehicles sector are happening very rapidly. Furthermore, many factors influence the most appropriate choice of fuel and technology (see section 2 below). As such this document cannot and does not aim to provide a straightforward recommendation of one fuel/technology over another. This document tries to synthesise some of the main conclusions from relevant reports, and document experiences from individual authorities.

The document presents an initial overview of some of the main factors which influence the choice of alternative technology/fuel type. It then provides a more detailed overview on each fuel/technology. The most mature technologies are dealt with at the beginning, progressing to the less mature technologies at the end. The document aims to indicate where information relates to trials or regular operation. The document aims to cover the main fuels and technologies currently available in commercial or trial form in Europe.

[1] http://www.uitp.org/sites/default/files/cck-focus-papers-files/FPNov2011.pdf

The Clean Fleets consortium would like to hear about further experiences with the technology and fuel types covered in this report, or updated information on what has already been covered. This feedback is invaluable for those authorities with less experience experimenting with innovative bus solutions.

1.1. Trials and demonstrations

Transport providers can work with manufacturers to undertake trials of bus prototypes to test newly developed technologies and explore whether or not they have the potential to fit the requirements of a public transport organisation. Due to the human and financial resource implications and the relatively high risk of bus 'down time', these trials often require external funding. Trials are usually conducted on a small scale and on less crucial routes to minimise service disruption. Trials have the benefit of encouraging innovation and help to mainstream newly developed technologies. They also help manufacturers establish whether improvements need to be made, in order for their vehicles to perform optimally in real life conditions.

Demonstrations are used to test whether a technology could take over from a normal 'in service' vehicle, after the technology has been successfully trialled. These demonstrations should not imply significant cost increases to the organisation and the buses should be used in the same way as a normal 'in service' vehicles. Using demonstration buses before purchasing allows the transport operator to test the passenger acceptance, real world performance and practicalities of the vehicle before any significant investment is made into a fleet, including any infrastructure requirements.

1.2. Adapting existing diesel vehicles

Where it is not considered practical to replace vehicles, various smaller-scale adaptations may help to increase the efficiency and lower local pollutant emissions of standard diesel buses. Several newer technologies are outlined in a report[2] produced by the LowCVP initiative in the UK, including:

- **Lightweighting** - optimising material use to reduce the vehicle mass.
- **Smart alternators** - control excitation so that the alternator only charges the battery under deceleration (overrun) conditions.
- **Smart clutched compressors** - (e.g. Knorr Bremse EAC) control the parasitic load on the engine either via depressurising and/or declutching.
- **Rankine heat recovery** (exhaust or coolant) - a system to recover waste heat from either exhaust gas hear or coolant, to drive an additional power turbine to generate energy. Further development of this technology is needed, however.
- **Infinitely variable transmission** (IVT) – a system using no discrete gears. Further development is needed.
- An **Arrive and go** (stop-start) **battery system** – reduces fuel used during idle by stopping the engine when the vehicle is stationary.

[2] www.lowcvp.org.uk/assets/reports/LowCVP-Ricardo%20Bus%20Roadmap%20FINAL.pdf

- **Low rolling resistance tyres** and **tyre pressure monitoring**
- **Driver training** (repeated to avoid "training decay") and **driver advisory systems**
- Specifying **low energy technologies for auxiliaries** such as LED lighting , CCTV, ticket machines, passive cooling technologies (solar reflective glazing/paint)
- Consider installing **solar PV**

In terms of local air pollutants (particularly NO_x and particulates), the Euro VI standards (which have been in effect for all buses sold since 1 Jan 2014) should in theory reduce such emissions to negligible levels.

The Finnish Technological Institute (VTT) has monitored real time emissions from Euro VI buses, which are so new that there are no official test results yet. Results showed that these buses actually had higher NO_2 emissions than older Euro III buses, but that the total NO_x emissions were lower. Importantly, particulate matter (PM), considered to be the most harmful pollutant to human health, was also found to be significantly lower.

2. Factors influencing fuel/technology selection

Public authorities across Europe are operating under different financial, social and environmental conditions so there cannot be one clear fuel or technology option for all public buses. This section provides a short overview of some of the most important factors.

2.1. Subsidies, tax incentives, funds etc.

The availability of financial support for the introduction of alternative fuels and technologies, including tax incentives (reduced vehicle tax for cleaner vehicles, lower tax on cleaner fuels etc.) and subsidies/grants, varies substantially from country to country. This is often the most important factor in determining whether such technologies are cost-effective, and which fuel/technology to choose.

Funds, tax incentives or subsidies for the outright purchase of clean or energy efficient buses include the UK's **Green Bus Fund** and the German Ministry for Environment's fund for **hybrid and electric vehicles**). Croatia, by contrast, offers no financial incentives to alternative fuels or technologies.

Some cities also operate direct support schemes – Helsinki, for example, pays a premium to contractors who provide second generation biofuels.

2.2. Total cost of ownership/life cycle cost

Cost, of course, remains the primary decision factor for the majority of public authorities. However the extent to which authorities are able to take into account the life cycle cost/total cost of ownership of a vehicle can have a major bearing on the selection of vehicle type. Many alternative fuel/technology options have higher upfront investment costs, both in terms of the vehicles, and the infrastructure required, but can demonstrate cost savings over the life cycle of the vehicle due to lower fuel consumption/prices, and potentially longer lifespans and lower maintenance costs.

With strict budgetary pressures, many public authorities remain focused on immediate cost rather than long term savings – a factor exacerbated in many cases by split budgetary responsibilities between departments responsible for purchasing, and those responsible for operation. In such cases, it may be necessary for new mechanisms for funding these vehicles to be developed.

As indicated in 2.1, the impact of fuel duty, vehicle tax, and available subsidies clearly also has a significant impact on investment decisions.

2.3. Prioritisation of air pollution or CO_2 emissions

A major determining factor in fuel/technology selection is your priority in terms of environmental performance. Bus transport is a significant contributing factor to local air pollution in European cities. Where local air pollution is a substantial problem, a city may prioritise vehicle selection based on emissions of NO_x and particulates over energy efficiency or CO_2 performance. Some authorities may have strict CO_2 reduction targets, which would favour alternative vehicle options and others may aim to achieve a reduction in both local and global air pollution. The level of ambition, and therefore the extent to which the authority may be prepared to financially invest in new solutions, will also obviously play a major role.

2.4. Availability of fuel and refuelling infrastructure

The highly differentiated availability of a refuelling infrastructure for alternative fuel types has a major impact on the practicality of selecting certain vehicle types. The type of area being served by a bus route (whether urban, short distance, high occupancy, or rural, long distance, low occupancy for example). Often a decision to invest in a new form of vehicle fuel/technology will need to go hand in hand with investment in refuelling stations, or a wider programme of incentivisation for vehicle uptake in the private sector. The very heterogeneous pattern of renewable energy generation, gas grid development and biofuel production contributes to this situation. Sweden, for example, has a highly developed production of biogas, whereas in other countries very little biogas is available.

2.5. Topography, route and climate

The physical conditions under which the buses will operate can also have a major impact on the right choice of fuel/technology – for example how hilly a route is, the distance between stops, the density of passenger occupation, conditions of extreme heat and extreme cold.

2.6. Scope of replacement activities

The extent to which a new technology may be introduced will also be in part determined by the approach to bus replacement within the fleet. The introduction of a new refuelling infrastructure will likely only be cost effective where a major fleet overhaul is occurring. Where individual vehicles are being replaced, different fuel/technology choices may be most appropriate.

2.7. Whole Fleet

A greater benefit may be achieved by replacing a high number of vehicles which provide modest CO_2 and/or air quality related improvements rather than one or two buses which provide significant improvements.

3. Alternative fuel/technology overview – pros and cons

The table below gives a summarised overview of what are typically considered the most important advantages and disadvantages for each alternative fuel/technology type covered in the more detailed section below.

As indicated in section 2, this can only provide a general picture, and the most appropriate selection will heavily depend on local conditions and priorities.

	Pros	Cons
Gaseous fuels		
Compressed Natural Gas (CNG)[3]	Major savings in PM and NO_x emissions compared to traditional diesel (but not to Euro VI) buses	Natural gas is a non-renewable, fossil fuel and WTW CO_2eq emissions are not significantly better (or can be even worse) than traditional diesel engines.
	Relatively lower premium on cost of acquisition of CNG buses compared to other technologies	Some safety concerns reported regarding storing gas on board
	Mature market, numerous experiences identified	
Biofuels		
Biomethane/ biogas	Very significant WTW CO_2eq savings compared to traditional diesel buses, especially when methane emissions are avoided. WTW emissions tend to be lower than FAME, HVO and ethanol derived from cereals (although higher than wood/wheat straw ethanol or BTL).	The potential volume of production from waste is relatively small. A much larger potential comes from the gasification agricultural products.
	PM emissions almost zero. Up to 30-80% reduction for NO_x recorded in comparison to traditional diesel engines (though not Euro VI models).	Fuel prices and availability will strongly depend on local market conditions and the supply chain.
	Technology the same as CNG, therefore there is a relatively well developed market, and a lower premium on cost of	Some safety concerns reported regarding storing gas on board

[3] More information on LNG, LPG and GTL can be found in Section 4. Performance in terms of local emissions and CO2 emissions are similar to CNG, with some variations. Costs and range may vary considerably.

	acquisition of biogas buses compared to newer technologies	
	It is a renewable fuel made from organic materials including waste products	
Biodiesel (FAME)	WTW CO_2eq savings can be very high compared to traditional diesel →	But this strongly depends on feedstock (waste oils cause the lowest emissions, palm oil the highest – depending on processing methods)
	Tailpipe PM10 emissions can be significantly lower than traditional diesel →	Although PM2.5 and NO_x emissions can be higher
	No premiums for cost of vehicle acquisition	Fuel supply costs depend on local market conditions and may depend on financing e.g. tax relief
	It is a renewable fuel derived from vegetable oils and waste oils.	Implications of converting land away from natural habitats or from food-related cultivation
Hydrotreated Vegetable Oil (HVO)	WTW CO_2eq savings can be very high compared to traditional diesel, and even better than FAME →	But again this strongly depends on feedstock and processing methods (e.g. sunflower HVO causes half as many emissions as soybean HVO)
	It is a renewable fuel derived from vegetable oils, waste cooking oil, animal fat or fatty residues.	Local emission reductions not as high as other alternative technologies/fuels
		Supply is relatively limited
		Implications of converting land away from natural habitats or from food-related cultivation
Biomass-to-Liquid (BTL)	Has the lowest WTW CO_2eq emissions of any biofuel. Only 10% of the emissions from palm oil HVO or FAME biodiesel.	Fuel supply costs depend on local market conditions and may depend on financing e.g. tax relief
	No premiums for cost of vehicle acquisition	Local emission reductions not as high as other alternative technologies/fuels
	It is a renewable fuel derived from biomass e.g. farmed or waste wood	
Bioethanol	WTW CO_2eq from ethanol derived from wheat straw and wood are very low compared to all other biofuels covered except BTL. Emissions from ethanol derived from cereals are comparable with FAME and HVO.	Limited supplies in most European countries
	It is a renewable fuel produced through the fermentation of organic materials.	There is limited fuel supply in most European countries and costs depend on local market conditions and financing e.g. tax relief

Hybrids		
Diesel electric	WTW CO_2eq emissions savings can reach around 30% compared to traditional diesel buses, as can tailpipe emissions →	However this varies according to what extent the electric motor is used. It is strongly dependent on the duty cycle, the topography of the route, congestion and driver efficiency.
	This is now a reasonably mature technology, with similar reliability to a standard Diesel bus.	Diesel is a fossil fuel.
		Costs of acquisition can be 50% more when compared to traditional diesel buses.
CNG/ethanol/ biodiesel electric hybrids	Has the advantages of a diesel electric vehicle, but with lower WTW and tailpipe emissions than diesel.	Very limited experiences so far
Plug-in electric hybrids (PHEVs)	Significantly lower WTW CO_2eq emissions compared to traditional diesel buses →	However, WTW CO_2eq emissions strongly depend on the origin of the electricity used, and on the proportion of time operated in full electric mode
	Lower energy consumption compared to diesel-electric hybrids.	Relatively immature technology therefore there are limited experiences with this technology type.
	Flexibility to operate in EV mode in noise and pollution-sensitive areas.	
Electric (BEVs)		
Electric BEVs	High potential for WTW CO_2eq savings, almost 100% →	WTW CO_2eq and embedded NO_x and SO_x emissions totally depend on the origin of the electricity used.
	Zero tailpipe emissions and noise pollution	Relatively immature technology therefore currently very high relative costs of acquisition. Costs associated with infrastructure can vary widely depending on how it will be used and any existing infrastructure. There are limited experiences with this technology type.
		The need for recharging can limit flexibility
Hydrogen		
Hydrogen fuel cells	High potential for WTW CO_2eq savings, almost 100% →	WTW CO_2eq emissions depend on hydrogen production methods.
	Zero tailpipe emissions	Immature technology therefore it is only possible to use the buses as part of a trial or demonstration.
	Have shown good performance during trials and have high route flexibility, comparable to diesel buses.	There is a lack of experience with hydrogen as a fuel, therefore there is little safety legislation.

MARKET READY FUELS AND TECHNOLOGIES

4. Gas fuels

There are two main gas fuels from fossil sources:

- **CNG** (compressed natural gas) is methane derived from oil and gas fields, stored under pressure for use as a vehicle fuel.
- **LPG** (liquefied petroleum gas) is a mixture of butane and propane, a by-product of the petrol refinement process

Liquefied natural gas (**LNG**) and Gas-to-liquid (**GTL**) fuels are also covered in this section as they are derived from natural gas, but their use in European buses is currently quite limited.

Note: Biogas/biomethane is considered under the biofuels section below.

4.1. CNG

Technology

In Europe, CNG is more typically used in HDVs and buses, whereas LPG is usually used in cars and light vans. For this reason CNG is covered to a greater extent in this section. CNG buses can also run on biomethane (Biogas), a renewable fuel source produced from organic materials (see biofuels section below).

Heavy duty vehicles are often designed to use gas only, but 'dual-fuel' models exist, which burn both gas and diesel in a diesel engine simultaneously. The Clean Truck project and the LowCVP study[2] indicate that current models however have a low gas substitution ratio at urban bus speeds/loads.

Performance

WTW CO_2eq emissions[4]	Relatively small benefit, or even small negative impact, usually reported in relation to traditional diesel engines. The type of gas extraction process, quality of the gas and distance from source to refuelling station significantly influence WTW CO_2 emissions, as can the efficiency of the engine itself.
NO_x, NMHC, PM	A major advantage of CNG buses is the reduction of other harmful emissions. Particulate emissions tend to be negligible, or even zero. NO_x emissions reductions in comparison to traditional engines are also substantial (the LowCVP report[2] indicates reductions of 30% to 80%). Bus manufacturers are moving away from lean burn CNG buses, as NO_x emissions are too high.

[4] Assessment of the CO_2 emissions throughout this document is based on the *well to wheel* (WTW) emissions (including the production as well as the use of the fuel), rather than from *tank to wheel* (TTW) (only considering the use of the fuel) as they are under the Clean Vehicles Directive.

	It should be noted that in comparison to Euro VI requirements, the benefits of CNG are not significant.
Noise	In regards to noise pollution, gas buses are generally considered to be quieter than comparable diesel vehicles, (especially when idling). Cooling fans may potentially be noisier. People may also need time to adjust to different typical noise patterns to standard buses.
Cost aspects	Purchase price is typically higher for CNG buses, with some reports indicating a 20-30% increase compared to traditional diesel buses before Euro VI was mandatory.[5] [6] Some new refuelling infrastructure and safety modifications may also be required at bus depots. Fuel costs are similar to diesel – price of gas is slightly lower (although this is heavily dependent on taxation), but consumption is typically slightly higher. A limited WTW CO_2eq saving potential, coupled with refuelling infrastructure and vehicle costs, means using CNG implies a relatively high cost per tonne of CO_2eq avoided[7]
Other considerations	Some cities have expressed safety concerns (particularly in relation to roofed exchange hubs for passengers, and use and storage in enclosed spaces such as underground garages and long tunnels), although opinions vary on this point. The existence of effective safety guidelines and legislation is relevant in mitigating such concerns. CNG buses may demonstrate lower acceleration due to lower torque, especially on steep inclines.

Market development

While natural gas supply is unlikely to be a serious issue at least in the medium term, infrastructure and market barriers are likely to be the main factors constraining further development of CNG. However, as one of the first established alternative vehicle fuel types, the market for CNG buses has become well developed over the last few decades in some few European countries, especially those with a well connected national gas grid. Although there are some existing concerns that CNG buses have a lower range than other technologies, it is now generally considered that CNG vehicles perform equally to buses run on standard diesel[8]. Safety worries about potential fire risks mean that some authorities are now focusing on other solutions, but in other cases, appropriate bus and depot design have mitigated these concerns.

[5] http://www.compro-eu.org/doc/D2.1_Analysis%20of%20clean%20buses%20market.pdf

[6] http://www.uitp.org/mos/focus/FPNov2011-en.pdf

[7] JEC – Joint Research Centre – EUCAR – CONCAWE collaboration, Well-to-Wheels Report, Version 3c, 2011: http://iet.jrc.ec.europa.eu/about-jec/downloads

[8] http://www.compro-eu.org/doc/D2.3_Cost%20effectivness%20analysis%20of%20the%20selected%20technologies.pdf

Practical Experiences

- **Zagreb** City Holding – subsidiary ZET (100% owned by the City of Zagreb), currently leases 60 CNG buses, 40 of which are articulated. These vehicles have been refueled at the newly built gas filling station since October, 2013. There are some issues in regards to the fact that there are only two filling stations in Zagreb and that the buses have a relatively limited range compared to conventional vehicles. Further information.
- The City of **Rijeka**, Croatia, installed a CNG filling station in May 2013. It is used to refuel 11 buses and 10 mini buses operated by the City. Further information.
- Around 75% of the 400 buses in the **Nantes** Conurbation, including both standard and articulated buses, run on CNG. Since the decision was made to favour this solution in the year 2000, special refuelling infrastructure for CNG and has been installed in the depots. The buses were more expensive to purchase but the cost of CNG is generally substantially lower than that of diesel. There have been some reactions from residents regarding start up noise during the early morning or night. Further information: [A] [B]
- The Municipality of **Bourgas** (Bulgaria) has been operating CNG buses on its public transport network since 2008. The collaboration between the City's public transport company Burgasbus EOOD, the Czech bus manufacturer TEDOM, and Unicredit Leasing Ltd. resulted in an eight-year leasing contract approximately worth €2.5 million. The TEDOM buses met the Euro V emissions standard required at the time, are less noisy and more fuel efficient than traditional diesel buses, with fuel costs around half the price and maintenance costs far lower. Burgasbus EOOD's bus drivers were trained and licensed by TEDOM. Due to the buses' user-friendliness, especially in terms of comfort and accessibility, the buses are very popular and its implementation is regarded as successful. In terms of cost-effectiveness however, the buses have not fully met the expectations. Further information: [A] [B] [C]
- In Germany, **Bremen** no longer sees CNG as a viable option due to the tax relief on gas fuel ending in 2018, along with the associated infrastructural needs and impracticalities of the technology in terms of the range on heavily used lines.
- The City of **Hannover** experienced problems with the noise patterns of their CNG vehicles, although most sources agree that gas buses are up to 3 decibels quieter than comparable diesel buses.
- **Helsinki** had at fleet of some 100 CNG buses, but the number has been diminishing, mainly due to high maintenance costs. In addition, natural gas buses cannot enter the main (underground) bus terminal in Helsinki (see section on biogas), Further information.
- **Dublin** has found that for low-floor buses the space to mount tanks presents significant difficulties. Trials of single deck buses with roof mounted tanks demonstrated a lower range in comparison to diesel vehicles.
- **Porto's** public transport operator (STCP) has operated a fleet of 255 standard and articulated CNG buses since 2009. The models used are MAN NL 233 CNG and MAN NL 310 CNG. These vehicles performed better in terms of emissions than comparable diesel models, produced less noise emissions and have been well accepted by drivers and passengers. Further information

- The **Hague** and its public transport operator 'HTM Personenvervoer NV' arranged the purchase of 135 MAN "Lion" E 2866 DUH04 low-floor CNG buses. The buses comply with The Hague's strict requirements on NO_x. The purchase was grant funded by a national fund that finances local climate initiatives. The introduction of the CNG buses helped to decrease emissions, including PM. However, there have also been safety concerns due a CNG bus fire in the area in 2012, causing a 15m long horizontal flame from the side of the bus. According to safety regulations flames should go vertically to avoid injuries. As a consequence, all gas buses in The Hague had to undergo a safety check. The Dutch safety board also published a report to investigate the cause. It identified the release of natural gas when the cylinders heat up as the safety issue that caused the fire. Further information: [A] [B] [C] [D] [E] [F] Full report. English Summary.
- The City of **Salamanca** purchased five new 12m CNG buses using Iveco's 491 Irisbus model incorporated into Castrosúa's "City Versus" bodywork. All buses are equipped with low floors and ramps for push chairs and people with disabilities, an integral low floor, LED signage etc. It is hoped that the purchase of these vehicles will contribute towards the Coty's environmental commitments to decreasing air pollution. Further information.
- In 2011 **Barcelona**'s public transport provider TMB incorporated 80 new CNG buses into its urban fleet, amounting to 376 CNG buses altogether. This was a result of the collaboration between TMB and Gas Natural Fenosa and their joined ambition to improve the City's air quality. Another 204 CNG buses are to be added to Barcelona's fleet by 2015. TMB states that the CNG engines hold the following benefits: a 90% reduction in NO_x emissions, almost no PM emissions, a 20% decrease in CO emissions, lower noise levels and no production of ash or solid residue. The overall experiences of the operator and passengers have been very positive. Further information: [A] [B] [C]

4.2. Other gas technologies

LPG

LPG (liquefied petroleum gas) is a mixture of butane and propane, a by-product of the petrol refinement process.

- One of **Vienna**'s public transport operators, Wiener Linien, runs an entire fleet of LPG buses. The introduction of LPG as an alternative fuel began in the sixties and since 2001 LPG engines have been successively replaced with better performing models. Compared to traditional diesel engines it has been found that the LPG models emit less CO and NMHC than traditional diesel models, and significantly less NO_x and PM, however CO_2 emissions are higher. Further information: [A] [B]
- In 2012, the City of **Valladolid** in Spain became the first in Europe to operate an electric-LPG hybrid bus. The Tempus Autogas was developed by Spanish energy company Repsol and bus manufacturer Castrosua and has a range of 60km with batteries and a total of 300km with a generator. Depending on the route and operating level, the technology allows for up to 40% fuel savings compared to conventional vehicles. It reportedly produces significantly lower noise, CO_2 and NO_x emissions. Tempus models range between 9,6m to 11,6m in length. Further information: [A] [B] [C]

- In Romania, **Braila** and **Iasi** have been operating LPG buses since 2009. Overall their experience has been quite positive, but Braila found that the fuel consumption is increasing annually, potentially due to the wear rate. No new acquisitions on such fuel are foreseen for the coming few years in these two cities, or elsewhere in Romania at the time of writing. Further information.

LNG

To avoid the cost implications and impracticalities of transporting natural gas by pipeline or compressed in flasks/containers over long distances, it can be converted into a liquid form. LNG is created by cooling the gas to a liquid at around -160ºC, which we can then be shipped out more safely and efficiently. The liquefaction process requires the removal of the non-methane components like carbon dioxide, water, butane, pentane and heavier components from natural gas. LNG is a clear, colourless, non-toxic liquid that occupies up to 600 times less space than natural gas. When LNG reaches its destination, it is often returned to a gas at re-gasification facilities. Heavy duty vehicles can sometimes store the fuel as liquefied natural gas (LNG) which allows more fuel to be stored and increases range. For city buses the need is not so great for the long range LNG gives and as such there are few experiences identified:

- A series of demo-runs took place in 5 Polish cities (**Torun, Gdynia, Olsztyn, Warsaw** and **Katowice**) in 2012 using Polish manufactured “Solbus”. Local emissions were reportedly very low without any need for additional filtering, with PM emissions reaching almost zero. Refuelling time is also greatly reduced, and fuel costs approximately 10% lower. Further information.
- In early 2012, **Beijing** Public Transportation Group introduced 100 LNG-powered clean energy buses, equipped with FTP (Iveco) engines. China National Petroleum Corporation (CNPC) also installed the required fuelling stations along the bus routes. According to PetroChina, the LNG-powered vehicles emit 90 per cent less particles compared to Diesel buses. Replacing Beijing’s current 15,000 buses by LNG-powered ones is approximately equivalent to taking 750,000 cars off the road in terms of emissions. Further information: [A] [B] [C]

Gas-to-Liquid (GTL)

Gas-to-Liquid (GTL) refers to the conversion of natural gas into synthetic diesel fuel. GTL can be used as an alternative to diesel or can be blended and used in the existing diesel distribution system. GHG emissions from GTL diesel are slightly higher than those of conventional diesel. GTL can reduce local emissions of PM by around 30% and NO_x by around 8-10% compared to traditional diesel.

Imported GTL diesel has been on the Swedish market since 2002. In Europe in general, in the medium term, GTL diesel will be available in limited quantities for use either in niche applications or as a high quality diesel fuel blending component[1]. There are so far very limited examples of buses using GTL as fuel:

- GTL has been used in various vehicles within Västernorrland and Västerbotten, the “BioFuel Region” of Sweden. In 2005, a GTL diesel and biodiesel blend called “paradiesel” was launched by FramTidsbränslen AB. The City of **Sundsvall** currently operates four Scania diesel buses in daily traffic using Paradiesel. Emission tests have shown that paradiesel containing 5 % biodiesel reduces CO_2 emissions by 4-10 %. Moreover, the benefits of GTL diesel fuel (e.g. good cetane number and cold flow properties and fully soluble with ordinary diesel) can also be found in paradiesel. Further information.

- Tests by the Finnish research Institute (VTT) and the AVL Motor Test Centre (AVL-MTC) have shown that, although some GTL fuels may reduce local emissions from older vehicles, they make very little difference in modern vehicles.
- Some trials in London and Rotterdam have shown that buses running on high concentrations GTL of have reduced particulate and NO_x emissions. Rotterdam is considering GTL as a fuel for their bus fleets in the future.

5. Biofuels

Biofuels are renewable transport fuels derived from organic materials. The term biofuels encompasses an ever-increasing number of different fuel types – differentiated by the source material, the manufacturing process and the type of fuel ultimately created (gaseous, petrol or diesel equivalent, suitable for blending). They include biogas (biomethane) and liquid biofuels, including biodiesel and bioethanol. Newer fuels such as bio-DME and biomethanol are also being developed.

Assessing the GHG-performance of biofuels is complex. When burned in vehicle engines biofuels emit greenhouse gases, just like burning fossil fuels. However, as the organic material used to produce these fuels absorbs CO_2 as it grows the overall CO_2eq emissions may be very low – this advantage is only appreciated when CO_2 emissions are assessed from "well to wheel" (WTW) including the production as well as the use of the fuel, rather than from "tank to wheel" (TTW) only considering the use of the fuel, as they are under the Clean Vehicles Directive.

Many consider biofuels to be the most economical way of significantly decreasing WTW CO_2eq emissions[9]. Lifecycle emission impacts are however highly variable and dependent upon how and where they are produced. Direct CO_2 impacts are heavily impacted by the processing and manufacturing methods (including what by-products are produced and how these are dealt with), the use of artificial fertilisers, and the efficiency of the fuel produced. Concerns have also been raised relating to land use change, and the impact on food prices – with critics claiming that demand for land to grow crops for biofuels leads to both virgin land being turned into fields, and to biofuel crops replacing food crops. Others point out that a large number of brownfield sites are available in Europe for cultivating fuel crops. This debate is a complex one, with little consensus yet reached.

To guarantee that the biofuels used in EU are sustainable, all biofuels must fulfil extensive sustainability criteria, excluding feedstock grown on virgin land, carbon-rich land, land with

[9] An in depth study comparing WTW CO_2eq emissions from biofuels compared to conventional diesel found a reduction of between 30-95% is possible from traditional feedstocks and 85-95% from lignocellulosic feedstocks or waste materials - Fuel and Technology Alternatives for buses: http://www.vtt.fi/inf/pdf/technology/2012/T46.pdf

high biological diversity and must reduce GHG-emissions currently by at least 35 % - which will be increased to 50 % from 2017 (according to the current proposal) and later on 60 %.

A distinction is often made between *first generation* biofuels, taken to mean those produced from crops grown solely for that purpose, and *second generation* biofuels, taken to mean those produced from the waste products of forestry or agriculture. However, definitions are not clearly agreed.

Calculated CO_2eq WTW savings vary hugely according to study and fuel type – from 30% to over 100% reductions (i.e. climate positive impacts). As such, specific values are not provided in the individual biofuel sections below.

5.1. Biomethane

Technology

Biogas is a renewable fuel that can be used in place of natural gas to power vehicles. It is produced from organic materials, which are broken down by microbial activity or gasification. Biogas is upgraded for use as a vehicle fuel by removing hydrogen sulphide, carbon dioxide and moisture, at which point it is known as biomethane. It may also be injected into the national gas grid as the composition of the molecules is the same as natural gas.

Biogas can be produced in dedicated anaerobic digestion plants using sewage, animal/ agricultural waste or agricultural products as feedstock. It can also be sourced from landfill sites. As with natural gas, biomethane can be liquefied (LBM) or compressed (CBM) in order to store, transport and use it more easily as a vehicle fuel.

The potential volume of production of biogas from waste is relatively small. A much larger potential comes from the gasification of cellulosic feedstock.

Performance

WTW CO_2eq emissions	When made from waste material biogas provides high GHG savings compared to traditional diesel. Liquid manure for example, provides especially significant reductions, where methane emissions are also avoided. Biogas produced from landfill has a slightly lower WTW CO_2eq benefit (though still highly significant) due to the processing and transportation requirements.
NO_x, NMHC, PM	PM emissions almost zero. Up to 30- 80% reduction for NO_x recorded in comparison to traditional diesel engines (though not Euro VI models).
Cost considerations	Cost implications will typically be the same as for CNG, as the technology is the same. Some reports indicate a 20-30% increase.[6] [10] Some new refuelling infrastructure and safety modifications may also be

[10] http://www.compro-eu.org/doc/D2.1_Analysis%20of%20clean%20buses%20market.pdf

	required at bus depots. Stockholm reports practically identical costs with diesel, following reductions in initially higher servicing and maintenance costs. Fuel prices will strongly depend on local market conditions and the supply chain. When made from waste material, biogas provides relatively low cost GHG savings[11].
Other considerations	Origin of organic matter used to produce biogas is key to environmental impact. Perceived safety concerns about gas explosions, as with CNG

Market development

The uptake of biogas as a fuel tends to be greater in countries with a well-developed national gas grid and an existing market for CNG vehicles. Sweden is an exception with local biogas production network development in part being driven by public transport demand. Findings from the European MADAGASCAR Project show that those Member States with well-developed markets for CNG buses running on natural gas are more likely to invest in large scale biogas plants for vehicle fuel. Sweden, the Netherlands, Germany and Austria are key examples of countries that already have plants for upgrading biogas for this purpose. Biogas fuel tax exemptions in Germany and Sweden have also been significant in helping to increase the uptake of biomethane powered buses.[12]

In other cases, the occurrence of biomethane used to power vehicles has been dictated by the availability of gas from large expanse of agricultural land.

The UrbanBiogas project deals with organic urban waste for biogas development.

Practical experiences

- In **Stockholm**, biogas was first introduced in 2003. Within the latest tender, the city guarantees to deliver biogas at a series of depots at a fixed price, and the operator is obliged to use a minimum quantity of biogas from these depots. Today, over 400 biogas buses operate in the City of Stockholm and the number will double in the coming years. One of the depots (Söderhallen) is connected directly to a nearby sewage treatment plant. Positive impacts include annual savings of around 3000t CO_2, 400kg CO, 20t NO_x and 300kg PM as well as a reduction in noise pollution. In terms of costs, in 2008 the operation of biogas buses was approximately 20% higher than

[11] JEC – Joint Research Centre – EUCAR – CONCAWE collaboration, Well-to-Wheels Report, Version 3c, 2011: http://iet.jrc.ec.europa.eu/about-jec/downloads

[12] www.madegascar.eu/fileadmin/dam/madegascar/downloads/2010/MADEGASCAR_publishable_report_light.pdf

standard diesel buses – by 2012 the costs were almost identical, due to a significant reduction in the costs for servicing and maintenance. Further information: [A] [B] [C]

- In the **Skåne** region of Sweden almost every bus is run on biomethane or natural gas. The biogas produced in Skåne mainly derives from sewage. Further information.
- The town of **Reading** in the UK now use the largest fleet of gas powered vehicles in the UK, with 35 such buses on the road. The entire fleet is fuelled with 100% biogas generated from agricultural waste. The transport operator is now making a large investment to convert the depot for the purposes of this fuel. Safety concerns have been mitigated through the adaptation of the bus depot, which has been fitted with a specially designed roof and ventilator. Also, the gas storage kit is located on the roof of the bus in a bid to ensure passenger safety. Further information. Clean Fleets Case Study.
- **Helsinki**´s bus company (HeLB) has been using gas-driven buses since the late nineties and at one time it had a fleet of almost 100 CNG buses. However, these first generation vehicles are gradually being replaced with Euro VI diesel models. At the time of writing there are now only 47 gas driven vehicles, 7 of which use biogas. According to the operator, the gas models suffered more technical problems than diesel buses, causing the company additional maintenance and repair costs two or three times higher than with diesel buses. In addition, gas buses are not allowed into the Helsinki bus terminal due to safety concerns. The terminal is situated below a large shopping centre and there is a glass wall separating the buses from the shops. The rescue authorities have estimated the risks of an explosion in the shopping centre are too high if a gas-driven bus catches fire in the terminal. Further information.

5.2. Biodiesel (FAME)

Technology

FAME (Fatty Acid Methyl Ester) is derived from natural vegetable oils including oilseed rape, sunflowers and soybeans etc. FAME can also use waste oil as a feedstock.

Performance

WTW CO_2eq emissions	Strongly determined by origin and processing methods. Waste vegetable or animal oil cause the lowest emissions of all FAME fuels, with sunflower oil biodiesel emitting three times as much, rape seed over four times the amount and soybean five times as much per MJ energy. Palm oil biodiesel emission can be higher still, depending on processing methods. As well as depending on feedstock used, WTW emissions depend on the by-products from the production process used (e.g. CH_4, plant meal, glycerin). Best performing biodiesels can provide WTW savings of between around 70 – 85% compared to conventional diesel.
NO_x, NMHC, PM	Significant decrease in PM10 emissions have been shown (up to 60%), but there can sometimes be an increase of smaller PM2.5 emissions.

	NO_x emissions can be slightly higher than conventional diesel.
Cost and other considerations	No increase in the price of the vehicles, or in maintenance costs, however fuel supply may require financing. FAME from vegetable oils or waste can be produced with only marginal additional costs.

Practical Experiences

- **Stockholm** Transport has 400 buses that use 100% FAME from rapeseed, saving approx. 60% CO_2 compared to fossil diesel. Stockholm has also recently opened the first public dispenser of 100% HVO. No problems have so far been encountered with either. Further information (p. 24).
- As part of the overall strategy of the City of **Burgos** to decrease local emissions from public vehicles and with the help of CiViTAS, the city purchased 27 new 100% bio diesel buses EURO IV-V Engine. Moreover, the municipality established four new petrol stations providing bio diesel. The replacement of all vehicles of Burgos' public fleet with bio fuel (or CNG) vehicles, resulted in significant emissions reductions. Further information.
- Since 2005, all buses in the City of **Graz** have run on 100% FAME produced from used cooking oil. The City established a collection system for used oil from restaurants and private households. Although the City found no economic gain from the use of cooking oil, there was an improvement of the City's image, due to the ecological benefits of their approach. In terms of PM, however, biodiesel buses do not show any advantage over conventional diesel buses. In 2013, Graz purchased 53 EEV emission standard buses, 50 of which were articulated. All 53 buses had no particle filter, so that the use of bio-diesel was still possible. With the planned procurement of 8 new Euro VI Diesel buses in 2014, the City is currently switching back to conventional buses. The decision not to continue with biodiesel buses was based on the fact that bus manufacturers seem to have ceased the production of biodiesel buses. The reason for this is twofold: (1) bus manufacturers were not willing to invest in developing high quality engines suitable for current emissions requirements, taking into account the contentious issue of creating demand for biodiesel crops and (2) the producers were not able to produce a high quality biodiesel. Further information.
- **Rotterdam** (RET) experimented with the use of biodiesel in modified bus engines, but this was not a success. The fuel clogged the filters causing mechanical problems, so RET decided not to continue with biodiesel. Further information.
- **Dublin** Bus has some limited experience with operating standard vehicles on low % blends of biodiesel. While there are no technical issues with this, the main obstacle has been the high cost of biodiesel compared to standard diesel. Further information.

5.3. Paraffinic diesel (HVO and BTL)

- **HVO (Hydrotreated Vegetable Oil)**

Technology

HVO is a high-quality paraffinic diesel resembling GTL with no limitations on end-use. It is also derived from natural vegetable oils or waste cooking oil, but can also use animal fat (tallow) or fatty residuals from the paper industry. Future feedstock include pyrolysis oil from cellulosic feedstock, enzymatically treated lignin and algae or bacteria.

Performance

WTW CO_2eq emissions	Currently, HVO tends to show a slightly better climate performance than FAME, however this depends on both the type of vegetable oil and processing method. HVO from sunflowers and from palm oil (derived from a methane capture process) emit around half as much gCO_2eq/MJ compared to soybean and regular palm oil diesel. Emissions from HVO from rape seed and pure vegetable oil from rapeseed fall somewhere between the two[13]. Biodiesel derived from unsustainably grown palm oil has a very low climate performance. Biodiesel made from palm oil residues make the palm oil even cheaper, thus promoting even further use of palm oil. Using waste cooking oil provides a very high climate performance, but does encourage an increased use of cooking oil by making it economical to change oil much more often.
NO_x, NMHC, PM	Some sources state that HVO can reduce tailpipe emissions of PM by around 30% and NO_x by around 10% compared to traditional diesel. Others state that local emissions are similar to regular diesel, however using HVO in buses makes good use of waste industrial and domestic cooking oil.

Market development

HVO is commercially available in parts of Europe but current global production could supply only a very limited proportion of EU diesel demand, it currently remains a niche product. Future feedstock supply is also limited.

Practical experiences

- HVO-fuelled buses were trialled in the **Helsinki** region from 2007-2010. The trial (Optibio) was organised by Neste Oil, Helsinki Region Transport (HSL) and Proventia Emission Control, together with VTT Technical Research Centre of Finland and four

[13] JEC – Joint Research Centre – EUCAR – CONCAWE collaboration, Well-to-Wheels Report, Version 3c, 2011: http://iet.jrc.ec.europa.eu/about-jec/downloads

local bus companies. Data collected by VTT show that particulate emissions were reduced by 30% and NO_x emissions by 10%. Following advice from NGOs, palm oil based biodiesel is no longer accepted by **Helsinki**. Vehicle operators are now paid a bonus by HSL for the use of sustainable biofuels as defined by Directive 2009/28/EC. The current fleet includes vehicles running on fuels derived from various waste products. Further information: [A] [B] [C]

- **London** launched a pilot scheme to run 120 buses on 10 routes with a blend of 20% used cooking oil and biodiesel derived from other food waste products. Carbon emissions of each bus have been reduced by about 15%. They are refuelled in the Barking depot, where a 50,000 litre storage tank has been installed, so the new fuel can be mixed on site. TfL is considering running the whole bus fleet with a certain percentage of biodiesel. As the buses do not require any mechanical changes, this would not just be more eco-friendly but also cost-effective. Further information.

- **BTL (Biomass To Liquid)**

Technology

BTL is a high-quality paraffinic diesel similar to HVO and GTL. Like HVO, BTL is sometimes referred to as “renewable diesel”. It is produced through the gasification of biomass such as farmed or waste wood into a syngas (synthesis gas). This is then converted into diesel using the Fischer-Tropf process similar to GTL.

Performance

WTW CO_2eq emissions	BTL diesel from farmed wood and especially waste wood has the lowest WTW CO_2eq emissions of any type of biofuel. Emissions constitute just 10% of that emitted by palm oil HVO or FAME biodiesel.
NO_x, NMHC, PM	BTL can reduce local emissions of PM by around 30% and NO_x by around 10% compared to traditional diesel.
Cost considerations	No increase in the price of the vehicles, or in maintenance costs, however fuel supply may require financing. HVO from vegetable oils or waste can be produced with only marginal additional costs. Some sources state that BTL is considerably more expensive than FAME or HVO. Others claim that BTL processes have the potential to save substantially more GHG emissions than current biofuel options at comparable costs[16].
Other considerations	Certification of the product is important, since its quality may interfere with the engines and with operation costs.

Market development

Current global production of BTL could supply only a very limited proportion of EU diesel demand, so it currently remains a niche product and is not yet widely commercially available. Issues such as land and biomass resources, material collection, plant size, efficiency and costs may limit the application of process to make BTL fuel.

5.4. Bioethanol (E95)

Technology

Bioethanol (E95 or ED95) is a liquid fuel that can be used in a slightly-modified compression-ignition engine. This is different from the bioethanol used in light duty vehicles (E85). It is produced by the fermentation of starch, sugar and cellulose plants (such as corn, sugar beet, cassava or wheat, or cellulosic materials such as switchgrass and woodchips), and then used as a blend with, or as a direct substitute for petrol.

WTW CO_2eq emissions	The use of bioethanol holds substantial GHG emission reductions, due to the fact that few, if any, fossil fuel inputs are needed. CO_2eq emissions are highly dependent on feedstock used, as well as the by-products from the production process used. Ethanol from wheat straw produces the least emissions, with farmed and waste wood ethanol around double the amount. Ethanol produced from sugar cane, sugar beet, corn and wheat produce between double and five time the amount depending on the crop and the processing method. The Concawe report[14] indicates a saving of 68% in comparison to conventional diesel; the Best project[15] reports between 83-88% reductions. Technological developments may provide even better performance.
TTW NO_x, CO_2, CO, PM & NMHC	Few independent studies have been made into new ED95 buses but they have been able to go beyond Euro V to meet the Enhanced Environmentally Friendly Vehicle (EEV) emissions standard. It is anticipated that there will be a new Euro VI version launched, but this will depend on demand and the investment in type approval of the buses.
Cost considerations	Adaptation of engines required. Fuel cost is highly influenced by taxation policy.
Other considerations	Engine / Fuel Injection Equipment (FIE) must be recalibrated to allow for reduced calorific value of fuel.

[14] http://iet.jrc.ec.europa.eu/about-jec/sites/iet.jrc.ec.europa.eu.about-jec/files/documents/wtw3_wtw_report_eurformat.pdf WTW Analysis of Future Automotive Fuels and Powertrains in the European Context - EUCAR, CONCAWE and JRC

[15] http://www.best-europe.org/upload/BEST_documents/environment/Exhaust%20emission061129.pdf

	Bioethanol is biodegradable and less explosive and less poisonous than mineral oil fuels.

Market development

In other parts of the world, particularly Brazil, this type of fuel is widely used. In Europe, Scania is the only current supplier of bioethanol buses though other companies are considering entering the market. Some consider Bioethanol to offer amongst the best ways financially to reduce emissions, particularly given the large volume potential. However, this is strongly dependent on tax incentives. As all ethanol has several other applications some countries have been reluctant to give the same tax incentives for ethanol as for other low-carbon fuels and the fuel has hence proved to be too costly for European transport authorities without some form of tax relief. Sweden is an exception with a well developed and successful bioethanol market.

Practical experiences

- **Stockholm** has 25 years of experience with bioethanol buses (operating on E95 fuel) and currently has approximately 700 of them in their fleet. Stockholm is expanding their fleet of bioethanol buses in order to reach their target of 50% renewable fuels by 2015. Another 150 bioethanol buses are in operation in 7 other cities across Sweden. Further information: [A] [B].
- Local politicians in **La Spezia** are also keen to add more bioethanol buses to their local fleet of 3, but are concerned about fuel costs. There is no tax exemption for bioethanol in Italy, and fuel costs are about 70% higher as a result. According to a survey conducted after the BEST trial, drivers in La Spezia stated that the bioethanol vehicles were of sound quality, were comfortable and good to drive, but that the engine power was quite low due to the engine type and the fuel used. Further information.
- Although a fuel pump has already been installed, the **Madrid** bus operator EMT has decided not to expand its existing bioethanol bus fleet due to cost implications. In fact, all 5 buses have now had their modifications reversed. Further information.
- Spanish and Italian cities that have had successful trials with bioethanol still have large reservations due to significantly higher fuel cost implications. In Spain and Italy, Bioethanol does not enjoy the same tax incentives as biodiesel. Further information (p. 21-24).

6. Trolleybuses

Technology

Trolleybuses are electric buses that use overhead wires for the supply of electricity. Most modern trolleybuses have some Auxiliary Power Unit (APU) to allow some independent operation. The APU can consist of a smaller Diesel engine or a battery.

Trolleybuses offer the advantages of electric buses, without the problems related to the need for battery storage (reduced range, cost of battery replacement, placement of battery):

- Electric propulsion has a strong torque – which may be of advantage especially in hilly areas.
- The vibration of a Diesel engine is missing – extending the lifetime of electric buses in comparison to standard Diesel buses.
- Electric powertrains have fewer mechanical parts (in comparison to standard gearboxes).
- Electric brakes may recuperate energy - modern trolleybuses may be equipped with supercaps to increase the efficiency of the operation (recuperation).

There are hybrid versions of trolleybuses under development to operate on battery power for longer stretches, and then recharging when the bus is again attached to the overhead wires. This is seen as an option to reduce the impacts of the overhead wires but keeping the operational advantages of recharging the electric system in operation.

Further information on new generation trolleybuses: [A] [B] [C] [D].

Performance

WTW CO_2eq emissions	Trolleybuses can reduce GHG emissions by up to around 95%, provided the energy is from renewable energy sources. Even if the energy mix is mainly based on coal, trolleybuses still reduce GHGs by about 30% compared to diesel buses. They also use regenerative braking and thus generate energy savings of up to 25%.
NO_x, NMHC, PM, SO_x & CO	Trolleybuses produce no tailpipe emissions, but embedded emissions including carbon, nitrogen and sulphur oxides, depend on the proportion and type of fossil fuels used to generate electricity for the national grid.
Cost considerations	The authors of this report have not so far identified reliable and comparative data on cost considerations for trolleybuses, however the following points provide an indicative assessment: • A major cost consideration is whether an overhead wire system is already in place, and whether it requires modernisation. One estimate puts the cost of new overhead wire infrastructure at €1 mill. per km. • Operating costs are relatively low due to lower energy consumption costs in comparison to diesel fuel. Lower maintenance costs and a longer lifespan than diesel buses have also been highlighted.

	• These savings must be set against typically higher purchase costs.
Other considerations	One of the main advantages of electric buses is the low level of noise pollution. Cost effective performance depends strongly on driver behavior.

Market development

The technology has been used for over 100 years and currently there are more than 300 cities world-wide that operate trolleybuses. There are various suppliers of trolleybuses in Europe and all over the world – often in combination of a bus OEM with a supplier of the electric components. There are cities extending or even building new trolleybus systems.

The conductive recharging through overhead wires is a mature and robust technology, whereas inductive recharging for buses has rather reached a pilot test phase.

Practical experiences

IN USE:

- In 2012, the City of **Salzburg**, Austria purchased a new trolleybus and announced the €2.7 million extension of the trolleybus system to the surroundings of the City. This will allow three diesel buses to be taken off the road and save around €50,000 annually in operational costs including personnel, energy, vehicle maintenance and maintenance of the power generation facilities. It will also reduce CO_2 emissions by 200 tonnes per year along with PM and NO_x emissions. Salzburg's trolleybus network has an approximate length of 100 kilometres, with 86 trolleybuses and a daily capacity of 140,000 passengers. A survey showed that passengers widely accept trolleybuses and generally consider them more environmentally friendly, modern and quiet than diesel buses, contributing to a more positive image of their City. Further information.
- In **Tallinn**, Estonia, trolleybus systems were introduced in 1965 and it currently operates eight routes. The City decided that it needed more flexibility than older generation trolleybuses, which depend entirely on overhead wires, can offer. They are therefore being replaced by alternative vehicles including CNG, hybrid and new generation trolleybuses, which can operate for short distances without electric contract. Transport company Tallinna Linnatranspordi uses 91 trolleybuses currently, 51 of which are new low-floor Solaris/Ganz T12 and T18 articulated models. Due to the fact that Tallin has found trolleybuses to be more than twice as expensive to purchase than standard buses, and that the network is costly to maintain, the City will now focus its efforts on acquiring CNG and hybrid buses. Further information.
- In **Gdynia**, Poland, conventional buses were retrofitted in late 2012 to provide the City with new low floor trolleybuses, replacing older models**.** Further information.
- In **Lausanne**, Switzerland, 27 new SwissTrolley4 buses have now been delivered, 22 of them were in service by December 2013. These models are replacing old generation two-axle trolleybuses and high floor trailers. Further information.

TRIALS AND DEMONSTRATIONS:

- In 2012, the bus operator Barnim in **Eberswalde**, Germany, introduced the first battery-hybrid trolleybus in Europe, as part of the TROLLEY project. The new vehicle differs from existing hybrid trolleybuses, in that it does not run on electricity and diesel, but on a lithium-battery and electricity from the catenary, meaning zero tailpipe emissions. Additionally, the bus can also run on supercapacitors, which constitute the third electric drive system of the bus. Test rides have shown that the trolleybus hybrid can run 18km only powered by the battery. In operation, the bus could run a wireless distance of 5km, which required a charging time of only 20 minutes. Further information: [A] [B].
- The first Exquicity trolleybus was introduced in public service in January 2014 **in Genève**, Switzerland by the transport operator TPG. The vehicle is entirely low-floor and has a capacity of 127 passengers, 41 seated and 86 standing. The cost of each bus is 29.4 million CHF (~€725,000). The first vehicle will now be tested extensively and a timetable is being made available to the public who which to try out the new trolleybus. Further information.
- New model Solaris/Skoda Electric Tr 27 trolleybuses have been trialled in **Plzen**, Czech republic since July 2013. **Sofia** Transport Authority has been testing the first of 50 such models they have ordered, since December 2013. The remaining buses will be delivered during 2014/2015 with a total cost of around €26.9 million. Further information.
- By late 2013, 20 Solaris trolleybuses were delivered to **Lublin**, Poland. Eight models are already operational and the remaining 12 will enter service in early 2014. This is the first time the City has used diesel engines to operate the trolleybuses away from the overhead wires. Further information.

7. Hybrids

A hybrid vehicle is one which uses two different energy sources. It is typically used to refer to *hybrid electric vehicles* (HEVs), which combine a conventional internal combustion engine with an electric motor. The batteries or supercapacitors which the electric motor uses are continually recharged by the engine or from energy generated during braking – energy that would otherwise be wasted as heat.

Although standard diesel is the most common fuel used to power the internal combustion engines, ethanol- and CNG-hybrids have also been developed.

“Plug-in hybrid electric vehicles (PHEVs) are now being developed in which the electric batteries can also be charged by being plugged in to the electricity grid. These are fitted with a larger battery which allows the vehicle to travel further in electric only mode.

‘**Hybrid assist’** kits involve fitting an energy storage device (a battery or capacitor) which is linked to the transmission via a drive belt or direct engine connection. **High speed flywheels** can be used to store additional energy and release to either supplement or replace the engine. The energy released is either mechanical – via a gearbox, or electrical, via the motor.

7.1. Diesel-hybrids

Technology

Types of hybrids include series hybrids, parallel hybrids, and blended hybrids. In a **series** hybrid there is no mechanical link between the engine and drive axle. The engine powers a generator that charges the battery pack (range extenders are small generators which charge the battery if its state of charge drops below a certain level). The battery pack drives an electric motor that turns the bus wheels via a conventional rear axle. In a **parallel** hybrid the engine powers the drive axle and a generator that can either charge the battery pack or directly drive the axle. **Blended** hybrids use a combination of the two types of drive systems.

Performance

WTW CO_2eq emissions	Emissions savings from diesel-electric vehicles vary according to what extent the electric motor is used. This is strongly dependent on the duty cycle, and affected by aspects such as the topography of the route, congestion and driver efficiency. Much higher savings can be achieved in urban environments due to frequent speed changes. 30% reductions in fuel use have been reported. A survey of members of the Hybrid User Forum in 2013 indicated a typical fuel consumption saving of 20% for 12m buses, 22% for double-deckers and 13% for 18m buses. These figures are a considerable improvement on 2011, where fuel consumption was found to be similar to conventional diesel.[16] Emissions can be further reduced by the replacement of conventional diesel with biodiesel.
NO_x, NMHC, PM	Reductions in local emissions are directly linked to reduced diesel consumption, so can be up to 30% lower.
Cost considerations	Currently hybrids remain significantly more expensive to buy than conventional diesel buses (typically 50% higher). The Hybrid User Forum indicated that maintenance costs for 12m and double-decker buses are similar to conventional diesel, whereas 18m buses can have slightly or significantly higher maintenance costs. Battery replacement can also lead to significant costs, however sufficient warranties on batteries can help mitigate this risk. No special infrastructure required.
Other considerations	It is generally agreed that noise emissions from diesel-electric hybrids are up to around 3 decibels lower than conventional buses.

[16] http://hybriduserforum.eu

Market development

Diesel-electric hybrids are commercially available having been trialled and used for 10-15 years in some European countries. New models are still being developed by a range of manufacturers and are continually becoming cheaper. There are different reports as to the current % availability of buses diesel-electric buses, ranging from very high in London and Rotterdam to between 70 – 83% reported by MVG in Munich. 12m single and double decker vehicles with longer established technology seem to be currently performing better than 18m buses using newer technologies, according to the European Hybrid User Forum.

Practical experiences

IN-USE:

- Since first trialling hybrids in 2006, Transport for **London** (TfL) now has over 650 hybrid buses in the London fleet including 113 'New bus for London' diesel-electric vehicles, a result of all the knowledge gained previously by TfL and the manufacturers they work with. TfL plan to have over 1700 hybrid vehicles in their fleet by 2016, with 600 of these being the 'New Bus For London'. These buses have the same proportion of availability as standard diesel buses. Clean Fleets Case Study.
- In **Helsinki**, there are a few hybrid buses already in operation and the City plans to buy more due to benefits of lower CO_2, NO_x and PM 2.5 emissions. Further information.
- The City of **Hannover's** fleet operator ÜSTRA first tested the Urbino hybrid bus in 2008. The City experienced a successful operating phase of ten hybrid buses between 2011 and 2013, therefore ÜSTRA subsequently purchased an additional 9 Solaris Urbino 18m articulated buses with an Allison H 50 EP™ (parallel diesel) hybrid system. Hannover has made a commitment to continue focusing on hybrid buses in the near future due to its positive experience with the technology in terms of reliability, fuel-efficiency, quick acceleration time, smooth slow down and quiet operation. The latter has been very well received by passengers and residents. During stop and go runs, reductions in fuel consumption, emissions and noise pollution are significant, as is recovered braking energy. Further information
- **Dordrecht** is the first city with an entire local bus fleet of hybrids, composed of 12 m Volvo Diesel-electric hybrid buses. The hybrid bus project was made possible through a joint venture between the province Zuid Holland and the bus operator Arriva NL. After the initial introduction of one trial bus in early 2011, the City of Dordrecht now operates its entire city bus fleet which amounts to 27 vehicles with Volvo (7700 B5 LH) hybrid buses. The average fuel usage of a Volvo Hybrid has been shown to be around 13-17% lower than its DAF and Mercedes Benz counterparts. Drivers have reported that the buses are user-friendly, comfortable and reliable. There have been some reported issues with cooling, exhaust pipes and vibration and noise in the passenger compartment and high maintenance costs. Further information: [A] [B].
- The EU-funded RTD project "Hybrid Commercial Vehicle" has a goal of a 30% reduction in fuel consumption compared to standard diesel vehicles and a decrease in the costs of a hybrid system. The stop-and-go drive-cycle of urban buses is a good starting point for hybrids with recuperating brake energy technology. The HCV project established the independent "Hybrid User Forum" to obtain direct, ongoing feedback on

the acceptance of hybrid HDVs by operators, drivers and passengers. Its membership represents a total of 62,000 buses on the road in Europe, including over a thousand hybrids. The 2013 User survey among the members of the Hybrid User Forum shows maturing technology in 12m and double-decker buses and some low level of user satisfaction with the existing 18 m hybrid buses. Further information [A] [B] [C] [D].

TRIALS AND DEMONSTRATIONS:

Current:

- **Reading** Transport has 31 diesel-electric hybrids in its fleet. These vehicles were purchased with the assistance of the UK Green Bus Fund as a demonstration project – a subsidy necessary to cover the higher purchase cost at that time. According to Reading Transport, although fuel costs are lower than conventional buses, this does not compensate for the higher purchase price over the lifecycle of the vehicle. In terms of availability, the operator says that there are usually 28 out of 31 buses operational on any given day, but that they do benefit from a lot of support from the manufacturers. Further information.
- The City **Rotterdam**´s transport operator (RET) own two diesel electric Mercedes Citaro buses. RET has adapted the infrastructure of the depot for these buses and has trained mechanics for small repairs. The Mercedes models have proved to be very reliable with over 90% availability. Recent tests have shown that fuel savings are around 23% compared to a standard diesel model. RET is considering introducing more diesel-electric buses into their fleet but only if high availability is assured, they may lease the buses in order to transfer the responsibility for this. Further information (p. 20).
- As a result of COMPRO Program, **Nantes**, together with **Angers**, launched a trial with diesel-electric hybrid buses. 3 such vehicles are currently under testing in Nantes, along with 2 in Angers. Performance is said to be very good so far.
- In **Bremen**, various diesel-electric hybrid buses have been tested since 1998 – mainly 18 m articulated ones. Recently trialled diesel electric buses did not fulfil the expectation in terms of reduction fuel consumption and of availability. Especially in winter times, the electric heating consumed much of the savings of recuperating.
- In general the evaluation from **Munich** shows that the promised reduction targets for diesel consumption are only reached by the solo buses and performance of articulated buses is quite low in terms of diesel reduction.
- LVB in **Leipzig** had a similar experience to Munich, although the reduction rates for diesel fuel consumption are not as high as in Munich, even for solo buses. Leipzig also trained its drivers in eco-driving techniques for hybrid buses, which shows promising evaluation results so far with 5% savings registered on fuel consumption through optimised driving style. The training material for eco-driving of clean vehicles is part of the EACI STEER project ACTUATE. Further information.

Older:

- **Palencia** had a negative experience ten years ago when trialling a previous generation Mercedes diesel-electric prototype. However, the City has now decided to tender for new hybrid electric buses.
- The City of **Dublin** found that improvements in fuel economy of hybrid buses were not as high as expected and reliability of the vehicle was poor in comparison to diesel vehicles. However this was an early version of a hybrid double decker bus and Dublin Bus understands that recent models have improved in these areas. It the organisation's intention to try out further demonstrators to verify this.

Under consideration:

- **Freiburg**´s transport operator (VAG) considered purchasing a diesel-electric Mercedes bus in 2011. Due to the fact that the purchase price at that time was around twice that of a diesel bus, the company decided that the vehicle was too expensive to be of benefit. Subsidies were offered by Baden Wurttemberg if more than 10 diesel-electric vehicles were bought, but attempts at joint procurement across the region were unsuccessful.
- Diesel-electric hybrids were also considered by **Horarios do Funchal**, Portugal, in fact a tender for three buses and four minibuses was released in 2009. The offers did not meet the technical requirements of the authority and plans to buy such models were later abandoned as the technology was not considered appropriate for the steep topography of the area.

LESS MATURE TECHNOLOGIES

7.2. CNG- and Ethanol-electric hybrids

Technology

CNG hybrid buses operate in a similar way to diesel-electric hybrids, but use compressed natural gas or bioethanol rather than diesel to generate electricity to power the vehicle when stored electricity has been used. Environmental benefits of using diesel-electric hybrids can also be increased by replacing diesel with CNG, ethanol or biodiesel.

Market development

Some experimentation has been undertaken with alternative fuel electric hybrids, such as CNG and ethanol, but these are currently only in trial phase. Some CNG- and ethanol-electric hybrids have been trialled and used successfully but the market for these vehicles is not yet well developed.

Practical experiences

- **Barcelona** has introduced a prototype CNG electric hybrid bus to its city fleet, the outcome of a collaborative project between Transports Metropolitans de Barcelona (TMB) and Gas Natural Fenosa. Two electric motors were added onto an operational 12m Iveco bus for traction, along with ultracapacitors to store electricity and a system to recover energy from braking. The bus is therefore powered purely by the energy from the electric motors and only uses the natural gas engine as a generator of electricity when the ultracapacitors are empty. The results of this project were very positive and after testing and improvements, the hybrid vehicle saved up to 30% natural gas consumption and a similar proportion of emissions. Further information.

- **Lithuania** attempted to purchase CNG-electric hybrid buses in 2011, but the two bids that were received were rejected due to the inexperience of the providers with such vehicles.
- After conducting a trial with Scania hybrid electric-ethanol buses in 2011, **Stockholm** tested 6 of these models. They saved around 15 % fuel compared to a standard ethanol bus, however, they were used on rural routes. The City believes that inner city use would potentially have lead to further savings. The trial was said to work well, with only a few moderations required. The launch is still pending as there is very little interest both for hybrids and ED95. In fact the buses are in the garage waiting for the demand to rise.

7.3. Plug-in Hybrids

Technology

A plug-in hybrid electric vehicle (PHEV) is powered by a battery which can be charged from an external power source. It has an on board engine which can also recharge this battery. The key application of this is the ability to run in all electric most of the time but retain the range to complete any journey.

With very high fuel economy, 'plug-in' hybrids offer even greater emissions benefits than diesel hybrids depending on driving mode.[17] The amount the bus will run on electric only mode will be highly dependent upon route characteristics, charging frequency and vehicle & energy system configuration.

Performance

WTW CO_2eq emissions	These vehicles are being trialled at present, so these figures are preliminary; also emissions will be route specific and depend on how much the vehicle required the engine to be running. CO_2eq reduction is highly dependent upon recharging regime / frequency, and on whether renewable electricity is used. One report estimates a 75%-80% reduction (based on renewable electricity generation) and up to 90% by using biodiesel instead of standard diesel[2]. Optimum in urban and semi-urban routes.

[17] http://ec.europa.eu/environment/life/project/Projects/index.cfm?fuseaction=search.dspPage&n_proj_id=3977

NO_x, NMHC, PM, SO_x & CO	Reductions in local emissions are said to be substantial, more precise figures will result from further development and testing. There is the potential to run these vehicles in electric only mode through areas with poor air quality.
Cost considerations	Fuel consumption savings can be considerable (75%-80%). Due to the fact that the technology is still in development and the buses are not commercially available, purchase costs cannot be given accurately.
Other considerations	Less noise during electrical operation, especially during take offs from bus stops. Vehicle performance can be very much dependent on the driving conditions, environment and driving style of the driver.

Market development

Plug-in hybrids are a relatively new technology so further trials are required to test performance but they do have potential to reduce local emissions and noise levels in sensitive areas. Range and recharging speed still require further development.

One benefit of the technology is that buses can choose to run on electricity only, through certain areas such as zero emission zones, or those areas sensitive to noise pollution. TfL is interested in understanding more about 'geofencing' and potentially using range-extended hybrids to operate in EV mode in hotspots.

This technology could witness accelerated development if trials (including in London) prove successful as the flexibility of a hybrid offers huge operational benefits. Wireless recharging adds additional capability and improves grid energy utilisation. An optimum future solution could be a plug-in hybrid combined with a renewable fuel.

Practical experiences

TRIALS AND DEMONSTRATIONS:

- **Umeå** had one Hybricon bus in operation for 2 years connecting the city centre with the airport. Experiences with this vehicle were good, however the cost was high. Further information.
- The City **Rotterdam**´s transport operator (RET) is trialling NEMS VDL buses, plug-in electric buses with range extenders. The infrastructure of RET's depot has been adapted for these buses and mechanics have been trained for small repairs. The first goal of this pilot with the prototype e-Busz was to test the energy saving potential. During a trial, the company encountered software and mechanical problems with these models. After evaluation and consultation with the RET, these buses are now being improved and upgraded by e-Traction to meet the operational uptime. The e-Busz Plug-In Hybrid concept is a very flexible since it can drive significant distance (about

80km range) in pure electric mode which is important in zero emission zones, but can also drive more or less continuously and longer distances thanks to its diesel-electric range extender. Depending on the driving mode the total energy consumption reduction of the bus is a minimum of 25% to over 50% compared to a diesel bus. Further information.

- The Life+ funded project HyperBus project is enabling a demonstration of Volvo's new plug-in hybrid vehicles on existing public bus routes in the cities of Gothenburg and Stockholm. The project runs until 2014 and has involved the participation of technology developers, manufacturers, energy providers, public transport operators and relevant authorities. At the time of writing this project had not produced any results. Further information [A] [B]
- In May 2013 **Gothenburg** are field testing these plug-in models. Gothenburg's Public Transport company has high environmental targets; by 2025 95% of their fleet is to be non-fossil fuel powered and the aim is also that energy efficiency will increase. Further information.
- **Stockholm** will start a new trial with eight plug-in buses in August 2014 as part of the Zero Emission Urban Bus System (ZeEUS) demonstration project. They will be charged at the end stations. Other cities involved in this project aiming at extending fully electric solutions to the wider urban bus network include Barcelona, Bonn, Glasgow, London, Münster, Plzen and Rome. Further information: [A] [B]

8. Fully Electric Buses

Technology

Electric vehicles (EVs) that are powered solely by a rechargeable battery are known as either full electric, all electric, pure electric or battery electric vehicles (BEVs). Buses using this technology have no need for an internal combustion engine as they rely entirely on powerful batteries to run an electric motor. Some buses, known as opportunity electric buses, are charged en route either at charge points throughout the bus circuit or at first and final stops. Others have their batteries recharged overnight and are therefore known as overnight electric buses. Another charging regime is to combine the two by charging the vehicle overnight and topping up the battery when the vehicle is operating. Route flexibility is dependent on recharging infrastructure.

Performance

WTW CO_2eq	Emissions savings from BEVs are dependent on how the electricity is generated. The grid mix across Europe varies and the emissions savings will be almost 100% if renewable sources of electricity are used. It has been estimated that even with CO_2eq intensive electricity generation the savings will be at least 30%.
NO_x, NMHC, PM, SO_x & CO	Full electric buses produce no tailpipe emissions, which means no local pollutatns. Embedded emissions including carbon, nitrogen and sulphur oxides,

	depend on the proportion and type of fossil fuels used to generate electricity for the national grid.
Cost considerations	These vehicles are still not widely commercially available so precise figures for acquisition cannot be given. The Low CVP report[2] estimates costs of €5000 more than traditional diesel buses for maintenance plus around €100,000 extra for infrastructure. The City of Vila Nova de Gaia, for example, paid around €500,000 to purchase the Cobus 2500EL. The batteries may need to be replaced at some point, probable after 8-12 years of use. Costs and risks related to batteries could be spread and/or minimised by leasing the batteries separately. Although initial investments will be high, BEVs provide the benefit of savings in fuel costs and potentially less maintenance requirements, as there are fewer moving parts.
Other considerations	These buses are less flexible as they will be designed to run on a specific route according to recharging regime. With some systems, delays on busy lines could cause problems due to the charging regime. Recharging could be an issue for smaller fleets or longer bus lines, but there are many other parameters that may influence this. EVs are suitable for operating in urban areas with stop/start operation.

It may not be possible to replace an entire fleet of city buses with BEVs because they may not be suitable for some routes.

Market Development

Battery electric vehicles have only become commercially available very recently, but it is estimated that it will become a mature technology by around 2015. It is one of the best options in the medium term for zero tailpipe emissions. For wider adoption the range of these vehicles needs to improve and/or the costs of fast charging facilities must decrease.

Practical experiences

IN USE:

- The City of **Vienna** has purchased a fleet of 12 electric microbuses, whose batteries are charged by pre-existing overhead power lines for trams, using a pantograph (extendable arm) on top of the bus. The bus has a range of up to 150 km, a top speed of 62km/h and a capacity of 30 passengers. The total energy demand is supplied by the entrained battery system including heating and air conditioning. The main advantages compared to diesel or gas buses are regarding energy demand, which is about 60% lower, low maintenance costs, low noise emissions and zero tailpipe emissions. At night, the batteries in the bus depot are slowly charged with 15kw. The battery capacity is 96 kw/ h. Clean Fleets case study.

- In July 2014, 35 buses will enter service at **Amsterdam**'s Schipol airport, making it the largest all electric fleet in Europe. Further information.

TRIALS AND DEMONSTRATIONS:

Current:

- In 2011, the City of **Vila Nova de Gaia** (Portugal) started commercial testing of a full electric 25 seat (total capacity 67) Caetano Bus (Cobus 2500 EL). The bus was shown to run for between 100 and 150 km without charging, equivalent to around 8-10 hours. Recharging the batteries of the bus from 10% to 90% SOC (state of charge) took less than 3 hours. After the positive experience in the testing period in Gaia, as well as in the German cities of Offenbach and Wiesbaden, the Cobus EL 2500 is now certified to run on regular roads and ready for market and series production. Further information: [A] [B] [C].
- In 2011, the City of **Umeå** in Sweden tested fully electric buses on standard routes, with very good results. Assumptions were made that this technology would be profitable with a diesel price of over 2€/l but BEVs were found to be profitable even below this price. Due to the fact that there is a pure wind and hydro plant power in Umeå, buses can run fully on clean energy, well-to-wheel. The buses use LTO-batteries that can be charged for 1 hour drive in 6 minutes. Hybricon provides the city with the whole system, including charging stations. The City of Umeå has a startup plan for up to ten 12m buses and 20 articulated 18m buses. Further information [A] [B].
- In 2013, **Bremen**'s public transport company (BSAG) tested an 8m electric bus from the manufacturer Siemens / Rampini, which it borrowed from the City of Vienna (see information above). The bus does not generate direct or indirect CO_2 emissions, because it is charged in Bremen with electricity from renewable sources. Bremen is also undertaking a trial with three small battery electric buses, which are charged overnight from the grid at the depot and a 12m BEV will also soon be trailled. It has been motivated to look into BEVs due to relatively high NO_x emissions and issues with noise pollution. Existing mechanics trained to repair electric components in trams have skills that are transferable for working on electric buses. Further information: [A] [B].
- The City of **Copenhagen**, which has a target to become a zero carbon city by 2025, is undertaking a two-year trial with two full-size (12m) all electric buses. We have acquired 62 vehicles ourselves. Our objective is that by 2015, 85 per cent of the municipality's own vehicles should be electric, hydrogen or hybrid powered. Currently, 15% of the municipal vehicles are EVs. Furthermore, the infrastructure for the municipal EVs is under development. Technical specifications have been determined, and by the end of 2012, a contract will have been signed with one or more suppliers of charging posts for the City's own fleet. Further information: [A] [B] [C] [D].
- London has begun trials of pure electric buses, starting in 2013 with two BYD 12m buses operating on two routes. This year they are being joined by four Optare pure electric single deck buses likely to be operating in Hounslow. Further information: [A] [B]

Considered:

- Electric rechargeable buses are expected in **Nantes** in the near future.

- **Hannover's** Fleet operator ÜSTRA is planning a fully electric bus project. Further information.

9. Hydrogen fuel buses

Technology

Some buses are powered by hydrogen whereas others exist as hydrogen hybrid vehicles. Hydrogen can be used in a converted petrol engine or to power a 'fuel cell', which acts rather like a battery.

Hydrogen fuel can be produced by reforming steam from natural gas, by breaking down a hydrocarbon source (such as natural gas, fossil fuels or ethanol) or by the electrolysis of water. Electrolysis powered by renewable or low carbon energy sources (such as nuclear) offers significantly higher WTW CO_2eq savings than steam reformation or electrolysis powered by conventional energy. At this stage of market development however, it may be worth postponing a deeper analysis of the implications of hydrogen production methods. Vehicles using hydrogen as fuel can also exist as hybrid vehicles.

A hydrogen fuel cell combines hydrogen with oxygen, producing water. This process generates electricity, which powers the electric motor that drives the vehicle. The only emission from a fuel cell bus is water, which forms a vapour cloud as it leaves the exhaust and enters the atmosphere.

Performance

WTW CO_2eq emissions	These vehicles do have a high potential to reduce GHG emissions, but this strongly depends on hydrogen production methods and WTW savings therefore vary hugely. Total CO_2eq emissions can even be higher than with petrol or diesel fuels if non-renewable energy is used in the production process. Hydrogen from non-fossil sources (biomass, wind, nuclear) offers low overall GHG emissions but hydrogen produced through electrolysis using current EU-mix electricity results in higher GHG emissions than producing hydrogen directly from natural gas. If hydrogen is produced from natural gas: • WTW GHG emissions savings can only be achieved if hydrogen is used in fuel cell vehicles. • The WTW energy use / GHG emissions are higher for hydrogen ICE vehicles than for conventional and CNG vehicles[2].
NO_x, NMHC, PM, SO_x & CO	Zero tailpipe emissions mean the local air quality is not affected although WTW emissions of e.g. NO_x and SO_x will depend on the hydrogen production process.
Cost considerations	These vehicles are still in trial and demonstration phase, therefore have extremely low production numbers which means costs are currently

	significantly higher than conventional buses. Maintenance is also said to be considerably higher. Requires hydrogen filling stations to be installed at bus depots.
Other considerations	Hydrogen fuel cell buses have shown very good performance during trials and have high route flexibility, comparable to diesel buses. Cost premiums and lack of infrastructure are proving to be a barrier to most at this stage and there are some reports of problems with the current range of the vehicles, practical difficulties of storing fuels, planning issues with storage facilities and the availability of fuel. Legislation on the use of Hydrogen as a fuel is immature, with much of it based on the industrial use of Hydrogen. Due to the risk of explosion, Hydrogen buses are not allowed to be used indoors, in garages or underground and even long tunnels in some cases. A possible solution would be to use biomethanol and convert it to hydrogen only when it is used.

Market development

Hydrogen ICE vehicles will be available in the near-term at a lower cost than fuel cells. On-board reformers could offer the opportunity to establish fuel cell vehicle technology with the existing fuel distribution infrastructure. However, indirect hydrogen through on-board autothermal reformers offers little GHG benefit compared to advanced conventional powertrains or hybrids.

If hydrogen production methods do use renewable energy, fuel cell buses are considered to be one of the most promising zero local emission technologies in the longer term. Taking into account the current methods of hydrogen production, Transport for London (TfL) predicts that overall fuel cell vehicles produce 50% less CO_2 than a diesel vehicle. Currently the most economical source of hydrogen is from steam-methane reforming using natural gas. In the short term at least, natural gas is the only viable source of large scale hydrogen. These vehicles will depend on fossil fuels until hydrogen is more commonly used and it becomes viable to produce and distribute hydrogen in larger quantities. Significant changes are already taking place, with increasing proportions of renewable electricity available in some countries. If hydrogen is increasingly required for energy storage, the cost of renewable hydrogen may be driven down to competitive levels over the next 5-10 years. However, some sources say that renewable sources of hydrogen still have a limited potential.

More efficient use of renewables may be achieved through direct use as electricity rather than road fuels applications[2].

Practical experiences

- In the context of CHIC, the Clean Hydrogen in European Cities project, **Oslo** has introduced 5 hydrogen buses (13 meter). This was made possible through a close collaboration of international companies within this project. A newly installed hydrogen fuelling station has been fulfilling the city's increased demand for hydrogen. Oslo's bus drivers report that the passengers show high interest in the new buses and were positive about the low noise levels they produced. Further information.

- In **Cologne** the local chemical industry produces hydrogen as a by-product, which RVK uses as a cheap means to power buses. This pioneering project was made possible by the close collaboration between cross-national political actors, local authorities, research institutes and businesses, including HyCologne. These organisations had the shared aim of reducing noise and polluting emissions through the use of hydrogen fuel. In 2009 APTS (Advanced Public Transport Systems) started the production of the RVK's first fuel cell-hybrid bus, which was introduced in 2011. Further information: [A] [B] [C] [D].
- Following a series of European trial projects (see below) **London** has operated one of its entire routes on eight hydrogen fuel cell buses since 2011 and a refuelling station has been built in the City. Despite the fact that hydrogen buses are expensive, TfL decided to purchase the vehicles, thus gearing hydrogen buses towards commercialization and making them more affordable for future purchasers. The three main objectives of TfL's project were to reduce CO_2 emissions, to improve air quality and to reduce noise pollution as the hydrogen buses are quieter than their diesel powered predecessors. Further information: [A] [B].

Hydrogen fuel cell buses:

TRIALS AND DEMONSTARTIONS:

- Between 2003 and 2007, nine European cities took part in the Cleaner Urban Transport for Europe (CUTE) trial to reduce air pollution and noise by testing the first generation of zero-emission fuel cell buses. Mercedes Citaro buses were used, which were built by Daimler Chrysler. The result was that the bus used more than twice the energy of diesel buses and Hydrogen conversion had a low efficiency. GHG performance was very poor but these results cannot be considered relevant today as these trials were conducted on an older generation of hydrogen bus to those available now. The CUTE study ended in December 2005, but seven cities including **Amsterdam**, **Barcelona**, **Hamburg**, **London**, **Luxembourg**, **Madrid** and **Reykjavik** took part in a one-year extension trial as part of HyFLEET: CUTE. Further information.
- A further project named CHIC with similar aims began when HyFLEET:CUTE ended. The project involves integrating 26 FCH buses in daily public transport operations and bus routes in five locations across Europe - **Aargau** (Switzerland), **Bolzano/Bozen** (Italy), **London, Milan**, and **Oslo**. Daimler developed a new generation of hydrogen buses for this new project, based on the ones tested in these cities. In London a hydrogen fuelling station was built at the bus depot. Further information.
- Mercedes have also successfully trialled hydrogen fuel cell buses in **Rotterdam** and the technology is now being considered by the City's bus operator (RET). Further information.
- **Arnhem** is also experimenting with hydrogen buses. Further information: [A] [B].

Hybrid hydrogen buses:

TRIALS AND DEMONSTRATIONS:

- **Oslo** bought 5 Van Hool hybrid fuel cell buses in 2012 as part of a project which began 17 years ago. The 5 buses are now being used every day on the roads of the Norwegian capital as part of a European hydrogen bus demonstration project. The hydrogen bus is now ready for market and the Dutch Hymove has developed a prototype with in-wheel motors. Further information: [A] [B].
- In 2012, **Hamburg's** public transport company HOCHBAHN purchased aCitaro FuelCELL-Hybrid bus, which uses regenerative braking. The model was shown to emit low levels of noise and to be 8-10 kg/100km more energy-efficient than its diesel predecessors. It is the first of seven fuel cell-hybrid model buses to be introduced by HOCHBAHN. Further information.
- Diesel-Hydrogen hybrids have been tested extensively in the Port of **Antwerp** for the last 3 years using similar engine types to diesel Buses. 31 Straddle carriers have been fitted with a retrofit on board H_2 system which uses spare kinetic energy, to generate H_2 on demand, which creates improved combustion efficiency and converts normally wasted hydrocarbons into additional energy at the point of combustion, which helps to reduce fuel consumption. Further information.
- **Cologne**'s regional public transport company put two 'local zero-emission' hybrid electric hydrogen fuel cell buses into operation in 2011, which will run in regular service for 5 years. The bus model, which can run up to 300km on 40kg hydrogen, was developed by a Dutch-German consortium under the leadership of the Düsseldorf based company Vossloh Kiepe and the Dutch-based bus manufacturer APTS. The Hydrogen used is a by-product of the chemical industry which is located in the vicinity of Cologne. Further information: [A] [B].
- **Amsterdam** are trialling a further two models of the above mentioned hybrid electric hydrogen fuel cell buses. Further information.

10. Buses with standard combustion engines

Significant improvements can be made by updating the bus fleet with newer models. For those public authorities or transport operators that lack the resources to purchase, trial and/or develop infrastructure for innovative bus technologies. Those public authorities that are engaged with innovative bus technologies should also consider the rest of their fleet.

Emissions of motor vehicles are controlled by EC legislation stipulating which 'Euro standard' new models must meet. These cover NO_x, THC, NMHC, CO and PM – they do not cover CO_2 emissions. Since January 2013, heavy duty vehicles have had to conform to the Euro VI emissions standard under Regulation (EC) No. 595/2009. Amongst other factors, this establishes common technical requirements for the type-approval of heavy duty vehicles, engines and replacement parts that have an effect on emissions. Euro standards have been made progressively more stringent every few years in order to ensure continuous improvements within the manufacturing industry.

Previous legislation which set out the Euro IV and Euro V emissions standards (Directive 2005/55/EC) also defined a non-binding standard called Enhanced Environmentally-friendly Vehicle (EEV). This standard went further than the Euro V standard, especially in terms of limits on NO_x emissions and was therefore seen as a step closer to Euro VI compliance before it came into force.

Experiences:

- **Bremen** wanted to go a step further than Euro V emissions standards before they came into force and realised the cost was only 1-2% higher than that of EURO IV vehicles. The buses are equipped with closed particulate filters and SCRT-technology to reduce the PM10 and NO_x emissions. The only extra requirement was for diesel exhaust fluid (AdBlue) to be used. Bremen began testing EEVs in 2006 and now almost the entire bus fleet meets this emissions standard. The contract that the municipality has with Bremen's public transport provider (BSAG) stipulates that buses should meet at least the EEV standard.
- **Freiburg** (VAG) have recently tendered for two Euro VI buses. The organisation stated that the buses it buys have to have an availability of nearly 100% as it is working within a very tight fleet management capacity and the available new technologies are not yet trusted to guarantee this kind of performance.
- Stakeholders from **Helsinki** commented that the Finnish Technological Institute (VTT) has monitored real time emissions from Euro VI buses, which are so new that there are no official test results yet. Results showed that these buses actually had higher NO_2 emissions than older Euro III buses, but that the total NO_x emissions were lower. Importantly, particulate matter (PM), considered to be the most harmful pollutant to human health, was also found to be significantly lower.

Clean Fleets – about the project

The Clean Fleets project (www.clean-fleets.eu) assists public authorities and fleet operators with the implementation of the Clean Vehicles Directive and the procurement or leasing of clean and energy-efficient vehicles.

Clean Fleets project partners

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