CiViTAS
Cleaner and better transport in cities

POLICY NOTE

Smart choices for cities

Clean buses for your city

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Preface

Thank you for reading the first policy analysis of the CIVITAS WIKI Policy Analyses series. The mission of the CIVITAS WIKI project is to provide information on clean urban transport and on the CIVITAS Initiative to EU city planners, decision-makers and citizens. With its policy documents WIKI wants to inform people in the cities on a number of topics that currently play an important role in urban mobility.

The first policy analysis focusses on the topic of clean buses. This is a hot topic because the introduction of clean buses is necessary in order to reach the EU air quality targets. This document gives in-depth background information to make a decision on which bus to choose.

Within the CIVITAS WIKI project in total eight policy analyses will be produced. Cities can suggest topics for research to the CIVITAS WIKI team. This can be done via the CIVITAS secretariat or using the CIVITAS thematic groups. So if you have a topic you want to know more about, please let us know!

We hope you enjoy reading.

The CIVITAS WIKI team

This publication was produced by the CIVITAS WIKI consortium. The policy note was compiled by Nina Nesterova (TNO, the Netherlands) and Ruud Verbeek (TNO). Special recognitions are to Janiek de Kruijff (TNO) and Marc Bolech (TNO) for their valuable contributions to the document and Tariq van Rooijen (TNO) and Cosimo Chiffi (TRT, Italy) for the review of the manuscript.

Summary

This policy analysis provides clear and in-depth information which will guide policy makers in European municipalities, public transport operators and other local decision makers in their choice of clean(er) public transport. First, it defines drivers and challenges that influence municipalities to look at 'cleaner' bus options. Second, for five main energy carriers available in the market today it identifies the available and most promising bus technologies. Third, it compares the most promising bus technologies with respect to operational characteristics, pollutants and GHG emissions, costs and maturity. Finally, it discusses how to take decisions on cost-efficiency of clean(er) public transport today, keeping in mind both EU short term 2020 and long term 2050 targets.

The main conclusions of the policy note with respect to the main bus technologies are as follows:

- Diesel buses are still the most economical buses with the lowest total cost of ownership (TCO). With the latest Euro VI engine technology, pollutants and GHG emissions are very low and comparable to Euro VI natural gas engines.

- Natural gas buses are readily available from the major manufacturers, but costs are higher and emission advantages over diesel have diminished with the introduction of Euro VI (diesel) technologies.

- Buses running on biofuels are more and more widespread. Their TCO is comparable to the TCO of diesel buses. Pollutant emission with biofuels (biodiesel, HVO, bio-methane, bio-ethanol) will depend on the particular type and blend of that biofuel, but with Euro VI engine technologies, the differences will most probably be very small. GHG emissions will most probably be lower for all biofuels, but this is quite dependent on the feedstock and the production process.

- Diesel hybrid and gas hybrid buses can reduce GHG and pollutant emissions by around 20%. Hybrid buses will have somewhat higher TCO as regular buses but this may diminish over time.

- Full electric buses are starting to become commercially available. Driving range and costs of batteries are still an issue. Where a trolleybus network exists, wider utilisation of these buses should be considered.

- Hydrogen fuel cell buses are considered a promising option, but are currently still in an experimental stage. Purchase costs for prototypes are very high.

- For both electric and hydrogen fuel cell buses high investment costs in infrastructure are necessary.

In the short term, introduction of clean(er) buses can contribute to the implementation of EU 2020 targets[1] in several ways. For diesel buses, high blends of first or second generation biodiesel can be used to increase the renewable energy share above the blending limit. For gas engines, biogas can be used to increase the renewable share (up to 100%). The application of hybrid drivelines with diesel or gas engines can further reduce GHG emissions by about 20%.

In the longer term and heading to the achievement of the EU 2050 target[2], full electric buses and possibly also H2 fuel cell buses show the most promise, thanks to their high energy efficiency and possible combination with renewable solar or wind energy. In this context it is important to start building experience in pilot series with 2035 and later technologies, because full development with competitive prices will take several decades.

Therefore, if financial resources allow, municipalities and public transport operators should aim for the zero emissions or options that come closest to it. Alternatively, especially within the current economic and financial crises, conventional diesel buses (Euro VI) and their hybrid configurations represent a good environmentally friendly option as well.

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1 EU Renewable Energy Directive (RED) target of 2020 is the use of 10% biofuels for transportation (on energy basis). The 2020 target of the EU Fuel Quality Directive (FQD) is 6% CO_2 reduction.

2 The EU 2050 target for transportation is a reduction of GHG emissions of around 60% compared to 1990.

Introduction

Local governments and decision-makers need to make sustainable and cost-efficient decisions that on one hand contribute to global, European Union (EU) and national goals and on the other hand fulfil the specific requirements of each individual city. This is often a challenging task. This policy note intends to facilitate the decision-making process of European municipalities on how to make their public transport fleet cleaner by providing information on available and most promising clean(er) bus fuels and technologies.

Global concerns about climate change, public health and energy security are translated into concrete sustainability targets on European level and on national levels. For cities (urban areas), air quality is generally more important than global warming. This means their first priority is the reduction of pollutant emissions such as NOx, NO_2 and particulates.

The EU is committed to reducing greenhouse gas (GHG) emissions, aiming at 20% emission reduction below 1990 levels by 2020 and 80-95% emission reduction for all sectors combined by 2050. The 2050 reduction target for transport is about 60%. Being the second biggest GHG emitting sector after energy (24.2% of total EU emission in 2010), transport receives special attention within emission reduction policies, with particular focus on the road transport. Urban transport is responsible for about a quarter of total CO_2 emissions from transport according to the 2011 European Commission (EC) White Paper on transport. By 2025 urban mobility is forecasted to double[3]. With the clear EU objectives to increase public transport[4] and introduce new CO_2 regulations for vehicles, European municipalities will face new challenges in making cost-efficient and environmentally friendly decisions.

Operating the whole day in a city, buses are the backbone of many European public transport systems. Even though far behind private cars, in 2011 buses and coaches covered 512 billion passenger-kms providing 7.8% of the passenger mobility in the EU. Almost 50% of the EU motor coaches, buses and trolley buses in the EU are more than 10 years old[5]. With a relatively low number of modern bus fleets corresponding to the Euro V standard, buses contribute significantly to local pollution.

Buses are still a part of the municipality fleet in a majority of EU Member States. By choosing a cleaner bus solution, local decision makers can contribute to the decarbonisation of urban transport and improve air quality in their cities. There are different ways to reduce emissions from buses. These include improving vehicle technology or powertrains, as well as considering alternative fuels to power vehicles.

This policy note focuses on the clean(er) energy sources for buses and on associated bus technologies. When selecting the most ideal energy source, local decision-makers are faced with different type of questions:

- What are the options available and which energy source/technology to choose for a bus?
- What are the advantages/disadvantages of the different options?
- What are the costs of these options?
- Which fuels require installation of additional infrastructure and what are the associated costs?

The objective of this Policy Note is to provide municipalities, local decision makers and public transport operators with information that can guide them in the initial choice of a clean(er) energy source and associated bus technology. In this policy note we first describe drivers and challenges that influence decisions related to purchasing a 'cleaner' bus. We than present and compare the main available clean energy sources and the most promising associated bus technologies. Comparison is usually made with a regular diesel single deck bus[6].

3 Mc Kinney, 2012

4 EC, "A Roadmap for moving to a competitive low carbon economy in 2050", COM (2011)112.

5 Eurostat

6 Ricardo, 2012: 12t, 9.7m length, capacity seats/standees 38/24; EURO V mission standard, tare weight 8.1 t

Drivers and challenges

Several drivers and challenges shape a municipality's decision to purchase a 'cleaner' bus fleet. On the global level, these include high-level EU commitments to reduce emissions, or more concretely the GHG emission reduction targets for Member States. Drivers and challenges also include public health concerns and related air quality issues, as well as the upcoming shortage of fossil fuels and the necessity to switch to alternative sources of energy. On the local level, in the context of ongoing economic crises, municipalities have to take cost-efficient decisions in distributing limited budgets which also comply with their own targets on air quality and noise reduction and that consider EU and national legislation with respect to bus fleets (e.g. Euro standards).

Policy measures

On the global level several EU policies encourage municipalities to look at the 'cleaner' choice for a local bus service.

First, the high-level EU commitments to reduce GHG emissions are translated to concrete targets on individual Member State level and for specific European sectors. The 2011 EC White Paper 'Roadmap to a Single European Transport Area – Towards a competitive and resource efficient transport system' aims to reduce transport GHG emissions by 60% in 2050 compared to 1990. As around 70% of transport-related GHG emissions are from road transport, the paper specifically aims for emission reduction of around 60%.

Second, the public health concerns and in particular the issue of air quality are still of major concern in Europe. The EC has policies in place limiting national totals of four major air pollutants and each Member State is further developing concrete policies in order to comply with EU legislation.

Third, addressing a growing concern of energy security and anticipating the potential shortage of fossil fuels, the EU established specific targets to reduce the dependence on oil, encouraging the use of renewable energy sources. In this respect, the Renewable energy Directive (2009) sets bidding targets for all EU Member States to achieve a 20% share of energy use from renewable sources by 2020, and in particular a 10% share of renewable energy use in the transport sector.

Finally, respecting the EU legislation on noise limits in metropolitan areas is also of a concern to municipalities.

Addressing these challenges requires enormous efforts such as the simultaneous implementation of sustainable policies in localities and regions. In order to achieve this (as well as other EU-specific goals on the city level, e.g. air quality, congestion, noise reduction), the EC has developed a set of strategies, policies and measures which present the general EU vision for the urban transport and provide a concrete legislative framework for its development (Box 1).

Air quality is addressed by regulations establishing pollutant emission limits for different types of vehicles. The established Euro standards (Table 1) define varying limits on carbon monoxide (CO), hydrocarbons (HC), nitrogen oxides (NO_x) and particulate matter (PM) tailpipe exhaust emissions from new road vehicle engines under specific vehicle condition. Different standard numbers refer to the limits required from vehicles introduced after specific dates. The new Regulation 595/2009 on type approval of motor vehicles and engines with respect to emissions from heavy duty vehicles (Euro VI) will be implemented from January 2014. This standard foresees a reduction of 80% in NO_x and 66% in PM emissions compared to the Euro V stage limits which entered into force in October 2008.

The standard means that as from January 2014 the Original Equipment Manufacturers (OEMs) have to produce buses which do not produce emissions more than those established by Euro VI emission level. For the municipalities the standard indicates the most environmentally and air-quality friendly pure diesel bus options available on the market. When buying a new bus fleet, municipalities can purchase Euro VI compliant buses or just upgrade their bus fleet with buses of a higher Euro standard.

Table 1. European standard for emissions from buses and heavy duty vehicles

Emission level and year of enforcement		Test procedure (operating conditions)	Carbon monoxide	Hydro-carbons	Non-methane hydrocarbons	Methane	Nitrogen oxides	Particulate matter
			CO (g/kWh)	HC (g/kWh)	NMHC (g/kWh)	CH4 (g/kWh)	NOx (g/kWh)	PM (g/kWh)
Euro VI	2014	steady states, WHSC	1.5	0.13	-	-	0.4	0.01
		transient, WHTC	4	-	0.16	0.5	0.46	0.01
Euro V	2008	steady states, ESC	1.5	0.46	-	-	2	0.02
		transient, ETC	4	-	0.55	1.1	2	0.03
Euro IV	2005	steady states, ESC	1.5	0.46	-	-	3.5	0.02
		transient, ETC	4	-	0.55	1.1	3.5	0.03
Euro III	2000	steady states, ESC	2.1	0.66	-	-	5	0.1
		transient, ETC	5.45	-	0.78	1.6	5	0.16
Euro II	1996	steady states, 13-mode	4	1.1	-	-	7	0.15
Euro I	1991	steady states, 13-mode	4.5	1.1	-	-	8	0.36
Euro 0	1988	steady states, 13 mode	11.2	2.4	-	-	14.4	-

Source: http://www.unece.org/index.php?id=28534

Box 1

Policies, strategies and measures providing a framework for the development of the clean(er) public transport in Europe

Policies, strategies and measures reflecting the vision on European urban mobility

- Green Paper 'Towards a new culture for urban mobility' (COM(2007) 551)
- Action Plan on Urban Mobility (COM (2009) 490)
- White Paper on Transport 'Roadmap to a Single European Transport Area – towards a competitive and resource efficient transport system' (COM (2011) 0144)
- Expected Urban Mobility Package (2013)

Policies, strategies and measures aiming to reduce GHG emissions and improve air quality

- The Ambient Air Quality Directives (Directives 96/62/EC ('Framework Directive') and four 'daughter directives' 1999/30/EC, 2000/69/EC 2002/3/EC, 2004/107/EC and Council Decision 97/101/EC).
- The National Emission Ceilings directive (Directive 2001/81/EC)
- The 2005 Thematic Strategy on Air pollution (COM(2005) 446)
- The EU Air Source Abatement Policy Framework
- New Air Quality Directive (Directive 2008/50/EC)
- Regulation 595/2009 on type-approval of motor vehicles and engines with respect to emissions from heavy duty vehicles (Euro VI)

Policies, strategies and measures aiming to reduce CO_2 emissions and to address energy security

- A Strategy for competitive, sustainable and secure energy (COM(2010) 639)
- Green Paper - Towards a secure, sustainable and competitive European energy network (COM(2008) 782)
- Action Plan for Energy Efficiency: Realising the Potential (COM(2006) 545)
- Directive on the promotion of the use of energy from renewable sources (Directive 2009/28/EC amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC) and proposal
- Renewable Energy Road Map. Renewable energies in the 21st century: building a more sustainable future' (COM(2006) 848)

Policies and strategies addressing noise levels in urban areas

- Directive 70/157/EEC193 concerning the permissible sound level and the exhaust system of motor vehicles (further amending Directive 2007/34/EC)
- Council Directive 97/24/EC194
- Commission green paper on future noise policy (COM(96)540)
- Directive 2001/43/EC
- Environmental Noise Directive (2002/49/EC)

Current market situation

Responding to the targets established on national levels the municipalities are taking different actions to improve their local bus fleet. As a result, already 11% of the European bus fleet is less than two years old, which means that they meet Euro V emission standard. Nonetheless, much more needs to be done as almost 50% of the fleet in 2011 was more than 10 years old, with buses belonging to the Euro III standard or lower (Figure 1).

As indicated in Figure 2 situation varies a lot per country.

Figure 1. Distribution of age of buses in EU-28, 2011

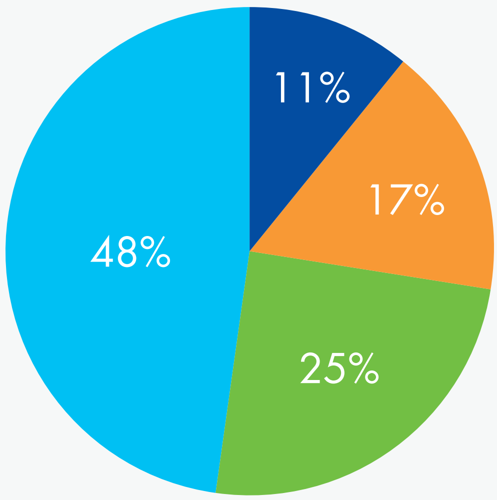
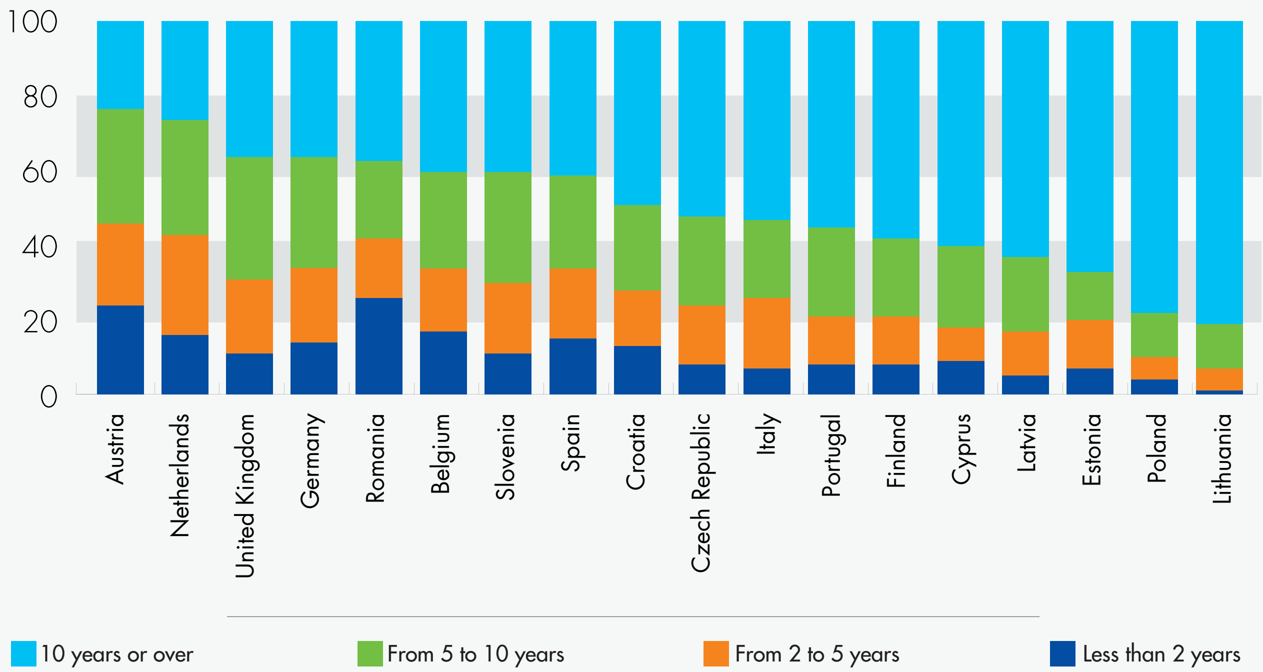


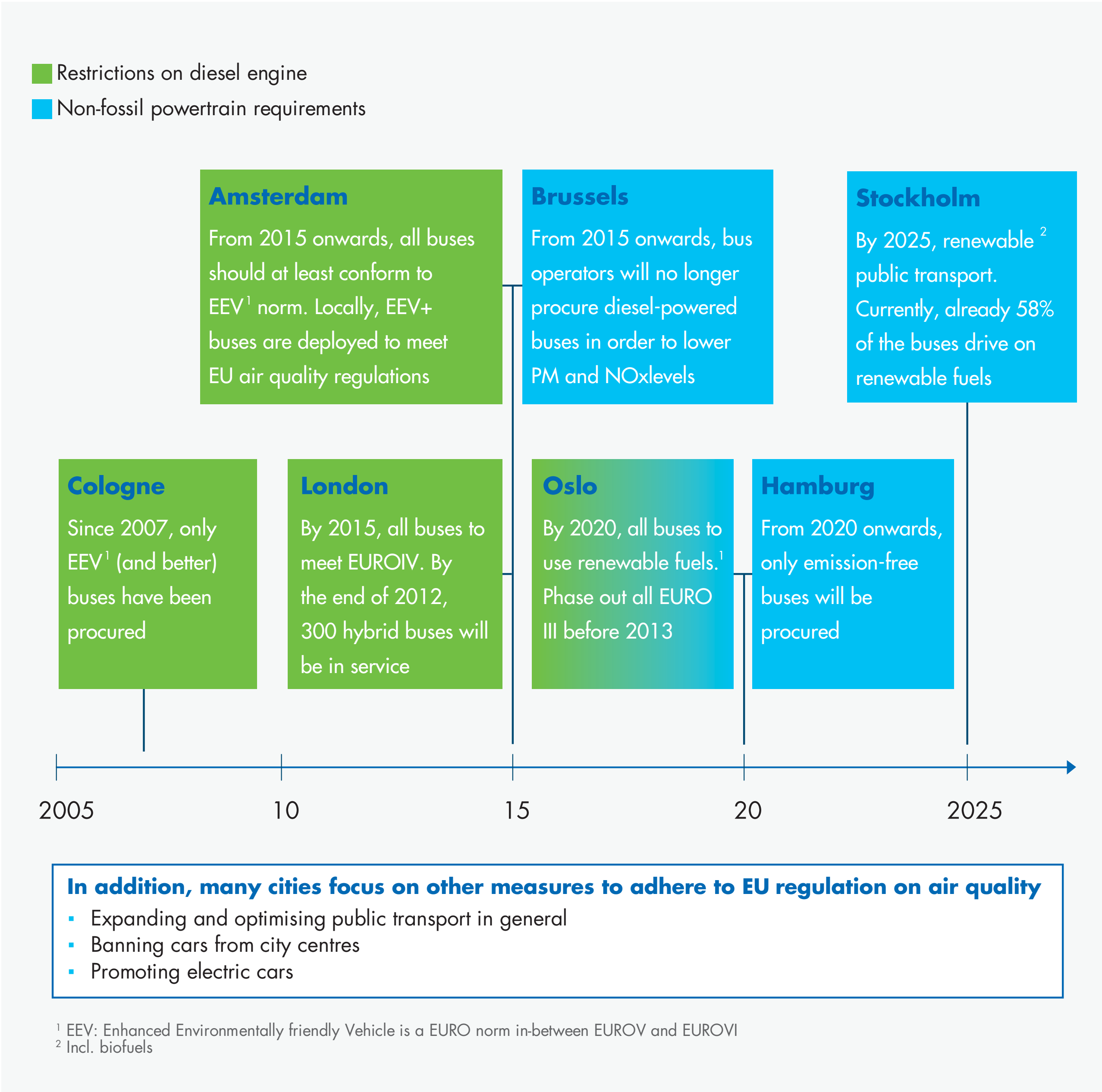
Figure 2. Distribution of age of buses in EU-28, per country, in percentages, 2011



Source: Eurostat

Some countries and cities are more advanced than others with respect to introducing cleaner bus fleets. As summarized by McKinsey (2012), 'a number of cities are already focused on cleaner public transport, while many bus operators are renewing their fleet or deploying low-emission powertrains'.

Figure 3. European cities focusing on clean powertrains for public transport



Source: McKinsey (2012)

There is still much potential for contributing to the decarbonisation of European road transport and addressing the issue of local air pollution by acting on urban buses. Introducing alternative powertrains or alternative fuels is one of the options already implemented by cities (Figure 3) and is addressed in this policy analysis.

Challenges in introducing the cleaner buses

Local decision makers are faced with a range of challenges when they introduce clean buses in municipality fleets.

First, there is a lack of information on available and most promising clean(er) bus options that could be implemented. What is a clean(er) bus and why? What type of alternative powertrain or energy carrier to choose and why? How to assess the 'cleanliness' of your own bus fleet?

Second, the purchase price of the most advanced technologies is very high, which can lead to higher exploitation costs. With the budget available, service level remains the same or possibly decreases and the price of public transport can rise, leading to a decrease in passenger flows. On some occasions, special funding from national and EU authorities (e.g. through CIVITAS programme) is available, bridging limited availability of local resources with the necessity to achieve EU 2020 targets. However, in all cases, local decision makers are expected to take the most cost-efficient solution. Should they buy the newest and cleanest bus, thus investing directly into the most environmentally and energy-efficient technology? Should they opt for second-hand buses which are cheaper but improve air quality and CO_2 emissions to a limited degree? Or should they invest in moderate energy-efficient bus options?

Third, if they switch from one bus technology to another, what additional infrastructure do they have to introduce?

Finally, they must consider innovations that could help public transport develop very fast and definitely faster than the life cycle of the buses. In this context it might be difficult and expensive for public authorities to keep up with the innovation. Due to the long tradition of diesel engines, diesel buses have a lot of advantages – the efficiency, maintenance and exploitation costs of the diesel bus are predictable. Many questions, however, still remain. What are the advantages of other bus technologies, taking into consideration that Euro VI technology bus is getting close by environmental standards to the buses running on alternative fuels? How can clean(er) buses address municipalities' other road transport concerns such as congestion, road transport safety and security?

This policy analysis aims to answer some of these questions.

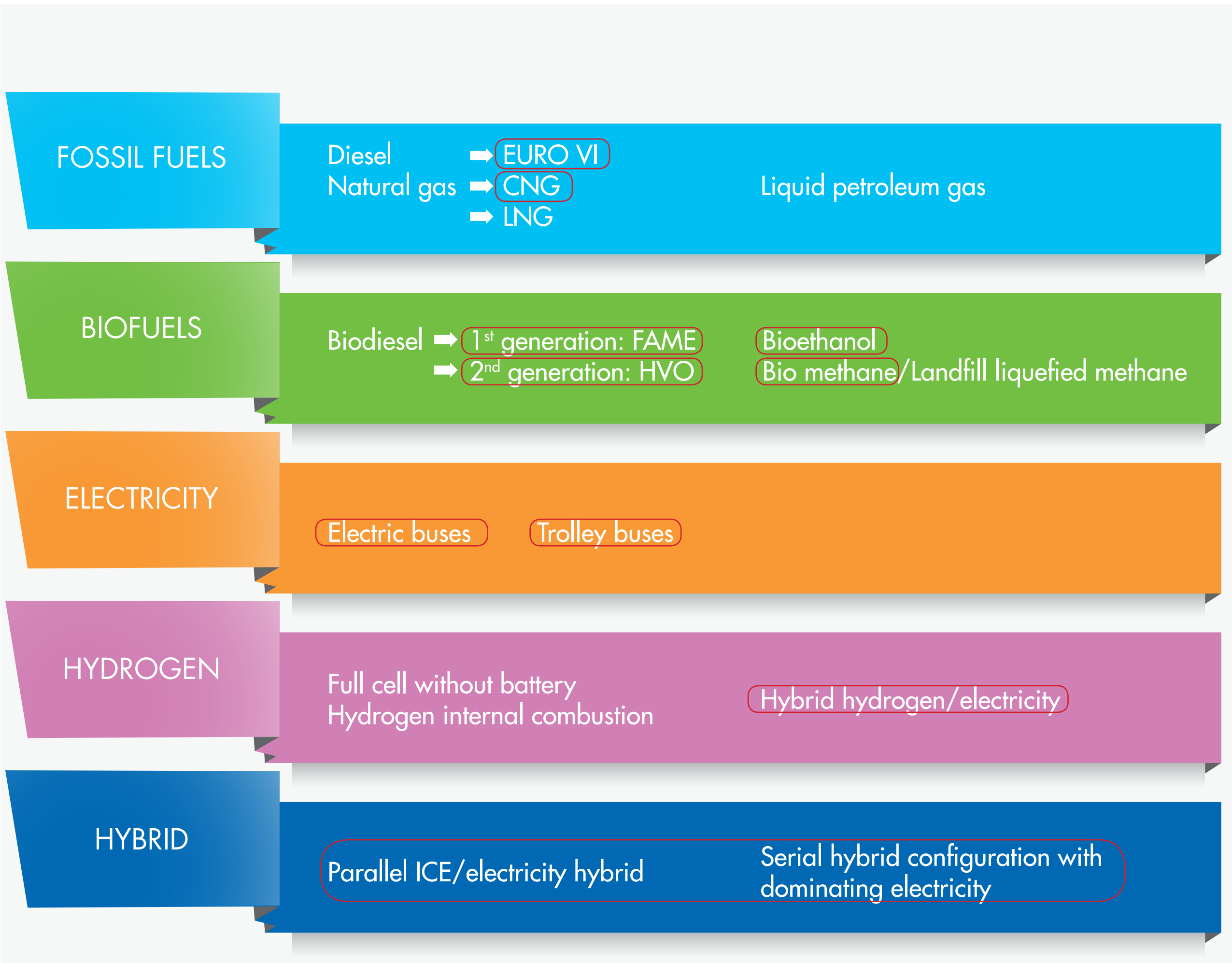
What are the clean(er) bus options?

Four main energy carriers are available for buses: fossil fuels, biofuels, electricity and hydrogen. For all these options different bus technologies exist, using one fuel or a combination of energy carriers (hybrid). Buses running on compressed natural gas (CNG), 2nd generation of biofuels, electricity and hybrid configurations combining electricity with hydrogen or diesel are considered as most promising from technological and environmental point of view. At the same time, with introduction of Euro VI emission standards for diesel buses, those technologies become as 'clean' as their alternatives.

Fossil fuels, biofuels, electricity, hydrogen and hybrid configurations are the energy carriers available for buses. For each energy carrier several bus technologies were tested by manufacturers, with some of them being more promising from the sustainability point of view than others (Figure 4).

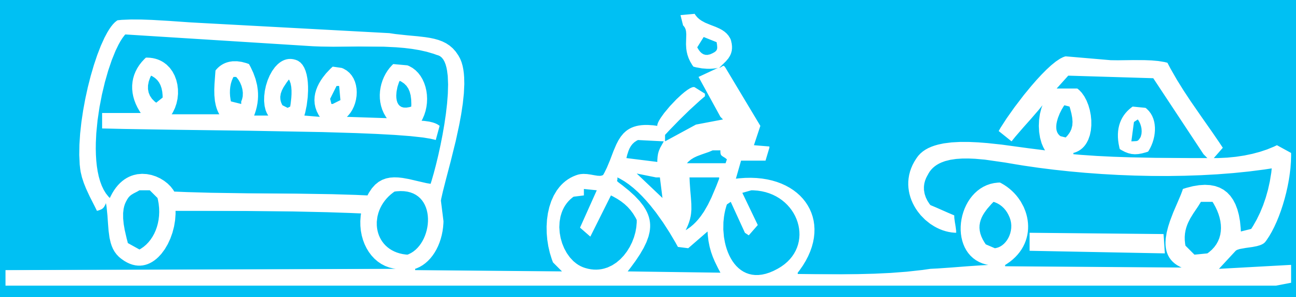
The next sections present detailed factsheets for all highlighted combinations of bus technology and energy carrier. As the technical maturity of these combinations varies significantly, projected data have been used in some instances (main sources are McKinsey (2012), Verbeek R (2013), TNO/CE Delft (2012)).

Figure 4. Possible and most promising bus technologies for different energy carriers



Source: TNO (in red circles are the most promising options)

FOSSIL FUELS



FOSSIL FUELS

Fossil fuels, which are non-renewable resources, are formed by natural processes and typically include coal, petroleum and natural gas. One of the main actual concerns related to them is that world reserves are being depleted much faster than new ones are being made. Another major concern is that from the burning of fossil fuels within vehicles, the highest amount of GHG gases is released to the air (in particular, CO_2) in comparison to other energy sources required to propel the vehicle.

With respect to fossil fuels, bus technologies can run on diesel, compressed natural gas (CNG), liquid natural gas (LNG) and liquid petroleum gas (LPG).

Using LPG for buses was popular some years ago, but proved to require very expensive investments in fuelling infrastructure. It also had a negative impact on engine durability, posing high safety concerns as well.

Although LNG buses have a very high operational range, the very high investment in fuelling infrastructure makes them a less attractive option for cities over buses running on CNG.

With introduction of Euro VI standard for vehicles, buses running on the regular diesel are becoming as clean emission-wise as those running on alternative sources, representing a promising for future option. Currently Euro V bus technology is on the market and is presented in the Factsheet below. Euro VI buses are highly comparable to Euro V buses in operational performance, infrastructure needs and costs yet differ for projected emissions.

Figure 5. Euro VI bus

Source: http://www.benzinsider.com/2012/09/mercedes-benz-citaro-euro-vi-takes-bus-of-the-year-2013-award

Euro V and Euro VI buses

Bus technology with conventional diesel combustion engine, running on regular diesel fuel and fulfilling Euro V and Euro VI emission standards for buses

Emissions

GHG	Measure	Euro V	Euro VI
CO_2eq	g/km	1000	1000
NOx	g/km	3,51	1,1
PM10	g/km	0.10	0.03

Thanks to expected improvements in bus driveline and body by 2020, CO_2 emissions from buses will be further reduced to 900 g/km.

Noise emissions: standing 80 dB; pass by 77 dB (McKinsey, 2012)

Operational performance

Range: 600-900km

High route flexibility

Good performance on acceleration

Energy consumption 2012: 4.13 kWh/km

Energy consumption 2030: 3.89 kWh/km

Refuelling needed every 2nd day

Short refilling time: 5-10 min

Infrastructure

High European coverage with refilling stations

Costs

- Indication of purchase price: +/- 220,000 euro per bus
- Indication of maintenance cost: 0.10 – 0.15 euro cent/km
- Vehicles can be sold with a market price available for the second-market.
- TCO[7] Euro V 2012: 2.1 euro/km
- TCO Euro VI 2030: 2.5 euro/km

7 All TCO figures further in the document combine McKinsey 2012 findings and TNO estimations. Total cost of ownership includes purchase, financing, running, infrastructure and emission costs.

Figure 6. Euro V Bus

Source: http://commons.wikimedia.org/wiki/File:GVB_1101.JPG

Factors to take into consideration

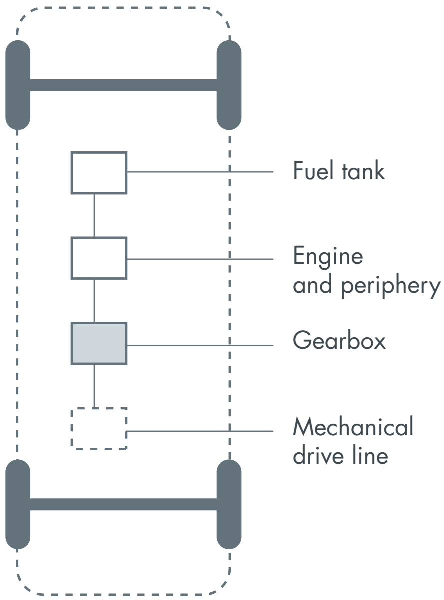
Diesel buses can produce less emissions by using a blend of diesel with biofuel.

CO_2 reduction can be achieved by improving the efficiency of the engine and by improvements in the 'soft side', like changing driving behaviour.

Main advantages: due to the long tradition of diesel engines the efficiency, maintenance and exploitation costs of diesel buses are predictable; filling infrastructure is in place; buses can be adapted for the usage of biofuels relatively easily.

Main disadvantage: within growing concern of diminishing fossil fuel resources in the long-term these buses might have to be adapted to use another energy source.

Diesel powertrain



Bus running on CNG

CNG buses run on the conventional CNG combustion engine. Gas is delivered by a standard gas distribution grid and is compressed to the required pressure to pump it into the vehicle. Conversion of regular diesel buses into CNG buses existed previously, but is no more advisable due to more strict emission standards for buses.

Emissions

GHG	Measure	CNG 2013	CNG 2020
CO2eq	g/km	1000	800 - 850
NOx	g/km	1.4-4.5	0.88
PM10	g/km	0.005-0.03	0.024

Noise emissions: standing: 78 dB; pass-by 78 dB

Operational performance

Range: 350 – 400 km

High route flexibility

Energy consumption 2012: 5.21 kWh/km

Energy consumption 2030: 5 kWh/km

Refilling every 2nd day

Short refilling time: 5-10 min

Infrastructure

Requires specific filling infrastructure (special pump and buffer tank for fast filling) or adaptation of existing filling infrastructure. Connection to the existing gas network is necessary, otherwise a specific CNG grid must be built.

Cost

- Indication of purchase price: +/- 250.000 euro per bus
- Indication of maintenance cost: 0.15 eurocents/km
- TCO 2012: 2.1 euro/km
- TCO 2030: 2.6 euro/km
  Maintenance necessary for period leak check activities.

Extra specific safety requirements can lead to extra costs ranging from 20k per CNG bus (e.g. fire detection systems, fire distinguishing systems).

Factors to take into consideration

The main difference between regular diesel bus and CNG bus is in terms of local pollutants. The scale of this benefit for CNG buses is decreasing, as diesel vehicles emit less and less local pollutants to satisfy EU emission standards (especially Euro VI). If biogas (e.g. biomethane) is used to power CNG buses, emissions will decrease.

Main advantages: CNG offers energy diversity benefits as it does not rely on oil. Gas refuelling systems can be transformed to hydrogen refuelling systems, so potentially could be a step between diesel and hydrogen.

Main disadvantage: Being a non-renewable source of energy the same concerns as diesel arise: the production of gas in Europe continues to decline.

High safety concerns exist because of possible gas leaks, rapid flammability of CNG and risk of fire.

In total 167 CNG buses were introduced to European cities by measures implemented in CIVITAS II and CIVITAS Plus projects. Main drivers to introduce CNG buses were necessity to upgrade old bus fleets and improvement of environmental image through environmentally friendlier vehicles. Lack of political support and national regulations not adapted to the implementation of CNG buses were reported by several cities as a barrier to implementation and introduction of the CNG bus fleet. Other barriers include difficulties in obtaining permission necessary for the construction of the CNG fuelling stations, technological challenges with some new and retrofitted CNG buses and no market confidence in this type of the fuel.

CNG powertrain

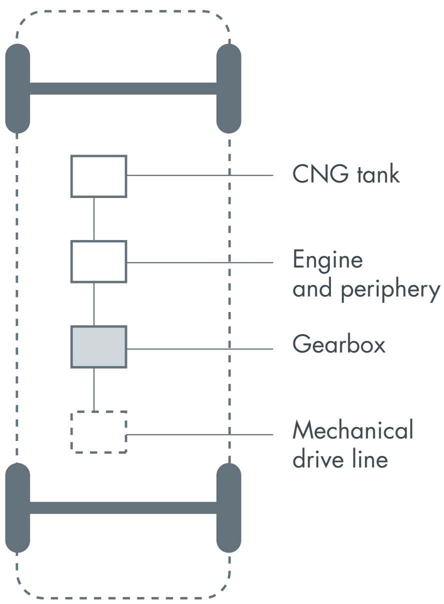


Figure 7. CNG Bus

Source: CIVITAS, Bologna

BIOFUELS

BIOFUELS

The generic term 'biofuels' is used to describe fuels derived from organic material. Different processes are available for the production of biofuel which explains the diversity of its form: biodiesel, bioethanol, biogas.

Box 2

'1st generation' biofuels are obtained by directly converted harvested biomass (e.g. sugar cane, wheat, palm oil). Being first introduced over 10 years ago, today the use of 1st generation biofuels is no more encouraged at EU level as production can have severe environmental and socioeconomic impacts. Most important is the impact on food prices and food security (as biomass is not being used for nutrition but for fuel production). Other impacts include effects on GHG, on quality, deforestation and biodiversity loss.

'2nd generation' biofuels exploit non-food crops and crop waste, and their sustainable production is supported by EU policies. The major problem with the 2nd generation biofuels is that they are not yet commercially available.

The quality of biofuels is also characterised by two generations. The 1st generation is cheaper but offers less quality, while the 2nd generation boasts a more sophisticated production process and is cleaner yet more expensive.

1st generation biodiesel (Fatty Acid Methyl Ester, or FAME) is one of the most used 1st generation biofuels to power the buses. Because of the unsustainable production it is not recommended for long-term use, but is still available as the production of 2nd generation biofuels is not yet widespread. Research, development and implementation today focusses on 2nd generation biofuels and in particular on HVO (Hydrotreating vegetable oil: advanced biodiesel made by treating vegetable oil or animal fat with hydrogen). Buses running on FAME and HVO are highly comparable in operational performance, infrastructure needs and costs, yet differ in projected emissions (see Factsheet: FAME/HVO buses).

Biomethane is used to fuel CNG buses, thus validating sustainable production of gas used to power CNG buses and improving overall environmental performance.

Whether used to power buses, private cars or any other vehicles, biofuels are almost always blended with conventional fuels.

Buses running on FAME/HVO

This bus technology uses biofuels to power the bus. When diesel buses are adjusted to use biofuels, each type and blend of biofuel requires specific minor motor modifications. Therefore buyers must have a clear initial understanding of what kind of biofuel or biofuel blend will be used in the specific bus.

Emissions

GHG	Measure	Euro V diesel	Euro V FAME 100	Euro V HVO100
CO2eq	g/km	1000	500 and more	500 and more
NOx	g/km	3,51	4.39	3.16
PM10	g/km	0.10	0.04	0.08

Emissions from biofuel buses depend on the feed stock used to produce the biofuel and on the biofuel blend used. For lower blends, emission benefits will be proportionally less.

Noise: liquid biofuels have no significant effect on noise.

Operational performance

Range: 570-850 km

High route flexibility

Good performance on acceleration

Energy consumption 2012: 4.13 kWh/ km

Energy consumption 2030: 3.89 kWh/ km

Refilling every 2nd day

Short refilling time: 5-10 min

Infrastructure

Same filling infrastructure as for diesel can be used: widespread presence of filling stations across Europe. In some cases a special tank for biofuels may be needed.

Costs

- Indication purchase price: +/- 220.000 euro/bus
- TCO FAME (B100) 2012: 2.22 euro/km
- TCO HVO (B100) 2012: 2.35 euro/km

Currently both HVO and FAME are more expensive than regular diesel fuel.

Things to take into consideration

EU targets to increase the share of renewable energy sources for transport combined with the targets to increase the use of sustainable biofuels requires higher usage of biofuels for transport. Only 7% blend of FAME with diesel is permitted according to fuel specifications. Higher blends of FAME are not supported by OEMs due to concerns over fuel quality and stability.

Very limited current supply of HVO: current HVO global production equates to only 1% of European diesel demand (produced by Nestle Oil in Finland, the Netherlands and Singapore). It is expected to remain a significant 'niche fuel' up to 2020 due to low supply volumes.

To make sure buses run on the clean biofuel, transport operators can ask for clean fuel certificates from fuel providers.

Main advantages: only slight motor modifications of the diesel bus are necessary in order to use biofuels and to achieve significant reduction in emissions.

Main disadvantages: for each particular type/blend of biofuel specific motor modifications are to be done.

Biofuel production certificates must be requested from suppliers.

Diesel powertrain

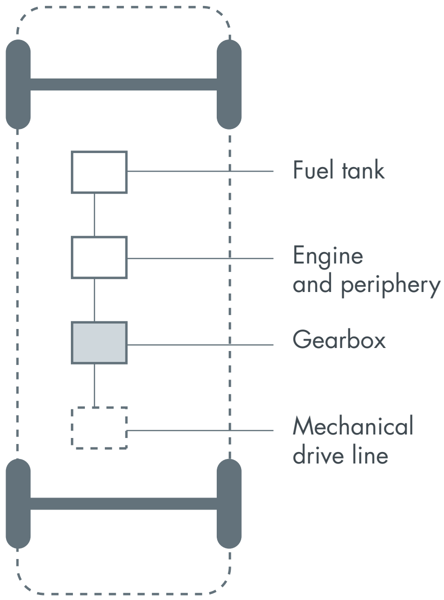


Figure 7. Biofuel Bus

Source: CIVITAS, Ljubljana

Bus running on bioethanol

Bioethanol is primarily sourced from sugarcane, grain/corn/straw or forestry waste. Diesel buses cannot be adapted for the bioethanol usage. Buses operate on 100% of bioethanol which cannot be blended with another type of fuel.

Emissions

GHG	Measure	Euro V diesel	Euro V bioethanol
CO2eq	g/km	1000	400-600
NOx	g/km	3,51	3.51
PM10	g/km	0.10	0.10

Noise: Similar to diesel vehicles

Operational performance

Range: 400-600 km (depending on a tank)

High route flexibility

Good performance on acceleration

Energy consumption 2012: 4.13 kWh/km

Energy consumption 2030: 3.89 kWh/km

Refilling every 1or 2 days

Short refilling time: 5-10 min

Infrastructure

Same filling infrastructure as for diesel can be used but specific pump for bioethanol has to be installed as well as larger storage tank.

Costs

- Indication purchase price: +/- 250,000 euro/bus
- TCO 2012: 2.52 euro/km

Things to take into consideration

Main advantages: provide alternative power source to diesel

Main disadvantages: Very limited current worldwide production of bioethanol.

Within CIVITAS II and CIVTIAS Plus projects 304 buses running on biodiesel (mostly first generation) were put into operation. For some cities the drivers to choose biodiesel bus were political support and commitment to improve the quality, environmental performance and public transport service. At the same time, the main barriers included lack of political support (introducing relevant legislation on biofuels and biofuel blends and giving permission to install biofuel fuelling stations), lack of experience in dealing with biofuels and blends of bus manufactures, infrastructure managers and bus drivers and doubts on the quality of the fuel.

CNG powertrain

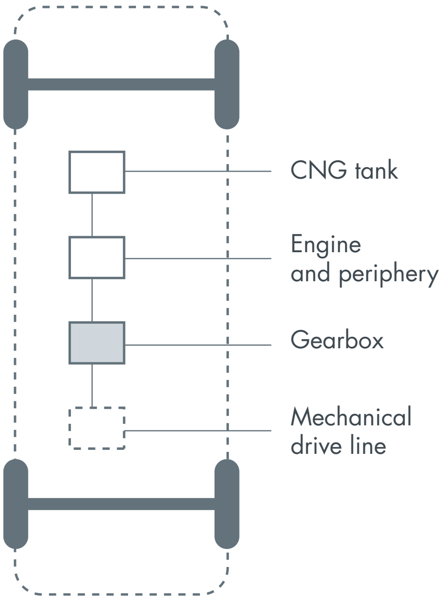


Figure 8. Bioethanol bus

Source : www.best-europe.com

ELECTRICITY

ELECTRICITY

Electricity is the main energy carrier powering electric buses and trolley buses. In the case of electric buses this is done via the rechargeable battery integrated into the bus. Trolley buses are supplied with electricity via overhead wires. Electric buses represent the cleanest technology currently available on the market, producing zero local emissions and therefore having the best impact on the local air quality. They are usually also characterized with a low level of noise. Regarding the CO_2 emissions of electricity-powered vehicles, it is important to consider the source of electricity and its production process.

Electric buses represent a new technology entering market, using batteries as the main power source. Batteries can be recharged overnight at the main bus location (overnight charging powertrain) or at fixed spots along the bus route (opportunity charging powertrain).

Trolley buses are considered a very mature technology. These are electricity-powered buses using an external electricity source. Most common are technologies fully connected to the power supply all along the way. Currently also partly connected technologies are being tested, but they are not yet widely implemented options.

Figure 9. Battery electric bus

Source: http://www.ovpro.nl/bus/2012/09/18/den-bosch-test-elektrische-bus-volvo-7700/

Electric bus

A bus that is driven by a purely electric motor powered by batteries charged with electricity. The vehicle has no other power source other than the battery. Two types are available:

- *Opportunity e-buses aim to minimize the weight of the battery by recharging en route at passenger stopping points. They have medium battery capacity (typically 40-60 kWh) and need regular charging from the grid at intermediate stops.*
- *Overnight e-buses carry the weight of battery required to drive the entire route without recharging. They have a large battery capacity (typically >200kWh) and recharge the battery from the grid only at the depot.*

Emissions

GHG	Measure	Electric bus
CO2eq	g/km	500
NOx	g/km	0
PM10	g/km	0

Noise: Lower noise level than standard diesel buses (electric motors are quieter than combustion engines).

Operational performance

Opportunity – charging buses:

- Short free range of <100 km.
- Limited route flexibility
- Recharging needed multiple times a day
- Short recharging time: 5-10 min
- Energy consumption 2012 (based on prototypes): 1.8 kWh/km
- Energy consumption 2030: 1.58 kWh/km

Overnight – charging buses:

- Medium free range: 100 - 200 km;
- Higher route flexibility
- Recharging at the end of each day
- Very long recharging times: more than 3 hours
- Energy consumption 2012 (based on prototypes): 1.91 kWh/km
- Energy consumption 2030: 1.68 kWh/km

Both for opportunity and overnight-charging buses charging time depends on the power of charging station and battery technology.

In service life is estimated to be 12-15 years, depending on duty cycle, ambient conditions and charge rate.

Figure 10. Electric bus

Source: CIVITAS, La Rochelle

Infrastructure

Require charging points within the bus depots and along the routes at bus stops. Infrastructure cost is +/-10000 euro/per bus/per station.

Costs

No information on residual value yet, as technology is entering the market.

Battery replacement cost are significant.

Service life of the vehicles is estimated to 10-15 years, depending on duty cycle, ambient conditions and charge rate.

Estimations based on prototype phase:
Opportunity e-buses

- Indication purchase price: +/- 400.000 per bus
- TCO 2012 3.2 euro/km
- TCO 2030 2.9 euro/km

Overnight e-buses

- Indication purchase price: +/-350-500.000 euro per bus
- TCO 2012 5.5 euro/km
- TCO 2030 3.8 euro/km

Factors to take into consideration

Opportunity electric buses are considered promising in terms of projected costs.

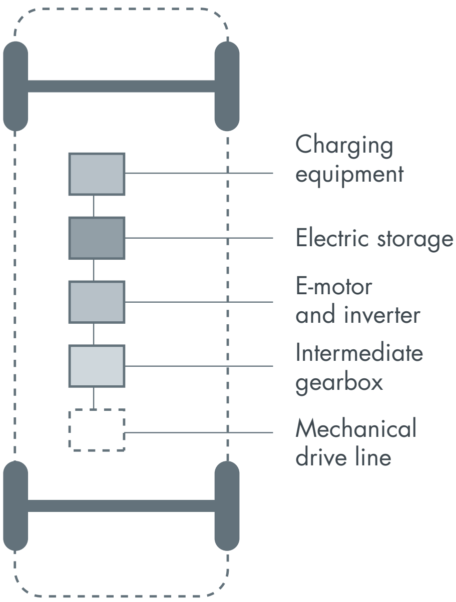
Overnight electric buses are not expected to meet average daily range requirements nor carry a sufficient number of passengers due to the weight of the batteries within the next 10 years.

Rapid advances in technology, therefore careful market study need to be done before the purchase in order to select the best possible option available on the market

Main advantages: one of the cleanest available technology

Main disadvantages: high purchase price, TCO and investment in infrastructure

Electric powertrain



Trolley buses

Electric powered rubber-tyred bus with current provided either via overhead line or ground contact. It always has an auxiliary power unit (small motor) or electric battery available to cover short distances without overhead wiring.

Emissions

GHG	Measure	Trolley bus
CO2eq	g/km	500
NOx	g/km	0
PM10	g/km	0

Noise: Lower noise level than standard diesel buses (electric motors are quieter than combustion engines). Similar to battery electric vehicles.

Operational performance

Range: unlimited within the network providing constant electricity supply

Flexibility within the network. Flexibility beyond the network is only possible using an auxiliary power unit or battery.

High performance on acceleration

Does not incorporate refuelling or recharging time in normal operation (except when auxiliary power unit needs to be recharged).

Refilling needed every few days; power supply for most operations provided continuously through overhead network.

Energy consumption 2012: 1.80 kWh/km

Energy consumption 2030: 1.71 kW/km

Infrastructure

Require an overhead wiring network (including transformers and high voltage connections).

Costs

- Indication purchase price: 400,000-450,000 euro per trolleybus
- Indication of infrastructure construction cost: 1-1.5 million euro/km
- TCO 2012: 3.1 euro/km
- TCO 2030: 3.4 euro/km

Figure 11. Trolley bus

Source: CIVITAS, Brno

Factors to take into consideration

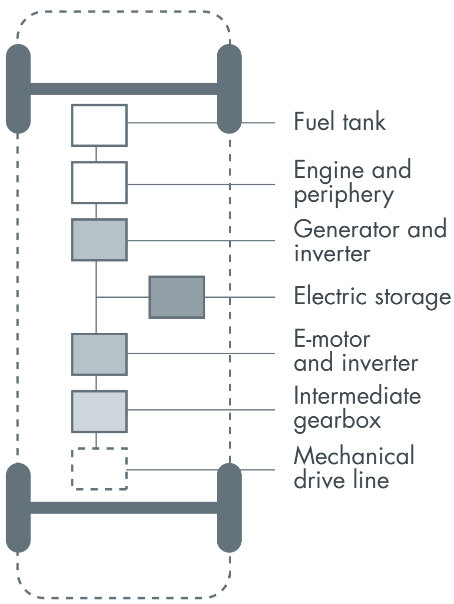
The availability of a tram network could lower the investment costs of a trolley bus overhead network .

It is possible to use trolley buses with diesel engines, combining the advantages from both powertrains; electricity in the city centre and diesel outside the city. This could also lower the required investment costs for the overhead network.

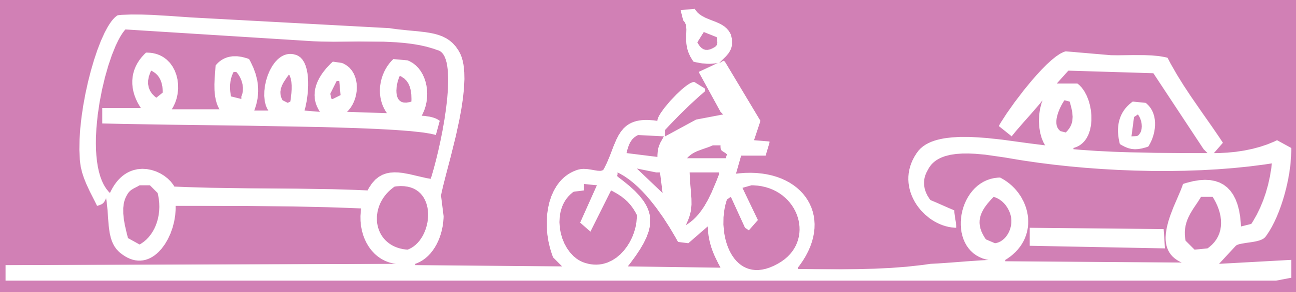
Main disadvantages: trolley buses currently often cost twice as much as conventional diesel buses due to low production volumes. However, once economies of scale are achieved the price will fall.

Main advantages: offer energy diversity, one of the cleanest available technologies.

Trolley bus powertrain



DIESEL HYBRID: HYBRID/ELECTRIC



DIESEL HYBRID: HYBRID/ELECTRIC

Two diesel hybrid bus technologies are currently available on the market: parallel hybrids with electric and conventional drives (small electric motor assists diesel motor), and serial hybrid configuration with dominating electric system (full electric motor powered by diesel generator). Currently the trend is towards serial hybrid buses. Strong arguments for serial hybrid include the much higher brake energy recovery, possibility for zero emissions range, and better basis for transition towards plug-in and fully electric buses.

Figure 12. Diesel Hybrid bus

London's new Routemaster hybrid double deck bus with three doorways and two staircases accommodates 80 passengers; September 16, 2013, at bus stop in Bloomsbury, London, UK. © Ron Ellis / Shutterstock.com

Serial hybrid diesel/electricity bus

Conventional engine and e-generator unit produces full driving power. Fully electric driving for smaller distances (<10 km), larger range possible, depending on a capacity of battery.

Emissions

GHG	Measure	Hybrid diesel/ electric	Euro V diesel
CO2eq	g/km	700	1000
NOx	g/km	2.8	3.51
PM10	g/km	0.08	0.10

Noise: Standing: 69 dB; Pass-by 73 dB

Operational performance

Range: 600-900 km.

High route flexibility

Refilling needed only after every 2nd day

Short refilling time: 5 minutes

Energy consumption 2012 (based on test fleets): 3.34 kWh/km

Energy consumption 2030: 3.17 kWh/km

Infrastructure

Regular diesel filling infrastructure. Electric battery is recharged by recuperating braking energy with no need any specific charging infrastructure.

Cost

- Indication purchase price: 270,000 euro per bus
- Projections based on the test fleet
- TCO2012 2.4 euro/km
- TCO2030 2.6-2.7 euro/km

Figure 13. Serial hybrid diesel/electricity bus

Source: CIVITAS, Ghent

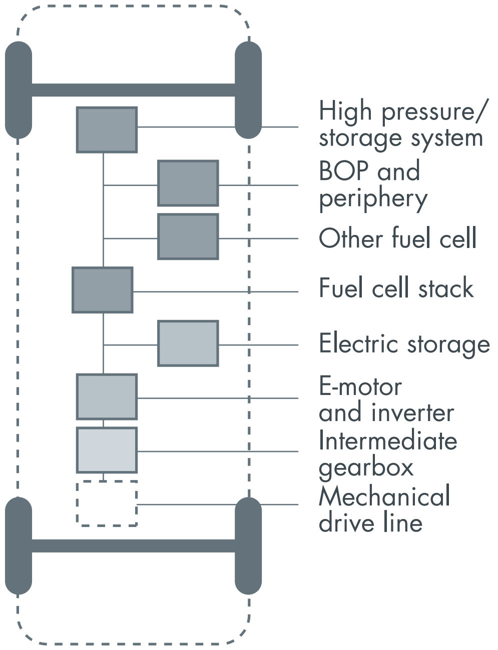
Factors to take into consideration

Hybrids (especially serial hybrids) also offer the opportunity to cover short distances in purely electric drive. A precondition is electrification of the auxiliary systems, representing a technology which isn't yet at the state of the art in hybrid powertrains. Given this precondition and a battery capacity of at least 30 kWh, these vehicles can drive for approximately 10 km purely on battery power with no local emissions. This option is particularly attractive for routes in old city centres, as well as where low levels of noise and emissions are required to reduce local pollution.

Main advantages: reduced emissions

Main disadvantages: More costly and probably heavier bus (this leads to more road and tyre wear, as well as a reduced number of passengers with the same number of axles compared to a regular diesel bus).

Serial hybrid powertrain



HYDROGEN

HYDROGEN

Hydrogen is a fuel which uses electrochemical cells. Fuel cells convert the chemical energy of hydrogen into electric energy to power the vehicle. Hydrogen can be formed either by steam reforming in an industrial process, via conventionally or renewably powered electrolysis or by conversion of methanol. The overall emissions of hydrogen fuel therefore depend on its production process. Today hydrogen fuel is not yet widespread but it is considered as one of the most promising options for the future.

Three types of bus technologies running on hydrogen are already available on the market: fuel cell engine without battery, hydrogen internal combustion engine and combined hydrogen with electric battery. The first option for buses has been already used previously, but did not prove efficient as it requires large fuel cells, leading to significant energy consumption. The second option was tested by companies such as BMW and MAN and did not prove to be feasible. The hybrid bus configuration of a fuel cell system and electric drive is currently the most promising option with respect to hydrogen buses. At the same time, this option is still in an experimental stage and not yet in widespread use.

Figure 14. Hydrogen dispenser for vehicles.

Hybrid hydrogen fuel cell/electricity bus

Bus technology using serial hybrid configuration of fuel cell system and electric drive. Electric battery is recharged while driving by recuperation (capacity typically ~20kWh); Hydrogen tank pressure typically 350 or 700 bar

Emissions

GHG	Measure	Hydrogen
CO_2eq	g/km	1500
NOx	g/km	0
PM10	g/km	0

Noise: Hydrogen fuel cell: standing 63 dB; pass-by 69 dB

Operational performance

Range: 200-400 km (depends on tank size of hydrogen)

High flexibility in routes

Electric drive used for acceleration

Refilling every day at the end of operation

Short refilling time: 10 min

Energy consumption 2012 (based on test fleets):
3.2 kWh/km

Energy consumption 2030: 2.72 kWh/km

Infrastructure

Requires specific filling infrastructure that includes specific equipment in fuelling stations and supply infrastructure. Hydrogen fuelling stations are relatively scarce in Europe but new stations are being built, mainly in Germany, Italy and Scandinavian countries.

Costs

- Indication purchase price: 800,000 Projections based on the test fleet
- TCO 2012 4.6 euro/km
- TCO 2030 3.2 euro/km

Fuelling and supply infrastructure are very expensive.
Very high maintenance cost

Figure 15. Hybrid hydrogen fuel cell/electricity bus

Source: Presentation: F. van Drunen (GVB) at ZE bussen, Amsterdam, 25-6-2013

Factors to take into consideration

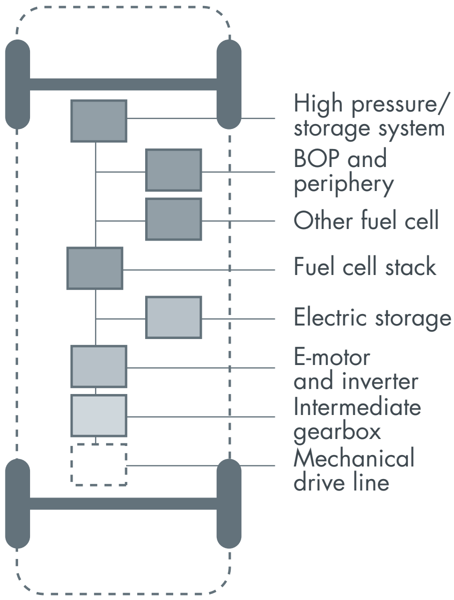
Great potential due to the availability of the resources. Hydrogen fuelling stations are relatively scarce in Europe but new stations are being built mainly in Germany, Italy and Scandinavian countries. In 2012 there were approximately 58 refuelling stations under operation in Europe, mostly in Germany. Approximately 30 additional stations will be built by 2015 throughout Europe. Some 90% of the existing stations deliver less than 50 kg of hydrogen a day (HyRaMP, 2010).

CO_2 emissions from hydrogen buses highly depend on the hydrogen production method.

Main advantages: a renewable energy source with good potential for production.

Main disadvantages: safety concerns as hydrogen is highly flammable.

Hydrogen fuel cell hybrid powertrain



WHICH ENERGY CARRIER TO CHOOSE FOR YOUR BUS?

Comparing different bus options

Appropriate bus options for a city will depend on a range of factors: size of the city, existence of a certain type of infrastructure (e.g. trolley network), budget available, overall city policy on reduction of CO_2 emissions, local pollutants and noise. Comparison of different energy carriers for your bus according to the set of criteria will help you in selecting one of the most appropriate solution for your city.

Comparison technology, infrastructure and operational performance

All described technologies are in different maturity stages. Table 2 gives an indication on bus comparison according to various operational parameters. More detailed comparison of bus technologies on the variety of indicators is provided in Annex 1.

One of the main advantages of the diesel bus is its long term history of implementation, well known operational performance and significant availability in Europe with necessary fuelling infrastructure. Diesel/electric hybrid buses have been in production for a number of years already and are starting to find a niche in some European countries. Trolley buses have been in operation for decades and are considered to be in a very mature technology stage. Tests are being conducted on hydrogen fuel cell and fuel cell hybrid buses since the late 1990s with the latest technologies still in experimental stage. Electric buses are being deployed around the world and have been in commercial service for about two years. This is constantly evolving technology and the newest applications are currently being trialled throughout Europe.

A variety of bus technology options running on alternative to diesel fuel is currently available on the market (Figure 4).

Table 2. Comparison of bus technologies on some operational characteristics

	Fossil fuel			Biofuel				Electricity			Hydrogen	Hybrid
Bus technology/energy source	Euro V	Euro VI	CNG	FAME B100	HVO B100	Bio-methane	Bioethanol	Opportunity	Overnight	Trolley	Hybrid hydrogen/ electric	Serial hybrid electricity/diesel
Fuel caracteristics												
Renewable/not												
Energy security												
Operational performance												
Range, km												
Zero emission range, km												
Route flexibility												
Infrastructure												
Current market penetration												

Source: TNO, where green represent the highest characteristics/performance within an indicator, red the less optimal option and orange the option in between.

All fuel types, expect fossil fuels are a-priory renewable fuels and in the case of energy shortage present a viable alternative to diesel and CNG buses. The current availability of these fuels differs significantly from electricity in that they represent the most secure renewable energy source options.

Almost all of the buses have a comparable operational performance. All, expect e-buses, offer a daily range of more than 300km, which is usually what is required for the medium sized European city. Refuelling/recharging time varies in general from 5 to 10 minutes, with only overnight e-bus requiring several hours for recharging (3-5 hours depending on battery type). Trolley buses are bound to the overhead network and do not need recharging time during normal operation. Operating range in purely electric mode (which is very important from an emission reduction point of view) depends significantly on bus technology, trolley bus, and hydrogen fuel cell, with parallel hybrid buses offering the highest performance values.

Diesel buses benefit from higher European availability with the fuelling infrastructure. This is also beneficial for the buses running on biofuels and CNG, as only small modifications are necessary in order to adapt fuelling infrastructure to those needs. The European Commission recently published a proposal for a Directive on the development of an alternative fuel infrastructure in Member States. The Commission obligates the Member States to develop an action plan and sets a target for electric vehicle charging points to be met by Member States. This step can also impact the municipalities' decision in favour of certain bus technologies.

Comparison emissions

A clear understanding of the differences between CO_2 emissions contributing to the global warming and local pollutant emissions (NOx, PM_{10}) that impact on air quality is necessary. For example, buses running on FAME perform better in reducing CO_2 but can increase local emission level. On the other hand, CNG buses have no advantage on CO_2 reduction, but considerably decrease local pollutants. In general, Euro VI diesel buses provide significant improvement on CO_2 and local emissions, decreasing the difference in emissions with other alternative fuel options. Running on the regular diesel is becoming increasingly cleaner. The most environmentally friendly bus fleets are those running on electricity, providing zero local emissions and reducing CO_2 emissions to 50-100% compared to diesel values.

- TTW (Tanks to wheels, or tailpipe CO_2 emissions) refers to CO_2 emissions produced directly by vehicles.

Table 3. Comparison of bus technologies on their environmental performance

Bus technology/energy source	Fossil fuel			Biofuel				Electricity			Hydrogen	Hybrid
	Euro V diesel	Euro VI diesel	CNG	FAME B100	HVO B100	Bio-methane	Bioethanol	Opportunitiy	Overnight charging	Trolley bus	Hybrid hydrogen/electric	Serial Hybrid electricity/diesel
CO2eq, g/km	orange	orange	red	orange	orange	orange	orange	green	green	green	red	green
NOx, g/km	red	orange	orange	red	orange	orange	orange	green	green	green	green	orange
PM10, g/km	red	green	green	orange	orange	green	orange	green	green	green	green	orange
Noise standing, dB	red	red	orange	red	red	orange	orange	green	green	green	green	green
Noise passing by, dB	red	red	orange	red	red	orange	orange	orange	orange	orange	orange	orange

Source: TNO, where green represent the most environmentally friendly option, red the less optimal option and orange an option in between.

- WTT (Well to tank) refers to CO_2 emissions emitted during fuel/electricity production and distribution.

- WTW (Well to wheel) refers to CO_2 emissions produced during fuel/electricity production, distribution and vehicle use.

In the case of biofuel, electricity and hydrogen it is also important to consider that the total produced emissions depend on the production and distribution of their fuel/energy carrier. The experts distinguish Tanks to Wheels and Well to Tank emissions that together form Well to Wheel emissions. Therefore for these sources sometimes a wider range of possible emissions reductions is indicated. For example, electric and hydrogen buses emit zero TTW emissions, but considering the emissions necessary for production and distribution of electricity (WTT), in general CO_2 emissions (WTW) will vary from 0 to 500 g/km. Municipalities looking to maximise reduction of emissions are advised to ask for the Clean fuel certificates from the fuel/electricity suppliers or decarbonise their electricity grid.

Table 3 gives an indication on the comparison of environmental friendliness of different bus technologies. More detailed comparison is provided in Annex 1.

Comparison economy

Cost estimates presented in this report are only indicative and can vary from country to country (especially with respect to operational costs which depend on fuel taxes, labor costs, etc). Their main purpose is to give a basis of comparison between the regular Euro VI diesel bus technology and buses operating on alternative sources. Total Cost of Ownership (TCO) analysis takes into account all capital costs that accrue to the bus owner during the expected life cycle of the vehicle. TCO includes the retail price, fixed and running costs.

Table 4 gives an indication on the comparison of bus technologies by cost. A more detailed comparison is provided in Annex 1.

Buses running on fossil fuels and biofuels are the least expensive currently available technologies. CNG and bioethanol buses have a relatively low purchase price but require high investment in fuelling infrastructure. The price of an electric bus can be twice as much the price of a diesel bus (from 30 to 100% higher of diesel Euro V bus price) and is highly dependent on the price of electric battery. Hybrid hydrogen buses currently represent the most expensive bus technology from the options presented.

Table 4. Comparison of bus technologies by economic performance

	Fossile fuel			Biofuel				Electricity			Hydrogen	Hybrid
Bus technology/energy source	Euro V	Euro VI	CNG	FAME B100	HVO B100	Bio-methane	Bioethanol	Opportunitiy	Overnight	Trolley	Hybrid hydrogen/ electric	Serial hybrid electricity/diesel
Indication purchase price, 1000 euros	green	green	green	green	green	green	green	orange	red	orange	red	green
TCO 2012, euro/km	green	green	green	green	green	orange	orange	orange	red	red	red	green
TCO 2030, euro/km	green	green	green	green	green	orange	orange	orange	red	red	orange	green
Additional infrastructure investment, 1000 euros	green	green	red	orange	orange	red	red	orange	red	red	red	green

Source: TNO, where green represents the cheapest option, red the most expensive option and orange an option in between.

Diesel buses and trolley buses have already been in operation for a long time. Their operational characteristics and associated costs are well known, e.g. maintenance costs and second-hand market value. This is not the case for electric buses, for example, where residual value of the vehicle is not available and where there is no clear evidence on the requested maintenance cost.

Comparison other considerations

In choosing a bus option, local decision makers might also find it necessary to take the following in consideration:

- While demonstrating significant improvements on emissions, Euro VI and CNG buses do not comply with long-term policy on reducing the number of vehicles running on fossil fuels and may face in the long-term higher operational prices due to the increase of fuel prices;
- CNG buses, as well as bioethanol, hydrogen and hybrid diesel/electric buses have higher safety concerns;
- HVO, bioethanol and hydrogen represent attractive alternative fuel options for buses, but current European production of these fuels is very limited;
- Buses running on electricity are today considered the most 'clean' technology, but remain very expensive and require high investment in charging infrastructure.

Achieving short term and long term targets

With an average lifetime of about 12 years, the buses that are bought today will remain in operation until at least 2025. Therefore if the EU 2020 and 2050 targets are to be achieved, changes must be made now, especially for the EU 2020 target. For the 2050 transportation target of 60% GHG reduction, it is important to start up pilots with technologies which can potentially fulfil this target so that large scale implementation can begin in 2035 and in the following years. This is a very challenging task, because financial limitations today have to be combined with a long term vision of zero emission European cities. Cost efficient decisions must consider future development of oil supply, new trends in regulatory environment and major changes of bus technology.

Different powertrains show advantages in different areas of performance. In current economic conditions, two key criteria for deciding which bus technology to develop in the city among alternative technologies are costs and GHG emissions.

Current decisions

Diesel buses have a relatively low purchase cost and low Total Cost of Ownership (TCO). They offer high route flexibility and benefit from Europe-wide availability of fuelling infrastructure. The latest introduction of Euro VI diesel engine technology demonstrated a very low pollutant emissions level. Efficiency, maintenance and exploitation costs are predictable for Euro VI diesel buses, so is the bus residual value on the second-hand market.

Natural gas buses are readily available but the purchase price is about EUR 30,000 higher than for the diesel bus. In addition, they require relatively expensive fuelling stations of about EUR 1 million (for a fleet of 100 buses this would amount to about 10,000 Euros per bus). A similar higher purchase price accounts for ethanol buses, while a hybrid (electric) system would add another EUR 50,000. The TCO of these alternative fuels and drivelines are higher than for the standard diesel buses, even though for natural gas and hybrid systems the fuel costs would be lower. Zero-emission technologies reveal that full electric buses are currently twice as expensive as standard diesel buses (400,000 and 500,000 Euros). In addition there are restrictions in driving range and little experience with maintenance costs during its lifetime. Hydrogen fuel cell buses are not directly for sale as fully developed products. They are only available for special demonstration projects. The prices are then probably high (EUR 800,000 or more). The TCO for electric and Hydrogen fuel cell buses is at least twice as expensive as standard diesel buses.

Pollutant emissions are no longer one of the main selection criteria for new buses because Euro VI diesel buses will also have very low pollutant emissions such as NOx, NO2 and particulates. In the long term, the main selection criteria should be CO_2 emissions and energy consumption, as well as the possibility to use renewable fuel (biofuels or renewable electricity).

Buses running on biofuels represent relatively a cheap alternative to diesel buses, reducing CO_2 emission levels almost by half compared to Euro V and VI diesel bus running on fossil diesel. Local pollutant levels can be higher or lower depending on the type and blend of biofuels used. In general, second generation biofuels (HVO) show lower levels of emissions but the price is substantially higher than for regular diesel. Biodiesel is often used in blends with regular diesel, such as B30 (30% biodiesel in diesel) or HVO30 (30% HVO in diesel). The possibility to use higher blends than B7 (7% biodiesel or FAME) or HVO30 should specifically be checked with the bus manufacturer as there are some technical and legal restrictions involved. Sometimes some small technical modifications or modifications in maintenance are necessary. Diesel fuelling infrastructure can be easily adapted and at low cost for filling biofuel buses.

Buses running on electricity are currently considered the most environmentally friendly bus technologies existing on the market. Depending on electricity source they produce at least 50% less CO_2 than diesel buses and do not have any local pollutant emissions. As the quality of electricity mix improves in Europe, the electric powered sources will automatically become cleaner. At the same time, these buses are limited in operational range: trolley buses are limited by their overhead network and the range of opportunity-charging electric buses depends on availability of charging infrastructure. Currently these buses represent the most expensive option with a high cost and high investment related to the charging infrastructure and/or overhead network. In cities where trolley networks already exist, the utilisation and further development of this network is considered the most environmentally friendly and energy efficient option for the bus.

Diesel hybrid buses show slightly higher purchase cost than regular diesel buses but can reduce GHG emissions by only up to 20%. They can offer an attractive bridging technology for the medium term.

Finally, hydrogen fuel cell buses represent a very promising technology but are currently in an experimental stage. Depending on the hydrogen production sources they can reduce GHG emissions by up to 70%. These buses do not represent a mature technology yet and are currently the most expensive and require high investment in infrastructure network.

Future outlook

To meet the EU 2020 Renewable Energy Directive and Fuel Quality Directive targets, it is necessary to run a part of the vehicle fleet on biofuels such as biodiesel, biogas, bioethanol or renewable electricity[8]. First generation biodiesel (FAME) is already mixed with diesel fuel by up to 7% (by volume). This is the so called blending limit for standard diesel. Higher blending volumes are not possible because they are not compatible with many vehicles (especially cars). Buses run in fleets with their own fuel stations, so it is relatively simple to use a higher blend of biodiesel. This may give way to the first generation biodiesel system (compatibility to be checked with vehicle manufacturer) or HVO which is fully compatible to quite high percentages. Alternatives to (bio) diesel buses are biogas /natural gas or bio-ethanol buses, but these are somewhat less economical options. The technology of biogas and natural gas buses is the same, provided biogas is upgraded to natural gas quality (this is also necessary from a fuel standardisation and maintenance point of view). Bioethanol buses are also an option, although currently only one manufacturer (Scania) provides this technology. Another way of contributing to the EU 2020 targets is through the installation of hybrid (electric) drivelines. This can be combined with all combustion engines such as diesel, gas and ethanol and may reduce fuel consumption (and CO_2 emission) by up to some 20%.

Large-scale introduction of extremely low CO_2 technologies is needed from 2030 onwards to build a full fleet of these technologies by 2050. These are currently not widely available, but it is very important to get to know what these technologies are and to start building experience through pilot series. If manufacturers see a market arising, then R&D funds will become available which will result in better and more efficient designs and much lower prices. It is important to realise that these are lengthy processes which can easily take several decades.

For meeting the EU 2050 GHG targets, it is best to opt for technologies with the lowest (well-to-wheel) energy consumption and which offer good opportunities for using renewable fuels. For bus application, this would be full electric buses, and over time possibly also hydrogen fuel cell buses. This is because of the dynamic driving behaviour of a bus, where the electric driveline with brake energy recovery shows high efficiencies. The driving range and costs of batteries are still considerable issues. Strategies where the batteries are charged at the end of every round trip or at bus stops may solve this. Also batteries will become much cheaper over time. Electricity and also H2 can be produced in a renewable way with solar and wind energy. They could also be produced from biomass, but for the long term, it is much better to use biomass to produce liquid biofuels. These can then be used in applications where liquid fuel is the only practical and also more energy efficient option, such as for inland and sea ships and for long haulage trucks.

8 Kampman, 2013

Conclusions

In this study, bus technologies have been compared with respect to operational characteristics, pollutant and GHG emissions, costs and maturity. The conclusion with respect to the main bus technologies are as follows:

- Diesel buses are still the most economical buses with the lowest Total cost of ownership (TCO). With the latest Euro VI engine technology, pollutant and GHG emissions are very low and comparable to Euro VI natural gas engines.
- Natural gas buses are readily available from the major manufacturers, but costs are higher and pollutant emissions advantages compared to diesel have diminished with the introduction of Euro VI (diesel) technologies.
- Buses running on biofuels are more and more widespread. Their TCO is comparable to the TCO of diesel buses. Emission from biofuels will highly depend on the particular type of biofuel and particular blend of that biofuel.
- Full electric buses are starting to become commercially available. Driving range and costs of batteries are still an issue. Where trolleybus networks exist, wider utilisation of these buses should be considered.
- Hydrogen fuel cell buses are considered as a promising option, but are currently still in an experimental stage. Purchase costs for prototypes are very high.
- For both electric and hydrogen fuel cell buses high investment costs in infrastructure are necessary.
- Diesel hybrid buses have comparable TCO to diesel buses but can reduce GHG emissions by up to 20% only.

For all these technologies renewable fuels or energy carriers are available. The GHG reduction and other performance indicators regarding sustainability criteria are quite dependent on the source of the biomass and the production of the biofuel.

The technologies are also judged with respect to their ability to contribute to the 2020 and 2050 European objectives of GHG reduction and the application of renewable energy carriers.

EU 2020 targets: 10% biofuels content and 6% GHG reduction of conventional fuels, 20% GHG reduction

Introduction of clean(er) buses can contribute to the implementation of EU 2020 targets in the following ways:

- Installation of hybrid drivelines with diesel or gas engines can reduce GHG emissions by about 20% but costs are higher.
- For diesel buses, high blends of first or second generation biodiesel can be used to increase the renewable energy share above the blending limit.
- For gas engines, biogas can be used to increase the renewable share (up to 100%).

EU 2050 target: 60% reduction of GHG emissions for transport

Full electric buses and possibly also H2 fuel cell buses show the most potential in contributing to the long term objectives, thanks to their high energy efficiency in combination with the possibility to use solar or wind renewable energy. It is important to start building experience in pilot series with 2035 and later technologies because full development with competitive prices will take several decades.

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Glossary

CNG	Compressed natural gas
CO	Carbon monoxide
CO_2	Carbon dioxide
EC	European Commission
EU	European Union
FAME	Fatty Acid Methyl Ester
GHG	Greenhouse gas
HC	Hydrocarbons
HVO	Hydrotreated vegetable oil
LPG	Liquid petroleum gas
NO_2	Nitrogen dioxide
NOx	Nitrogen oxide
OEM	Original equipment manufacturer
PM	Particulate matter
TCO	Total cost of ownership
TTW	Tank to Wheel
WTT	Well to Tank
WTW	Well to Wheel

Annex 1. Comparison of bus technologies on a set of indicators

Bus technology/ energy source	Fossil fuel			Biofuel			Electricity			Hydrogen	Hybrid
	Euro V diesel	Euro VI diesel	CNG	FAME B100	HVO B100	Bioethanol	Opportunitiy	Overnight charging	Trolley bus	Hybrid hydrogen/ electric	Serial Hybrid electricity/ diesel
Fuel availability											
Renwable fuel or not	Non renewable	Non renewable	Non renewable	Depends on feedstock used	Depends on feedstock used	Renewable	Renewable	Renewable	Renewable	Depends on hydrogen production	Combination
Current fuel/ energy source availability	High, decreasing in the long term	High, decreasing in the long term	High, decreasing in the long term	Rather high	1% of total diesel demand	Very limited	High	High	High	Limited	High
Possibility of bus technology to adapt to another fuel/energy carrier	Yes, for biofuels use	Yes, for biofuels use	Yes Biogas (upgraded to natural gas quality) is possible	Yes, to diesel	Yes, to diesel	No	Possible for the usage of fossil or sun, wind based electricity	No	No	Possible for the usage of fossil or bio, sun, wind based hydrogen	Yes to fully electric
Powertrain configuration	Conventional diesel combustion engine	Conventional diesel combustion engine	Conventional CNG combustion engine	Biofuel adapted conventional diesel combustion engine	Biofuel adapted conventional diesel combustion engine	Conventional engine adapted for the ethanol usage	Purely electric motor with medium battery capactiy	Purely electric motor with high battery capactiy	Electric powered bus with overhead line or ground contact	Serial hybrid configuration of fuel cell system and electric drive	Serial hybrid configuration of dominating electric system
Operational performance											
Range, km	600-900	600-900	350-400	570-850	570-850	400-600	<100	100-200	Limited by electric supply network	200-400	600-900
Zero emission range, km	No	No	No	No	No	No	<50	150	>300	>300	No
Route flexibility	High	High	High	High	High	High	Limited	High	Limited	High	High
Refueling/ recharging needs	Every 2nd day, 5-10 min	Every 2nd day, 5-10 min	Every 2nd day, 5-10 min	Every 2nd day, 5-10 min	Every 2nd day, 5-10 min	Each 1 – 2 days, 5 – 10 min	Multiple time a day	Every day, 3-8 hours	No	Every day, 5 - 10 min	Every 2nd day, 5 -10 min
Energy consumption, kWh/km	4,13	4,13	5,21	4.13	4.13	4,13	1.8	1.91	1.8	3.2	3.34
Infrastructure											
Need in additional infrastructure	No	No	Yes	No	No	Yes	Yes	Yes	Yes	Yes	No
EU coverage with fuelling infrastructure	High	High	Low	High	High	Low	Limited	Limited	Limited	Very limited	High

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Bus technology/ energy source	Fossil fuel			Biofuel			Electricity			Hydrogen	Hybrid
	Euro V diesel	Euro VI diesel	CNG	FAME B100	HVO B100	Bioethanol	Opportunitiy	Overnight charging	Trolley bus	Hybrid hydrogen/ electric	Serial Hybrid electricity/ diesel
Emissions											
CO2eq, g/km	1000	834	1000	≥ 500	≥ 500	400-600	0 - 500	0 - 500	0 - 500	1500*	700 - 1000
NOx, g/km	3,51	1.1	1.4-4.5	4.39	3.16	3.51	0	0	0	0	3.51
PM10, g/km	0.10	0.03	0.005-0.03	0.04	0.08	0.10	0	0	0	0	0.10
Noise standing, dB	80	80	78	80	80	80	n/a	n/a	62	63	69
Noise passing by, dB	77	77	78	77	77	77	n/a	n/a	72	69	73
Economy											
Indication purchase price, 1000euro	+/- 220	+/- 220	+/- 250	+/-220	+/-220	+/-250	+/-400	350-500	+/-300	800	270
TCO 2012, euro/ km	2.1	2.1	2.1	2.22	2.35	2.52	3.2	5.5	3.1	4.6	2.4
TCO 2030, euro/ km	2.5	2.5	2.6	n/a	n/a	n/a	2.9	3.8	3.4	2.72	2.7
Additional infrastructure investment, 1000 euro	No	No	500-1000 per fuelling station	+/-50	+/-50	+/-200 per fuelling station	+/-10 per bus per station	+/-100 per bus per station	1000 euro/ km	100 per bus per station	No
Other considerations											
Main advantages	Efficiency, maintenance and exploitation costs are predicatble, as well as residual (or second-market value)	Efficiency, maintenance and exploitation costs are predicatble, as well as residual (or second-market value)	Offers energy diversity	Provide good improvements in emissions with relatively low additional investments	Provide good improvements in emissions with relatively low additional investments	Offers energy diversity	Offers energy diversity, one of the cleanest available technology	Offers energy diversity, one of the cleanest available technology	Offers energy diversity, one of the cleanest available technology	Renewable energy source with probable good opportunities for production	Reduced emissions
Main disadvantages	Upcoming shortage of fossil fuels and EU regulations on clean vehicles in the cities in 2050	Upcoming shortage of fossil fuels and EU regulations on clean vehicles in the cities in 2050	Safety concerns (additional costs possible to fulfill safety requirement) Upcoming shortage of fossil fuels	Special type approval for Euro VI. Then still increasing maintenance costs. More expensive than diesel	Special type approval for Euro VI (not needed for HVO30). Much more expensive than diesel	Only one HD engine supplier (Scania) Safety concerns (additional costs possible to fulfill safety requirement)	High purchase price and investments in infrastructure ; no yet information on second-market value and long-term usage constraints	High purchase price and investments in infrastructure ; no yet information on second-market value and long-term usage constraints	Currently very expensive	Safety concerns	Might have safety implications due to high voltage system

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