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
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 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, 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% CO₂ 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, NO2 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 CO2 emissions from transport according to the 2011 European Commission (EC) White Paper on transport. By 2025 urban mobility is forecasted to double. With the clear EU objectives to increase public transport and introduce new CO2 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. 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 then 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.

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3 Mc Kinney, 2012


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 (NOx) 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 NOx 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

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

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

- 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 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
- 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 CO₂ 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)
- 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

**Policies and strategies addressing noise levels in urban areas**

- Commission green paper on future noise policy (COM(96)540)
- Directive 2001/43/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.
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

<table>
<thead>
<tr>
<th>Country</th>
<th>Measures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amsterdam</td>
<td>From 2015 onwards, all buses should at least conform to EEV(^1) norm. Locally, EEV+ buses are deployed to meet EU air quality regulations.</td>
</tr>
<tr>
<td>Brussels</td>
<td>From 2015 onwards, bus operators will no longer procure diesel-powered buses in order to lower PM and NOx levels.</td>
</tr>
<tr>
<td>Cologne</td>
<td>Since 2007, only EEV(^1) (and better) buses have been procured.</td>
</tr>
<tr>
<td>London</td>
<td>By 2015, all buses to meet EUROIV. By the end of 2012, 300 hybrid buses will be in service.</td>
</tr>
<tr>
<td>Oslo</td>
<td>By 2020, all buses to use renewable fuels.(^1) Phase out all EURO III before 2013.</td>
</tr>
<tr>
<td>Hamburg</td>
<td>From 2020 onwards, only emission-free buses will be procured.</td>
</tr>
<tr>
<td>Stockholm</td>
<td>By 2025, renewable(^2) public transport. Currently, already 58% of the buses drive on renewable fuels.</td>
</tr>
</tbody>
</table>

In addition, many cities focus on other measures to adhere to EU regulation on air quality:

- Expanding and optimising public transport in general
- Banning cars from city centres
- Promoting electric cars

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\(^1\) EEV: Enhanced Environmentally friendly Vehicle is a EURO norm in-between EUROV and EUROVI

\(^2\) Incl. biofuels


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 CO2 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

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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\textsubscript{2}) in comparison to other energy sources required to propel the vehicle.

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*

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

<table>
<thead>
<tr>
<th>Emissions</th>
<th>GHG</th>
<th>Measure</th>
<th>Euro V</th>
<th>Euro VI</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO₂eq</td>
<td>g/km</td>
<td>1000</td>
<td>1000</td>
<td></td>
</tr>
<tr>
<td>NOx</td>
<td>g/km</td>
<td>3.51</td>
<td>1.1</td>
<td></td>
</tr>
<tr>
<td>PM10</td>
<td>g/km</td>
<td>0.10</td>
<td>0.03</td>
<td></td>
</tr>
</tbody>
</table>

Thanks to expected improvements in bus driveline and body by 2020, CO₂ 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.
- TCO7 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.
Diesel buses can produce less emissions by using a blend of diesel with biofuel.

CO₂ 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.
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.

**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).

### Emissions

<table>
<thead>
<tr>
<th>GHG</th>
<th>Measure</th>
<th>CNG 2013</th>
<th>CNG 2020</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO2eq</td>
<td>g/km</td>
<td>1000</td>
<td>800 - 850</td>
</tr>
<tr>
<td>NOx</td>
<td>g/km</td>
<td>1.4-4.5</td>
<td>0.88</td>
</tr>
<tr>
<td>PM10</td>
<td>g/km</td>
<td>0.005-0.03</td>
<td>0.024</td>
</tr>
</tbody>
</table>

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

**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.

### 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.

### Emissions

<table>
<thead>
<tr>
<th>GHG</th>
<th>Measure</th>
<th>Euro V diesel</th>
<th>Euro V FAME 100</th>
<th>Euro V HVO100</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO2eq</td>
<td>g/km</td>
<td>1000</td>
<td>500 and more</td>
<td>500 and more</td>
</tr>
<tr>
<td>NOx</td>
<td>g/km</td>
<td>3.51</td>
<td>4.39</td>
<td>3.16</td>
</tr>
<tr>
<td>PM10</td>
<td>g/km</td>
<td>0.10</td>
<td>0.04</td>
<td>0.08</td>
</tr>
</tbody>
</table>

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.
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.

Source: CIVITAS, Ljubljana

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

<table>
<thead>
<tr>
<th>GHG</th>
<th>Measure</th>
<th>Euro V diesel</th>
<th>Euro V bioethanol</th>
</tr>
</thead>
<tbody>
<tr>
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</tr>
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<tr>
<td>PM10</td>
<td>g/km</td>
<td>0.10</td>
<td>0.10</td>
</tr>
</tbody>
</table>

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 1 or 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 CIVITAS 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.

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 CO₂ 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

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 >200 kWh) and recharge the battery from the grid only at the depot.

### Emissions

<table>
<thead>
<tr>
<th>GHG</th>
<th>Measure</th>
<th>Electric bus</th>
</tr>
</thead>
<tbody>
<tr>
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<td>500</td>
</tr>
<tr>
<td>NOx</td>
<td>g/km</td>
<td>0</td>
</tr>
<tr>
<td>PM10</td>
<td>g/km</td>
<td>0</td>
</tr>
</tbody>
</table>

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.
Smart choices for cities
Clean buses for your city

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
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

<table>
<thead>
<tr>
<th>GHG</th>
<th>Measure</th>
<th>Trolley bus</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO2eq</td>
<td>g/km</td>
<td>500</td>
</tr>
<tr>
<td>NOx</td>
<td>g/km</td>
<td>0</td>
</tr>
<tr>
<td>PM10</td>
<td>g/km</td>
<td>0</td>
</tr>
</tbody>
</table>

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 kWh/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
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.
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.

### 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

### Emissions

<table>
<thead>
<tr>
<th>GHG</th>
<th>Measure</th>
<th>Hybrid diesel/electric</th>
<th>Euro V diesel</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO2eq</td>
<td>g/km</td>
<td>700</td>
<td>1000</td>
</tr>
<tr>
<td>NOx</td>
<td>g/km</td>
<td>2.8</td>
<td>3.51</td>
</tr>
<tr>
<td>PM10</td>
<td>g/km</td>
<td>0.08</td>
<td>0.10</td>
</tr>
</tbody>
</table>

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

### 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
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).
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

**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

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**Emissions**

<table>
<thead>
<tr>
<th>GHG</th>
<th>Measure</th>
<th>Hydrogen</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO₂eq</td>
<td>g/km</td>
<td>1500</td>
</tr>
<tr>
<td>NOx</td>
<td>g/km</td>
<td>0</td>
</tr>
<tr>
<td>PM10</td>
<td>g/km</td>
<td>0</td>
</tr>
</tbody>
</table>

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

CO₂ 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.

Source: Presentation: F. van Drunen (GVB) at ZE bussen, Amsterdam, 25-6-2013
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 CO₂ 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

<table>
<thead>
<tr>
<th>Bus technology/energy source</th>
<th>Fossil fuel</th>
<th>Biofuel</th>
<th>Electricity</th>
<th>Hydrogen</th>
<th>Hybrid</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Euro V</td>
<td>Euro VI</td>
<td>FAME B100</td>
<td>HVO B100</td>
<td>Bioethanol</td>
</tr>
<tr>
<td>Fuel characteristics</td>
<td></td>
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<tr>
<td>Renewable/not</td>
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<td>Energy security</td>
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<td>Operational performance</td>
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<td>Range, km</td>
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<td>Zero emission range, km</td>
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<td>Route flexibility</td>
<td></td>
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<td>Infrastructure</td>
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<tr>
<td>Current market penetration</td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

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 CO₂ emissions contributing to the global warming and local pollutant emissions (NOₓ, PM₁₀) that impact on air quality is necessary. For example, buses running on FAME perform better in reducing CO₂ but can increase local emission level. On the other hand, CNG buses have no advantage on CO₂ reduction, but considerably decrease local pollutants. In general, Euro VI diesel buses provide significant improvement on CO₂ 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 CO₂ emissions to 50-100% compared to diesel values.

TTW (Tanks to wheels, or tailpipe CO₂ emissions) refers to CO₂ emissions produced directly by vehicles.

<table>
<thead>
<tr>
<th>Bus technology/energy source</th>
<th>Fossil fuel</th>
<th>Biofuel</th>
<th>Electricity</th>
<th>Hydrogen</th>
<th>Hybrid</th>
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<tr>
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<td>Green</td>
<td>Orange</td>
<td>Green</td>
<td>Orange</td>
</tr>
</tbody>
</table>

**Table 3. Comparison of bus technologies on their environmental performance**

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 CO₂ emissions emitted during fuel/electricity production and distribution.

WTW (Well to wheel) refers to CO₂ 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 CO₂ 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

<table>
<thead>
<tr>
<th>Bus technology/energy source</th>
<th>Fossil fuel</th>
<th>Biofuel</th>
<th>Electricity</th>
<th>Hydrogen</th>
<th>Hybrid</th>
</tr>
</thead>
<tbody>
<tr>
<td>Euro VI</td>
<td>Euro VI</td>
<td>CNG</td>
<td>FAME B100</td>
<td>HVO B100</td>
<td>Bioethanol</td>
</tr>
<tr>
<td>Overnight</td>
<td>Trolley</td>
<td>Hybrid hydrogen/electric</td>
<td>Serial hybrid electricity/diesel</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Indication purchase price, 1000 euros</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TCO 2012, euro/km</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TCO 2030, euro/km</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Additional infrastructure investment, 1000 euros</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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 CO2 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 CO2 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 CO2 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. 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 CO₂ emission) by up to some 20%.

Large-scale introduction of extremely low CO₂ 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.

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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.
References


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http://epp.eurostat.ec.europa.eu/portal/page/portal/eurostat/home/

M.McDonald, R.Hall, T.Felstead, G.Sammer, O.Raider, Dr. R.Klemenschtsit (2010), CIVITAS Pointer, Cluster report 2: Clean Vehicles and Fuels, Deliverable 2.2


Glossary

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>CNG</td>
<td>Compressed natural gas</td>
</tr>
<tr>
<td>CO</td>
<td>Carbon monoxide</td>
</tr>
<tr>
<td>CO2</td>
<td>Carbon dioxide</td>
</tr>
<tr>
<td>EC</td>
<td>European Commission</td>
</tr>
<tr>
<td>EU</td>
<td>European Union</td>
</tr>
<tr>
<td>FAME</td>
<td>Fatty Acid Methyl Ester</td>
</tr>
<tr>
<td>GHG</td>
<td>Greenhouse gas</td>
</tr>
<tr>
<td>HC</td>
<td>Hydrocarbons</td>
</tr>
<tr>
<td>HVO</td>
<td>Hydrotreated vegetable oil</td>
</tr>
<tr>
<td>LPG</td>
<td>Liquid petroleum gas</td>
</tr>
<tr>
<td>NO2</td>
<td>Nitrogen dioxide</td>
</tr>
<tr>
<td>NOx</td>
<td>Nitrogen oxide</td>
</tr>
<tr>
<td>OEM</td>
<td>Original equipment manufacturer</td>
</tr>
<tr>
<td>PM</td>
<td>Particulate matter</td>
</tr>
<tr>
<td>TCO</td>
<td>Total cost of ownership</td>
</tr>
<tr>
<td>TTW</td>
<td>Tank to Wheel</td>
</tr>
<tr>
<td>WTT</td>
<td>Well to Tank</td>
</tr>
<tr>
<td>WTW</td>
<td>Well to Wheel</td>
</tr>
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</table>
### Annex 1. Comparison of bus technologies on a set of indicators

<table>
<thead>
<tr>
<th>Bus technology/energy source</th>
<th>Fossil fuel</th>
<th>Biofuel</th>
<th>Electricity</th>
<th>Hydrogen</th>
<th>Hybrid</th>
</tr>
</thead>
<tbody>
<tr>
<td>Euro V diesel</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Euro VI diesel</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>CNG</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>FAME B100</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>HVO B100</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Bioethanol</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
</tbody>
</table>

#### Fuel availability

<table>
<thead>
<tr>
<th>Fuel availability</th>
<th>Renewable fuel or not</th>
<th>Current fuel/energy source availability</th>
<th>Possibility of bus technology to adapt to another fuel/energy carrier</th>
<th>Powertrain configuration</th>
<th>Operational performance</th>
<th>Infrastructure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non renewable</td>
<td>High, decreasing in the long term</td>
<td>Yes, for biofuels use</td>
<td>Conventional diesel combustion engine</td>
<td>Range, km 600-900</td>
<td>Yes, for biofuels use</td>
<td>Need in additional infrastructure</td>
</tr>
<tr>
<td>Non renewable</td>
<td>High, decreasing in the long term</td>
<td>Yes, for biofuels use</td>
<td>Conventional CNG combustion engine</td>
<td>Zero emission range, km No</td>
<td>Yes, for biofuels use</td>
<td>EU coverage with fuelling infrastructure</td>
</tr>
<tr>
<td>Non renewable</td>
<td>High, decreasing in the long term</td>
<td>Yes, to diesel</td>
<td>Biofuel adapted conventional diesel combustion engine</td>
<td>Refueling/recharging needs Every 2nd day, 5-10 min</td>
<td>No</td>
<td>High</td>
</tr>
<tr>
<td>Depends on feedstock used</td>
<td>Rather high</td>
<td>Yes, to diesel</td>
<td>Biofuel adapted conventional diesel combustion engine</td>
<td>Refueling/recharging needs Every 2nd day, 5-10 min</td>
<td>No</td>
<td>High</td>
</tr>
<tr>
<td>Depends on feedstock used</td>
<td>1% of total diesel demand</td>
<td>Yes, to diesel</td>
<td>Biofuel adapted conventional diesel combustion engine</td>
<td>Refueling/recharging needs Every 2nd day, 5-10 min</td>
<td>No</td>
<td>High</td>
</tr>
<tr>
<td>Renewable</td>
<td>High</td>
<td>No</td>
<td>Conventional engine adapted for the ethanol usage</td>
<td>Refueling/recharging needs Every 2nd day, 5-10 min</td>
<td>No</td>
<td>High</td>
</tr>
<tr>
<td>Renewable</td>
<td>High</td>
<td>No</td>
<td>Biofuel adapted conventional diesel combustion engine</td>
<td>Refueling/recharging needs Every 2nd day, 5-10 min</td>
<td>No</td>
<td>High</td>
</tr>
<tr>
<td>Renewable</td>
<td>High</td>
<td>No</td>
<td>Biofuel adapted conventional diesel combustion engine</td>
<td>Refueling/recharging needs Every 2nd day, 5-10 min</td>
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<tr>
<td>Renewable</td>
<td>High</td>
<td>No</td>
<td>Conventional engine adapted for the ethanol usage</td>
<td>Refueling/recharging needs Every 2nd day, 5-10 min</td>
<td>No</td>
<td>High</td>
</tr>
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#### Operational performance

<table>
<thead>
<tr>
<th>Operational performance</th>
<th>Range, km</th>
<th>Zero emission range, km</th>
<th>Route flexibility</th>
<th>Refueling/recharging needs</th>
<th>Energy consumption, kWh/km</th>
<th>Need in additional infrastructure</th>
<th>EU coverage with fuelling infrastructure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Range, km</td>
<td>600-900</td>
<td>No</td>
<td>High</td>
<td>Every 2nd day, 5-10 min</td>
<td>4.13</td>
<td>No</td>
<td>High</td>
</tr>
<tr>
<td>Zero emission range, km</td>
<td>No</td>
<td>Yes</td>
<td>Low</td>
<td>Every 2nd day, 5-10 min</td>
<td>5.21</td>
<td>No</td>
<td>High</td>
</tr>
<tr>
<td>Route flexibility</td>
<td>High</td>
<td>Yes</td>
<td>High</td>
<td>Every 2nd day, 5-10 min</td>
<td>4.13</td>
<td>No</td>
<td>High</td>
</tr>
<tr>
<td>Refueling/recharging needs</td>
<td>Every 2nd day, 5-10 min</td>
<td>No</td>
<td>High</td>
<td>Every 2nd day, 5-10 min</td>
<td>4.13</td>
<td>No</td>
<td>High</td>
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<tr>
<td>Energy consumption, kWh/km</td>
<td>5.21</td>
<td>Yes</td>
<td>Low</td>
<td>Every 2nd day, 5-10 min</td>
<td>4.13</td>
<td>Yes</td>
<td>High</td>
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#### Infrastructure

<table>
<thead>
<tr>
<th>Infrastructure</th>
<th>Need in additional infrastructure</th>
<th>EU coverage with fuelling infrastructure</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>No</td>
<td>High</td>
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<tr>
<td>Bus technology/energy source</td>
<td>Fossil fuel</td>
<td>Biofuel</td>
</tr>
<tr>
<td>-----------------------------</td>
<td>------------</td>
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</tr>
<tr>
<td>Euro V diesel</td>
<td>1000</td>
<td>≥ 500</td>
</tr>
<tr>
<td>Euro VI diesel</td>
<td>834</td>
<td>≥ 500</td>
</tr>
<tr>
<td>CNG</td>
<td>1000</td>
<td>≥ 500</td>
</tr>
<tr>
<td>FAME B100</td>
<td>1.1</td>
<td>3.16</td>
</tr>
<tr>
<td>HVO B100</td>
<td>4.39</td>
<td>3.51</td>
</tr>
<tr>
<td>Bioethanol</td>
<td>0.04</td>
<td>0.10</td>
</tr>
<tr>
<td>Opportunity</td>
<td>0.08</td>
<td>0.10</td>
</tr>
<tr>
<td>Overnight charging</td>
<td>0.10</td>
<td>0</td>
</tr>
<tr>
<td>Trolley bus</td>
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<td>0</td>
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</tbody>
</table>

### Emissions

<table>
<thead>
<tr>
<th></th>
<th>CO2eq, g/km</th>
<th>NOx, g/km</th>
<th>PM10, g/km</th>
<th>Noise standing, dB</th>
<th>Noise passing by, dB</th>
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</thead>
<tbody>
<tr>
<td>Bus technology/energy source</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fossil fuel</td>
<td>1000</td>
<td>3.51</td>
<td>0.10</td>
<td>80</td>
<td>77</td>
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<tr>
<td>Biofuel</td>
<td>834</td>
<td>1.1</td>
<td>0.03</td>
<td>80</td>
<td>77</td>
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<tr>
<td>Electricity</td>
<td>1000</td>
<td>4.39</td>
<td>0.04</td>
<td>80</td>
<td>77</td>
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<tr>
<td>Hybrid hydrogen/electric</td>
<td>1000</td>
<td>3.16</td>
<td>0.08</td>
<td>80</td>
<td>77</td>
</tr>
<tr>
<td>Hybrid serial hydrogen/electric/diesel</td>
<td>1000</td>
<td>3.51</td>
<td>0.10</td>
<td>80</td>
<td>77</td>
</tr>
</tbody>
</table>

### Economy

<table>
<thead>
<tr>
<th></th>
<th>Indication purchase price, 1000euro</th>
<th>TCO 2012, euro/km</th>
<th>TCO 2030, euro/km</th>
<th>Additional infrastructure investment, 1000 euro</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fossil fuel</td>
<td>+/- 220</td>
<td>2.1</td>
<td>2.5</td>
<td>No</td>
</tr>
<tr>
<td>Biofuel</td>
<td>+/- 220</td>
<td>2.22</td>
<td>2.6</td>
<td>+/- 50 per fuelling station</td>
</tr>
<tr>
<td>Electricity</td>
<td>+/- 220</td>
<td>2.35</td>
<td>2.9</td>
<td>+/- 50 per bus per station</td>
</tr>
<tr>
<td>Hybrid hydrogen/electric</td>
<td>+/- 220</td>
<td>2.52</td>
<td>3.8</td>
<td>+/-100 per bus per station</td>
</tr>
<tr>
<td>Hybrid serial hydrogen/electric/diesel</td>
<td>+/- 220</td>
<td>3.2</td>
<td>3.4</td>
<td>1000 euro/km per station</td>
</tr>
</tbody>
</table>

### Other considerations

<table>
<thead>
<tr>
<th></th>
<th>Main advantages</th>
<th>Main disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Efficiency, maintenance and exploitation costs are predictable, as well as residual (or second-market value)</td>
<td>Offers energy diversity</td>
<td>Upcoming shortage of fossil fuels and EU regulations on clean vehicles in the cities in 2050</td>
</tr>
<tr>
<td>Efficiency, maintenance and exploitation costs are predictable, as well as residual (or second-market value)</td>
<td>Provide good improvements in emissions with relatively low additional investments</td>
<td>Upcoming shortage of fossil fuels</td>
</tr>
<tr>
<td>Offers energy diversity</td>
<td>Provide good improvements in emissions with relatively low additional investments</td>
<td>Special type approval for Euro VI. Then still increasing maintenance costs. More expensive than diesel</td>
</tr>
<tr>
<td>Offers energy diversity</td>
<td>Offers energy diversity, one of the cleanest available technology</td>
<td>Only one HD engine supplier (Scania)</td>
</tr>
<tr>
<td>Offers energy diversity</td>
<td>Offers energy diversity, one of the cleanest available technology</td>
<td>Safety concerns (additional costs possible to fulfill safety requirement)</td>
</tr>
<tr>
<td>Renewable energy source with probable good opportunities for production</td>
<td>Offers energy diversity, one of the cleanest available technology</td>
<td>Safety concerns</td>
</tr>
<tr>
<td>Reduced emissions</td>
<td>Upcoming shortage of fossil fuels and EU regulations on clean vehicles in the cities in 2050</td>
<td>Safety concerns</td>
</tr>
<tr>
<td>Currently very expensive</td>
<td>Safety concerns due to high voltage system</td>
<td>Safety concerns</td>
</tr>
<tr>
<td>Might have safety implications</td>
<td>Safety concerns</td>
<td>Safety concerns</td>
</tr>
</tbody>
</table>
Smart choices for cities
Clean buses for your city

POLICY NOTE