CIVITAS
Cleaner and better transport in cities

POLICY NOTE

Smart choices for cities

Alternative Fuel Buses

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Preface

Thank you for reading the policy note 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.

This policy analysis focuses on the topic of alternative fuel buses for public transport. This is a hot topic because the introduction of the clean buses is necessary in order to reach the EU air quality targets and clearly impacts a cities CO_2 footprint. This document gives in-depth background information to come to a decision on a which bus to choose for your city.

In total eight policy analyses have been produced within the CIVITAS WIKI project.

We hope you enjoy reading,

The CIVITAS WIKI team

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

Summary

This policy note provides information, which can help policy makers at European municipalities, public transport authorities and local decision makers for their choice of clean(er) public bus transport:

- Drivers and challenges have been defined to give a scope on the decision options for alternative fuel buses.
- The most promising bus technologies were identified for the four main possible energy carriers available on the market today.
- Important information for these energy carriers and technologies have been presented in fact sheets.
- The most promising bus technologies have been compared with respect to *operational characteristics, pollutant and greenhouse gas (GHG) emissions and costs.*
- It is discussed how one can make decisions on cost-efficient and clean(er) public transport today, keeping in mind both short-term local needs and long term targets.

Which technology to choose largely depends on the local situation, political motives, specific operational and environmental requirements that need to be met. Furthermore, it is not a only 'bus technology' that determines the sustainability of a bus, but quality of fuel in terms of Well-to-Tank (WTT) GHG emissions, used by this bus technology, which can either make or break sustainability.

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

- With the latest Euro VI engine technology, local pollutant emissions are very low and comparable to Euro VI natural gas engines. For diesel buses the TCO (Total Cost of Ownership) is well-known. Depending on the engine specifications, the buses can run on a blend of regular and biodiesel.
- 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) technology. Alternatively, the buses can run on biomethane, see below.
- Renewable bio alternatives for fossil fuels provide a good sustainable alternative to currently existing fossil fuels. Buses running on these biofuels (bio-diesel, -CNG, -ethanol) are becoming more widespread. Well-to-wheel (WTW) GHG emissions can be decreased with the use of biofuels, but the extent depends on the pathway of the fuel (feedstock and the production process). For some biofuels, the effects of ILUC (Indirect land-use change) on GHG need to be considered. For local pollutant emissions with biofuels, the differences with Euro VI buses running on regular diesel fuel have become very small.
- Hybrid buses running on fossil fuels can reduce the tank-to-wheel GHG emissions by around 20 to 30%. Hybrid buses will have a somewhat higher TCO compared to regular buses, depending on the exact technology. Hybrids with zero emission capability are more complex and more expensive than hybrids that do not have this functionality, but obviously offer the advantages of partial zero emission operation.
- Full electric buses are commercially available and are deployed in some EU cities. Their local emissions are zero at the location of use and the noise emissions are lower than diesel buses. The electric bus has a very efficient powertrain, but the WTW GHG emissions still largely depend on the production method of electricity. Several factors can significantly influence the TCO and the operational capability. This requires solutions with specific trade-offs (both technical, operational and economic) like passenger capacity vs. weight of battery, overnight charging vs. operational schedule, opportunity charging vs flexibility of service. Another important aspect to be solved, similar to the car market, is the standardisation of the charging point.

- Where trolleybus networks exist, maintaining the nets should be safeguarded and wider utilization of these trolley buses should be considered. Semi-trolley (in-motion charging) is the latest innovative concept that may offer further benefits with regard to minimizing impacts on the schedule and keeping battery size and resulting impacts on costs and passenger capacity small.

- Hydrogen fuel cell buses are currently still in an experimental stage. Their local emissions are zero and the noise emissions are lower than diesel buses. GHG emissions largely depend on the origin or production method of the hydrogen. The powertrain is much less efficient than that of an electric bus. Hydrogen may be a good option complementing a fleet with electric buses to cover for the longer bus lines. The purchase costs for prototypes buses on hydrogen are still very high and a wider introduction of this technology is not foreseen in the short term.

- For both electric and hydrogen fuel cell buses, often high initial 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], national targets and local targets for both CO_2, air quality and noise in several ways.

Euro VI technology represents a very clean standard with regard to NO_x and PM tail-pipe emissions. Euro VI, whether it be diesel or natural gas, can thus improve local air quality, especially when a substantial number of buses of an older generation are replaced. For diesel buses, blends of preferably second generation biodiesel can be used to increase the share of fuels with low(er) GHG emissions above the blending limit.

The same applies for gas engines regarding local air-quality. Biogas can be used to increase the share of fuel with low total GHG emissions.

The application of hybrid drivelines with diesel or gas engines can further reduce GHG emissions by about 20%. Certain types of hybrids can run in zero-emission mode and have the advantages that they can still work long bus lines. Therefore, this type of hybrid may be an interesting solution for cities where local zero emissions are needed but where a full electric bus falls short with regard to the daily production (range, passengers).

Cities can start to phase-in electric buses now. In addition to the advantages of zero local pollutant emissions, the buses also emit less noise. The main issues are the uncertainty about the costs related to the battery (lifetime), infrastructure and possible reduced deployability of the electric bus due to a limited autonomy and the required charging time.

An electric bus with a relative large battery, which is charged overnight, can work short to medium length bus lines with sufficient reliability. With alternative charging concepts, like opportunity charging, even longer and more frequent bus lines can be operated using smaller batteries on-board, hereby reducing the costs of the battery. Compared to diesel buses, when electric buses are to be deployed, one has to deal with the extra dimension of the charging concept and infrastructure that increase system complexity. The design of an entirely optimized schedule, in which electric buses are being operated, probably requires more experience, hence more time. A stepwise electrification of a bus network seems the most sensible approach. The first introduction of a significant number of electric buses in a network however requires immediate adaptation of the public transport organisation.

Given the high intrinsic costs and immaturity of hydrogen buses it is advised to employ these buses in living labs. In these labs, the technology can be operated in the real world. With the emphasis on data collection and distribution, this would lead to a rapid gain in knowledge for all stakeholders. For hydrogen it is advised to look for local opportunities, locations where hydrogen is readily available for instance as a by-product of a production process or as temporary energy storage of excess production of renewable energy. Hydrogen buses could be deployed where electric buses cannot meet a high daily production on long bus lines, due to the limitations of the battery. Although costs for hydrogen fuel cell buses are expected to decrease, the hydrogen bus comes with intrinsically high costs of the fuel cell, the high pressure tanks, a battery and the infrastructure.

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.

In the longer term and heading to the achievement of the EU 2050 target[2], electric buses show the best perspective, possibly complemented by hydrogen buses for the longer bus lines. This is because of the high energy efficiency of the full electric powertrain, which in combination with the possibility to use renewable energy and production methods, leads to low GHG emissions and energy use. For hydrogen the lower efficiency of the powertrain makes it a less attractive option with regard to WTW GHG and energy consumption. One advantage compared to electric buses is that the autonomy (range) is higher and refilling takes significantly less time, which means that a hydrogen bus is better deployable for the longer bus routes with higher daily mileages.

It is important to start building up experience in living labs and even to start working out plans to phase-in electric buses in the existing fleets. For electric buses the general consensus is not to go for a big bang approach, i.e. from diesel to electric in one go, but to stepwise phase-in of batches of electric buses in the existing fleet.

Given the short term potential to reduce local air pollution, noise and the long term potential to reduce total GHG emissions and energy use, municipalities and public transport operators should aim for zero emission technology as much as possible.

Conventional diesel and gas buses (Euro VI) and their hybrid configurations remain a good and reliable option with regard to local air pollution. Biofuels with low total GHG emissions are needed in high blend rates to achieve long term goals.

Consideration of the choice of a bus concept for a city should no longer be performed by a single party. The fact that the choice relates to local opportunities, societal impacts (locally and globally), costs and operational performance means that the main players (authorities, public transport organisations, OEMs) need to enter into a dialogue and discuss the options, in the light of public goals, and start building knowledge, experience and confidence together.

The value of TCO as a tool to calculate costs is limited when only the costs for the operator are concerned. Instead, Total Financial Engineering should be considered, which not only includes CAPEX (Capital Expenditure) and OPEX (Operational Expenditure), but solutions for financing as well. Furthermore, it is advised to include the societal impacts (GHG, air pollution, noise) in the TCO, because the explicit attribution of impacts or costs (reductions) to the options will help to make a good choice with regard to the short and long term goals for your city.

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

Introduction

Introduction

This CIVITAS policy note focuses on alternative fuel buses for public transport. This is a hot topic because the introduction of the clean buses will help to reach the EU air quality targets and the buses can clearly impact a cities CO_2 footprint. The objective of this policy note is therefore to provide municipalities, local decision makers and public transport operators with information that can guide them in the initial strategic choices of a clean(er) and more energy efficient bus concept.

Conventional diesel buses for public transportation in cities are flexible to operate, are widely used and the latest generation of Euro VI buses has become significantly cleaner compared to the previous generations. Today, however, propulsion technologies are much diversified[3]. Public transport authorities can choose between a substantial number of other propulsion technologies for their buses, like hybrid buses, electric buses, fuel cell buses and a range of alternative fuels, which offers new opportunities with regard to local emissions and sustainability. This means that an optimal solution can be chosen, which is tailored to the specific needs of the cities. At the same time, local governments need to make cost-efficient decisions. This is often a challenging task. Therefore, this policy note intends to facilitate the decision-making process of European municipalities on what fuel and technology to choose for the buses that are used for public transport. This is done by providing a range of facts about the available bus concepts and by comparing them on a number of relevant criteria. The facts are based on literature and real world data. This policy note is about choosing the right bus concept for your city.

3 UITP, 2015

Background

Global concerns about climate change, public health and energy security are translated into concrete sustainability targets on a European level, on national levels and even for cities. The EU is committed to reduce greenhouse gas (GHG) emissions, aiming at 20% emission reduction below 1990 levels by 2020 and 80-95% emissions reduction for all sectors combined by 2050. The 2050 reduction target for transport is about 60%. In 2016, for cities (urban areas), air quality is still generally more important than global warming. This means their first priority is the reduction of pollutant emissions such as NO_x, NO_2 and particulates. By 2025, urban mobility is forecasted to double[4] and in combination with the clear objective of EU to increase the share of public transport[5] and new CO_2 regulations for vehicles to be respected, European cities will face new challenges in making cost-efficient and environmentally friendly decisions.

Operating the whole day, buses are the backbone of many European public transport systems. Buses are an important part of the municipality public transport fleet in majority of the EU Member States. Even though this is far behind private cars, in 2011 buses and coaches covered 512 billion passenger-kms providing 7.8% of the passenger mobility in EU. The age of almost 50% of the EU motor coaches, buses and trolleybuses in EU is more than 10 years[6]. With relatively low numbers of modern bus fleet corresponding to the Euro VI[7] standard, buses contribute a lot to local pollution. And although modern propulsion technologies are readily available, diesel and bio-diesel fuelled buses constitute, with a share of 90%[8], by far the largest share of the bus fleet in 2015.

By choosing a cleaner and more energy efficient or low carbon bus concept, local decision makers can contribute to the decarbonisation of the urban transport and improve the air quality in their cities. There are however differences between bus concepts that may impact operations and costs substantially and each bus concept has characteristics that may be optimal for one city but not for another.

4 McKinsey, 2012

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

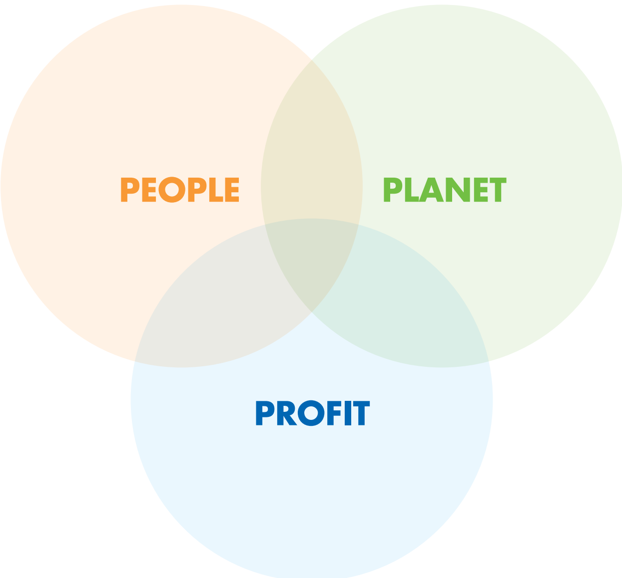
6 Eurostat

7 as of 31 December 2014

8 UITP, 2015

Scope

This policy note evaluates different city bus concepts which use different fuels/energy carriers and propulsion technologies including their infrastructure, but does not consider measures like accelerated scrapping, increasing the average operational speed of buses, eco-driving courses, a shift in transport mode or increasing the passenger transport efficiency of the bus system, which are all good ways to improve the sustainability of transport of people.



Objective

This policy note focuses on the clean(er) energy sources and technologies for buses with the people, planet, profit approach in mind.

While selecting one technology, local decision-makers are faced with different types of questions:

- What are the available options for bus propulsion technologies and energy sources to choose from?
- Will the choice impact sustainability (GHG emission, energy use, air pollution, noise) and how much?
- Will the choice impact operations and service level?
- Will the choice impact costs? Which expenses need to be considered for the calculation of the total *cost of ownership*?

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 strategic choice of a clean(er) and more efficient energy bus concept. In this policy note we first describe *drivers* and *challenges* that influence decisions of a purchase of the "cleaner" bus. We then present and compare and evaluate the main available bus concepts. Comparison is usually made with a regular 12m Euro VI diesel bus[9]. The policy note concludes with an elaboration on what is needed to achieve the short and long term goals for the cities, from initial idea to a pilot, to a living lab, to early market introduction, and to future sustainable public transport.

9 Single deck, 12m length, capacity 80-100 persons, EURO VI emission standard, empty mass in running order 11.5 t

Drivers and challenges

Local, regional, national and global drivers

Several drivers and challenges give scope to a municipality decision to look at the "cleaner" choices for a bus. On a *global* level, these are the high level EU commitments to reduce emissions, translated to the concrete GHG emission reduction targets for the Member States, public health concerns and related to this air quality issues and the EU air quality targets, fuel security and the necessity to switch to alternative sources of energy. On a *national* level, policies may aim at longer term targets and on a *regional* level, employment may play a role for instance. The decision, however needs to be taken at the *local* level. In times of rapidly changing economic conditions, municipalities have to make cost-efficient decisions in distributing limited budgets which also comply with for instance their own local targets on air quality and noise reduction.

Global		GHG target, UNFCCC Kyoto / Paris
EU		GHG target, action plans, EU legislation
Member State		GHG target, incentives, stimulation programs, tax schemes, agreements
Regional		Employment, economic development, mobility
Local		Air quality, noise, traffic, cities green image, mobility

EU Policy measures

On the supra national level, several EU policies encourage municipalities to look at the "cleaner" choice for a local bus service or the policies provide the framework in which a choice for a bus fuel needs to be made.

In this paragraph the most important EU policies have been summarized concerning climate, (renewable-) energy, fuels, health, mobility and economics.

Greenhouse gas emission

The high level EU commitments to reduce GHG emissions are translated to concrete targets on each individual Member State level and for the particular European sectors. The 2011 EC White Paper 'Roadmap to a Single European Transport Area – Towards a competitive and resource efficient transport system' sets an objective to reduce transport GHG emissions by 60% in 2050 compared to 1990. As around 70% of transport-related GHG emissions come from road transport, it is addressed specifically with an objective of emission reduction of around 60%.The Transport White paper states as one of its objectives to 'Halve the use of 'conventionally-fuelled' cars in urban transport by 2030; phasing them out in cities by 2050; achieve essentially CO_2-free city logistics in major urban centres by 2030".

Air quality

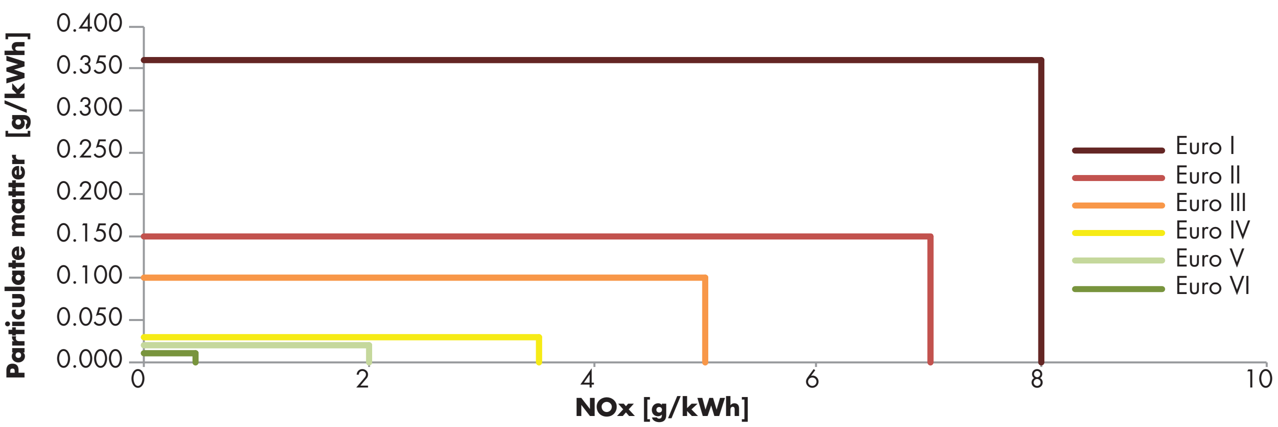
The public health concerns and in particular the issue of air quality are still of major concern in Europe. The EC has put the 'clean air quality package' in place. This package sets out new interim objectives for reducing health and environmental impacts up to 2030. It defines the required emission reduction requirements for the key pollutants (PM, SO_2, NO_x, VOCs, NH_3 and CH_4) for 2020 and 2030 and the policy agenda that will be necessary to achieve the objectives, including a revised National Emission Ceilings Directive (NECD). The EU air quality standards (Ambient Air Quality Directive (AAQD) or New air quality directive (2008/50/EC) have not been revised. These standards are local concentration limit values for the air pollutants which are most harmful to health, which have to be respected everywhere in the EU. Achieving the air quality standards often require a combination of local measures, addressing air pollution hotspots, and reducing background emissions by implementing the NECD. Cleaner buses can help to achieve these targets.

Pollutant emissions of heavy-duty engines and vehicles

The air quality is addressed by regulations establishing pollutant concentration limits for the ambient air (New Air quality directive) and for national emission ceilings (NECD) as listed above. As road vehicles contribute to the local ambient concentrations of pollutants and to the background concentrations, their emissions are regulated with standards, i.e. emission limits for a range of pollutants controlled in a type approval procedure. For the pollutant emissions of road vehicles, so-called Euro standards[10] define varying limits for tailpipe exhaust emissions of carbon monoxide (CO), hydrocarbons (HC), nitrogen oxides (NO_x), particulate matter (PM) and particle number (PN, as of Euro VI), which are to be checked with a special test at type approval. Each few years, a new standard becomes effective and each time the standard becomes more stringent with lower limits and improved test procedures and requirements. The limit standards are accompanied by a range of other measures that heavy-duty engine and vehicles have to comply with, including, amongst others, durability of pollution control devices, in-service conformity, conformity of production and on-board diagnostics.

Heavy-duty vehicles registered in the EU after December 2013 need to be type approved according to the new Euro VI standard, which comprises of buses as well. This standard requires a reduction of 80% in NO_x and 66% in PM emissions over the engine type approval test compared to the Euro V stage limits, which entered into force in October 2008. As of Euro VI, an on road test with a Portable Emission Measurement System was also introduced and together with some other improvements, like the addition of a particulate number measurement and limit, this has led to a large decrease of the real world emissions of heavy-duty vehicles from Euro V to Euro VI of especially NO_x and PM emissions[11]. Both are very relevant for today's air-quality in EU cities. For local authorities, the Euro VI standard indicates the most environmentally and air quality friendly conventional bus option available on the market.

The Euro VI standard has provisions that require checks under real driving conditions. Still, not all normal operating conditions are checked. This means that under especially low loads and low commercial speeds, which can be typical for heavy traffic urban bus operation, the emission of NO_x can rise substantially above values one would normally expect, while taking account of the limits[11]. The actual emission level under these conditions depends on the technology and effort taken by the OEM to reduce these emissions. On-road emission screening tests can be applied to check whether vehicles purchased, or to be purchased, fulfil the expectations and needs.



Development of European standards for tail pipe emissions from diesel engines of buses and other heavy-duty vehicles, from Euro I (1993) to Euro VI (31 December 2013)

10 http://ec.europa.eu/environment/air/transport/road.htm

11 TNO 2014, The Netherlands In-Service Emissions Testing Programme for Heavy-Duty 2011-2013

Greenhouse gas emissions of heavy-duty vehicles

Given the importance of transport in the EU emissions, the Commission adopted a strategy in July 2016 on low-emission mobility. This strategy identifies the key levers in the field of transport, including EU-wide measures on low and zero-emission vehicles and alternative low-emissions fuels. The Communication identifies three priority areas for action:

- Increasing the efficiency of the transport system by making the most of digital technologies, smart pricing and further encouraging the shift to lower emission transport modes,
- Speeding up the deployment of low-emission alternative energy for transport, such as advanced biofuels, electricity, hydrogen and renewable synthetic fuels and removing obstacles to the electrification of transport,
- Moving towards zero-emission vehicles. While further improvements to the internal combustion engine will be needed, Europe needs to accelerate the transition towards low- and zero-emission vehicles.

According to the Commission, cities and local authorities will play a crucial role in delivering this strategy as they are already implementing incentives for low-emission alternative energies and vehicles, encouraging active travel (cycling and walking), public transport and bicycle and car-sharing /pooling schemes to reduce congestion and pollution.The Strategy draws on existing mechanisms and funds.

The Commission will accelerate work to curb carbon dioxide emissions from lorries, buses and coaches. They currently represent around a quarter of road transport carbon dioxide emissions and their share is set to grow while the EU has neither fuel efficiency standards for them, nor a system to monitor their carbon dioxide emissions.

Concerning CO_2 emissions of HDV, the EU is developing an instrument to measure the CO_2 emissions of heavy-duty vehicles. This instrument is a simulation tool called VECTO which enables the determination of the CO_2 emission through a hybrid approach of measuring components and modelling the CO_2 emission of each individual whole vehicle: EC[12]: "…With the support of this tool, the EC intends to propose legislation which would require CO_2 emissions from new HDVs to be certified, reported and monitored…". According to the latest Communication, the Commission intends to curb the CO_2 emissions of heavy-duty vehicles and introduce future standards for the CO_2 emissions.

Energy security

Addressing a growing concern of energy security and anticipating on the potential shortage of fossil fuels, the EU set up targets to reduce the dependence on oil, encouraging the use of the renewable energy sources. In this respect, the Renewable Energy Directive sets binding targets for all EU Member States to achieve a 20% share of energy use from renewable sources by 2020, and, in particular, a 10% of renewable energy use in the transport sector.

In 2015, new rules came into force which amend the current legislation on biofuels – specifically the Renewable Energy Directive and the Fuel Quality Directive - to reduce the risk of indirect land use change and to prepare the transition towards advanced biofuels.

Low carbon economy

The European Commission is looking at cost-efficient ways to make the European economy more climate-friendly and less energy-consuming. Its low-carbon economy roadmap (COM (2011) 112) suggests that:

- By 2050, the EU should cut emissions to 80% below 1990 levels
- Milestones to achieve this are 40% emissions cuts by 2030 and 60% by 2040
- All sectors need to contribute
- The low-carbon transition is feasible & affordable.

For transport the roadmap shows that emissions from transport could be reduced to more than 60% below 1990 levels by 2050. In the short term, most progress can be found in petrol and diesel engines that could still be made more fuel-efficient. In the mid- to long-term, plug-in hybrid and electric cars will allow for steeper emissions reductions. Biofuels will be increasingly used in aviation and road haulage, as not all heavy goods vehicles will run on electricity in future.

12 http://ec.europa.eu/clima/policies/transport/vehicles/heavy/index_en.htm

Noise

The EU legislation concerning noise limits in urban areas is also of a concern for municipalities. The EU noise policy concerns an Environment Action Programme to 2020, 'Living well, within the limits of our planet', and the European Union committed to significantly decrease noise pollution in the Union, moving closer to levels recommended by the World Health Organisation, by 2020. This will require implementing an updated Union noise policy aligned with the latest scientific knowledge, measures to reduce noise at source and improvements in city design. Directive 2002/49/EC about the 'assessment and management of environmental noise' (the Environmental Noise Directive – END) is currently the main EU instrument to identify noise pollution levels and to trigger the necessary action both at Member State and at EU level.

Mobility and transport

"...With the Urban Mobility Package, the Commission reinforces its supporting measures in the area of urban transport by, sharing experiences, show-casing best practices, and fostering cooperation, providing targeted financial support, focusing research and innovation on delivering solutions for urban mobility challenges. The central element of the Urban Mobility Package is the Communication "Together towards competitive and resource efficient urban mobility"[13]..."

With the "White Paper on Transport "Roadmap to a Single European Transport Area – towards a competitive and resource efficient transport system"[14], the European Commission adopted a roadmap of 40 tangible initiatives for the next decade to build a competitive transport system that will increase mobility, remove major barriers in key areas and fuel growth and employment. At the same time, the proposals will dramatically reduce Europe's dependence on imported oil and cut carbon emissions in transport by 60% by 2050. By 2050, key goals will include:

- No more conventionally-fuelled cars in cities.
- 40% use of sustainable low carbon fuels in aviation; at least 40% cut in shipping emissions.
- A 50% shift of medium distance intercity passenger and freight journeys from road to rail and waterborne transport.
- All of which will contribute to a 60% cut in transport emissions by the middle of the century.

Alternative fuels

European policy supports alternative fuels by the Clean Power for Transport package. According to Directive 94/2014/EU on the development of an alternative fuels infrastructure, which is the cornerstone of the CPT package, member states will have to develop a plan (National Policy Framework) to establish a network of refuelling stations for natural gas vehicles in cities, ports and along the Trans-European-Network for Transport (TEN-T).

Procurement

The European Commission gives guidelines on financial incentives for clean and energy efficient vehicles in a report[15] on the application of Directive 2009/33/EC on the promotion of clean and energy efficient road transport vehicles.

Synopsis of 2009/33/EC[16]

"...The Directive on the Promotion of Clean and Energy Efficient Road Transport Vehicles aims at a broad market introduction of environmentally-friendly vehicles. Public procurement can be a powerful market mover for the introduction of new technologies. The Directive extends to all purchases of road transport vehicles, as covered by the public procurement Directives and the public service Regulation. The Directive requires that energy and environmental impacts linked to the operation of vehicles over their whole lifetime are taken into account in purchase decisions. These lifetime impacts of vehicles shall include at least energy consumption, CO_2 emissions and emissions of the regulated pollutants of NOx, NMHC and particulate matter. Purchasers may also consider other environmental impacts. Two options are offered to meet the requirements: setting technical specifications for energy and environmental performance, or including energy and environmental impacts as award criteria in the purchasing procedure. If the impacts are monetised for inclusion in the purchasing decision, common rules shall be followed, as defined in the Directive for calculating the lifetime costs linked to the operation of vehicles. This internalisation of external costs into new vehicle procurements will improve the contribution of the transport sector to the environment,

13 Together towards competitive and resource-efficient urban mobility, Brussels, 17.12.2013 COM(2013) 913 final

14 WHITE PAPER Roadmap to a Single European Transport Area – Towards a competitive and resource efficient transport system, Brussels, 28.3.2011 COM(2011) 144 final

15 GUIDELINES ON FINANCIAL INCENTIVES FOR CLEAN AND ENERGY EFFICIENT VEHICLES, 28 February 2013, [SWD(2013)27]

16 http://ec.europa.eu/transport/themes/urban/vehicles/doc/synopsis.pdf

climate and energy policies of the Community by reducing energy consumption, CO_2 emissions and pollutant emissions. This Directive is expected to result, in the longer term, in a wider deployment of clean and energy efficient vehicles. Increased sales will help reduce costs through economies of scale, resulting in progressive improvement in the energy and environmental performance of the whole vehicle fleet…"

Addressing these challenges requires enormous efforts such as the simultaneous implementation of sustainable policies in localities and regions. In order to achieve it (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 on one side present the general EU vision for the urban transport and on another side provide a concrete legislative framework for its development (Box 1).

Policies, strategies and measures reflecting the vision on European urban mobility and economics of clean transport

- White Paper on Transport "Roadmap to a Single European Transport Area – towards a competitive and resource efficient transport system" (COM (2011) 0144)
- *Green Paper "Towards a new culture for urban mobility" (COM(2007) 551)*
- *Action Plan on Urban Mobility (COM (2009) 490)*
- *Urban Mobility Package (2013)*
- *A Roadmap for moving to a competitive low carbon economy in 2050 (COM(2011) 112 final)*
- *Directive 2009/33/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of clean and energy-efficient road transport vehicles*

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

- *White Paper on Transport "Roadmap to a Single European Transport Area – towards a competitive and resource efficient transport system" (COM (2011) 0144)*
- *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 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)*

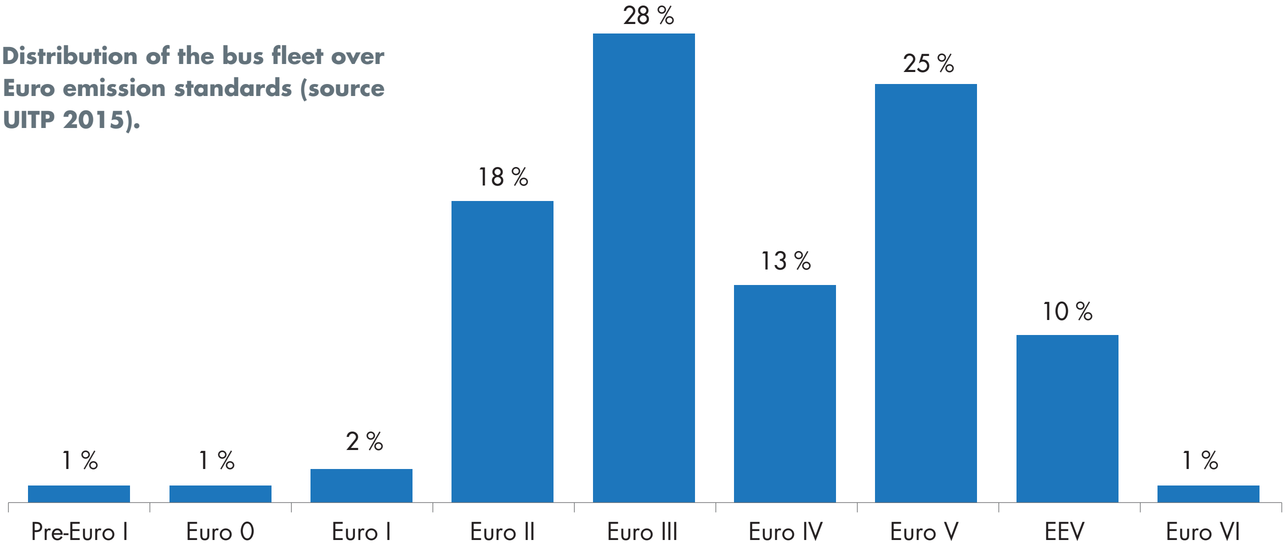
Current market situation

Responding to the targets set up at national level, municipalities are taking actions in order to improve their local bus fleet. As a result, currently already 36% of the European bus fleet fulfils at least the Euro V emission standard, Figure 1. Still, a lot is to be done as almost 52% of the fleet in 2015 fulfils Euro III and lower emission standards. About 10%[17] of the bus fleet in 2015 has an alternative non-(bio)diesel propulsion. A bus life cycle is about 12 years.

Some countries and cities are more advanced than others in introduction of cleaner bus fleets.

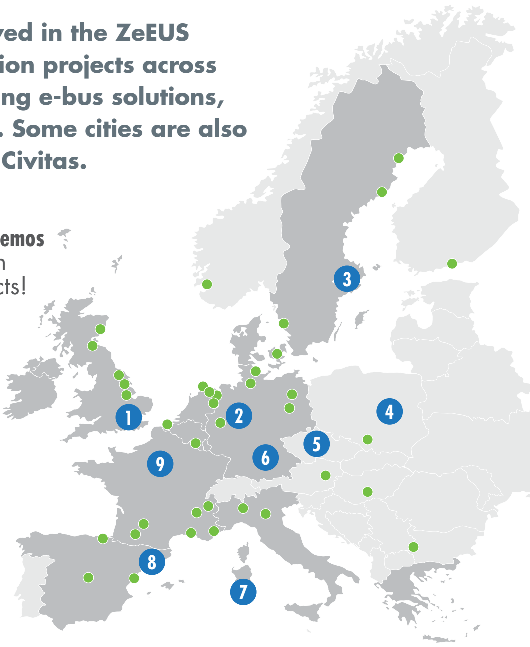
There is still a big potential to contribute to decarbonizing of European road transport and address the issue of local air pollution by acting on urban buses. Introducing alternative powertrains is one of the options already implemented by cities and is addressed in this policy note.

Distribution of the bus fleet over Euro emission standards (source UITP 2015).



Cities involved in the ZeEUS demonstration projects across Europe testing e-bus solutions, source UITP. Some cities are also involved in Civitas.

Observed Demos
More than
60 contacts!



1. **LONDON**
   3 plug-in hybrid Double deck Alexander Dennis
2. **BONN**
   6 x Sileo Bozankaya 12m
3. **STOCKHOLM**
   8 plug-in hybrid VOLVO 12m
4. **WARSAW**
   10 fully electric SOLARIS 12m
5. **PLZEN**
   2 fully electric SKODA 12m
6. **MÜNSTER**
   5 fully electric VDL 12m
7. **CAGLIARI**
   6 x battery trolleybus (4 x Vossloh Kiepe A330T 12m and 2 x Solaris T12 12m)
8. **BARCELONA**
   2 fully electric IRIZAR 12m
   2 fully electric SOLARIS 18m
9. **PARIS**
   20 fully electric BOLLORE 12m

17 UITP, 2015, Position paper, BUS SYSTEMS IN UROPE : TOWARDS A HIGHER QUALITY OF URBAN LIFE AND A REDUCTION OF POLLUTANTS AND CO2 EMISSIONS, June 2015

Challenges in introducing the clean buses

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

Firstly, there is a lack of information on the available and most promising clean(er) bus options. What is a clean(er) bus and why? What type of alternative powertrain or energy carrier can be chosen and why? How to assess the "cleanliness" of your own bus fleet? Also, there is often limited experience with the full scale operation of these buses. Pilots have been executed, for instance with battery electric buses and different types of charging infrastructure, but these pilots were often limited to the operation of a few buses on short bus lines. How will a whole fleet of these buses operate in full business? What additional infrastructure do you have to introduce?

Secondly, the purchase price of the most advanced technologies can be very high, which may lead to higher exploitation costs. With the budget available, service levels may be affected and the price of public transport may rise. In some cases, special funding from local, national or EU authorities is available, bridging limited availability of local resources with the necessity to achieve the targets set. However, in any situation, local decision makers are expected to pick the most cost-efficient solution, while today they are often challenged to buy the newest and cleanest bus, thus investing directly into the most environmentally and energy-efficient technology instead of opting for a second-hand option.

Finally, innovations that could be beneficial for public transport develop very fast and definitely faster than the life cycle of the buses. So 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. So what are the advantages of other bus technologies, taking into consideration that the environmental standards of a Euro VI technology bus is closing in on that of the buses running on alternative fuels?

What are the different bus concept options?

There are four main energy carriers available for buses:

1. fossil fuels,
2. biofuels,
3. electricity and
4. hydrogen.

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

ENERGY CARRIER	Possible fuels and technologies
FOSSIL FUELS	**Diesel Euro VI** **Natural gas CNG** Natural gas LNG Liquefied Petroleum Gas
BIO FUELS	**Bio diesel: 1st generation fame** **Bio diesel: 2nd generation hvo** **Bio ethanol** **Bio methane**
ELECTRICITY	**Autonomous electric: over-night, opportunity charging** **Trolley** **Semi-trolley, hybrid trolley or in-motion charging**
HYDROGEN	**Fuel cell** Internal combustion engine
HYBRIDS	**Internal combustion engine + electric powertrain.** **With or without plug-in facility and zero emission capacity**

Possible bus technologies and fuels for different energy carriers. In bold the selected

Fact sheets

In the sections below, fact sheets are being presented for the combinations of bus technology and energy carrier and energy grid (fuel, gas, electricity) .

- Diesel
- Compressed Natural Gas (CNG) and biomethane
- Bio-diesel: Fame and HVO
- Bio-ethanol
- Electricity: opportunity and over-night charging
- Electricity: trolley
- Diesel: diesel/electric hybrid
- Hydrogen: hydrogen/electric hybrid

These sheets contain a range of important specifications per technology or fuel. These are gathered from various sources (literature, OEM vehicle specification sheets), are brought together in the fact sheets and are used for semi-quantitative comparison of the technologies in chapter 4:

- Operational performance, [McKinsey, 2012], [CE, 2013], [TNO, 2014], [JEC, 2014], [TNO, 2015]:
  - Autonomous range
  - Refilling time,
  - Route flexibility
  - Energy consumption Tank-to-wheel (TTW). Typical values are presented based on UITP SORT 2 or actual average operation at commercial speeds around 18-22 km/h. Real-world energy consumption may vary depending on typical operating conditions such as route, topography, climate, driving style, payload, etc.
- Infrastructure:
  - required infrastructure and
  - coverage of the infrastructure
- GHG emissions, [JEC, 2014], [FQD, 2009/30/EC], [McKinsey, 2012], [TNO, 2015]:
  - GHG TTW in $CO_{2\,E}$, (incl. N_2O and CH_4 (GWP_{25yr})
  - GHG WTW in $CO_{2\,E}$, (incl. N_2O and CH_4 (GWP_{25yr})
- Pollutant emissions, [McKinsey, 2012], [CE, 2013], [TNO]:
  - NO_x TTW (tail-pipe),
  - PM_{10} TTW (tail-pipe, thus excluding particulates from braking, tyres and road)
- Noise emissions, [McKinsey, 2012]: as expressed in dB(A).
- Costs, [McKinsey, 2012]:
  - Purchase costs of a single 12m bus.
  - Total cost of ownership. The TCO depend on a lot of variables. These variables change over time. Buses with non-conventional technology differ in maturity which causes uncertainties and unpredictable behaviour of cost elements today over a full life cycle and probably become cheaper due to technical developments and growing sales volumes. Volatility of fuel prices affect the total costs and proved to be subject to large deviations due to supply strategies of global players heavily impacting the market. To make a comparison between energy carriers (fuels) and technology on costs, figures have been used from [McKinsey, 2012]. These figures include projections of increasing fuel prices for future scenarios. It is assumed that these projections remain valid, despite the large dip of the price of crude oil in oil 2016. To settle for uncertainty in costs the comparison between fuels and technologies is done semi-quantitative (chapter 4). External costs costs and benefits to the society as a whole have not been considered. External cost of transport, amongst which buses, can be found in [AEA, 2014]
- Things to be taken into consideration
- Main advantages
- Main disadvantages

Fossil fuels

Fossil fuels are formed by natural processes and typically include coal, petroleum and natural gas. These are non-renewable resources and one of the main concerns is that world reserves of fossil fuels are being depleted. 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.

Bus technologies can run on the following fossil fuels:

- Diesel. Regular diesel may be blended with bio-diesel, for instance B7, B30,
- Gas-to-liquids (GTL) 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 expensive investments in fuelling infrastructure. Furthermore, LPG had a negative impact on engine durability and additionally represents a safety concern.

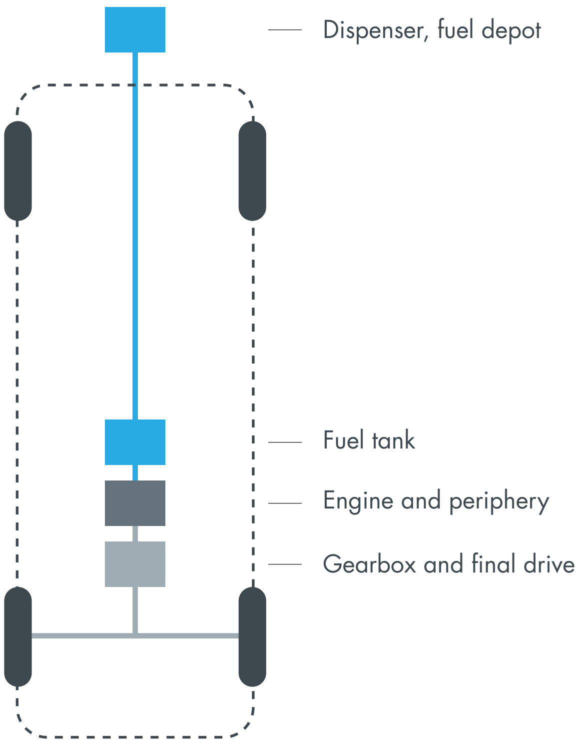
LNG buses have a very high operational range but at the same time require a high investment in the fuelling infrastructure. This make them a less attractive option for cities than buses running on CNG.

With the introduction of Euro VI standard for engines in 2014, buses running these engines on regular diesel are becoming as clean with regard to local pollutant emissions, as the buses running on alternative sources/powertrains and are therefore a promising option. Currently, Euro VI engine technology is on the market and is presented in the factsheet below. Euro VI buses are highly comparable to Euro V buses for the operational performance, infrastructure needs and costs and differ for the tail-pipe emissions.

Euro VI diesel bus performing a real world emisisions test

The baseline, Euro VI diesel buses

DIESEL POWERTRAIN



Technology

Bus technology with a conventional diesel combustion engine, running on regular diesel fuel, fulfilling Euro VI emission standards (as of 2014) used as a baseline for this policy note.

Diesel engines are well developed products with a relatively high efficiency (~40%). Diesel combustion in the engine takes place automatically because of the high temperature after compression of the air-fuel mixture and the low self-ignition temperature of diesel. Nevertheless, diesel is a relatively safe fuel because it does not evaporate much. The quality of the fuel has improved drastically due to the decrease of the content of sulphur and poly-aromatic hydrocarbons. This lead to a decrease of noxious emissions and application of particle filters and catalysts became possible.

Fuel

Currently, the diesel fuel needs to contain a fraction of biodiesel, today mainly FAME. The actual fraction differs per country. The requirements for blending biofuels are laid down in the Renewable Energy Directive

Operational performance

Diesel fuel is relatively safe and has a very high energy density. Therefore, the autonomous range is high and refuelling times are short.

Range: 600-900km

High route flexibility

Good performance on acceleration

Energy consumption 2016: 4,1 kWh/km[18]

Refuelling needed every 2nd day

Short refilling time: 5-10 min

Infrastructure

Fuel storage and dispensers are most often located at the operators facility.

Environment: GHG and pollutant emissions

A diesel engine by itself has relatively high NOx and PM emissions but as of Euro VI engines need to meet stringent requirements regarding pollutant emissions. To achieve this, Euro VI diesel engines are equipped with a particle filter and a NOx reduction system. The efficiency of the latter may decrease somewhat at lower operational speeds typical for heavy bus lines, possibly leading to an increase in the NOx emission.

18 Energy consumption is the energy in the fuel expended. For regular diesel 1 liter equals about 10 kWh of energy.

Diesel		Euro V	Euro VI
GHG WTT	gCO_2e/km	1383	1317
NOx TTW (direct)	g/km	3.5	0.5-1.1
PM10[1] TTW (direct)	g/km	0.1	0.015

1Excl. PM from brakes, tires and road

Noise

Buses with a diesel powertrain still emit a substantial amount of noise which is, amongst others, caused by the typical combustion sound of a diesel engine. For modern engines, this noise has gradually reduced somewhat by application of advanced fuel injection systems and noise isolation techniques. External costs for noise of (diesel) buses are substantial and vary depending on the time of day [AEA, 2014].

Noise emissions: standing 80 dB; pass by 77 dB

Costs

Indication of purchase price: +/- 220.000 euro per bus

OPEX and CAPEX, reliability, useful life and resale value are well-known.

Things to take into consideration

A Euro VI diesel bus is equipped with emission reduction systems, which effectively reduce NOx and PM emissions from the engine to very low values. The use of bio diesel or GTL therefore hardly affects the tail pipe emissions anymore.

CO_2 reduction can be achieved by improving the efficiency of the drive line, tyres and auxiliaries and by improvements in the "soft side", like changing driving behaviour. Also indirect GHG emissions can be reduced by using biodiesel, see the factsheet about biodiesel.

Main advantages: Due to the long tradition of diesel engines, the efficiency, maintenance and exploitation costs of diesel buses are predictable; a fuelling infrastructure is in-place; these buses can relatively easy be adapted for the usage of biofuels.

Main disadvantages: Fossil diesel is a non-renewable source of energy and for the long term concerns about energy security arise.

Bus running on compressed natural gas (CNG)

Technology

A mature bus technology with a conventional (otto, spark ignition) combustion engine fulfilling Euro VI emission standards (as of 2014), running on compressed natural gas, or bio-gas. The efficiency of this engine type is somewhat lower than that of a diesel engine.

Natural gas engines are well-developed and the market for these engines is well developed over the last decades too. Especially in some EU countries with a national gas grid.

Fuel

The quality of regular natural gas (calorific value) varies somewhat per country or source and largely depends on the actual composition. The engine control adapts to differences in quality.

Operational performance

Due to the somewhat lower efficiency than a diesel engine the natural gas engine consumes more energy.

Natural gas contains far less energy per litre than diesel. Therefore, the gas needs to be compressed and stored in relatively large tanks. The autonomy is therefore typically a little lower than for diesel buses. Refuelling generally takes as long as diesel so that CNG buses are now considered more or less equal to diesel vehicles in terms of operational performance.

Range: 350 – 400 km

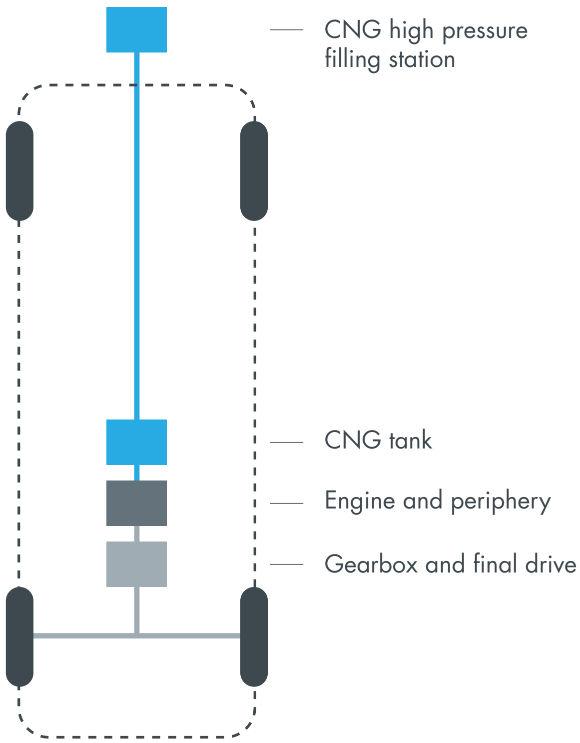
High route flexibility

Energy consumption 2016: 5,2 kWh/km

Refilling every 1st or 2nd day

Short refilling time: 5-10 min

CNG



Infrastructure

Natural gas requires a specific filling infrastructure (special compressor and buffer tank for fast filling). Gas is supplied via a connection to an existing gas network or delivered at the local depot.

Environment: GHG and pollutant emissions

The lower efficiency of the engine and the lower CO_2 emission of natural gas per unit of energy combined leads to comparable TTW CO_2 emissions as for diesel. The WTT CO_2 emission depends on the production and distribution of the gas. Gas engines were seen as the cleanest technology for decades. With the introduction of Euro VI diesel engines have become very clean in the real world and the difference in pollutant emissions between diesel and gas engines has almost diminished

Natural gas engines run stoichiometric, which means that if the fuel-air mixture control is accurately a three-way catalyst can clean the exhaust gasses with high efficiency.

(Bio-) CNG	**Examples pathway**		**Euro VI**
GHG WTT	EU mix	CO2e/km	1277
	Municipal waste	CO2e/km	273
	Liquid manure	CO2e/km	-1288
NOx TTW (local)		g/km	<1
PM10[1] TTW (local)		g/km	<0.01

[1] Excl. PM from brakes, tyres and road.

Noise

Due to a different combustion process natural gas engines emit less noise than diesel engines.

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

Cost

Indication of purchase price: +/- 250.000 euro per bus

Purchase costs of CNG buses are higher than diesel due to the large CNG tanks on the roof, a reinforced bus frame and safety measures. When no infrastructure (gas lines, storage, compressor) is present, additional capital expenditure costs are to be taken into account.

Things to take into consideration

The main difference between a regular diesel bus and a CNG bus was in terms of local pollutants for generations before Euro VI. This benefit for CNG buses has almost diminished, as Euro VI diesel vehicles emit very little pollutants as well. If biogas (e.g. biomethane) is used to power a CNG bus, the GHG emissions from the bus will be lower, actual GHG emission reductions depend on the source of the biogas.

Conversion of regular diesel buses into CNG buses has been done in the past, but is not advisable due to more strict emission standards that the buses will need to fulfil.

Main advantages: Lower noise emission than diesel engines. Can be fuelled with biomethane to reduce WTW GHG emissions. Pollutant emissions are very low, most probably still somewhat lower than Euro VI diesel emissions.

Main disadvantages: Natural gas is a non-renewable source of energy and the same concerns about energy security as for diesel arise. Safety concerns exist because of the possibility of gas leakage and ignitability of CNG resulting in an increased 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: existing necessity to upgrade an old bus fleet, combined with the possibility to reduce local emissions and to improve environmental image due to the introduction of environmentally friendlier vehicles. Lack of political support and national regulations not to adapt to the implementation of CNG buses were reported by several cities as a barrier for the implementation and introduction of the CNG bus fleet. Other barriers reported concerned the difficulties to get the necessary permission for the construction of the CNG fuelling stations and technological problems with some new and retrofitted CNG buses.

LNG

Natural Gas can be liquefied by cooling it to very low temperatures at around -160 °C. In this form, it can be shipped and it contains more energy per unit of volume. Therefore, LNG is only used for applications where a high autonomy is required. For LNG, the degradation of the fuel quality in the tank is an issue. This happens because heavier fractions (such as ethane, propane, butane) separate from the gas and remain in the tank. The residue, still containing high GWP methane, needs to be blown-off to the air. Gradual heating of the fuel in the tank may lead to boil-off of high GWP methane as well.

CNG Bus

Source: http://upload.wikimedia.org/wikipedia/commons/c/c1/Arriva_561_MAN_Lions_City_Groningen.jpg

Biofuels

Biofuel is a generic term used to describe the fuels derived from organic material. Different processes are used for the production of biofuels, which explains the diversity of its form: biodiesel, bioethanol, biomethane. Whether used to power buses, private cars or any other vehicles, biodiesels are usually always blended with conventional fuels, for instance B7 or B30 diesel.

From the point of view of fuel quality, there are two generations of biofuels, the1st generation is cheaper and is of a lesser quality and the 2nd generation has a more sophisticated production process and is therefore more expensive. The compatibility with the engine is better for HVO than for FAME because the quality of HVO is generally better and more stable.

With regard to the feedstock, there are two generations as well:

"1st generation" biofuels are fuels obtained by directly converted harvested biomass (e.g. sugar cane, wheat, palm oil). First introduced over 10 years ago, nowadays the usage of the 1st generation of biofuels is no longer encouraged at the EU level, as their production can have severe environmental and socioeconomic impacts. First and foremost is the impact on food prices and food security (as biomass is not being used for nutrition but for the fuel production). The production of biofuel from certain crops is expected to lead to indirect land-use change, which is likely to increase the WTW CO_2 emissions significantly. Other impacts include deforestation and loss of biodiversity.

"2nd generation" biofuels are exploiting non-food crops, such as farm slurry and municipal waste, 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 commercially available in large quantities. The same goes for waste cooking oil.

FAME biodiesel (Fatty Acid Methyl Ester) is one of the most used 1st generation biofuel to power buses. Because of the unsustainable production, its usage is no longer advised for the long-term, but is still implemented as the production of the 2nd generation biofuels is not yet widespread. Research and development, and implementation efforts are nowadays focused on the 2nd generation of biofuels and in particular on HVO (Hydrotreated vegetable oil: advanced biodiesel made by treating vegetable oil or animal fat with hydrogen). Euro VI buses running on FAME and HVO are highly comparable in operational performance, infrastructure, costs and local emissions with regular diesel. However for biofuels, the GHG emissions may differ and largely depend on the feedstock and production process. (see Factsheet: FAME/HVO buses). Certificates may be needed to prove the sustainability of the fuel.

Biogas (biomethane, bioCNG) can be used to fuel CNG buses. WTT GHG emissions depend on the production method and source. Biomethane can be delivered at the depot or be mixed with fossil gas in the normal infrastructure. Certificates may be needed to prove the sustainability of the fuel.

Buses running on biodiesel

Technology

Most diesel engines are adjusted to the use of low blends of biofuels, with each type and blend of biofuel requiring specific minor engine modifications. Up to 30 % is possible without modification of the engine but the actual fraction differs per engine type. Therefore, there should be a clear initial understanding with the OEMs what kind of biofuel or biofuel blend can be used in a specific engine. For Euro VI, given the more complex aftertreatment systems and sophisticated fuel systems, FAME can mostly blended only up to 7%. For HVO generally higher blends (up to 30%) are possible due to the better and more stable quality of this fuel compared to FAME. Generally, the frequency of maintenance increases.

Fuel

FAME and HVO are the most common biodiesels. Most biodiesel is blended with regular diesel. FAME (Fatty Methyl Ester) is esterified oil (plants, animal fat or waste cooking oil). The molecule contains a lot of oxygen because of which the energy content per kg is lower than diesel. The quality of FAME is less stable than HVO. HVO (Hydrotreated Vegetable Oil) and also BTL (Biomass to Liquid) are other well-known high-quality biodiesels. Like FAME, HVO is produced from plant oil or animal fat in some cases. HVO contains less oxygen than FAME and is more similar in quality to regular diesel.

Operational performance

Due to the lower volumetric energy content (-5 to -10%), the autonomy is lower than for diesel buses.

Range: 570-850 km

High route flexibility

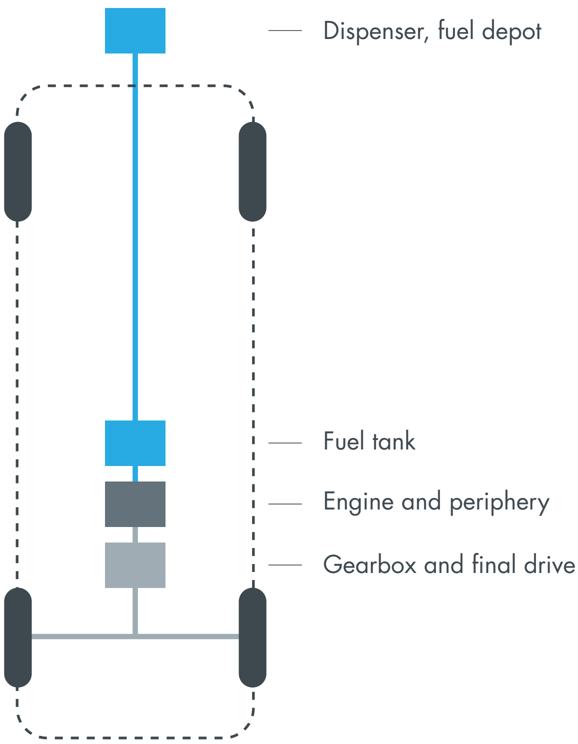
Good performance on acceleration

Energy consumption 2016: 4,1 kWh/ km

Refilling every 2nd day

Short refilling time: 5-10 min

DIESEL POWERTRAIN



Infrastructure

Most biodiesel is sold as low blend (<7%) via the regular filling stations and distribution network. The use of biodiesel as a low-blend component in transport fuel (up to 7 percent in Europe for the time being according to EN 590) does not require any changes in the distribution system, therefore this avoids expensive infrastructure changes. For these blends, the same filling infrastructure as for diesel can be used.

High blends (B20-B100) are offered in dedicated filling stations and require special storage.

Environment: GHG and pollutant emissions

GHG emissions from biodiesel buses depend on the feed stock used to produce the fuel and, to a lesser extent, on the production process. GHG for biodiesel produced from waste cooking oil can be up to 90% lower. For some feed stock (cereal and starch rich crops, oil crops and sugar

Biodiesel	Examples pathway		Euro VI
GHG WTT	FAME Tallow oil	CO2e/km	391
	FAME Waste cooking oil	CO2e/km	205
	FAME Rapeseed (w/wo ILUC[1])	CO2e/km	1487/669
	HVO Waste cooking oil NExBTL	CO2e/km	120
	HVO Meal NExBTL	CO2e/km	842
	HVO rapeseed (w/wo ILUC[1])	CO2e/km	1487/669
NOx TTW (local)		g/km	0.5-1.1
PM10[2] TTW (local)		g/km	0.015

1 ILUC, indirect land-use change is likely to increase WTW CO_2 emissions significantly. 2015/1513/EC presents provisional factors (gCO2e / MJ of burned fuel) for cereal (maize, rise, wheat, ..) and starch-rich crops, oil crops (palm, soybean, rapeseed, …) and sugar crops (cane, beet, …).

2 Excl. PM from brakes, tyres and road.

crops) indirect land-use change may increase WTW CO_2 emissions. The EC provides provisional emissions for ILUC in 2015/1513/EC. The GHG emissions also depend on the blend rate. For lower blends, GHG emission benefits will be proportionally less.

For Euro VI engines running on biodiesel, the pollutant emissions are not significantly different due to the very efficient emission reduction systems on-board of this generation.

Noise

Liquid biofuels used in diesel engines have no significant effect on noise.

Costs

Indication purchase price: +/- 220.000 euro/bus

The purchase price is the same as a diesel bus. Currently (2016) both HVO and FAME are more expensive than regular diesel fuel. Due to the lower energy density than regular diesel (FAME~ -10%, HVO ~-5-10%) the fuel consumption is higher.

Things to take into consideration

EU targets to increase a share of renewable energy sources for transport combined to the targets expanding the use of sustainable biofuels require higher usage of biofuels for transport. Only 7% blend of FAME with diesel is permitted by fuel specification. 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.

The WTT CO_2 emission and energy use depend on the feedstock and production method. Fuel certificates should be asked to make sure that the fuel fulfils sustainability requirements.

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

Main disadvantages: for each particular type/blend of biofuel, specific motor modifications must be performed.

Within CIVITAS II and CIVTIAS Plus projects, 304 buses running on biodiesel (mostly first generation) were implemented. For some cities, the drivers to choose for biodiesel buses were politically supported and committed to improve the quality, environmental performance and service of the public transport. Reported as the main barriers in running biofuel buses were: a lack of political support (in introduction of relevant legislation on biofuels and biofuel blends and in giving permissions to install biofuel fuelling stations), a 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. There are bio fuels, however, which are chemically as stable as diesel. HVO for instance. In that case there are no problems with degrading fuel and system fouling anymore.

Bus running on bioethanol

Technology

Usually, passenger cars use otto engines and run a 85% blend of ethanol/petrol. For trucks and buses, a diesel engine with minor adaptations (OEM) can be used to run on the high bioethanol-diesel blends E95 .

Fuel

Bioethanol is a liquid fuel primarily sourced from sugar cane, grain/corn/straw or forestry waste and is mainly used for buses in very high blend with diesel (E95 or ED95). Low blend e-diesel (up to 15% ethanol to diesel) is not commonly used. The energy density of ethanol is lower than diesel. Bioethanol is available in commercial volumes globally.

Operational performance

Range: 400 – 600 km. Due to the lower volumetric energy content (-30 to -40% for 100% ethanol), the autonomy is lower than for diesel buses.

High route flexibility

Good performance on acceleration

The efficiency of the powertrain is comparable to one using a diesel engine.

Energy consumption 2016: 4,1 kWh/km

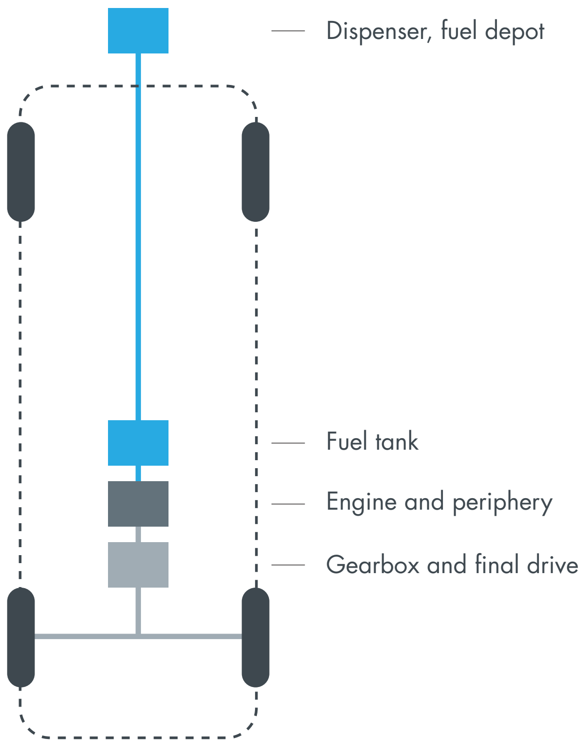
Refilling every 1or 2 days

Short refilling time: 5-10 min

Infrastructure

The same type of filling infrastructure as for diesel can be used, but a specific pump for bioethanol has to be installed as well as a larger storage tank.

OEM ADAPTED DIESEL POWERTRAIN



Environment: GHG and pollutant emissions

There is not much data available about the CO_2 emission and local pollutant emissions of his technology.

Fulfilling Euro VI standards for pollutant emissions it is expected that these will be very low and comparable to other Euro VI technology.

WTT GHG emissions depend largely on the production method.

Bioethanol	Examples pathway		
GHG WTT	Wheat straw	CO2e/km	137
	Wheat lignite	CO2e/km	1279
	Sugar beets, slops not used (w/ wo ILUC[1])	CO2e/km	599/792
NOx[2] TTW (local)		g/km	0.5-1.1
PM10[2, 3] TTW (local)		g/km	0.015

1 ILUC, indirect land-use change is likely to increase WTW CO2 emissions significantly. 2015/1513/EC presents provisional factors (gCO2e / MJ of burned fuel) for cereal (maize, rise, wheat, ..) and starch-rich crops, oil crops (palm, soybean, rapeseed, …) and sugar crops (cane, beet, …).

2 No reliable emission data available for Euro VI.

3 Excl. PM from brakes, tyres and road.

Noise: Similar to diesel vehicles

Costs

Indication purchase price: +/- 250,000 euro/bus

The purchase price of a bus is somewhat higher as a diesel bus.

Fuel costs are higher due to the higher fuel consumption and the higher price per litre.

Things to take into consideration

There is currently only one supplier (OEM) of this technology.

Main advantages: ethanol provides an alternative source to diesel and potential reduction of GHG depending on the feed stock.

Main disadvantages: Limited local availability.

Electricity

Electricity is the obvious energy carrier for powering electric buses and trolley buses. Electric buses typically use a rechargeable battery to store the energy on-board and are charged statically. Trolley buses are commonly supplied with electricity via the overhead wires and are charged dynamically like with trains. Buses driving on electricity are considered as the cleanest technology currently available on the market, producing zero local emissions and therefore have the largest impact on the local air quality. They are usually also characterised with a lower level of noise than buses with combustion engines. Regarding the WTW GHG emissions of electricity-powered vehicles, it is important to consider the source of electricity and its production method.

Battery electric bus

Battery electric buses are rapidly gaining in market share. Due to the relatively low energy density of a battery compared to diesel, the autonomy of these buses is significantly smaller than for conventional buses. The battery can be recharged slowly overnight or at large intervals at the main bus depot (overnight charging) or at higher frequencies along the bus line and at terminus (opportunity charging). Recharging a battery (especially with a slow charge) can take a considerable amount of time, which means that the employability, i.e. the hours available for daily duty, is not as high as for diesel buses. This in turn results in additional costs for the TCO, for extra buses and probably bus drivers. In addition, batteries are expensive, large batteries mean less passengers (more buses may be needed) and large batteries mean a somewhat higher energy consumption. Technical solutions are being developed to overcome as many of the shortfalls as possible in employability and high

Battery electric bus at the test circuit for UITP SORT electric energy consumption tests

costs associated to the use of batteries as the main energy storage. The main technical solutions are:

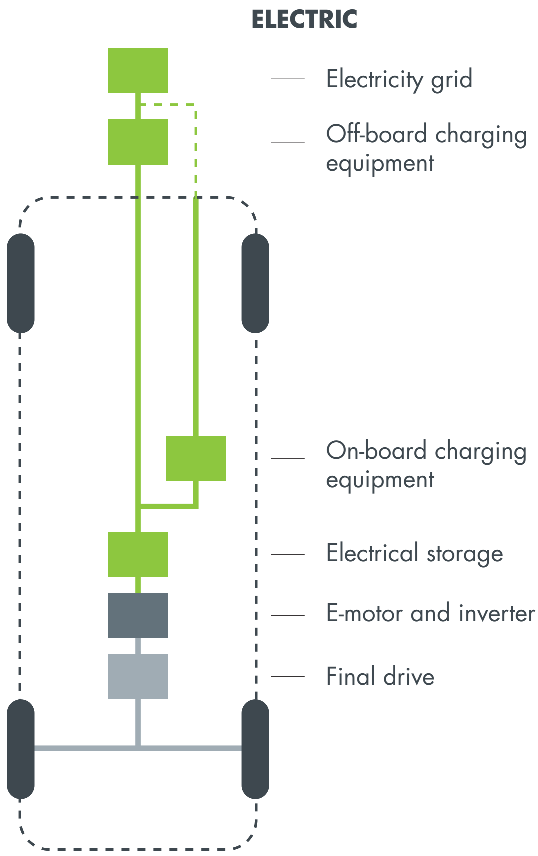
- Higher energy density batteries
- Lower energy consumption of the bus and auxiliaries to increase the autonomous range, including energy management and energy prediction systems
- High power fast charging systems
- Special opportunity charging technology, for instance by inductive charging, or conductive charging (via a pantograph) at some selected bus stops
- Semi- or hybrid trolley (IMC, in-motion charging)

Trolley

Trolley buses are considered as a very mature technology. These are often dominantly electricity-powered buses, using overhead wiring infrastructure as external electricity source. An APU (auxiliary power unit) is used to provide some autonomous operation (to overcome short distances without overhead wiring or to serve as limp-home). Older variants have generator sets on-board. Today, a battery is expected to take over this functionality. Technologies fully connected to the power supply all along the way are most common. Currently, also partly connected hybrid- or semi-trolley technologies using in-motion charging are being tested with a battery on-board to overcome the sections without overhead wiring.

Trolley bus in Lyon (F).
Source: https://commons.wikimedia.org/wiki/File:Trolley-bus-place-des-terra.jpg

Battery electric bus



Technology

A bus that is driven by an electric motor and which is purely powered by batteries charged with electricity. Two main charging strategies have been considered:

1. Opportunity charging electric buses aim to minimize the weight of the battery by regular recharging en route at bus stops. They have a small to medium battery capacity (typically 20-60 kWh).

2. Overnight charging e-buses have a large battery capacity (typically 200-350 kWh) which is required to drive longer distances (150-250km) without recharging. The battery is typically charged from the grid at the depot over-night, but to increase the diurnal employability this type of electric bus can be recharged during the day, for instance at central bus stations.

Operational performance

The electric powertrain is very efficient and very suitable for stop and go operation. In addition, energy can be regenerated by electric braking. This leads to very low energy TTW consumption compared to technologies using internal combustion engines.

Opportunity charging buses:

- Short autonomy very dependent on capacity of the battery and actual energy use: <100 km.
- Limited route flexibility
- Recharging needed multiple times a day
- Short recharging time: 5-10 min
- Energy consumption 2016: 1.4 kWh/km

Overnight charging buses:

- Medium autonomy, very dependent on capacity of the battery and actual energy use: 100 - 250 km;
- Higher route flexibility
- Recharging at the end of each day or during the day
- Very long recharging times: more than 3 h
- Energy consumption 2012 (based on prototypes): 1.6 kWh/km

In case of an overnight charged bus the empty mass of the bus can be rather high due to the large and heavy battery. This affects the passenger capacity. As an example a 2-axle 12m 300kWh electric bus can transport 70 compared to about 100 persons for the 12m diesel.

Both for opportunity and overnight-charging buses, charging times depend on the power of the charging station and the battery technology.

The useful life of the bus chassis and powertrain, excluding the battery, is estimated to be 12-15 years. the electric propulsion in particular is expected to have a longer life than an internal combustion engine. The useful life of a battery is expected to last shorter but how much depends a lot on operating and charging conditions of the battery. Several aging tests in laboratories are on-going.

Battery electric bus	Examples pathway		Euro -
GHG WTT	EU mix medium	CO2e/km	711
	Wind offshore	CO2e/km	0
	Electricity EU mix coal	CO2e/km	1474
	Electricity NG 7000 km	CO2e/km	731
NOx TTW (local)		g/km	0
PM10[1] TTW (local)		g/km	0

[1] Excl. PM from brakes, tyres and road. Due to regenerative braking EV's have less PM emission from the brakes than conventional vehicles.

Infrastructure

Electric buses require a dedicated infrastructure, i.e. charging points within the bus depots and/or along the routes at bus stops. On-board charging equipment and charging points are mature products. Opportunity charging with a pantograph (conductive) or inductive are in an early adoption stage.

Environment: GHG and pollutant emissions

WTT GHG emissions depend largely on the energy production method.

Local pollutant emissions and TTW GHG emissions are zero.

Noise: Lower noise level than standard diesel buses.

Costs

Indication purchase price: 320 000 to 500 000 Euro per bus.

Purchase prices largely depend on the battery capacity.

Battery replacement cost are expected to be significant and largely depend on size (capacity) and ageing.

There is no information on scrap value yet, as technology is only just entering the market.

Significant additional capital expenditure costs are to be taken into account for the charging infrastructure. Operating Expenses of full network operation of this technology are not available. Some expenses are expected to increase, for instance due to the increased complexity of operation of this type of bus. Other expenses are expected to decrease, like general maintenance costs.

Things to take into consideration

Opportunity charging electric buses are considered promising in terms of projected costs. Its main limitation is the reduction of the service flexibility and the impact of traffic irregularities on opportunity e-bus revenue service. Such irregularities may result in time shortage for opportunity charging by a delayed service or in a situation when two or more e-buses (regular and delayed services) claim for space at a single charging point. This means that establishing a reliable system of opportunity charged e-buses requires not only charging standardisation, but also embedding such a system into a more complex urban mobility scheme, including such measures as dedicated bus lanes, traffic light preferences for urban transit, IT tools for e-bus scheduling and online control. There is a very close link between opportunity e-bus systems and the smart city concept .

Overnight charging electric buses are not expected to meet average daily autonomy requirements nor carry a sufficient number of passengers due to the weight of the batteries for intensive bus lines. Therefore, this type is today considered not suitable for whole day operation on frequent bus lines with a high degree of passenger occupancy. The technology is suitable though for shorter daily operations and low demand bus lines.

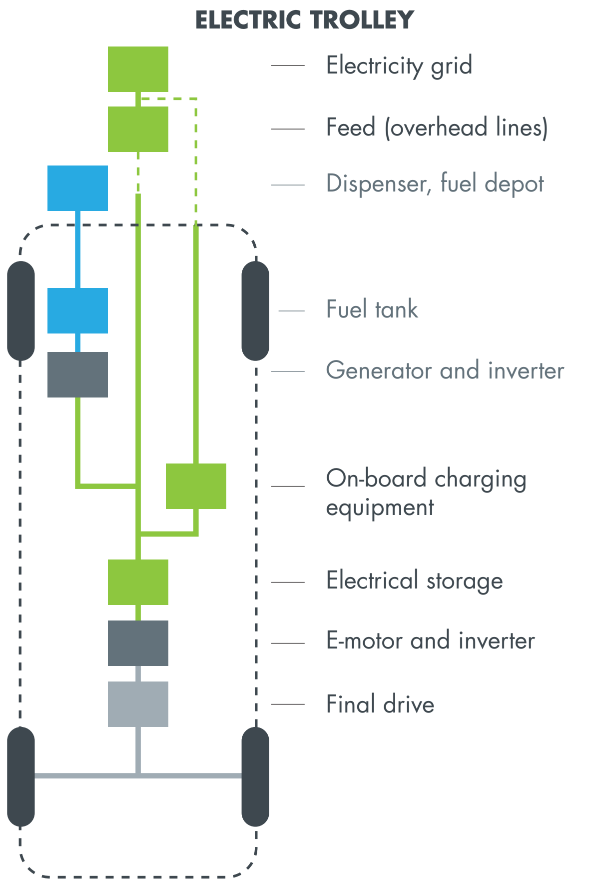
The technology, especially for the battery and infrastructure, is still improving.

Main advantages: Electric buses are one of the cleanest technologies available given the local zero emission of pollutants and lower noise emissions. Electricity can be produced from sustainable sources.

Main disadvantages: high purchase price, TCO calculations and investment in infrastructure is needed. Uncertainty about the useful life and costs of the battery.

Trolley buses

Electric powered rubber-tyred bus with a roof-mounted current collection via an overhead line. It always has an auxiliary power unit (small engine) or electric battery available to cover short distances without overhead wiring for emergency reasons.



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.

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

The powertrain is very energy-efficient.

Energy consumption 2016: 1,4 kWh/km

Infrastructure

Require an expensive overhead wiring network (including transformers and high voltage connections). The existence of an overhead wiring infrastructure makes a large difference in the costs.

Environment: GHG and pollutant emissions

WTT GHG emissions depend largely on the production method.

Local pollutant emissions and TTW GHG emissions are zero.

Trolley bus	**Examples pathway**		**Euro -**
GHG WTT	EU mix medium	CO2e/km	711
	Wind offshore	CO2e/km	0
	Electricity EU mix coal	CO2e/km	1474
	Electricity NG 7000 km	CO2e/km	731
NOx TTW (local)		g/km	0
PM10[1] TTW (local)		g/km	0

[1] Excl. PM from tyres, brakes, road and overheat lines.

Noise: Lower noise level than standard diesel buses. Similar to battery electric vehicles.

Costs

Indication purchase price: 400,000-450,000 euro per trolleybus

Capital expenditure is especially high for a new trolley network given the high costs for the infrastructure. Obviously, cities can benefit from an infrastructure if it this is already present.

Things to take into consideration

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

Semi-trolley or charging in motion options can be considered. When running in an area without network, buses can run on an auxiliary power source, like a battery or a diesel generator set. This would also lower the required investment costs for the overhead network.

Main advantages: trolley buses are one of the cleanest technologies available given the local zero emission of pollutants and lower noise emissions. Electricity can be produced from sustainable sources.

Main disadvantages: overhead lines, trolleybuses currently often cost double the price of a conventional diesel bus due to low production volumes, but once economy of scale is achieved, the price may reduce. Also the expected lifetime of a trolley bus is longer (about 20 years). When no infrastructure is available initial high capital expenditure (infra) and operational expenditure (maintenance of infra) are applicable.

Serial hybrid electric bus

Source: http://www.rtvoost.nl/archief/default.aspx?nid=118594#prettyPhoto

Hybrid: diesel/electric

A hybrid vehicle uses two sources of motive power. The most common type: the hybrid electric vehicle (HEV) uses a combination or an internal combustion engine and an electric drive system (electric motor/generator and battery and/or capacitors). The layout of the powertrain can still be different. Generally, two sub-types of hybrids are distinguished.

- parallel hybrids have an internal combustion engine (e.g. diesel, CNG) and a coupled electric motor to assist the engine, to regenerate braking energy and to charge the battery. These types can be further categorised depending on how the power sources are balanced. In most cases the combustion engine is dominant, however no exclusive mode (electric only or internal combustion only) can be used so they are referred to as mild hybrids.

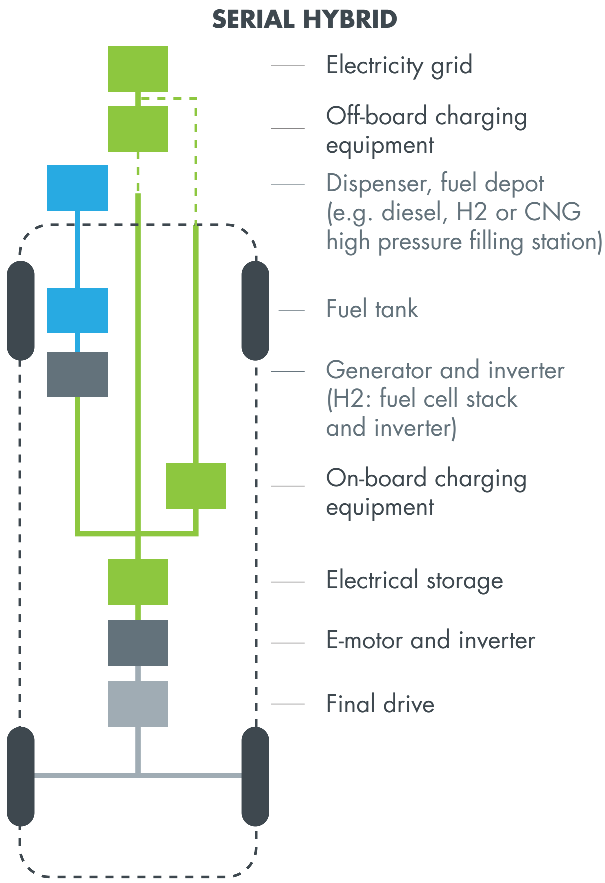
- serial hybrids have an internal combustion engine that produces electricity to charge a battery and provide energy to power the electric motor(s) which in turn propel the bus. Most types can connect to the electricity grid to charge the battery (plug-in). Depending on the capacity of the battery they can offer a substantial zero-emission range. Serial hybrids can be battery dominant, in that case they are often called 'plug-in hybrid electric' or extended range electric vehicle or range extended electric vehicle. Their counterparts are the serial hybrids types where the battery is small, these types often offer limited zero-emission range, yet they have the benefit of the regeneration of braking energy. Instead of a generator set running on diesel, in principle, a (bio-) CNG of bioethanol engine or a fuel cell stack can be used to charge the battery.

Currently, the trend is towards serial hybrid buses. Arguments are the much higher brake energy recovery, the possibility to have a substantial zero emissions range and the better basis for transition towards fully electric buses. The latest innovation in hybrid bus technology is towards (serial hybrid) plug-in (PHEV or REEV, Range Extended Vehicle). These typically operate in a similar fashion to the conventional hybrid bus but are fitted with a larger electric battery enabling longer electric-only range. They offer opportunities to improve air quality and cut greenhouse gas emissions. GPS devices can be fitted to ensure zero emission operation in areas of poor air quality such as Low Emission Zones, switching to hybrid operation after leaving the zone

Serial and parallel hybrid diesel/ electricity bus

Serial hybrid: A driveline combining an internal combustion engine (diesel, CNG), generator, battery and electric motor in serial set-up. To operate with zero emissions, all auxiliaries need to be propelled with e-motors. This increases the overall complexity.

Parallel hybrid: A driveline combining an internal combustion engine (diesel, CNG), generator, battery and electric motor in parallel set-up



Operational performance

Range: 600-900 km.

High route flexibility

Refilling needed only after every 2nd day

Short refilling times: 5min

Energy consumption 2016: 3,3 kWh/km

The energy consumption depends on the overall system layout and the duty cycle. Buses are heavier and can regenerate braking energy. The combustion engine can be run more efficiently. The highest savings, up to 30%, can be achieved in heavy congested urban stop and go traffic.

The higher empty mass can affect the passenger capacity.

Infrastructure

Depends on the fuel of the internal combustion engine.

Plug-in types require a charging infrastructure in addition.

Environment: GHG and pollutant emissions

TTW GHG emissions are generally lower than the respective powertrains with a single motive power source, because of the lower energy consumption. Because of the higher efficiency of the powertrain, the local emissions are also thought to be lower. However, exact effects for NOx rather depend on the duty cycle as the catalyst to reduce NOx may cool down when the engine is shut-off for longer periods of time.

Hybrid, diesel-electric		**Euro VI**
GHG WTT	CO2e/km	1054
NOx TTW (local)	g/km	0.5-1.1
PM10[1] TTW (local)	g/km	0.015

[1] Excl. PM from brakes, tyres and road. Because serial hybrids have regenerative braking, the PM emission from the brakes is lower than for conventional vehicles.

Noise

Noise emissions are lower when a bus operates fully electric.

Standing: 69 dB; Pass-by 73 to 78 dB depending on the driving mode

Cost

Indication purchase price: 220,000-300,000 euro per bus

Due to the higher complexity and more components, hybrid buses are generally more expensive than a conventional diesel bus. This can be up to 50% and depends on the level of hybridisation.

Things to take into consideration

Hybrids (especially serial hybrids) also offer the opportunity to undertake short distances in purely electric drive. A precondition is an electrification of the auxiliaries. This option is particularly attractive where the route crosses a densely populated area or ancient city centre, where low levels of noise and local emissions are required to reduce local pollution.

Main advantages: lower fuel and energy consumption in (heavy-) urban traffic.

Main disadvantages: More costly and probably heavier (a heavier bus will lead to a reduced number of passengers given the same amount of axles).

Hydrogen

Hydrogen fuel cell buses are powered by fuel cells which convert the chemical energy of hydrogen into electricity and deliver electrical energy into the powertrain. Hydrogen is, typically, stored compressed in tanks on the roof of the bus with hydrogen refuelling facilities normally located at the bus depot. These buses produce no TTW greenhouse gases or air pollution in use; water vapour is the only tailpipe emission.

Hydrogen can be produced from a variety of sources including fossil fuel-based industrial processes and the electrolysis of water using renewable electricity.

Three types of bus technologies running on hydrogen are available on the market:

1. an internal combustion engine running on hydrogen.
2. a serial hybrid hydrogen fuel cell with electric battery and drive, without or with a small battery (fuel cell dominant),
3. a serial hybrid hydrogen fuel cell with electric battery and drive (battery dominant)

The first option was tested by OEMs and appeared not a feasible one for buses. The second one has already been used previously, but did not prove to be very efficient. The latter is the recommended option.

Hydrogen buses with fuels cells employ these cells to convert the chemical energy from the hydrogen into electricity for motive power. Typically, PEM (Protone Exchange Membrane) type fuel cells are used. A battery is used to buffer the energy produced by the fuel cell stack which cannot be run very dynamic power outputs and a battery can also be used to store regenerated energy from braking. Large tanks are needed and are typically placed on the roof to store the hydrogen under very high pressure (350 or 700 bar) and a special infrastructure (filling station) is needed to fill the tanks to the required high pressures. Another option is to use an on-board reformer, but this will probably offer little or no GHG benefit.

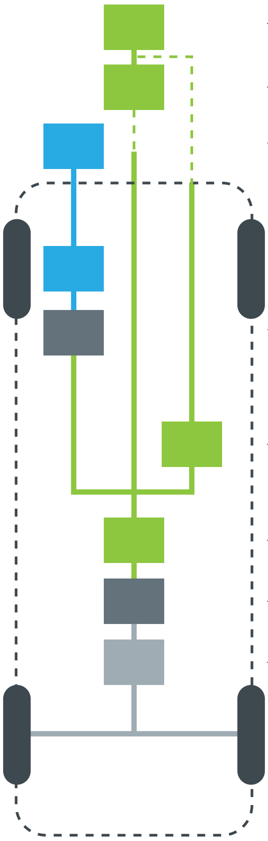
Hydrogen can be produced in several ways, either from steam reforming from natural gas, via conventionally or renewably powered electrolysis and by the conversion of a hydrocarbon fuel such as methanol, ethanol, natural gas. The energy use and GHG emission of the hydrogen fuel therefore depends on its production process. Nowadays, hydrogen fuel is not widespread yet, but it is considered as one of the most promising options for the future.

A hybrid bus configuration of fuel cell stack, and battery-electric drive is currently seen as a promising option for buses, because of the potential to use renewable electricity to produce the hydrogen. This may, in theory, yield high GHG reductions. However, the technology is still in its experimental stage, is not yet widespread and is therefore very expensive. In addition, one can debate whether it is efficient to use electricity to produce hydrogen, because the electricity can also be used directly for electric battery vehicles.

Hybrid hydrogen fuel cell bus

Bus technology using a serial hybrid configuration of a fuel cell stack and an electric drive. An electric battery is generally used as accumulator to store energy produced by the fuel cells and to store energy that is recuperated by braking. The hydrogen to fuel the fuel cells is stored in cylindrical tanks at a pressure of typically at 350 bar.

SERIAL HYBRID: HYDROGEN FUEL CELL



Operational performance

Range: 200 – 400 km, the range depends on tank size of hydrogen and the storage pressure. A higher pressure of 700 bar would increase the range at the same volume of the storage tanks.

High flexibility in routes.

Refilling every day at the end of operation.

Short refilling time: 10 min

Energy consumption 2016: 3,1 kWh/km

The higher empty mass affects passenger capacity. This can be solved by adding an extra axle if a high capacity is needed.

Infrastructure

Hydrogen requires a specific filling infrastructure, that includes a specific dispenser and supply infrastructure to provide the hydrogen to the vehicle at 350 bar. Hydrogen fuelling stations by today are relatively scarce in Europe, but new stations are being build, mainly in Germany, Italy and Scandinavian countries.

Environment: GHG and pollutant emissions

Local pollutant emissions and TTW GHG emissions are zero.

WTT GHG emissions depend largely on the production method.

Hydrogen, fuel cell electric	**Examples pathway**		**Euro -**
GHG WTT	EU mix (thermal)	CO2e/km	1290
	NG 7000km (electrolysis)	CO2e/km	2516
	Electricity EU mix (electrolysis)	CO2e/km	2849
	Electricity wind (electrolysis)		47
NOx TTW (local)		g/km	0
PM10[1] TTW (local)		g/km	0

[1] Excl. PM from brakes, tyres and road. Because fuel cell hybrids have regenerative braking, the PM emission from the brakes is lower than for conventional vehicles.

Noise

The noise emissions are low and comparable to electric buses. The cooling fans that cool the fuel cell stack can produce additional noise compared to electric buses.

Costs

Indication purchase price: EUR 800.000. Mainly prototypes or special build, very small series are available.

Without economy of scale the technology will remain expensive.

CAPEX are high due to the fuelling and supply infrastructure which are very expensive.

Maintenance cost are still high, this is partly caused by the fact that most buses are prototypes.

Things to take into consideration

Hydrogen fuelling stations are relatively scarce in Europe, but new stations are being build, mainly in Germany, Italy and Scandinavian countries. As of 2012, approximately 58 refuelling stations are under operation in Europe, mostly in Germany. Approximately 30 additional stations are in preparation through 2015 throughout Europe. GHG emissions from buses using hydrogen highly depend on the hydrogen production method.

Main advantages: hydrogen buses are one of the cleanest available technologies given the local zero emission of pollutants and lower noise emissions. Electricity can be produced from sustainable sources.

Main disadvantages: The technology is not mature yet. Safety concerns are associated with the high pressure fuelling and storage of hydrogen. The powertrain is less efficient than a full electric one. Very high vehicle and infrastructure costs.

Comparison

In this chapter, the bus technologies and energy carrier options have been compared. The following criteria have been used for the comparison:

Environment

- Air quality: NOx and particulate matter emission
- Climate: WTW GHG emission
- Noise

Operational

- Route flexibility
- Charging time
- Autonomous range
- Infrastructure
- Maturity

Economy (qualitative)

Air-quality

In general, the Euro VI diesel bus already provides a good improvement on local emissions compared to earlier generations. In heavy urban driving conditions (low commercial speeds), the NOx emissions of Euro VI diesel buses may still increase as the emission reduction catalyst (SCR=Selective Catalytic Reduction) cools down. The liquid biofuels will have comparably low local emissions as of Euro VI and the gaseous fuels will probably still show a small advantage. The full electric and hydrogen buses have zero tail pipe emissions and therefore represent the options that lead to the largest improvement in local air-quality. Buses with an electric propulsion brake partially electric. This leads to a reduced emission of particles from the brakes.

Page 43. Representation of the criteria air-quality, climate and noise of the bus concepts.

Air quality: considers NOx and PM10

Climate: GHG figures are expressed in gCO_2eq (per MJ of the final fuel) as the sum of the contributions of CO_2, CH_4 and N_2O taking into account their respective Global Warming Potential (GWP).

1 hybrid diesel-electric buses emit no NOx and PM if they can and are running in zero emission mode. During zero emission mode the NOx reduction system may cool down and afterwards temporarily operate less efficiently, possibly resulting in locally higher NOx emissions. Exact effects depend on the drive cycle.

2 no emission data available

3 ILUC, indirect land-use change is likely to increase WTW CO_2 emissions significantly.

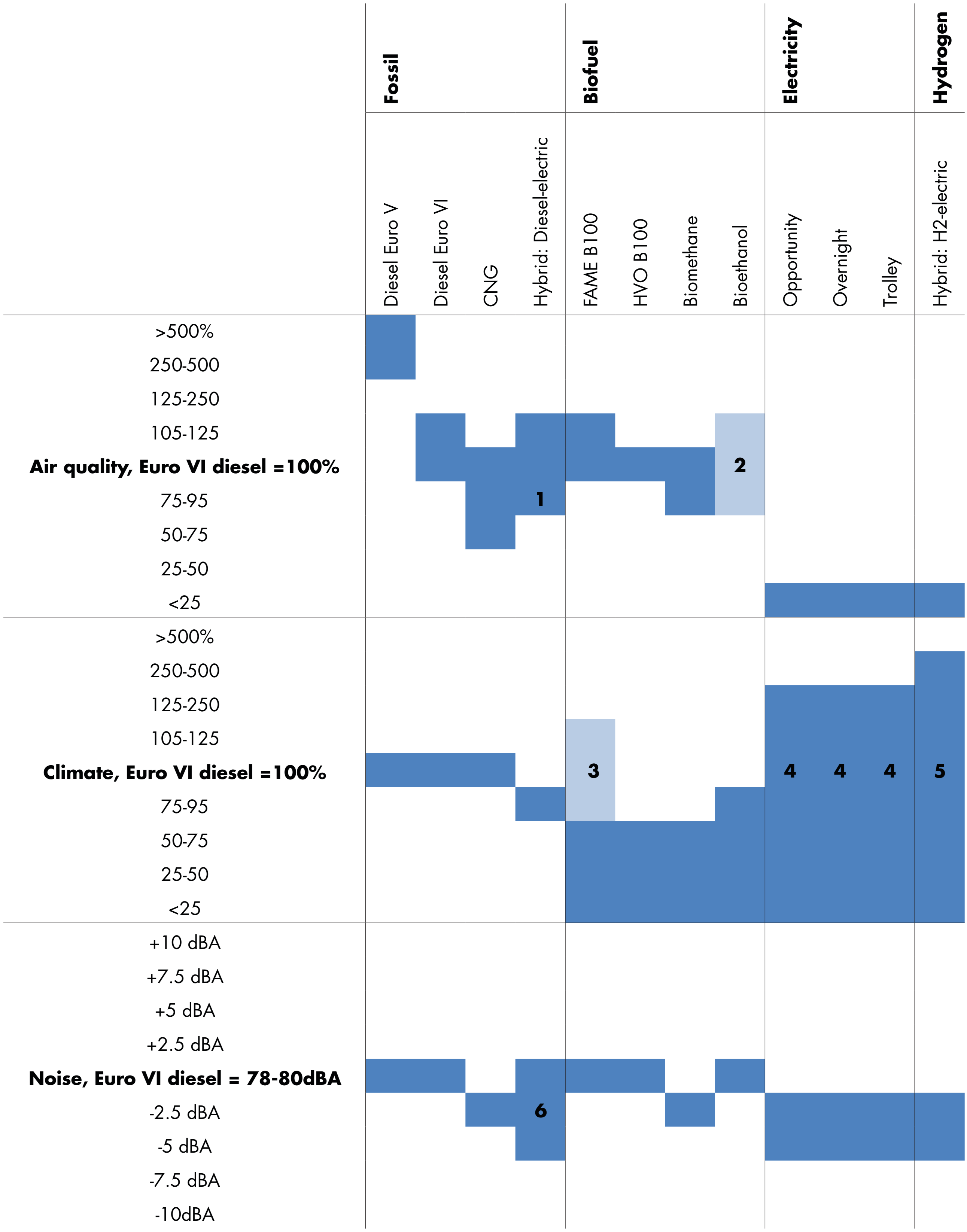
4 highest GHG emissions for production of electricity from coal, lowest from sustainable sources in this case wind. The WTW GHG emissions of the medium EU mix for electricity is 30% lower than diesel GHG emission.

5 WTW GHG emissions are high for electrolysis using electricity from a non-renewable source. GHG are low for electrolyses with a renewable source, e.g. wind.

Reforming using natural gas (EU mix) leads to comparable GHG emissions as diesel.

6 diesel electric hybrids, that can run in zero emission mode, produce noise emissions comparable to diesel buses in diesel mode but less noise in full electric zero emission mode. Advantages of electric propulsion is greatest at low speeds and when idle. At speeds higher than 50-60 km/h, noise levels of technologies converge as noise from the tyres becomes more dominant.

Environment: air-quality, climate and noise



Climate

In the case of biofuels, electricity and hydrogen, the total produced WTW GHG emissions are very much dependent on the pathway (production and distribution) of their fuel/energy carrier. Depending on the exact pathway, the WTW GHG emission can either decrease or increase compared to the Euro VI diesel bus. For bioethanol and biomethane, most pathways lead to a reduction of the WTW GHG emission, however differences between fuels can still be substantial. Also for FAME and HVO, large differences exist between the GHG emissions of the pathways. For these fuels, the differences largely depend on the feedstock and the effect of ILUC (indirect land-use change) for some specific crops which may increase GHG emissions substantially. For electricity and hydrogen, certain production methods (coal, electrolysis) may still lead to a large increase of the WTW GHG emissions and others (wind, solar) to a very large decrease of the WTW GHG emissions. When climate is an important driver, one should therefore certainly consider the source of the energy and the GHG emissions of the pathway. To make sure that the supplied electricity or fuel meets the required specification regarding the projected GHG emission, it is advised to arrange it in a contract and for instance demand certificates from the fuel/electricity supplier.

The experts distinguish between Tanks to Wheel and Well to Tank emissions that together form the so-called Well to Wheel emissions.

TTW (Tanks To Wheels) refers to emissions produced by the burning of the fuel and is emitted at the tail pipe of the vehicle. Electric buses do not have TTW emissions, fuel cell hydrogen buses only emit water, hence they are often called 'zero emission buses'.

WTT (Well To Tank) refers to emissions emitted during fuel or electricity production and distribution. Especially for bio-fuels, electricity and hydrogen, a large variety of pathways exit with possibly large differences in GHG emissions. For bio-fuels produced from certain types of crops, indirect land-use change is likely to increase the WTT CO_2 emissions significantly.

WTW (Well To Wheel) refers to the total emissions produced during fuel/electricity production, distribution and the burning of the fuel.

For the determination of the greenhouse gas emissions, not only CO_2 emissions are considered but also CH4 and N2O, gases, which have a very high global warming potential (GWP) and which may be emitted by the vehicle or during production and distribution of the electricity or fuel. These emissions are summed up, taking account of the GWP of each gas and are often expressed as CO_2e or CO_2eq.

Noise

Although noise from diesel engines has gradually reduced over time, due to improvements in diesel engine control and hardware, buses with a diesel powertrain still emit a substantial amount of noise. Introduction of electric, hydrogen and hybrid buses generally reduces environmental noise [Hill et al., 2012]. External costs for noise of buses are substantial and vary depending on the time of day. Diesel electric hybrids that can run in zero emission mode, produce less noise in full electric, zero emission mode, but produce comparable noise emissions in diesel mode. The advantage of electric propulsion is greatest at low speeds and when idling. At speeds higher than 50-60 km/h, noise levels of technologies converge as noise from the tyres becomes more dominant.

Notes on energy security

From [Hill et al., 2012]

"…In the short-term, conventional fuels score well because a high proportion of the vehicle fleet is able to use them and prices are currently low. Costs are projected to increase over time, and indicators for surplus capacity show that oil-derived fuels become less secure as global stocks are depleted.

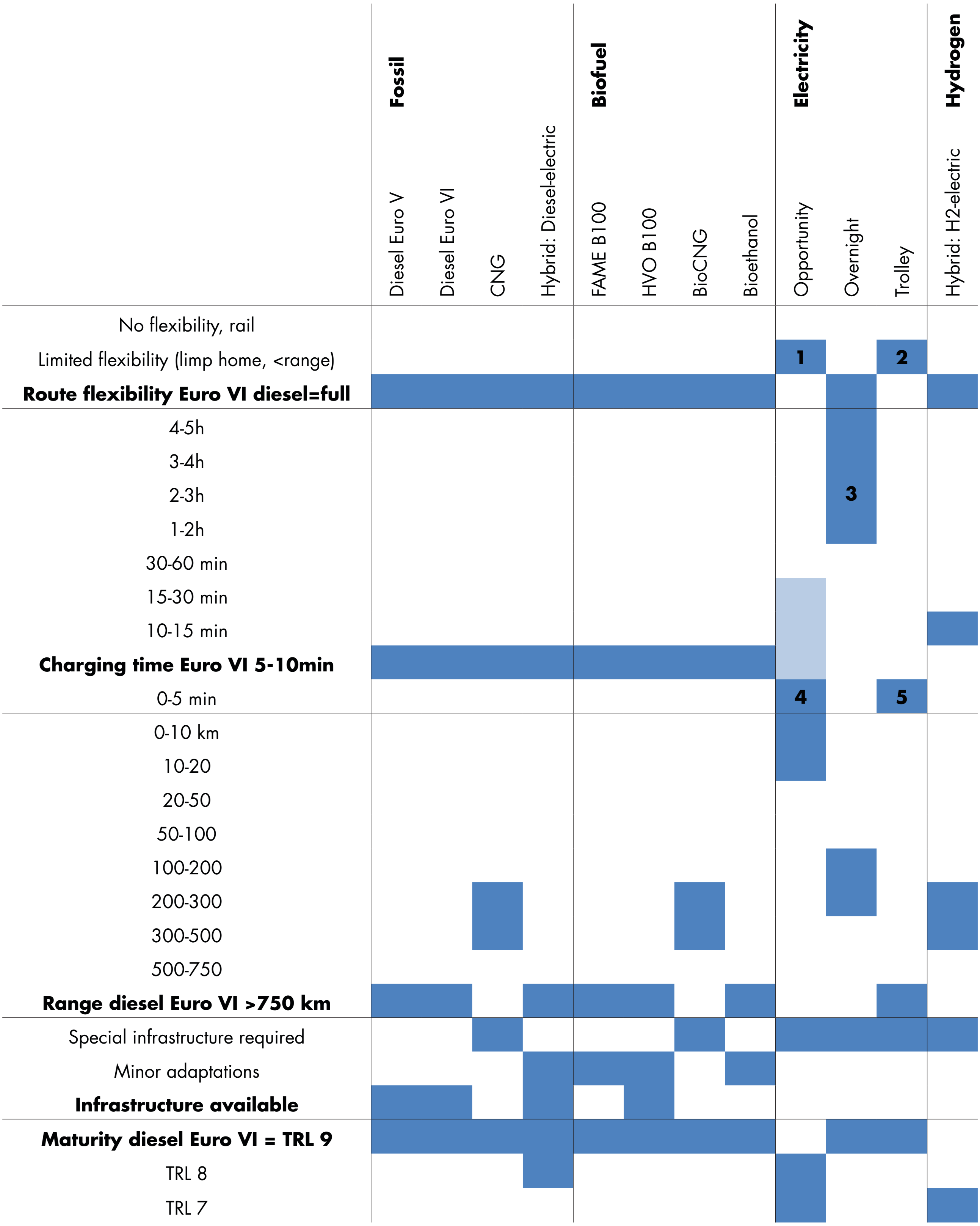
In the longer term, oil-derived liquid fuels also become more susceptible to supply disruptions. Biofuels also show a reduction in energy security due to increasing resource concentration, poorer supply resilience and a lack of surplus capacity.

Electricity and hydrogen are the only fuels that become more secure, due to increased contributions from renewable technology production.

GHG policies could lead to significant benefits for transport energy security…"

Operational performance, infrastructure, maturity

Representation of operational characteristics of the bus concepts.



1 opportunity charging electric buses have limited route flexibility as the battery is relatively small and the vehicle needs to drive from charging point to charging point.

2 trolley buses obviously have a low route flexibility due to the fact that they need the overhead wires to operate. Usually though, trolley buses have an auxiliary power unit (generator set, battery pack) that provides some autonomy (e.g. for limp home).

3 Charging time for overnight charging electric buses largely depends on the battery and charging system. At a relaxed charging speed of 0.2C it takes 5 hours to fully charge the battery, at fast charging at 1C it can take an hour for a full recharge. In general, faster charging decreases the battery lifetime.

4 Opportunity charging electric buses are charged during regular bus stops. Depending on the set up of the charging system, the battery and the topography and line characteristics additional stop time may be needed.

5 Energy supply is in principle continuous through the overhead wires.

TRL 7.	system prototype demonstration in operational environment
TRL 8.	system complete and qualified
TRL 9.	actual system proven in operational environment (competitive manufacturing in the case of key enabling technologies; or in space)

Autonomy (range) and charging time

All buses, except electric 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 the overnight electric 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 in normal operation. Operating range in purely electric mode (which is very important from emission reduction point of view) varies a lot per bus technology, with diesel trolley bus, hydrogen fuel cell and parallel hybrid offering the highest values.

Infrastructure

Bus fleets with diesel buses often have their own fuel depot that is supplied through normal fuel distribution over the road. For the buses running on biofuels small modifications may be necessary to the depot.

For CNG and biomethane a connection is needed to a gas network and in that case still needs to be compressed. Or the gas can be supplied over the road.

For electric and hydrogen buses a special charging or filling infrastructure is required which at the moment is not present in most cities.

For electric buses the infrastructure may be a dedicated system to match a certain bus type (battery and charging system (plug, inductive, pantograph)) and can, depending on the concept chosen, be placed on different locations. 'Overnight charging' will most of the times be done end of bus line, at central locations or in the depot. Opportunity charging will be performed along the bus line. Trolley buses require a special overhead wiring network. Cities with such a network can keep on using it and take advantage of the low local emissions and if electricity is renewable, the advantage of low GHG emissions as well.

Hydrogen buses require a dedicated filling station which is able to fill the hydrogen at 350 bar. The hydrogen needs to be produced on location and stored temporarily at high pressure, or the hydrogen needs to be transported over the road to the filling station.

Maturity

The main advantages of the diesel bus are its high maturity, the long history of exploitation and the well know operational performance, reliability and costs of these buses. This also accounts for CNG buses.

Diesel/electric hybrid buses have already been in production for a number of years and are starting to find a niche in some European countries. The technology is mature, but experience with the operation and servicing of this type of bus technology is lacking behind (less than 1% of EU PT Bus fleet is hybrid as compared 17% in the USA. Plug-in hybrids with substantial autonomous zero emissions range are not very common in 2016.

For battery electric buses, many pilot programs have been running in the last decade throughout Europe, which means that the experience with this technology is growing

rapidly. The buses powertrain itself is relatively mature while batteries, charging infrastructure and also the auxiliaries on-board (HVAC) are still developing in time. Batteries can carry increasingly more energy per unit of weight and can be charged faster. New charging solutions, like opportunity charging (pantograph, induction, in-motion charging) are being extensively trialled in several cities in Europe and new HVAC technologies and controls are being developed to reduce the use of energy from the battery. The operation of battery electric buses on a small scale on a less intensive bus route was challenging years ago. Nowadays, battery electric buses are employed in gradually growing numbers and on more intensive bus lines in more than 30 cities in Europe.

Pilots programs have been running hydrogen fuel cell electric buses since the late 1990s. The technology of the fuel cell is not mature yet. The integration of this technology in the powertrain of a bus is rapidly improving and seems to converge to the technology of battery dominant fuel cell buses. This concept which uses a relatively large battery has several advantages: the battery is able to store a lot of the energy from regenerative braking and can act as a buffer for the electricity produced by the fuel cells. This is an advantage, since fuel cells cannot deliver their electric power very dynamically.

Trolley buses have been in operation for decades in specific cities and are considered to be a mature technology. Experience is mainly with the operators who employed this type of bus.

Economy

Any cost estimate needs to be taken with care, as they often have an indicative purpose and can vary from case to case (especially operational costs being depended on fuel taxes, labor costs, etc). Total Cost of Ownership (TCO) analysis in principle, takes into account all CAPEX and OPEX that accrue to the bus operator during the expected life cycle of the vehicle, but exact TCO values cannot be presented. Figures depend on a large number of costs which can vary a lot per city and technology.

Buses running on fossil fuels and biofuels are probably still currently the cheapest available technologies. CNG and bioethanol buses have relatively low purchase prices, but additionally require a high investment in the fuelling infrastructure. The purchase price of buses running on electricity is higher as the purchase price of a diesel bus (from 30 to 100% higher of diesel Euro V bus price) and are highly dependent on the price of the electric battery. The battery technology is becoming better and cheaper. Hybrid hydrogen buses are the most expensive bus technology presented.

Diesel buses and trolley buses have been in operation for a while and 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 information about the residual value of the vehicle, maintenance cost and battery replacement costs are not yet widely available.

The unit production costs of hydrogen buses are very high but have been decreasing and are likely to decrease further in the next decade. However, hydrogen buses will have intrinsic high costs associated to the technology. This is caused by the expensive fuel cells, high pressure storage tanks, the traction battery and the special infrastructure.

Other considerations

When choosing a bus technology, local decision makers might also find it useful to take the following in consideration:

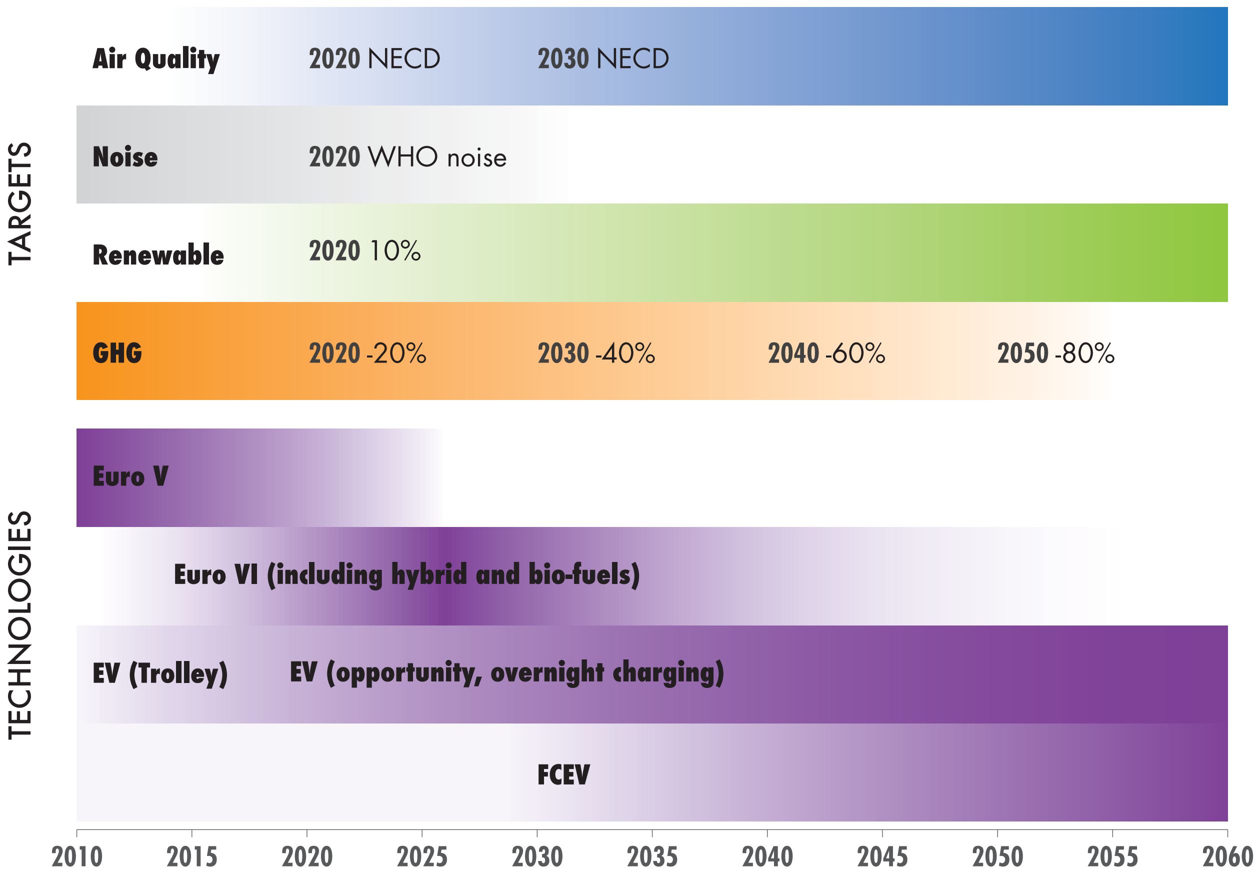
- CNG buses, as well as bioethanol, hydrogen and hybrid diesel/electric buses have higher safety concerns;
- HVO, bioethanol, bio-CNG and hydrogen represent attractive alternative fuel options for buses, but current European production of these fuels is still very limited;
- Buses running on electricity are nowadays considered the most “clean” technology.

Choosing the right bus for your city

There is no single best solution for all cities. The most appropriate bus option(s) for a city will depend on a number factors:

- The local conditions (topography of the city, climate, bus line characteristics).
- Local opportunities:
  - The existence of a certain type of infrastructure (e.g. trolley network).
  - Local, regional development (technology).
  - Local availability of resources (e.g. fuels).
- The city and regional development plans (mobility, housing, employment, …).
- Health in terms of local air quality and noise emission levels.
- Budget.
- The cities policy on GHG emissions.
- The cities policy on energy security.
- Imago building (green city).
- Fit to policies at different other levels (national, supra-national) (sustainability, energy security, renewable energy, air-quality and urban mobility)

Example of technology transition, matching short and long term targets.



All are probably important criteria and the list may not be exhaustive. Also the importance of each of the criteria might differ from city to city and the time horizon for fulfilling the may be different too (consider short term vs. long term). Therefore, the local authority first needs to:

- identify the relevant criteria,
- prioritize the criteria and
- define the time horizon (short term vs. long term).

Examples of criteria important for the Short Term are 'Health (Air- quality and noise)', 'green city frontrunner', 'economy (employment)', 'urban mobility'.

Examples of criteria important for the Long Term are 'energy security', 'climate', 'future efficient mobility system'.

In addition the following could be considered.

- Start now. Not necessarily with a big bang, but phase-in your new technology. This helps to gradually bring this new technology to the market, break through the well-known 'chicken and egg problem' and will help to accelerate towards economy of scales.
- Harmonised methods for procurement should allow enough freedom for new and better solutions.
- Removal of restrictions in the technical specifications of a tender can lead to increasingly more creative solutions, offering better services for the whole public transport chain.
- The main players (PTO, PTA and OEMS) need to enter into dialogue and discuss options in the light of private and public goals, and start building knowledge, experience and confidence together. Affordable and timely implementation of complex technology projects is crucial to meeting deadlines for EU environmental legislation.
- Competitive dialogue as defined by EU Procurement Directives should be considered.
- Use local opportunities. This may additionally benefit regional development.
- Move away from TCO and focus on Total Financial Engineering and include the valuation of societal impacts. Today, the TCO is considered as the tool that could help to justify a choice for a certain bus concept. In the TCO, however, often only the CAPEX (capital expenditures) and OPEX (operational expenditures) are considered. Given the possible goals of cities regarding air quality, noise, GHG emissions and the use renewable energy, it is advised to include societal effects (for instance as external costs) explicitly in the evaluation. This should be also accompanied by city policies that would consider the internalisation of this cost that are usually external to the transport authority.
- Different financial and non-financial instruments are available and can be used to help implementing new clean technology:

Non-financial

- Concession period (to increase time of amortisation)
- Structure of the procurement (competitive dialogue[19])
- Structure of the concession
- Settlements for taking over buses
- The roll of public authorities (clear, consistent and steady goals and policies)

Financial

- Lease concepts
- Loans and participations
- Subsidy
- Valuation of societal impacts (noise, pollution, GHG emission)
- Warranties (removing financial risks)

19 EU Procurement Policy, Explanatory note Competitive Dialogue

Current decisions

Diesel buses have a relatively low purchase cost and TCO, offer a high route flexibility and benefit from a Europe-wide availability of fuelling infrastructure. The latest introduction of Euro VI diesel engine technology finally resulted in a very low pollutant emissions level. Efficiency, maintenance and exploitation costs are predictable for Euro VI diesel buses as well as the bus residual value in the second-hand market.

Sustainable biofuels reduce the CO_2 emission levels compared to Euro V and VI diesel bus running on fossil diesel. For these fuels local pollutants are at a comparable low level. In general, second generation biofuels (HVO) show lower levels of GHG 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 for its use. Sometimes some small technical modifications or modifications in maintenance are necessary. In the end diesel technology will be able to run 100% second generation biodiesel, like HVO. Diesel fuelling infrastructure can easily be adapted, and at low cost, for the fuelling of a biofuel bus.

Natural gas buses are readily available but the purchase price is higher than for the diesel bus. In addition, they require relatively expensive fuelling stations.

Buses running on electricity are currently considered as most environmentally friendly bus technology existing on the market. The GHG emissions largely depending on the electricity source, but for the EU mix of electricity production are lower than diesel. The technology also allows for a gradual growth towards the use of renewable energy. When the quality of the electricity mix becomes cleaner, the electric powered sources will automatically become cleaner as well. The local pollutant emissions are zero. At the same time, these buses are limited in the operational range: trolley buses are limited by their overhead network: opportunity and overnight charging electric buses are limited by the availability of charging infrastructure.

In cities with a trolley network, the utilisation and further development of this network is considered as 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%. The plug-in variant can offer an attractive bridging technology in the medium term.

Finally, hydrogen fuel cell buses are still in an experimental stage and as they are not a mature technology, they currently have the most expensive purchase price and require high investment in infrastructure network as almost no infrastructure is present. The technology will be extensively trialled in Europe in the next decade. As for electric buses, the use of renewable sources (solar, wind, ..) leads to large reductions of WTW GHG emissions. However, when hydrogen produced with electrolysis of non-renewable sources the WTW GHG emissions and energy consumption are significantly higher. There are some characteristics of fuel cell buses that need to be considered. The technology has an intrinsically lower energy efficiency than electric buses on the powertrain level. The buses are heavy due and lose passenger capacity because of that. Also the costs are expected to stay higher than other technologies, because of the complex powertrain which contains many expensive components (high pressure tanks, safety related components, a battery, fuel cells, if needed an extra axle to obtain a higher passenger capacity). In the shorter term hydrogen fuel cell buses technology will probably be an interesting niche for cases where local excess hydrogen is available and battery electric buses cannot deliver on daily production (the longer bus lines).

Achieving short and long term targets

Outlook

With an average lifetime of about 12 years, the buses that are bought today will remain in operation until at least 2028. Therefore, if EU 2020 and 2050 targets are to be achieved, changes must be made now, especially for the EU 2020 target.

For 2050, there is 60% GHG reduction target for transportation. For this target it could already be considered to make a start with the phase-in of technologies which can potentially fulfil this target in the longer term. For instance, full electric buses can run on electricity from both non-renewable and renewable sources. Implementation of such a new technology is a very challenging task, because financial limitations today have to be combined with a long term vision of zero emission for European Cities. Cost efficient decisions need to comprise of the consideration of 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. Under current economic conditions, the two key criteria for the decision-making for the development of bus technology in the city are **costs, pollutant emissions and GHG emissions** from the alternative technologies.

To meet the EU 2020, Renewable Energy Directive and Fuel Quality Directive targets, it will be necessary to run a part of the vehicle fleet on biofuels such as biodiesel, biogas, bioethanol or renewable electricity[20]. First generation biodiesel (FAME) is already mixed with diesel fuel up to 7% (by volume). This is the so called blending limit for standard diesel. Higher blending volumes are not possible because it is not compatible with many vehicles (especially cars). Buses are run in captive fleets with their own fuel station, so it is relatively simple to use a higher blend of biodiesel. This may be first generation biodiesel (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 less attractive 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 standardization 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, are the application 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) up to some 20%.

Large scale introduction of extremely low CO_2 technologies are needed from 2030 onwards, in order to have a full fleet of these technologies in 2050. However, technology which can achieve this, the full electric bus, is already entering the market. Electric bus technology and charging infrastructure is starting to become mature and several solutions are available to match the local needs regarding the supply of electricity to the bus. Electric bus technology comes with the advantages of zero local emissions and lower noise emissions than the conventional buses which means that this technology could contribute to a short term reduction of local pollutant and noise emissions. Electrification of the bus fleet will be challenging, because current processes regarding the purchase and operation of bus transport are still fully focussed on the use of conventional diesel buses. Plug-in hybrids could be the stepping stone solution in cases where very locally 'zero emission' is required, but the line demands high productivity and distances to be covered.

To meet the EU 2050 GHG targets, it is best to go for technologies with the lowest (well-to-wheel) GHG emissions, energy consumption and good possibilities for using renewable fuels or renewable energy sources. For buses, this would be full electric buses. Over time possibly also hydrogen fuel cell buses can have a role, although from the point of view of energy consumption hydrogen fuel cell buses are less attractive, unless for instance locally hydrogen is available as waste or by-product.

20 Kampman, 2013

Conclusions

In this study, bus technologies have been compared with regard to operational characteristics, pollutant (air quality) and greenhouse gas (GHG) emissions (climate), noise emissions, costs and maturity. Which technology to choose largely depends on the local situation, political motives, specific operational and environmental requirements that need to be met. This means that there is not one single best bus fuel and technology for all cities.

Furthermore, it is not only 'bus technology' that determines the sustainability of a bus, but also the quality of fuel in terms of Well-to-Tank (WTT) GHG emissions, used by a bus technology, which can either make or break sustainability.

Taking the main criteria into account, the following conclusions with regard to the bus technologies can be drawn:

- Diesel buses are still the most economical buses (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 almost diminished with the introduction of Euro VI diesel technology. Alternatively, the buses can run on biomethane.
- Buses running on biofuels are becoming more widespread. Their TCO is comparable to the TCO of diesel buses. Possible advantages of less pollutant emissions have diminished with the introduction of Euro VI diesel technology. Well-to-Wheel (WTW) GHG emissions from biofuels will highly depend on the particular type of biofuel and/or particular blend of that biofuel.
- Full electric buses are becoming commercially available. The powertrain is very efficient in terms of energy consumption. The WTW GHG emissions also depend on the production method of the electricity. Autonomy (range) and costs of batteries are still an issue. Several factors can influence the TCO and the operational capability and require specific trade-offs (both technical than operational and economic).
- Where trolley-bus network exists, wider utilisation of these buses should be considered.
- Hydrogen fuel cell buses are currently still in an experimental stage. Their local emissions are zero and the noise emissions are lower than diesel buses. WTW GHG emissions largely depend on the origin or production method of the hydrogen. Purchase costs for prototypes are very high and infrastructure is scarcely available.
- For both electric and hydrogen fuel cell buses, high investment costs in infrastructure are necessary.
- Hybrid buses have a little higher TCO than diesel buses, but can reduce WTW GHG emissions by up to 20-30%

Regarding the pollutant emissions, Euro VI combustion engines are a moving target. With NO_x and PM emissions at very low levels, the benefit for the air quality of the introduction of gas engines and zero emission technology has decreased significantly.

For buses with a combustion engine, as well as for zero emission buses, renewable fuels or energy sources are available. The GHG emission reduction is often very much dependent on the source and the production of the fuel or energy carrier.

The technologies have also been judged with respect to their ability to contribute to the 2020 and 2050 European objectives for 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:

- The application 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%).
- Start to consider the phase-in of electric buses, possibly with plug-ins as stepping stone to service long bus lines.

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

Full electric buses and in specific cases possibly also hydrogen fuel cell buses show the best perspective to contribute to the long term objectives. For electric buses this is because of the high energy efficiency. Both technologies can use solar or wind renewable energy.

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Glossary

CAPEX	Capital Expenditure
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	Hydro-treated vegetable oil
LNG	Liquid/liquefied Natural Gas
LPG	Liquid/liquefied petroleum gas
NO_2	Nitrogen dioxide
NOx	Nitrogen oxide
OEM	Original equipment manufacturer
OPEX	Operational expenditure
PM	Particulate matter
TCO	Total cost of ownership
TTW	Tank to Wheel
WTT	Well to Tank
WTW	Well to Wheel

NOTES

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Smart choices for cities

Alternative Fuel Buses

CIVITAS

CIVITAS
Cleaner and better transport in cities

POLICY NOTE