



Expert Group on Clean Bus Deployment

D.1 Technology/Trends

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1 INTRODUCTION

1.1 EU POLICY CONTEXT. TRANSPORT GHG EMISSIONS-RELATED TARGETS AND AIR QUALITY OBJECTIVES

Transport, which accounts for almost a quarter of total EU GHG emission, is part of the Effort Sharing Regulation that will have to reduce emissions by 30% by 2030 based on 2005 levels, together with other important sectors such as agriculture, buildings and waste management. Under the Paris Agreement, which aims to strengthen the global response to climate change, the EU has committed to “holding the increase in the global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels”. Different scenarios to meet these targets are explored in the European Commission’s 2050 long-term climate strategy; all require a reduction of transport emissions of at least 60% by 2050 in order to meet the objective of holding global temperature increase below 2°C; further reductions, going up to 90%, will be required in order to limit it to 1.5°C. Due to continuous fleet renewal, other emissions (local pollutants) are expected to improve dramatically by 2030.

1.2 CLEAN BUS DEPLOYMENT INITIATIVE BY DG MOVE: LINKS WITH OTHER INITIATIVES FROM THE COMMISSION

In the last few years, the European Commission has rolled out several initiatives to promote further deployment of clean buses. They are all interlinked and should be coherent and properly implemented. The recently adopted revision of the Clean Vehicles Directive, the DAFI Action Plan and the evaluation of the DAFI which is currently being performed are among them. They are closely linked to the initiative on Clean Bus Deployment.

1.3 CURRENT BUSINESS-MODEL SET UP IN EUROPE: STRENGTHS AND WEAKNESSES

There are various business models in the European Bus Market, which have an impact on the choice of technologies by regions and cities. See annex for a description.

2 DESCRIPTION OF POWERTRAINS AND FUELS

2.1 POWERTRAINS

Since transport must decarbonise and tackle air quality issues in the urban areas over the coming decades, it will be necessary to procure carbon-neutral and low/zero emission buses in ever increasing numbers. It is a question for cities whether they wish to procure buses which are zero tailpipe emission and have the potential to fully decarbonise (full electric and hydrogen), or other technologies which are not zero tailpipe emission but better than Euro VI. To this end, alternative fuels (gaseous and advanced liquid biofuels, and hybrid solutions) are also part of the solution.

2.1.1 COMBUSTION ENGINES

Combustion engines are currently the dominant powertrain in the European Bus market. Euro VI C buses are the minimum legal requirement for new EU buses: they are not the subject of this report but serve as a baseline comparator. Euro VI steps D and E will follow.

2.1.2 HYBRID

Hybrid vehicles represent an alternative propulsion system technology to traditional automatic transmission engines. The use of a hybrid-electric propulsion system allows for collection and re-use of kinetic energy normally wasted in braking and may allow for engine down-sizing and partial electric-only operation, including engine shut-off at idle.

2.1.3 PLUG-IN HYBRID

Plug-in hybrid buses (PHEVs) are hybrid electric vehicles with rechargeable batteries that can be recharged by connecting them to an external electric recharging power source or alternatively by an ICE.

2.1.4 BATTERY ELECTRIC

Full battery electric buses (BEVs) are vehicles with an electric propulsion system that uses electrical energy stored in rechargeable battery packs. Different types of charging system are available:

- Overnight charging: Battery electric buses are charged statically from the grid at the depot using mechanical and electrical equipment, mainly overnight.
- Opportunity charging: Battery electric buses are recharged on-route. They have medium battery capacity and need regular high-power charging from the grid at intermediate stops or at the bus terminal.

2.1.5 FUEL CELL ELECTRIC

A fuel cell electric bus (FCEV) is an electric bus that includes both a hydrogen fuel cell and a battery pack. The energy required for the bus to operate or recharge the battery, is provided by hydrogen stored on board. The fuel cell is used to generate electricity through an electrochemical reaction that produces only water and heat as by-products.

2.1.6 TROLLEY BUSES

Trolley buses are electric buses which are powered by two overhead wires. The current collection is made from two poles over the vehicle. This energy is not stored on-board the vehicle. Recent developments include the possibility to add energy storage on-board the trolley buses. This usually means that the trolley buses are equipped with batteries

but other options such as fuel cells are also possible. The energy storage on board the bus, allows it to operate where the overhead lines are not present.

2.2 FUELS/ENERGY CARRIERS

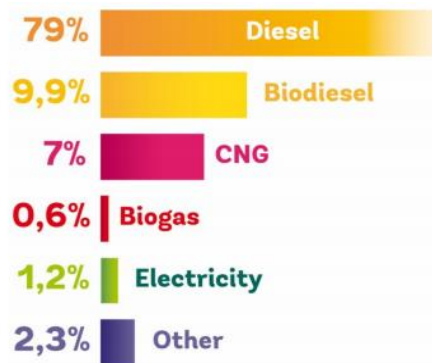
The availability of respective energy to operate the above-mentioned powertrains is fundamental for further deployment of the related technologies. Further deployment of alternative fuels will require investments in infrastructure and the adaptation of operational systems/strategies of city buses. Moreover, the investment in the production of the energy has to be considered. See the annex for fuels definitions.

3 SIZE OF MARKETS

3.1 TOTAL BUS AND COACH MARKET (CITY/INTERCITY/COACH)

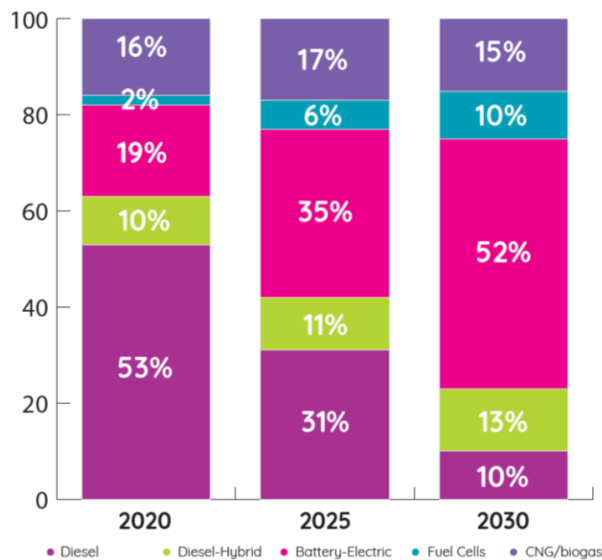
Total market development in the market below (vehicles equal or over 12-meter - the standard for city buses)¹ has been quite stable over the last 10 years with annual registration of approximately 28.000 units. The approximate split in volume for coach and city segment is 48% for high floor, medium floor and 52% for low floor, low entry, double deck buses (source: ACEA Bus & Coach (BC) Manufacturers).

The table below reflects the fleet composition (vehicles equal or over 12-meter) in the EU in 2013 (source: UITP).



3.2 TRENDS – POWERTRAINS AND FUELS

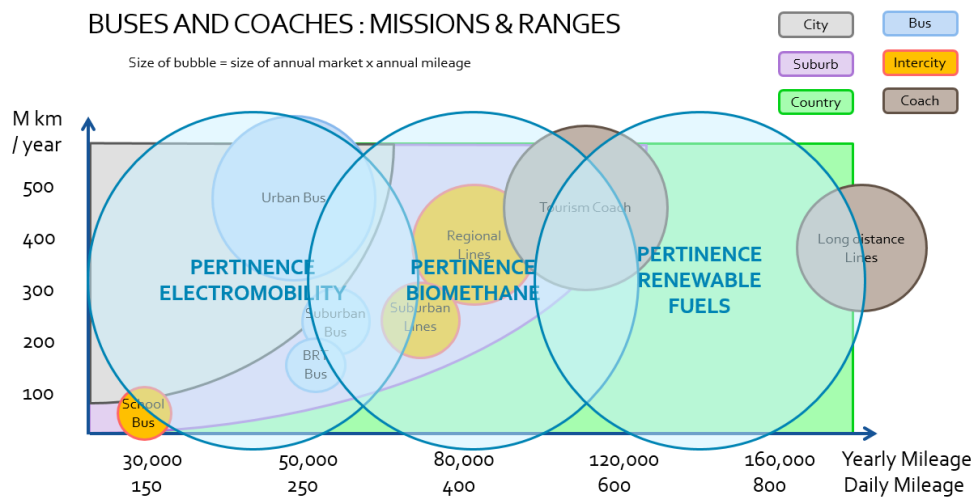
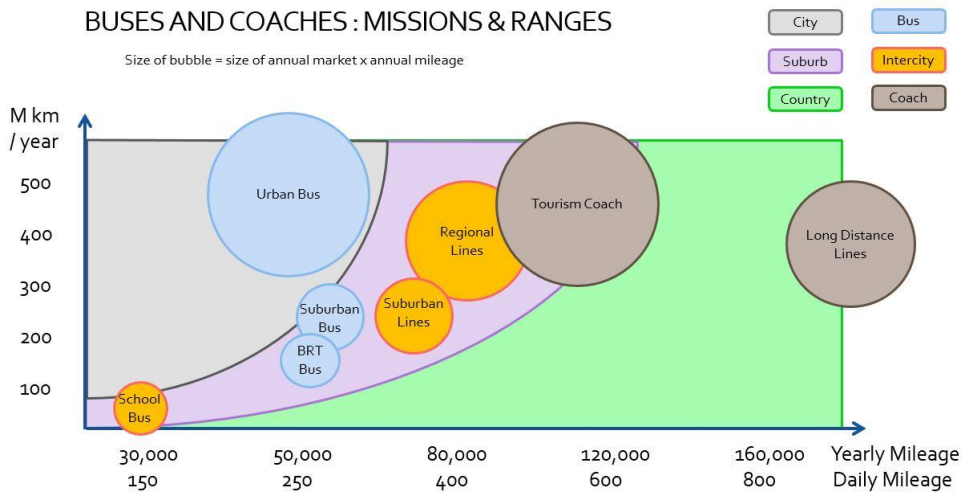
The graph below (source: ZeEUS and UITP VEI Committee) shows the trend up to 2030:



¹ New registrations of BC above 3.5t was 40.380 units in 2016 (ACEA Pocket Guide 2017-2018)

3.3 DESCRIPTION OF PUBLIC TRANSPORT SEGMENTS

Urban buses, intercity buses and coaches have different mission profiles and annual mileages. The pertinence of fuels and technology on each segment depends mostly on the daily mileage. For example, for regional or international lines as well as tourism coaches, renewable fuels, biogas and hydrogen might be the most pertinent to enable longer-range applications. On the other hand, battery electric buses are the most relevant for urban applications.



Source: Iveco, Daimler, MAN, Scania, Volvo

For electromobility, the range is a matter of energy storage capacity, operating concept and operating conditions including thermal comfort. Generally speaking, opportunity charge buses, trolleybuses and fuel cell buses would have more daily mileage potential than overnight charge buses.

4 INDUSTRIAL MATURITY AND TIMING

4.1 DESCRIPTION OF TRL (TECHNOLOGY READINESS LEVEL)

4.1.1 Vehicles

Diesel, CNG buses and trolley buses are all fully mature technologies and are on the market since decades. Aside from trolley buses, other electric or part-electric technologies are more recent and have different levels of deployment and market penetration. Fully electric buses have matured in recent years with more than 400,000 operating -under specific local political and social conditions- in China, with 9,500 new e-buses added each week². Some European cities are now embarking on an electro mobility strategy by procuring electric buses (e.g. tender for a thousand battery electric buses in Paris). Overall the market share for electric buses is expected to increase rapidly. Next to the approximately 1.800 battery electric buses already in use in European cities today, fuel cell electric hydrogen buses are close to full maturity and some cities have started to operate them (e.g. the first 45 buses in the Cologne region have started operation). The Chinese government has recently removed subsidies to support the uptake of fuel cell electric vehicles, a similar path that the one undertaken on the battery electric vehicles 10 years ago.

4.1.2 Energy and Network

The availability of respective energy to operate the above-mentioned powertrains is fundamental for further deployment of the related technologies. Further deployment of alternative fuels will require investments in infrastructure and the adaptation of operational systems/strategies of city buses. Moreover, the investment in the production of the energy has to be considered. As a short summary;

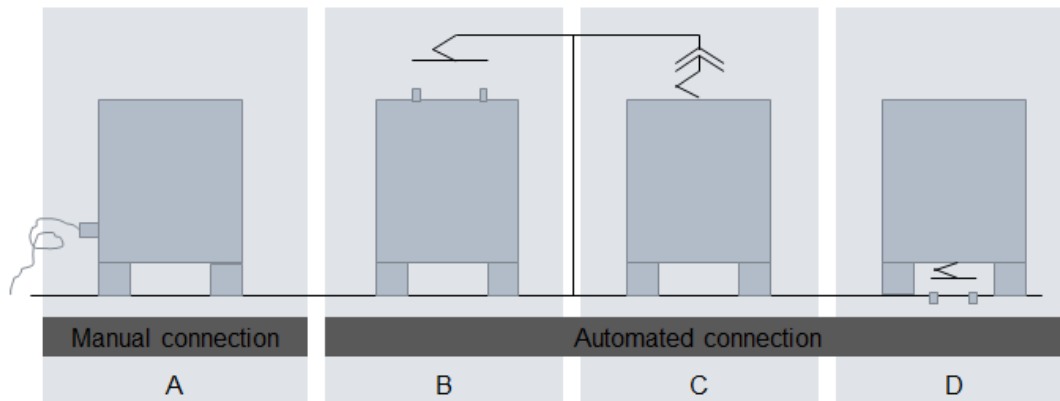
- Diesel (B7) is available all over Europe
- Biodiesel (B30/B100) and HVO/XTL Fuels are currently unevenly available across Europe. However, they can be delivered by existing tanker truck logistics wherever there is market demand and taxation is favorable.
- CNG - Gas supply is available in all countries and in most areas, with a specific infrastructure required to compress the gas at 200 bars.
- Electricity is available everywhere, with a suitable voltage and charging infrastructure needed at the depot, terminal and/or at bus stop.
- Hydrogen for fuel cell electric buses require refuelling stations to be installed (typically at the bus depot).

4.2 STANDARDISATION

Public transport stakeholders are currently developing a common standard to have the ability to use buses from different manufacturers and help inspire confidence in the technology.

² According to [Bloomberg New Energy Finance](#) (BNEF), an industry research firm focused on "helping energy professionals generate opportunities", China had about 99 percent of the 385,000 electric buses on the roads worldwide in 2017, accounting for 17 percent of the country's entire fleet: no details on the type/mission of the vehicles are provided though

Electric buses: Cen/Cenelec has got the mandate from the EU Commission to make a recommendation for standardization, to be decided end of 2019. Preliminary discussions show as follows with the following main standards:



*Source: UITP Standardisation Charging Committee

When it comes to fuel cell buses, an internationally recognised protocol SAE J2601-2 has been developed (*Fueling Protocol for Gaseous Hydrogen Powered Heavy Duty Vehicles*). No standardisation issues are noted on the fuel cell electric bus side.

CNG / LNG vehicles have standards for infrastructure and nozzles as well as components used on the natural gas vehicles. Interoperability is guaranteed through Europe.

5 COMPARISON OF TECHNOLOGIES

When comparing technologies, a number of parameters must be taken in to consideration. One obvious parameter is TCO (Total cost of ownership) but environmental benefits like PM, NO_x, CO₂, energy and noise are also very important. In a total analysis at a procurement situation for a bus operator there are also many other parameters that must be taken in to consideration: earlier experiences of a certain bus model, service network, spare parts, training, warranty, delivery time and others. In this report focus is on TCO and environmental benefits, but more information can be found in the newly updated UITP Tender Structure Document.

With regards to TCO, main cost parameters are

- Capital (function of purchase price of the system, interest rate and depreciation time)
- Fuel/energy
- Driver
- Maintenance /Repair / Tyres
- Admin/Garage / Miscellaneous (as far as the cost are directly linked to the vehicles, such as cost for infrastructure of refueling, recharging of new energy buses, taxes, insurances etc.)

When comparing various drive train technologies in terms of capital cost, it can be observed that a standard diesel bus is today normally the cheapest product among various bus technologies to purchase, followed by hybrids, gas buses, and up to various electric buses with higher initial prices. From a TCO point of view, capital cost is normally between 10-15 % of total TCO for a standard diesel bus.

Fuel for a diesel bus can also be estimated to some 10-15 % of total TCO, but energy cost for an electric bus is much lower compared to a diesel bus. However, for electric buses cost for battery contract and/or battery exchange during a life time of 8-10 years has to be added, unless it's not included in price of the bus itself. However such cost shall be recognized in maintenance & repair.

The remaining cost for maintenance & repair, and admin/depot can be estimated to some 20-30 % in total.

For the purpose to compare different drivetrain solutions, in terms of environmental friendliness, however the cost of the drivers can be neglected due to the fact that the drive train solution has no impact on the cost of the drivers.

Costs related to a technology must also involve the maintenance of the energy supply devices and related organization to commit to system availability rate (such as uptime / surveillance for the chargers overnight & opportunity charge or gas compression redundancy). These costs are those to be paid by the operators and PTAs.

Alternative powertrains can lead to attractive TCO or not, compared to Diesel, depending on the mileage, price gap between fuels or energy, local incentives and tax conditions.

Fuel & energy consumption can be estimated thanks to the standardized protocols, known as SORT. They are written and published by UITP. Such protocols exist for ICE vehicles diesel (liters / 100 km), gas (kWh / 100 km) and electric (kWh / km) including battery electric and fuel cell hydrogen vehicles.

CO₂ Emissions can be calculated Tank-to-Wheel, by multiplying fuel consumption by the CO₂ conversion factor. These values have been set and released in February 2019 according to CONCAWE/JEC (2018).

The CO₂ values are the one applicable according to the Second Mobility Package of the Commission, related to the upcoming proposed CO₂ Declaration which in that case becomes mandatory for bus & coaches by earliest 2021. The technical methodology to declare CO₂ emissions will be the VECTO tool Eventually the VECTO tool shall replace

SORT measurements over time. It is important to underline that the VECTO tool and Tank-to-Wheel method does not address the whole CO₂ emission picture.

In addition, it is important to take into consideration the CO₂ emission reduction brought by renewable fuels, gaseous or liquid. The same principle, as an addition, can be applied to the electricity employed for powering and recharging e-buses. In that case, this is known as the Well-to-Wheel concept.

PTAs and operators can monitor separately their CO₂ emissions as WTW, in order to keep track of the total CO₂ emission. This can be done by using UITP Tender Structure Document Annex IV.

In addition, ZEV (Zero Emission Vehicles – see definition below) bring additional benefits to the community. Research brings evidence of noise reduction and no local pollutants (PM, NO_x).

The revised **Clean Vehicle Directive** is discarding the monetization principle. The clean vehicles must now be chosen between a set of defined technologies:

- 1) Zero emission vehicles;
 - A zero-emission HDV is a vehicle without an internal combustion engine, or with an internal combustion engine that emits less than 1 g CO₂/kWh, or that emits less than 1 g CO₂/km; this includes electric vehicles (battery, hydrogen fuel cell, trolleybus).
- 2) Low emission vehicles;
 - A low-emission HDV is a vehicle that is powered by alternative fuels as defined as in the Directive 2014/94/EU (so-called “DAFI” Directive).
 - ‘Alternative fuels’ should serve, at least partially, as a substitute for fossil oil sources and include, inter alia:
 - electricity (in case of plug-in Hybrid)
 - biofuels (liquid or gaseous fuel for transport produced from biomass)
 - synthetic and paraffinic fuels
 - natural gas, including biomethane, in gaseous form (CNG and LNG)
 - liquefied petroleum gas (LPG).

Their use in vehicles should be demonstrated through a contract or a similar instrument and shall not be blended with conventional fossil fuels.

The revised Clean Vehicle Directive sets to Member States percentage targets of acquisition of clean vehicles, applying to public procurement of Class I buses. Half of the target applicable needs to be zero-emission buses.

The percentage targets are:

Dates and minimum Targets of acquisition of Clean Vehicles for Public Procurement	from 2021 until 2025	from 2026 till 2030
De, Au, Fr, It, Es, Be, NL, Lx, Sw, Fi, CZ, UK	41 to 45%	60 to 65%
Other E.U. Countries	27 to 34%	33 to 47%

These targets do not apply directly to each contracting authority, but are set on the basis of the aggregate procurement in a given Member State. This means that, within a Member State, different levels of ambition might be set for different cities; each Member State will decide how to share the effort between different authorities when transposing the Directive.

Regarding TCO, it has to be noted that the resale value of vehicles is not taken into account, due to the fact that no set market exists for second-hand new-energy vehicles. A long concession duration (minimum above 8 years) is advocated in order to maximize the amortization of the vehicles and related infrastructures.

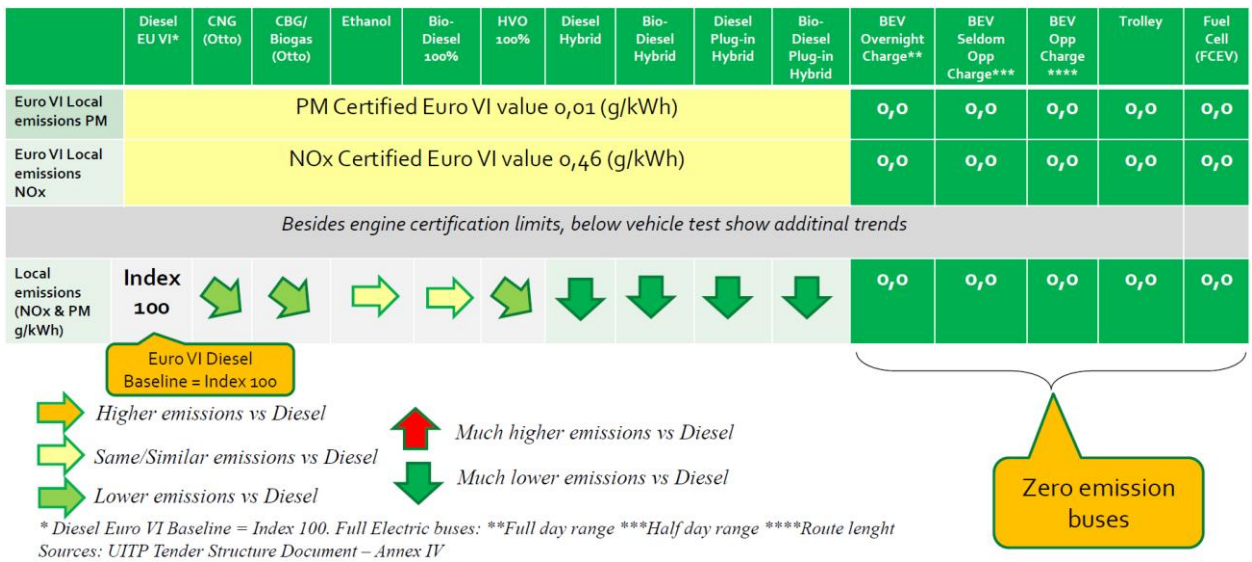
6 EMISSION COMPARISON OF POWERTRAINS AND FUELS

6.1 TOTAL EMISSIONS

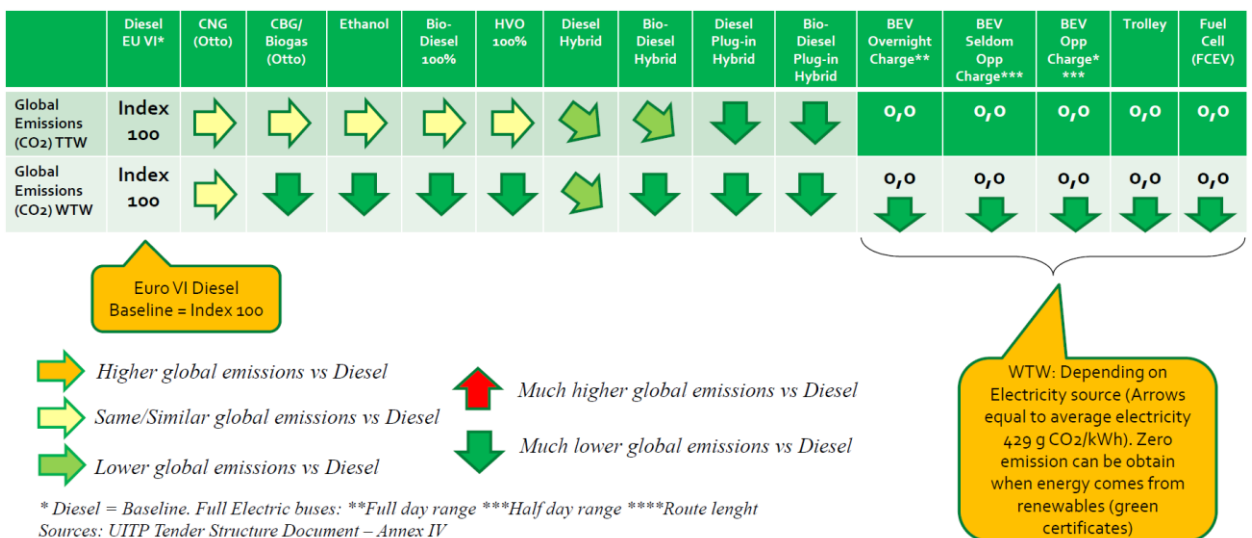
The current CO₂-legislation focuses on tank-to-wheel calculations, based on the responsibility for the vehicle manufacturers. However, from an overall perspective in relation to greenhouse gas emissions overall emissions levels, including upstream and downstream, should also be taken into account.

In terms of impacts on local air quality, on the other hand, the key issue is the level of tailpipe emissions of PM and NO_x.

Comparison of technologies – air pollutant emissions (baseline diesel EURO VI=Index 100)



Comparison of technologies: - CO₂ emissions (baseline diesel EURO VI=Index 100)

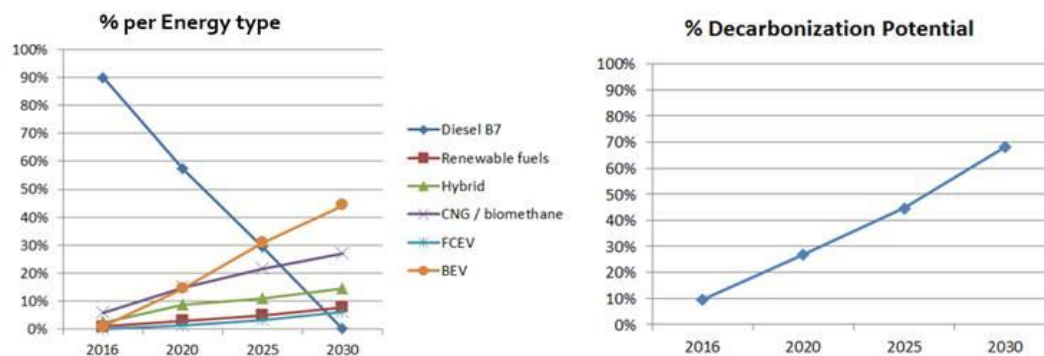


6.2 TREND OF RENEWABLE POTENTIAL OF ENERGIES IN EUROPE

Approximately 80% of new electricity generating capacity added to the EU grid is renewable. Therefore, the European electricity grid, looking towards the year 2050 is becoming lower carbon intensive and is more efficient than what can be delivered by any liquid fuel:

- Electricity: the average EU electricity mix was already below 300 gCO₂/kWh in 2016³, and its carbon intensity is expected to diminish further. Both BEB and FCB have the potential to be fueled with renewable or carbon free electricity and therefore can be zero emission – they are the only two technologies that can be zero emission.
- Renewable sources may provide a low carbon solution when produced from biogenic waste material or when its sourcing is shown to be sustainable as short-term cycle energy crops, or animal manure. However, the use of energy crops can lead to increases in indirect land use change and to undesirable environmental impacts (such as putting pressure on the amount of land available for food-growing crops). Liquid biofuels: can deliver a low emission solution when recovered from waste.
- Renewable gas: produced from various biomass sources and injected to the gas grid. Local production and use is also possible. There is also concern that methane leakage could offset the environment benefits of biogas (with 1-3% of the methane escaping during processing).⁴

This graph takes into account the choice between propulsion types and the evolution of their shares in the market in the next years (UITP), together with their renewable contribution, in order to visualize the trend of decarbonisation potential of the city bus fleet put in service.



Sources : UITP (energy split), Iveco analysis of European registrations

In recent contracts, PTA often request the use of green energy guaranteeing a complete emission free operation. This is done today by purchasing « Green certificates » and is applicable to biodiesel, biogas, electricity and hydrogen.

³ <https://www.eea.europa.eu/data-and-maps/indicators/overview-of-the-electricity-production-2/assessment-4>

⁴ <http://www.sgc.se/ckfinder/userfiles/files/EF2015-158+methane+emissions+measuring.pdf>, at page 8

7 CONCLUSIONS

Today alternative powertrains, fuels and supplies are available, providing low emission or zero tailpipe emissions buses. Further deployment can be enhanced through procurement. All the parties involved in public transport tenders need to adapt their business models to be part of a changing public transport landscape. The conclusion with respect to the main bus technologies are as follows:

- Diesel Euro VI buses serve as a baseline comparator.
- Combustion buses running on biofuels have comparable cost of ownership. Environmental advantages highly depend on the type and source of the biofuel. HVO fuels are the most common and, depending on sourcing and scalability, will have good environmental properties.
- Gas (natural and renewable gas) buses are available with comparable costs of ownership. On a WtW basis, CO₂ emissions can only be significantly reduced when using renewable gas. Future supply availability and scalability of renewable gas would require a case-by-case consideration. Dedicated investment in refuelling infrastructure is required for natural gas in general.
- Fully electric buses are zero tailpipe emission. Different charging systems exist and offer different solutions depending on range and recharging possibilities. Battery costs, range, and carbon intensity of the grid are improving which will provide additional benefits in the future. Dedicated investment in recharging infrastructure is required. The use of renewable electricity provides the best WtW performance of EVs.
- Hydrogen fuel cell electric buses are zero tailpipe emission and are a promising option for longer range applications or routes with high energy use. TCO is higher than Diesel Euro VI but is expected to reduce as technology continues to mature. Improvements to the carbon intensity of the grid will also provide additional benefits to future fuel cell buses. Dedicated investment in refuelling infrastructure is required.
- Hybrid diesel Euro VI and plug-in electric buses have comparable TCOs and abate pollutant and carbon emissions reductions to a level dependant on the route characteristics and size of the battery.
- While Diesel Euro VI is the baseline for this analysis, it is important to recall that at this point in time still a lot of older diesel buses are in use with emission levels below Euro IV (up to 45% of today's vehicle fleet), and there are specific situations where replacing these older bus fleets with internal combustion engine Euro VI buses can still represent an improvement in the short-term, especially when combined with renewable fuels.
- The potential for introducing cleaner buses is huge. A variety of technologies are available to serve the public transport demand for cleaner technologies in different areas. Especially in urban environments, zero-emission technologies offer the best outcome both in terms of local emissions and noise pollution. However, it has to be noted that there is no 'one size fits all' and that due to different operational requirements other technologies may be better suited in some cases, especially outside urban environments.
- It should also be taken into account that - even if the total cost of ownership is going down - the initial expenditure for clean technologies is still relatively high. Therefore, additional funding will be required in the next coming years to overcome this gap and come to mass deployment of zero- and low-emission buses.

Technologies should also be assessed with respect to the ability to contribute to European and local objectives for air quality and GHG reduction and to the Paris Climate Agreement objectives. An additional consideration relates to the opportunity to support the European industry's competitiveness.

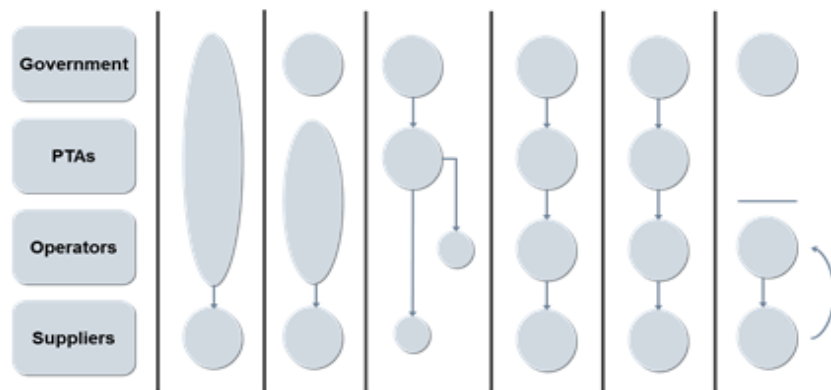
In an attempt to preserve air quality in cities, many municipalities have committed themselves to procure only Clean Buses and/or establishing Low Emission Zones or Zero-emission zones. Considering the lifetime of buses, these cities need to procure the appropriate clean buses or zero emission buses already today. Further decarbonisation performance, as required under the Paris Agreement, of all technologies, depends on renewable energy developments, together with issues around availability, scalability and origin.

ANNEX

CURRENT BUSINESS-MODEL SET UP IN EUROPE: STRENGTHS AND WEAKNESSES

There are several business models in the global bus business. They are detailed in the models 1 to 6 below.

BUSINESS MODELS EUROPE



2

1. Government & PTA & PTO as same entity (very rare – exist in the Middle East and other places outside Europe)
2. Traditional business model in Continental Europe (old examples from large cities, but is somewhat gradually changing to business model nr 4 or 5)
3. Traditional business model for cities in France outside Paris, where the PTA's is owning the buses and the PTO's are responsible for the operation
4. Standard business model in, for example, Scandinavian countries (Gross model), where PTA's are issuing tenders towards the PTO's that are offering their services for a fixed cost during the tendering period. Revenues to remain to the PTA's. PTO's running the operation on a km basis model. Especially cost to be managed by the PTO's
5. Coming business model in, for example, Scandinavian countries, where the revenue is transferred to the PTO's. PTO's to ensure passenger satisfaction to get revenues, but also to manage the cost of operation.
6. Final example from UK outside London and greater Manchester, where everyone can start a bus line and to collect fares based on certain fixed rules.

FUELS - definitions

DIESEL (EN 590 B7) - is still the main fuel for buses in Europe and it is available everywhere in the EU. Pollutant emissions from the latest Euro VI heavy-duty vehicles have been slashed to near-zero levels. Fuel consumption have been decreased too, delivering a significant reduction of CO₂ emissions. More than 90% of all buses are fuelled by standard diesel or with bio diesel. Today, conventional diesel contains up to 7% of biodiesel meeting EN 14214.

BIODIESEL (B30/B100) - the usage of bio diesel specifically differs a lot between markets, due to the actual supply of that fuel. The supply potential is big. However, each Member State applies a different taxation.

CNG - Natural gas engines and vehicles technologies are mature and available on the market. The CNG is stored at 200-250 bars on board the vehicle.

CBG/BIOGAS- Biomethane is a renewable version of natural gas produced from organic material. Bio-methane can be produced from renewables or feedstock of non-biological (gasification) and biological (anaerobic digestion and gasification) origin, such as energy crops, agricultural wastes and residues, animal manure organic fraction of municipal waste and sewage sludge.

ETHANOL- is the largest renewable fuel globally. It is mostly used as low blend (5-20%) fuel in petrol vehicles and in flexifuel (E85) vehicles. It is also available as fuel for heavy duty vehicles since 1990s for dedicated compression ignition (diesel) vehicles as a high blend fuel with similar energy efficiency as diesel engines, ED95, consisting of 95% ethanol and 5% additives and ignition improver. ED95 is an approved certification fuel for heavy duty vehicles in Europe.

XTL FUELS - are paraffinic fuels according to EN15940. Two categories of XTL fuels are commercialized: HVO and GTL. HVO is Hydro-Treated-Vegetable fuel. It is obtained from vegetable oils, used cooking oils, animal fat. As for Biodiesel, each Member State applies a different taxation for HVO. GTL is Gas-To-Liquid, transforming gas into synthetic liquid fuel. XTL are dedicated to replacing Gasoil used in Diesel-powered vehicle with very minimal adaptation or no adaptation. Unlike Biodiesel made through esterification, XTL has a good storage stability, lack of pollutants, good filtration properties and low oil dilution drawbacks. XTL/HVO should be added to the list of approved certification fuels in order to get all emission, CO₂ and fuel economy benefits in buses.