



Expert Group on Clean Bus Deployment

D.2 Procurement and Operation

This document has been prepared for the European Commission. However, it reflects the views only of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

Version 1.0

Prepared by:

UITP

Umberto Guida, Aida Abdulah

TransDev

Marc Vanhoutte

Reviewed by:

City of Copenhagen

Mikkel Krogsgaard Niss

Bolloré-Blue Solutions

Dorothee Coucharrière, Alexandre Desneux

hySOLUTIONS

Heinrich Klingenberg

Van Hool

VINCKX Luc

EIB

Per Als

CNH Industrial (IVECO)

Jean-Marc Boucheret

Alstom

Solene Messonnier

VITO

Carlo Mol

Hydrogen Europe

Sabine Skiker

POLIS

Thomas Mourey

ORGALIME

Toma Mikalauskaite

Table of Contents

TABLE OF CONTENTS	3
ABBREVIATIONS AND ACRONYMS	4
1 INTRODUCTION	5
2 MODELS FOR OPERATION AND PROCUREMENT	6
3 PROCUREMENT OF CLEAN BUSES	7
4 DEFINITION OF THE OFFER AND ASSOCIATED RISKS	8
4.1 RISKS	9
5 OPERATION OF CLEAN BUSES	11
5.1 UNDERSTANDING OF THE OPERATIONAL CONTEXT	11
5.2 PREPARATION FOR SERVICE	12
5.2.1 COMMISSIONING	13
5.2.2 TRAINING OF DRIVERS	13
5.3 SERVICE OPERATIONS	13
5.4 MAINTENANCE AND DEPOT	15
5.4.1 DISPOSAL OF MATERIAL	15
5.4.2 DEPOT MANAGEMENT	16
6 COSTS	17
7 CASES	18
7.1 ALL STOCKHOLM PUBLIC TRANSPORT BUSES BECAME CLEAN	18
7.2 THE COPENHAGEN MODEL FOR CHARGERS IN PUBLIC SPACE	19
7.3 FIRST LEARNINGS FROM ELECTRIC BUS FLEETS IN THE NETHERLANDS (43 + 100 BUSES)	20
7.4 PUBLIC DEMAND FOR ZERO-EMISSION BUSES IN HAMBURG	21
7.5 HELSINKI BUS OPERATIONS SWITCHING TO ALTERNATIVE FUEL HVO. ...	22
7.6 STRASBOURG BUS OPERATION SWITCHING TO ALTERNATIVE FUEL XTL .	22
7.7 THE PARIS MODEL FOR CHARGER AT DEPOT	23
7.8 EXPANDING ZERO-EMISSION BUS ROUTES IN LYON WITH TROLLEYBUS	24
7.9 FLASH-CHARGING E-BUS IN GENEVA	25

ABBREVIATIONS AND ACRONYMS

AC	Alternating current
AFI	Alternative Fuel Infrastructure
BEV	Battery Electric Vehicle
CP	Charge Point
DC	Direct Current
DSO	Distribution System Operator
EC	European Commission
EIB	European Investment Bank
ELENA	European Local ENergy Assistance
EU	European Union
EV	Electric Vehicle
ISO	International Organization for Standardisation
ITS	Intelligent Transportation System
LDV	Light Duty Vehicle
MS	Member State
PHEV	Plug-In Hybrid Electric Vehicle
POI	Point Of Interest
POU	Point Of Use
PTA	Public Transport Authority
PTO	Public Transport Operator
...	

1 INTRODUCTION

Transport accounts for almost a quarter of total EU GHG emissions. Urban buses represent just the 8% of transport emissions (per passenger per km) i.e. buses contribute less than 3% to the total EU GHG emission; however, they have an impact on local air quality (NOx, Particles (PN)...) and noise within city centres.

Fleet renewal and/or extension is a top priority for bus operators, driven by the aim to reduce operating costs, increase energy efficiency and improve the quality and efficiency of the service and the wish to contribute to the city efforts to reduce the impacts of transport. For this, operators are looking to cleaner bus technologies that provide better environmental bus performances in terms of reduced local emissions and noise levels.

All this can significantly contribute to fostering a modal shift towards cleaner and integrated public transport, achieving a multiplier effect and improving air quality, urban mobility and the wellbeing of citizens in Europe.

Today the market offers a wide array of clean powertrain technologies for the urban bus, providing a good set of alternatives to the transport operators. Such technologies, described in the D1. Technology and trends document (section 2), present different environmental performances and operational capabilities. Many tests and experiences carried out during the last years have shown that there is not "one-solution-fitting-all" scenario, and that the choice depends strongly on the specific local operational context under the banner "a chosen technology performs well when put in its best operational conditions".

It is therefore a political decision for cities, first whether to support clean bus deployment through integrated plans and strategies, and second, to select the solution that will help achieve the city's targets in terms of emissions reduction, noise levels, and other environmental, economic and societal targets.

From the operational point of view, it is fundamental that the technology chosen, while improving environmental performances, has no negative impact on the fundamental service of the urban bus, which is to provide efficient, reliable and comfortable transport to the passengers. Any reduction in the quality of the service will produce irremediably a shift towards private motorised transport.

Clean buses change bus operation and bus procurement, since most of the bus technologies are depending on a dedicated charging system or dedicated fuelling infrastructure. This requires special attention since it significantly differs from the operation of conventional buses. The fuelling infrastructure for diesel buses (and diesel-hybrids) has no major issues, as the buses could be fuelled in a normal station in case the fuelling station at the bus depot would be out of service. Battery electric buses require opportunity chargers installed at the end stops of the line, at selected bus stops along the line and/or centralised charging at the bus depot during the day or overnight. In the case of fuel cell buses, a hydrogen refuelling station, typically located at the bus depot, is required.

2 MODELS FOR OPERATION AND PROCUREMENT

Within the EU, there are several ways to organise public transport with buses.¹ For the purpose of this memo, they are reduced to two **models for the procurement and contracting** of diesel bus operation that are expected to be reused for electric buses:

1. The Public Transport Authority (PTA) buys the buses and could own them or not. They can be then operated by the PTA (in this case PTA and operator are the same) or by a private public transport operator (PTO). The PTA procures buses from the market according to the EU regulation on procurement.
2. The PTA tenders out the operation of the bus system according to the EU procurement regulation. The operator procures, owns, and operates the buses. In this case, the operator can procure the buses without being obliged to comply with the EU public procurement regulation. The tender can be technology neutral (with specifications for low/zero emissions and low noise levels), but it could also specify the use of a given technology.

Hereafter, these two models for bus procurement are handled together whenever possible, but in some cases, it is needed to consider them separately. For both models, there are different possible organisations for the procurement of the additional bus charging equipment, electricity, filling stations, etc.

The **charging / refuelling infrastructure** can be procured in many different ways, depending on the local applicable rules and policies. Consequently, there are different roles for the PTA, operator, and other private stakeholders (e.g. gas company, electricity supplier) depending on the business models chosen:

- Build / procure and own the charging / refuelling infrastructure
- Energy / fuel production and transport to the station
- User of the charging / refuelling infrastructure
- Service and maintenance of the charging / refuelling infrastructure

Hereafter we present three models for **clean bus infrastructure procurement**:

1. Procured, owned and operated by the same entity, e.g. opportunity charging station procured and owned by PTA. Or hydrogen/gas refuelling station at the depot, or overnight charging infrastructure at depot procured and owned by the operator.
2. Managed by an infrastructure operator or bought separately as a mere infrastructure. It is based on an investment by the private infrastructure operator, based on a business case justifying the investment connected to a substantial bus fleet and gas consumption. The Compressed Natural Gas (CNG) station is maintained by the supplier/energy supplier and can be also public.
3. Handled through a contract for operations, honoured with a payment per kWh (OPEX²), or an up-front payment of the entire installation costs (CAPEX³).

Electric bus, like trolleybuses, require an electric infrastructure for charging, plus a voltage conversion connected to the grid. In the case of **fuel cell buses**, the hydrogen can either be produced directly at the refuelling station (on-site production) or delivered from a hydrogen production plant.

These infrastructure procurement models do not heavily affect alternative fuels such as **biodiesel, paraffinic fuels (XTL)**. In this case, the PTA specify performances in terms of environmental targets and operator prove the renewable origin with the certificates and invoices from the fuel supplier⁴.

¹ Annex IV of UITP Tender Structure document on "Main business models for the provision of bus services".

² OPEX : Operating expenditures

³ CAPEX: Capital expenditures

⁴ e.g. the gas supplier is to provide guaranteed Renewable Energy Certificates for the biomethane

3 PROCUREMENT OF CLEAN BUSES

The transition to cleaner fleets implies a change in procurement methods, switching from vehicle procurement to system procurement, in which complexity may arise through the need to procure an integrated charging/refuelling infrastructure.

There are several methods for procuring complex systems and they differ depending on the technical solutions available, the feasibility to implement the solution, the financial framework, legal requirements, local competition, the avoidance of risks in the company and a variety of other conditions.

As widely demonstrated, there is **no one-size-fits-all solution**. However, there are some standard elements that each OEM delivers. When procuring and operating clean buses, many choices are to be made in the procurement phase that will influence operations later. The best financial and operational results are reached when a bus system is based on standard elements. But these standard elements differ from city to city and from tender to tender due to differences in legislation, tradition, tender model, public transport organisation and so on. And as the market of clean buses is emerging, it is not yet completely defined with standards, which makes clean bus procurement even more difficult.

When **planning and procuring clean bus systems**, the tendering party shall consider the following topics in a market dialogue with the possible bidders:

- Definition of the proposed concept for vehicles, infrastructure and operation from the specified operational requirements: required range, daily mileage, energy management, charging time, degree of necessary flexibility in line use (sufficient load times or short intervals), passengers capacity and comfort.
- Infrastructure needed to maintain, refuel/charge the buses based on technology choices (overnight, automated connection devices, hydrogen, gas...) and route constraints.
- Timely provision of all required authorisations and permits for the civil works and installation of the corresponding infrastructure: hydrogen refuelling station, gas station (including storage of a large quantity of hydrogen or gas), or electric installations (including lithium battery charging authorisation in the zone).
- Design and integration of the required infrastructure (availability of space, integration in city design) in the urban landscape as well as in the electricity network (adequate design of the power grid, economic use of energy, smart charging)
- Training and communication for first responders (fire brigade mainly but also police)
- Training on new skills for staff (driving service as well as workshops technicians)
- Adaptations in bus depot, e.g. technical preparation of the workshops (including high-voltage, gas and hydrogen safety aspects). Also consider the provision of technical support by the manufacturers (maintenance contract or flying doctors, availability of critical spare parts etc.)

4 DEFINITION OF THE OFFER AND ASSOCIATED RISKS

Developing and implementing clean bus systems involve a fundamental paradigm shift, which for the first time requires a comprehensive monitoring of the energy use to safeguard an efficient operation. Therefore, an **in-depth analysis of the objectives** to be reached in terms of energy consumption, emissions savings, transport needs and line constraints shall be carried out in close cooperation between the PTA and the operator. This is essential in order to make the best technical offer while ensuring operation.

The tender specifications for clean buses are usually quantified for the worst case conditions (battery aging, driver variability, climate variability, traffic conditions). The optimisation of fleet operation can help managing worst conditions. For this reason, it is recommendable to carry out **feasibility studies** following a **system approach**: involving all stakeholders from early planning stages and taking into account the infrastructure and the operational context.

Each technology presents advantages and drawbacks. An early and systematic comparison of the prerequisites given on site and/or the requirements to be met is key to achieve a large transformation process at low-risk and without quality loss. Additionally, it shall be ensured that the solution proposed is based as much as possible on standardised interfaces and protocols to ensure interoperability among different brands.

One of the most critical points to ensure a reliable and attractive bus service is the question of the **ranges** to be achieved with the respective technology.

The range of a **battery electric bus** depends not only on technology but on the deployment profile and the topographical and seasonal conditions of the line. There are currently two main strategies to charge electric buses:

- **Overnight slow charging** at the depot.

This solution requires clear specifications on the daily mileage, comfort and passenger's capacity, etc. to prepare the best offer. However, the improvement of the electricity grid could be required for some locations of depots.

In this case, buses are equipped with a large battery pack (even >300 kWh) which represents a high investment (significant part of the total cost of the vehicle). Such batteries might need to be replaced during the life time of the buses (which can be longer than a diesel bus) which is likely to generate additional costs.

The weight of the batteries could impact the total passenger capacity of the bus (due to weight limitation by regulation).

If the range on a single charge is not enough to cover full-day operation and/or the passenger capacity requested is not manageable, the operation will require additional buses (intra-day charging can help optimise buses and line services).

In the longer run, considering the expected evolution of the battery market in terms of energy density and cost, the buses (new or the same with new batteries) will allow an increase of autonomy and/or passengers, and this would reduce the number of additional buses required.

- **Opportunity automated fast charging** at the terminal, at selected bus stops, or even in the depot.

Fast charging enables having smaller battery packs on board, which allows more passenger capacity but lower operation range and the need of more often charging during the daily operation. The impact on the total price of the vehicle is anyway not high, as smaller but different (and maybe more expensive) batteries are necessary.

Also in this case the batteries might need to be replaced.

The weight of the batteries is lower, and by this the passenger's capacity of the buses can be less impacted in order to respect the weight limitation by regulation.

It requires an extra planned time, sufficient to allow the required charging, and this could lead to more buses in operation compared with traditional combustion buses.

It also requires to define the ownership of the land on which the charging stations are built on.

Finally, having fast charging equipment at both ends of the line can reduce the flexibility of the system (road works, deviations etc.), which could impact the entire bus network operation.

Opportunity charging doesn't not necessary have to happen at the end of the line, but can happen in the depot (or dedicated off-line areas) when it has a positive impact on the operations; however, the needed high charging power has to be considered.

The use of flash-charging stations at selected bus stops can allow to increase battery life (keeping the State Of Charge high) and lower the fast charging time at the terminals, with less impact on the operations.

The **location of the chargers** shall consider the accessibility to and availability of connection points with sufficient power supply, especially when in public space, shall be explored with the local administration and the grid operator. Experiences in different countries show that it may be difficult to obtain permits in due time to build charging stations before starting the operation: on this regard, the installation of chargers at the depot is much easier.

Even if the price of a fast charger can vary, depending on the charging capacity, from 8-12 times of the price of a slow charger (DC chargers), and besides this there is the cost for the installation of these chargers and the connection towards the grid, the installation cost for a fast charging system is not 8-12 times higher than when only slow charging is applied. This is because the total number of chargers can be reduced, as the buses will not have to be charged all at the same time. This depends on the operational conditions.

Fuel cell buses range and refuelling are similar to those of diesel buses. The challenge is the cost of both vehicle and refuelling stations, as well as the supply of hydrogen to the depots and its safety, in particular if larger quantities are to be stored on site. For this purpose, coordination with the approval authorities is recommended. Also, hydrogen generation is CO₂ intensive when produced with fossil fuels and energy intensive when produced by electrolysis and grid electricity. As a result, today the use of hydrogen is mostly attractive if it is available as a by-product or from renewable redundant energy, as it offers a way to store large amount of surplus of renewable energy in the form of hydrogen.

4.1 RISKS

The launch of the operation of a new clean bus system can be delayed because of misalignment between the delivery of buses and the readiness of the infrastructure required, which very often involves long and complex processes to obtain the corresponding permits for civil works, grid connection, installation of storage capacities, etc. It is recommended to consider a longer tendering phase, as well as a longer installation phase, carefully planning for permits and authorisations in parallel.

In case a part of the system (vehicle or infrastructure) fails, there is no or little impact in the system: every component of the system shall be reliable from the start.

The proposed system shall be affordable on a lifetime (with reference to the TCO⁵). In the case that every risk is transferred to the suppliers, the prices will be very high. Every supplier and sub-supplier will add a risk premium to the costs making clean bus systems economically unfeasible without external funding.

Due to the risks associated with the introduction of a complete new concept for bus transport, procurement procedures for buses and related infrastructure which are leaving sufficient scope for intensive and detailed technical and functional coordination with manufacturers should be chosen. In particular negotiated procedures should be preferred to address properly features such as energy consumption, availability and capacity, as well as environmental impacts, as these features have a significant meaning on the cost and operations of the future transport service.

With the introduction of large clean bus fleets and the involvement of different stakeholders, an efficient way to handle responsibilities, ensure quick and avoid piling costs is a "turnkey solution", where the bus manufacturer is responsible for the whole system. A turnkey solution reduces operational risks, but may add risks and costs the project in case permits are not granted beforehand. Example of a turnkey solution are the systems in Eindhoven and Schiphol.

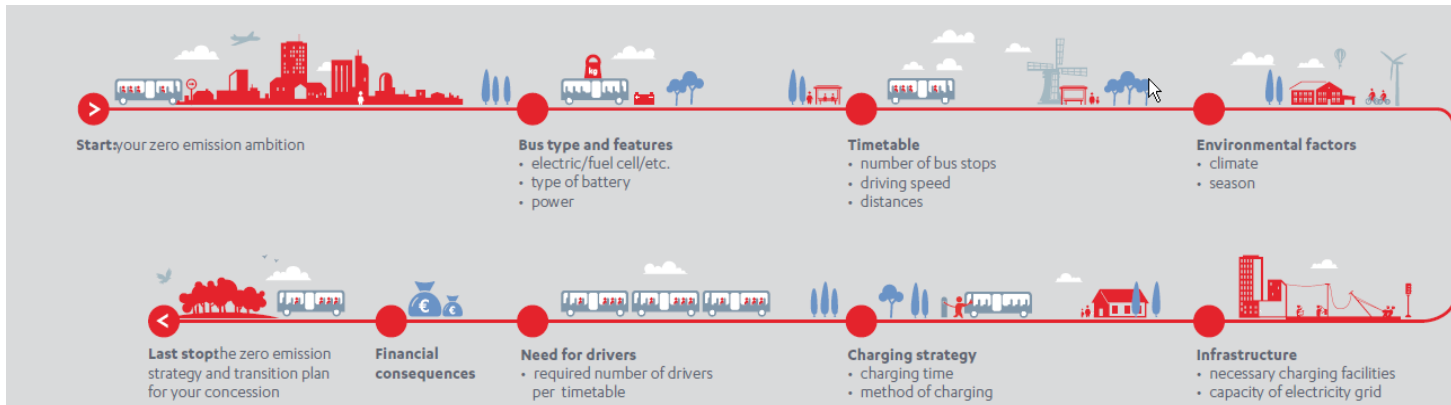
However, cities may have special demands for design and may not grant permits to the charger of a turnkey partnership. For that reason, some cities make special tenders for charging infrastructure. This may reduce costs and the risks for not getting permits. On the other hand, operational risks are higher. An example of separate tenders for chargers and buses can be found in Copenhagen.

Separate tenders for charging equipment will become more common when standardisation has been fully applied.

⁵ Total Cost of Ownership

5 OPERATION OF CLEAN BUSES

The procurement of zero-emission buses should be in accordance with the requirements of the later day to day operation. For the operation to be a success, the following steps should be considered. There may be a structural way through the steps, but also inter-dependencies between the steps: the choice of infrastructure may result in different time tables and the charging strategy and choice of bus are depending on each other.



When it comes to the first-time deployment of a completely new system, its introduction, especially with a larger number of buses, should not be carried out all at once, but successively, in order to identify possible weaknesses in good time and to avoid risks.

5.1 UNDERSTANDING OF THE OPERATIONAL CONTEXT

To describe a bus route, it is necessary to take into account a number of typical parameters such as traffic density, numbers of stops (either for the boarding and alighting of passengers or simply required by the environment), route topography, passenger capacity, and commercial speed.

SORT is a method developed by UITP in 2004 for measuring fuel consumption and is used to compare different buses presented in a call for tender. For many, SORT is the most reliable protocol to compare the fuel consumption of several bus manufactures in a call for tender. It is a real-life test, e.g. not an engine test but a test with a full-size bus on a test track (on-the-road); a new version, E-SORT, includes measurements for electric buses.

Commercial speed can be seen as the key parameter differentiating distinct operation patterns. Indeed, the graph above shows that any change of route severity impacts on commercial speed and thus on consumption, which is inversely proportional.

SORT has identified three base cycles, each characterised by the average commercial speed on the bus route. Bus lines can be then characterised according to their commercial speed as follows:

- **SORT 1:** heavy urban cycle with commercial speed up to 12 km/h
- **SORT 2:** easy urban (mixed) cycle with commercial speed up to 18 km/h
- **SORT 3:** easy suburban (peri-urban) cycle with commercial speed > 25 km/h

5.2 PREPARATION FOR SERVICE

The introduction of clean buses requires a clear analysis of its operational conditions:

- 1) a Policy analysis: to understand the impact of urban transport policies on public transport, urban mobility patterns and objectives, the existence or non-existence of zero/low emission zones, air quality and noise reduction targets, etc.;
- 2) an operational analysis for the whole bus (routes, timetables...) and energy network.

The analysis of the existent and/or new **line** shall take into account the following parameters:

- Length, Topography, traffic profiles
- Time table or frequency, speed profiles
- Climate conditions: weather, temperature, needs for heating/aircon
- Number of stops, constraints-bus schedules,
- Required passenger capacity along the day (number of passengers)
- Number of buses and drivers
- max operative autonomy, recharging/refilling supply capacity

Also aspects relative to the **infrastructure** should be considered like:

- Construction constraints: cost of charging/filling points, required permits, licenses, if required, costs for land acquisition, etc.
- Design constraints: urban integration of bus stops and the charging/refilling points, safety, and reliability issues.

The organisation of the **service** requires to solve a set of questions and trade-offs:

- Driving autonomy (for e-buses): depot charging vs opportunity charging
- Weight of the bus: weight of empty vehicle vs passenger capacity
- Chargers/refilling: manual vs automatic
- Normal/High Power charging with respect to the battery life
- Driver/bus utilisation vs. charging time
- Standardisation/interoperability/flexibility: Interface/communication protocol between vehicle and charger, share charging amongst lines from different bus operators or different buses, docking station, crossing.
- Grid management, peak management: how to control the energy required and the distribution to optimise the system.
- Costs: infrastructure, energy supply/consumption/stability of electricity cost
- Energy provision: renewable energy/use of PT power network (trams, metro)
- Contractual framework: to address the electricity cost and needed volumes.
- Maintenance: vehicles infrastructure, predictive maintenance system and inspections with alerts.
- Specific safety procedures.
- Urban strategy: aligned with the charging infrastructure

Based on the technology adopted, it could be necessary to adapt the service in terms of time-table, number of buses available to the daily service, and the drivers' number and roster. At the same time, the service accessibility could be impacted in terms of frequency, line topography. In some cases this could influence the choice of the technology solution for the bus route.

Another aspect to be considered is the presence of other electrified modes that could bring to define the operation for accessing to a shared infrastructure, but could also create important synergies in terms of energy accessibility and availability (from metro or, tram substation).

5.2.1 COMMISSIONING

Acceptance of the vehicle should be done by considering the following:

- Physical verifications (docking, crossing, ...), e.g. parking tolerances of bus position under charging infrastructure (or refuelling time and constraints for hydrogen/gas buses)
- System Performances (travel time, accessibility, comfort, safety)
- Easy handling for service staff when loading or refuelling, possibly additional training on site
- Verification of the subsystems (fixed installations)
- Intelligent Transit Systems, including driver assistance tools
- Testing & commissioning of all relevant subsystems
- Verification of the compliance of buses and their infrastructures with the regulatory requirements of the country

Then, it has be considered also a commissioning phase for the infrastructure and, at the end, a final acceptance of the whole bus system.

5.2.2 TRAINING OF DRIVERS

Training of drivers to drive clean buses is absolutely necessary especially when the drivers recharge/refuel the bus. The drivers need to learn the functionalities of the bus and how to operate it with special consideration of regular monitoring of the energy status of the bus. Further it is important that they learn the concept of the bus; when, where and how to charge, range of the bus, safety instructions and so on to know and take the necessary measures in case of emergency.

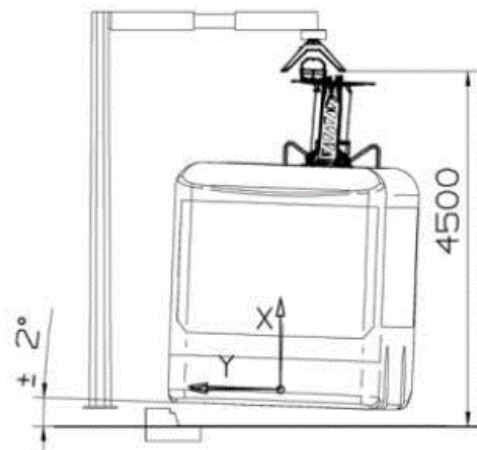
Eco driving is essential, and the driver plays a key role in lowering the level of used energy as possible. Experiences from Copenhagen shows that in two specific buses, the best drivers used 30% less energy than the worst drivers. Because buses must be designed to worst case (worst driver, worst weather and the worst traffic situation), it is key, to reduce energy consumption due to bad driving. These considerations apply to fuel cell buses, not related to autonomy but in terms of fuel savings. Tools assisting the driver for eco and comfort driving are very helpful, in particular in initial phase.

In the case of zero emission buses, less energy is inside the bus and the heating energy is not free (coming from diesel motor). So, the training in thermal comfort management may be one of the key points.

For example in Eindhoven, where articulated buses are used in a Bus Rapid Transit (BRT) system with dedicated bus lanes and with traffic light priority, the drivers have learned to use the service brakes only at bus stops. This means that deceleration is done only while regenerating electricity. This has led to a more efficient planning of battery charging (for traction, it's not new, because it is the same as for Hybrid buses)

5.3 SERVICE OPERATIONS

The drivers detailed shift plan is given to them by the planners (vehicles, schedules, rotation, charging, etc...). Buses must be made available to start the drivers shift plan; meaning that they must have enough energy in the batteries to execute the planned shift. "Smart charging" and "Charger monitoring" of the battery charging activity are the way to manage this.



- "Smart charging" means that buses that are allocated towards a dedicated shift and connected to the charging system are getting charged on time to get enough energy in the batteries to be able to run the shift, and to set the batteries to the right working temperature. The planning system must be connected with the charging system and with the allocated charging location of the bus (which bus, where, when and how).
- "Charging monitoring" means that it is automatically monitored whether the charging system actually starts charging and that the charging speed is respected in function of what the smart charge system has calculated.

At the time to start service, vehicle readiness (for example in terms of minimum charge for performing the whole service or part of it until the need to be recharged) should be checked: preconditioning of the batteries (depending on the adopted technology) can improve the daily autonomy, before the safe unplugging from the charging station is ensured.

Each technology has its most suitable operational scenarios (rural lines, center lines...) that would depend on the general economy of the service, and the level of emissions in relation to the local environmental policies in place. This could pose some limitation to the capacity of the operator to move buses from one line to the other during the service.

In case of battery buses, when buses are running their shift plan it must be indicated when the driver has to connect the bus to the charging system.

This is based on the energy status of the batteries and with the purpose to avoid that the batteries are getting too deeply discharged; battery charge is impacted by different factors, like traffic conditions, start-stop frequency, use of on-board auxiliaries; it is therefore important that the operator has clear knowledge not only of the position and real vs schedule time of each vehicle, but also the bus operational capabilities (autonomy according to the traffic and vehicle conditions).

In fact, during winter or summer period a lot of electric energy is used for heating or cooling, and therefore the planning of the shift has to be reworked.

Therefore it is needed to monitor the state of charge of the batteries while the bus is in operation, and planners can, where necessary, adjust the drivers shift or the schedule for charging operation avoiding to get too many buses in for charging at the same time.

This could mean that more chargers would have to be installed and that the peak of energy consumption, when charging, is high within a certain time frame, with a higher energy costs as result. In addition, the access to shared charging stations need to be regulated as different operators (or modes) could require the use of the station at the same time: this could have implications on service contract as it could bring an undesired delay.

As a consequence buses that are still have enough energy in the batteries to continue the operation would be planned for charging. For this reason a "Telematic system" must be available in the bus for battery monitoring in real time.

When vehicle charging is done at selected stops (supercapacitors, SRS...), the presence of on-board systems for automatic docking of the bus to the stop/charging point would speed-up the charging operation.

In case of opportunity charging during operation, they should happen in full safety and in the most automatic way as possible.

Different safety scenarios with the Fire Department and the Police Department should be tested, related to both operational scenario (service or depot) and propulsion technology (battery, FC/hydrogen, gas...) in order to identify the critical points (high-voltage systems, batteries, hydrogen tanks) and define necessary and standardised processes and documentation to be able to react quickly and safely in an emergency.

5.4 MAINTENANCE AND DEPOT

The maintenance procedure shall ensure the vehicle safety and quality of the service with minimum costs, including the minimum off-service time of the vehicle.

New clean propulsion technologies can require substantial changes in the workshop organisation, maintenance equipment, tools and processes, safety and security procedures. The workshop must be re-organised for the maintenance and inspection activities. The following aspects need to be considered:

a) Regarding workshop staff:

- Organising training in handling electric and/or hydrogen components (hybrid diagnostics systems, hybrid, high-voltage and gas systems, handling hazardous materials).
- Develop the new skills required for maintenance and repair staff by putting great care to proper training for working on electric components.
- Creating and communicating procedures for handling high voltage systems, based on the already existing standards.
- Categorising workshop staff regarding which activities they are allowed to do (creating groups regarding different level of skills).
- Organising training in fire prevention and firefighting. The personnel shall be trained on a regular basis about safety norms and fire prevention that are in accordance with the law in force

b) Maintenance & repair - workshop organisation:

- With new propulsion systems, a lot of equipment is placed on the roof (like batteries, gas or hydrogen tanks...), therefore a platform could be used that is placed on both sides of the bus to enable the maintenance staff to work on these components. Such platforms are today already well present in order to access to HVAC systems.
- Creation of specific workplaces for working on batteries.
- Implementation of specific inspection procedures.
- Dedicated diagnostic equipment and specific tooling will be needed.
- Telematic systems must be available for real time monitoring the vehicle with the purpose to do "Predictive maintenance".
- With Hydrogen and gas buses in the workshop, sensors will have to be installed together with automatic roof evacuation systems to avoid explosion in case of leakage.
- Repair activities that cause sparks should not be carried out in the proximity of hydrogen or gas buses. When such interventions have to be carried out, it is advisable to purge the hydrogen or gas from the tanks.

Future fleets will be characterised by buses with different propulsion systems. The maintenance instruments and tools should be standardised to allow their usage on many bus types. Such variety of bus types would also require new procedures and automated systems for the measuring and management of stock of spare parts.

5.4.1 DISPOSAL OF MATERIAL

In many cases the battery pack of electric buses will likely be replaced during the lifetime of the bus. A proper organisation should be implemented to assure correct waste disposal, compliant with European and local regulations.

Removed batteries can have a second life. The batteries are removed because they have lost energy capacity which makes it impossible to continue the operation as it was planned. These batteries can be used for slow power energy storage, enabling cheap available charging power, then reducing power costs (ex: Amsterdam).

Batteries can also be dismantled: raw materials especially these which are rare and expensive can be recuperated and the rest will then be treated as waste disposal compliant with European and local regulations.

Fuel cell rare earth material can be recycled, while the stacks only need to be replaced once in the lifetime of the bus.

5.4.2 DEPOT MANAGEMENT

Besides the buses that are developed as overnight charging buses, also opportunity charged buses need to be charged slowly in the depot during the night. This is needed to be able to balance the voltages between the battery cells (needed to assure the life time of the batteries).

Just like the workshop, also the depot parking areas need to be adapted to allow charging of the buses overnight.

Also in this case, particularly relevant are the safety and security procedures and system compliance.

Having a fleet of buses in the depot for charging purposes needs to reorganise the parking places and set up procedures to connect and disconnect the buses to the charger (cable and plug).

The staff that will assure the connections will have to be trained in connecting, in verifying if the charging has started and in what to do in case the charging doesn't start.

Once the connection has been made and the charging has started, a monitoring system must be in place alerting the staff when for one or another reason the charging has interrupted.

In case of electric propulsion, the bus need to be plugged to the charger for the time necessary to charge it. High number of buses in a depot, charging at the same, require a smart charging system that would control the process of charging by optimising the energy needs of the depot versus the time of parking of the vehicles⁶, and considering the need to bring the batteries on working temperature.

When the complete fleet is electric and these are all in the depot for charging during the night, it could be that there is not enough place to locate these buses for having them charged with cable and plug. In this case buses can also be slowly charged via an automated connection device (like pantograph on the roof or ground-based solution), this allows the positioning of the buses in the middle of the depot.

Fuel cell buses need to be connected to a power supply outlet so that water used to cool the fuel cell does not freeze at night. It is expected that technology improvements will no longer require this connection in a near future.

⁶ Levelling out the charging load over the available period for charging, will reduce the peak consumption of electricity and by this reduce the energy price.

6 COSTS

There are several cost drivers for clean buses, and potentially some elements making bus operation cheaper in midterm depending on local taxes, grid price structure and much more.

Today, zero emission buses are more expensive than traditional buses. Since technologies are quite new, components are still expensive; in addition, there are other aspects impacting the investment costs (CAPEX) that shall be taken into account:

- The charging and refuelling infrastructure to be installed.
- In the case of battery electric buses:
 - o Potentially, the need of extra buses compared with the size of a traditional fleet (especially for bigger fleets).
 - o The availability and accessibility of powerful connections to the energy grid.
 - o The charging time could lead to an increase of the drivers' working hours and with this, an increase of the number of drivers and other staff at the depot.

The operational costs (OPEX) of zero emission buses could potentially become lower than diesel buses due to lower energy prices (but this can differ between countries), but maintenance costs are still unknown due to the few operational years for zero-emission buses so far.

Traditionally, busses have a lifespan of 8-15 years depending on several factors (e.g. the lifespan of the PTO's contract with the PTA). The tendency is, for TCO optimisation to increase the lifespan to 20 years or more (similar to electric trolley buses that have been around for almost a century). Whenever a bus is taken out of service, new buses with the newest emission standard will be asked for, when procuring new busses. This system results in gradually better emission levels from public transport. Since there is no need for better emission standards, zero-emission busses could have a much longer lifespan than traditional buses. Furthermore, they could be refurbished and reused in contracts normally asking for new busses.

This would help lower the OPEX which would allow finance the higher CAPEX. Possible measures to lower the OPEX with clean buses:

- Longer contracts (minimum 10 years).
- Transfer of buses and charging infrastructure to the next operator at their residual value.
- Requirements for new buses will be phased out in tenders for zero emission buses.
- Implementation of standardised infrastructure components in order to allow different bus brands to use the same infrastructure. Otherwise the different lifetimes (charger: >20 y, bus: >10 y) could be a problem.
- Don't put age restrictions on electric buses within contracts (vehicle requirements), but instead the quality of the service and the comfort for the passengers.

7 CASES

7.1 ALL STOCKHOLM PUBLIC TRANSPORT BUSES BECAME CLEAN

In 2018 Stockholm phased out the last fossil fueled bus - the complete fleet of 2,300 buses operated in the county of Stockholm now consist of biodiesel, biogas, bioethanol, hybrid and plug-in hybrid buses.

- The Stockholm Public Transport Authority made an environmental (ISO 14000) analysis of its operation in 2001, followed by the decision to gradually phase out all fossil fuels from the public transport system during a 20 years period.
- A bus replacement plan was made to gradually – in the normal tender and bus replacement/tendering process – replace the fleet with clean buses.
- All tenders from 2001 onwards had specific functional and environmental demands. This has led to mix of technologies: ED95, biogas, biodiesel and also biodiesel hybrids.
- Necessary infrastructure and depot investments were normally financed and owned by the PTA.
- Other measures to facilitate the transition and minimise cost have varied over time, e.g. residual value measures such as takeover guarantee of gas and ethanol buses at end of an operator's contract. For a period of time the PTA also owned buses with new technology via their Financing company in order to overcome problems with low or uncertain residual value of new technologies, which made them unattractive for normal leasing companies.
- Key for Stockholm's operation have been functional demand setting and consistency in keeping political environmental targets and politically controlled fiscal prerequisites stable.



Source: Scania. Photo Dan Boman

<https://www.scania.com/group/en/electric-buses-part-of-the-switch-to-fossil-free-transport/>

7.2 THE COPENHAGEN MODEL FOR CHARGERS IN PUBLIC SPACE

The City of Copenhagen has decided to request that all tenders for buses starting to operate from 2019, are operated by 100% zero emission busses. It can be difficult for the PTOs to get permit to install chargers during the tendering for bus operation.

The PTA, Movia, expects, that the PTOs will add a large risk premium to their bid for bus operation, if they are uncertain about getting a permit to install chargers, or they will use a different technology.

Movia has decided to make a separate framework tender for urban chargers, that the PTOs should use, in case they are proposing opportunity charged busses in the bus tenders.

The bus tenders are technology neutral asking for zero emission busses. In case the PTO wants to use opportunity charge, an amount corresponding to the price of the urban chargers, are added to the PTO's offer to the bus tender.



Source: Sustainable Bus

<https://www.sustainable-bus.com/news/copenhagen-arriva-sweden-electric-bus-rout-vdl-citea/>

7.3 FIRST LEARNINGS FROM ELECTRIC BUS FLEETS IN THE NETHERLANDS (43 + 100 BUSES)

Development of two large high capacity ZE bus fleets.

1. Zuid-Oost Brabant concession.

- 43 electric articulated buses in operation in Eindhoven. Around 215 ZE buses in operation planned by end 2024
- Short period for preparing bid.
- Opportunity charging chosen because of demand for high passenger capacity and long daily services (20h and 300km/day).
- No possibilities to look for opportunity charging on the lines (impossible to make agreements with city authorities (they are not the PTA) within this short period.
- Solution found regarding opportunity charging at the depot which is located at only 1.5 km from the exchange point.

2. Amstelland Meerlanden concession

- 100 electric articulated buses in operation around Schiphol and on R-net. 266 high capacity electric buses in operation planned within end of 2020.
- Opportunity charging locations and grid connections (cables) foreseen in the tender and supplied by the authorities.
- Additional opportunity charging in two depots in the region, managed by the PTO.
- The operation with the e-buses started 4.5 months too late because of problems to get the construction permits on time and problems with the construction



Source: VDL Groep

<https://www.vdlgroep.com/nl/vdl-groep/duurzame-projecten/duurzame-elektrische-stadsbussen>

7.4 PUBLIC DEMAND FOR ZERO-EMISSION BUSES IN HAMBURG

- Directive from city government to procure emission-free buses only from 2020
- Pre-test before full procurement with different types of e-buses (battery, plug-in, fuel cell, range-extender)
- 2017: decision to procure 90 battery busses with central charging on bus depot
- Range of buses at 150 km with external heating (25% of overall bus fleet)
- Study for large scale energy supply and grid: most depots at medium voltage, 1 large depot need to be refurbished with 110 KV connection
- Installation of charging infrastructure on two bus depots from 2017
- Fuel cell buses as a backup when required range not covered by battery busses



Source: Sustainable Bus

<https://www.sustainable-bus.com/news/hamburger-hochbahn-to-purchase-530-electric-buses-between-2021-and-2025/>

7.5 HELSINKI BUS OPERATIONS SWITCHING TO ALTERNATIVE FUEL HVO.

Renewable paraffinic diesel fuel (HVO100, meets EN 15940) has been used by many bus operators since 2008 in Helsinki area. Diesel fuel storage tanks at bus depots were emptied and filled with HVO100. No extra actions were needed since chemically similar paraffinic molecules exist naturally also in standard diesel fuel. Oil companies deliver HVO100 using the same tanker trucks as standard diesel fuel.

Oil companies needed to reserve separate storage tanks for paraffinic diesel besides standard diesel fuel tanks at bulk terminals. However, extra logistic costs are minimal compared to the cost caused by renewable feedstock being more expensive than fossil crude oil. In August 2018 HVO100 was sold publicly at service stations in Finland at about 1.50 eur/liter when standard diesel fuel was about 1.35 eur/liter (incl. VAT). Government supports alternative fuels in Finland so that fuel tax is 26.3 c/liter for HVO and 53.02 c/liter for standard diesel fuel. From those values it is possible to estimate very roughly that HVO without taxes is about 95 c/liter and standard diesel about 56 c/liter.

7.6 STRASBOURG BUS OPERATION SWITCHING TO ALTERNATIVE FUEL XTL

In parallel to implementing CNG buses, Strasbourg Bus Operator, CTS was looking for an improvement of the emission footprint of its existing diesel bus fleet, and chose to investigate the potential of new alternative fuels.

XTL or paraffinic fuels are specified under EN15940 and each Member State has provided authorisation to commercialise these fuels since end 2016.

The XTL fuel delivery cannot match the usual established mass capillarity network of the one of gasoil fuel. Therefore a dedicated supply chain has to be implemented by the fuel supplier, with drawbacks in term of distance, flexibility and add costs.

In that case the vicinity of a Shell fuel hub to Strasbourg was able to kick start the experimentation since mid-2016, with 76 alternative-fueled buses in operation.

7.7 THE PARIS MODEL FOR CHARGER AT DEPOT

The City of Paris has decided to demand, that all bus tenders starting to operate from 2019 and onwards, are operated by 80% electric buses.

48 electric buses are already running, and 76 additional buses will be deployed in 2019. The PTO just launched a new tender for 1000 electric buses to be running from 2020 and onwards. Overnight charging was preferred since it brings enough autonomy and passenger for RATP operation (also for other big European cities such as Brussels).

The deployment for each depot is in 3 steps:

- Electric transformer (HT/BT) procurement
- Buses tender
- Charging stations tender



Source: RATP

<https://www.ratp.fr/en/groupe-ratp/newsroom/ratpdev/open-tour-paris-launches-first-100-electric-hop-hop-sightseeing-bus>

7.8 EXPANDING ZERO-EMISSION BUS ROUTES IN LYON WITH TROLLEYBUS

In order to provide direct connections from two suburbs to Lyon city centre and its main railway station, Sytral, Lyon's PTA, chose to create two new electric articulated bus routes. The suburbs are located on hills, 150 m above the city centre, so the electric mode to climb as fast as cars, up to 8% slope is the natural solution. Trolleybus installation with continuous overhead power contact delivers the power required for traction as well as heating and cooling in this continental metropole.

Procurement for trolleybus routes is organised through different lots:

- Consultancy : Assistance to the PTA in order to study and provide specs for the several tenders described afterwards
- Project Management : Assistance to the PTA for the implementation and commissioning of the civil engineering works and supplies
- Supply of trolleybuses
- Supply and installation of overhead lines
- Supply of the power generation (substations connected to medium high voltage city grid). These last two lots can be combined in 1 single lot. In some cases, the vicinity of an existing tramway sub-stations can simplify the connection.
- Supply of signalization system (traffic light priority, signal about voltage, connections to vehicles and operator's back office)

As of today, 43% of the bus trips are electric thanks to trolleybus routes. This will grow as these bus routes will expand from 9 today to 14 in the next years.



Source: Sustainable Bus

<https://www.sustainable-bus.com/news/lyon-metropolitan-transport-authority-released-the-strategy-for-2020-and-beyond/>

7.9 FLASH-CHARGING E-BUS IN GENEVA

The electric bus system installed in Geneva looks like a regular trolleybus, except on the roof: instead of the usual trolley poles which connect overhead lines, this e-bus has a controlled moving arm that connects, in less than a second, to an overhead receptacle integrated into the bus shelter. The high-power flash-charging technology feeds the onboard batteries for 20 seconds, the time it takes for passengers to get on and off the bus. So passengers don't have to wait for the bus to charge.

The first articulated bus (18.75 m length) for 133 passengers ran under real-life operating conditions from May 26, 2013 to end 2014 on line 23 from Geneva's airport (terminus) to the nearby Palexpo Exhibition Centre (flash-charging station). Based on the results, a decision was taken to deploy TOSA on the full line 23 (12 kilometers, 12 buses) in 2018.

The system can be used like trolley – or diesel buses – i.e., frequency and stopping times remain unchanged.

This is especially important during peak hours and directly impacts costs. Timetables can be maintained without the need for extra operating hours or additional buses.



Source: ABB

<https://new.abb.com/news/detail/17282/abb-flash-charging-ebus-solution-reaches-a-new-milestone-of-half-a-million-km>