D 4.1 - Pre-normative technology roadmap and new use cases in electric bus and truck charging

Keywords	Charging technology and solution, charging use case, heavy duty electric vehicle, technology roadmap
Abstract	*This document is outlining the foreseen developments in the heavy-duty (HD) vehicle fast charging, especially in electric buses and trucks, with the aim of supporting and facilitating the future standardisation efforts on charging technologies by creating a clear overview of popularity of charging technologies and the end users' needs.* *The required input for the work was collected by reviewing the existing literatures and conducting surveys and interviews on end users and technical stakeholders. According to the findings from surveys and interviews, pantograph on the roof and plug-based charging are the most commonly used charging technologies currently. This trend is very likely to continue in the future, since 1) pantograph on vehicle roof, 2) pantograph on infrastructure and 3) plug were graded as charging technologies with the highest potential by the participants of technical survey. Static and conductive charging have higher potential, as compared to dynamic and wireless charging. Nevertheless, inductive charging can be the future charging solution for HD EVs, only if the current bottlenecks in the technology can be addressed. These bottlenecks include a high price, low efficiency, lack of standardisation, and safety concerns. Achieving interoperability was repeatedly mentioned as the main challenge in today's charging technologies. Providing full interoperable charging system has been one of the focuses of ASSURED project, which is successfully achieved by developing a set of standards with high technical robustness, developing communication protocol that is clearly integrated into the regulation, and performing conformance and interoperability testing.* *The data collected in the course of this work are synthesized into a roadmap, which can act as a basis for future standardisation efforts. Furthermore, based on the conducted analysis on the expected upcoming charging technologies and solutions, three new use cases are proposed in this deliverable to fulfil the future PTOs' and cities' needs.*

ACRONYMS

AC: Alternating Current
ACD: Automated Connection Device
BEV: Battery Electric Vehicle
BMS: Battery Management System
BRT: Bus Rapid Transit
CAN: Controller Area Network
CCS: Combined Charging System
CEN: European Committee for Standardisation
CENELEC: European Committee for Electrotechnical Standardisation
CHAdeMO: CHArge de MOve
CP: Control Pilot
DC: Direct Curernt
DSO: Distribution System Operators
E-bus: Electric Bus
EC: European Commission
EMI: Electromagnetic Interference
ERS: Electric Road Systems
E-truck: Electric Truck
EV: Electric vehicle
EVSE: Electric Vehicle Supply Equipment
GB/T: Guobiao Standards Recommended
GB: Guobiao Standards
HCV: Heavy Commercial Vehicle
HD: Heavy Duty
ICCPD: In-Cable Control and Protective Device
IEC: International Electromechanical Commission
IMC: In Motion Charging
LCV: Light Commercial vehicle
MCV: Medium Commercial Vehicle
OEM: Original Equipment Manufacturer
PE: Protective Earth
PHEV: Plug-in Hybrid Electric Vehicles
PKI: Public Key Infrastructure
PLC: Power Line Communication
PTA: Public Transport Authority
PTO: Public Transport Operator
RCD: Residual-Current Device
SAE: Society of Automotive Engineers
TCO: Total Cost of Ownership
TRC: Trasporto Rapido Costiero
TRL: technology readiness level
TUA: Trasporto Unico Abruzzese
V2G: Vehicle-to-Grid
V2X: Vehicle-to-Everything
Wi-Fi: Wireless Fidelity

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1. Executive Summary

This document is outlining the foreseen developments in the heavy-duty (HD) vehicle fast charging, especially in electric buses and trucks, with the aim of supporting and facilitating the standardisation of charging technologies by creating a clear overview of popularity of charging technologies and the end users' needs. The required input for the work was collected by reviewing the existing literatures and conducting surveys and interviews on end users and technical stakeholders. Based on the collected data are synthesized into a roadmap, which can act as a basis for future standardisation efforts. Furthermore, based on the conducted analysis on the expected upcoming charging technologies and solutions, three new use cases are proposed in this deliverable to fulfil the future PTO and cities' needs.

2. Introduction

This deliverable aims at supporting and facilitating the future standardisation efforts on charging technologies by creating a clear overview of popularity of charging technologies and the end users' needs. The deliverable provides a pre-normative roadmap of charging technologies for HD EVs, which can be used as a guide for standardisation and decision making focusing mainly on charging technologies and solutions but also addressing their enablers and constraints. Furthermore, three new charging use cases are presented in this deliverable to fulfil the future PTOs' and cities' charging technology needs.

The work started by collecting background information through already existing charging technologies from the project partners and from public information sources. A survey and interviews were performed on the end users (public transport authorities and operators, and cities) to chart out their views on the existing technologies and the potential of the upcoming technologies. A similar survey with supporting interviews were performed on ASSURED technical partners and external technical stakeholders, aiming to find out the views of the technology partners. Some of the findings from the surveys and interviews are:

- Currently, pantograph on the roof and plug-based charging are the most used charging technologies. This trend is very likely to continue in the future, since 1) pantograph on vehicle roof, 2) pantograph on infrastructure and 3) plug were graded as charging technologies with the highest potential by the participants of technical survey.
- Static and conductive charging have higher potential, as compared to dynamic and wireless charging. Inductive charging can be the future charging solution for HD EVs, only if the current bottlenecks in the technology can be addressed. These bottlenecks include a high price, low efficiency, lack of standardisation, and safety concerns.
- The application of both opportunity and depot charging will continue in the future. Nevertheless, the balance of their implementation depends on the different factors such as vehicle mission, battery capacity, operator need, etc.
- Achieving interoperability and lack of simple and robust standards were repeatedly mentioned as the main challenges in today's charging technologies.
- Full interoperability can be reached by[1]:
    - Developing a set of standards with high technical robustness,
    - Developing communication protocol that is clearly integrated into the regulation,
    - Performing conformance and interoperability testing.

Furthermore, a literature review of available use cases and roadmaps was conducted, which served as another input source to the roadmap. All the collected inputs from the literature review, surveys, and interviews were synthesised and analysed to form ASSURED charging technology roadmap. Finally, to address the upcoming PTO and cities' needs, new charging use cases were built based on the analysis.

[1] Having full interoperability has been the focus of ASSURED project, which is successfully achieved by following these three steps.

3. Overview of charging technologies and their standardisation

In this chapter, we first present an overview on the existing charging technologies and the present the global overview their standardisation.

3.1 CHARGING TECHNOLOGIES OVERVIEW

Charging stations are regarded as the point of fuelling EVs. Cords, connectors, and interface with the power grid are the key equipment of a charging station. Good charging infrastructure is one of the key factors for deployment of EVs. Charging of a vehicle can be static or dynamic. Static charging refers to charging of a vehicle that is not moving and that is expected to stay in the same position during the whole charging session. Dynamic charging on the other hand means that the vehicle is charging while it is moving in normal traffic. There are several technologies available for charging electric vehicles. Based on type of energy transfer, charging infrastructure is categorized into following types:

- Conductive (or contact) charging
- Inductive (or wireless) charging
- Battery swapping

Furthermore, two well-known charging scenarios include:

- Depot charging
- Opportunity charging

3.1.1 Conductive charging

Conductive charging includes the use of physical connections between the electronic device's battery and the power supply. It requires a metal-to-metal connection between the charger and the vehicle. Advantages of the conductive system are good efficiency and less exposure to electromagnetic field compared to the inductive charging, while disadvantages include maintenance costs because of the contact between conductor and the collector, visual impact, and safety issues regarding the exposed live wire (Emre, et al., 2014). The charging technologies which are operated by conductive charging are:

- Plug-based charging
- Infrastructure mounted charging contact device (ACD)
- Roof mounted ACD
- ACD connected to side or on roof of vehicle
- Ground-based ACD
- Catenary charging
- Flash charging

3.1.1.1 PLUG-BASED CHARGING

In plug-based charging, vehicle is connected to charging equipment using plugs and cables. Energy transfer capacity depends on power handling capacity of the cable and the connector connecting the charger to the vehicle. The battery pack of an electric vehicle can only be charged by DC power. The power source available from the grid is AC, and hence needs to be converted to DC before it reaches the battery pack. In the case of an AC charge point, the AC is converted to DC by equipment in the vehicle (on board charger). Space and weight considerations tend to limit the power of chargers built into the vehicle. A DC charging point converts AC to DC outside the vehicle and thus bypasses the on-board charger, as shown in Figure 1. A DC charging point is not limited to any significant degree by space or weight, meaning that it is able to accommodate much higher charging currents and the charging times for the batteries can be much shorter compared to AC charging. In addition to high-power DC chargers, there are also low-power DC depot chargers available in the market.

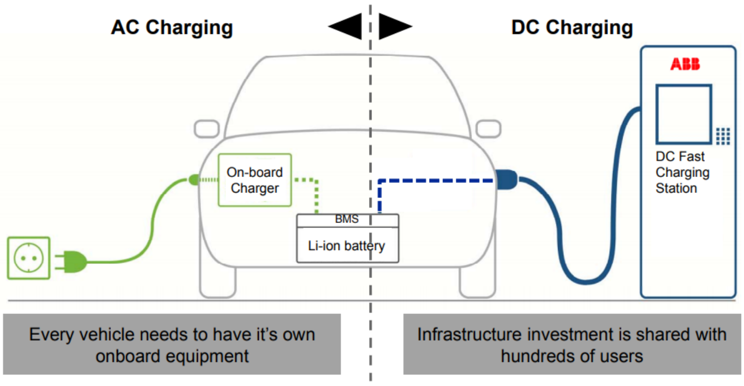

Figure 1. AC Charging vs DC Charging (picture: ABB)

There are four different types of electric vehicle charging systems referred to as "Modes", which are defined by the IEC 61851-1 standard (IEC, 2017a).

- Mode 1 AC charging is quite simply plugging into an existing socket outlet without an in-cable control box. It has no safety and communication systems. Charging uses non-dedicated cables with a household plug. Since it has no shock protection, it is widely not recommended for any other than light vehicle charging (e-bikes etc.).
- Mode 2 AC charging uses a standard socket outlet but the cable between the socket outlet and vehicle incorporates an "In-Cable Control and Protective Device" (ICCPD) set to a specific charging power and providing residual-current device (RCD) protection on equipment. Mode 2 may be a satisfactory charging solution for those with modest charging requirements such as some two wheelers and plug-in hybrid electric vehicles (PHEVs).
- Mode 3 AC charging is designed solely for the recharging of EVs, and the vehicles are supplied by a separate dedicated circuit. The Mode 3 charging points are suitable for residential, public, and workplace / commercial applications. Mode 3 charging points use a specific protocol to allow the charging point and the vehicle to exchange information during the charging process (BEAMA, 2015).
- Mode 4 DC charging systems are specific EV charging equipment with dedicated connectors and communication between the EV and charger is needed for voltage/power control. Output is DC with the charger built into the charging point itself and this is the core difference to Mode 3, which provides AC and uses the vehicle's on-board charger. Mode 4 charging is the typical charging method used for HD vehicles.

3.1.1.2 Infrastructure mounted ACD

Automated connection device (ACD) is mounted within the charging station, typically on a pylon or within a building infrastructure (Figure 2). When a vehicle reaches the charging position, pantograph connects to the vehicle. The setup requires wireless communication between the vehicle and the charger, as the pantograph down request needs to be transmitted from the vehicle to the charger before there is contact available between the systems.

This type of connection simplifies the vehicle structure and lowers the bus fleet cost and bus weight but shifts some of the costs on the charging network side. Inverted ACD system makes electrification of other vehicle classes (such as trucks, vans, or work machines) easier, as the vehicle is required to include light rails for the contact. A drawback of the system is that a single pantograph failure can affect multiple vehicles.

Figure 2. Infrastructure mounted ACD (ABB)

3.1.1.3 Roof mounted ACD

In roof mounted ACD system, a pantograph is placed on top of the bus (Figure 3). This simplifies the charging stations, as the connector on the infrastructure side is static. Since the ACD is mounted on the vehicle, the cost of a charging station is lower, but the pantograph will add some weight, height, complexity, and cost to the vehicle.

The communication between a charger and a vehicle is using PLC, as with passenger cars. The roof mounted ACD system is thus very close to the fast chargers currently deployed for private vehicles. The major difference is the power handling capability of the physical connection.

Figure 3. Roof-mounted ACD (Photo: VTT)

3.1.1.4 ACD connected to side or on roof of vehicle

This charging solution is not as common as the others. In this solution, the positioning of the ACD or its counterpart shall be free at any height on all side of the EV depending on its specific purpose and space requirements, therefore, it is suitable for the vehicles that have weight and space limitation for installing the system on the middle of the vehicle roof. The

European standardisation for this solution is under development in prEN 50696 – Contact Interface for Automated Connection Device (CENELEC, 2021). Figure 4 shows the mechanical arrangement for this charging solution.

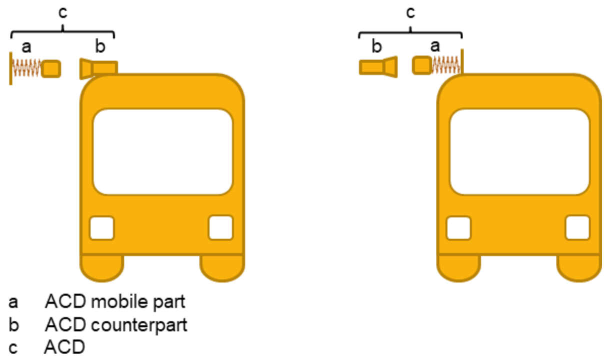

Figure 4. Overview of ACD connected to side (left picture) or on roof of vehicle (right picture).

3.1.1.5 Ground-based ACD

With ground based ACD (Figure 5), the power is supplied through a conductive device (rails or pads) embedded in the road or track surface at the bus or tram stop. When the vehicle is stationary over the device, a current collector shoe lowers automatically and makes contact to charge the battery.

The current standardisation of the ground based ACD is using Wi-Fi for the charging communication, like the infrastructure mounted ACD. However, the system is currently using three contact pads (DC+, DC-, PE), which means that the fourth required signal (Control Pilot, CP) is transmitted also wirelessly, utilizing inductive coil embedded with the ground contacts.

Figure 5. Ground-based ACD (Alstom SRS)

3.1.1.6 Dynamic conductive charging

An overhead line, or overhead wire, is used to transmit electrical energy to trams, trolleybuses, or trains at a distance from the energy supply point. A pantograph is mounted on the vehicle roof and connected to high voltage electric lines over the vehicle for charging the vehicle while in motion (Figure 6). Smaller battery can be used in the vehicle, which decreases vehicle cost but increases the charging infrastructure cost.

Figure 6. Catenary charging of hybrid trucks (picture: Scania)

The new IMC (in motion charging) e-BRT (e-bus rapid transit) system makes the overhead line technology attractive for bus traffic. IMC battery-equipped buses recharge their batteries while running on sections with overhead lines and they can operate without connection to the overhead lines on battery power, providing more flexibility in their choice of route. As example, the seaside resort of Rimini is currently running acceptance tests for its new IMC buses and the vehicles are destined to serve the new Rapid Coast Transport (Trasporto Rapido Costiero – TRC) express line from Rimini to Riccione. Furthermore, TUA (Trasporto Unico Abruzzese) is introducing the IMC buses to operate the eight-kilometre link between the two coastal cities of Pescara and Montesilvano (Bufe, 2021).

Conductive solution based on the ground-based feeding system is successfully used on tramway systems. Currently, research is ongoing on dynamic conductive charging utilising a movable arm underneath the vehicle (Figure 7). Connection is made by the arm, which automatically detects when the rail is near and lowers to the rail on the road to begin charging.

Figure 7. Underneath dynamic charging (Ravenscroft, 2018)

Another example of dynamic charging from the ground, also at a deployment phase after the testing phase, is Alstom APS solution for electric road systems (ERS) (Figure 8). In this system, electricity is collected with a retractable current collector device by the vehicles in motion from short metallic segments installed at the roadway surface.

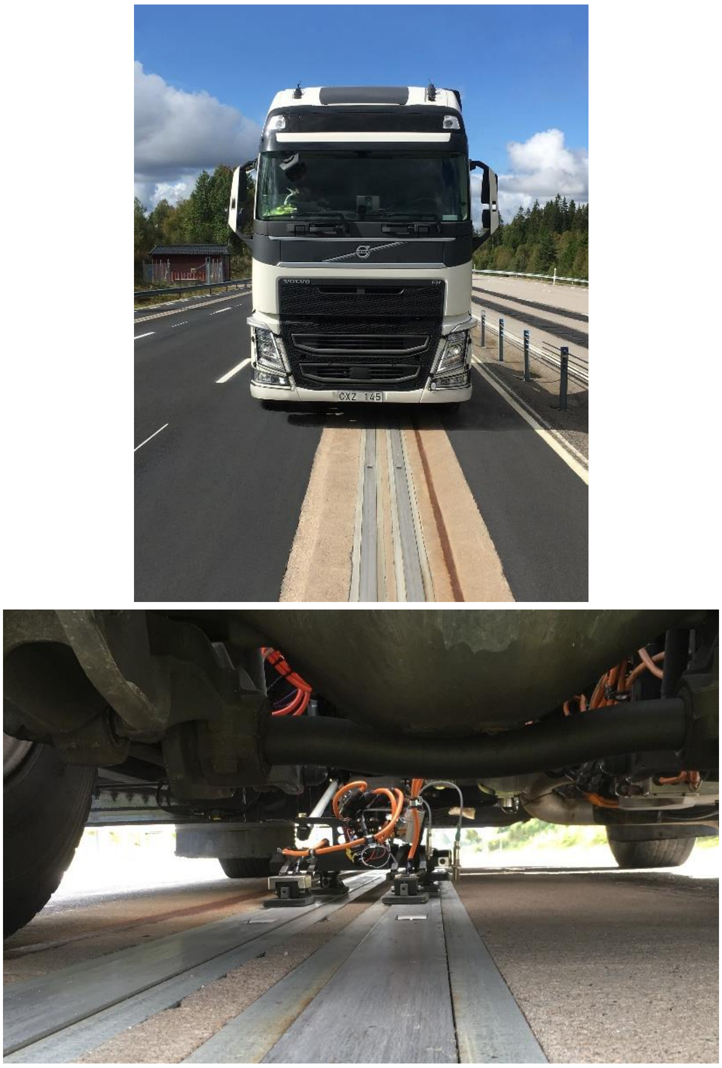

Figure 8. Dynamic charging from the ground (Alstom APS solution for ERS)

3.1.1.7 TOSA CHARGING

Flash charging stations at selected bus stops provide a short high-power boost charge while passengers are getting on and off the bus. These are very high-power charging stations, typically 600 kW. This system uses a laser-controlled moving arm, which connects to an overhead receptacle for charging at bus shelters, instead of the usual trolley poles to overhead lines, as shown in Figure 9.

Figure 9. TOSA charging system (Hitachi-ABB)

3.1.2 Inductive charging

Generally, wireless charging is categorised into two technologies: capacitive charging and inductive charging. The capacitive power transfer is used for low power applications and the inductive power transfer for high power applications (AL-SAADI, et al., 2018). Inductive charging uses an electromagnetic field to transfer energy between two objects through electromagnetic induction. This is usually done with a charging station. Energy is sent through an inductive coupling to an electrical device, which can then use that energy to charge batteries or run the device. Inductive charging is based on high power inductive energy transfer between components buried underground and receiving equipment installed beneath the vehicle. Roadside components communicate with the vehicle to start the contactless charging process automatically as soon as the vehicle completely covers the charging segment. The invisible system transfers energy without contacts currently at reasonably high level of efficiency, but efficiency is still lower than in contact charging. E-vehicles can be charged rapidly and seamlessly either in motion (dynamic inductive charging) or at rest (static inductive charging) without the need for extra fleet vehicles or batteries.

3.1.2.1 Dynamic inductive charging

In dynamic inductive charging (Figure 10), dynamic power is transferred to the vehicles from the roads they are driving on. The basic principle is to power an electric engine within the vehicle from an external power source that is built into the road infrastructure. The energy is transferred wireless through a magnetic field and no physical connection between the road and the vehicle is required. A conductor (comparable to the primary side of a transformer) inside the road generates a magnetic field that can be obtained in the vehicle and converted into electrical current. The powertrain of the truck needs to be tightly integrated with the power transfer technology, which needs to be integrated with the electric road design, which in its turn needs to be integrated with the regional power grid (Viktoria Swedish ICT, 2013). High investments are required in establishing the physical infrastructure.

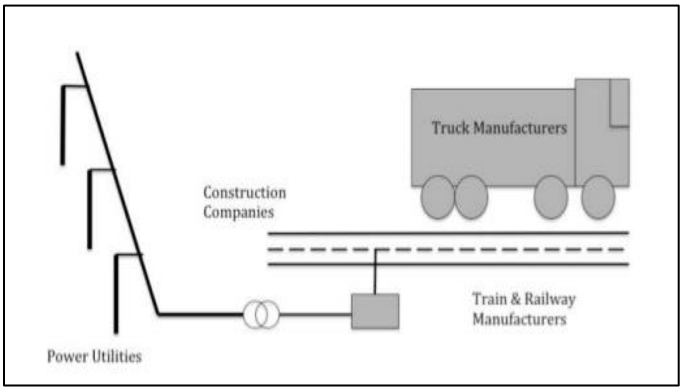

Figure 10. Dynamic inductive charging (Viktoria Swedish ICT, 2013)

3.1.2.2 Static inductive charging

For fast charging at convenient times, charging points are integrated where vehicles typically stop along their route. Charging points include loading docks for delivery vans, taxi waiting areas, depots for car-sharing pools as well as private and company garages. Induction allows for electricity to move to a battery without physical contact. Inductive charging plates are usually located at ground level and typically the bus either lowers itself as near to the induction plate as possible or a mechanism moves the plate up to the bus

(Marcon, 2016), to increase the efficiency of the energy transfer. Figure 11 shows a static inductive charging station for electric buses in Wenatchee, Washington.

Figure 11. Static inductive charging (Lambert, 2018)

3.1.3 Battery swapping

In battery swapping, instead of connecting vehicle to charging points and waiting for vehicle's battery to charge, vehicles discharged battery or battery pack can be swapped for a fully charged one. In battery swapping, the batteries must be easily accessible and located. The battery pack has to be designed in such a way that it can be easily swapped from the vehicle. The battery swapping system can be installed at a remote location (e.g., along a highway between two cities) and one or more technicians can be stationed at the location for operating the system. For battery swapping, to become a mainstream technology, interchangeable battery packs that are similar for various manufacturers must be available. The infrastructure required for the battery packs is complex and expensive, and the technology also suffers from high capital expenses of the additional battery packs required for the operation (Furnari, et al., 2020). Nevertheless, offering Battery as Service reducing reduces the high upfront price of EVs by separating battery ownership and cost (Wood, 2020).

3.1.4 Depot charging

Depot charging allows vehicles to be connected and charged while parked at the depot, generally overnight, or if necessary, during the day as well. Vehicle is connected to charging equipment typically using plugs and cables, but also ACDs are used in some depots.

3.1.5 Opportunity charging

In opportunity charging, vehicle is connected to the high voltage charging equipment with the help of an ACD, typically a pantograph. When a vehicle reaches the charging location, the ACD connects the charging setup. The communication between the vehicle and charging equipment is set by means of Power Line Communication (PLC) or Wi-Fi, depending on the type of the ACD. The energy transfer is done in few minutes with the help of control devices and electronics that are gathered in a heavy-duty cabinet, placed in a suitable housing. Underground cabling connects it to the pylon where the charging contact device (ACD) is mounted.

3.2 GLOBAL OVERVIEW OF STANDARDIZATION

For the U.S. auto industry, Society of Automotive Engineers (SAE) standard J1772 is the governing document for electric vehicle (EV) charging (SAE International, 2012a). This document defines the requirements for electric vehicle supply equipment. As per J1772, charging system has three functions: AC-DC rectification, voltage regulation to a level that permits a managed charge rate and physically connecting the charger to the vehicle (Tuite, 2012). The SAE J3105 is to standardize the interface between the overhead infrastructure and the vehicle (SAE International, 2020a). It has a common area of specifications in communication, interface, power flow and safety (Kosowski, 2017). The IEC (International Electrotechnical Commission) 61851 standard used in Europe (IEC, 2017a) and GB/T (Guobiao standards recommended) 20234 (Zheng, 2014) used in China were derived from J1772 and has similar requirements, adapted for the European and Asian ac line voltages. Most terminology differences are superficial. Where the SAE standard describes “methods” and “levels,” the IEC and GB (Guobiao) standard talks about “modes,” which are virtually the same (Tuite, 2012). Standards for overhead charging infrastructure are not fully established and several committees are formed by U.S. and the European Union to form set of standards for overhead charging infrastructure.

In the following sections, the safety and charging standards for HD EVs are presented.

3.2.1 Safety standards

Table 1 presents international safety standards for electric vehicles. These standards tend to cover both light commercial vehicles and heavy-duty vehicles. However, due to technical differences between light EV and HD EVs, further differentiation in standardisation is required. This need has already led to SAE safety standards (Table 2) for HD EVs and their batteries (ITF, 2020).

Table 1. International safety standards for electric vehicles (ITF, 2020)

ISO 6469 1-3	Specifications for batteries and high-voltage systems on electric vehicles (ISO, 2019a; ISO, 2018a; ISO, 2018b)
ISO 6469 4	Specifications for batteries and high-voltage systems on electric vehicles following a collision (ISO, 2015a)
ISO/DIS 21498	Specifications for high-voltage systems on electric vehicles (ISO, 2018c)
ISO 12405	Specifications for lithium-ion battery packs and systems (ISO, 2018d)
ISO 21782	Specifications for electric propulsion components (motor, inverter, DC-DC converter) and their combinations (motor system) for electric vehicles (ISO, 2019b; ISO, 2019c)
SAE J1766	Recommended practice for electric and hybrid vehicle battery systems integrity in the event of a collision (SAE International, 2005)
SAE J2929	Safety standard for electric and hybrid vehicle propulsion battery systems using lithium-based rechargeable cells (SAE International, 2011)
SAE J2344	Guidelines for electric vehicle safety (SAE International, 2010)
SAE J2464	Recommended practices on electric and hybrid electric vehicle rechargeable energy storage system (RESS) safety and abuse testing (SAE International, 2009a)
UL 2580	Specifications and stress tests for large electric vehicle batteries aiming to mitigate the risk of fire and electrical hazards (UL, 2020)

Table 2. SAE safety standards addressing battery requirements for heavy electric vehicles (ITF, 2020)

SAE J2910	Recommended practice for design and testing hybrid electric or fully-electric trucks and buses for electrical safety (SAE International, 2014)
SAE J3004	Standardisation of battery packs for fully electric and hybrid trucks and buses (SAE International, 2012b)
SAE J3125	Integration of battery pack systems in bus electrification (SAE International, 2016)

3.2.2 Charging standards

The main international charging standards for plug-based charging, inductive charging, and battery swapping are listed in Table 3. While technical standards for EV charging aim to cover a broad range of vehicle categories, the focus of the presented standards in Table 3 is on passenger cars not HD EVs (ITF, 2020).

Table 3. Main international charging standards for plug-based charging, inductive charging, and battery swapping of EVs (ITF, 2020)

	Plug-based charging
IEC 62196	Series of standards for conductive charge connectors (plugs, socket-outlets, vehicle connectors and vehicle inlets) for electric vehicles (IEC, 2014a; IEC, 2016b; IEC, 2014b)
IEC 61851	Series of standards covering safety-related specifications on the charging station, the electromagnetic compatibility and the communication between vehicle and charger (including vehicle to grid functionality) (IEC, 2017a; IEC, 2017b; IEC, 2018; IEC, 2014c; IEC, 2014d; IEC, 2020a)
ISO 17409	Specifications for the connection of electric vehicles with an external electric power supply (ISO, 2020a)
ISO 15118	Series of standards for vehicle-to-grid communication interfaces, protocols and data requirements (ISO, 2019d; ISO, 2014; ISO, 2015b; ISO, 2018e; ISO, 2018f; ISO, 2020b; ISO, 2021)
SAE J1772	Specifications for conductive charge connectors (plugs, socket-outlets, vehicle connectors and vehicle inlets) for electric vehicles (most relevant for North America and Japan) (SAE International, 2012a)
SAE J2953	Requirements and specification by which a specific electric vehicle and charger can be considered interoperable (SAE International, 2013)
SAE J3068	Electric vehicle power transfer system using an AC three-phase capable coupler (SAE International, 2018)
	Inductive charging
IEC 61980	Series of standards and specifications for the equipment needed for the wireless transfer of electric power from the supply network to electric road vehicles (IEC, 2020b; IEC, 2019b; IEC, 2019c)
ISO 19363	Safety and interoperability requirements for the on-board equipment that enables magnetic field wireless power transfer for electric vehicle charging (ISO, 2020c)
SAE J1773	Recommended practices on electric vehicle inductively-coupled charging (SAE International, 2009b)
SAE J2954	Specifications on safety, interoperability and electromagnetic compatibility of wireless power transfer for light plug-in electric vehicles (SAE International, 2020b)
	Battery swapping
IEC 62840	Series of standards for electric vehicle battery swap systems (IEC, 2016a; IEC, 2019a)

In 2015, to tackle the lack of charging infrastructure standardisation in Europe, the European Commission (EC) requested the European Committee for Standardisation (CEN) and the European Committee for Electrotechnical Standardisation (CENELEC) in a mandate 533 (M/533) to develop and adopt appropriate European standards (ENs), or to amend existing European standards, for alternative fuels infrastructure (European Commission, 2015). According to this mandate, the developed European standards should include technical specifications with a single solution for e-bus supply connectors and socket outlet (based on the standard developed for electric passenger cars and light duty vehicles, if possible), and a single solution for e-bus wireless recharging. In 2018, CEN-CENELEC eMobility ad-hoc e-bus Steering Group established the first version of their recommendation that contained manual plug charging and three fast charging solutions with infrastructure mounted, roof mounted, and ground-based ACDs, hence differing from the EC's request for a single solution for supply connectors (CEN-CENELEC eMobility Coordination Group, 2018). Table 4 presents the list of CEN-CENELEC recommendations for conductive charging of HD EVs. Some of these standards (outlined by red) are currently being developed and expected to be finalised by end of 2021 at the latest.

In 2020, SAE international issued SAE J3105 standard for ACD charging.

Table 4. CEN-CENELEC recommendations for conductive charging of HD EVs (CEN-CENELEC eMobility Coordination Group, 2018). This table is updated according to the latest status of the standards.

		Connector (plug-based charging)	Roof mounted ACD	Infrastructure mounted ACD	Ground-based ACD
Communication	Application to network layer	ISO 15118-2 Ed1	ISO 15118-20 Ed1		
	Physical to datalink layer	ISO 15118-3		ISO 15118-8	
Electrical safety and EMC		IEC 61851-1, IEC 61851-21-2, IEC 61851-23			
		ISO 17409 Ed1	IEC 61851-23-1 ISO 17409 Ed2		
Mechanical interface		IEC 62196-3 Configuration FF	EN50696 Annex B	EN50696 Annex A	EN50696 Annex C

4. Methodology

This chapter presents the methodology that we used to outline the foreseen developments in the HD vehicle fast charging and establish the roadmap. In the first section, we present a literature review on the existing research, use cases, and roadmaps. In the second section, we introduce the surveys and interviews that were performed for collecting end users' and technical partners' perception of the existing and future charging technologies.

4.1 Literature review

As the number of HD vehicles increases in the market, their charging also needs to evolve. Therefore, a new set of future-proof policies and strategies are required to fulfil all the charging needs. Lucien et al., (2020) provided a roadmap for electric truck charging infrastructure deployment. In this work, the recharging needs of electric trucks are categorized into three charging use cases: depot charging (overnight charging), destination charging (typically at distribution centres), and public charging (along highways or at charging hubs in urban areas). According to this work, to cover half of the distance driven by truck in the Europe by electric trucks, policymakers should address these three charging uses cases adequately. In early phases of transmission to electric trucks, depot charging will serve about 80% of the truck charging needs, while destination charging covers 15% of the total energy, and public charging about 5%. However, in long term, focus on improving public charging will be necessary to fulfil urban and regional deliveries and the long-haul operations charging needs, with increasing dependency on public charging as longer trips are electrified.

Figure 12 presents the current and near future roadmap of these three charging use cases for e-truck (Welch, et al., 2020). According to this figure, the charging technology will move toward high power DC charging, which increases the infrastructure cost.

Charging use cases	Type	Power	Cost
Depot night charging	AC DC	11-44 kW 20-50 kW	$ $$
Customer site/ Distribution centre	DC	20-50 kW 150-350 kW 1-3 MW	$$ $$$ $$$$
Public charging / City hubs	DC	150-350 kW 1-3 MW	$$$ $$$$

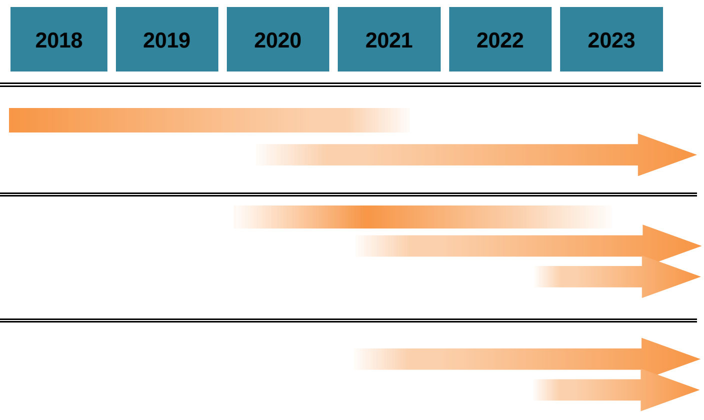

Figure 12. Availability and cost range of charging use cases for e-trucks (Welch, et al., 2020)

According to (Sudhakar, 2019), improvement of ultra-fast charging (with more than 1 MW capacity), interoperability between chargers, and network expansion will be the focus for next ten years. Figure 13 presents Sudhakar's roadmap for commercial electric truck and bus charging infrastructure technology between 2010 and 2030.

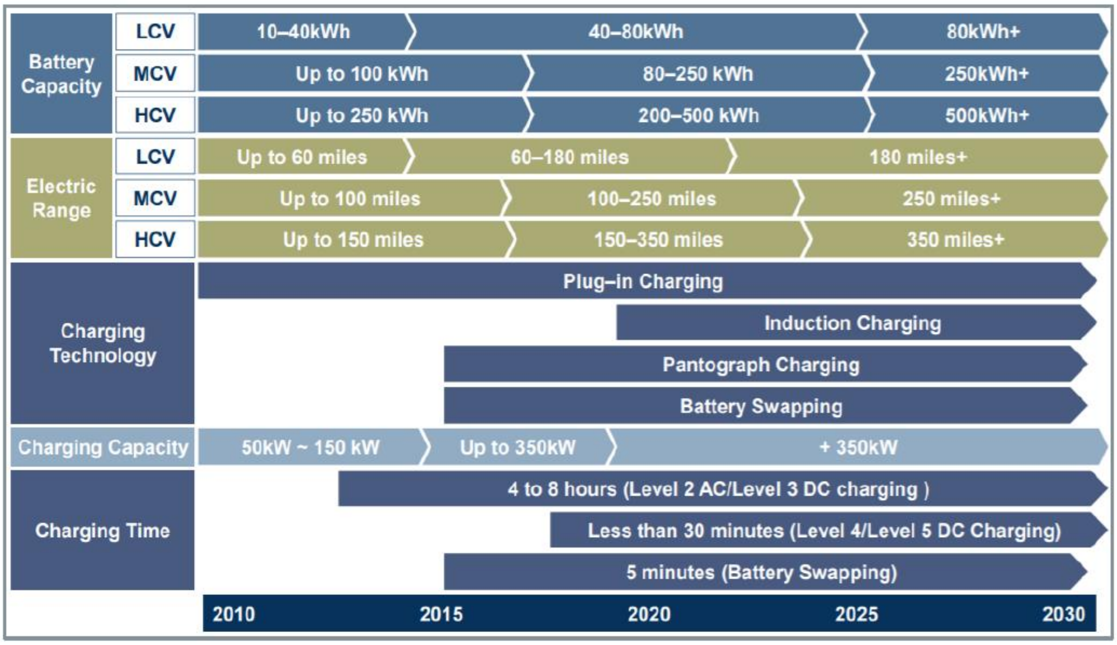

Figure 13. Electric truck and bus charging infrastructure technology roadmap (Sudhakar, 2019)

Currently, 350-600 kW fast DC chargers are developed for medium and HD trucks and higher charging power are being introduced to the market, e.g. GB/T developing standards for up to 900 kW.

Despite of the development of charging power, low AC and DC power will be still required for applications such as intercity fleets that have time to charge over long periods, either overnight or during operational hours at depots. Whereas, DC fast-charging is suitable for fleets that must charge rapidly at dedicated facilities or along travel corridors. Therefore, the fleet charging solution and use case need to be defined according to location, and time needed to charge (Welch, et al., 2020).

As the charging power increases, the utilities also need to be prepared in advance to assure the grid readiness for responding to the increasing demands. For example, depending on the required power, the grid may require upgrades, which can take 48 months or longer. Table 5 provides several typical power scenarios and their required grid upgrades (Black & Veatch, 2019).

Table 5. Typical power scenarios and the required grid upgrades (Black & Veatch, 2019).

No distribution circuit upgrades (Up to 1 MW)	• Often, site loads below 1 MW can be supported with a new service transformer connected to the local distribution grid. • Required months: 0-2
Supply conductor upgrade, no grid upgrades (Up to 1 MW)	• The supply conductor may require replacement to serve the increased load. The service transformer may also be replaced with a larger size. • Required months: 0-2
Medium voltage service, no grid upgrade (Over 2 MW)	• The manager may have to take primary service at medium voltage to allow for multiple service transformers (customer owned) behind the meter if the site load exceeds standard service transformer and low voltage switchboard ratings (typically around 3000 A). • Required months: 0-5
Grid upgrade deployment: re-conductor or new line equipment (Over 1 MW)	• The overhead or underground wire may require upsizing to increase the load capacity and improve voltage regulation on the feeder if the charging load overloads the distribution circuit. • Required months: 6-36
Substation upgrade: new transformer bank (Over 10 MW)	• An overloaded transformer bank is either replaced by a larger bank in the substation or an additional bank is added. • Required months: 18-36
New substation (Over 20 MW)	• A new utility or dedicated high voltage substation may be required for very large installations. • Required months: 24-48

Smart and flexible charging can be used to aid the grid to response to the HD EVs demand. Smart Electric Power Alliance (2019) recommended a set of load management strategies and planning tools to assist the utilities in preparing for an EV future. In ZeEUS project, a number of market-based simulations of optimal scheduling of bus charging were run to evaluate the revenue potential of different business models. According to this work, energy arbitrage combined with reduction of demand charges resulted in modest savings for the CSO. The savings from price-controlled charging (energy arbitrage business model) were greatest when only overnight charging was allowed. However, in this case the battery cost was extremely high. Allowing opportunity charging lowered the total cost, which indicates that the higher power prices at daytime are compensated by the reduced battery and charger costs. This was even true if a service charge was added to the opportunity charging energy price to cover the infrastructure costs (Ikäheimo, et al., 2018).

In general, battery with higher capacity requires longer charging time, compared to the lower capacity battery. For example, most e-trucks take more than two hours to fully recharge on the fastest available charging systems, whereas other HD vehicles with high battery capacity have to plug in overnight to fully recharge a drained battery (GEOTAB, 2020).

E-trucks with ranges of 150-300 km, with batteries in the order of 100-200 kWh, are likely to play an increasing role in urban areas. This will primarily be for 'last mile' delivery, and for vocational vehicles that operate on a local route and return to a depot for re-charging on a regular basis. Meanwhile, with continuous increase in energy density, it is expected to have heavier vehicles with range of 500 kWh over next 3-5 years (Panayi, 2019). Nevertheless, the need for unnecessarily large battery capacities can be reduced by having sufficient high-power infrastructure with easy access for short range vehicles or the fleets that have the possibility of opportunity charging.

Dynamic charging solutions, such as overhead catenary or in-road charging systems, can extend vehicle ranges while reducing needs for heavy and costly batteries (Welch, et al., 2020). According to Lucien et al. (2020) a pan-European dynamic charging system can be the most climate friendly and cost-efficient solution. To ensure the interoperability and the rollout of the dynamic charging system across Europe, however, the European policy makers must provide a single standard for dynamic charging solutions (Lucien, et al., 2020). Otherwise, companies start pushing their individual charging solution that would not be interoperable with others, as we already can see several companies and projects have started piloting their dynamic charging solutions in Europe, for example:

- Elways in Sweden – a ground-based system (Elways AB, 2018),
- Elonroad in Sweden – a ground-based system, slightly different from the Elways's solution in being mounted on top of the road (Elonroad, 2017),
- eHighway in Sweden and Germany – overhead line-based system (Jovanović, 2019),
- Smartroad Gotland started in Sweden and soon moving to Germany, wireless electric road system (Smartroad Gotland, 2021).

4.2 DATA COLLECTION USING SURVEYS AND INTERVIEW

Two surveys, namely the end-user survey and technical survey, and a set of interviews were carried out to collect the views of different stakeholders on the future needs and potential of charging technologies. The target vehicle groups in the surveys were battery electric buses, trucks or other heavy-duty vehicles and the charging technology types included in the surveys are illustrated in Figure 14.

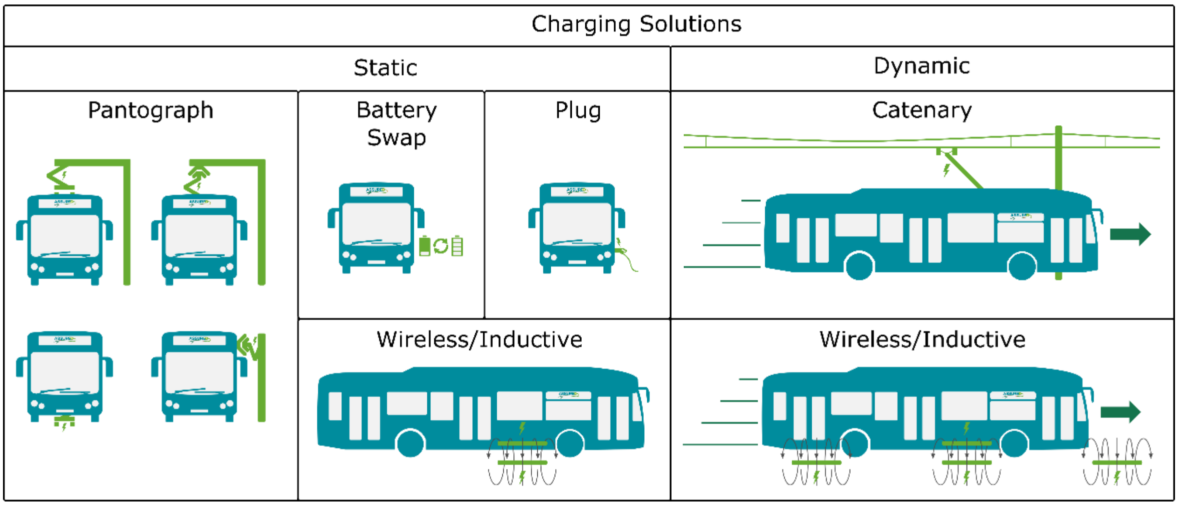

Figure 14. Overview of charging technologies presented in end user and technical surveys (figure from TNO)

The details of the surveys and the interviews are described in the following subsections.

4.2.1 End user survey

The purpose behind this survey was to chart out the views of end users (public transport authorities and operators, cities) on the existing technologies and the potential of the upcoming technologies with the aim of maximizing the adaption rate of the future charging technologies standards by matching the standards to the end users' needs. Table 6 summarises the target participants, goal, output, and target audience of the results of the end user survey.

Table 6 – End user survey

Target Participants	Owners/users or future owners/user of electric buses, trucks or other heavy-duty vehicles Examples: public transport companies, city governments, logistics companies, construction companies
Goal	To maximize the adoption rate of future charging technologies standards by matching the standard to the needs of the end user.
Results	An overview of the charging infrastructure user needs
Target Audience of the results	Standardization committee members

TNO designed the initial version of the survey and VTT and UITP reviewed the survey. VTT and UITP conducted the survey by sending it out to the internal and external ASSURED end user partners. The result analysis of this survey is summarised in Section 5.1. Total of 25 participants responded to the end user survey. To ensure that the respondents match with the requirements of the target participants, the participants were asked if their organisation currently own/use or aim to own/use in future the target vehicles. The participants who answered "No" to these questions were not allowed to continue responding to the rest of the survey. 11 (out of 25) of respondents answered "No"; therefore, they were dropout, and the survey was continued with 14 participants.

4.2.2 Technical survey

The target participants, goal, output, and target audience of the results of the end-user survey is summarised in Table 7.

Table 7 – Technical survey

Target Participants	Organizations with in-depth knowledge of charging infrastructure for electric buses, trucks or other heavy-duty vehicles Examples: charger production companies, charging service providers, research organizations, electric bus/truck production companies
Goal	To smooth and speed up future standardization processes for charging infrastructure, by creating an overview of charging concepts' popularity and their perceived potential.
Results	An overview of charging concepts' popularity and their perceived potential
Target Audience of the results	Standardization committee members

VTT designed the initial version of the survey. After TNO amended the initial draft, VTT and UITP reviewed the survey for a final check. VTT conducted the survey by sending it out to the internal and external ASSURED technical organisations. Total of 20 individuals responded to this survey. The result analysis of the technical survey is summarised in Section 5.2.

4.2.3 Interviews

In both end user and technical surveys, the respondents were asked about their interest to participate in a follow up interview after the survey. 4 of end user respondents and 11 of technical respondents answered “Yes” to this question. At the end, 3 of the end user respondents (PTO or standardisation experts) and 4 of the technical respondents (EV experts or standardisation experts) participated in individual interview sessions, which were held remotely by UITP and VTT, respectively. The interview questions were designed by analysing all the surveys responses and then, if required, customised based on the responses of each individual interviewee to the survey. A report of the interviews is provided in Section 5.3. It has been agreed that the interviewees’ personal information remains confidential in this document.

5. Results from surveys and interviews

5.1 End user survey

In this section, we present a summary of the end user survey results. As explained in Sub-section 4.2.1, relatively large portion of participants (11 out of 25) did not comply with the target audience of the end user survey and thus they were not allowed to continue with the survey.

5.1.1 Charging technologies owned/used by the end users

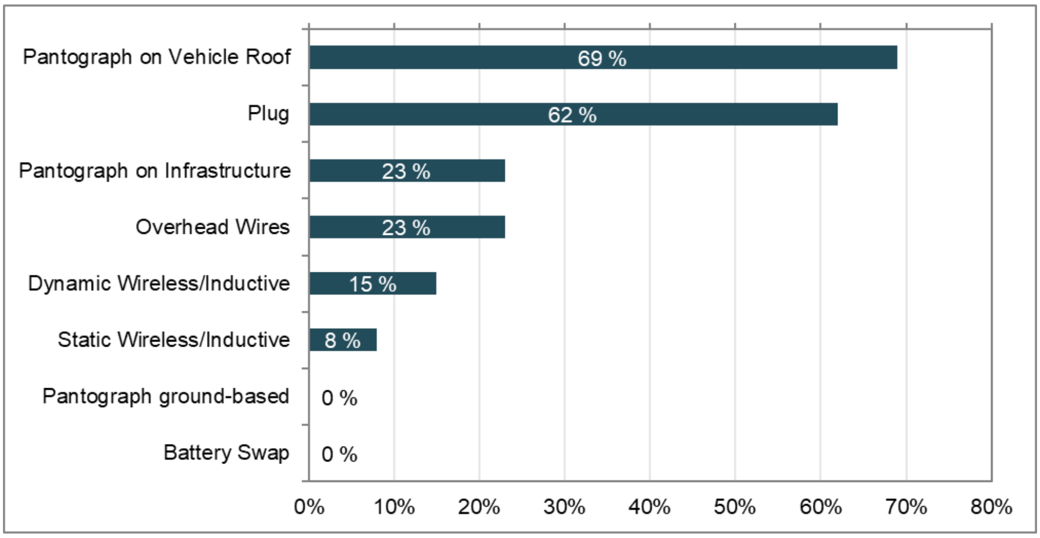

Figure 15. Charging technology types that end users own/use. Pantograph on the roof and plug based charging are the most common used charging technologies among the end user survey participants.

Pantograph on the roof and plug based charging are the most common used charging technologies among the end user survey participants (Figure 15). These technologies are almost 3 times more popular than pantograph on the infrastructure and overhead wire (catenary) solutions. Some of the reasons for the end user organizations to choose a specific charging technology includes:

- Pantograph on vehicle roof:
  - Optimal use of time when the e-bus is at the terminal, during regular stops.
  - Guarantees for the best system availability and the fastest opportunity charging.
  - Choosing pantograph on the roof over the pantograph on infrastructure for maintenance reasons, single point of failure: to avoid problem in the infrastructure if the pantograph is broken. In pantograph on vehicle roof, if a technical problem occurs in the pantograph, the infrastructure can be still used by other buses.
  - Wanting to charge with the same system in opportunity charging and depot (not plug in).
- Plug:
  - Choosing plugs over pantograph-based infrastructure, as the cost of pantograph-based infrastructure was too high for the number of buses that were deployed with overnight charge solution.

- Pantograph on the infrastructure
  - Public tendering for the complete package (Bus and infrastructure). Pantograph on the infrastructure was the best offer.
- Conductive charging:
  - Choosing conductive over inductive. Conductive is a more optimum solution (plug in as well as standard and inverted pantograph). Energy efficiency of inductive is only around 90% (much less than conductive and that energy is lost/wasted).
- Overhead wire:
  - To use the currently existing contact network.
  - The use of overhead wires and trolleybuses were extended to hilly landscape and the areas with heavy passenger demand and full day operation.
  - The overhead wire technology is chosen for fleet of older and historic trolleybuses.
  - This technology is suitable for places in a city that the infrastructure already exists for utilisation.

5.1.2 Future goals of end users' organisations regarding charging technologies

The end users were asked to present their organisations' short term and long-term goals regarding charging infrastructure. Some of their goals include:

- For year 2020:
  - Purchaser of 35 electric buses with dynamic charging, range up to 15 km
- For year 2021:
  - Construction of 2 fast chargers 360-380 kW.
  - 5 fast charging places.
  - 2-pole opportunity charging infrastructure for e-buses.
  - Overnight charging solution with pantograph-on-bus (large fleet >30 e-buses).
  - Overnight plug charging solution (city with few e-buses)
  - Receiving 23 electric articulated buses.
- For year 2022:
  - 3 fast charging places.
  - Power Connection for 8 MW.
- For year 2023:
  - Around 50 e-buses with overnight charging.
  - IMC infrastructure for double articulated and articulated battery trolleybuses.
  - Pole opportunity charging infrastructure for e-buses.
- For year 2024:
  - BRT line with 20 buses with opportunity charging.
  - Wireless/inductive charging.
  - IMC infrastructure for standard articulated battery trolleybuses.
- For year 2025:
  - Purchase of 85 e-buses with dynamic charging, range up to 20 km.

    - Every new bus will be a zero-emission bus with associated charging infrastructure.
- For year 2030:
    - The whole fleet of public transport buses will be zero emission with associated infrastructure.

5.1.3 Biggest challenge regarding charging technology

The end users were asked about their organisations' biggest challenge concerning charging technology. Some of the most mentioned concerns include:

- Having a reliable communication line with easy diagnostics
- Finding location for charger installation / Complication regarding land ownership and building the infrastructure
- Power availability

5.1.4 Wishes for future charging infrastructure product/service

The respondents would like the following charging infrastructure products/services to be developed further in the future:

- Cheap and reliable ultra-fast charging
- More Involvement of national energy suppliers in this aspect
- Transformer station
- Interest in wireless charging

5.1.5 Ranking the priorities for charging infrastructure

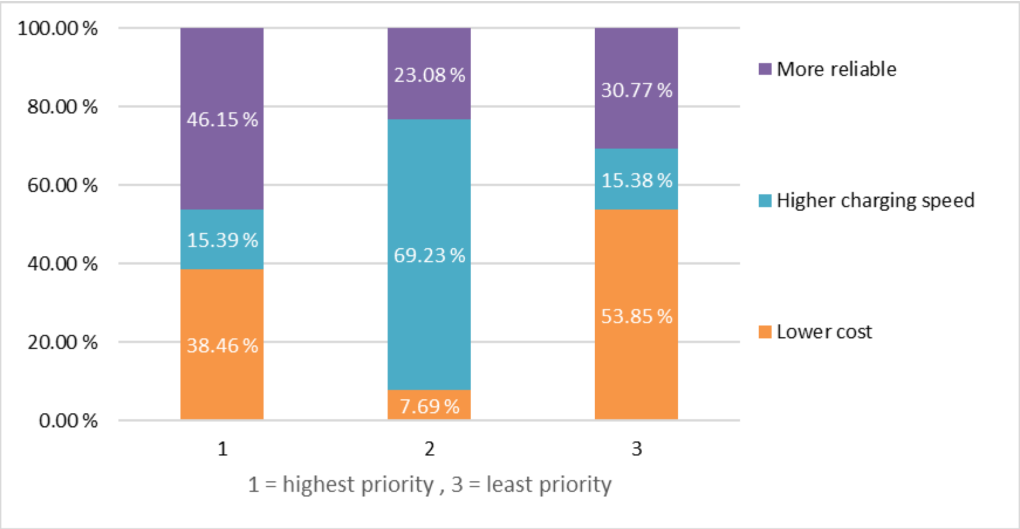

Figure 16. Ranking the priority of charging infrastructure improvements. To end users, having more reliable charging infrastructure is more important than having lower infrastructure cost.

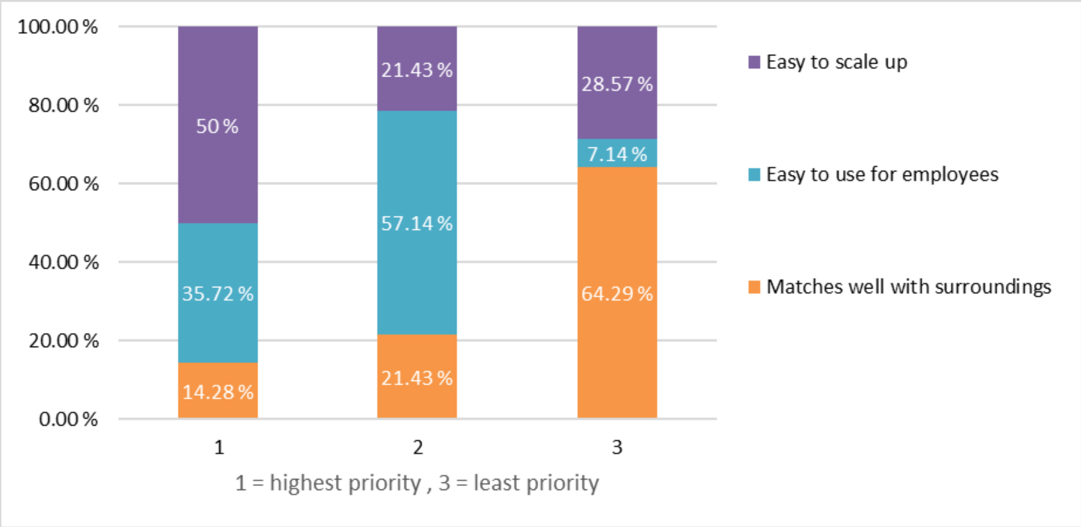

Figure 17. Priorities in charging infrastructure characteristics. To end users, the ease of scaling up the charging infrastructure is almost as important as the ease of use for employees.

The reliability of charging infrastructure is more of importance to end users than having lower infrastructure cost. Furthermore, the ease of use for employees and ease of scaling up the infrastructure have higher priority over the need for infrastructure to match well with surrounding areas.

5.1.6 Importance of interoperability

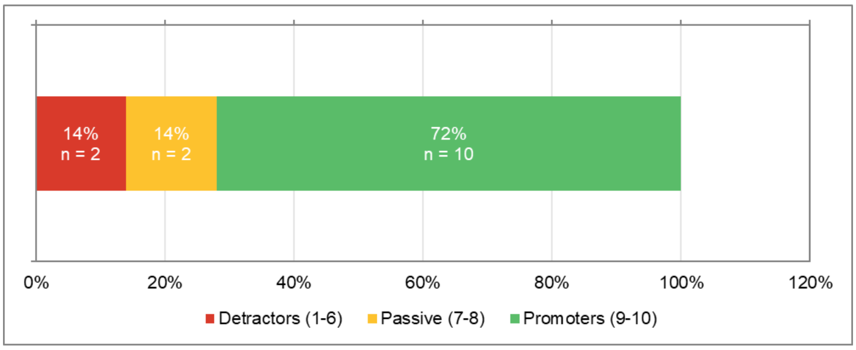

Figure 18. Importance of interoperability between chargers and EVs of different brands. 72% of end user respondents believe that interoperability between charges and EVs of different brands is very important.

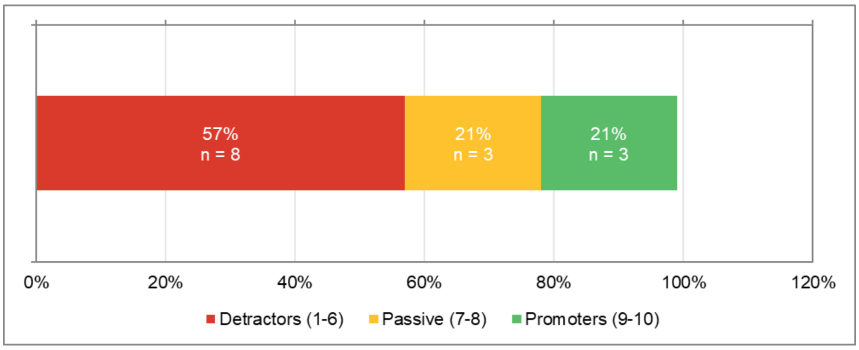

Figure 19. Importance of interoperability between chargers and different EV types (e.g., buses and trucks). Only 21% of end user respondents believe that interoperability between charges and different EV types is very important.

End users agree that chargers and vehicles of different brands should become interoperable. However, the interoperability between different types of vehicles (e.g. buses and trucks) is not of importance to them.

5.2 TECHNICAL SURVEY

In this section, we present a summary of the technical survey results. As explained in Sub-section 4.2.2, 20 individuals responded to this survey.

5.2.1 Charging technologies known to technical respondents

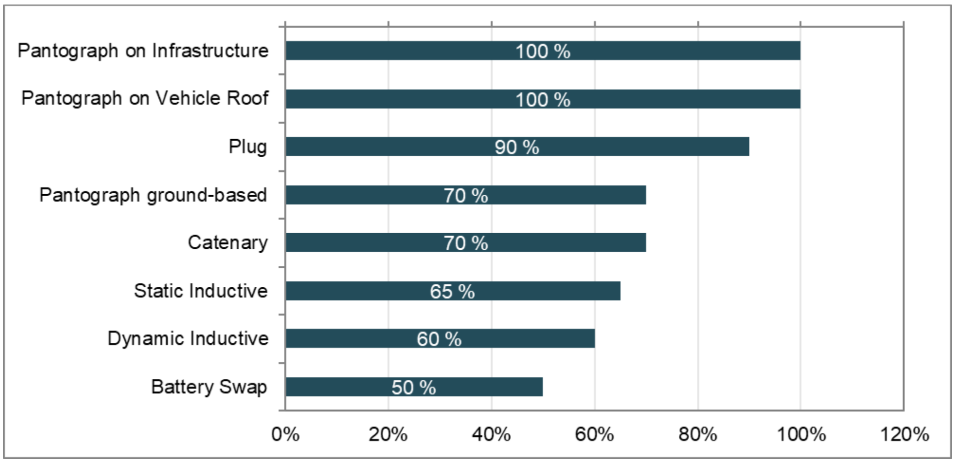

Figure 20. Familiarity with different charging technologies. All the technical respondents are familiar with infrastructure mounted and roof mounted ACDs.

All the respondents are familiar with infrastructure mounted and roof mounted ACDs. However, only half of them are familiar with battery swapping technology. Surprisingly, 2 (out of 20) respondents indicated that they are not familiar with plug base charging.

5.2.2 Potential of different charging technologies

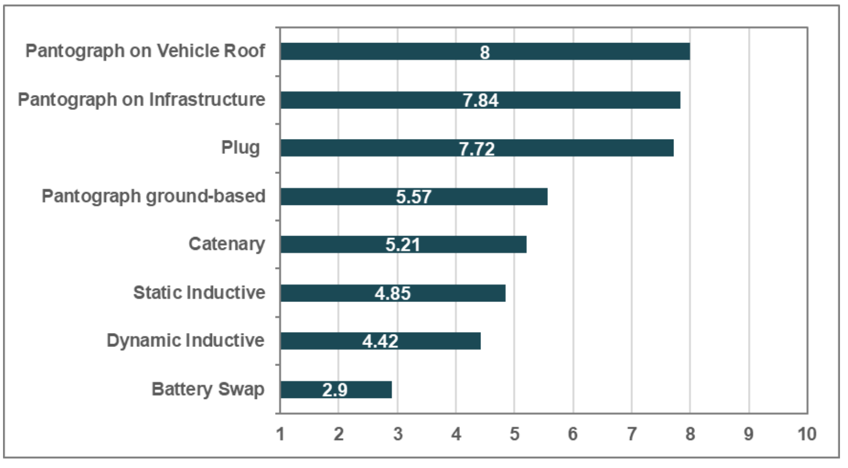

Figure 21. Rating the potential of different charging technologies, 1 = Low potential and 10 = High potential. Pantograph on vehicle roof, pantograph on infrastructure and plug are graded as the highest potential charging technologies.

Figure 22. Rating potential of static charging vs. dynamic charging, 1 = Static and 10 = Dynamic. 30% of technical respondents believe that only static charging has potential in the future, whereas 20% believe that static and dynamic charging have same potential.

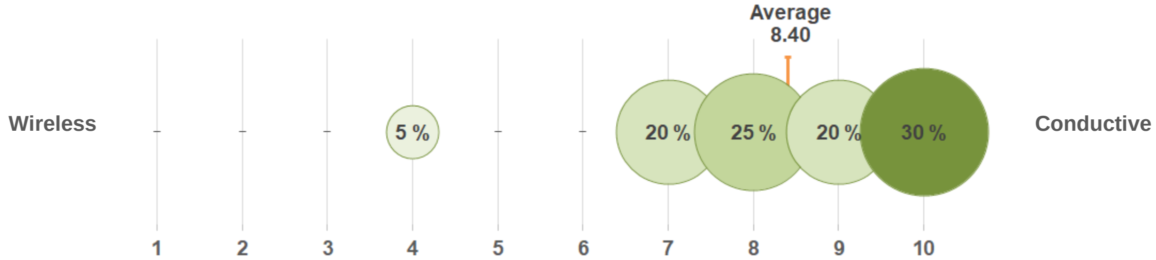

Figure 23. Rating potential of wireless charging vs. conductive charging, 1 = wireless and 10 = conductive. 30% of technical respondents believe that only conductive charging has potential in future.

The results from the technical survey clearly show that 1) pantograph on vehicle roof, 2) pantograph on infrastructure and 3) plug are graded as the highest potential charging technologies. Furthermore, the static and conductive charging have higher potential, as compared to dynamic and wireless charging.

Some of the respondents' motivations in rating the charging technologies include:

- Lower costs of roof mounted and infrastructure mounted ACDs and plug charging compared to other charging technologies.
- Higher efficiency and power of conductive and static charging over inductive and dynamic charging.
- No available standards for some of the solutions.

5.2.3 Challenges in today's charging technologies

The following are the most frequently mentioned challenges in today's charging technology according to the technical survey respondents:

- Providing power needed by grid,
- Interoperability,
- Standardisation,
- Batteries: capacity, cost, BMS (battery management system), aging,
- Installation (permitting, grid connection, space requirement),
- Fleet management, demand response and its complexity.

5.2.4 Influence of energy storage development on charging technologies

According to the technical survey results, development in energy storage (e.g. batteries) will increase:

- The attractiveness of depot charging, smart charging, and participation to frequency and congestion market,
- Charging with renewable energy,
- Driving range and number of EVs for long distance travels,

and decrease:

- Need for opportunity and route charging,
- Weight of buss and charging time,
- Purchase and maintenance costs.

5.2.5 Different aspects to consider in long term (2030) charging technology goals

The following are the most frequently mentioned goals for charging technology in long term:

- Super-fast opportunity charging.
- Minimizing the grid instability by: smart charging, Vehicle-to-grid (V2G) charging, fleet and grid management, local storage.
- Worldwide charging standards for all types of vehicles.
- Increased battery capacity with lower price [that results in increasing depot charging, preferably with plug (as it is cheaper and has low maintenance).
- Availability in all remote places in Europe.

Table 8 summarises the respondents' opinion on including other aspects in long term goals of charging technology.

Table 8. Respondents' opinion on including different aspects in long term goals of charging technology.

	Aspects to include in long term goals of charging technology			
	Vehicle-charger interoperability	**Interoperable charging between different vehicle types**	**Automated charging without human involvement**	**Cyber security**
Proponent (%)	100%	90%	90%	80%
Opponent (%)	0%	10%	10%	20%
Reasons for opposing	NA	- Not required as trucks use mainly only CCS charging by plug. - Opposing due complexity.	- Risk for safety - Unreliability of sophisticated systems	- Complexity - Not an immediate threat, the necessity can be reviewed in 5 or 10 years.
Barriers to achieve	- Lack of technical harmonization - Lack of standardisation - Too many players - Complexity of standardization and misinterpreting it	- Similar barriers to vehicle-charger interoperability - Different mechanical interfaces and charging technologies - Charging infrastructure adaptation	- Risk for safety (e.g., communication and Cybersecurity issues) - Reliability - Lack of suitable technology, including lack of automated authentication and payment methods, functionality - Required space	- Hackers, human mistake - Lack of expertise - Lack of validation protocols - Ensuring protection of the communication - No definition of public key infrastructure (PKI) architecture at EU level
Solution to barriers	- Robust and unified standards - Market maturity - Conformance and interoperability testing - Proper vehicle design and harmonisation of solutions	- Similar solutions to the ones for vehicle-charger interoperability - Common mechanical interface for light and duty vehicles	- Well defined standards - Further technology development of autonomous driving - Trusted and encrypted non-wired communication interface - Robust design	- Standardisation and certification - Ensuring a safe communication: encrypted communication - Definition of PKI architecture at EU level - Collaboration of players to achieve a cybersecurity test specification

5.3 INTERVIEWS REPORT

The topics that were discussed during the interviews are categorized and summarised in the following.

5.3.1 End users interview

Q1. How to encourage the national energy suppliers to contribute more in charging technologies?

According to two of the interviewees, the key to motivate the energy suppliers is implementation of large-scale renewable energy and low carbon energy strategies:

- **Interviewee A:** Energy suppliers are per definition interested in e-mobility projects as this implies more electricity use. They do not contribute to the investment of e-mobility projects. Incentives for energy suppliers could be the use of renewable energies in the form of an incentive to compensate emissions, and to invest in these projects.

- **Interviewee B:** For projects requiring bus system and charging infrastructure, it is possible for a bus OEMs to have a role in the cooperation with energy suppliers or distribution system operators (DSO). But it is not the usual situation. However, energy production should be less carbon-intense/clean(er); this is a political point/responsibility, as bus OEMs are doing their part of the job (by producing cleaner buses).

Q2. How challenging you see finding a suitable location for charger installation and availability of power to that location?

The interviewees did not face any issues with power availability or with installation of their current charging infrastructures. However, they believe the approach “line by line” could be an issue for the extension of the system and pre-planning for future extension of the current lines is necessary.

Q3. Have you heard of any problem that driver would face for positioning of the vehicle or using a paint mark on the sidewalk as a parking location indicator for driver?

Currently, no standard indicator is available to support the driver to position the vehicle correctly. End users have different solutions for positioning of the vehicle. In some cases Wi-Fi communication are used. Some charging systems allow great tolerance while positioning the bus. Visual marks have been used in different locations as well and no specific challenges with this regard is reported. However, having a fully automatized system may allow the driver to focus more on the driving and the passengers.

Q4. How do you see the potential growth of catenary charging solution for city buses?

All the interviewees think that catenary charging solution is interesting only for cities with a developed trolley system to extend/upgrade network. For cities without experience/existing network not interesting as the total cost of ownership (TCO) is high.

5.3.2 Technical interview

Q1. How do you see the growth potential of the following charging technologies and solution?

- **Plug charging and pantograph charging**

  The question on growth potential of plug charging and various pantograph-based charging was asked from Interviewees D and F.

  According to Interviewee D experience, more customers are requesting only plug solution, mainly due to the maintenance and TCO cost of pantograph solutions. There are already some projects developing automated robots that connects the plugs to the vehicle automatically and since it is an add-on to an existing technology, it does not need specific standards. In addition, for ground-based solution, it is difficult to get permission for groundwork, especially in public places for opportunity charging but may be easier in private lands for depot charging.

  In case of other pantograph solutions, Interviewee D stated that only 5% of their pantograph-based vehicles have infrastructure mounted pantograph, because use of charging infrastructure for preheating is possible with roof mounted pantograph but currently not possible with Infrastructure mounted pantograph. Also market has more roof mounted pantograph than inverted systems and the Interviewee does not see a shift on this in future. Lack of finalised standardisation is constraint on roof mounted pantograph solution. The existing vehicles are already using CCS plug standards, in which the length of CP line should be around 10 meters. But this distance is not long enough for HD EV charging and a better solution is required.

From Interviewee F's point of view, the biggest advantage of plug charging is that the number of the providers for this technology is much higher than other technologies. It is world widely known and used. The standards are available and tested. Furthermore, with the development of battery capacity, the vehicle can be easily charged at depot with plug solution. In addition, currently plug is the only interoperable solution for companies that have different type of vehicles (bus and truck). Onn the other hand, the growth potential of ground-based pantograph is low, due to lack of standardisation, high price, and limited number of OEMs and charger suppliers for this technology.

Unlike to Interviewee D's point of view, Interviewee F believes infrastructure mounted pantograph may have higher potential in the future as it is being advertised more in the market.

- **Inductive charging**

  Interviewees believe that inductive charging has very high growth potential in the future, only if the current bottlenecks in this technology can be addressed effectively:

  Interviewee D: Currently the efficiency of inductive is low and the cost is very high, especially for HD vehicles. Inductive charging on long term has good potential but in long term (e.g. in 20 years). Even then it can be beneficial, only if the use rate is high.

  Interviewee E: Efficiency of inductive charging is lower than conductive charging. Also the safety and potential life hazard of the inductive charging for HD EVs should be investigated deeply. If these two challenges are addressed effectively and the standards for this charging is available, inductive charging would be the future solution.

  Interviewee F: The power of inductive charging can reach 200-300 kW in practice. But currently limited number of suppliers and OEMs focusing on this solution. There have been some pilots on inductive charging but some of them have already stopped. The cost of inductive charging is higher than conductive charging and it will not have high potential in the market within next ten year unless it becomes standardised and cheaper.

  Interviewee G: Wireless dynamic charging has more potential than wireless static.

- **Catenary charging solution for city buses?**

  All the technical interviewees shared same point of view as the end user interviewees on catenary charging solution. Catenary will continue to be used for trolley buses in city areas with already existing the charging system.

- **Opportunity charging and depot charging**

  According to the interviewees, the application of both opportunity and depot charging solutions will continue in future. Nevertheless, the balance of their implementation depends on the different factors such as vehicle mission, battery capacity, operator need, etc.:

Interviewee D: Both solutions will be required in future. Depot charging will remain important, as vehicle will still need to be charged overnight. However, if the vehicle has the opportunity to charge between the operations (for example during the driver's breaks), opportunity charging would be beneficial. In this case, there would be no need to have heavy battery and the energy consumption can be distributed on the grid. Charging solution and technology affects all these factors:

- Battery size: possibility to have opportunity charging reduced battery size.
- Pantograph increase TCO, and maintenance and infrastructure cost.
- Grid cost: depends on the required power and time of charging.

Charging technology providers offer customised calculation for their costumers to assess which solution would be the most beneficial charring solution for them.

Interviewee E: For operation and flexibility, opportunity charging is better. But different factors should be considered when selecting between these opportunity and depot charging solutions. These factors include investment cost, law and authorization (possibility of having fast charging at downtown), and PTO and PTA opinions on the matter.

Interviewee F: The choice between opportunity charging and depot charging depends on the need of vehicle, operator, and routes. Also, the density of batteries is improving. With lager batteries with same weight and costs, the operators will select larger batteries. Therefore, for standard buses more and more depot charging will become more attractive to the operators, as they must install the infrastructure only at one place and would have better control of the charging stations, for example they can use them for smart charging.

Articulated buses and the buses with high driving range, still have small battery and high energy consumption. Therefore, in the beginning they require more of opportunity charging and depot charging will become more dominant when their battery capacity improves.

Interviewee G: I am looking for a battery system that allows the costumers to operate the vehicle in a day with a single charge and at the end of the workday they can charge the vehicle at the depot very fast within one hour, however, the development of this type of battery system requires long time and may happen after 2030. Another option is to have intermediate fast charging sessions of 10-20 min during day, to extend the battery.

Q2. What is your opinion about ultra-fast charging? What factors can affect/limit the power level and what do you think will be the charging power level for example in 2030?

To summarise the answers to this question, the development of fast and ultra-fast charging is already ongoing. Fast charging (up to max 1 MW power) is sufficient for charging city buses and commercial vehicles. Ultra-fast charging can be used for long haul trucks.

Interviewee D: CharIN is already working on fast charging. But ultra-fast charging (with power level up to 3 MW) is not necessary for commercial HD EVs, but suitable for ferries, boats, airplanes. For commercial vehicle, charging with 1 MW power will be sufficient. 3 MW charging power may be used for long haul vehicles, but the battery needs to be developed more. Furthermore, on charging infrastructure side it is possible to have electronics that support ultra-fast charging, but on the vehicle side there would be challenges to provide components that can handle that amount of current, both in terms of technology and cost (the price can increase dramatically). Therefore, the rollout of ultra-fast charging may happen in long term.

Interviewee E: The required power level depends on the vehicle charging needs. Ultra-fast charging (more than 1 MW) is not required for buses. For long haul HD trucks different solutions are possible:

- Ultra-fast charging, which requires large battery,
- Battery plus fuel cell
- Dynamic charging.

Interviewee F: A big question mark is the evolution of battery density, which will have impact on what charging technology would be needed. For trucks, fast or ultra-fast charging opportunity charging will be needed, as they must stop every 4-5 hours to have break of 45 min. For intercountry coaches and trucks, we need high speed charging solutions with larger battery capacity, or if dynamic charging is used, charging standardisation at least at European level is required. However, this might achieve in longer terms (e.g., 2040).

Interviewee G: It is expected to have ultra-fast charging battery to allow all type of charging in less than one hour. For this, we require a battery technology that on one hand would have large power density and on the other hand would allow constant charging. But according to our roadmap, this may happen by 2040.

Q3. In your opinion, what are the main challenges in charging technology?

In the interviews, achieving interoperability and lack of simple and robust standards were repeatedly mentioned as the main challenges in today's charging technologies:

Interviewee D: Interoperability is still one of the biggest challenges both during the pre-charging and charging process. Technology is developing faster than the standards and there are still loopholes in standards that needs to be addressed.

Interviewee E: Interoperability is the main challenge. Interoperability requirement depends on the type of the vehicle. For HD buses, the complete interoperability with all charging brands is not required, as they are charged at specific (previously planned) charging stations. But for medium or other HD vehicles, complete interoperability is needed, as the vehicle can be used by different customers at different cities or locations. Another challenge is assuring the electric safety and fire hazard. Safety of charging solutions should be investigated more with real charging scenarios, especially for inductive charging.

Interviewee G: The biggest challenge is to find a common, simple, and standard charging protocol.

Q4. How to improve standardisations?

According to the answers, simplified standards and robust communication methods needs to be developed:

Interviewee D: The key is that the high-power plug would not use CP communication but a more robust communication. CP communication is based on 12 V, which is low voltage level and in case of long cable, there will be high voltage lost that causes communication problem.

Interviewee F: The standards regarding infrastructure mounted charging technology are already advanced and it is just question of time when these standards will be available. The potential issues can still be regarding physical dimension and tolerances for positioning, and the other one is the communication. There are standards for communication, but not all the companies are implementing all the aspects in same manner. To solve this problem, a set of test protocol should be available to perform conformance testing to validate the charging technology.

Interviewee G: ISO 15118 is very complicated with several layers and understanding this standard is very difficult for the customers. Our common objective should be to develop a charging protocol which is simple and built on simple hardware architecture, to avoid difficult implementation and different understanding between bus OEMs and charger providers. In addition, the communication protocol should be reconsidered. OEMs and charger providers have been following CHAdeMO standard (with CAN communication) for more than 20 years. CAN communication is reliable. However, the currently developed European standards is based on PLC communication. PLC protocol is fine for low power charging but not adapted for heavy duty application and it is generating a lot of difficulties.

Q5. How can we reach full interoperability?

All the interviewees believe that full interoperability can be reached by:

- Developing a set of standards with high technical robustness,
- Developing communication protocol that is clearly integrated into the regulation,
- Performing conformance and interoperability testing

Having a third party to assure the interoperability is a good solution. However, the practicalities for selecting the third parties should be investigated more. Following are opinions of Interviewees D, E, and G on this matter:

Interviewee D: This could be a solution, but we should avoid that the third party would have monopoly position. Interoperability should be a test protocol that can be done by the companies which perform performance tests, or the OEMs (if can prove that they are qualified of performing interoperability test).

Interviewee E: Charger and vehicle interoperability assessment indeed is required for product verification. Since all the manufacturers may not have the means of this assessment, testing service support can be used to perform this task. But an interoperability certificate should not be necessary, as long as the manufacturers can assure that their products work properly.

Interviewee G: It is a good suggestion to have a third party that can assess interoperability and issue an interoperability certification.

In the surveys, unifying charging technology was mentioned as a possible way for reaching full interoperability. However, the interviewees did not agree with this method:

Interviewee D: This limits the development of EV. We are at the start of EV development and bounding the manufacturer to a certain technology may limit the development of EV technologies.

Interviewee E: Technologies are developed according to the market requirement. The technology, standardisation, and interoperability has been achieved to some extend for mode 4 of charging. While for pantograph electromechanical solution is fixed but the communication is still under discussion and standardisation for communication needs to be finalised and tested.

Q6. How do you see the future of bidirectional charging (V2X, X = grid, building, bus) for HD EVs, do you find it beneficial?

The interviewees' answers to the future of bidirectional charging varied from being very beneficial to not being beneficial:

Interviewee D: Few organisations are working on bi-directional charging. But it is not beneficial for commercial vehicles. Because commercial vehicles are either driven or being charged and there is not a lot of room to use it in V2G technology. This technology can be beneficial for personal vehicles but not for commercial vehicles. Furthermore, energy is wasted as it is transferred once from grid to vehicle and then again from vehicle back to grid. Instead, it is better to have smart cities rather than smart grid, in which everything is connected with each other, and the charging schedule and the required amount of energy is defined. Therefore, no extra amount of energy is taken from grid.

Interviewee E: To implement this solution effectively the flow of the money should be clarified. Because currently the bidirectional charging is beneficial for grid but not for the HD EV users. Bidirectional charging can be beneficial, only if good business models are developed for it, for example the operator can benefit by performing bidirectional charging between the grid and large energy storages that are installed at their depot. Another business model can be the usage of V2V technology, to optimally manage the fleets.

Interviewee G: Smart charging and bidirectional technology become more beneficial as the number EVs increases and the HD EVs have high potential to play important role in this technology, especially in big cities such as Paris.

Interviewee F: Buses and trucks, can be used as frequency regulation at depot. Otherwise, there is efficiency losses during bidirectional charging, which is not beneficial to the operators.

6. Synthesized charging technology roadmap

Figure 24 presents our roadmap for charging technologies. Data collected from the literature review, surveys and interviews were used as the starting point of sketching this roadmap.

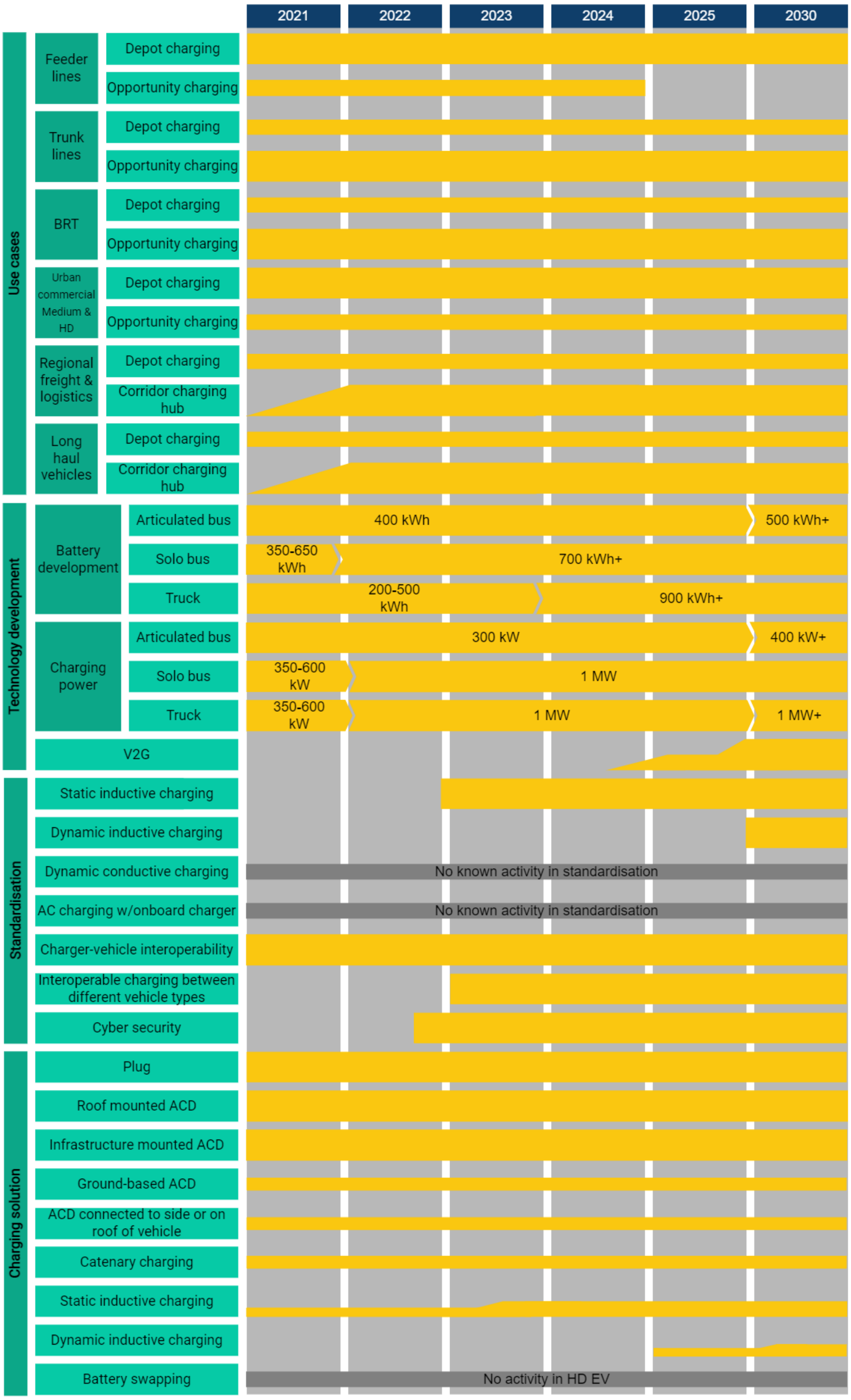

Figure 24. ASSURED charging technology roadmap.

6.1 USE CASES

The use cases are generic descriptions of different types of vehicles performing various operational transportation tasks. In Figure 24, the roadmap for depot and opportunity charging use cases is plotted for three different public transport bus services: feeder lines that bring people from a transit hub (or trunk routes) to a destination or vice versa, trunk routes, which are transport lines with very short headways and distinguishable fleet and Bus Rapid Transit (BRT), which includes public transport bus services with operating characteristics and capacity of rapid transit systems.

For feeder lines, currently the fleets are charged at the depot overnight or at terminals during the breaks. As the capacity of the batteries increases, it is expected that the fleet in feeder lines would use the maximum available battery size and only recharge the vehicle at depot overnight. For trunk lines and BRT, both depot and opportunity charging will be utilized. The share of opportunity charging, however, would be larger than the depot charging, since the fleets of these lines have long hours of operating and the opportunity to share the charging infrastructure during the operation.

Another technology that can facilitate the charging of the public transport fleets and make the overhead line technology attractive for bus traffic is the new e-Bus Rapid Transit (e-BRT) system. With e-BRT, battery-equipped buses recharge their batteries while running on sections with overhead lines known as In Motion Charging (IMC) and they can operate without connection to the overhead lines on battery power, providing more flexibility in their choice of route. As an example, the seaside resort of Rimini is currently running acceptance tests for its new IMC buses and the vehicles are destined to serve the new Rapid Coast Transport (Trasporto Rapido Costiero – TRC) express line from Rimini to Riccione. Furthermore, TUA (Trasporto Unico Abruzzese) is introducing the IMC buses to operate the eight-kilometer link between the two coastal cities of Pescara and Montesilvano.

In trucks, several types of trucks and truck-trailer combinations serve a multitude of different operations and requirements for both powertrain and infrastructure (Liimatainen, et al., 2019). There are various ways to group the HD vehicles and their operations to use cases (Plötz & Speth, 2021). For the purposes of this paper, the following grouping of use cases is made:

- Urban commercial medium and heavy-duty vehicles in various uses: deliveries, logistics, urban freight, refuse collection, utility vehicles and earth moving & construction
- Regional freight and logistics serving various transports for communities, agriculture, industry, trade, logistics chains and hubs,
- Long-haul trucks in industrial freight and logistics with various trailer combinations up to high tonnages and single missions exceeding 400 km.

These use cases will have different charging requirements. The short-range urban and regional operations use private charging at depots, terminals, and hubs, where the available charging times could be a few hours per night. This depends on the scheduling of operations, and possibly fast recharge opportunities during the operations or mission. The regional and especially long-haul use cases will likely need to resort to very fast charging in addition to the origin-destination charging. The location, dimensioning and operations of the corridor charging hubs for HD-EVs should be designed to support the electrification potential in the best possible way. Long haul operations will likely utilize static charging, in-motion charging and hydrogen & fuel cells solutions concurrently, with the most systemically viable combination.

6.2 TECHNOLOGY DEVELOPMENT

6.2.1 Battery development

Various vehicle categories and end use cases have different energy needs and charging specifications. The battery development in the presented roadmap is classified according to the vehicle categories, i.e., urban, regional, and long-haul trucks and buses. Generally, the longer independent and continuous operation without charging a use case requires, the larger the traction battery capacity needs to be from the design basis, and secondly, the more the operations need to rely on opportunity fast charging en-route (in addition to end stop charging).

Currently, various chemistries and designs are available and market ready for EVs. Li-ion batteries with different chemistries are continuously developing for buses and trucks. The battery technology should be selected according to the vehicle application, as it affects the choice of charging solution. Use cases requiring very fast charging need to have batteries and management systems suited for that. For example, nickel-manganese-cobalt (NMC) batteries are suitable for opportunity charging use cases. NMC modular batteries technology with range of 640 kWh are developed and tested for articulated electric buses and are expected to go into series production in the first half of 2021 (Linder, 2020). Another technology in the market especially for larger-capacity battery packs is lithium iron phosphate (LFP), which also has better safety than NMC. Alongside with capacity increase, the development is towards improved cycle life of batteries, scalable, modular, and lightweight designs. Recent years have brought rapid annual cost reduction for traction batteries combined with improved performance, largely explaining the much-improved market acceptance for these products and commodities.

Various next generation battery chemistries, such as semi or fully solid-state with advanced composite or Li-metal anodes or other ionic systems are being developed. These technologies have currently a lower technology readiness level (TRL), but they could further make battery e-trucks and buses more competitive in mid to long term (IEA, 2020).

As for articulated buses, there are OEMs that are manufacturing buses with battery capacity of up to 400 kWh, which can be used for both depot charging and fast charging on route. This battery capacity may be sufficient for articulated buses for next few years, as they drive with low speed and short distances.

6.2.2 Charging power

The terms 'fast charging' and 'high power charging' are not explicit when brought to the HD-EV context with traction battery capacities and voltages, which are different from light duty (LD) EV context. In the end, the limiting parameter for a battery system in charging is the C-rate (charging current in relation to capacity), and for the charging interface the current capability. The most relevant measures for the charging, are the time used for the charging event, and the energy that can be on-boarded during that time.

In Table 9, our proposal for HDV charging classification and terminology charging power vs. capacity values are presented. The battery C-rate describes in this case the speed of charging, and it is related to the battery capacity *C*, expressed in As or more commonly in Ah. The unit of C-rate is usually 1/h, and it denotes the rate at which a battery is charged. C-rate can be also defined with the ratio of charging power to battery capacity, and it is then known as CP-rate (IEC, 2004), (Rubenbauer & Henninger, 2017). Similar terminology as with LDVs is used (Falchetta & Noussan, 2021), but the power levels for HDVs are higher for each class than with LDVs because their batteries are typically of higher capacity. Other possible terms to be used are *low power*, *rapid*, *super,* and *high-power charging*, but in our classification only adjectives *slow*, *normal*, *fast,* and *ultrafast* are used, to avoid misinterpretations.

Table 9. Terminology for HDV conductive charging, and related C-rates. Values are typical, and they may vary.

	Charging Voltage	Charging Current	Charging Power	Battery capacity	C-rate of charging	Notes
Slow HD-EV charging	400 VDC, 800 VDC	60 A – 400 A	50 kW – 150 kW	50 kWh – 250 kWh	0.2 C – 1 C	
Normal HD-EV charging	400 VDC, 800 VDC	200 A – 800 A	150 kW - 400 kW	50 kWh – 250 kWh	0.5 C – 2 C	
Fast HD-EV charging	Up to 1.5 kVDC	300 A – 1 kA	200 kW – 1 MW	100 kWh – 500 kWh	2 C – 5 C	Over 800 V charging voltages not yet standardized
Ultrafast HD-EV charging	Up to 1.5 kVDC	800 A – 3 kA	1 MW – 4.5 MW	250 kWh - 1 MWh	4 C – 10 C	Over 800 V charging voltages not yet standardized

There are various enablers in the development of fast charging. Burnham et al. (2017) investigated different infrastructural and economical aspects that require further consideration when deploying charging at 400 kW and above. The most important aspects were standardization, coordination, security, grid resources, power demand peaks and the costs.

Standardization is important to ensure safety and to increase interoperability and backward compatibility. Coordination between multiple utilities include EVSE network operators, and authorities having jurisdictions over permitting, siting and regulation of charging stations. Cyber and cyber-physical security of fast charging infrastructure is becoming more and more important. Consideration of existing grid resources and planning future fast charging installations and networks is also a key aspect, and it is related to management of the intermittent, high-power demand by fast charging stations. Finally, the costs of the charging infrastructure, installation, fast charging-capable battery electric vehicles (BEVs), and operation must be considered.

High power DC charging system and ultra-fast charging are under development and their standardizations are not finalized yet. According to the results of the surveys, end users' organizations are looking towards high power and megawatt charging solutions for their short-term plans. According to the interviews, fast charging (typically several hundreds of kW and up to 1 MW) will be sufficient for commercial HD-EVs and ultra-fast charging (above 1 MW) be more suitable for long haul vehicles and trucks. Nevertheless, the battery and vehicle components need to be developed further to withstand the high amount of current in ultra-fast charging (C-rate 4 or more). Considering the required technology development, ultra-fast charging rollout for HD-EVs is not expected before 2025.

6.2.3 V2G bidirectionality potential

Bidirectional V2G technology is considered to act as a potential revenue source emerging from participation in the flexible energy market and providing benefits to grid by for example, voltage and frequency regulations (Noel & McCormack, 2014). The bidirectional functionality could also enable e.g., fleet operator's optimization behind the grid connection in charging and energy use. Despite the advantages V2G technology provides to both the energy providers and consumers, utilization of this technology depends on the use cases when it comes to HD-EVs. For example, V2G technology is cost effective for vehicles such as electric school buses, if they have a short operating schedule and can be parked and connected to charger for a long period of time during a day with few additional transportation tasks. Furthermore, commercial HD fleets can be another example in which the V2G can be beneficial if the V2G technology would not interfere with the fleets operation scheduling (Mohamed, et al., 2014), (Moghaddam, et al., 2018), (Moghaddam, et al., 2019), (Parastvand, et al., 2020), (Al-Hanahi, et al., 2021); as they have predefined timetables and routes and all the fleets are usually parked for a long time at a centralized location (depots or public parking places).

Communication standards (ISO/IEC 15118, IEC 61850) are established for EVs to facilitate the V2G technology rollout. Nevertheless, the technology has not been widely used across Europe even for passenger EVs. In the following are some actions that will help to increase the use cases of V2G technology (EGVIA, 2020):

- Testing of V2G protocols and standards.
- Developing advance analytics and algorithms to predict charging patterns and shape grid optimization.
- Establishing a robust data collection infrastructure.
- Enabling the communication of system parameters and status, including market details in the electromobility value chain.

Considering all these factors, we expect to see the utilization of bidirectional chargers with V2G technology in HD EVs to start with a slow pace in mid of 2024 and reach a mature market by end of 2030.

6.3 STANDARDISATION

6.3.1 Charging solutions

Currently there are no European standards for inductive charging. However, international standardisation work for wireless power transfer has already started and it is scheduled to be done in relevant IEC project teams in close cooperation with ISO. The standards for Static and dynamic inductive charging are expected to be ready by end of 2022 and end of 2025, respectively. No standardisation work for dynamic conductive charging and AC charging with on-board charger is scheduled for the time being.

6.3.2 Interoperability

The standards developed for HD-EV facilitates the interoperability between charger and vehicle. These standards are either finalized or currently being finalized. However, to achieve full interoperable solution, the standards need to be simplified to be understandable for OEMs and end users, interoperability and conformance testing should be widely available, and the communication challenges should be addressed effectively.

Standardising the charging between different types of vehicles (e.g., trucks and buses) rarely has been under discussion. According to the end user survey (Figure 19), this interoperability may not seem relevant, as currently operators are not operating buses and trucks at the same time. Nevertheless, 90% of technical respondents think that the interoperability between different vehicle types should be part of future charging technology goals. As the number of HD-EVs increases, different stakeholders, fleet operators, and commercial businesses can profit from this interoperability, for example at public charging hubs. The standardisation work on such technology may start within next two years.

6.3.3 Cyber security

Secure communication between the vehicle and EVSE as well as between the charging station and grid are essential aspects for fast and smart charging. The secure communication protocols between the vehicle and the charging station are presented in the standard ISO 15118-2 (ISO, 2014). In a broader sense, cyber security issues (Acharya, et al., 2020), (Antoun, et al., 2020) are going to be included in the standardization in a near future, and proposals for charging infrastructure cyber security has been done already (ElaadNL & ENCS, 2019). Having a detailed set of protocols that ensures cyber security is essential in near future, before significant cyber security challenges arise with the expansive usage of HD EVs.

6.4 CHARGING SOLUTIONS:

6.4.1 Conductive charging:

Due to simplicity and low costs, plug-based charging solution remains as one of the most common solutions for HD EVs, especially for depot charging. Roof mounted ACD will continue serving as the most common solution with automatic connection for opportunity charging, primarily in urban buses. The application infrastructure mounted ACD solutions will continue as well but may not be used as widely as roof mounted ACDs. One aspect that may attract the attention of the bus OEMs towards the infrastructure mounted ACD is the vehicle weight reduction, and thus, the increased vehicle capacity. For example, a roof-pantograph can weigh around 85 kg (Pirooz, et al., 2020).

The popularity of ground-based and side mounted ACDs will be less than other ACD solutions. These solutions may be used mostly in HD trucks or vehicles that do not have enough of area on the roof to install the ACD. Furthermore, the standardization for these two solutions is not ready, which slows down their implication to the market.

As for catenary charging solution, currently a few catenary systems demonstrations on highways are developed and being tested (IEA, 2020). But the expansion of this technology requires commitment from different countries and a well-defined set of standards. Till then the share of catenary charging system in the expanding HD EV market remains small.

6.4.2 Inductive charging

Static and dynamic charging solutions have been developed and being tested for HD EVs (SOLUTIONSplus, 2020; Kane, 2021). The market share of inductive technologies may increase slightly after the relevant standards are published. Nevertheless, these solutions will not be as popular as conductive charging solutions, unless their efficiency for HD EVs in terms of cost and energy transfer is proven and their safety concerns are addressed.

6.4.3 Battery swapping

IEC has established IEC 62840 standard on EV battery swap system (IEC, 2016a). A commission implementing decision C(2015)1330 (European Commission, 2015) includes a standardization request for “a European standard containing technical specifications with a single solution for battery swapping for EVs”, to be completed by 2022. However, these standards are not targeting HD EVs specifically, and no activity for battery swapping of HD EVs exists in the market for the time being.

7. Use cases for electric bus/truck charging

7.1 NEW USE CASES:

Based on the data collected in this document, we propose the following use cases for future charging technologies:

- Transport corridor
- Urban transport
- Regional delivery

7.1.1 Transport corridor

The vehicles that can be considered in transport corridor use case include long distance trucks and coaches (intercity buses). Economic and political aspects play an important role in determining the charging solution in this use case. Nevertheless, other factors such as the number of times that the vehicle can stop for recharging should be considered as well when choosing the charging solution. The charging solutions suitable charging solution for the transport corridor are:

- Charging along corridor, in which the charging system is installed along the roadways to charge the vehicles while driving. Inductive or conductive dynamic charging technologies can be used in this case. This charging solution is utilised to extend driving range and decrease the vehicle battery size.
- Charging at terminals and hubs, which can be used for vehicles with short mission profile. In this case the vehicle should have the opportunity to recharge when reaching an adequate state of charge and depending on the mission profile, the vehicle may require larger battery size as compared to charging along corridor case.

As mentioned previously, to achieve an interoperable transport corridor across Europe, a high level of commitment from all the member countries is required to establish and enforce a well-defined set of standards for charging, communication, cyber security, and billing system. It is worth mentioning that an interoperable transport corridor does not necessarily mean to have one single charging technology across Europe, but rather to select the charging technology based on regional preferences and follow a unified standard within that region.

7.1.2 Urban transport

When it comes to public urban HD EVs, the operators may prefer the vehicle to have the maximum battery capacity in order to schedule the operation schedule more freely. Nevertheless, the vehicle mission profile and structural limitations should be considered when choosing the vehicle powertrain and battery size and capacity. Table 10 presents the four different alternatives to charging solution for urban transport use case, which can be chosen based on the vehicle mission and needs.

Table 10. Alternatives to charging solutions for urban transport

	Depot charging	Charging at logistic terminals	Charging hubs	Shared use of tram catenary
Description	Charging at depot overnight or fast charging at depot in one end of operation route	Fast and ultra-fast charging at logistic terminals when driver is on break or is changing	Common use of charging infrastructure for buses, delivery trucks and vans, taxis, etc.	Using tram infrastructure for charging electric buses in urban area.
Vehicle example	Delivery trucks, shuttle buses	City buses, city delivery, city maintenance (garbage trucks, snowplough …)	Buses, delivery trucks and vans, garbage trucks, taxis, etc.	HD municipal fleet, e.g. city buses
Requirements and limitation	Large battery size and capacity.	This charging solution requires a well-planned fleet and charging management. Possible environmental limitation on installing charging infrastructure in city.	This charging solution requires a well-planned fleet and charging management. Possible limitation on the number of charging points and grid capacity*.	Well suited for the areas with already existing infrastructure, as installing infrastructure to new areas can be constrained by installation costs and bad visual impact. Possible limitation on grid capacity.
Possible charging technology	Plug charging, ACD charging	ACD charging	Plug charging, ACD charging	ACD charging
Charging power	50-450 kW	300kW+	50-450kW	200 kW
Charging infrastructure ownership	Privately owned	Owned privately or by city	Ownership should be re-evaluated	Municipal or private companies
Advantages	Possibility of offering a grid cooperative option to the users (V2G).	Efficient time management for charge of vehicle and minimising the out-of-service time (time spent for charging).	Increases charging accessibility for HD EVs across the city. Reduced infrastructure and maintenance costs.	Charging at depot or terminal is not required during operation. Significant cost saving when sharing the existing charging infrastructure.
Disadvantages	High infrastructure and maintenance costs.			Very costly to expand the infrastructure to new city areas.

* Various services and tools are available for fleet management and selecting the optimal numbers of stations and charging locations, e.g., Smart eFleet software (Anttila, et al., 2019).

7.1.3 Regional delivery

Regional delivery use case includes the vehicles that are operating in the rural areas such as logging, agriculture, and post-delivery. For this use case majority of charging stations may be privately owned with plug charging technology at depot. However, the regional delivery vehicles can use the transport corridor, in case of having access to one.

8. Conclusion

This document is outlining the foreseen developments in the heavy-duty (HD) vehicle fast charging, especially in electric buses and trucks, with the aim of supporting and facilitating the standardisation of charging technologies by creating a clear overview of popularity of charging technologies and the end users' needs.

The required input for the work was collected by reviewing the existing literatures and conducting surveys and interviews on end users and technical stakeholders. Based on the collected data, a charging technology roadmap, which can act as a basis for future standardisation efforts, and three new charging use cases were proposed to fulfil the future PTO and cities' needs.

Some of the findings from the surveys and interviews include:

- Currently, pantograph on the roof and plug-based charging are the most used charging technologies. This trend is very likely to continue in the future, since 1) pantograph on vehicle roof, 2) pantograph on infrastructure and 3) plug were graded as charging technologies with the highest potential by the participants of technical survey.
- Static and conductive charging have higher potential, as compared to dynamic and wireless charging. Inductive charging can be the future charging solution for HD EVs, only if the current bottlenecks in the technology can be addressed. These bottlenecks include a high price, low efficiency, lack of standardisation, and safety concerns.
- The application of both opportunity and depot charging will continue in the future. Nevertheless, the balance of their implementation depends on the different factors such as vehicle mission, battery capacity, operator need, etc.
- Achieving interoperability and lack of simple and robust standards were repeatedly mentioned as the main challenges in today's charging technologies.
- Full interoperability can be reached by:
    - Developing a set of standards with high technical robustness,
    - Developing communication protocol that is clearly integrated into the regulation,
    - Performing conformance and interoperability testing.

Having full interoperability has been the focus of ASSURED project, which is successfully achieved by following these three steps.

Finally, based on the data collected during this work, a few use cases for future charging technologies of electric bus/truck are presented.

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