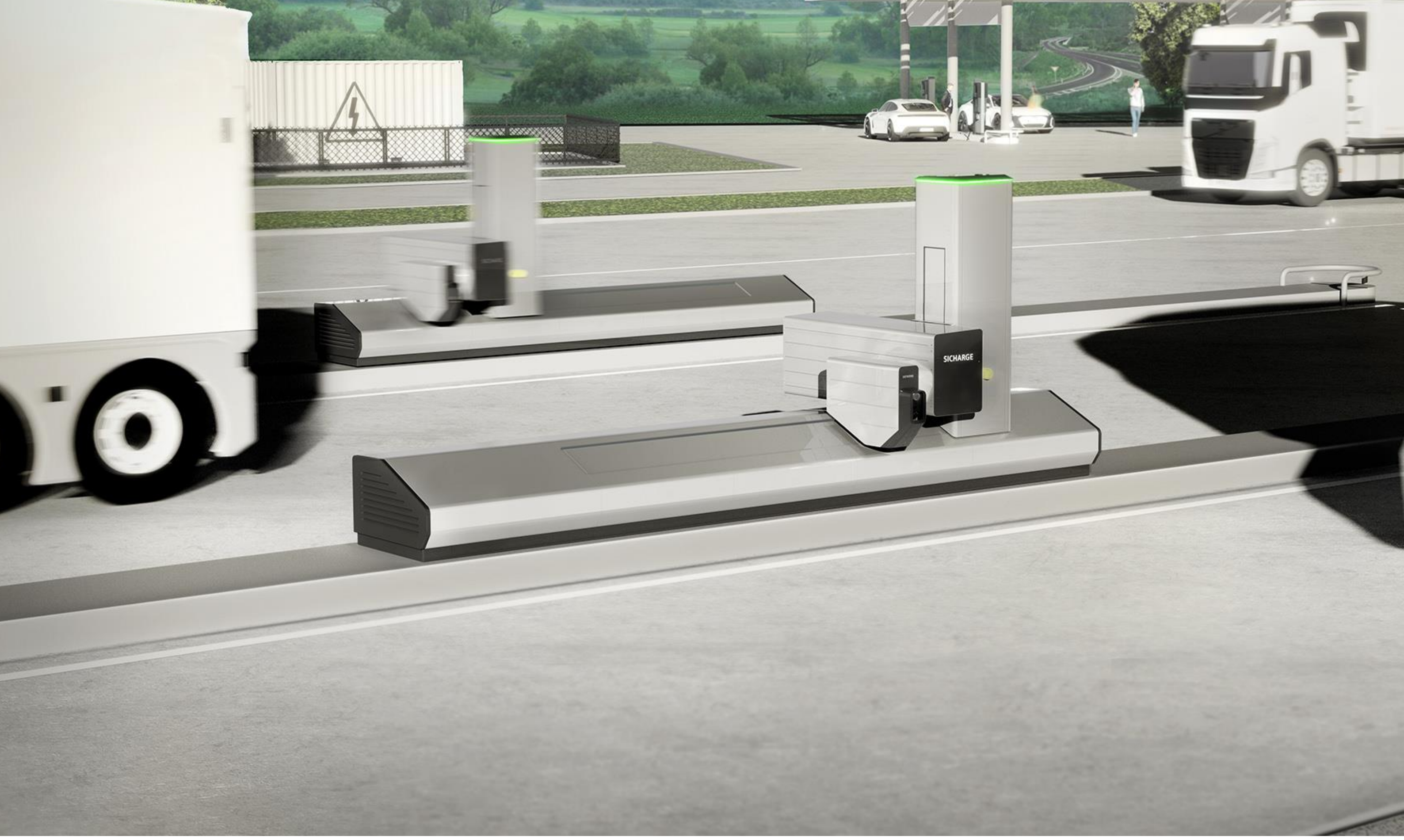

Charging Solutions for Electric Commercial Vehicles Depots

This paper focuses on challenges faced by depot owners in their quest to electrify their fleet, current and future possible solutions for successful deployment and acceptance of electric commercial vehicles solutions.

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Mobility 2 Grid

Contents

List of figures

List of Tables

Glossary

AFIR	Alternative Fuel Infrastructure Regulation
eBus	Electric Bus
ECV	Electric Commercial Vehicle
eTruck	Electric Truck
EV	Electric Vehicle
eVTOL	electric Vertical Take-Off and Landing aircraft
HDV	Heavy Duty Vehicle
HPC	High Power Charger
IK	Mechanical Impact Protection
IP	Ingress Protection
WPT	Wireless Power Transfer

Executive summary

The following document discusses the challenges of electrifying bus and truck depots and fleets, focusing on the transition from internal combustion engine vehicles to battery electric buses (eBus) and trucks (eTruck). For the sake of simplicity, they will be referred to as electric commercial vehicles (ECVs) unless a specific situation requires reference to eBus or eTruck. It also presents possible solutions for specific problems encountered in ECV depots and fleets.

Key points:

1. The push towards ECVs in transportation sector, including public transportation (eBus) and logistics (eTruck), is driven by environmental regulations and sustainability goals at local, national and European levels.
2. ECV adoption in the above-mentioned sectors depends on the large-scale availability of a functional and reliable charging infrastructure that can fulfill the specific fleet's needs. These needs include:
    - High-power charging
    - Overnight charging when parked at home depots/destination locations
    - Opportunity charging during the day
3. These challenges could have specific solutions such as dock charging and automatic charging robots:
    - Dock charging systems minimize the footprint of the charging infrastructure and eliminate obstacles for the vehicles during the parking process (charging cables lying on the ground, at risk of being damaged during the backwards parking maneuver).
    - Automated robotic charging systems autonomously connect the charging coupler to the ECV, making the charging process easy and straightforward for the users, which translates in higher efficiency of the charging process and positive user interaction.

    Key factors for the successful implementation of these solutions are:
    - Understanding customer needs
    - Engaging stakeholders from an early stage of the project
    - Ensuring regulatory compliance
4. Future innovations are focused on areas such as bidirectional charging, wireless charging and megawatt charging. The aim of these innovations is to accelerate the electrification of commercial vehicle fleets.
    - Wireless charging
      Can simplify the user experience, as there's no need for a classical interaction between the user and the charging station. Currently, wireless charging stations offer 11 kW of power, but this is just the first step in a technological development that is set to expand in the future.
    - Bidirectional charging
      Allows vehicles to discharge electricity back to the grid, making it a viable business case for the depot and fleet operators, due to the potential for cost savings in operational expenses through the intelligent utilization of pricing schemes available at their location.
    - Megawatt charging
      Higher power transfer rates represent a key solution for large-scale adoption of eTrucks in international and long-distance logistics. These solutions ensure that mandatory breaks for long-haul drivers are used efficiently by refilling or topping up the batteries in 10-45 minutes, as opposed to the hours required by conventional charging solutions.

Introduction

The transportation sector is undergoing a major transformation, driven primarily by European legislation that requires industry stakeholders to reduce the environmental impact of internal combustion engine (ICE) vehicles, especially on the heavy duty vehicles (HDV – lorries, buses, coaches), as they are responsible for more than a quarter of greenhouse gas (GHG) emissions from road transport in the EU, and for over 6% of total EU GHG emissions[1]. Until recent years the development focus was towards electric cars (EVs) while ECVs were neglected due to a lack of charging infrastructure and batteries with a capacity high enough to fulfill the specific needs of these types of vehicles.

The trend towards electric mobility is driven by several factors:

1. Environmental regulations and sustainability goals:
   The European authorities have developed regulations that push the adoption of zero-emission vehicles, one of the most important of them being the Regulation (EU) 2019/1242[2] and its amendments[3], which set ambitious targets for the current and next decades. According to these targets, there must be a 90% reduction of allowed emissions in 2040, compared to the targets set in 2019.

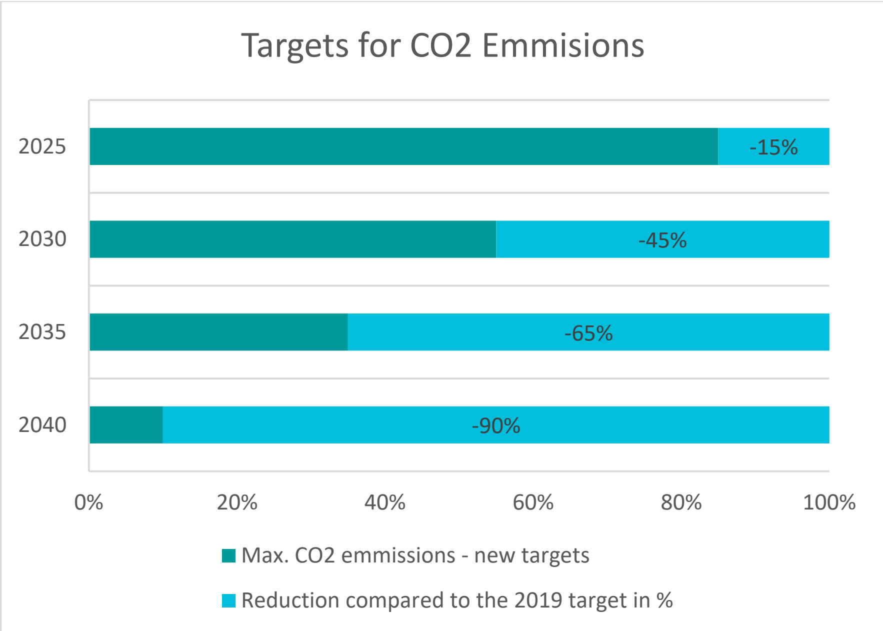

Figure 1: Targets for HDV CO_2 emission reduction valid from 26.06.2024
Source: climate.ec.europa.eu

2. Advancements in battery technology:
   As a result of the advancements made in recent years in the field of battery technology, currently the electric HDVs can reach a range of 600-800km, which makes them a viable alternative for the ICE trucks, this includes

[1] See Reducing CO_2 emissions from heavy-duty vehicles - European Commission
[2] See EUR-Lex - 02019R1242-20240701 - EN - EUR-Lex
[3] See Regulation - EU - 2024/1610 - EN - EUR-Lex

the argument of reaching a lower TCO compared to diesel trucks for some specific HDV models[4] until 2030 (ca. 10% - see subchapter 3).

3. Total Cost of Ownership (TCO):
An analysis[5] regarding reaching parity in zero-emission truck total cost of ownership by 2030 has shown that until the end of the decade ECVs will be the choice over the diesel-powered counterparts. The analysis was performed for a HDV long haul, with a 350 km daily range (90K km per year) and 350 kW engine power. It shows that in 2030 the TCO for the truck used in this analysis should be 11.5% lower than for a diesel truck. This reduction will be driven primarily by a forecasted 25% decrease in charging infrastructure costs, as well as a forecasted 50% reduction in up-front vehicle costs.

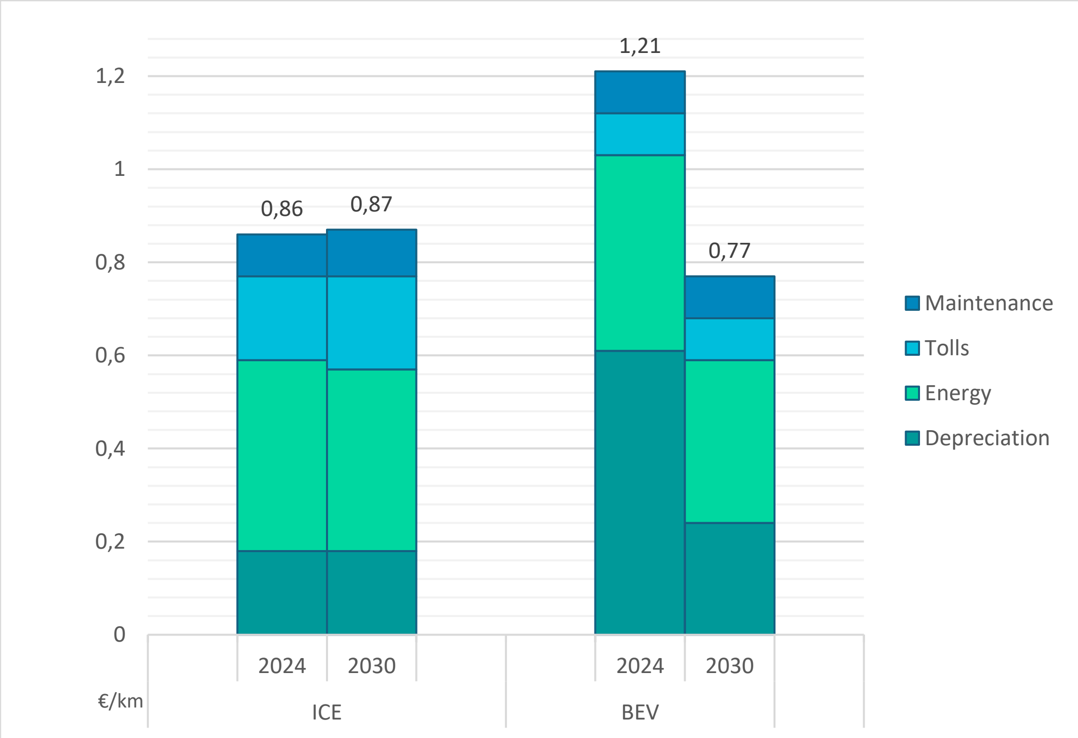

Figure 2: TCO in Germany €/km
Source: McKinsey Center for Future Mobility

The Importance of Charging Infrastructure for ECVs:

In April 2024 the European Union adopted its Alternative Fuel Infrastructure Regulation (AFIR) which sets legally binding targets among others for the number of public charging stations along the TEN-T corridor. These targets are valid from 2025 onwards and have 2030 as deadline for the full implementation. In terms of charging infrastructure, the targets are clear: fast recharging stations of at least 350 kW for electric trucks and other heavy-duty electric vehicles need to be installed every 60 km along the TEN-T core network and every 100 km on the more extensive TEN-T comprehensive network[6].

[4] See Der ultimative MAN Leitfaden zum Laden von Schwerlast-LKW
[5] McKinsey Center for Future Mobility - The bumpy road to zero-emission trucks
[6] See Alternative fuels infrastructure: Council adopts new law for more recharging and refuelling stations across Europe - Consilium

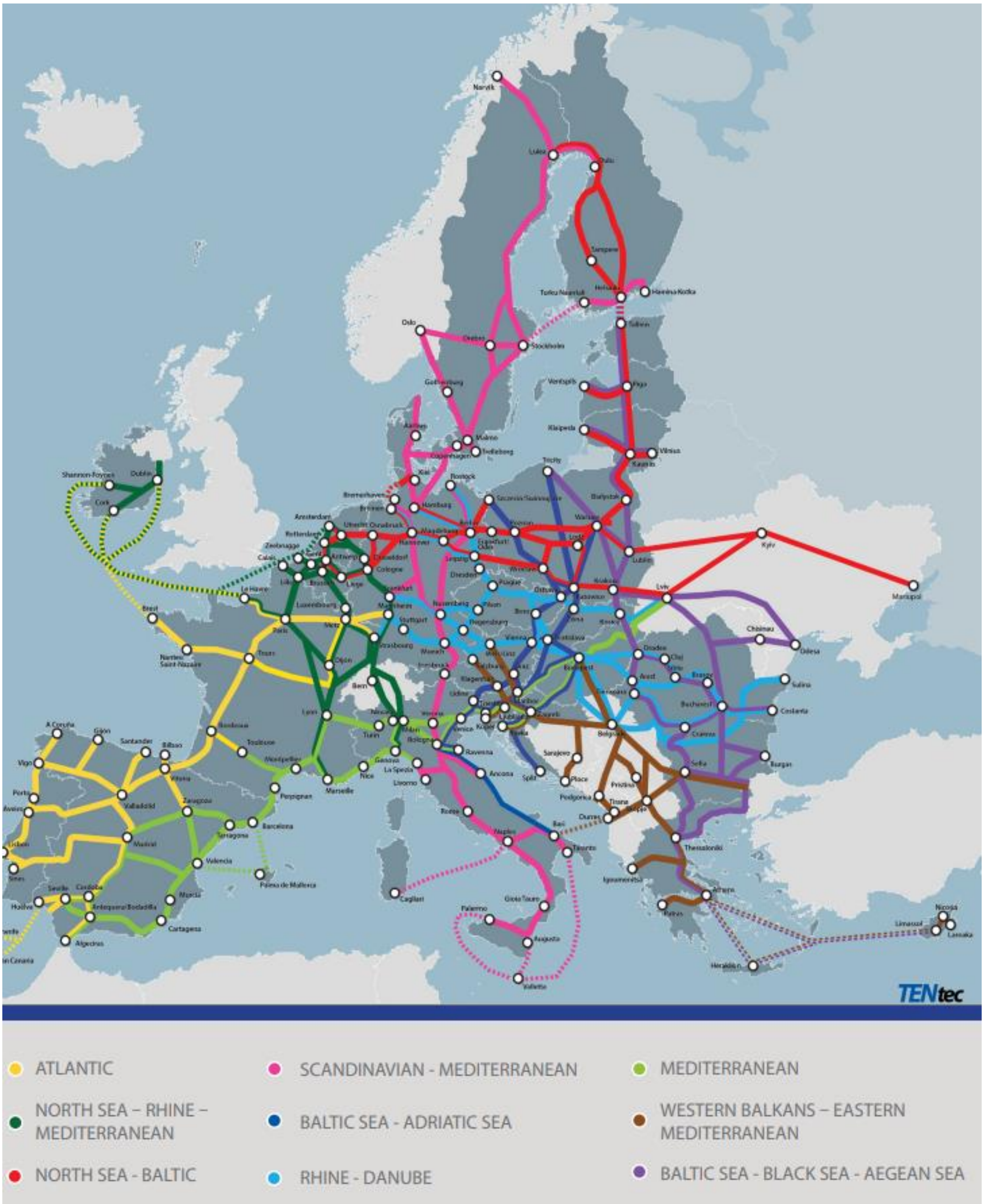

Figure 3: TEN-T map: Alignment of the European Transport Corridors
Source: TEN-T map library of the European Commission

The above-mentioned targets set the main direction for the development of charging solutions: high power charging. This direction is relevant because it is giving an impulse for collaboration and innovation between the stakeholders (fleet operators, utilities companies, policymakers and technology providers) by setting a unified path and shared goal.

Charging requirements

There are three main types of ECVs currently on the market:

1. Light commercial vehicles (LCVs) under 3.5t currently account for the majority of eTrucks. They are primarily used in urban transport for last-mile delivery of goods, with a fixed coverage area, though routes can vary daily. The typical daily distance covered by these vehicles is between 100 and 200 kilometers.
2. Medium-duty (3.5 - 12t) eTrucks are primarily used for regional distribution of large goods volumes or for transporting goods that require a vehicle larger than a van. The typical daily mileage range is between 200 and 400 kilometers.
3. Heavy-duty (above 12t) eTrucks are primarily used for long-distance transport, typically on a point-to-point basis, thereby enhancing the predictability of the route. These eTrucks can travel a daily range of 400-800 kilometers.

Based on the utilization of these ECVs (e.g. last mile delivery, regional routes or long-haul routes), there are three primary charging patterns, each of which has distinct advantages that make them suitable for specific applications and scenarios:

1. <u>Overnight charging:</u>
   Currently this charging pattern is the solution of choice for most eTruck fleets. The charging process takes place during the off-peak hours, when the fleet is parked on the premises of the fleet owner. Slower Level 3[7] charging solutions (DC charging), ranging between 50 - 120 kW, are chosen as the standard option, as they allow for efficient charging with relatively low investment, making sure that the fleet can cover the next day's planned distances.
2. <u>Opportunity charging:</u>
   Truck drivers are required to take mandatory breaks, usually 45 minutes after driving for 4.5 hours. If planned with care, these breaks can be used to top-up the eTrucks available charge, reducing the disruptions in the planned schedule and following the regulations regarding the compulsory rest time. This charging pattern requires high power chargers (HPC) ranging from 400 kW up to 1MW, as the batteries need to be topped up in the most efficient way possible in the short time-window the drivers have at their disposal. This pattern can be used also for eBus top-up during the 15-minute break between roundtrips they make on a regular day.
3. <u>Destination charging:</u>
   In certain scenarios the range of the eTrucks is not sufficient to cover the daily needs of the fleet operators, that's why destination charging is the charging pattern that fits this use case. Usually, destination charging solutions are found at the locations where the eTrucks are loaded / unloaded, this process takes usually 1-3 hours: warehouses, logistic hubs, distribution centers. The range of the HPC is between 150 - 400 kW, offering the balance between charging speed and costs. This means that fleet operators can use eTrucks with smaller battery packs, which reduces the initial investment.

[7] also known as Mode 4 in Europe

Innovative Charging Solutions with potential usability in depots

Overview of current innovations and trends

The electric vehicle (EV) sector is currently one of the most innovative fields, with solutions in both hardware and software areas. To achieve a high level of acceptance and deployment, there are key issues that need to be addressed, including range anxiety, charging time, infrastructure availability and the impact of charging process complexity on user experience.

1. Fast charging:
   Charging stations with DC powers ranging from 50kW to 400 kW and above are contributing to the reduction of time spent at a charging station. Additionally, the widespread availability of charging location across the most populated areas and highways are critical for the minimization of the range anxiety experienced by most of the new or prospective EV users. The advancements in this area have pushed the capabilities towards of 1 – 1.2 MW and even higher, which means ultra-fast charging. This is advantageous for ECV fleet owners and depot operators, as they can keep the downtimes to a minimum.
2. Wireless / inductive charging:
   This is one of the solutions that has the potential to improve the user's experience, as it simplifies the charging process, by eliminating the need for physical plug-in connections.
3. Robotic charging:
   Robotic charging systems have the potential to improve the overall user experience and efficiency of the charging process by autonomously connecting the charging coupler to the EV (car, bus or truck). It could be a solution in the high-power charging segment, where the cables weight might represent a problem for certain users.

Solutions for specific eBus and eTrucks applications:

The solutions presented in the next pages were addressed and studied as part of the Mobility2Grid research campus, funded by the Federal Ministry of Education and Research. They are addressing problems often found in depots and loading/unloading docks, such as the variable length of electric vehicle charging cables (ECVs), the variable position of the charging connector inlet (CCS), and the challenging handling of heavy charging cables for high-power or megawatt charging solutions.

Solution 1: Dock charging

This solution is focused on the specific problem represented by the variable length of the ECVs arriving in a parking spot or at a delivery location.

The truck depots but also the loading / unloading docks must accommodate a variety of trucks with different lengths, which can make the charging process challenging. Since the position of the CCS inlet on LCVs, buses, and medium/heavy-duty trucks is not standardized, depot operators face the challenge of serving vehicles of different brands and models with the same charging infrastructure. There are already options available, but their application domain can be limited by factors like available space, depot layout or deterioration risks.

1. Floor-mounted columns:
   To ensure that a charge point can serve various vehicle models, long cables are necessary, which come with several challenges:
   - Cables and plugs lying on the ground can get damaged if driven over, causing downtime and additional maintenance costs.
   - Improper cable handling and usage can lead to safety issues, such as creating tripping hazards.
2. Ceiling-mounted cabinets:
   In depots and for en-route charging scenarios, gantries are used to minimize the footprint of the charging infrastructure and eliminate obstacles for maneuvering buses and trucks as much as possible. These installations come with their own challenges:
   - Hanging cables can be damaged, causing downtime and additional maintenance costs.
   - The charging infrastructure must be flexible in both the driving direction and perpendicular to it, ensuring that vehicles can be parked without restrictions in the depots.

Figure 4: Initial situation

The dimensions of the vehicles must be considered:

According to the Road Traffic Registration Regulations (StVZO), there are specific limits for the trucks including eTrucks. §32 StVZO* stipulates the maximum length of motor vehicles and trailers as outlined below:

- Truck: 12m
- Trailer - truck: 16.5m
- Trailer - train: 18.75m

While the minimum truck length is not regulated, in practice the minimum length of 9.6m can be calculated for the short cab version (6.1 m loading area + 3.5m short cab length), leading to a range of at 9.15m that should be covered by the proposed charging solution.

In addition, the height and width of the trucks are also regulated in Europe: max 4m height and max 2.55m width[8].

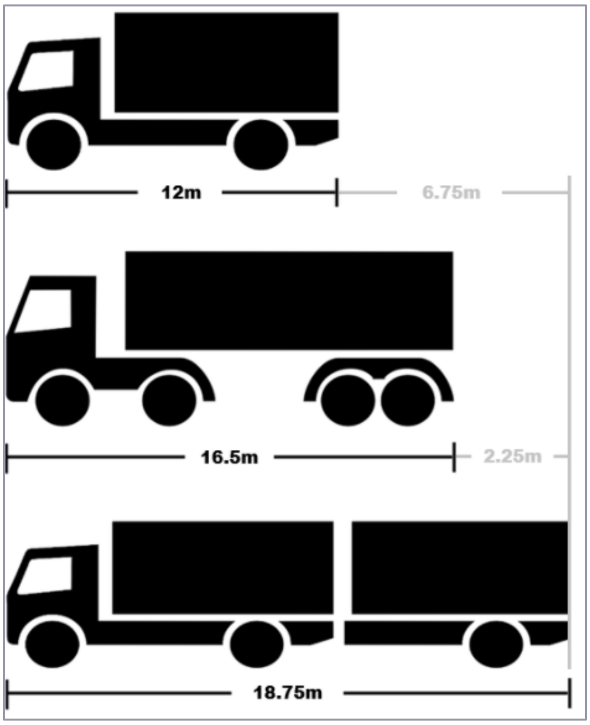

Figure 5: Maximum length for trucks acc. to §32 StVZO

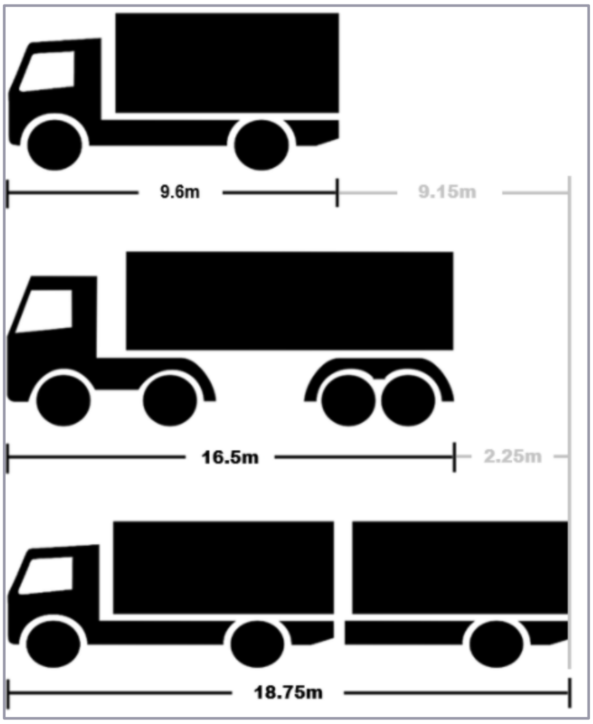

Figure 6: Calculated range between the maximum length and minimum calculated length for trucks

Main challenge:

One of the main challenges in covering the minimum 9.15m range was represented by the cable management solution. Several solutions have been considered, ranging from manual mechanical cable pulls up to solutions including electric cable reels. The primary objective was to develop a cost-optimized modular blueprint that can be applied at every customer site, which minimizes recurring efforts and considers various cable management solutions that fit different customer requirements.

[8] See Directive - 96/53 - EN - EUR-Lex

Analyzed solutions:

Solution 1: Mechanical cable pulls

It consists of a simple manual cable pull. The main advantage is the low implementation price, but it has a couple of disadvantages in terms of extension length and usability, as the extension length of max 4.5m can't cover all the possible scenarios.

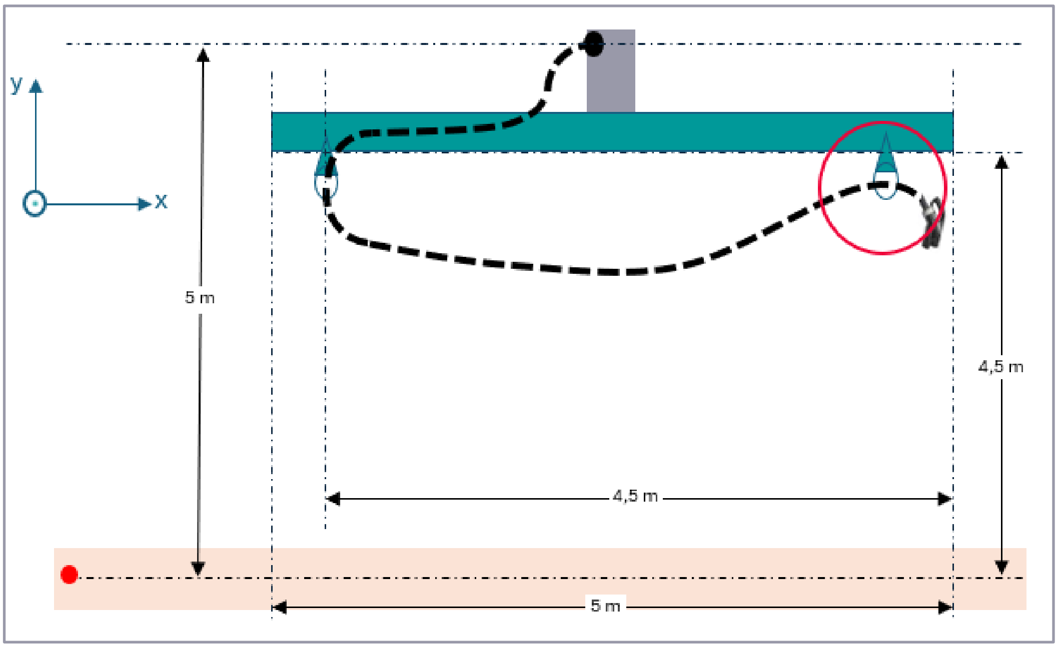

Figure 7: Mechanical cable pulls concept sketch

Solution 2: Mechanical + electrical cable pulls

Consists of a mix between a mechanical and an electrical cable pull. It brings improvements in terms of cable handling, but the flexibility remains low, a remote control is needed to control the electrical part of the assembly, and the lifting speed is relatively low.

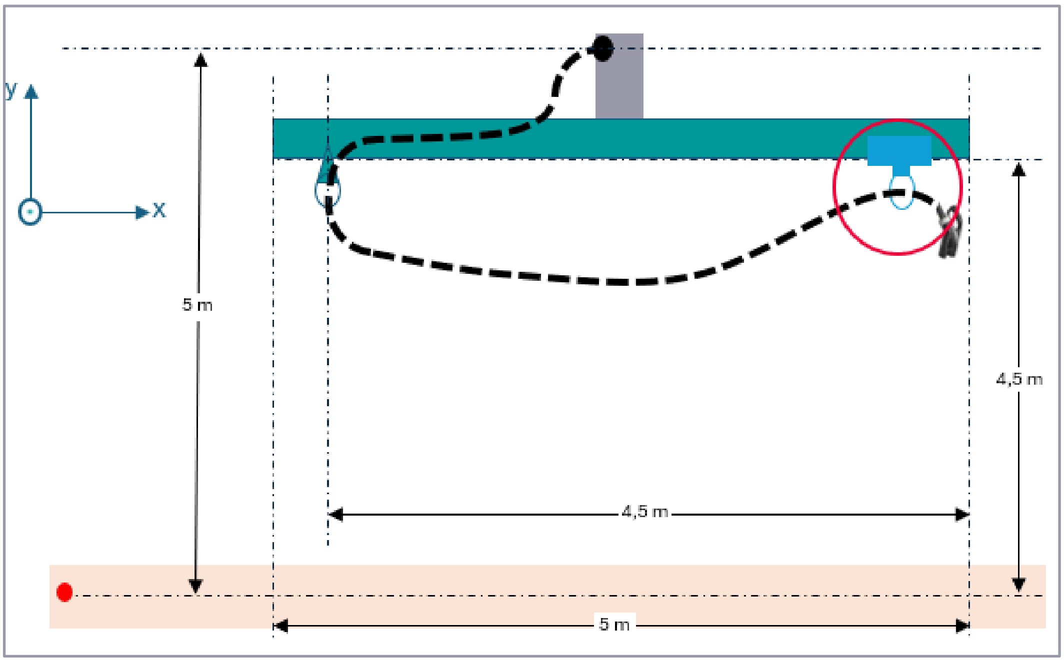

Figure 8: Mechanical + electrical cable pulls concept sketch

Solution 3: Rail for cable routing

The cable is hung from rolls that can move on a rail, increasing the flexibility, if the cable length is increased as well. If a standardized cable is used, only 4-5m of flexibility will be achieved. Also, the dispenser can be placed only asymmetrically for the best results in terms of efficient cable length usage.

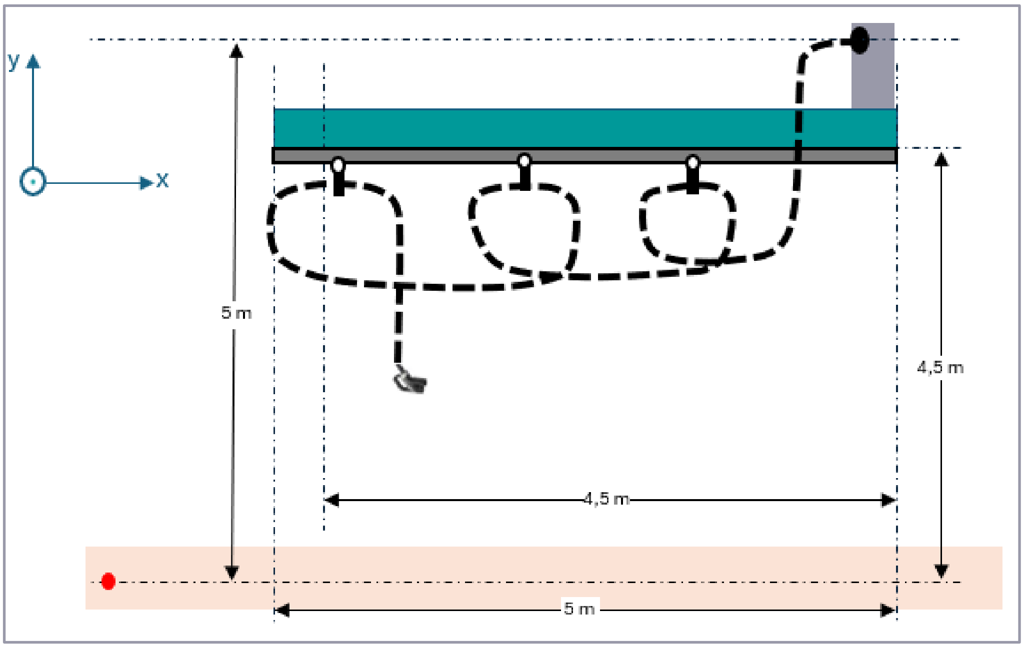

Figure 9: Single rail concept sketch

Solution 4: Parallel rails for cable-routing

The cable is hung from rolls that can move on parallel rails. The main advantage of this solution is represented by the fact that the flexibility is increased through the possibility to place the dispenser symmetrical on the gantry, but on the other hand, additional space is required for the parallel rails.

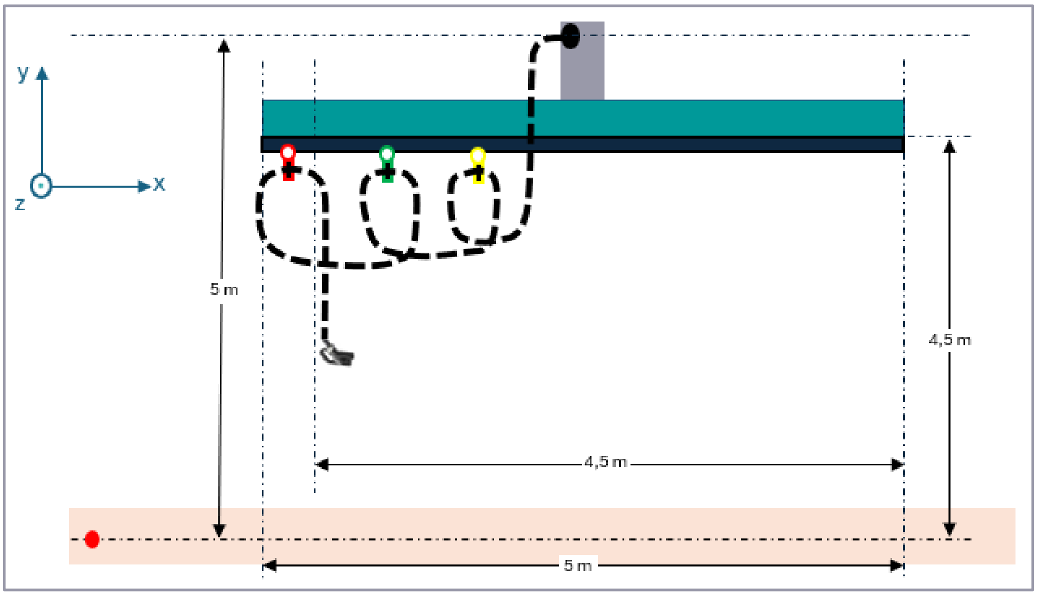

Figure 10: Parallel rails concept sketch

Solution 5: Cable reel

This solution provides higher flexibility in comparison to the previous versions (up to 7m usable cable length), but it comes with the disadvantage of increased installation costs and additional weight, both as result of the additional reel that must be mounted together with the dispenser.

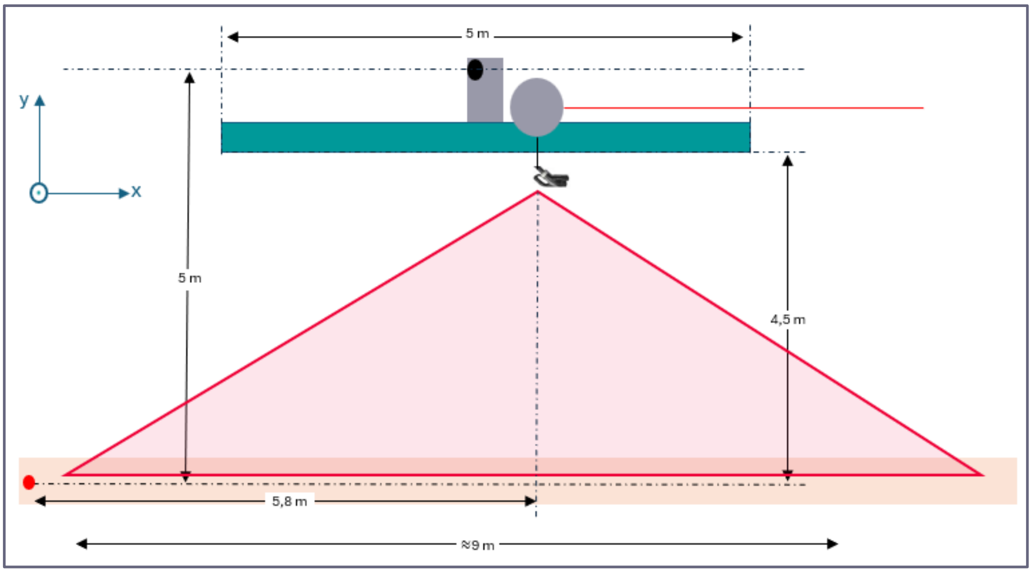

Figure 11: Cable reel concept sketch

Solution 6: Modular gantry

The proposal for this solution is a modular gantry with overhead steel traverse that can accommodate between 2 and 5 vehicles, independent of their length, paired with a cable management solution that can be customized according to the customer's needs and budget (hanging, reel, wire rope, cable on rail).

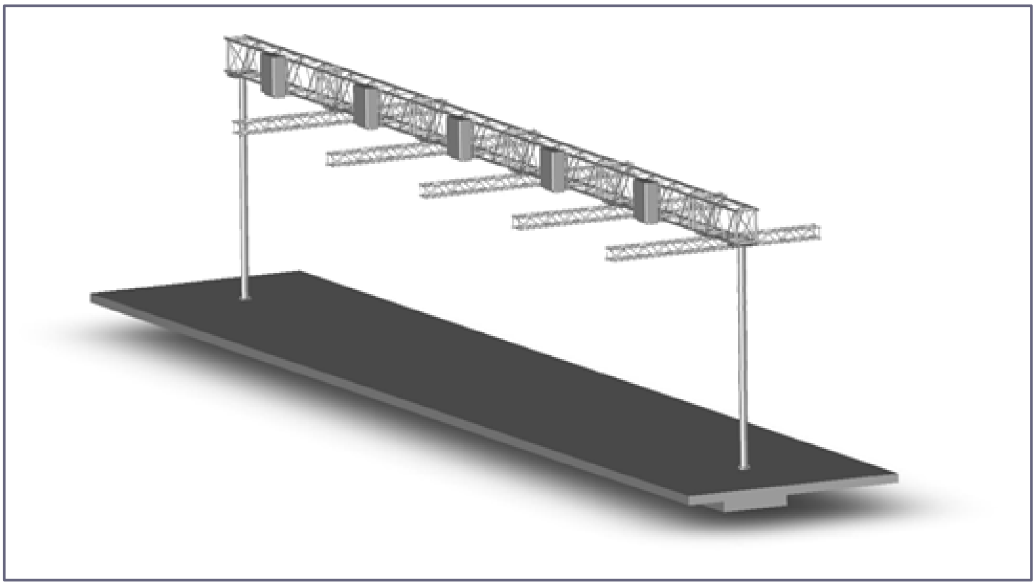

Figure 12: Modular gantry concept

The main advantage of this solution is represented by the high adaptability to various layout conditions available at customers' sites (e.g. parallel or fishbone layout).

Parallel layout:

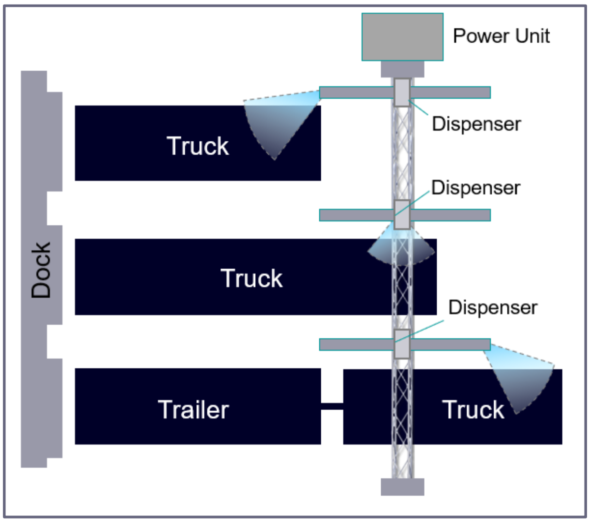

Figure 13: Chosen solution applied for a parallel layout truck dock

Fishbone layout:

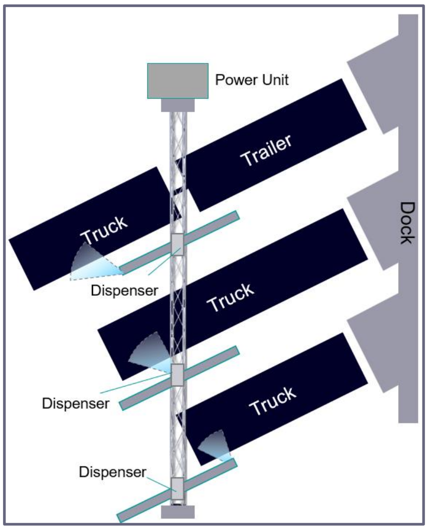

Figure 14: Chosen solution applied for a fishbone layout truck dock

The following table shows the characteristics of each solution. The main contributing factors in the final decision were the cable handling and the flexibility of each solution:

NR	SOLUTION	CABLE HANDLING	FLEXIBILITY	RELIABILITY	COSTS
1	Mechanical cable pulls	Low	Low	Low	Low
2	Mechanical + electrical cable pulls	Medium	Low	Medium	Low
3	Rail for cable routing	Medium	Low	Medium	Medium
4	Parallel rails for cable routing	Medium	Medium	High	Medium
5	Cable reel	High	Medium	Medium	High
6	Modular gantry	High	High	Medium	High

Table 1: Solutions comparison

The excellent cable handling and the high amount of flexibility offered by the modular gantry solution have made it the chosen solution, as it has managed to reach the proposed goals:

- ✓ Develop a cost-optimized modular blueprint that can be applied at every customer site
- ✓ Minimize recurring efforts (construction, structural calculations)
- ✓ Consider various cable management solutions that fit different customer requirements

Figure 15: Implementation suggestion for groups of 5 trucks

Solution 2: Automatic charging

In the quest towards a higher adoption rate for the EVs, including eBuses and eTrucks, the simple and efficient operation of a charging station is on top of the priorities list for the R&D teams.

One of the solutions that have shown promising results in this direction is robotic charging, which is basically a system that can be deployed at truck stops and distribution centers and it can autonomously connect the charging coupler to the truck / bus, replacing the manual process performed currently by the driver.

Currently there are several technical concepts that are taken into consideration:

1. Wireless charging:
   Wireless charging technology uses electromagnetic induction to transfer power from a charging pad to the vehicle's onboard charging system, eliminating the need for physical plug-in connections. While a promising solution, the relatively low number of wireless power transfer (WPT) capable ECVs is one of the factors that has hindered until now the large-scale adoption of this technology.

2. ACD-U (Automated Charging Device Underbody):
   A specific charging connector is integrated into the vehicle underbody so that the periphery of the vehicle is free while charging. It's a solution that, along with the need of a new connector on the car's underbody, poses several additional challenges, including the need for civil work for the installation and a high risk of failure in adverse weather conditions.

3. ACD-S (Automated Charging Device Side):
   A solution which uses the common vehicle inlet (CCS) on the vehicle side that is used for manual charging for automatic connection. The connection interface on the vehicle may include a moving part as well.
   a) Mobile:
      A costly option, that requires additional battery storage and is unsuitable for outdoor usage of the collaborative robots, due to the higher ingress protection (IP) and mechanical impact protection (IK) requirements than for indoor use.
   b) Stationary:
      An option that offers a key advantage – flexibility, while using the standardized charging coupler and has a focus on DC for fast charging.

Main challenges:

1. Flexibility: Serve all possible eBus and eTruck configurations and communication protocols.
2. Charging speed: An important factor in keeping the downtimes to a minimum and making use in the most efficient way of compulsory legal breaks for long-haul drivers.
3. Robustness: A prerequisite for being able to cope with functioning in outdoor environments
4. Safety: For unfenced operation in public spaces without the risk of injuries for the people that might find themselves in vicinity of the robot during operation.

Proposed solution:

This solution can theoretically work with any type of EV (from a passenger car to a delivery vehicle or even a large truck), as it uses the existing CCS charging connectors and cables.

Depending on the type of vehicle, from sports cars to trucks, the charging ports are installed in different places on the vehicle and at different heights. Sometimes they're also tilted slightly upward, and the vehicles don't always park at the same distance from the charging station, or they stop at a slight angle.

The way the charging connector has to move in to connect to the port depends on all these factors. To make it work, optical sensors can be used together with an AI solution trained to recognize different charging ports in images and to determine their precise position and orientation. That data is used to calculate how the robot needs to move to connect the car to the charger, and the axes are controlled by automation technology.

To accommodate these different types of vehicles, with charging points in different places and at different heights, such a system must use a linear motor positioning system and computer vision.

This requires the vehicle to park in a specific place and the linear motors position the connector in the *x* and *y* directions, guided by the computer vision system that targets the open connector port. An arm with the CCS connector then extends out to the vehicle to make the connection.

The working principle is straightforward: when a vehicle enters the charging station, it aligns with the charging robot and opens the charging flap. The sensors detect the vehicle and start the process. The cameras and AI algorithms search for the inlet along the vehicle and once found the final position of the plug is calculated, then the robot adjusts it and plugs it in the car's inlet. The charging process starts then via plug & charge which allows automatic authentication without the need for human intervention. At the end of the charging process the robot returns to the parking position and waits for the next vehicle.

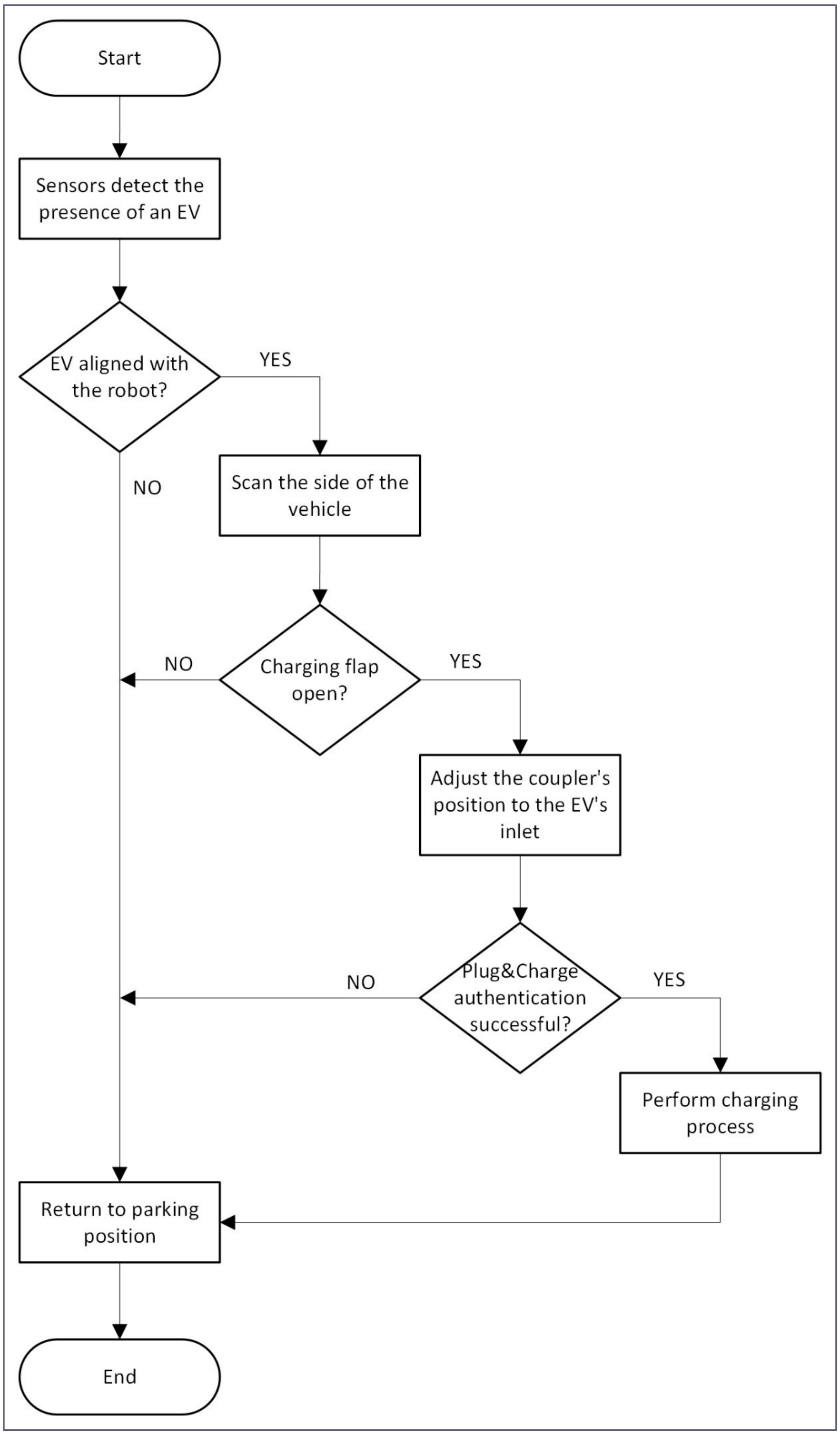

Figure 16: Logical scheme for the automatic charging process

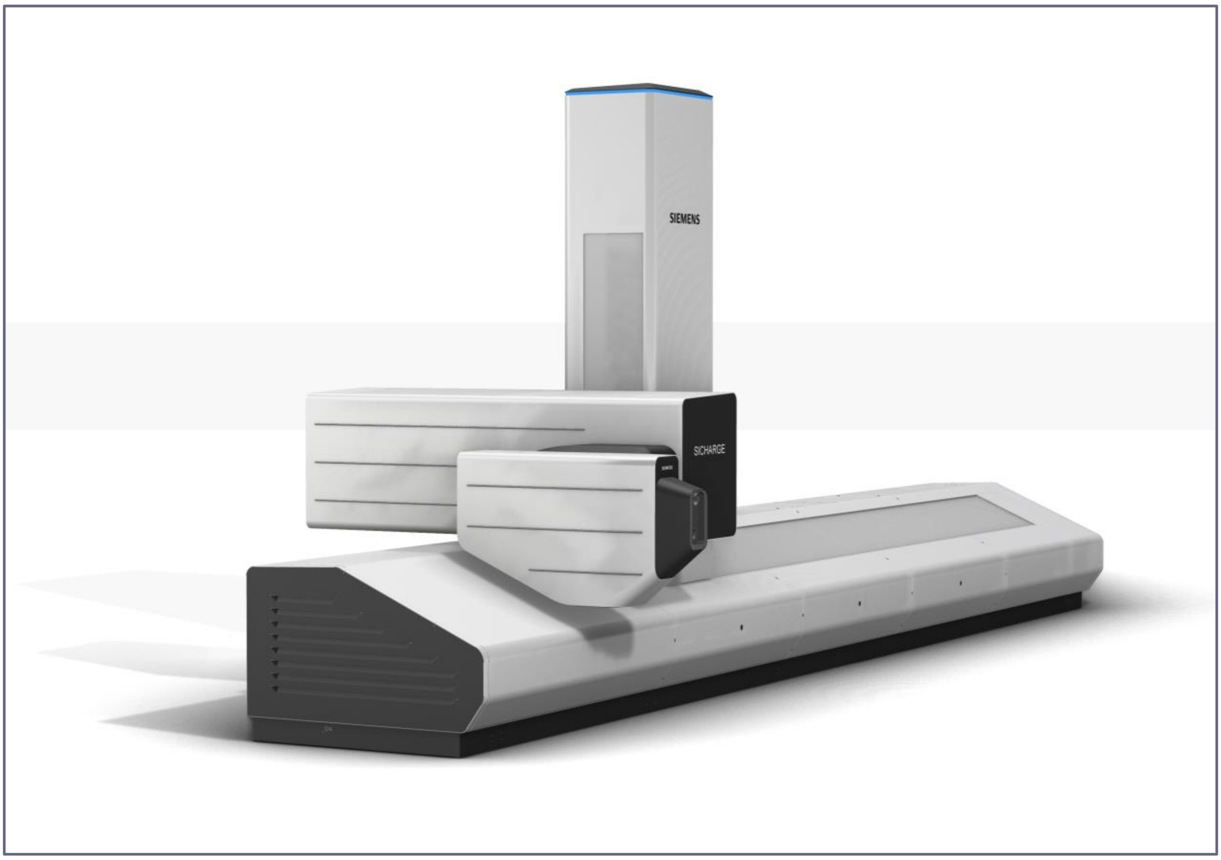

Figure 17: Automatic charging robot

The answers this solution could provide to the previously mentioned challenges will be detailed in the following pages:

1. Flexibility:
   The proposed solution has a horizontal travel of over 2000 mm and a vertical travel of more than 1000 mm, which allows it to serve all the possible EVs, from small vehicles to long haul eTrucks.

Figure 18: In-field application for various EVs

In addition, the ability to pan and tilt the charging head increases the system's flexibility: a 20° pan range is used to accommodate possible vehicle misalignment and different socket positions, while a 35° tilt range allows the robot to tilt the plug according to the socket's installation angle.

Figure 19: Pan motion

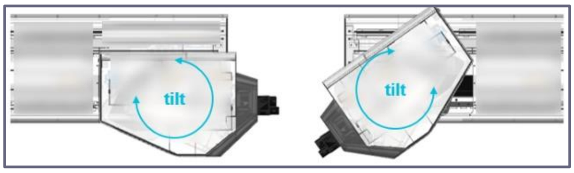

Figure 20: Tilt motion

A special feature of this solution could be the use of communication protocols between the EV and the charging robot, which makes the whole process more reliable and ensures that the interoperability with various ECVs could be possible in a secure and autonomous manner. Also, through adhering to the requirements of specific norms (IEC 61851-24, IEC 61851-27, IEC 61851-28) future proof features should be in place, e.g. the integration with energy management systems and increasing the confidence of the depot owners that the electrification of their fleet is the way to go.

2. Charging Speed:
   Fast-charging levels could be achievable if it’s coupled to a dedicated HPC. Specific for eTruck and eBus applications, levels above 1 MW would be theoretically possible with a MCS coupler.

Figure 21: High Power package for eBus & Truck application

3. Robustness:
   The possible IP54 certification can ensure the full outdoor durability, ensuring an operation between -25°C and +50°C.

4. Safety:
   Secure deployment in open spaces can be ensured by a dedicated system developed with certified safety sensors. These sensors have the purpose of detecting the presence of people / animals / objects in the active functioning area and stop the movement of the mobile parts, so a possible collision-caused injury can be avoided.

The constructive solution allows different parking lot layouts (parallel or continuous), offering multiple options for accommodating the various vehicle lengths and types.

Serial layouts:

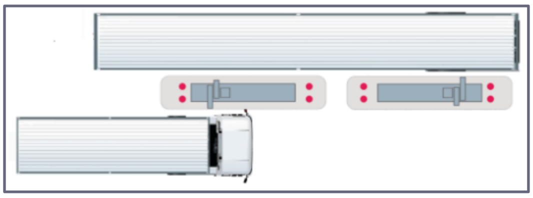

Figure 22: Serial layout - EVs in the same direction

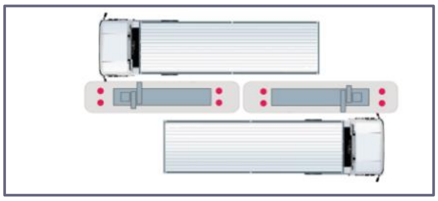

Figure 23: Serial layout - EVs in opposite direction

Parallel layouts:

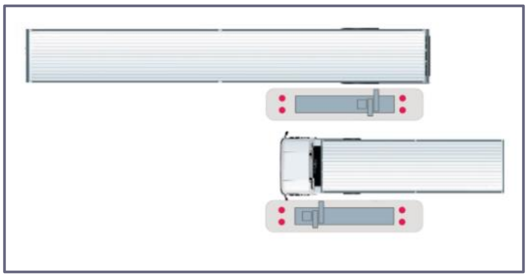

Figure 24: Parallel layout - same orientation

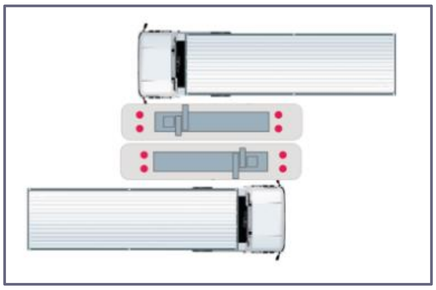

Figure 25: Parallel layout - opposite orientation

Visualization of a parallel layout:

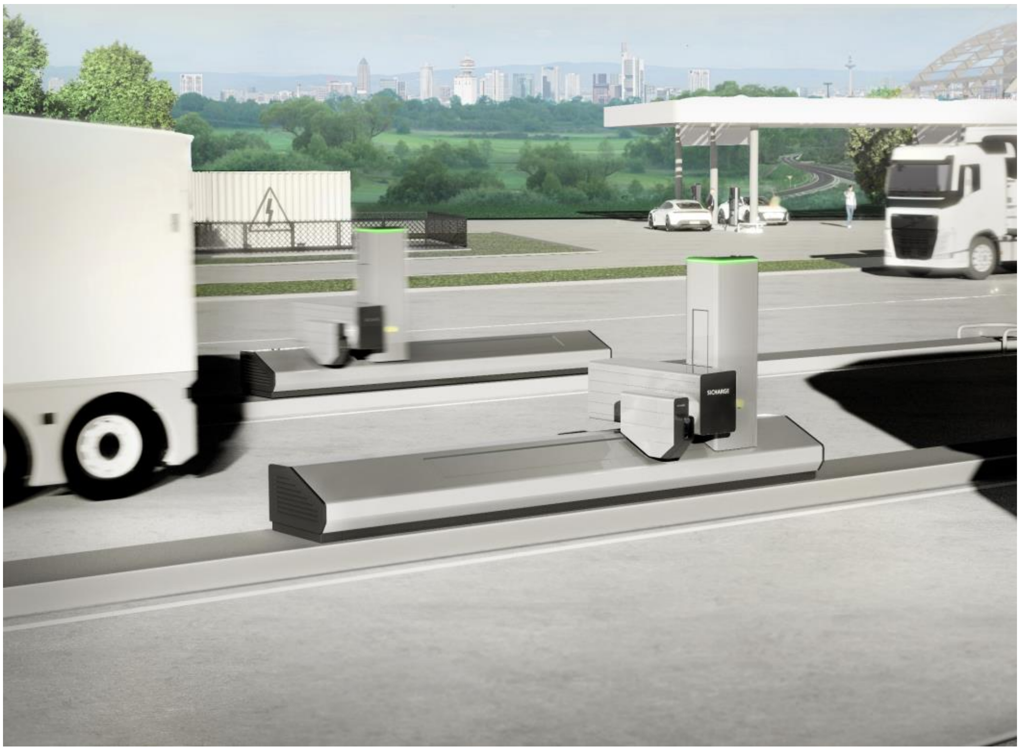

Figure 26: Parallel layout in an eTruck parking

Of course, the decision regarding the layout of a parking lot takes into consideration not only the length of the EVs that will use the charging infrastructure, but also the mating space.

According to IEC DTS 61851-27:2024 (current valid version at the time of writing this paper), an automatic charging robot has a mating space or combination of mating spaces to indicate the volumes and orientations in which the manipulator can mate the vehicle connector to the vehicle inlet. Thus, the mating space is a collection of ranges of 6 degrees of freedom. The dimensions of the mating space can be dependent on design and installation. For un-mating, the robot needs to consider the tolerances for allowed passive vehicle movement according to ISO TS 5474-5. The mating space can't overlap with the home space.[9]

The solution analyzed has the following advantages:

- Highest flexibility to reach all kinds of inlets
- Full outdoor durability
- Capable of MCS and CCS2 charging
- No additional dispenser needed

The standardization process is ongoing at national and international level and several norms are going to be released soon, both for infrastructure and vehicles. Having the plan in place, the challenge now is to stay on track with the planned release of all the relevant norms and standards.

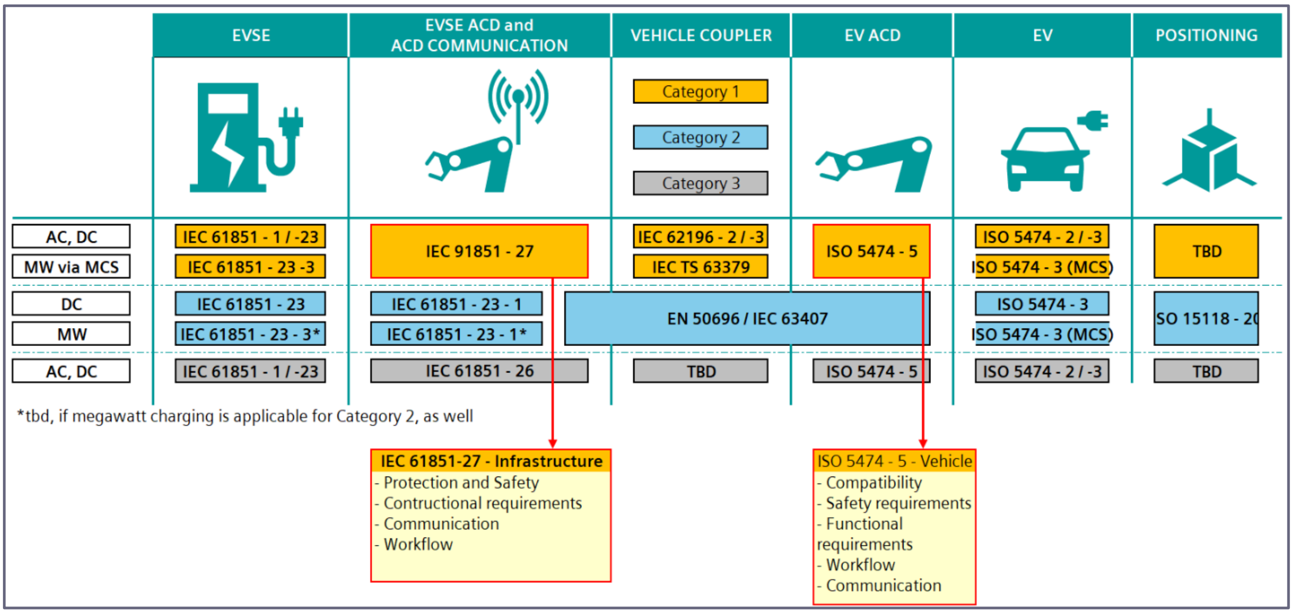

Figure 27: Standardization plan for ACD

9 IEC TS 61851-27- Electric vehicle conductive charging system - Part 27: EV supply equipment with automated connection of a vehicle coupler according to IEC 62196-2 or IEC 62196-3

Outlook

Overview of future innovations and trends

The wave of innovation in EV charging solutions will continue in the coming years, with exciting technologies and solutions waiting to be released to the market. Every involved stakeholder plays a specific role:

1. Fleet operators:
   Bring an understanding of the operational requirements and charging needs for their ECV fleets. Their early involvement in the implementation projects ensures that the solutions developed for this market segment are tailored for its specific needs.
2. Utility companies:
   Bring the knowledge needed to overcome the grid integration challenges.
3. Technology providers:
   Are responsible for the development of innovative hardware and software solutions and for complete system integration, to ensure interoperability and integration of emerging technologies (e.g. wireless charging and V2G).
4. Policymakers:
   Can support the electrification of the transportation sector through sound legislative initiatives, supportive policies and regulations, and incentive programs. Their role is to shape the regulatory framework and secure funding opportunities for stakeholders, in particular depot / fleet operators and charging technology providers.

Currently the most important innovation topics are bidirectional charging, wireless charging, megawatt charging and dynamic overhead conductive charging.

1. Bidirectional Charging
   A bidirectional charging solution allows for an ECV not only to draw electricity from the grid, but also to discharge it back to the grid when parked for extended periods. The most frequent use case scenarios are:
   - Emergency power supply
   - Tariff optimized charging
   - Load balancing
   - Peak shaving
   - Spot market trading
   - Ancillary grid services

   Mixing some of these use cases (e.g. tariff optimized charging with spot market trading and peak shaving) can be an effective cost-reduction solution for the depot and fleet owners, with cost savings of up to 10.000€/year/vehicle[10].

   Additionally, bidirectional charging can help achieve a fleet owner's sustainability goals by acting as a high-capacity storage for renewable energy sources (e.g. from wind turbines or from PV installations).

[10] See Multi-Use Optimization of a Depot for Battery-Electric Heavy-Duty Trucks by Florian Biedenbach and Kai Strunz

Future development will focus on increasing efficiency across the full power spectrum by reducing conversion and switching losses.

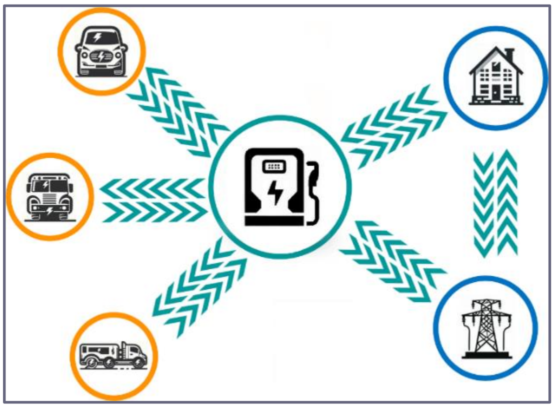

Figure 28: Bidirectional charging

2. Wireless Charging:

   Wireless charging has gained a lot of traction in recent years, as it can prove to be a decisive factor in the adoption of EVs. In the current state of development, most solutions are stationary wireless charging solutions, where a wireless charging pad is installed at a specific location and the vehicles can be charged just by parking above them. The main challenges faced by the industry are related to the fact that the market still needs to be developed. There is a co-dependence between the availability of the charging infrastructure and the availability of WPT-capable EVs, that influences the market entry. Another challenge is staying interoperable within the existing standards when serving the market requirements (higher power classes, flush/buried-mounted, metering, etc.)

   Technology providers are working on these issues, and we can expect to see in the next years wireless charging stations capable of increased power transfer rates, with improved alignment and positioning capabilities (especially due to the advancements in the field of vehicle-to-infrastructure communication), all at a reduced price-level compared to the current state.

Figure 29: Wireless charging station concept

3. <u>Megawatt Charging</u>
   The next "big thing" in terms of charging power is the Megawatt Charging technology, as it's the one that can drive the large-scale adoption of ECVs by managing to refill a battery during the mandatory break (45 minutes for each 4.5h driven) and ensure that the vehicle will be able to reach the next charging station without any range anxiety.

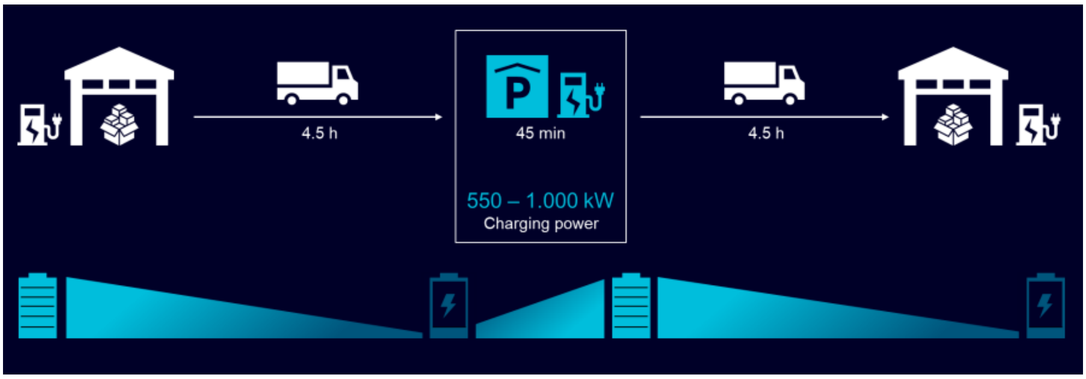

Figure 30: Megawatt charging concept

The new industry standard for the Megawatt Charging is the MCS standard, with the following specifications:

- Max. power ~3.75MW (1250V, 3000A)
- Plug weight ~2.5 kg
- Cable weight: between 10kg (3m, 1000A) and 25kg (3m, 3000A)

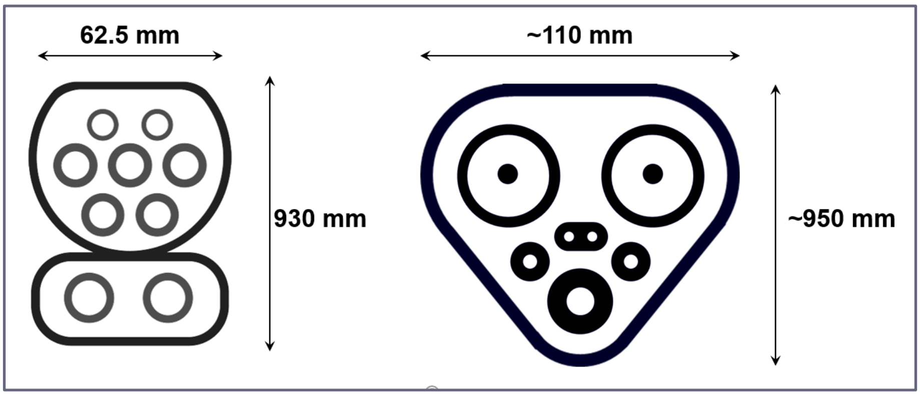

Figure 31: CCS2 coupler (left) – MCS coupler (right) comparison

The heavy weight of the cables (as specified above) represents a problem for most users, but the solution could be the widespread use of automated robotic charging solutions, which can eliminate the need for human intervention during the process of coupling and decoupling the charger to and from the EV.

In the future, the use cases for Megawatt Charging will go beyond ECV applications and we could see it present in eFerries and eVessels applications, as well as in electric Vertical Take-Off and Landing aircrafts (eVTOL) or electric mining trucks.

4. <u>Dynamic Overhead Conductive Charging</u>
   Overhead charging, also known as pantograph charging, requires the use of a retractable / extendable arm that allows the connection between an eBus and the charging station located above it without the need of manual intervention for the mating process.

It has certain advantages that make it a promising future method for charging eBuses, even though the technology is not necessarily new:

- Overhead charging systems are usually high-power charging systems, with all the advantages that derive from using such a solution, especially short charging times.
- Since it's an automated process, the bus drivers don't need to be involved in the mating process between the eBus and charging station anymore.
- It requires a reduced amount of wiring in comparison with the classical charging systems.

Conclusion

The electrification of the transportation sector has begun and will continue in the following years. Our main takeaways can be summarized as follows:

1. Understand the needs of the customers (depot and fleet owners) and offer them the solution that fits their needs.
2. Engage the stakeholders in the planning of charging solutions: fleet operators, charging technology providers, utility companies and policymakers. Their collaborative approach is the only path towards successful electrification of bus and truck fleets and depots
3. Modular and scalable designs are the answer: As seen in the Dock Charging project, it's not enough to have a good solution for a particular application, it must be flexible, so that it can be applied to most of the interested depot and fleet operators. project. In the Automatic Charging Project, the same lesson could be learned: scalability and flexibility were the key factors that made it a successful solution not only for regular EVs, but also for ECVs and have led to it being the go-to solution for Megawatt Charging depot concepts.
4. Integration with the commercial fleet management solutions and electrical grid: smart charging is the key towards the future mass adoption of ECVs. The integration of energy management platforms and grid-interactive solutions (V2G / V2X) makes the operation of electric fleets more energy efficient, but also more cost efficient by reducing the operation costs.
5. Regulatory compliance and policy alignment: just like the technology is evolving, the regulatory landscape is also constantly evolving, and the industry standards are adapting to the new developments. Electric mobility needs clear and supportive rules, standards and laws to be successful, one of the most important being ISO 15118-20.

If these best practices are adopted by the stakeholders involved, we will be on the right track towards a successful and more sustainable deployment of the charging infrastructure needed for the large-scale introduction of electric buses and trucks.

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