Alliance for Batteries Technology, Training and Skills

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Desk Research Report IV.

Charging Batteries of Electric Vehicles and Other Electric Means of Transport & Job Roles and Skills

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List of Abbreviations

AC	Alternating Current
AFIR	Alternative Fuels Infrastructure Regulation
BaaS	Battery as a Service
BET	Battery Electric Truck
BEV	Battery Electric Vehicle
BHDV	Battery -Heavy-Duty Vehicle
BMS	Battery Management System
CCS	Combined Charging System
CEI	Cathode Electrolyte Interphase
CHAdeMO	Charge de Move (Charge for Moving)
CO_2	Carbon Dioxide
CP	Control Pilot
DC	Direct Current
EASA	European Union Aviation Safety Agency
EPBD	Energy Performance of Buildings Directive
EU	European Union
GVW	Gross Vehicle Weight
HDV	Heavy-Duty Vehicles
ICE	Internal Combustion Engine
IEC	International Electrochemical Commission
LNG	Liquified Natural Gas
MCS	Megawatt Charging System
NO_x	Nitrogen Oxide
OEM	Original Equipment Manufacturer
PE	Physical Earth
PHEVs	Plug-in Hybrid Electric Vehicles
R&D	Research and Development
RF	Radio Frequency
SEI	Solid Electrolyte Interphase
SoC	State of Charge
SoH	State of Health
SO_x	Sulphur Oxide
SPIC	State Power Investment Corporation Limited
V2G	Vehicle-to-Grid
V2H	Vehicle-to-Home
V2L	Vehicle-to-Load
V2X	Vehicle-to-Everything
VVR	Vehicle-to-Vehicle Recharging
WPT	Wireless Power Transfer

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Executive Summary

Chapter 1, *Battery Charging,* examines the basic principles of battery charging and elaborates on one of the biggest challenges relevant to the electrification of European transport: the degradation of batteries. It also explains the common practice of charging an electric battery not entirely but to around 80% of its capacity.

Chapter 2, ***Passenger Cars,*** studies the aspects of battery charging of the most crucial road transport segment predetermined to electrify in the coming decades. It analyses various types and locations of charging by wire, wireless technology, and battery swapping. Solutions easing the impact of the charging on the grid and innovative services relevant to battery charging are also covered. Examples of relevant job roles and qualification requirements are shown.

Chapter 3, *Trucks and Buses*, analyses battery charging options relevant to the emerging segment of heavy-duty vehicles. A significant part of this segment is expected to electrify, no matter how challenging the task is, considering the weight of the batteries needed and the weight of the vehicle's load - especially during long-haul and international travels. Apart from the standard wired charging, the chapter studies alternatives, such as wireless or pantograph charging in a depot, bus stop, or on the road. Examples of relevant job roles and qualification requirements are shown.

Chapter 4, ***Motobikes***, sheds light on the electrification of the motorcycle segment and relevant charging options, which are somewhat similar to the passenger cars segment. Examples of relevant job roles and qualification requirements are shown.

Chapter 5, *Micromobility*, covers a dynamically developing segment of micromobility devices used for short distances, such as mopeds, scooters and electric bikes. Besides standard charging options, innovative solutions are introduced mainly in shared mobility services, such as battery swapping or wireless charging of an e-bike or e-scooter in a stand. Examples of relevant job roles and qualification requirements are shown.

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Chapter 6, ***Aeroplanes,*** describes the first pilot projects of battery charging of aeroplanes, which might adopt similar charging solutions as heavy-duty vehicles. Due to the market's immaturity, no examples of job roles or qualifications are shown.

Chapter 7, *Trains*, showcases the charging of the first battery trains operating in Germany, using pantographs to top-up the energy while onboarding passengers at the station. Due to the market's immaturity, no examples of job roles or qualifications are shown.

Chapter 8, Vessels, examines commercial and leisure vessel charging options. In the case of large vessels, charging towers, moving charging devices, or automatic robotics arms need to be used, considering the thickness and weight of the cables needed to provide appropriate charging power. Examples of relevant job roles and qualification requirements are shown.

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Introduction and Methodology

Batteries in watches, mobile phones, or laptops have been with us for some time. With the technological improvements and cost decrease of lithium-ion batteries, gradual electrification of transport, household gadgets, power devices, and installation of energy storage in households, public and corporate premises have been made possible. Batteries are becoming an inseparable part of the life of Europeans.

Various aspects related to batteries in areas such as research and development, battery production, second life and recycling have been analysed in the previous ALBATTS reports[1]. The project has not yet analysed the very relevant topic of how batteries are charged, which is the focus of this report.

The relatively recently adopted EU legislation or legislation in the pipeline has boosted the **importance of charging batteries** in various ways and types of electric vehicles:

- The CO_2 regulation introducing fleet emission reduction targets on passenger cars reduction targets imposed on European car manufacturers with the effective phase-out of ICE vehicles in the EU in 2035
- The Clean Vehicles Directive introducing compulsory procurement targets for public fleets
- The (currently being revised) Energy Efficiency Directive (EPBD) introducing targets for charging infrastructure installation in buildings
- The Alternative Fuels Regulation (AFIR) introducing compulsory charging infrastructure targets for each EU member state, not only for passenger cars but also for heavy-duty vehicles.

As a combined effect of the regulation mentioned above and other factors, a massive deployment of public and private charging infrastructure is needed, opening new job opportunities and requiring a **skilled workforce.**

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[1] See ALBATTS WP5 reports D5.1 – D5.9 and WP4 reports D4.1 – D.4.9 at www.project-albatts.eu/en/results

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This report examines the theoretical basics of battery charging and analyses in more detail the battery charging of the most **significant mobile applications** of batteries – passenger cars, heavy-duty vehicles, motorcycles, micromobility devices, vessels, and even aeroplanes and trains. Charging of batteries of vans is not dealt with separately since it is relatively identical to charging of passenger cars.

The report was compiled by members of the **Work Package 5 – Intelligence in Mobile Battery Applications** - of the ALBATTS project. The information in the report comes from open internet sources, using data from job advertisements published by companies, using the know-how of the ALBATTS project partners and other sources.

The findings on job roles, qualifications and skills relevant to charging batteries in the transport segment will be further elaborated in the upcoming **WP5 Sectorall Intelligence report.**

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1 Battery Charging

Batteries transform chemical energy stored in them into electrical energy. They are composed of electrochemical cells consisting of electrolytes, cathodes, and anodes. An electrical current is produced when a device is connected to an external circuit, and a chemical reaction occurs, allowing electrons to move from the anode to the cathode. Direct connections between batteries and gadgets are made possible by wire technologies, such as conductive wires, which also enable the movement of electricity through actual physical routes.

On the other side, wireless technologies provide wired connections with options. Battery charging without physical contact is made possible via inductive charging, which transfers energy between coils using electromagnetic fields. While solar charging uses sunlight to power batteries using photovoltaic cells, Radio Frequency (RF) energy harvesting absorbs ambient radio frequency signals and transforms them into electrical energy. These cable and wireless technologies offer a variety of battery-powered device powering methods, each with unique benefits and applications based on requirements and limitations[2].

1.1 WIRED TECHNOLOGY

Wired technology plays a crucial role in battery systems, enabling efficient and reliable power transfer through conductive pathways, such as busbars and interconnects, to establish electrical connections between individual battery cells, modules, and external components. The following types of wired technologies are used to charge car batteries. [3]

Electrical connection

Using wired technology, the battery and the item it powers are directly electrically connected. Positive (+) and negative (-) connections on the battery are typically connected to matching terminals on the device, as shown in **Figure 1.**

[2] Bai, H., Costinett, D., Tolbert, L. M., Qin, R., Zhu, L., Liang, Z., & Huang, Y. (2022). Charging Electric Vehicle Batteries: Wired and Wireless Power Transfer: Exploring EV charging technologies. *IEEE Power Electronics Magazine*, 9(2), 14–29. https://doi.org/10.1109/mpel.2022.3173543

[3] Mohammed, S. a. Q., & Jung, J. (2021). A Comprehensive State-of-the-Art Review of Wired/Wireless Charging Technologies for Battery Electric Vehicles: Classification/Common Topologies/Future Research Issues. *IEEE Access*, 9, 19572–19585. https://doi.org/10.1109/access.2021.3055027

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Figure 1: Electrical wire connection[4]

Conductive Wires

Electrical energy is transmitted between the battery and the device using conductive wires or cables. To reduce resistance and ensure effective power transfer, these wires comprise materials with good conductivity, such as copper or aluminium, as shown in **Figure 2.**

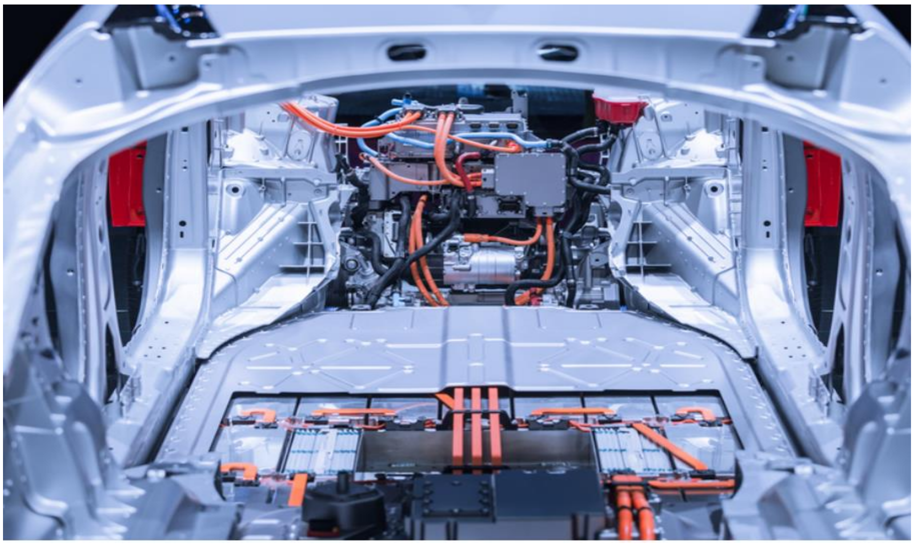

Figure 2: Conductive Wires[5]

[4] Bhor, S. (2022). Proliferation of electric passenger car to bolster demand for passenger electric vehicle sound generators. *TechBullion*. https://techbullion.com/proliferation-of-electric-passenger-car-to-bolster-demand-for-passenger-electric-vehicle-sound-generators/

[5] Sickels, D. (2023). Hyundai, SK On to build EV Batteries in Georgia. The Buzz - *Electric Vehicle News*. https://www.thebuzzevnews.com/hyundai-sk-on-ev-batties-georgia

Positive and Negative Terminals

The battery's positive terminal is attached to the device's positive terminal, while its negative battery terminal is attached to its negative terminal. Doing so completes the electrical circuit, and the electrical current can flow, as shown in **Figure 3.**

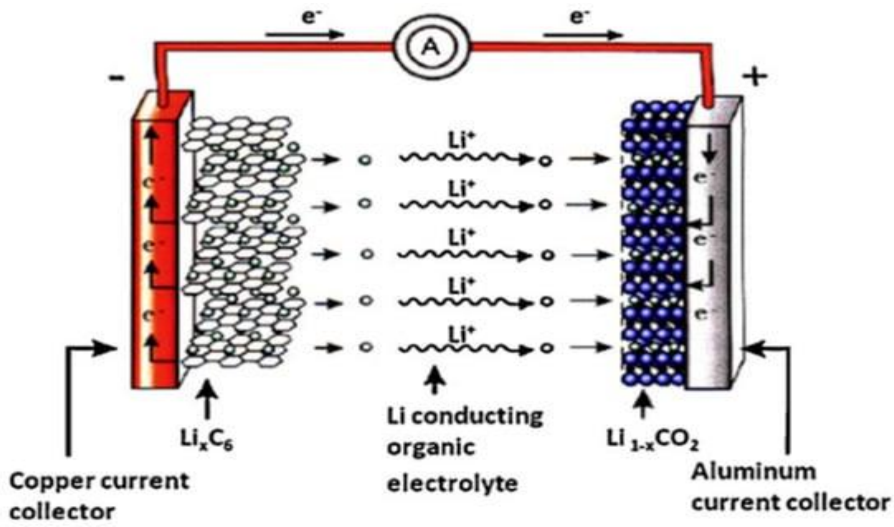

Figure 3: The schematic diagram of the working principle of a battery [6]

Power Transmission

The electrical energy stored in the battery is delivered through the wires to power the gadget when the connected connection closes the circuit. The cables carry the current from the battery's negative terminal to the device's positive terminal.

Charging and Discharging

Battery charging is mainly done over wired connections. When the battery is being charged, an external power source is wired into the battery, allowing electricity to flow into the battery to restore its energy. Similar to how a battery discharges, electrical energy is provided to the device via the connected connection, as shown in **Figure 4**.

[6] Ndeugueu, J. L. (2010). Ion transport mechanisms and relaxation phenomena in structurally disordered materials.*ResearchGate*.https://www.researchgate.net/publication/215545669_Ion_Transport_Mechanisms_and_Relaxation_Phenomena_in_Structurally_Disordered_Material

Figure 4: Charging of electric vehicle[7]

1.2 WIRELESS TECHNOLOGY

Wireless technology in battery systems involves implementing wireless charging or power transfer methods, utilising electromagnetic fields or resonant coupling to transmit energy from a power source to the battery without physical connections, enabling convenient and flexible charging capabilities. Theoretic efficiency is up to 90%.

Several types of smartphones, smartwatches, and other portable electronics support wireless charging. Without using any physical connections, these devices can be charged by setting them on compatible docks or charging pads. The prospect of wireless charging is also finding application in electromobility. [8]

Inductive Charging

Wireless charging systems using inductive charging technology are used by some electric vehicles. Parking the car over a charging pad, which transmits power through electromagnetic fields, enables the battery to be charged, as shown in **Figure 5**.

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[7] Kitching, H. (2023, July 6). Road trips lose power as charger outages leave northern Ontario EV drivers stranded. *CBC*. https://www.cbc.ca/news/canada/thunder-bay/ev-charger-outtages-northern-ontario-1.6895863

[8] Vishnu, K., Nema, R. K., & Ojha, A. (2020). Various types of wireless battery management system in EV. In 2020 *IEEE International Students' Conference on Electrical,Electronics and Computer Science* (SCEECS). https://doi.org/10.1109/sceecs48394.2020.115

Figure 5: Wireless car charging on the left[9] and inductive charging on the right[10]

Wireless Power Transfer

Experimental or cutting-edge technologies like radio frequency energy harvesting and wireless power transfer employing resonant coupling are being investigated for various battery types. These technologies seek to deliver power across great distances.

Radio Frequency (RF) Energy Harvesting

Radiofrequency waves in the environment are captured and turned into valuable electrical energy using RF energy harvesting equipment. By absorbing RF energy from sources such as Wi-Fi signals, radio waves, or cellular networks, it can be used to recharge small batteries or power low-energy devices.

Convenience and Mobility

Without the trouble of physically connecting cables, wireless technologies offer the simplicity of charging or powering batteries. Mobility is made possible since gadgets can be powered or charged by simply placing them on charging pads that are compatible with them or are within a specific charging range.

[9] Groves, J. (2023). Genesis trialling wireless charging in Korea. *CAR Magazine*. https://www.carmagazine.co.uk/electric/what-is-electric-car-wireless-charging-wevc-and-how-does-it-work-/

[10] Turpen, A. (2018, May 29). BMW i launches wireless charging for plug-in hybrids. *New Atlas*. https://newatlas.com/bmw-wireless-charging/54792/

1.3 BATTERY DEGRADATION DUE TO FAST CHARGING

Battery degradation resulting from fast charging concerns electric vehicle owners since the battery pack and its State of health (SoH) are essential for the range and residual value of the vehicle. The degradation of Li-ion and Li-metal battery electrodes at fast charging has been among the main challenges in e-mobility. While fast charging offers the advantage of reduced charging time, it raises concerns regarding potential adverse effects on battery health.

To understand EV battery lifespan, it is crucial to understand fast charging, its mechanisms, and its different levels. Generally, electric vehicles can be charged more slowly (typically up to 22 kW) using **alternating current (AC),** which uses the vehicle's onboard charger to convert the current from AC in the socket, wallbox or a stationary AC charging station to direct current (DC), as the lithium-ion battery cannot directly handle AC.

On the other hand, **direct current** (**DC) charging (typically up to 350 kW)**, also known as fast (or ultra-fast) charging, eliminates the need for the onboard charger and enables the battery pack to receive much higher levels of current and voltage directly.

Damage to Battery Electrodes Due to High Current and Voltage

When lithium-ion batteries are subjected to fast charging, several adverse effects on battery electrodes occur. Applying high current and high voltage during fast charging exerts significant pressure on the battery. As a result, lithium ions are forcefully extracted from the cathode and transferred to the anode. This process leads to the **formation of cracks** in the cathode and the generation of dendrites on the electrodes. Consequently, the capacity of the lithium-ion cells diminishes, and the battery's internal resistance increases. These phenomena contribute to the overall degradation of the battery.

High-Temperature Degradation

Fast charging is a convenient feature that allows batteries to be charged quickly, reducing the time required for powering devices. However, it is vital to consider the potential drawbacks associated with fast charging, particularly regarding high-temperature degradation. When a battery is subjected to fast charging, the internal resistance of the battery rises. This resistance causes an increase in heat generation due to the high current flowing through the battery during the charging process. Excessive heat can lead to **chemical reactions and physical changes** within the battery, resulting in the degradation of its capacity over time.

The capacity of a battery refers to its ability to store and deliver electrical energy. A decrease in capacity means that the battery cannot store as much energy as before, resulting in shorter usage times and decreased overall performance.

To mitigate the impact of high-temperature degradation, battery manufacturers and researchers are actively developing techniques to improve the thermal management of lithium-ion batteries. This involves implementing materials and designs of the Battery Management System (BMS) and other components to dissipate heat more efficiently, preventing excessive temperature rise during fast charging. By addressing this issue, lithium-ion batteries' capacity and overall performance can be enhanced, ensuring a more reliable and efficient energy storage solution.

Low-Temperature Lithium Plating

Lithium plating specifically affects the anode of the battery. Instead of lithium ions intercalating into the anode material as intended, the lithium atoms accumulate on the anode's surface, forming a **layer of inert lithium metal**. This lithium plating hampers the battery's ability to generate electricity effectively, resulting in decreased performance and compromised overall capacity.

The presence of lithium metal on the anode surface not only diminishes the battery's performance but also poses safety risks. The accumulation of lithium metal can lead to the formation of dendrites that can grow over time and cause internal short circuits within the battery. These short circuits can result in overheating, thermal runaway, fires, or even explosions.

Researchers and battery manufacturers are exploring various strategies to mitigate the occurrence of low-temperature lithium plating. These include developing advanced battery materials, improved electrolytes, and innovative charging algorithms. The adverse effects of

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lithium plating can be minimised by optimising the charging protocols and ensuring appropriate temperature conditions, thereby enhancing the reliability, performance and endurance of lithium-ion batteries subjected to fast charging.

1.4 CHARGING PRINCIPLE

Why Do Electric Cars Charge Slower After 80% Full? [11]

When the battery is charged at a lower percentage of its capacity, it charges faster as the charger supplies the maximum current. However, the charging current decreases as the battery reaches around 80% of the capacity. This reduction in current occurs due to the **increased heat** generated by the battery during this stage, unlike during the initial charging phase.

At this point, the battery's ions require stabilisation. Consequently, the charger switches to a slower charging mode for the remaining 20% to ensure optimal battery performance. This approach preserves the battery's lifespan and maintains its overall health.

Charging to maxiumum 80%[12]

Increased exposure to high voltage is detrimental to Lithium-ion batteries, leading to accelerated degradation. To protect the battery's lifespan, car owners can adjust their vehicle settings to stop charging at 80%.

The charging point operators can program fast chargers to stop charging at 80%. Depending on the operator's policy, the limit may be set at 90% or 95%. This approach is taken because the time required to charge the battery from 80% to 100% may be equivalent to the time to charge it from the start to 80%. It can reduce the waiting time for the other users of electric cars wanting to use the same charging point, increase utilisation of the charging point, and improve its economy. Many electric car models enable the owner to set a charging limit in the car or relevant application.

[11] Jones, P. (2022). Why do electric cars charge slower after 80% full? (Explained) -. *Motor & Wheels*. https://motorandwheels.com/electric-cars-charge-slower
[12] Davis, J. (2022). The Real Reason Why Your EV Won't Fast Charge Over 80 Percent. *HotCars*. https://www.hotcars.com/real-reason-electric-vehicles-wont-fast-charge-over-80-percent/

1.5 CONCLUSION OF DEGRADATION PROCESS AND CHARGING

In conclusion, fast charging poses a significant challenge due to the degradation of electrodes. There are two primary categories of degradation mechanisms associated with fast charging. The first category arises as a direct result of the increased overpotential caused by fast charging. It includes degradation mechanisms such as the growth of lithium dendrites on anodes and structural instabilities in cathodes.

The second category consists of degradation mechanisms that exist regardless of the charging rate but are exacerbated by the non-uniform distribution of lithium concentration induced by fast charging. Examples include the growth of unstable **solid electrolyte interphase** (SEI) and **cathode electrolyte interphase** (CEI), mechanical degradation, and unfavourable processes related to electrode microstructures.

Considering the degradation mechanisms, as mentioned earlier, solutions addressing the challenges of fast charging at both the material and electrode levels are being developed. The composition of anodes and cathodes is being optimised in various ways. For anodes, the objective is to enhance electrode kinetics related to conduction and diffusion.

The goal for cathodes is to stabilise their original structure during charging. Surface modification and microstructure control play significant roles for both electrodes, aiming to accelerate kinetics and suppress detrimental side reactions. Future advancements in electrode engineering should focus on reducing fast-charging-induced overpotentials and mitigating the non-uniform distribution of lithium concentration, stress, and heat during fast charging.

This necessitates a profound understanding of kinetic limitations associated with electrode-related reactions. In addition to electrode engineering, attention should be directed towards optimising battery electrolytes. Enhancing lithium-ion conductivity and ensuring compatibility between the electrolyte and electrodes are crucial for enabling fast charging in lithium-based batteries. Manipulation of co-solvents, salt concentration, composition, and utilising novel electrolyte additives are promising avenues for improvement.

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Overall, addressing the challenges of fast charging requires a comprehensive approach involving **material optimisation, electrode engineering**, and **electrolyte enhancements.** By understanding and mitigating the degradation mechanisms associated with fast charging, researchers can pave the way for developing high-performance batteries capable of rapid charging while maintaining their integrity and longevity.

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2 Passenger Cars

2.1 BACKGROUND

The electrification of passenger cars has been driven, among other drivers, by advancements in lithium-ion battery technology, national and local regulations incentivising electric passenger cars, but most of all, by the **EU legislation.**

The most significant legislation on the EU level includes setting the CO_2 emission performance standards for new passenger cars and new light commercial vehicles (EU regulation 2019/631). It introduces fleet **CO_2 emission reduction** targets, pushing car manufacturers to increase electric vehicles' numbers on the market gradually. Approved within the "Fit for 55" package, the EU regulation 2023/851 tightens, even more, the existing emission reduction targets and, further to that, allows, starting from 2035, only zero-emission vehicles to be put on the market, except for ICE vehicles fueled solely by zero-emission synthetic fuels.

Among other drivers of electrification on the EU level is the revised Clean Vehicles Directive (Regulation 2019/1161), which introduces compulsory **zero-emission vehicle quotas** for public tenders of passenger cars, but also trucks and busses for each EU member state. According to the directive, Germany, for example, must purchase 38.5% of zero-emission vehicles by 2030.

Energy Performance of Buildings Directive (EPBD) 2010/31/EU introduces compulsory targets for charging infrastructure and **pre-cabling in buildings;** the revision is currently in the final stage of the EU legislative process, bringing even more ambitious targets.

The new Alternative Fuels Infrastructure Regulation (AFIR), based on Commission proposal COM(2021)0559, sets binding **public charging infrastructure** targets for each member state. For example, the AFIR requests there are charging points for passenger cars on the highways on the TEN-T core network (the most significant interstate highways) with at least 400 kW output in the distance not exceeding **60 km** from each other by 2025 and with at least 600 kW by 2030.

It also introduces charging infrastructure targets for the global TEN-T network (highways), targets reflecting the size of the fleet of BEVs and PHEVs of individual member states, and other provisions.

Socket outlets, inlets, plugs and vehicle connectors need to comply with EU Directive 2014/94 (Annex II.), EN 62196-2:2017 (Alternating current - AC charging), EN 62196-3:2014 (Direct current - DC charging), IEC 62196 and other international, EU or national norms and standards.

By 2030, Europe's market for electric vehicle charging stations is anticipated to reach **$34 billion**, growing at a CAGR of **25.9%** between 2023 and 2030.[13]

2.2 TYPES OF CHARGING

Public charging infrastructure in Europe

The 2019 Green Deal and the Sustainable and Smart Mobility Strategy target one million EV public recharging points and alternative fuel refuelling stations in the EU by 2025 and 3 million by 2030[14]. Europe has progressed impressively but still needs to speed up to reach its goals - according to the EAFO[15], there were **483,800** slow AC charging stations and **62,479** fast DC charging stations in the EU in 2Q of 2023.

Significant differences exist in the deployment of the charging infrastructure across the EU – most of the charging stations are concentrated in **Western and Northern Europe**, while Central and Eastern Europe lag behind. The situation also differs in individual member states where cities and busy transit roads have better charging infrastructure than remote regions.

Types of EV recharging connectors (plugs)

To establish common EU plug standards, the Alternative Fuels Infrastructure Directive (AFID) prescribed that, to ensure interoperability, charging points in the EU should be equipped with

[13] Europe Electric Vehicle Charging Stations Market - Opportunity Analysis and industry Forecast (2023-2030). (n.d.). https://www.meticulousresearch.com/product/europe-electric-vehicle-charging-stations-market-5277

[14] Eib. (2023). *ELDRIVE - CHARGING STATION NETWORK (IEU GT).* www.eib.org. https://www.eib.org/en/projects/pipelines/all/20220550

[15] Infrastructure | *European Alternative Fuels Observatory*. (n.d.-b). https://alternative-fuels-observatory.ec.europa.eu/transport-mode/road/european-union-eu27/infrastructure

at least the Type 2 standard (AC, "Mennekes") and the Combined Charging System (CCS) standard (DC).

Since adopting the AFID in 2014, most charging stations in the EU have adopted the Type 2 (Mennekes) standard for AC charging, and the CCS standard is increasingly common for DC charging. The CCS standard has replaced ChAdeMO, a charging standard developed by major Japanese car manufacturers in 2010 that also dominated the EU in the early years of e-mobility. Many charging point operators in Europe have invested in multi-standard chargers with CCS, CHAdeMO and Type 2 plugs, with the CHAdeMO standard being slowly phased out. A multi-standard charger can be seen in **Figure 6**.

Figure 6: Multi-standard charger (CHAdeMO, CCS, Type 2) funded by the CEF[16]

Charging modes

Battery Electric Vehicles (BEVs) and Plug-in Hybrid Electric Vehicles (PHEVs) get electric energy from external sources via a cable. Wireless charging is also being piloted, as elaborated later

[16] *Infrastructure for charging electric cars is too sparse in the EU*. (n.d.). https://op.europa.eu/webpub/eca/special-reports/electrical-recharging-5-2021/en/

Co-funded by the Erasmus+ Programme of the European Union

Alliance for Batteries Technology, Training and Skills - ALBATTS - Project number 612675-EPP-1-2019-1-SE-EPPKA2-SSA-B. The European Commission's support for the production of this publication under the Grant Agreement № 2019-612675 does not constitute an endorsement of the contents, which reflects the views only of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

in this chapter.[17] The International Electrotechnical Commission, under IEC, defined four ways of charging electric vehicles – Mode 1, 2, 3 and 4 as seen in **Figure 7**.

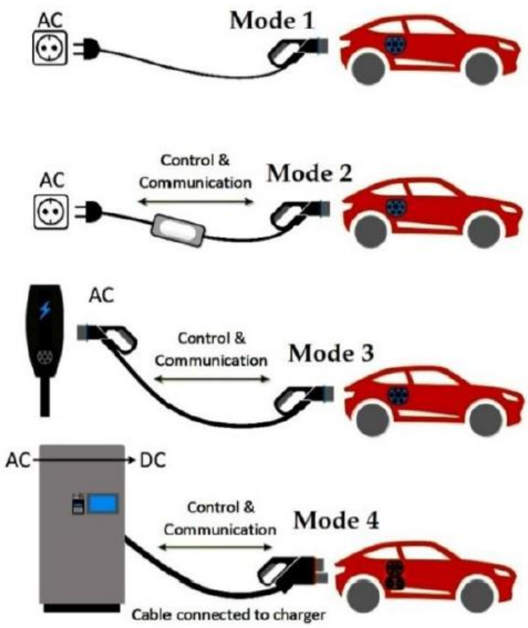

Figure 7: Typical vehicle charging modes[18]

Depending on the brand and type, the electric vehicles are typically able to receive power **up to 22 kW** using Mode 2 and 3 (AC charging) and **up to 350 kW** using Mode 4 (DC charging). AC charging uses an in-vehicle charger that converts AC current to DC, while DC charging bypasses the in-vehicle charger, and the current goes directly to the battery.

Mode 1 has no control box with a control/communication unit. It is considered unsafe and thus illegal to use in many countries.

Mode 2 typically uses a charging power ranging from **3.7 kW** (1-phase) to **11 kW** (3-phase) and can be used, e.g. for (a temporary) home charging or for opportunity charging in

[17] Skouras, T. A., Gkonis, P. K., Ilias, C. N., Trakadas, P., Tsampasis, E., & Zahariadis, T. (2019c). Electrical Vehicles: current state of the art, future challenges, and perspectives. *Clean Technologies*, 2(1), 1–16. https://doi.org/10.3390/cleantechnol2010001

[18] Skouras, T. A., Gkonis, P. K., Ilias, C. N., Trakadas, P., Tsampasis, E., & Zahariadis, T. (2019). Electrical Vehicles: current state of the art, future challenges, and perspectives. *Clean Technologies*, *2*(1), 1–16. https://doi.org/10.3390/cleantechnol2010001, page 6

a destination where no wall box (Mode 3) is installed. The 1-phase portable charger – see Figure 8- is often provided by the car manufacturer with a new car, which can be plugged into a standard home socket.

Figure 8: Mode 2: standard (1-phase) charging cable – 1x16 A (max 3.6 kW)[19]

The 3-phase charging requires a 3-phase charging cable – see **Figure 9** and a 3-phase inlet.

Figure 9: Mode 2 - 3phase charging cable 3x16 A (max. 11 kW)[20]

[19] WATT is Love. (2023, June 29). Besen EV portable charge (3,7kW) - WATT is Love. *WATT Is Love*. https://wattislove.com/en/ev-charging/besen-ev-portable-charger-3_7kw/

[20] Chytrý přenosný Wallbox EcoVolter (Typ 2 – 3x16A / 11kW) – *Nabij elektromobil*. (n.d.). https://www.nabijelektromobil.cz/product/prenosny-nabijeci-kabel-smart-typ-2-3x16a-

On the other side of the cable is a Type 2 (Mennekes) plug. It takes many hours to charge a vehicle with a bigger battery with a capacity of 80 kW or 100 or more kWh, so Mode 3 is much more suitable, also for safety reasons, for home charging.

Mode 3 – usually provides a charging power ranging from **3.7 kW to 22 kW** (or even 40 kW). It involves a charging station permanently connected to the ground or a wallbox mounted to a house. The charging station can be equipped with a cable with a male and female connector (Type 2 - Mennekes) on both sides – see picture **Figure 10** - or, in the case of public charging stations, the driver can use his cable; the manufacturer often provides the Mennekes cable with the vehicle.

Figure 10: Mode 3 charging cable[21]

Mode 4 – typically uses a DC charging station with a charging power of up to 350 kW. Some variants of CCS chargers can reportedly exceed this limit, reaching 500 kW or more. The charging cable is permanently connected to the charging stations. In Europe, it usually has a charging cable with two connectors – CCS 2 used by most European car manufacturers and sometimes also ChAdeMO. This example can be seen in **Figure 11**.

[21] *PHOENIX CONTACT* nabíjecí kabel TYP2 | 32A | 3fáze | 22kW |. (n.d.). https://www.evexpert.cz/p/315/phoenix-contact-nabijeci-kabel-typ2-typ2-32a-3faze?gclid=CjwKCAjww7KmBhAyEiwA5-PUSgbLVhrCAXEQfOHdLg6ROjUtq75HTrV6WybNE79UZqiUtVPKrf9eQRoCUPgQAvD_Bw

Figure 11: DC charging station[22]

Charging locations

It is estimated that around **80%** of all charging sessions occur at private premises at home or work (slow charging) and around **20%** at public charging points. An example of various possible charging opportunities is shown in **Figure 12**.

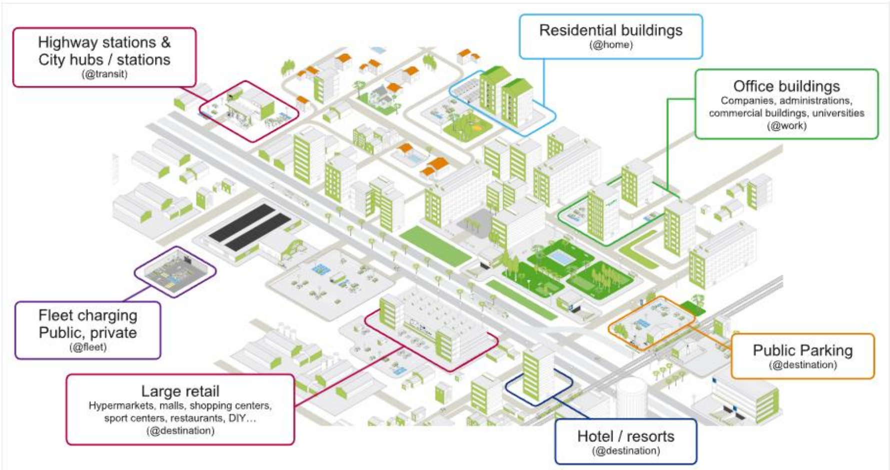

Figure 12: Examples of charging locations[23]

[22] ABB powers e-mobility with launch of first 350 kW high power car charger. (2018, April 24). *News*. https://new.abb.com/news/detail/4439/abb-powers-e-mobility-with-launch-of-first-350-kw-high-power-car-charger

[23] Electric Vehicle and EV charging fundamentals - Electrical Installation Guide. (n.d.). https://www.electrical-installation.org/enwiki/Electric_Vehicle_and_EV_charging_fundamentals

Charging can take place outside or inside buildings. Supported by the EPBD directive (see above), increasing numbers of EVs are expected to be charged inside garages of larger buildings, be it residential, administrative or other types of **buildings**. Installation of charging points and relevant safety measures, such as electronic fire alarms or sprinklers, depending on the safety regulations of the individual EU countries (the topic is not regulated at the EU level yet), will be required.

- **Non-public charging – home charging**

An electric vehicle can be charged outside or inside a house – see **Figure 13** using electricity from a grid or a **photovoltaic system**, often combined with **battery energy storage**. The energy gained from photovoltaics can be distributed according to customer needs to the vehicle or home devices, such as heating, lighting, and water heating.

Figure 13: Home charging of an EV[24]

So-called **"smart charging,"** as seen in Figure 14, optimises vehicle charging - using time slots outside the peak hours can help reduce the load on the electricity network and costs. Such a solution can avoid overloading of the network and even blackouts when people come home from work and start to charge all at the same time - typically in the evening hours.

[24] Searching for an electric vehicle charger? Find it at Wallbox chargers. (n.d.-b). *Wallbox USA Inc.* https://wallbox.com/en_us

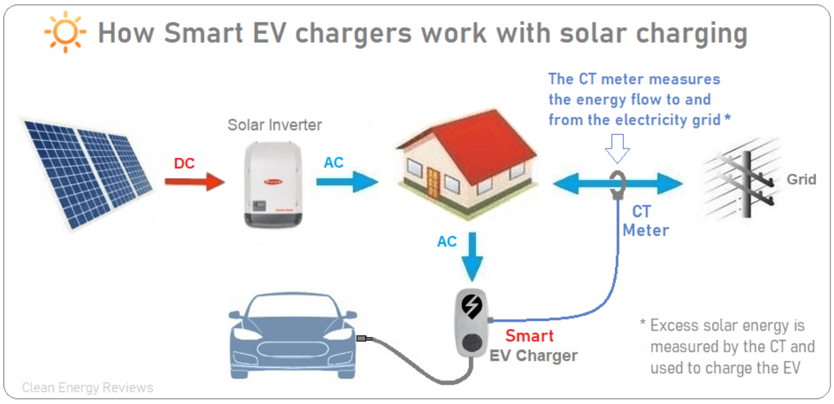

Figure 14: Visualisation of a home charging system using photovoltaics[25]

- **Non-public charging – workplace charging**

Employers allow their commuting employees to charge at the workplace since, in many cases, the car stays there for eight or more hours. This situation is similar to overnight home charging and is also perfectly suitable for **slow AC charging**, which puts less load on the grid and does not cause as much battery degradation as DC charging.

Of course, having at least some fast DC charging stations at the employer and a more significant number of AC charging stations (wallboxes) might be the most convenient combination. An example of workplace charging can be seen in **Figure 15**.

Figure 15: Workplace charging[26]

[25] Svarc, J. (2023). Home Solar EV charging explained — Clean Energy Reviews. *CLEAN ENERGY REVIEWS*. https://www.cleanenergyreviews.info/blog/solar-ev-charging

[26] *Evannex*. (2021, August 6). Tell Your Boss It's Time For EV Charging Stations At Work. InsideEVs. https://insideevs.com/news/525033/electric-car-charging-at-workplace/

- **Public charging**

As shown in picture **Figure 12** "Examples of charging locations" above, public charging typically takes place on highway rest stops (fast and ultra-fast DC charging), in streets (slow or fast), residential areas, institutions, parking lots, shopping centres, tourist attractions such as skiing areas and other points of destination.

According to EAFO[27], there were 528,022 publicly accessible charging points (468,486 AC and 59,536 DC stations) in 2. Q 2023 in Europe in 2. Q 2023. According to ACEA, 6.8 million public charging points are required in the EU by 2030 for consumer-driven EV adoption in the PC segment, with a high share of AC slow charging and €144 bn EVCI investments. On average, up to 14,000 public charging points need to be installed per week - only ~2,000 were installed per week when ACEA published the study in March 2022.[28]

The concept of **charging hubs,** as seen in **Figure 16**, where many charging stations are located in a single area, is becoming popular among charging point operators and drivers who have better chances of finding an unoccupied charging spot.

Figure 16: A charging hub with a photovoltaic roof[29]

[27] Infrastructure | *European Alternative Fuels Observatory*. (n.d.). https://alternative-fuels-observatory.ec.europa.eu/transport-mode/road/european-union-eu27/infrastructure
[28] ACEA, Wind Europe, SolarPower Europe, & Eurelectric. (2022, March). Research Whitepaper: European EV Charging Infrastructure Masterplan. *www.acea.be*. Retrieved July 31, 2023, from https://www.acea.auto/files/Research-Whitepaper-A-European-EV-Charging-Infrastructure-Masterplan.pdf
[29] May, T. (2022, July 7). Europe's most powerful EV charging hub opens in Oxford | Future Transport-News. *Future Transport-News*. https://futuretransport-news.com/europes-most-powerful-ev-charging-hub-opens-in-oxford/

Battery storage supporting charging stations

There are several advantages to integrating battery storage with EV charging infrastructure. Battery storage systems offer a continuous and dependable power supply to EV chargers by supplying extra power as needed. This leads to quicker charging times and less stress on the grid during moments of high demand. Additionally, battery storage makes it possible to integrate renewable energy sources into the grid, lowers utility costs, eventually benefiting consumers, and offers a dependable backup power source in case of crises or grid failures. An example of a charging station with battery storage can be seen in **Figure 17**.

Figure 17:Charging stations with battery storage and photovoltaics by AGreatE[30]

The charging speed of electric vehicles has been gradually increasing. However, it still takes some time, which the drivers need to spend somehow. That is why Audi and other (premium) brands are considering building charging lounges where the drivers can spend their time while charging – see **Figure 18**.

[30] AGreatE Inc. (2022, June 22). PBC | PV BESS EV Charging Station Systems - Battery Storage | AGreatE. *AGreatE*. https://agreate.com/pbc-pv-bess-ev-charging/

Figure 18: Audi charging lounge in Nuremberg[31]

Among the most significant challenges, especially in Central and Eastern Europe, is ensuring charging within large (prefab) **housing estates**, where home charging is impossible and when many people are concentrated and vehicles are parked within a relatively limited area. There is often a scarcity of parking places already now. In such a situation, reserving dedicated parking places only for charging EVs might be difficult.

In some city areas, see **Figure 19**, charging from streetlights is being tested since they have a connection to the grid and are not in use during the day. Nevertheless, the connection to the grid needs to be strengthened in most cases.

Figure 19: A street light combined with an AC charging station[32]

[31] World first: start of the Audi charging hub as an urban quick-charging concept. (n.d.-b). *Audi MediaCenter*. https://www.audimediacenter.com/en/press-releases/world-first-start-of-the-audi-charging-hub-as-an-urban-quick-charging-concept-14454

[32] Čtk. (2016, November 28). Www.denik.cz. *Pražský Deník*. https://prazsky.denik.cz/zpravy_region/v-praze-jsou-prvni-tri-tzv-chytre-lampy-nabizeji-ruzne-sluzby-20161128.html

Wireless charging

As an alternative or complement to the standard way of charging by cable, wireless charging is being explored by several car and infrastructure manufacturers. The main advantage is customer comfort - handling the cable and dealing with the (un)plugging is unnecessary. Hyundai Genesis GV60 or the FAW HongQi E-HS9, BMW 530e hybrid sedan are among the first EV models with wireless charging functionality.

The global wireless charging market for electric vehicles is expected to reach USD 377 million in 2030 at a CAGR of 88.4% from 2020 – 2030. Wireless charging is among the enablers to facilitate the future autonomy of vehicles.

- **Static wireless charging**

During wireless EV charging, electromagnetic induction is used to transmit electrical current, a process that is also known as inductive charging, similar to wireless charging of a mobile phone. A magnetic coil in the charger sends current to a magnetic coil on the bottom part of the vehicle.[33]
According to some sources, wireless charging can operate with an 88-93% efficiency, comparable to home charging by a Mode 2 wallbox or charging cable. One of the most critical conditions for effective charging is the exact positioning of the vehicle to ensure the proximity of the coils. Examples of wireless charging are shown in **Figure 20**.

[33] Charging Summit, E. (2022, December 22). Everything you need to know about wireless EV charging - EV. . . *EV Charging Summit Blog*. https://evchargingsummit.com/blog/everything-you-need-to-know-about-wireless-ev-charging/

Figure 20: Visualisation of wireless charging: Example A[34] and Example B[35]

- **Dynamic wireless charging**

Vehicles can also be charged while moving, requiring a specific infrastructure where the coils are placed underneath the road surface. This idea is being piloted by electric trucks on a selected part of roads in Gotland in Sweden. The efficiency is higher at slower speeds (e. g., in a traffic jam) where the charging power can reach 20-50 kW. An example of dynamic wireless charging can be seen in Figure 21.

Figure 21: Wireless charging solutions by Israeli start-up Electreon on the right and piloting of wireless dynamic charging - coils underneath the road in Gotland on the left[36]

Battery swapping

Battery swapping is another alternative to the standard way of charging a vehicle by cable. Chinese EV producer NIO, for example, aims to have over 4,000 swap battery stations worldwide by 2025. It has built over 1,300 swapping stations in China since 2018 and plans to

[34] Evatran. (n.d.). Why get wireless EV charging? | Plugless. *Plugls Power*. https://www.pluglesspower.com/learn-about-plugless-2/

[35] Science Scout. (2021, June 14). From wireless to dynamic electric vehicle charging: The evolution of Qualcomm Halo [Video]. *YouTube*. https://www.youtube.com/watch?v=UJaLjD7On-k

[36] Carscoops. (2022, December 23). Wireless Electric Vehicle Charging On The Move Is Becoming A Reality [Video]. *YouTube*. https://www.youtube.com/watch?v=gVLwLQgo66o

add another 1,000 in 2023.[37] It has started developing a battery-swapping infrastructure in Europe. NIO has several battery-swapping stations in Europe, Norway, Sweden, Germany and Denmark. The swapping stations can store and charge up to 13 battery packs.

The battery exchange is done automatically and takes around **5 minutes**, a significant advantage compared to standard fast or ultra-fast charging. The empty battery pack is removed from the vehicle and replaced by a charged one. The new generation of swapping stations shall store up to 22 battery packs and support the 800 V architecture.[38] Electric vehicles by NIO available in Europe have either 75 or 100 kWh capacity; another model with a 150 kWh solid-state battery has been announced. Besides battery swapping, NIO vehicle batteries can also be charged using standard charging by a cable. An example of this swapping station can be seen in **Figure 22**.

Figure 22: A battery swapping station by Nio[39]

The battery swapping concept seems very interesting, as the time needed to have the vehicle charged is comparable to the fuelling of an ICE vehicle. Nevertheless, this market is still niche, as leading European car manufacturers have not adopted the battery-swapping concept. The business case and viability remain to be seen.

[37] Writer, S. (2023, March 28). Chinese EV startup Nio to install 1,000 battery swap stations. *Nikkei Asia*. https://asia.nikkei.com/Spotlight/Electric-cars-in-China/Chinese-EV-startup-Nio-to-install-1-000-battery-swap-stations

[38] Princewill, H. (2022, December 22). NIO to Launch 3rd-Generation Battery Swap Station On December 24. *CarNewsChina.com*. https://carnewschina.com/2022/12/21/nio-to-launch-3rd-generation-battery-swap-station-on-december-24/

[39] Writer, S. (2023, March 28). Chinese EV startup Nio to install 1,000 battery swap stations. *Nikkei Asia.* https://asia.nikkei.com/Spotlight/Electric-cars-in-China/Chinese-EV-startup-Nio-to-install-1-000-battery-swap-stations

Innovative services and concepts relevant to EV charging (selection)

- **Vehicle-to-vehicle recharging (VVR)**

A concept related to charging a moving vehicle from another vehicle is referred to as vehicle-to-vehicle recharging (VVR). The aim is to charge the battery without getting off the route. The EV would request such a service from a designated charger vehicle on demand and receive electric power wirelessly while en route. The vehicle providing energy via wireless power transfer (WPT) would need to be semi-autonomous to engage/disengage during a trip.[40]

- **Vehicle to everything (V2X)**

Electric vehicles can not only take power from the grid, but some models (such as Nissan e-NV200, Nissan LEAF, Mitsubishi Outlander PHEV, Mitsubishi Eclipse Cross PHEV, some Hyundai Ioniq 5 variants, Kia EV9 and others) and charging stations can also put the energy back into the electricity network in a concept named **Vehicle2Grid**, V2G.

Having many V2G-compatible vehicles connected to a grid via AC charging stations can have several advantages in the future as it would help integrate renewal energy, enable peak shaving and support the overall **balancing of the grid**. Such a solution would reduce the need to invest in many large battery storages, otherwise needed.

Furthermore, vehicles with bi-directional power flow can be used as energy storage to provide energy, e.g. for a building (**Vehicle2Home**, V2H) or to charge an external device, such as power tools or camping equipment (**Vehicle2Load**, V2L).

Nevertheless, the increased degradation of the vehicle's battery is among the most significant challenges to be overcome, possibly with technological advancements in battery chemistry and battery management systems.

[40] O. N. Nezamuddin, C. L. Nicholas and E. C. d. Santos, "The Problem of Electric Vehicle Charging: State-of-the-Art and an Innovative Solution," in *IEEE Transactions on Intelligent Transportation Systems*, vol. 23, no. 5, pp. 4663-4673, May 2022, doi: 10.1109/TITS.2020.3048728.

- **Fleet management**

Software and other companies are developing solutions supporting fleet management to help handle and optimise larger fleets of EVs in company fleets and their charging and servicing.

- **Payments**

Innovative solutions are being developed for paying and invoicing for charging services, often as a part of the fleet management services mentioned above. The administration and facilitation of international charging roaming, where a vehicle registered in one country charges in another, is exceedingly complex.

Charging becomes easier with vehicles and charging stations with the **"Plug and charge"** functionality. The driver only plugs the cable in, and the vehicle identifies itself to the charging station, so there is no need to identify the driver with an RFDI chip or a credit card before the charging session can start.

- **Emergency and portable charging solutions**

No matter how well EV drivers plan their routes, sometimes they might end up with an empty battery without a charging station nearby. In such a situation, the drivers can use the help of another EV with the V2L functionality, as mentioned in the **V2X chapter**. They can also use portable energy storage or dedicated services providing emergency mobile charging assistance if available in the specific area, as shown in **Figure 23**.

Figure 23: Mobile charger by Quanta Technology[41]

[41] *Mobile EV charger and Tester - Quanta Technology*. (2023, February 6). *Quanta Technology*. https://quanta-technology.com/technology-integration-implementation/mobile-ev-charger-and-tester/

- **Robotic charging**

Plugging and unplugging the charging cable is relatively easy; however, dealing with the cables might be difficult particularly for women or the elderly. This might be the case, especially for premium vehicles charging at ultra-fast charging stations whose cables are thick enough to handle high power and need cable cooling with water, making the cables even heavier.

Considering customer comfort, innovative companies and research centres have been exploring ways to make the plugging and unplugging automatic. Robotic arms that can plug and unplug the cable are being tested and might become standard equipment for some (premium) charging stations in the future. For example, Hyundai has introduced the concept of a charging robotic arm, as shown in **Figure 24**.

Figure 24: Robotic arm by Hyundai[42]

As shown in **Figure 25**, Volkswagen Group came up with the idea of an automatic **mobile charging robot**. Upon a driver's request in an application, the robot finds the car in a parking lot and charges it using a movable module with batteries it carries behind. Once the charging of the EV is finished, the robot moves the battery and itself to a dock to recharge.

[42] Hyundai Motor Group. (2022, July 27). EV Auto Charging Robot | Hyundai Motor Group | Robotics Lab [Video]. *YouTube*. https://www.youtube.com/watch?v=lGAPtgvUia8

Figure 25: Automatic mobile charging robot by Volkswagen Group[43]

2.3 JOB, ROLES AND SKILLS

Numerous new jobs will be created to provide charging solutions for the growing fleet of electric vehicles and to fulfil the **AFIR, EPBD** and other EU regulatory targets concerning public charging infrastructure and charging infrastructure in buildings. **Planning, designing, installing, upgrading** and **maintaining** the existing and upcoming charging stations and their connection to the grid, photovoltaics, or battery energy storage systems will require much effort, investment and a qualified workforce.

Here are **examples of job roles and requirements** concerning skills and knowledge sought by companies and research centres in job advertisements. Some of these examples are from the US, and they mainly concern R&D and charging infrastructure rollout:

High Power Vehicle Charging Infrastructure Postdoctoral Research Associate

- Ph.D. in in Electrical Engineering (mechanical, automotive engeneering, or computer science).
- Knowledge of electric vehicle service equipment (EVSE) and EV technology, expertise in experimental design, data collection, programming, analysis, and testing.

[43] YOUCAR. (2020, December 28). *Volkswagen Mobile charging robot for electric cars* [Video]. *YouTube.*

Electric Vehicle Charging Hardware Systems Researcher

- Knowledge of electric vehicle technologies, such as high voltage batteries, inverters, and chargers; grid and electric vehicle supply equipment (EVSE), communication networks for integrated EV-Grid operation.
- Familiarity with low-voltage (<600V) electrical infrastructure components, design, and protection practices.
- Experience with digital real-time simulators, electrical system simulation programs
- Understanding of electric vehicle-related interface and communications standards
- Experience on projects using smart grid controls interface systems.
- Knowledge of utility-related standards.
- Experience with hardware testing and/or prototype system development.

Senior Charging Infrastructure Engineer

- Bachelor or higher degree in Electrical Engineering.
- Compliance, and classifications, design standards and guidelines.

Senior Reliability Engineer - High-Power EV Charging Hardware

- Relevant PhD or Master's degree and work experience.
- Experience with design, manufacturing, and/or deployment of outdoor-rated electronics used in communications, control, and/or power conversion.
- Familiarity with AC (<600V) and/or DC (<1250 V) electrical infrastructure components, design, and protection practices.

Senior Hardware Engineer

- Bachelors degree in Electrical Engineering or equivalent work experience.
- Experience in developing hardware for production products.
- Experience with test equipment, including oscilloscopes, logic analysers.
- Expertise in testing and troubleshooting electronic systems.
- Experience with power electronics, AC power systems.

Electric Vehicle Charging Technician

- An electrician or electrical repair experience or electric vehicle charging repair experience.
- Computer skills.

EV charging expert

- Bachelor's or master's degree plus product support or engineering experience
- Experience with and knowledge of working with utilities, solar installations, electrical contractors, getting permits, EV knowledge, working with interoperability between vehicle and charger
- Experience with site assessments to determine power requirements and evaluate charger locations, EV charger site design

3 Trucks and Buses

3.1 BACKGROUND

The EU CO_2 emission reduction goals and ways to achieve them are summarised in the "Fit for 55" package. It includes several initiatives to increase the ambition of the reduction targets, also in the transport sector.

3.1.1 EU emission regulation

The EU introduced emission targets for HDV (heavy-duty vehicles) – heavy lorries and tractors - in 2019 (EU Regulation 2019/1242). Their CO_2 emissions should decrease **by 15% in 2025 and 30% by 2030**. In 2023, the EU Commission proposed a revision of the targets to enlarge the scope to include urban buses, coaches, trailers and other types of lorries and make the targets for most of the types of HDVs stricter: **by 45% in 2030, 65% in 2035 and 90% in 2040**. According to the proposal, all newly registered city buses shall be emission-free (meaning battery electric or fuel cell) from 2030.

3.1.2 AFIR

To achieve the zero emissions goal set in the Fit for 55 package and help enable the expansion of e-mobility, the EU has approved AFIR (Alternative Fuels Infrastructure Regulation), which introduces, among others, compulsory density and output of public chargers (and hydrogen refuelling stations) for HDVs across Europe, leading to at least public 11,000 charging stations in 2030.[44]

- Core highways within TEN-T network: charging nod every 120 km or 15% coverage with a minimum of one charger with power 350 kW and a minimum of 1,400 kW per nod in 2025, charging nod every 120 km or 50% coverage with 2,800 kW per nod with minimum one 350 kW charger in 2027 and 3,600 kW nod every 60 km with minimum two 350 kW chargers in 2030;
- Secondary highways within TEN-T network: charging nod every 120 km or 15% coverage with a minimum of one charger with power 350 kW and a minimum of 1,400 kW per nod in 2025, charging nod every 120 km or 50% coverage with 1,400 kW per nod with minimum one 350 kW charger in 2027 and 1,500 kW nod every 100 km with minimum one 350 kW chargers in 2030;

[44] European Union Alternative Fuel Infrastructure Regulation (AFIR). (2023, April). *The International Council on Clean Transportation*. https://theicct.org/publication/afir-eu-april2023/

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- Urban charging nods: minimum charging power 150 kW per charger with a minimum of 900 kW; the minimum is 6x150 kW chargers per nod in 2025 and 1,800 kW, the minimum is 12x150 kW chargers in 2030;
- Secured truck parking lots: at least two 100 kW chargers in 2025 and four 400 kW charges in 2030;

3.1.3 Sales of electric trucks and buses

In 2021, China was the most significant player in zero-emission HDVs, with 91.7% of all sold vehicles. Europe came second with only 4.2%. Nevertheless, the European market is growing fast, as you can see in **Figure 26.** The most rapidly growing segments are electric buses and trucks with GVW (Gross vehicle weight) between 3.5 t and 12 t, being mostly sold in Germany and France.

The average battery capacity in heavy trucks was 288 kWh, while buses had an average battery size of 310 kWh. Light and medium trucks had a lower average battery capacity of 76 kWh.

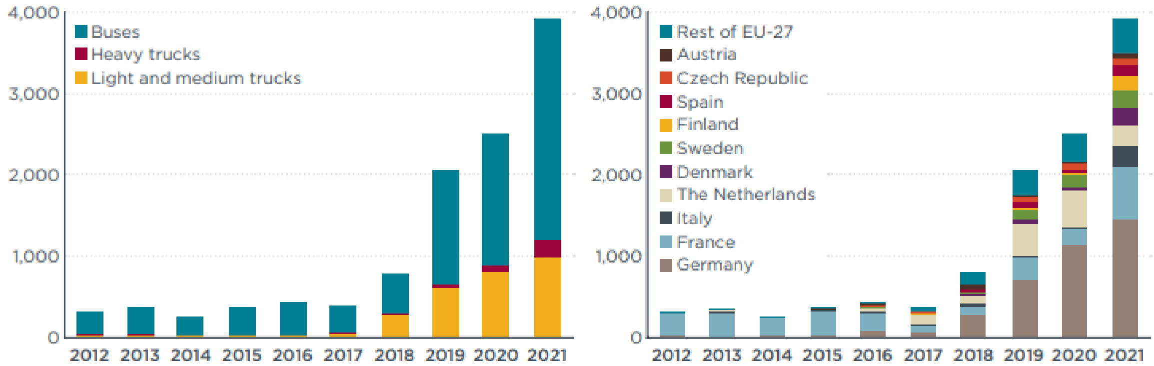

Figure 26: Zero-emission HDV sales in Europe[45]

[45] *Race to zero: How manufacturers are positioned for zero-emission commercial trucks and buses in Europe - International Council on Clean Transportation*. (2022, January 21). International Council on Clean Transportation. https://theicct.org/publication/race-to-zero-ze-hdv-eu-dec21/

3.2 TYPES OF CHARGING

3.2.1 ELECTRIC BUSES and their operation

The type of operation, length and schedule of the routes, significantly impact the type and power of charging. While urban, local and regional transport seems feasible, the most challenging for electric buses are long-distance and international rides.

Urban

Urban buses travel shorter distances within cities and nearby areas and can have a smaller battery capacity. Charging can be done using overnight charging in the depots or/and via pantographs at the bus stop when people get out and on the bus. The range of these buses is approximately 50-200 km (equivalent to a battery capacity of approximately 100-300 kWh)[46].

National

Buses operating on longer routes inside a country need a bigger battery capacity. Charging can be done overnight in depots, during the ride at stations, during breaks and at the final destination, using a combination of cables and pantographs. The range of these buses is approximately 100-400 km (equivalent to a battery capacity of approximately 200-500 kWh)[46].

International

Buses travelling long distances across two or multiple countries will require significant battery capacity, similar to trucks. Ultra-fast charging with power exceeding 1 MW using cabel or pantographs will be used during the ride at scheduled stops/compulsory driver rests (a driver must have a break every 4.5 hours with a minimum length of 45 minutes – often this is addressed with two drivers being present in a bus), and, potentially, using slower charging at the start and final destinations. The range of these buses is approximately 300-800 km (equivalent to a battery capacity of approximately 500-800 kWh)[46].

3.2.2 ELECTRIC TRUCKS and their operation

Like battery electric buses, the type of operation, length of the daily routes, and schedule will significantly impact electric trucks' charging type and power. Similar to other commercial

[46] Estimate of the author team - range and battery capacity depend strongly on the number of passengers and the route profile.

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vehicles, trucks are intended to be used as much as possible, ideally 24/7, to maximise their utilisation and profitability of the transport services provided. Again, long-hauls and international transportation will be among the most significant challenges.

The battery-electric truck (BET) market is still in the early stage (only about 0.1% of trucks being battery-electric[3]). Most of the BETs were sold in China and belonged to then the lighter side of the category, weighing between 3.5 and 8 tons. Nevertheless, the segment is expected to grow due to the implementation of sales phase-out targets for combustion engine trucks by the EU, governments and manufacturers, introducing more truck models, and expanding production capacity.[47]

Battery Heavy Duty Vehicles (BHDVs) battery technology is somewhat similar to Battery Electric Vehicles (BEVs). BHDVs use the same kind of batteries as passenger BEVs but on a larger scale. Passenger cars typically have one big battery pack at the bottom. In the case of BHDVs, several battery packs are connected to the truck or bus platform. Further information on this topic can be found in ALBATTS project **Desk Research 3**.[48] As discussed earlier in this report, technological improvements in the battery chemistry, technology and Battery Management System (to avoid or minimise battery degradation due to fast and ultrafast charging, for example) will be needed.

Urban

These trucks are typically used for short distances within cities and nearby areas. Typical use cases are supplying stores, delivering goods, waste collection and other urban logistics. Slower overnight charging in the depots by cables (or pantographs) can be expected, while fast charging (at depots or public charging stations) is expected to be used only occasionally. The range of these trucks is approximately 50-200 km (equivalent to a battery capacity of approximately 100-300 kWh)[49].

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[47] Bernard, M. R., Tankou, A., Cui, & Ragon, P.-L. (2022). Charging solutions for battery-electric trucks. *International Council on Clean Transport*. https://theicct.org/wp-content/uploads/2022/12/charging-infrastructure-trucks-zeva-dec22.pdf

[48] D5.7 Desk research and data analysis for sub-sector IMBA - Release 3. (2022, August). *Albatts*. https://www.project-albatts.eu/Media/Publications/67/Publications_67_20230602_125248.pdf

[49] Estimate of the author team - range and battery capacity depend strongly on the amount of cargo and the route profile.

National

These trucks are typically used for medium and longer distances between the cities and regions inside the country. They require larger batteries, higher towing capacity and are primarily intended for highway use. Fast and ultra-fast charging are likely to be the preferred options, combined with overnight charging and possibly also using (ultra)fast charging when uploading and unloading the cargo in logistic centres and at customers. The range of these trucks is approximately 250-500 km (equivalent to a battery capacity of approximately 300-500 kWh)[49].

International

Trucks in international transport travel very long distances between countries, often crossing numerous countries. These trucks need to have the largest battery packs to be capable of reaching long distances. Charging will be ultra-fast, with charging power exceeding 1 MW, fast charging the loading/unloading goods, during compulsory driver rests (a driver must have a break every 4.5 hours with a minimum length of 45 minutes), and potentially charging in depots during more extended breaks needed for vehicle maintenance, for example.

For international transport, trucks with a range of more than 400 km per charge and more, ideally sustained during most of their lifespan, will be required. On the other hand, a 400 km range might be enough with the **MegaWatt Charging System (MCS)**. To explain, MCS is a kind of charging connector developed by CharIN. This connector is mainly designed for large and medium heavy-duty vehicles. The maximum charging power of this connector is **3.75 MW** (3,000 A at 1,250 V DC)[50]. If we consider that in all EU countries, trucks and busses are limited to speed between 80 and 100 km/h and the driver must have a break every 4.5 hours with a minimum length of 45 minutes, so the break is long enough for charging the vehicles with battery capacity about 600 kWh which should be enough for that range. In general, the range of international trucks can range from 300-800 km (equivalent to a battery capacity of approximately 500-1,000 kWh)[49].

[50] CharIN Whitepaper Megawatt Charging System (MCS). (2022, November 24). https://www.charin.global/media/pages/technology/knowledge-base/c708ba3361-1670238823/whitepaper_megawatt_charging_system_1.0.pdf

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3.2.3 Wired stationary charging

In the case of wired charging, there are the same categories as in the case of electric vehicles. However, in the case of the BETs, level 3 and level 4 charging is assumed, as the lower levels do not provide enough power to charge large batteries.

The first, mostly lighter, electric truck models primarily relied on charging infrastructure designed for light-duty vehicles. However, more robust standards are now ready for commercialisation, offering opportunities for new applications. Wired stationary charging options vary, ranging from AC slow charging with a power of up to 43 kilowatts (kW) to DC fast charging with a power of up to 550 kW.

Higher power standards for trucks are being developed, such as China's ChaoJi, which is expected to deliver up to 900 kW, and the previously mentioned CharIN MegaWatt Charging System in Europe and North America, which could provide a charging capacity of **up to 3.75 MW**. The port and cable for MCS are shown in **Figure 27.** Currently, multiple charging standards are being utilised, and it is crucial to harmonise hardware and software standards to avoid multiple standards and enable economies of scale.[47]

Figure 27: Wired charging of electric truck[51] on the left and port and cable for MCS[52]

[51] Scharfsinn. (n.d.). *Electric truck batteries are charged from the charging station. iStock*. https://www.istockphoto.com/cs/fotografie/elektrick%C3%BD-n%C3%A1kladn%C3%AD-automobil-s-nab%C3%ADjec%C3%AD-stanic%C3%AD-gm1343828231-422397024

[52] Morris, C. (2022, June 21). *CharIN officially launches Megawatt Charging System for commercial EVs - Charged EVs*. Charged EVs. https://chargedevs.com/newswire/charin-officially-launches-megawatt-charging-system-for-commercial-evs/

Wired stationary charging is currently the predominant technology, but there are ongoing efforts to explore alternative solutions offering greater charging flexibility. Wired stationary chargers can be categorised based on their intended use[47]:

- overnight charging at private depots or public rest areas along highways (up to 100 kW),
- opportunity fast charging at destinations or along highways (up to 350 kW),
- opportunity ultra-fast public charging (above 1 MW).

The most common charging types, their typical locations, and estimated charging times are presented in **Table 1** below.[47]

Table 1: Summary of wired stationary charging types[47]

Charging type	Nominal power output	Charging standard	Location	Estimated charging times
Overnight	<43 kW AC 50-150 kW DC	Combined Charging System (CCS) or CHAdeMO	Depot, public parking space	8 hours
Opportunity fast	150-350 kW DC[53]		The public charging station, depot, destination location	0.5 hours
Opportunity ultra-fast	750 kW-3.75 MW DC	Megawatt Charging System (MCS) or ChaoJI	Public charging stations, depot, destination location	0.5 hours

3.2.4 Alternative charging solutions

In addition to wired charging, there are three emerging alternatives being tested[47]:

- battery **swapping**,
- overhead **pantograph** charging,

[53] Some versions of CCS chargers have been reported to reach 500 kW or more

- **wireless** charging.

These technologies can reduce charging time for battery-electric trucks and lower purchase costs and weight by allowing for smaller battery sizes. However, the deployment of these technologies is impacted by political, technical and business challenges.[47]

3.2.5 Battery swapping

Swappable battery technology could significantly reduce the time it takes to recharge an electric vehicle, whether a passenger or a heavy-duty EV. However, there are several obstacles to successful implementation. The lack of standardisation leads to using batteries of different shapes and sizes. The connection of batteries and their location in the vehicle also often varies. This results in the impossibility of using any EV model with any swapping station.

Another problem is the high investment costs of building swap stations. Batteries typically account for 30-40% of the total investment cost of building a swap station. The total cost of building such a station is approximately 1.5M USD, which is much more than the cost of building a conventional wired charging station.[47]

Replaceable battery technology is being promoted in China especially. Outside of China, battery-swapping technology is currently not very widespread. Under the Chinese business model, battery replacement is referred to as **"battery as a service" (BaaS).** Thus, transport companies pay only for the vehicle body (without batteries) when buying new electric trucks, significantly reducing the initial cost.[47]

For example, Sinopec's **swap station** can automatically change the battery in less than 3 minutes. The maximum capacity of this station is 168 services per day. The station contains a series of battery packs with a capacity of 282 kWh. Each battery pack can power the truck for approximately 140 km. The CO_2 reduction by this system is estimated at 3,550 tonnes per year. The swap station from Sinopec is shown in **Figure 28** on the left.[54]

[54] Zhang/CnEVPost, P. (2022b, July 20). Sinopec's first swap station for heavy trucks goes into operation. *CnEVPost*. https://cnevpost.com/2022/07/20/sinopecs-first-swap-station-for-heavy-trucks-goes-into-operation/

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Another example is a **mobile battery swap vehicle** by SPIC (State Power Investment Corporation Limited). In addition, SPIC has developed mobile battery exchange vehicles, pre-assembled charging boxes, mobile battery distribution vehicles and modular battery exchange skid stations. An example of SPIC's mobile battery exchange station is shown in **Figure 28** on the right. These products complement fixed charging stations and address constraints related to power capacity and land scarcity. Flexible deployment plans to adapt to specific business conditions, increasing the flexibility of the layout of the battery exchange station network.[55]

Figure 28: Sinopec's fixed battery swap station on the left[54] and SPIC's mobile battery swap vehicle (trailer) on the right[55]

SPIC has teamed up with major heavy truck OEMs (Original Equipment Manufacturers) at home and abroad to conduct research and development. So far, it has led the research and development of more than 42 battery-spawning electric heavy truck models. The company says that these products meet the needs of electrification applications in **short-distance** transportation such as ports, steel mills, mining areas, agriculture, cement mixing and many others.[55]

3.2.6 Charging with trolleys, pantographs

Heavy-duty vehicles and buses should be operated with as little loss of time as possible. Charging systems with plug connectors are now reaching their limits, since the amount of

55 Here Y. N. (n.d.). *Battery-Swap Electric Heavy-Duty Truck: A Low Carbon Transportation Like No Other - ESCI KSP*. Copyright Your Name Here 2011. All Rights Reserved. https://www.esci-ksp.org/archives/project/battery-swap-electric-heavy-duty-truck-a-low-carbon-transportation-like-no-other

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power they can transmit is limited by wire gage and weight. Pantographic charging may be the solution.[56]

[56] Leserer, J. (2021, May). *Charging by Pantograph: Short Charging Break fo Electric Commercial Vehicles*. VECTOR. https://cdn.vector.com/cms/content/know-how/_technical-articles/Emobility_Pantograph_ElektronikAutomotive_202010_PressArticle_EN.pdf

Dynamic charging with overhead lines - trolleys

Charging with trolleys while driving combines the advantage of efficient energy supply when driving on main roads (mainly highways), smaller initial investment (smaller batteries in vehicles) and minimisation of time loss during charging. Thus, the effective ratio between electrified kilometres and battery size can be determined. In addition, this technology uses extensive experience in constructing pantographs and trolley lines used for electrified trains, trams and trolleybuses. Overhead lines can be built with minimal traffic restrictions compared to on-road wireless charging.[47]

Nevertheless, its widespread use would obviously require international consensus to adopt this technology, adopt relevant standards and, of course, considerable investments in the trolley infrastructure across the EU.

Static charging with pantograph

Pantographs are available in several versions, as shown in **Figure 29.**

	Conductive Charging	Roofmounted Pantograph	Inverted Pantograph	Horizontal Pantograph	Underbody Pantograph
Graphical Illustration					
Communication Channel	Control Pilot	Control Pilot	Wireless	Control Pilot / Wireless	Control Pilot / Wireless
Applicable Standard	IEC 61851 - ISO 15118	IEC 61851 - ISO 15118	IEC 61851 - OppCharge	IEC 61851 - ISO 15118 OppCharge	IEC 61851 - OppCharge
Required Space	Less	High	Medium	Medium	Less
Weight	Charging inlet without cable, approx. 1 kg	Roofmounted incl. mechanics, approx. 85 kg	Rails, roofmounted approx. 15 kg	System for charging arm approx. 20 kg	Underbody plate approx. 20 kg

Figure 29: Pantograph versions[56]

- **Roofmounted pantograph**

One of the most commonly used variants is the roof-mounted pantograph, which is technically the simplest to implement. The driver conveniently operates it, and it functions similarly to the most common Combined Charging System (CCS) standard plug during the charging process.[56]

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Roof-mounted pantographs are developed by SIEMENS, for example. An example of this pantograph is in **Figure 30**. This pantograph can be adjusted to parking distance for optimised contact with the charging unit[57]. Operation is ensured by a 4-pole connection system: DC+ and DC– for the power transfer; Physical earth (PE) as a common ground and Control Pilot (CP) for communication[56].

Figure 30: Example of roof-mounted pantograph: from SIEMENS[57] on the left and from SOLARIS[58] on the right

- **Inverted pantograph**

Another variant is an inverted pantograph, where the pantograph is integrated into the charging infrastructure. The vehicle is equipped with a fixed counter-piece called a contact rail in this configuration. When the vehicle needs to charge, it automatically activates the drive control of the fixed structure and starts the charging mechanism.[56]

For example, ABB offers pantographic charging, shown in **Figure 31**. This solution is designed as an inverted pantograph, according to **Figure 29**. The main advantage of this solution is the possibility of fast charging with a wide range of power levels. Another advantage is the robust design and the possibility of remote diagnostics, which ensures a long service life. It is also possible to charge different brands of buses, as the pantograph meets international standards and undergoes interoperability testing. The main features of this solution from ABB are

[57] *Simply reliable: On-board pantographs for eBuses*. (n.d.-b). siemens.com Global Website. https://www.siemens.com/global/en/products/energy/medium-voltage/solutions/emobility/charging-pantograph.html
[58] eCity powered by Solaris. (2021b, August 16). *Pantograph or plug-in? How to choose the right charging system*. eCity Powered by Solaris. https://ecity.solarisbus.com/en/knowledge-base/pantograph-plugin-charging-system

a voltage range of 150-850 V, a power range of 150-300-450-600 kW and a fully automated connection.[59]


Figure 31: Inverted pantograph charging solution from ABB: e-bus during charging on the left[59] and retracted pantograph on the right[60]

- **Horizontal Pantograph**

The third option is a horizontal pantograph, where the vehicle has a large oval opening. The charging arm of the infrastructure is inserted into this hole to provide a connection. Along with the similar communication through the charging point and the absence of a plug point, the key difference lies in the safety contact mechanism compared to traditional CCS plugs and the previously mentioned pantograph systems. To ensure a reliable connection between the charging station and the vehicle, the charging station applies a constant force to the vehicle via the charging arm, which ensures a secure connection and facilitates a successful charging process.[56]

- **Underbody Pantograph**

In addition, there is another method which involves charging the vehicle from below. In order to accommodate the limited mounting space inside the vehicle, the moving part retracts into

[59] *Pantograph down for electric buses. (n.d.). ABB. https://new.abb.com/ev-charging/products/pantograph-down?_gl=1*5abxvf*_ga*MTAzNDY0MTE1LjE2ODUyODYzMDY.*_ga_46ZFBRSZNM*MTY4NTI4NjMwNi4xLjAu MTY4NTI4NjMwNi42MC4wLjA.&_ga=2.168449697.1633889764.1685286306-103464115.1685286306*

[60] ABB EV Charging. (2017b, September 15). *ABB is charging up life quality in smart cities* [Video]. YouTube. https://www.youtube.com/watch?v=9RuMdOQwS78

the floor and extends upwards when a connection to the vehicle needs to be made. From the perspective of the charging vehicle, this technology essentially acts as a reverse pantograph.[56]

3.2.7 Wireless charging

- **Stationary wireless charging**

Wireless inductive charging uses charging pads built directly into the ground. The energy transfer is provided by a magnetic field passing through two coils. One coil is placed in the road (primary coil), while the other is placed on the undercarriage of the electric bus (secondary coil). An example of wireless charging for electric buses is shown in **Figure 32**. This system usually uses a lower power level than cable or pantograph charging (50-250 kW), which results in longer charging times.[61]

Figure 32: Model illustration of wireless charging on the left[62] and practical example of charging pad by Wave on the right[63]

Wireless bus charging can generally be divided into depot charging and occasional charging. For depot charging, it might be preferable to use wired charging due to its greater efficiency. On the other hand, occasional charging uses a short battery recharge during the day (during

[61] *Electric Bus Basics. (n.d.-b). US Department of Transportation. https://www.transportation.gov/rural/electric-vehicles/ev-toolkit/electric-bus-basics*

[62] *IPT® Charge Bus Brochure | Wireless Charging Technology | Bus-News*. (2020, December 2). Bus-News. https://bus-news.com/download/ipt-charge-technology-bus-brochure/

[63] May, T. (2023, April 14). *Twin Transit Orders Additional WAVE Wireless Chargers | Bus-News*. Bus-News. https://bus-news.com/twin-transit-orders-additional-wave-wireless-chargers/

bus operation). Thus, the batteries are partly recharged at short intervals (e. g. 5 - 15 minutes) while waiting at a bus stop or terminal.

One of the advantages of occasional wireless charging is the positive effect on battery life. Shallow, more frequent battery charging is considered more economical than deep charging and discharging since more frequent shallow charging during operation maintains the State of charge (SoC) between 45 - 75%. In addition, wireless charging does not achieve the same power level (C-rate) as wired charging, so there is no unnecessary heating of the battery by high current and thus no such degradation.

Another benefit of intermittent wireless charging is the ability to reduce the size of the battery pack and therefore reduce the initial investment in the electric bus. On the other hand, building the charging infrastructure is rather expensive.[64]

Wireless charging can be automated relatively easily, so there is no need for the driver to get out of the car and connect anything manually. In addition, for use in urban transport, it is possible to precisely position the charging points where the bus anyway has to stop.

- **Dynamic wireless charging**

Dynamic wireless charging, sometimes referred to as in-road charging, can be used for longer routes.[64] This dynamic charging allows the battery to be recharged without stopping. This technology is being explored for other types of transport, such as personal electric mobility and heavy-duty trucks.

However, dynamic charging has many limitations, such as the complexity of energy transfer across the roadway, the high initial costs of building in-road charging, ensuring charging compatibility across different vehicle brands, and addressing the safety impacts of radiation from high-energy wireless charging to humans and animals.[47]

[64] Siddiqi, S. (2022, November 30). Opportunity charging vs depot charging. *PARKING Reviev*. https://www.transportxtra.com/publications/parking-review/news/72712/opportunity-charging-vs-depot-charging/

3.3 JOB, ROLES AND SKILLS

Job roles and skills may vary depending on the organisation's specific requirements or the industry involved. As electric buses and trucks are expected to proliferate, the demand for professionals with expertise in EV charging and related areas is expected to increase. Continual learning, staying updated on emerging technologies and industry standards, and adapting to evolving EV charging infrastructure are essential for professionals in these roles. Some of the positions are listed below, along with the basic skills required.

Charging Infrastructure Technician/Installer:

- Knowledge of electrical systems and components, ability to install and maintain charging infrastructure, understanding of safety protocols, troubleshooting skills, and familiarity with relevant codes and standards.

Charging Station Network Operator:

- Management of charging station networks, monitoring and maintenance of charging infrastructure, software and technical skills for network operation and maintenance, customer support, data analysis and reporting.

Fleet Manager/Transportation Planner:

- Understanding of electric vehicle technology and charging infrastructure, knowledge of fleet management principles, ability to plan and optimise charging schedules and routes, data analysis for efficient fleet operations, and familiarity with energy management systems.

Electric Vehicle Technician/Mechanic:

- Knowledge of electric vehicle systems, including charging systems, batteries, and electric drivetrains, ability to diagnose and repair EV charging-related issues; understanding of safety protocols for high-voltage systems, proficiency in electrical troubleshooting.

Energy Management Specialist:

- Understanding of energy management principles, knowledge of charging infrastructure and its impact on grid integration and demand response, ability to analyse energy consumption patterns and optimise charging strategies, familiarity with smart charging technologies and energy storage systems.

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Electrical Engineer:

- Design and engineering of charging infrastructure, proficiency in electrical system design and calculations, knowledge of power distribution, charging protocols, and electrical safety standards, and ability to develop and implement charging solutions for specific applications.

Customer Support and Service:

- Strong communication and interpersonal skills, ability to provide technical support and guidance to EV users and fleet operators, knowledge of charging processes and equipment operation, problem-solving abilities, ability to address customer inquiries and resolve issues.

4 Motorbikes

4.1 BACKGROUND

As an alternative to the passenger car for commuting, urban short to medium-distance transportation or as a sport and leisure riding device, motorbikes are expected to play an increasingly important role in future mobility, especially in crowded areas. The use of motorcycles is an essential part of the "Cities Mission", one of the recently launched initiatives of the European Commission to tackle major challenges,[65] better known as the "15-minute cities" paradigm, which is being phased in about 100 European cities[66].

The electrification of motorbikes has the potential to help solve two of the most critical challenges: the **pollutant and CO_2 emissions** (that are less stringent compared to passenger cars emission standards) and the **noise emission** levels, which are in some countries bypassed by some ICE motorcyclists using after-sales retrofitting, making the motorcycles deliberately, just for fun, noisier. Electrification of motorcycles will help eliminate the problem.

Some national and local authorities have introduced incentive schemes for electric vehicles, which in some cases also include motorcycles. The battery packs' energy capacity and prices have improved consistently over the last years. The public charging network is picking up. All these factors contribute to the steady growth of the electric motorcycle market.

Electric Motorcycle registration volumes showed an upward trend in all important EU markets for motorcycles, respectively: Italy (11,399 units, **+82.9 %** year-on-year), France (10,372 units, **+126.2%),** Germany (9,445 units, **+166.7%),** Spain (8,664 units, +57.7%) and the UK (109,300 units, +1.9%)(**see Figure 33 and Figure 34** [67]).

[65] Press corner. (n.d.). *European Commission - European Commission*. https://ec.europa.eu/commission/presscorner/detail/en/ip_21_4747,

[66] Press corner. (n.d.-b). *European Commission - European Commission*. https://ec.europa.eu/commission/presscorner/detail/en/IP_22_2591

[67] Ordonez, M. (2023). Registrations of motorcycles and mopeds in key European markets broadly stable during 2022. *acem.eu*. https://acem.eu/acem-statistical-release-registrations-of-motorcycles-and-mopeds-in-key-european-markets-broadly-stable-during-2022, 16.06.2023

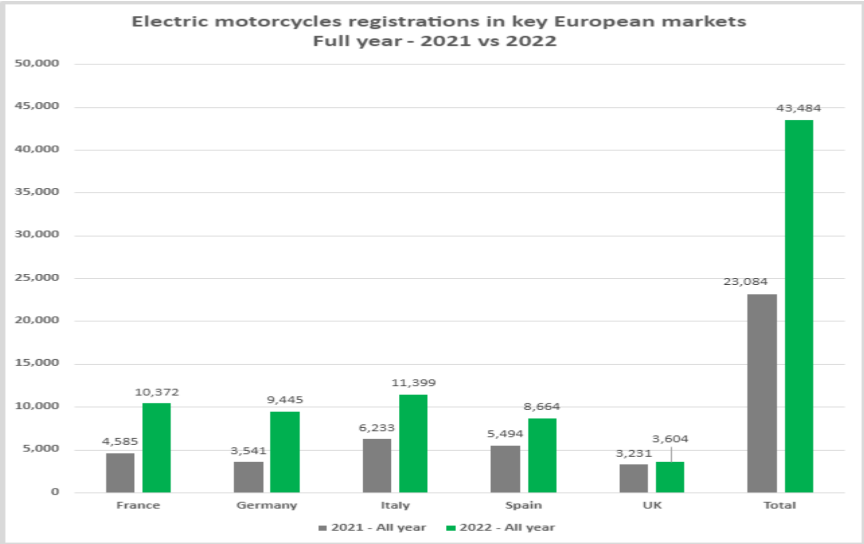

Figure 33: Electric Motorcycle registration[67]

	Jan - Dec 2020	Jan - Dec 2021	Jan - Dec 2022
Motorcycles (ICE + Electric)	880,763	949,480	950,437
Motorcycles (Electric)	18,007	23,084	43,484

Figure 34: Motorcycle registrations in the largest European markets[67]

It is anticipated[68] that global e-motorcycle sales will grow from roughly 1.1 million units in 2020 to 3.6 million by 2030 (**Figure 35**), at a compound annual growth rate of **14.4** percent.

According to a Comprehensive Report by Market Research Future (MRFR), the global electric motorcycles market is predicted to to have a value of around **USD 17.21 billion** by the end of 2030. In 2021, the electric motorcycle market was worth nearly USD 7.0 billion[69].

[68] Major motorcycle companies will electrify, eventually | *Greenbiz*. (n.d.). https://www.greenbiz.com/article/major-motorcycle-companies-will-electrify-eventually, 28.06.2023

[69] Future, M. R. (2023, May 2). Electric Motorcycle Market Projected to Reach USD 17.21 billion, with a CAGR of 11.90% by 2030 – Report by Market Research Future (MRFR). *GlobeNewswire News Room*. https://www.globenewswire.com/en/news-release/2023/05/02/2659345/0/en/Electric-Motorcycle-Market-Projected-to-Reach-USD-17-21-billion-with-a-CAGR-of-11-90-by-2030-Report-by-Market-Research-Future-MRFR.html, 29.05.2023

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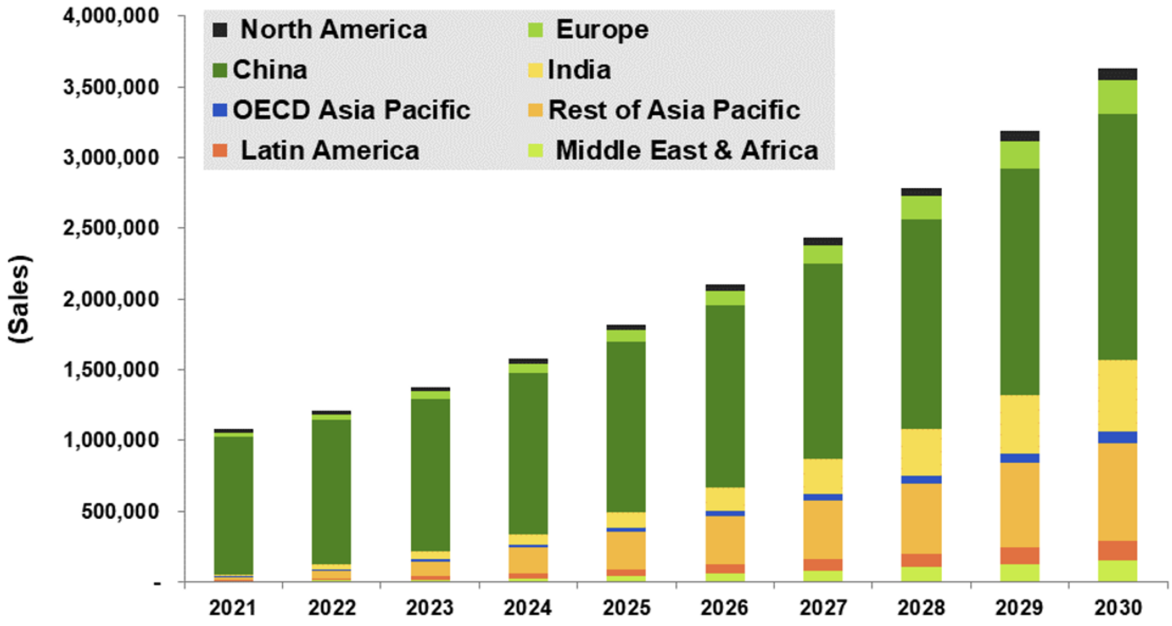

Figure 35: Annual sales of e-Motorcycles by regions and selected countries, world markets: 2021-2030[68]

Motorcycles are included in the L category vehicles, which comprise, among others, the following power-to-wheel vehicles[70]: L1e-A (powered cycles), L1e-B (mopeds), L2e (three-wheel mopeds), L5 (tricycles), L6e and L7e (quadricycles).

Regarding the **legislation** applicable in the field, electric motorbikes, except those with assistance up to 25 km/h and a maximum continuous rated power of 250 W, must comply with the European harmonised technical rules in **type-approval legislation**. Since January 2017, all new electric bikes subject to type-approval must comply with the rules laid down in Regulation 168/2013 and its delegated and implementing acts before they can be distributed in the European Union[71].

All electric motorcycles must also comply with the **Battery Directive** (2006/66/EC) requiring the collection and recycling of batteries, as batteries may contain metals such as zinc, copper,

[70] Table 1: L-category vehicles classification according Reg. 168 -Annex I. (n.d.). *ResearchGate*. https://www.researchgate.net/figure/L-category-vehicles-classification-according-Reg-168-Annex-I_tbl1_305403831,
[71] *EUR-Lex - 32013R0168 - EN - EUR-Lex*. (n.d.). https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32013R0168, 28.05.2023

manganese, lithium and nickel, which can present a risk to the environment and human health if they are incorrectly disposed of. [72]

Motorcycle batteries need to comply with battery **transportation regulations.** One of the major risks associated with transporting batteries and battery-powered equipment is the short-circuit of the battery due to the battery terminals coming into contact with other batteries, metal objects or conductive surfaces. Therefore, their transport is subject to strict rules, which have been internationally harmonised. Any Lithium-Ion battery over 100 Wh, which is the case of motorcycle batteries, is classified as Class 9 - miscellaneous dangerous goods under the dangerous goods regulations for transport by road (ADR)[73], by air (IATA & IACO) and by sea (IMDG).

The electric motorcycle market includes players such as:

- Energica Motor Company S.p.A. (Italy)
- Blacksmith Electric (India)
- Torkmotors (India)
- Electric Motion (France)
- Revolt Motors (India)
- Johammer e-mobility GmbH (Germany)
- LITO MOTORCYCLES (France)
- Husqvarna Motorcycles GmbH (Austria)
- TACITA SRL (Italy)
- Essence Motorcycles (France)
- Bell Custom Cycles (BCC) (US)
- Zero Motorcycles Inc. (US)
- Harley-Davidson Inc. (US)
- Razor USA LLC. (US)

[72] EUR-Lex - 02006L0066-20180704 - EN - EUR-Lex. (2018, July 4). https://eur-lex.europa.eu/eli/dir/2006/66/2018-07-04,

[73] ADR 2023 - Agreement concerning the International Carriage of Dangerous Goods by Road | *UNECE*. (n.d.). https://unece.org/transport/standards/transport/dangerous-goods/adr-2023-agreement-concerning-international-carriage,

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- Alta Motors (US).

4.2 TYPES OF CHARGING

The charging of the electric motorcycle is faster than in the case of passenger cars or light commercial vehicles, given that the batteries they use are much smaller (around 10-15% the size and capacity of those used by electric passenger cars), which requires substantially shorter charging sessions.

Electric motorcycles use the same standardised charger plugs as electric passenger cars and can be charged at home, work or public charging stations used by passenger cars, although not all motorcycles can use Mode 4 chargers (see **charging modes**). Only a limited number of brands and models can use the Mode 4 fast DC charging - LiveWire One[74] and any Energica[75] models, for example. Depending on how the electric motorcycle is used, charging with Mode 2 and 3 chargers (mostly at home) can often be sufficient.

Figure 36, Figure 37, and Figure 38 show common locations where motorbikes can recharge - at home or public charging stations for passenger electric vehicles.

Figure 36: Home charging using a common wall socket[76]

[74] LiveWire ONE electric motorcycle | *LiveWire*. (n.d.). https://www.livewire.com/livewire-one-electric-motorcycle, 25.05.2023
[75] Energica Motor Company S.p.A. (2023, March 27). Energica Motor Company – The italian electric motorcycle manufacturer. *Energica Motor Company*. https://www.energicamotor.com/us/, 23.05.2023
[76] Mik. (n.d.). *Arguments for Electric Vehicle Recharging Stations | V is for Voltage electric vehicle forum*. https://visforvoltage.org/forum/2911-arguments-electric-vehicle-recharging-stations

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Figure 37: Motorbike charging at a public station[77]

Figure 38: Motorbike charging at a public station[77]

4.3 JOB, ROLES AND SKILLS

- R&D – developing and designing batteries and other electric systems for e-motorbikes.
- Manufacturing – electric motor and battery pack assembly for e-motorbikes.
- Servicing – maintenance of electric motorbikes (motor and batteries), malfunction diagnosis, servicing or replacement of malfunctioning or end-of-life battery packs and refurbishing of the battery packs.
- Operation - assistance with charging.
- Disassembly - end-of-life e-motorbikes and battery packs.

[77] Chung, D. (2018). Where to Charge Electric Motorcycles? Motorcycle.com. https://www.motorcycle.com/mini-features/charge-electric-motorcycles.html, 13.06.2023

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- Thorough understanding of prototypes: hardware design, software development, EMC compliance, and functional testing.
- Embedded product development: in-vehicle and outside-vehicle deployment of various data protocols.
- Electrical power line installation and maintenance.
- Equipment testing.
- Technicians (switches, transmitters, and light fixtures).

The market is already scrambling for the workforce necessary to create, expand and maintain the infrastructure necessary to ensure the proper functionality of the electric vehicle fleet. For instance, the employers are offering on a single UK recruiting platform[78] over 350 jobs that are solely related to EV charging (which are also relevant for e-motorbikes), such as:

- Field Service Technician – EV Charging Units
- Senior Electrical Diagnostics Engineer – EV Charging (DC)
- Installation Project Engineer – EV Charging Installation
- Lead Control Systems Engineer – EV Charging
- Electrical Project and Standards Engineer – EV Charging Infrastructure.

[78] 343 EV Charging Jobs (NOW HIRING) | ZipRecruiter. (n.d.). *ZipRecruiter*. https://www.ziprecruiter.co.uk/Jobs/EV-Charging?utm_source=zr-go-redirect, 13.06.2023

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5 Micromobility

5.1 BACKGROUND

Electric micromobility includes small and lightweight personal mobility devices such as e-**bicycles, e-scooters, e-mopeds, e-skateboards, e-hoverboards** or other kinds of one or two-wheelers to be used by individuals to cover short distances within cities and city centres and last mile trips in rural areas.

The European electric microvehicles market size reached about **USD 943.8 million** in 2021. The market is expected to grow at a CAGR of **35.7%** between 2023 and 2028.[79]

The number of electric **bikes** sold in Europe is expected to rise, as seen in **Figure 39**

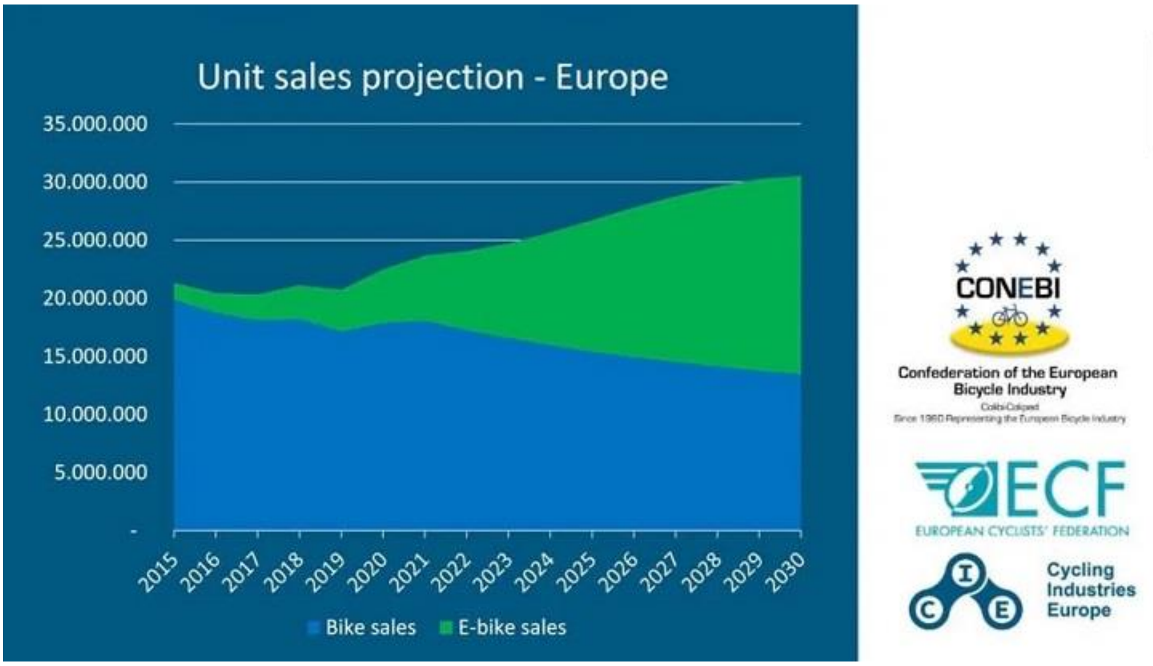

Figure 39: Unit sales projection - Europe[80]

[79] Europe Electric Micro Vehicles Market Report and Forecast 2023-2028. (n.d.). Expert Market Research. https://www.expertmarketresearch.com/reports/europe-electric-micro-vehicles-market

[80] Reid, C. (2020, December 2). E-Bike Sales To Grow From 3.7 Million To 17 Million Per Year By 2030, Forecast Industry Experts. *Forbes*. https://www.forbes.com/sites/carltonreid/2020/12/02/e-bike-sales-to-grow-from-37-million-to-17-million-per-year-by-2030-forecast-industry-experts/, 21.06.2023

In 2022, electric **moped** registrations reached **85,846 units** in the six European moped markets monitored by ACEM (Belgium, France, Germany, Italy, the Netherlands and Spain)[81]. This volume represents an increase of **17.4%** in comparison to 2021 (73,124 units) as can be seen on **Figure 40**.

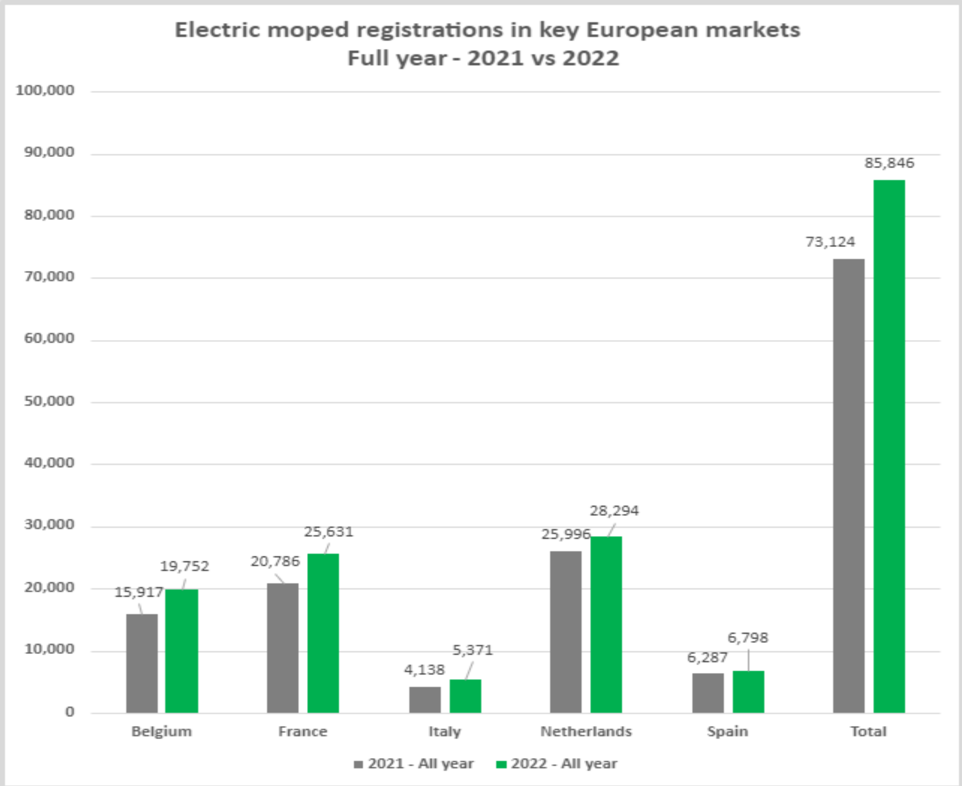

Figure 40: Electric moped registrations[81]

	Jan - Dec 2020	Jan - Dec 2021	Jan - Dec 2022
Mopeds (ICE + Electric)	280,440	264,807	255,909
Mopeds (Electric)	59,289	73,124	85,846

Figure 41: Trend of the mopeds in the largest European markets[81]

Driven by factors such as the increasing popularity of short-distance commuting, booming ride-sharing services in Europe, and due to various emission regulations, the European electric **scooters** market is projected to reach **$60.6 billion** by 2030, at a CAGR of **20.4%** from 2023–2030.[82]

[81] Ordonez, M. (2023). Registrations of motorcycles and mopeds in key European markets broadly stable during 2022. *acem.eu*. https://acem.eu/acem-statistical-release-registrations-of-motorcycles-and-mopeds-in-key-european-markets-broadly-stable-during-2022, 19.06.2023

[82] Europe electric scooter market to reach $60.6 billion and 23.1 million units by 2030. (n.d.). https://www.meticulousresearch.com/pressrelease/460/europe-electric-scooter-market-2030

5.2 TYPES OF CHARGING

The common way to charge an **e-bike** or another micromobility device's battery is to plug the charger that comes with the device into a domestic or public power outlet and connect it to the charging inlet of the battery pack. The charging time depends on the size and type of the battery, but it usually ranges from 2 to 6 hours to reach full capacity. However, one can also charge the battery to 80 percent in a couple of hours or less if the device supports fast charging.

An example of a charging facility for e-bikes is shown in **Figure 42**. [83]

Figure 42: Charging facility for e-bikes[83]

Especially in the case of rental scooters or e-bikes, **wireless charging** has been becoming available as a factory option or a retrofitting solution. It could be done by parking the device on a special charging pad or locking it in a dedicated slot in the dock.

A charger from a Latvian company producing wireless charging solutions Meredot, for example, consists of a charging pad that can be placed either above or below the ground. Existing e-scooters can be retrofitted with receivers, while new ones can have them built-in

[83] Pswan. (2021, June 28). New e-bike charging station answers boom in UK electric bike sales - Professional Electrician. *Professional Electrician*. https://professional-electrician.com/news/new-e-bike-charging-station-answers-boom-in-uk-electric-bike-sales/, 13.06.2023

during manufacturing. The pads are used in conjunction with software that enables operators to have a full overview of the State of charge of each vehicle. Alternatively, Meredot can operate and manage the charging network on behalf of clients[84].

Battery swapping concepts **Figure 43**, where an empty battery module is replaced by a fully charged one at a dedicated facility, is an interesting alternative to charging. With certain differences in their strategic approach, the operators use this concept to increase the reliability and accessibility of the fleet but also to improve the profitability and efficiency of the business.[85;86;87;88]

Figure 43: KYMCO's Ionex battery swap system[86]

[84] Magloff, L. (2023). Wireless charging technology for e-scooters. *Springwise*. https://www.springwise.com/innovation/mobility-transport/wireless-charging-technology-for-e-scooters/, 25.05.2023
[85] Guidehouse Insights. (2020, August 5). Battery Swapping Is Playing An Important Role In Micromobility. *Forbes.* https://www.forbes.com/sites/pikeresearch/2020/08/05/battery-swapping-is-playing-an-important-role-in-micromobility/?sh=6e6def896099, 23.06.2023
[86] Toll, M. (2022). KYMCO set to bring its battery-swapping electric scooters to Europe, upping arms race. *Electrek*. https://electrek.co/2022/05/06/kymco-set-to-bring-its-battery-swapping-electric-scooters-to-europe-upping-arms-race/, 23.06.2023
[87] *Bennetts*. (2021, November 3). Piaggio ONE electric scooter joins the battery swap revolution. Bennetts UK. https://www.bennetts.co.uk/bikesocial/news-and-views/news/2021/may/new-piaggio-one-electric-scooter, 23.06.2023
[88] Carey, N. (2022, March 25). E-scooters fall head over wheels for battery swapping. *Reuters*. https://www.reuters.com/business/autos-transportation/e-scooters-fall-head-over-wheels-battery-swapping-2022-03-24/, 23.06.2023

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At the European level, an initiative to phase in this technology was launched in September 2021 upon the establishment of the Swappable Batteries Motorcycle Consortium (SBMC)[89] , which includes the following players:

- Honda Motor Company
- KTM F&E
- Piaggio Group
- Yamaha Motor Company

Taiwanese company Gogoro,[90] for example, introduced a battery-swapping platform in China in 2021 to be used by urban electric two-wheel scooters, mopeds and motorcycles. It also develops its own line of electric scooters and offers its vehicle innovations to vehicle maker partners like Hero, Yamaha, Aeonmotor, PGO, eReady, and eMOVING. Its most important objective is implementing a widespread network of battery-swapping stations across China.

Honda KTM, Piaggio and Yamaha have signed an agreement to create a 'Swappable Batteries Motorcycle Consortium' with a view to standardising batteries in electric motorbikes globally.[91]

Figure 44: Remove a battery and replace it with a fully charged one[91]

[89] Williams, D. (2021, September 8). Swappable Batteries Motorcycle Consortium Is Now Official. *Ultimate Motorcycling*. https://ultimatemotorcycling.com/2021/09/08/swappable-batteries-motorcycle-consortium-is-now-official/, 23.06.2023

[90] Gogoro. (2021). Gogoro Launches Battery Swapping in China. *Gogoro*. https://www.gogoro.com/news/gogoro-battery-swapping-china-launch-hangzhou/, 23.06.2023

[91] Sutherland, D. (2022, September 23). Battery swap plan for a plug-in future: More firms sign up to scheme that aims to banish electric bike range a. *www.motorcyclenews.com*. https://www.motorcyclenews.com/news/electric-motorbike-swappable-batteries/, 23.06.2023

The US-based Lime is another example of a company switching its shared mobility businesses to swappable batteries. It has been present with its e-scooters and bikes with swappable batteries in several European cities.[92]

In Prague, for example, Lime has started providing its services with conventionally charged e-scooters but has switched to battery swapping to increase the efficiency and profitability of its services. Since the vehicles will not have to be taken from the streets to charge, there will be fewer operational tasks, which tend to be one of the highest costs associated with running a shared micromobility business. At the same time, by only needing to swap out the battery, more vehicles will be on the street for a longer time, providing better reliability to riders and a higher potential for earning revenue.

In 2021, LG Electronics Inc. introduced wireless charging solutions for electric scooters (**Figure 45**) as the South Korean tech giant eyes to expand its presence in the mobility sector[93]. **Figure 46** shows the possibility of wireless charging for electric bikes.

Figure 45: Kickgoing's electric scooter and its parking station with LG's wireless charging solutions[94]

[92] E-scooter & E-bike Sharing. (2023, June 16). Lime Micromobility. https://www.li.me/, 22.06.2023
[93] Yonhap. (2021, May 17). LG introduces wireless charging solutions for electric scooters - The Korea Herald. *The Korea Herald*. http://www.koreaherald.com/view.php?ud=20210517000176, 24.05.2023
[94] Reid, C. (2020, December 2). E-Bike Sales To Grow From 3.7 Million To 17 Million Per Year By 2030, Forecast Industry Experts. *Forbes*. https://www.forbes.com/sites/carltonreid/2020/12/02/e-bike-sales-to-grow-from-37-million-to-17-million-per-year-by-2030-forecast-industry-experts/, 21.06.2023

Figure 46: Electric bike wireless charging in a secure stand[95]

Some (cheaper, imported models of) micromobility devices might not have an overcharging prevention solution. An electric charge timer would be necessary to restrict any excess current flow to the battery[96]. Safety incidents are more likely to occur in the absence of overcharge solutions.

Over the last years, lithium-ion battery fires have occurred more often and with more severe consequences[97;98]. The main hazard associated with the overcharging and/or thermal runaway of the batteries in these devices is that they are usually charged indoors, sometimes close to the living areas of the inhabitants (garages, but even living rooms/bedrooms) and that the safety incidents can occur overnight in the sleeping time.

Electric bikes mostly come with an original charging cable, but it is noteworthy that e-bike chargers are not universal. Many e-bikes come with unique chargers specific to that bike's battery only[99].

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[95] Daymak. (2017, May 26). Daymak's NEW wireless charging stations for the EC1 SE eBike [Video]. YouTube. https://www.youtube.com/watch?v=6B_JsOPdNSk
[96] White, R. (2022, April 26). How to Charge Electric Bike Battery: All There Is to It! *eBike Savvy*. https://ebikesavvy.com/how-to-charge-electric-bike-battery-all-there-is-to-it/, 24.05.2023
[97] Sullivan, B. (2023, March 11). What's driving the battery fires with e-bikes and scooters? *NPR*. https://www.npr.org/2023/03/11/1162732820/e-bike-scooter-lithium-ion-battery-fires, 23.06.2023
[98] BBC News. (2023, May 18). E-scooter bursting into flames in a London home caught on video. *BBC News*. https://www.bbc.com/news/uk-england-london-65628754, 23.06.2023
[99] Balton, J. (2023). How to Charge an Electric Bike? Easy Step-by-Step Guide. Bicycle Guider - Bike Reviews, Cycling Advice, Best Picks | Mountain, Road, Hybrid, Electric Bikes and More. https://www.bicycle-guider.com/cycling-advice/how-to-charge-an-electric-bike/, 24.05.2023

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5.3 JOB, ROLES AND SKILLS

Some of the most important skills and competencies identified within this sector:

- Systems Engineer for Battery Management Systems (BMS) – one of the most desired job roles in the sector, requires studies in the field of electrical engineering and good knowledge of battery systems and lithium-ion cells, with strong programming skills.
- Product Design Manager – another job very desired in the shared micromobility – with the focus on a solid experience in building and shipping applications or software and different design tools Sketch, Flinto, InVision, Framer.
- Electrical Engineering Technicians with competencies in retrofitting, maintaining and repairing wireless charging units.
- Infrastructure development – with a focus on the development of proposals for new electric vehicle charging infrastructure, commercial activities related to the deployment of new charging infrastructure, identifying wider opportunities to unlock funding for new charging infrastructure, oversight of the delivery of publicly-funded charging infrastructure, provide effective and efficient project management of EV-related projects, including the management of internal colleagues, contractors and budgets, provide technical advice on EV charging matters and support for the deployment of the EV charging network.
- Infrastructure operation and maintenance – with a focus on activities specific to battery swapping stations: maintain charging units safety and functionality, defective battery replacement and shipping, provide assistance to end users to replace batteries, unlock charged batteries, pay for the service, etc.
- App Developer
- Data Analyst

In general, many job roles rely on solid IT skills and electronics/electrical engineering and experience in software engineering. Additional competencies include strong communication skills, business intelligence, measurement and test technology handling, and others.

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6 Aeroplanes

6.1 BACKGROUND

The electrification of the propulsion of aeroplanes is in a very **early stage** compared to other mobile applications. The weight of the batteries is among the most significant challenges, limiting take-off and range possibilities. Nevertheless, there have been some exciting pilot projects and first attempts at commercial use.

In 2019, the European Union Aviation Safety Agency (EASA) created a framework plan for battery and hybrid electric aircraft in Europe, creating a new category for small aircraft for up to 9 passengers and a maximum take-off weight of 3.175 kg. Categories for bigger aircraft are also in the process of certification, but due to the limitations of current battery technologies, it has been an unknown territory.[100]

Until 2020, no electric aeroplane was fully certified by the EASA. The **first certification** worldwide was in 2020 for a fully electric aircraft Pipistrel Velis Electro. The certification took only three years due to close cooperation between the company and EASA, ensuring the certified aircraft met a high safety standard. Apart from the safety standards, the aeroplane also received a first certification for its electrical engine.[101]

[100] *EASA releases new electric aircraft regulations - electrive.com*. (2019, July 8). electrive.com. https://www.electrive.com/2019/07/08/easa-releases-new-electric-aircraft-regulations/tps://www.electrive.com/2019/07/08/easa-releases-new-electric-aircraft-regulations/

[101] *EASA certifies electric aircraft, first type certification for fully electric plane world-wide | EASA*. (2020, June 10). EASA. https://www.easa.europa.eu/en/newsroom-and-events/press-releases/easa-certifies-electric-aircraft-first-type-certification-fully

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Figure 47: First certified single-engine battery-powered aircraft in the EU[102]

The Pipistrel is a small, single-engine powered aeroplane with only two seats. Its primary purpose is to train new pilots during circles around the airport, thus reducing costs (including maintenance costs) and emissions. The flight duration is around 50 min, enough for two testing circles for pilots in training courses.

Some start-ups are also developing other electric plant variants, including aeroplanes with vertical take-off.

6.2 TYPES OF CHARGING

Case study – Pipistrel aeroplane charging system

The Pipistrel Velis Electro is powered by a 57.6 kW single engine operated on 345 V DC with an internal battery totalling 24.8 kWh of nominal capacity. The standard charging rate takes around 90 minutes from 35% to 95% or 2 hours for a full charge. [103] A single-phase 240 V AC regular wall socket can be used for overnight charges or a three-phase 380 V AC connection to enable quick charging.

The Velis Electro has a DC GB/T 20234 connector used by Chinese electric cars. The company is developing a CCS connector used as a European standard for electric passenger cars and

[102] Pipistrel. (2023, April 13). *Velis Electro - Pipistrel*. https://www.pipistrel-aircraft.com/products/velis-electro/#1680717339675-b6d1143d-a61a1680811899143
[103] Hill, J. S. (2020, November 18). Pipistrel's all-electric aircraft wins leading Plane of the Year award. *The Driven*. https://thedriven.io/2020/11/18/pipistrels-all-electric-aircraft-wins-leading-plane-of-the-year-award/

vans in joint research with a GreenMotion (EATON) company from Norway. [102] The **Figure 48** below shows the differences between different charging cable connectors.

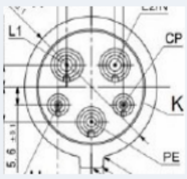
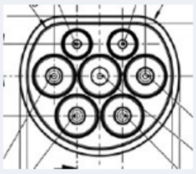
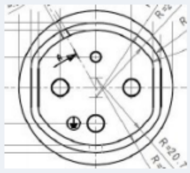
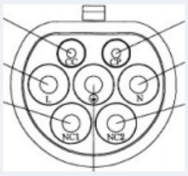
	IEC 62196-2:2010			GB 20234.2-2011
	Type1-U.S	Type 2-Germany	Type 3-Italy	China
Phase	Single phase	Single/Three phase	Single phase	Single phase (Three phase reserved)
Current	32A(80A U.S)	70A/63A	16A,32A/32A	16A,32A
Voltage	250V	480V	250V,250V/500V	250V/400V
Pin & interlock	5-pin, mechanical lock	7-pin, electronic lock	4-pin, 5-pin	7-pin, mechanical lock (optional electronic lock)
Control pilot pin	Two short pins	One short pin, one long pin		Two short pins
Male & female pin		Plug: male Vehicle connector: female		Plug: male Vehicle connector: male
Dimensions				

Figure 48: Table of different connectors used in different nations[104]

The Megawatt Charging System

The MCS, intended to be used by medium- and heavy-duty commercial vehicles, has been tested by ABB to charge Lilium Jet e-vtol 7-seater (see **Figure 49**). The goal is to charge it fully in 30 minutes to maintain the desired number of 25-30 flights per day.

[104] Herron, D. (2015, August 11). *China's electric car fast charging (GB/T 20234) to become world standard?* The Long Tail Pipe. https://longtailpipe.com/2014/02/13/chinas-electric-car-fast-charging-gb/

Figure 49: First prototype of Lilium Jet and Lilium Jet Charging Station at a regional airport [105]

Key requirements for the standard are now being discussed to include a single conductive plug that can handle 1250 V DC and 3000 A, Power Line Communication technology support, and the **ISO/IEC 15118** standard for smart, bidirectional charging. It must be touch-safe to the **UL2251** standard, and the handle must include a software-interpreted override switch. The MCS must also allow for automation and be cyber-secure.

Charging at such high voltage and current is very energy-intensive. The equipment will need robust cooling for both cable and connector. The liquid-cooled cable technology will be similar to that ABB already supplies to thousands of high-power DC fast chargers worldwide for networks such as IONITY in the EU and Electrify America in the US.[105]

[105] Nick. (2021, November 8). *ABB plans fast-charger network for electric aircraft - E-Mobility Engineering*. E-Mobility Engineering. https://www.emobility-engineering.com/abb-plans-fast-charger-network-for-electric-aircraft/

7 Trains

First trains running on electricity from batteries, instead of being powered by diesel engines, have been piloted in Germany since May 2023. Seven of these vehicles are already in test operation on the rails, and there shall be fifty-five of them in total in a year. They should be able to reach a maximum speed of 160 kilometres per hour. During braking, the energy is recuperated. The battery-powered trains, which are no longer than 50 meters, are designed for intercity service.[106]

Figure 50: Example of a battery train in Germany[106]

7.1 TYPES OF CHARGING

RailBaar company, for example, provides charging solutions for trains, and it utilises a platform side station charging concept, sometimes also used by electric buses, which they perceive as substantially less expensive and more versatile than existing overhead electrification structures.

The RailBaar charging station consists of a post to which the RailBaar is attached. Affixed to this stainless steel mechanism is the inverted aluminium pantograph fitted with copper conductors. These are connected to a power source via cables and have a flexible design, ranging from thin collectors for low-power charging to wide collectors for a high power charge.

[106] *Shift to Climate-Neutral rail transport: battery trains take the lead* | RAILTARGET. (n.d.). https://www.railtarget.eu/freight/shift-to-climateneutral-rail-transport-battery-trains-take-the-lead-5159.html

The pantograph is stored in a protective hood and can be lowered to the height of any train or raised to a suitable, safe height when not charging.

The original RailBaar concept is typically based on 750 V DC, although an AC version is under development along with a version with only two collector strips. The system has a power capacity of up to 800 kW to provide rapid charging and to allow trains to receive a top-up charge when waiting at the platform. It can take 10-30 minutes for a full charge depending on the battery size - a 120 kW battery is fully charged in 10-12 minutes - the number of coaches and the charger capacity, while a top-up charge can take 1-3 minutes.[107]

There are companies preparing different charging concepts, such as Furrer+Frey GB overhead pantograph charging, as seen in **Figure 51**.

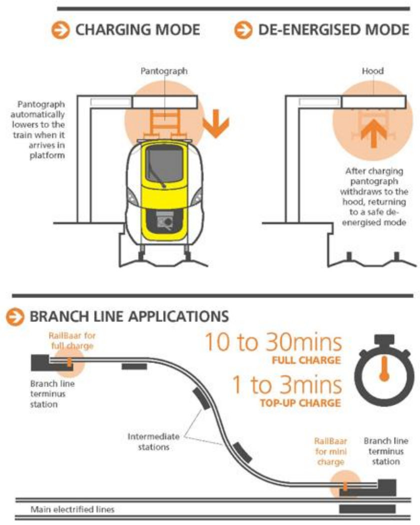


Figure 51: Overhead pantograph train charging[108]

[107] International Railway Journal. (2018, September 5). *Raising the Baar for battery-powered trains - International Railway Journal*. https://www.railjournal.com/in_depth/raising-the-baar-for-battery-powered-trains/
[108] AnonW. (2021, October 18). *How To Charge A Battery Train*. The Anonymous Widower. https://anonw.com/2016/01/14/how-to-charge-a-battery-train/

8 Vessels

8.1 BACKGROUND

Electricity will have significant cost benefits in a few years compared to marine diesel and other maritime fuels, primarily driven by regulation and taxation (the inclusion of transport in the ETS, national taxation). Electricity is, in many cases, **already available** in the port area without the need for costly infrastructure upgrades. On-shore charging is a low-hanging fruit in the journey towards a low-carbon Europe.

Ensuring **charging infrastructure** in the ports is necessary to enable the electrification of inland and maritime vessels. Moreover, vessels connected to shore power in port can turn off generators for needed energy onboard. The effect is cleaner air, reduced noise, and reduced emissions in the port area. Shore charging will reduce CO_2, NO_x, and SO_x emissions.

There is **no international standard** for maritime shore-side charging other than safety standards. More standardisations will empower flexibility and enable vessels to share the same port charging capacity. Standardisation is an enabler for less cost and more environmental benefits.

Class Society DNV publishes statistics (global numbers) for the electrification of the maritime fleet.

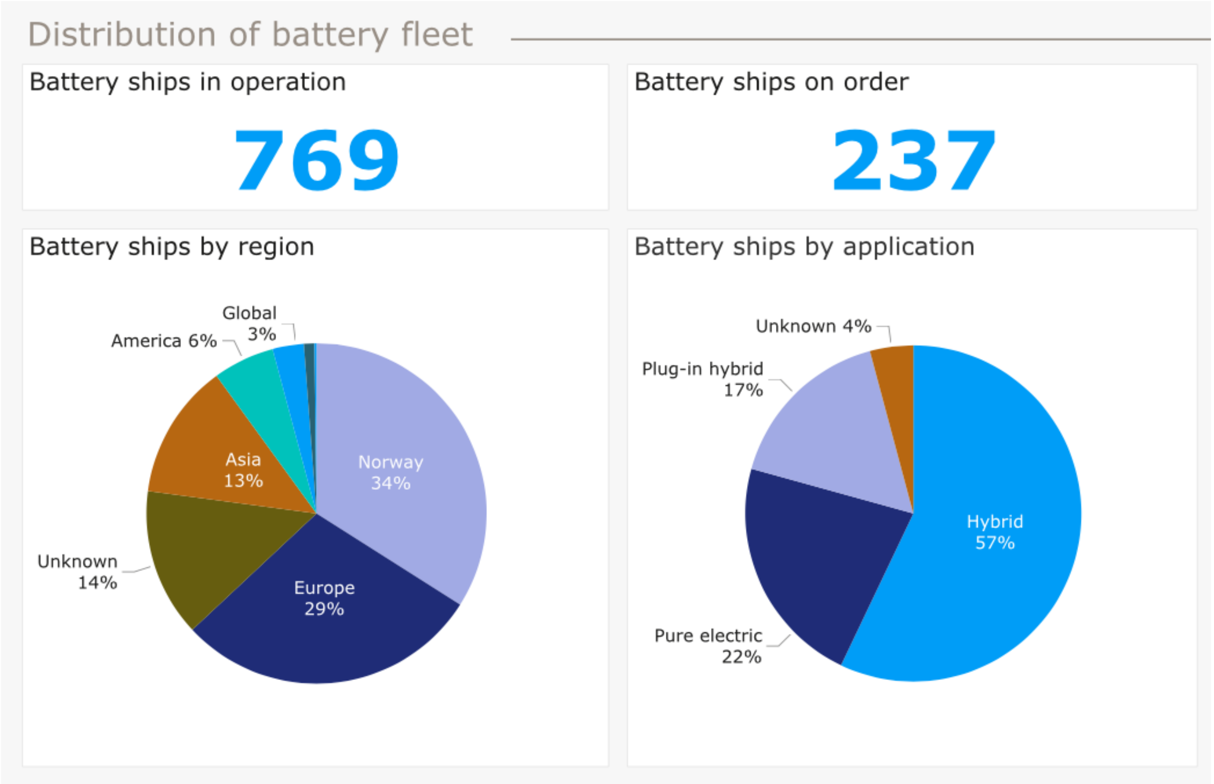


Figure 52: Distribution of the electrified vessels by region and by propulsion[109]

More than 1,000 vessels worldwide will soon be hybrid or fully electric. 63 % are registered in Europe, setting our region in the lead position.

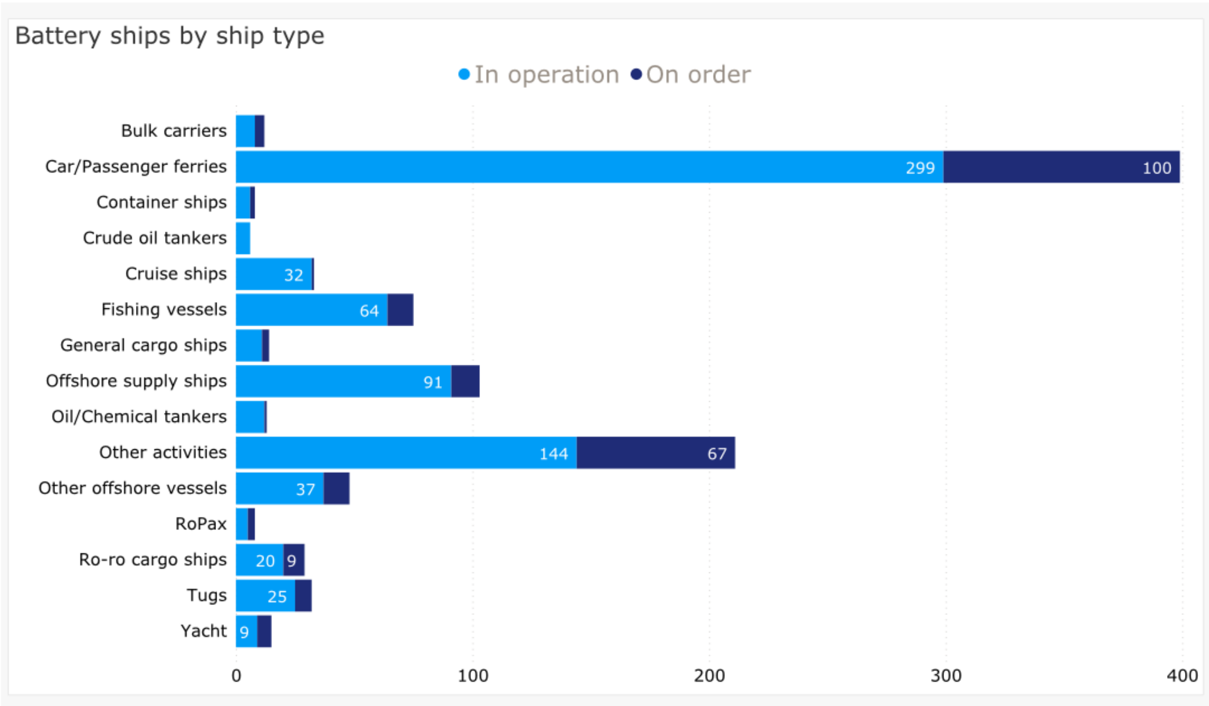


Figure 53: Types of electric vessels in operation[109]

Car/passenger ferries is the dominant vessel type for electrification.

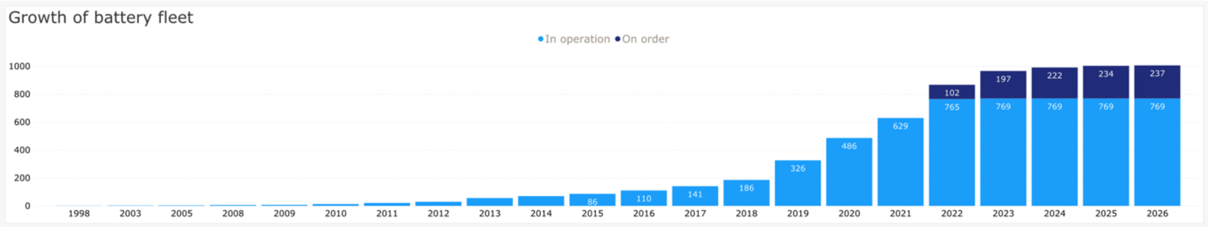


Figure 54: Battery fleet growth in years[109]

Growth started to pick up in 2019.[109] Corvus industry analysis[110] expects steep growth continuing to 2030 and beyond.

Drivers of change[111]

- EU policies and other regulatory demands (Fit for 55 / EU ETS)
- Differentiated Port tariffs (Environmental Port Index)[112]
- Industrial customer demands (for instance, oil companies demanding batteries onboard Platform Supply Vessels ready for shore charging to reduce CO_2 emissions as part of oil companies' ESG plans and reporting).
- Customer demands (for instance, passengers favouring cruise vessels with shore charging in port as part of passengers' sentiments toward polluting cruise vessels)
- Political incentive programs in tender processes (for instance, public procurement of new vessels in routes, demanding shore charging – and providing charging infrastructure in ports).

[109] *Statistic.* (n.d.). DNV. https://afi.dnv.com/statistics/58809abb-e949-4ff3-88c1-8392538fd5a6
[110] Corvus internal industrial analysis
[111] *Environmental Port Index | Cleaner Ports for a Greener World*. (n.d.). https://epiport.org/
[112] The Environmental Port Index, or the EPI, is a sophisticated but simple-to-use reporting tool, designed to help ship owners and port operators to chart a course for positive change. By aligning the operational and environmental benefits of following best practice sustainability at the port, the EPI empowers ships and ports to ensure a better future for their individual businesses and our shared industry, societies, and the planet.

8.2 TYPES OF CHARGING

From a power system view, solutions for power supply from shore consist of an interface to the main grid by a step-down transformer, possibly an energy storage system typically based on Li-ion batteries, power electronics converters responsible for AC/DC and DC/DC conversion, transformers for maintaining the galvanic isolation as well as voltage level adjustment, circuit breakers and cable management systems.

The shore-to-ship interface consists of plugs and receptacles, cable management systems, mechanical structures, and monitoring systems.

Technical specifications for chargers[113;114;115]

- High Voltage – Low Voltage
- Compensating Horizontal motion from tidewater and waves
- Compensating Vertical motion from vessel movement
- Autonomous vs manual connection and disconnection
- Charging power: typical 300 – 600 – 1,200 – 2,000+ kW
- Available grid capacity: charging solutions could be connected directly to the grid or a battery pack/container on shore.

The following European companies dominate the maritime charging market:

- Zinus (Norway)
- Stemmann (Germany)
- Cavotec (Switzerland)
- Wärtsilä (Finland)

Charging solutions come in different designs for different use cases: typical compact, telescopic, and classic designs. Power swap units are also available. Below are pictures of different solutions:

[113] *ladetårn - Søk*. (2021, September 7). Tu.no. https://www.tu.no/sok?query=ladet%C3%A5rn
[114] *SINTEF search - SINTEF*. (n.d.). SINTEF. https://www.sintef.no/en/search/?querytext=shore+charging
[115] Corvus internal industrial analysis

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Figure 55: 'Zinus' charging solution for 'Singapore's first fully electric ferry route[116]

Figure 56: Zinus Shore Power Cruiser[117]

[116] Habibic, A., & Habibic, A. (2022, March 14). Zinus' charging solution for Singapore's first fully electric ferry route. *Offshore Energy*. https://www.offshore-energy.biz/zinus-charging-solution-forsingapores-1st-fully-electric-ferry-route/)

[117] *Shore Power Cruiser*. (2023, March 1). Zinus. https://zinuspower.com/product/shore-power-cruiser/#hero

Figure 57: Stemmann FerryCHARGER solutions for electric ferries, picture from Norway.[118]

Figure 58: Cavotec AMP Mobile unit at Montreal's cruise terminal.[119]

[118] Solutions, C. (n.d.). *FerryCHARGER for electric ferries - Stemmann-Technik*. https://www.stemmann.com/nl/products/ferrycharger-for-electric-ferries

[119] *Canadian ports cut emissions with Cavotec shore power technologies*. (2017, October 26). Mynewsdesk. https://www.mynewsdesk.com/cavotec/blog_posts/canadian-ports-cut-emissions-with-cavotec-shore-power-technologies-63596

Figure 59: Wärtsilä charger for ports[120]

Technical specifications

There are few or no regulatory and standardisation requirements, so shore charging comes in many different types and specifications. Here are some examples to illustrate:

Figure 60: 3-phase AC plugs[121]

[120] *Charging – Marine vessel charging systems*. (n.d.). Wartsila.com. https://www.wartsila.com/marine/products/ship-electrification-solutions/shore-power/charging

[121] *Industrial Extension Leads ltd*. (n.d.). Industrial Extension Leads Ltd. https://www.industrialextensionleads.co.uk/plug--connector-types-explained-4-w.asp

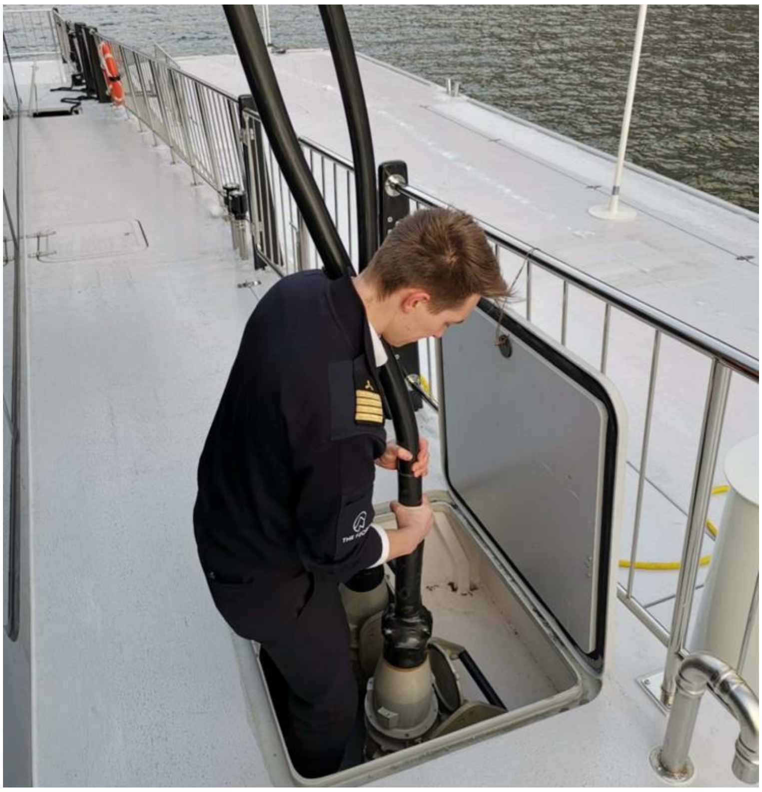

Figure 61: Manual connection of two cables for charging[122]

Figure 62: ABB IRB7600, an autonomous robotic arm used for charging[122]

[122] Karimi, S., Zadeh, M., & Suul, J. A. (2020). *Norwegian University of Science and Technology*. https://ntnuopen.ntnu.no/ntnu-xmlui/bitstream/handle/11250/2736779/IEEE_EM_Shore_to_ship_charging_Submission.pdf?sequence=2

Leisure boat applications

We observe an important driver of change in some countries - companies providing system solutions combining the charging infrastructure and new technology for vessel electric propulsion.

An example from Norway:

Vessel-building company EVOY AS and charging infrastructure provider PLUG AS offer a system solution for private leisure boats.

Figure 63: Shore charging Evoy leisure boat with Plug charger[123]

Figure 64: Evoy vessel and Plug shore charger[124]

[123] *"evoy" | Search | LinkedIn. (*n.d.). https://www.linkedin.com/search/results/content/?heroEntityKey=urn%3Ali%3Aorganization%3A18770660&keywords=evoy&origin=CLUSTER_EXPANSION&position=0&searchId=a3e594fa-0bb5-480c-9c01-7dd7a64e0e37&sid=EaU

[124] Hildonen, T. (2021). Åpnet verdens første lynlader for elbåter i Florø. *Bil24.no*. https://bil24.no/apnet-verdens-forste-lynlader-for-elbater-i-floro/)

EVOY AS

Evoy long-lasting Electric Boat Motor systems ranging from 120-400 hp.

PLUG AS

'Plug's ambition is to build a fast and high-power charging network along the Norwegian coast, publicly available AC & DC chargers for leisure boats, small workboats and fishing boats.

8.3 JOB ROLES AND SKILLS

Many new job roles and skills are foreseen to be required to enable a broad and efficient shore charging network for maritime usage across Europe. We define four key areas of future job roles:

1. R&D
2. Manufacturing
3. Servicing
4. Operation.

Open positions, Job Roles & Skills for selected key companies:

1. Stemmann (Germany) career pages had the following open positions (June 2023):
    - Industrialisation Engineer
    - Junior project manager
    - System engineer
    - Senior project manager
    - Regional sales manager
    - Tender manager
    - Field service technician
    - Sales Support.

2. Cavotec (Switzerland) career pages had the following open positions (June 2023):
    - Business Controller

- Mechanical Engineer - Charging Solution
- Electrical Engineer - Charging Solution
- Software and Controls Engineer - Charging Solution
- Quality Assurance Engineer
- Field Service Technician
- Mechanical Engineer (Moormaster) - Ports and Maritime
- Controls & Automation Engineer.

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Conclusions

This final desk research report of *Work Package 5 – Intelligence in Mobile Battery Applications,* of the ALBATTS project addresses **charging of batteries**, focusing on charging electric vehicles, trucks and busses, motorbikes, micromobility, aeroplanes, trains and vessels. This topic has not been analysed in previous ALBATTS reports.

The importance of having a qualified workforce to develop and implement solutions to ensure available and convenient **charging solutions** for electric vehicles and other means of transport has been raised by the increasing availability and popularity of electrified means of transport and by the recently approved pieces of **legislation**, such as the CO2 fleet regulations, AFIR, EPBD and others.

Chapter 1 – Battery Charging – describes the basic principles and ways of charging. It explains the recommendation of some OEMs and a relatively common practice of many EV drivers to charge the battery not entirely but to around **80%** only. It examines the problem of **degradation** of batteries due to fast charging. Among possible solutions to mitigate the degradation are technological enhancements in battery chemistry, design and battery management systems. It foresees the biggest challenges for **researchers** in the areas of **material optimisation**, **electrode engineering**, and **electrolyte enhancements**.

Chapter 2 – Passenger cars – examines the charging modes, wired, wireless and battery swapping technologies and private or public charging locations. One of the biggest challenges to overcome by the EU member states is implementing ambitious AFIR targets concerning public charging infrastructure rollout.

It will require **Electrical** and **Hardware Engineers** and other professionals to design and implement wired or wireless charging stations and battery swapping stations, deal with their connection to the grid, battery storage, photovoltaics system, smart charging and smart home systems, and create and implement innovative services and products relevant to charging.

The emerging innovative **services and products** relevant to charging may be related to Vehicle-to-Vehicle Recharging (VVR), Vehicle-to-Everything (V2X), fleet charging management systems, payments, emergency and portable charging solutions or (automated) robotic charging systems.

At the blue-collar level, technicians, particularly **electricians,** will be needed in large numbers to install, maintain and upgrade the stations; other personnel will be required to develop and maintain **software and payment systems**, deal with **trouble-shooting** or administrate building and other **approvals** or facilitate the connection of the stations **to the grid**.

Installing charging stations (mostly slow / AC) in garages of various types of residential, administrative, commercial or public buildings, boosted by the EPBD requirements, will need **building designers** to implement effective charging solutions. Since lithium-ion batteries are difficult to extinguish, ensuring the safety of EVs in buildings, mainly when these are being charged, will be an enormous task for the member states. Safe charging of more significant numbers of EVs in buildings might require the installation of **fire detection systems** by qualified professionals.

At least basic training concerning EV battery charging shall be provided to regular and more advanced training to **professional drivers** and **driving school instructors** and become part of the driving school curricula. **Charging network planners and managers, project and energy managers,** and **customer care representatives** must also be trained. Even more detailed training needs to be provided to **emergency first responders**.

Chapter 3 – **Trucks and Buses** – boosted by the EU legislation, such as CO2 fleet targets for heavy-duty vehicles and AFIR, the truck and bus segments are also determined to switch gradually from diesel to fuels such as electricity, hydrogen, bioLNG or other alternatives.

While the electrification of smaller and mid-size **trucks** for local and regional delivery seems technically and economically feasible, long-haul transport is challenging due to the capacity

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and weight of the batteries, which must be substantial for international journeys, combined with the weight of the truck's load.

Similar to other commercial vehicles, trucks are expected to be in use **24/7**, and there is not much room for lengthy charging, except for a limited number of breaks, such as compulsory driver rests, as is also required by the EU legislation. **Dynamic charging** of trucks using coils placed underneath the road surface is being tested on the Swedish island of Gotland on certain road sections.

Many charging sessions are expected to occur in private premises depots or while up- or unloading the load at customers. The **Megawatt Charging System** (MCS) is being developed to provide a solution to provide the battery trucks with appropriate charging power. Battery swapping is being tested with trucks in China.

Electric buses are, compared to trucks, not that uncharted territory. They have been present across Europe for years, mainly for inner-city journeys. Further to charging in depots, buses can **charge in stops** while passengers get in and out **wirelessly** or via various forms of **pantographs**. Similar to trucks, long international journeys by electric buses are among the most significant challenges.

Job roles and qualifications relevant to designing, rollout, maintenance and upgrading the charging infrastructure for trucks and buses are somewhat **similar to the segment of passenger cars**, the main difference being that much larger battery packs and charging power are needed.

Charging hubs in **logistic centres** and **resting areas** along highways must be designed and implemented, with sufficient parking space and power installation. **Depot charging** and charging opportunities when **up and unloading** the load at customers will need to be deployed for the trucks. Charging in depot installations will be necessary for buses, potentially combined with top-up charging opportunities at the **bus stops. Software solutions** ensuring smooth and effective **routes and charging planning** to avoid unnecessary queuing will be needed.

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Chapter 4 – Motorbikes – deals with the electrification of motorbikes, which do not require the installation of specific charging infrastructure. They can be charged at private premises from a socket or a wallbox or use public infrastructure built primarily for passenger cars. Job roles and skills relevant to the charging of electric motorbikes are thus largely similar to those mentioned in the passenger cars chapter.

Chapter 5 – Micromobility – addresses charging of micromobility devices used for short-distance travelling in cities, such as electric mopeds, bikes or scooters. These devices are often provided for rent within shared services. If operated privately (not as a shared service), they can be charged at home from a socket. There is already some dedicated **public charging infrastructure for e-bikes**, for example.

In the case of moped, bike, or scooter-**shared services**, innovative charging solutions are introduced, such as **battery swapping** in case of shared mopeds or scooters or charging e-bikes via a dedicated stand, in some cases wirelessly.

Designing and planning the public charging infrastructure requires **Electrician engineering** and technician professions with similar qualifications as needed for passenger car charging stations; only the capacity of the batteries and the power to charge them are substantially lower. **Software skills (app developer)** and **data analysts** are needed to monitor and plan the charging or battery swapping of the shared micromobility devices. Replacing the batteries in the shared micromobility devices might be executed with personnel with an elementary qualification.

Chapter 6 – Aeroplanes – examines the **first pilot projects** of electric planes. Fast charging options are being explored to charge batteries rapidly, including using the Megawatt Charging System (MCS), initially developed for trucks. Since the electrification of propulsion of aeroplanes is in an **early stage**, the chapter is relatively short and relevant job roles and qualifications are not identified.

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Chapter 7 – Trains – provides examples of battery trains and their charging, e.g., charging via pantographs in railway stations while passengers get on and off. Due to market immaturity, no specific job roles or qualifications were identified.

Chapter 8 – Vessels – touches upon the charging of batteries of commercial and leisure electric vessels. In the case of large vessels, charging towers, mobile charging assistants or (automatic) robotic arms are employed. **Mechanical, Electrical, Software, Controls and Automation Engineers** are among the desired professional backgrounds for the vessel charging segment.

The findings on job roles, qualifications and skills for charging batteries in the transport segment will be further elaborated in the upcoming **WP5 Sectorall Intelligence report.**

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