United Nations ECE/TRANS/WP.5/2023/5

Economic and Social Council

Distr.: General
26 June 2023

Original: English

Economic Commission for Europe

Inland Transport Committee

Working Party on Transport Trends and Economics

Thirty-sixth session
Geneva, 4–6 September 2023
Item 8 (a) of the provisional agenda
Review and monitoring of emerging issues and sustainable development goals: Transport Trends and Challenges in the road, rail, and inland waterways sectors

General trends and developments surrounding electric vehicles and their charging infrastructure – An analysis of options for enhanced sustainability of fuelling systems in the transport sector

Note by the secretariat

I. Introduction

1. Further to the request of the Working Party on Transport Trends and Economics (WP.5) at its previous session to designate its Transport Trends and Economics 2022–2023 publication on general trends and developments surrounding electric vehicles and their charging infrastructure, a draft publication as contained in ECE/TRANS/2023/4; ECE/TRANS/2023/5, ECE/TRANS/WP.5/2023/6, ECE/TRANS/WP.5/2023/7, and ECE/TRANS/WP.5/2023/8 has been elaborated by the secretariat and an external consultant and will be presented for feedback.

2. The present document provides an overview of sustainability options for fuelling systems in the road, rail, inland waterways and maritime transport sectors.

3. WP.5 delegates are invited to provide feedback and suggestions for improvement of the text and to deliver presentations on national case studies and best practice examples for inclusion in the final version of the publication.

II. Sustainable modes of transport: options and choices

4. The previous chapters have highlighted electric mobility as a promising alternative to conventional fossil fuel-based transportation systems. In line with this, the current chapter offers an overview of the development of electric mobility across multiple transport modes. It aims to showcase the progress made and challenges encountered in the transition. The chapter also examines the electrification of both private and commercial vehicles, considering advancements in road, rail, water, and air transport. Additionally, it delves into

the comparison between battery electric vehicles (BEVs) and other types of electric vehicles (EVs), as well as other alternative fuels.

A. Road transport

5. The electrification of road transport has witnessed a remarkable growth with the rising presence of BEVs and plug-in hybrid vehicles (PHEVs). This surge is fueled by various contributing factors such as the introduction of various EV models by manufacturers, the installation of public charging infrastructures by grid operators, and the support of governments through funding demonstrations, pilots, and the establishment of regulatory frameworks and incentives for EV adoption. Furthermore, the electrification trend of road transport has extended beyond cars. Notably, delivery vans, light trucks, buses, and two-wheelers have also embraced electrification, with ongoing developments in prototypes for larger electrified trucks. The technology requirements for EVs vary significantly depending on the mode of transport. Large and powerful batteries, efficient charging solutions, user-friendly technologies, and suitable procurement processes are all critical components to consider.

6. Table 1 provides an overview of various road transport vehicle types along with corresponding terms and definitions that will be referred to throughout this study. The gross vehicle weight (GVW) used in the table aligns with the IEA’s harmonized global definitions. Heavy-duty vehicles include both medium and heavy-duty trucks. For each type of goods vehicle, a range of potential use cases is provided. However, it is important to note that these use cases are not fixed and can vary depending on various factors.

Table 1
Definitions and basic characteristics of electric road transport vehicle types

Vehicle category	*Basic characteristics*
Passenger cars	
Private passenger cars	• Primarily use home charging, fast charging when needed • Positive user experience is a critical factor
Commercial passenger cars	• Typically use home and workplace charging, fast charging • Part of large organization and government fleet (bulk procurement) • Total-Cost-of-Ownership is an important driver
Shared passenger cars	• Often part of large organization and government fleet (bulk procurement) • Use cases: employee mobility, commercial shared mobility services, taxis, ride hailing services, Mobility-as-a-Service (MaaS)
Heavy-duty passenger vehicles	
(Public) buses	• Typically utilize depot and opportunity charging • Operate on fixed routes • Often procured by government or transit agencies
Light-duty goods vehicles	
Light commercial vehicles	• GVW < 3.5 tons • Use cases: last-mile delivery, urban goods delivery, small parcel delivery • Routes are usually predictable

Vehicle category	*Basic characteristics*
	• Charging often occurs at the company's premises
Heavy-duty goods vehicles	
Medium-duty truck (MDT)	• GVW 3.5 – 15 tons • Use cases: last-mile delivery, urban goods delivery, regional goods distribution, utility services, refrigerated goods delivery, waste collection, construction • Typically require large batteries and DC charging
Heavy-duty truck (HDT)	• GVW > 15 tons • Use cases: long-haul freight transport, heavy construction, specialized transport (e.g., large machinery)
Light vehicles	
Low-powered motorcycle	• Maximum speed 45 km/h • Use cases: shared mobility service in urban area • Usually employ home charging and/or battery swapping
Three-wheelers	• Usually employ home charging and/or battery swapping • Use cases: shared mobility service in urban area, or goods delivery in rural areas
Electric bike	• Use cases: private use and shared service • Typically use home charging (for private use) and charging at operator's premises (for shared service)

B. Passenger road transport

7. Different than in African and Asian continents, e-scooters are mainly used for shared mobility services in Europe. This mode is often used in urban environments for short trips. Therefore, fast and efficient battery swapping technologies are essential. This allows for continuous operation of the vehicle fleet without the need for significant downtime for charging. Electric shared passenger cars have also gained popularity in the past years. Electric public shared cars provide numerous advantages particularly for urban dwellers that can use them without the financial burden associated with owning a private vehicle and eliminate fuel costs. Many cities offer priority parking spots for shared cars and they can use charging points as parking spots, which further improves their accessibility. Many large organizations and governments also increase their electric car fleets to be used by their employees. For these commercial purposes, TCO perspective is an important consideration.

8. In the realm of private passenger cars, customer experience is paramount. The availability of home charging solutions significantly contributes to a positive user experience, as it provides the convenience of charging the vehicle overnight or during periods of inactivity. In most countries, commercial passenger car fleets have been a good starting point for electrification, because the high procurement cost is balanced by low maintenance and lower write-off, quickly leading to an attractive Total-Cost-of-Ownership (TCO). Additionally, technologies should facilitate a smooth interaction between the vehicle and the charging station, ensuring a user-friendly process.

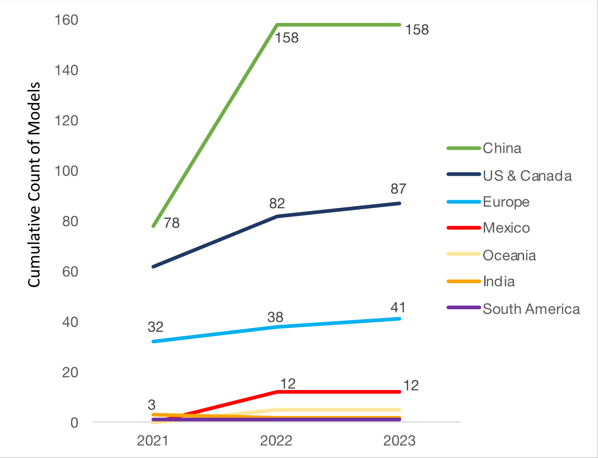
9. Public buses, as another crucial segment of transportation, often operate on fixed routes, making it predictable for charging infrastructure. Given their high visibility, these vehicles also play an important role in public perception of EV technologies. The procurement process for these vehicles usually involves governmental and municipal bodies, which calls for transparency and stringent regulations.

C. Freight road transport

10. Contrasting passenger cars, goods vehicles present distinct needs and characteristics. These vehicles predominantly operate on predetermined routes, similar to public bus systems. Consequently, their unique qualities require specific procurement focuses and infrastructure requirements. When procuring goods vehicles, durability and reliability are of utmost importance. This consideration arises from the vehicles' frequent usage and the essential nature of their tasks. In terms of infrastructure, charging stations are primarily installed within the company's premises to ensure easy access to charging facilities. This improves vehicle uptime and enables more predictable energy management.

11. In the case of medium-duty trucks (MDTs) and heavy-duty trucks (HDTs), which have high energy demands, large-capacity batteries are necessary. Consequently, these trucks are designed to accommodate direct current (DC) charging. This charging mode is advantageous due to its rapid charging times, a factor of paramount importance in the logistics sector where reducing downtime is a significant priority. Currently, the adoption rate of electric trucks within the spectrum of all road transport modes is the slowest, despite recent acceleration in this trend. It may be attributed to several factors, such as the higher upfront costs of electric trucks, limited battery technology capable of meeting the needs of these vehicles, and the lack of robust charging infrastructure. Nonetheless, ongoing advancements in technology and infrastructure are expected to increase the adoption of electric trucks is in the coming years. Additionally, the market has seen a growth of electric truck models recently (Figure I).

Figure I
Available models of electric MDT and HDT, battery and fuel cell



Source: ZETI Data Explorer.[1] Accessed on 5 June 2023.

D. Rail transport

12. Rail is the most energy-efficient mode of transportation among all surface modes. Furthermore, it is currently the only mode that offers a mature and readily available solution for widespread use in zero-emissions transport (ITF, 2021a). The electrification of rail eliminates all direct (tank-to-wheel) CO_2 emissions and other pollutants generated by trains. Diesel, which is commonly used as an alternative power source for trains, emits between 6 and 30 grams of CO_2 per passenger-kilometer (these values can vary significantly depending on the train's engine efficiency and load factor). (ITF, 2021b)

13. Despite having the highest concentration of electrified rail sections compared to other continents, approximately 45 per cent of all railway tracks in the European Union remain non-electrified.[2] Electrifying rail infrastructure requires substantial investments, involving

[1] https://globaldrivetozero.org/tools/zeti-data-explorer/

[2] www.railtech.com/rolling-stock/2023/05/04/will-battery-or-hydrogen-trains-be-the-future-the-vision-of-siemens-mobility/

the construction of new rail lines or the addition of infrastructure to existing lines in order to provide continuous electricity to trains. The costs for electrification range from EUR 0.5 million to EUR 2 million per kilometer (ITF, 2021b). As a result, it may only be economically justified for countries with high traffic volumes, where the low operational costs can offset the high infrastructure development expenses.

14. In cases where sections of rail are not yet electrified, both battery and hydrogen technologies serve as complementary solutions. Battery-electric train technology is suitable for shorter distances, while hydrogen trains are well-suited for sections longer than 100 kilometers that lack overhead lines.[3]

E. Waterborne transport

15. The adoption of electric propulsion systems is on the rise in both maritime transport and inland water transport (IWT). Integrated Full Electrical Propulsion systems are increasingly common in various types of ships, including passenger vessels, LNG tankers, shuttle tankers, cruise ships, ferries and offshore support vessels.[4] This development has been driven by significant advancements in battery technology.

16. Lithium-ion batteries are playing a crucial role in powering hybrid and all-electric vessels. Particularly for shorter ferry routes up to 50km, all-electric battery-powered ships are emerging. However, challenges arise when it comes to extended voyages due to limited battery capacity and energy storage capabilities. To address these challenges, there is promising potential in utilizing fuel cells that use hydrogen as a power source.

17. In terms of infrastructure, the implementation of shore power systems is being encouraged. Ports and inland waterway terminals are investing in shore power infrastructure, enabling ships and vessels to connect to the electrical grid while docked. This eliminates the need for ships to run their engines during port stays, resulting in reduced emissions and noise pollution. Furthermore, shore power allows vessels to tap into electricity from renewable sources, contributing to cleaner and quieter port and terminal environments. Battery-powered ships can utilize these facilities for charging purposes. Installation of shore power facilities is mandatory in core ports in the European Union from 2025. Shore power connections for ships with fixed connections to ports, such as ferries and liner shipping, are most relevant (ITF, 2021c).

F. Maritime transport

18. The transition to electric mobility in maritime transport has been relatively slow due to the market's lack of maturity. However, there is growing momentum for the adoption of electric and battery technologies in the shipping industry, thanks to advancements made in the automotive sector. Notable companies like Maersk, Siemens, and ABB are actively involved in the development and testing of electric propulsion and battery storage solutions for various types of ships, including ferries, tugboats, and drill ships.[5]

19. While ICEs currently dominate the industry, the ongoing efforts to develop electric and battery technologies in the maritime sector are gaining traction. The initial targets for electrification are short-distance vessels with inefficient operations, such as ferries, where battery packs can provide power for the entire journey. Challenges remain, particularly regarding recharging capacity for long-distance operations. However, the industry is actively exploring the combination of battery storage and fuel cells as a potential solution.

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[3] www.railtech.com/rolling-stock/2023/05/04/will-battery-or-hydrogen-trains-be-the-future-the-vision-of-siemens-mobility/

[4] https://trimis.ec.europa.eu/roadmaps/transport-electrification-elt

[5] www.cleantech.com/shipping-pollution-and-technology-electrification-and-energy-storage-in-maritime-shipping/

G. Inland water transport

20. Inland water transport (IWT) possesses distinct competitive advantages over other modes of inland transportation. These advantages include its capacity to transport significant volumes over long distances, its safety record, efficiency in terms of energy and costs, low emissions, and absence of congestion. Despite these benefits, CO_2 emissions from IWT are experiencing long-term growth, primarily due to the expansion of IWT itself and the slower adoption of sustainable fuels. Currently, a considerable number of vessels operating on the European waterways are at least 44 years old, equipped with diesel combustion engines that were installed during their original construction (ECE, 2020).

21. In recognition of this issue, several declarations have been made in the ECE region, including:

- The Ministerial Declaration “Inland Navigation in a Global Setting” adopted at the International Ministerial Conference on Inland Water Transport in Wroclaw (Poland) on 18 April 2018 (ECE, 2018), and the White Paper on the Progress, Accomplishments and Future of Sustainable Inland Water Transport (ECE, 2020) aimed to promote the utilization of alternative fuels or electro motion for water transport in urban environments;
- The Mannheim Declaration “150 years of the Mannheim Act – the driving force behind dynamic Rhine and inland navigation” adopted on 17 October 2018, aims to enhance the ecological sustainability of inland navigation by achieving a 35 per cent reduction in GHG emissions compared to 2015 levels by 2035, reducing pollutant emissions by at least 35per cent compared to 2015 levels by 2035, and eliminating greenhouse gases and other pollutants by 2050.[6]
- NAIADES III,[7] focusing on future-proofing European IWT, aims to shift a larger portion of freight transport to inland waterways, transition to zero-emission IWT, and promote smart IWT.[8]

22. While battery technologies for electric propulsion systems offer a promising 100 per cent potential reduction in CO_2e, NOx, and particulate emissions, they present a slightly lower technology readiness level (TRL) compared to their ICE counterparts (Table 1). From an environmental perspective, hydrotreated vegetable oil (HVO) and liquefied bio methane (LBM) offer significant advantages and are more advanced in terms of development.

Table 1
Comparative technological readiness of energy technologies for IWT

Technologies considered in the pathways	*Description*	*TRL (1-9) vessel application*	*TRL (1-9) fuel/energy production and supply*	*Emission reduction potential (in an ideal upstream chain)*		
				GHG/CO2e	*NOx*	*Particulate matters*
CCNR 2 or below, Diesel	Fossil diesel in an internal combustion engine which complies with the emission limits CCNR 2 or older engine.	9	9	0%	0%	0%
CCNR 2 +SCR, Diesel	Fossil diesel in an internal combustion engine which complies with the emission limits CCNR 2 and equipped with and additional	9	9	0%	82%	54%

[6] www.ccr-zkr.org/files/documents/dmannheim/Mannheimer_Erklaerung_en.pdf
[7] Communication from the European Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions.
[8] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52021DC0324

Technologies considered in the pathways	Description	TRL (1-9) vessel application	TRL (1-9) fuel/energy production and supply	Emission reduction potential (in an ideal upstream chain)		
				GHG/CO2e	NOx	Particulate matters
	Selective Catalytic Reduction system.					
Stage V, Diesel	Fossil diesel in an internal combustion engine which complies with the emission limits European Union Stage V.	9	9	0%	82%	92%
LNG	Liquefied Natural Gas in an internal combustion engine which complies with the emission limits European Union Stage V.	9	9	10%	81%	97%
	HVO in an internal combustion engine which complies with the emission limits European Union Stage V.					
Stage V, HVO	HVO stands for hydrotreated vegetable oil itself (without branding with fossil fuels) and all comparable drop-in biofuels (including e-fuels) as well as synthetic diesel made with captured CO2 and sustainable electric power.	9	9	100%	82%	92%
LBM	Liquefied Bio Methane (or bio-LNG) in an internal combustion engine which complies with the emission limits European Union Stage V.	9	8	100%	81%	97%
Battery	Battery electric propulsion systems, with fixed or exchangeable battery systems.	8	7	100%	100%	100%
H2, FC	Hydrogen stored in liquid or gaseous form and used in fuel cells.	7	7	100%	100%	100%
H2, ICE	Hydrogen stored in liquid or gaseous form and used in internal combustion engines.	5	7	100%	82%	92%
MeOH, FC	Methanol used in fuel cells.	7	6	100%	100%	100%

Technologies considered in the pathways	*Description*	*TRL (1-9) vessel application*	*TRL (1-9) fuel/energy production and supply*	*Emission reduction potential (in an ideal upstream chain)*		
				GHG/CO2e	*NOx*	*Particulate matters*
MeOH, ICE	Methanol used in internal combustion engines.	5	6	100%	82%	92%

Source: CCR (2022)

23. Nonetheless, battery technology has made significant progress. Battery-electric driven vessels have been operational in the ports of Rotterdam and Antwerp since 2017 (CCNR, 2020). At the time of writing, Emperium,[9] a Russian Federation based pioneering electric vessel manufacturing company, is launching electric vessels for regular passenger transportation and leisure voyages in multiple cities across the Russian Federation.[10] Additionally, electric vessels utilizing energy container technology have been operating on inland waterways of the Netherlands since 2021 (Box 1).

Box 1

First electric inland navigation vessel in the Netherlands

In a significant stride towards emission-free inland shipping, the Alphenaar, the first Dutch electric inland (navigation) vessel was launched in September 2021. Manufactured by Rotterdam-based Zero Emission Services (ZES), the vessel operates between Alphen aan den Rijn and Moerdijk, serving Dutch beer giant Heineken by transporting hundreds of containers of exported beer along this route. The Alphenaar utilizes ZESpacks, which are standard 20ft containers filled with batteries charged with green energy. These energy containers are equipped with safety and communication systems, and consist of 45 battery modules totalling 2 MWh, equivalent to the capacity of about 36 electric cars.

With a ZESpack of 2000 kWh, a barge can sail for 2 to 4 hours. By having two ZESpacks on board, it can travel 60 to 120 km. Initially, when there was only one charging station, two ZESpacks were required for the round trip of the Alphen aan den Rijn – Moerdijk route, with one for the outbound journey and one for the return trip. In terms of scaling, ZES envisions to establish 30 zero-emission routes by 2030.

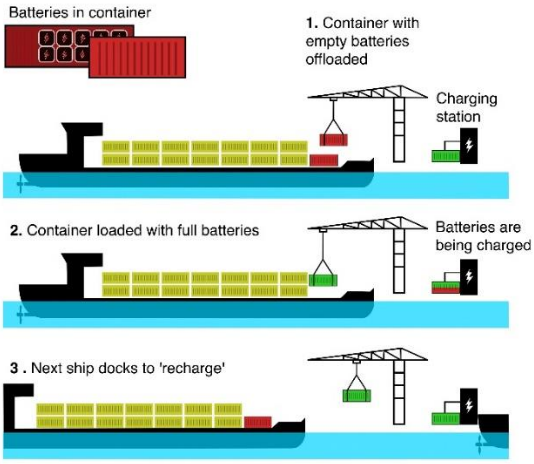
Swappable batteries and charging infrastructure

A ship departs with charged battery containers and, upon arrival at the next terminal, the containers are replaced with fully charged batteries in just 15 minutes. This innovative initiative has set a new standard for energy container technology. The fast-charging station has a capacity of 1 MWh and can recharge two ZESpacks simultaneously in 2.5 hours. The station costs approximately 1 million euros and can also be used to stabilize the electricity network or provide electricity temporarily at a facility. 20 charging stations will be needed to cover the Dutch IWT network.[11]

[9] https://emperium.ru/en/

[10] https://en.portnews.ru/news/338161/

[11] www.volkskrant.nl/nieuws-achtergrond/containers-vol-met-accu-s-vervangen-diesel-in-de-binnenvaart-hier-gebeurt-echt-iets-voor-milieu-en-klimaat~bf53e963/



Source: de Volkskrant (2021)

Key success factors

- Batteries are compatible with both new and existing vessels, requiring ships to be equipped with an electric propulsion line. The Alphenaar itself was retrofitted with the standard connector to accommodate the ZESpacks.
- Interchangeability is a feature which was previously limited to stationary installations. The energy containers can be easily swapped, and the standardized connectors are designed to adapt to advancements in energy storage technology, ensuring the system remains future-proof.
- The adoption of a pay-per-use model, where ship owners rent the battery container and pay only for the energy they use.
- Open access, allowing multiple providers and modalities to use the ZESpacks and charging stations.

Stakeholders' cooperation plays a crucial role. ZES was founded by ENGIE, ING (responsible for the financing and development of pay-per-use package), Wärtsilä (supplier of the initial ZESpacks, responsible for assembling and testing the energy containers), and the Port of Rotterdam, with support from the Ministry of Infrastructure and Water Management.

Source: Port of Rotterdam. Available at https://www.portofrotterdam.com/nl/nieuws-en-persberichten/eerste-emissievrije-binnenvaartschip-op-energiecontainers-in-de-vaart. Accessed on 29 May 2023.

H. Aviation

24. Aviation currently accounts for around 2.5 per cent of the global CO_2 emissions.[12] Without significant action to reduce emissions, the demand for flying is projected to increase by over 300 per cent compared to 2005 levels by the mid-21st century, resulting in a substantial rise in aviation's GHG emissions, according to the European Commission.[13] However, the aviation industry is actively exploring innovative approaches to incorporate electric mobility. Currently, electric mobility in aviation primarily applies to small vehicles that can operate on electricity. However, these vehicles have a lower payload capacity due to the weight of electric systems and batteries, which reduces the overall load capability of the aircraft.

[12] https://ourworldindata.org/co2-emissions-from-aviation#:~:text=Aviation%20accounts%20for%202.5%25%20of%20global%20CO2%20emissions&text=Most%20flights%20are%20powered%20by,to%20CO2%20when%20burned.

[13] www.weforum.org/agenda/2021/07/targeting-true-net-zero-aviation/

25. In September 2020, ZeroAvia, a startup, completed the world's first hydrogen fuel cell powered flight of a commercial-grade six-seat aircraft. The demonstration showcased a range similar to busy major routes such as Los Angeles to San Francisco or London to Edinburgh.[14]

26. When it comes to commercial aviation, specifically fixed-wing passenger aircraft, developing hybrid-electric models presents significant challenges with existing technology. The transition to electric propulsion in large aircraft, such as commercial airliners, introduces various technical and operational difficulties. Designing an effective hybrid or fully electric commercial aircraft is daunting due to the limited energy density of current batteries, the need for long-range flights, and high passenger and cargo loads. Nevertheless, these challenges are not insurmountable, and numerous aviation industry experts recognize the potential in electric and hybrid-electric aircraft development. Research and development efforts are taking place worldwide with the aim of making electric commercial aviation a reality.

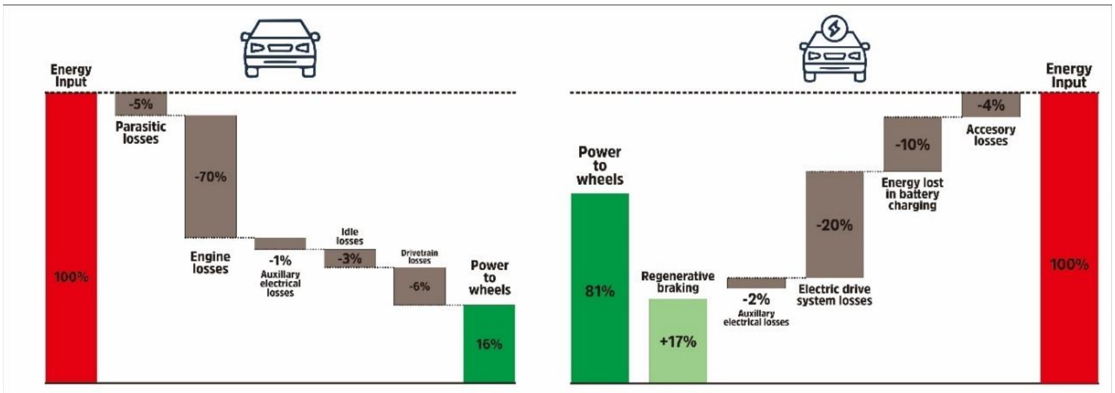
27. Airbus recently unveiled three zero-emission commercial aircraft concepts expected to be operational by 2035. These concepts include a turboprop design capable of seating up to 100 passengers, a turbofan design for 120-200 passengers, and a 'blended-wing body' design for up to 200 passengers.[15] Concurrently, Boeing is also working towards certifying a battery-electric aircraft through its joint venture, Wisk, while setting a target to achieve 100 per cent Sustainable Aviation Fuel (SAF) capability on all its planes by 2030.[16]

III. Battery electric and alternative fuels

A. Battery electric

28. Battery electric propulsion systems have emerged as a robust and sustainable alternative to conventional fuel sources across all modes of inland transport. This technology offers significant advantages over other alternatives. Batteries offer a 100 per cent reduction in GHG/CO_2e emissions and harmful pollutants, making them instrumental in mitigating climate change impacts. Additionally, BEVs are highly efficient, channeling around 80 per cent of the grid's electrical energy to the wheels. In stark contrast, internal combustion engine vehicles (ICEVs) are five times less energy-efficient due to energy losses incurred during the production, transportation, and conversion of fuels (Figure II).

Figure II
Efficiency of BEVs is five times higher than that of ICEVs



Source: Author, based on Energi Media (2021)

[14] www.zeroavia.com/press-release-25-09-2020

[15] www.airbus.com/en/newsroom/press-releases/2020-09-airbus-reveals-new-zero-emission-concept-aircraft

[16] https://investors.boeing.com/investors/news/press-release-details/2023/Boeing-Doubles-Sustainable-Aviation-Fuel-Purchase-for-Commercial-Operations-Buying-5.6-Million-Gallons-for-2023/default.aspx

29. While the upfront cost of BEVs may exceed that of other fuel-powered vehicles, they typically have lower operational costs. This is because electricity is less expensive than fossil fuel and hydrogen on a per-kilometer basis, leading to lower lifecycle costs. However, to reach sustainability targets, batteries need to showcase ultra-high performance exceeding their current capabilities. This ultra-high performance encompasses near-theoretical limits of energy and power, excellent durability and reliability, and enhanced safety and environmental sustainability. Furthermore, these high-performance batteries must scalable to facilitate cost-effective mass production, ensuring commercial success. Rechargeable batteries with exceptional round-trip efficiency are a vital technology, enabling energy storage for a plethora of applications. This significance is also reflected in the European Green Deal. Batteries have the potential to expedite the transition towards sustainable and intelligent mobility, support the supply of clean, affordable, and secure energy, and encourage the industry to embrace a cleaner, circular economy. (Battery 2030+, 2022)

B. Hybrid vehicles

30. Hybrid electric vehicles (HEVs) are a combination of ICEVs and BEVs. Some HEVs use gasoline or diesel to fuel a generator that charges a battery and/or powers an electric motor that propels a vehicle. Other HEVs use an ICE to propel a vehicle while an electric motor assists during acceleration. PHEVs are HEVs whose batteries can also be charged by plugging the vehicle into a power source. This means PHEVs can operate as either a BEV or a HEV.

31. Hybrid vehicles represent an important steppingstone in the transition to BEV technology. This technology has seen widespread adoption due to its many advantages, yet there are also several disadvantages to consider when comparing it to other alternative fuel sources (Table 2).

Table 2
Advantages and disadvantages of hybrid technology

Advantages	*Disadvantages*
(a) Better fuel efficiency than conventional ICEVs	(a) Higher upfront cost compared to conventional ICEVs
(b) Produce fewer emissions than conventional ICEVs, but not as clean as BEVs	(b) For longer journeys, hybrid vehicles depend on their ICE, negating some of the environmental benefits
(c) Do not solely rely on charging infrastructure, unlike BEVs	(a) The dual nature of hybrid vehicles introduces more complexity than traditional ICE or BEVs, which can potentially lead to higher maintenance costs.
(d) Can travel longer distances without refuelling compared to BEVs	(d) While cleaner than conventional ICEVs, hybrid vehicles cannot compete with BEVs or FCEVs. They also do not fully take advantage of renewable biofuels as some other vehicles might.

C. Hydrogen

1. Hydrogen truck

32. Hydrogen fuel cell technology has emerged as a promising solution for long-haul trucking, which poses a range of challenges such as long distances, unpredictable routes, strict driving-time regulations, high uptime requirements, and the need for high payload capacity. To address these challenges, hydrogen-powered fuel offers several advantages, including high energy density, fast refueling times, and a long driving range. This technology works by converting hydrogen gas into electricity through a fuel cell, which powers the vehicle's electric motor. Unlike traditional fossil fuels, hydrogen fuel cells produce only

water vapor as a byproduct, making them a clean and sustainable alternative for long-haul trucking.

33. McKinsey predicted that by 2035, as many as 850,000 hydrogen-fueled medium- and heavy-duty trucks (MDTs/HDTs) could be on the road in Europe.[17] It also argues that by 2030, the TCO to operate an HDT traveling 500 kilometers per day in Europe is estimated to reach €1.13 per kilometer for diesel, €1.03 for battery electric trucks, and €1.02 for fuel cell trucks.

34. Despite this significant development progress, there are still a number of challenges that must be addressed in order to fully realize the potential of hydrogen fuel cell technology for heavy duty transport. One of the most pressing challenges is the need for a robust infrastructure for producing, storing, and distributing hydrogen fuel. In many parts of the world, this infrastructure is still limited, which makes it difficult to scale up the use of hydrogen in heavy duty transport. There is a need to develop business models that can facilitate this process. Another major challenge is the cost of hydrogen fuel cell technology relative to conventional diesel engines. Although the cost of hydrogen fuel cell technology has been declining in recent years, it remains higher than that of diesel engines in most cases. However, as the technology continues to improve and economies of scale are achieved, the cost differential is expected to narrow.

Box 2

Switzerland drives forward with hydrogen truck fleet

Switzerland is leading the way in the decarbonization of heavy-duty transport by deploying fuel cell electric trucks. As of October 2022, 20 companies operating at least one heavy-duty hydrogen-electric truck have together driven over 5 million kilometers using 47 Hyundai XCIENT Fuel Cell trucks, covering more than 10,000 km per day and saving over 4,000 tons of CO_2 emissions. [18] Total deployment of 1,600 trucks by 2025 is planned (IEA, 2022a).

Switzerland's success in the deployment of fuel cell trucks can be attributed to a combination of factors, including supportive government policies, a well-developed hydrogen infrastructure, and a strong commitment from industry players. The country has set targets for medium- and heavy-duty fuel-cell electric vehicles to make up 8 per cent of sales by 2025 and 19 per cent by 2050.[19] It also adopted the LSVA (performance-related heavy vehicle charge) road tax in 2018 that levies trucks weighing more than 3.5 tons but waives the fee for ZEVs (IEA, 2022a). This tax relief is estimated to lead to an annual saving of around CHF 60,000 per truck.[20]

2. Hydrogen train

35. Hydrogen use in passenger rail is beginning to take off, especially in Europe. Hydrogen offers a solution to decarbonizing diesel rail lines where electrification is difficult and the distances are too far to be covered by battery electric trains (IEA, 2022a). There are ongoing efforts to improve the technology and infrastructure for hydrogen trains as more countries and regions invest in this technology. The deployment of hydrogen trains in the ECE region has been driven by the need for sustainable and clean transportation options, particularly in non-electrified rail lines.

36. Several countries including Germany, Italy, the Netherlands and Austria have tested the deployment of hydrogen trains in regular passenger service. Germany has had success with two hydrogen trains, which operated in regular passenger service for over a year and a half between 2018 and 2020, covering more than 180,000 kilometers. In 2022, there were 14 hydrogen-powered trains in operation in Germany, as part of the 41 trains ordered in

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[17] www.mckinsey.com/capabilities/operations/our-insights/global-infrastructure-initiative/voices/unlocking-hydrogens-power-for-long-haul-freight-transport

[18] https://hyundai-hm.com/en/2022/10/15/on-the-road-together-20-hydrogen-electric-trucks-drive-the-5-millionth-kilometer-together-2/

[19] www.iea.org/data-and-statistics/data-tools/global-ev-policy-explorer

[20] www.linkedin.com/pulse/switzerland-champion-hydrogen-roland-jansen/

Germany, replacing the existing diesel fleet. The trains have a range of approximately 1,000 kilometers.[21]

Figure III
Alstom's Corodia iLint hydrogen train

Source: Alstom[22]

D. Other alternative fuels

37. Biofuels, derived from organic matter such as plants or animal waste, have the potential to play a crucial role in reducing GHG emissions from the transportation industry, especially in the freight transport sector, as they are well-suited for long-distance travel. Biofuels are considered to be carbon-neutral, as the CO_2 emissions from burning the fuel are offset by the CO_2 absorbed during the growth of the plants used to produce the fuel. B100 reduces lifecycle GHG emissions by more than 50 per cent, while B20 at least 10% (EPA, 2014). Biofuels can be used in most gasoline and diesel engines with minimal modifications. Additionally, biofuels offer the added advantage of promoting demand for agriculture products. However, it is crucial to be mindful of the potential competition with food crops and take necessary precautions to avoid any adverse effects. In conclusion, the role of biofuels to complement electric mobility in long-haul freight transport needs to be strengthened.

38. Synthetic fuels, created through a chemical process from a carbon source, can be utilized in ICEs. These fuels, like methanol or dimethyl ether (DME) typically have a higher carbon footprint than biofuels due to the carbon source's fossil fuel origin. The use of synthetic fuels may require considerable changes to engine design and fueling infrastructure.

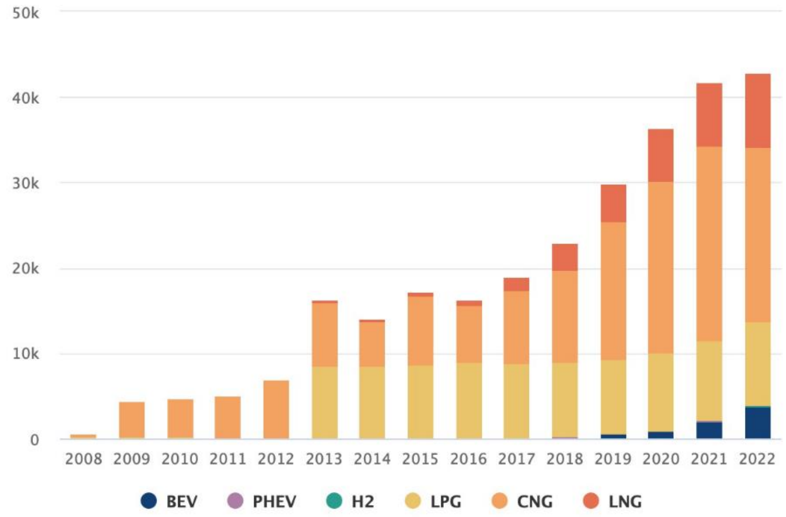
39. Natural gas is becoming an increasingly viable alternative to gasoline and diesel due to technological advancements. It offers higher cost-effectiveness, typically costing 30-40 per cent less than diesel fuel.[23] This has led to its widespread use in various countries, with compressed natural gas (CNG) and liquefied natural gas (LNG) being the most common forms. Countries with significant natural gas reserves, have adopted the use of natural gas as a fuel source. CNG is primarily used for commercial vehicles and light- to medium-duty vehicles, while LNG is a better substitute for diesel in HDVs. This aligns with the indicative distances provided by European Union (2014) which suggests distances between refueling points: 150 km for CNG and 400 km for LNG. In the European Union, CNG has emerged as the dominant choice of fuel in the heavy-duty truck market, followed by LNG. the past decade, both fuel types have witnessed a significant increase (Figure IV).

[21] https://fuelcellsworks.com/news/friday-fallback-story-worlds-first-hydrogen-trains-enter-regular-passenger-service-july-26-2022/#:~:text=BREMERVORDE%2C%20Germany%20—%20The%20world%27s%20first,of%20the%20city%20of%20Hamburg.

[22] https://www.alstom.com/press-releases-news/2021/6/coradia-ilint-alstom-presents-worlds-first-hydrogen-passenger-train

[23] www.iru.org/system/files/IRU%20Position%20-%20Accelerating%20the%20decarbonisation%20of%20road%20transport%20through%20the%20faster%20update%20of%20alternative%20fuels.pdf

Figure IV
European Union heavy-duty truck market, fuel type distribution



Source: European Alternative Fuels Observatory.[24] Accessed on 5 June 2023.

IV. Battery electric vehicles as the future of sustainable inland transportation

40. The future of sustainable and efficient inland transportation lies predominantly in BEVs. This is primarily due to their ability to significantly reduce GHG/CO2e emissions and harmful pollutants, essential characteristics to counteract climate change. With a high efficiency rate of around 80 per cent of the grid's electrical energy reaching the wheels, BEVs drastically surpass ICEVs and hybrids, which are five times less energy efficient.

41. Despite initial higher upfront costs, BEVs generally have lower operational expenses. This is a result of electricity being cheaper than fossil fuel and hydrogen per kilometer, ultimately leading to a reduced lifecycle cost. Additionally, ongoing advancements in battery technology aim to enhance performance, durability, safety, and scalability, vital factors in achieving cost-effective mass production and supporting a cleaner, circular economy.

42. Hybrid vehicles serve as a critical intermediary in the transition towards fully electric vehicles, blending elements of both ICEVs and BEVs. Nevertheless, they carry several disadvantages, including a higher upfront cost, reliance on ICE for longer journeys, potential for higher maintenance costs due to dual-system complexity, and, crucially, they still produce emissions, albeit lower than traditional ICEVs.

43. Hydrogen fuel cells present promising developments for long-haul trucking due to high energy density, fast refueling times, and clean energy production, as seen in Switzerland's leading example. However, significant challenges related to infrastructure, distribution, and cost must be addressed before their full potential can be realized.

44. Biofuels, synthetic fuels, and natural gas are additional viable alternative fuels, each with their unique strengths and limitations. But their benefits do not surpass the profound positive environmental impact and economic efficiency offered by BEVs. Hence, BEVs, backed by ongoing advancements in battery technology, remain the frontrunners in ushering in a sustainable future for inland transportation. This emphasizes the urgency for industries, governments, and society to focus on accelerating the adoption and development of BEV technology.

45. Based on the analysis in this chapter, it can be concluded that electrifying the road transport sector appears to be the most mature and promising solution in the near term. Given the advantages of battery electric technology over other alternatives, subsequent chapters in

[24] https://alternative-fuels-observatory.ec.europa.eu/transport-mode/road/european-union-eu27

the publication (covered in documents ECE/TRANS/WP.5/2023/6, ECE/TRANS/WP.5/2023/7, and ECE/TRANS/WP.5/2023/8) will focus on various modes of battery-electric road transport.