CER
The Voice of European Railways

Position Paper

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Alternative Propulsion Technologies in the European Railway Sector

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Executive summary

- **Rail is already one of the lowest-carbon modes of transport**, but reducing the remaining diesel-related emissions is essential to fully decarbonise the sector and position it as the leading sustainable alternative to more carbon-intensive transport modes.
- **Electrification remains the most effective solution to decarbonise the railway system**, although **alternative propulsion technologies are relevant in several cases**. These solutions include **biofuels, batteries, hydrogen**, and others.
- **Mature alternative propulsion technologies already exist**, capable of replacing diesel in both passenger and freight operations, where electrification, although technically the most efficient and powerful solution, is not economically feasible.
- **A technology-neutral approach is essential** to ensure implementation of the most economically suitable solutions depending on specific conditions.
- **EU support is critical to enable the large-scale deployment of mature technologies, if we want to achieve our decarbonisation objectives.**
- **Standardisation efforts should continue** through CEN/CENELEC and EuroSpec, but **the premature inclusion of alternative propulsion technologies in the Technical Specifications for Interoperability (TSI) should be avoided** to preserve flexibility, support innovation, and prevent technological lock-in.
- However, **minimum essential requirements where consensus can be achieved should be included in TSIs to avoid diverging solutions, prohibiting interoperability**. Furthermore, **disparity in the application of regulations between the different transport sectors for decarbonisation technology (such as hydrogen or biofuels) remain an issue**.
- **Synergies with military mobility**: dual-mode (electric/diesel) and dual-use rolling stock could be promoted to enhance railway resilience (i.e. in case of power outages), support civilian operations, and reduce emissions relative to diesel-only trains.
- Alternative propulsion technologies for military mobility could be introduced progressively, in step with advances in civilian applications.

1. Introduction

Accounting for less than 0.5% of EU transport greenhouse gas emissions[1], rail is already a frontrunner in Europe's decarbonisation. While this makes the rail sector a key enabler of the EU's climate objectives under the European Green Deal and the Paris Agreement, it also highlights the challenge: to go even further, the sector must address the remaining sources of emissions, primarily from diesel-powered trains.

In most cases, electrification of the network remains the most efficient and mature solution to decarbonise rail operations, and the railway system is actively transitioning to electrification. According to Eurostat the percentage of electrified railway lines increased from 53.8% to 57.4% from 2013 to 2023. Over 80% of the service provided by trains in the EU relied on electricity to operate.[2] **However, it is not feasible to electrify every line, yard or depot completely.** The cost of installing overhead contact lines (OCL) can be prohibitively high, especially in rural or low-traffic routes where a full cost-benefit return is lacking. In some cases, geographical characteristics or older infrastructure, such as tunnels and heritage lines, present technical constraints that make electrification extremely complex, if not impossible. **As a result, diesel traction continues to play a critical role in ensuring connectivity and mobility across Europe. It is also a contributor to resilience with regard to growing military mobility needs.**

The rail sector is fully aware of this challenge and is working actively to both maintain and revive non-electrified lines while seeking sustainable alternatives to diesel. **Several alternative propulsion technologies are already in use or under exploration**, especially for regional passenger services, where technological maturity and operational experience are more advanced. Nonetheless, freight applications are also within the scope of innovation and should not be overlooked.

With this position paper, **CER aims to showcase the readiness of the sector to implement sustainable alternatives to diesel-powered trains and to advocate for a European strategy supporting their deployment.** These alternatives include **biofuels, batteries, hydrogen**, and others. They contribute not only to further decarbonisation of the rail sector but also **reinforce rail's position as a one of the cleanest and most efficient alternative to other transport modes**, providing an additional argument to accelerate modal shift in support of Europe's climate goals.

[1]European Environment Agency (EEA). *Share of transport GHG emissions* (dataset/analysis).
[2]Eurostat. *Characteristics of the railway network in Europe* (statistical overview).

2. Advocating for a use case-based approach

Given the differences in energy and power requirements across rail applications such as shunting locomotives, freight trains, and passenger multiple units, and considering the diversity of local conditions including infrastructure availability, regulatory environment, and funding support, **it is essential to adopt a use case-based approach. This ensures that decarbonisation solutions are both effective and economically viable.**

This section outlines the range of alternative propulsion technologies available for rail and showcases concrete examples from CER members demonstrating their implementation in both passenger and freight operations. It underscores the importance of selecting the most suitable alternatives to diesel traction based on clearly defined criteria.

2.1. Overview of alternative propulsion technologies available for rail

CER focuses on three main categories of alternative propulsion technologies for rail: **biofuels** (including the special case of liquified natural gas), **batteries**, **hydrogen** and other renewable fuels from non-biological origin (RFNBO).

A key distinction is made between **bridge solutions**, which reduce CO_2 emissions and can be implemented in the short to medium term with existing or adapted infrastructure, and **long-term alternatives**, which align with the full transition towards decarbonisation.

Hybrid and dual-mode options that combine overhead contact lines, batteries, diesel, biofuels, and/or hydrogen are considered, as they provide operational flexibility and enable stepwise decarbonisation.

In addition, **retrofitting existing rolling stock** (modernising aging fleet and converting it to more sustainable alternatives) is a viable option to examine. It is either possible to integrate an on-board energy storage system or to modify the engine to support the use of biofuels, thereby reducing emissions, lowering capital investments, and lengthening the asset’s life cycle.

To support this analysis, the paper includes a table that provides a qualitative overview of alternative propulsion technologies from the user's perspective within the railway sector. Each option is assessed based on key criteria, including the maturity of the technology, the extent of modifications required to rolling stock and infrastructure, CO_2 emissions, resource availability, and overall energy efficiency. A more detailed description of each technology is available in the annex.

Table 1 - Qualitative summary of alternative propulsion technologies available for rail

Technology/ Assessment criterion	CO_2 Emissions	Availability of resources	Modifications needed (Rolling Stock/ Infrastructure)	Energy efficiency	Maturity
Diesel (for comparison)	High	High	None	Medium	Very high
Bridge solutions					
Dual-mode (Catenary/Diesel)	Medium-High	High	None	Medium-High	Very high
Liquefied Natural Gas (LNG)	Medium-High	High	Low-None	Medium	High
Biofuels					
FAME	Medium	Medium	Low-None	Medium	High
HVO	Low-Medium	Medium-High	Low-None	Medium	High
Dual-mode (Catenary/Biofuel)	Low-Medium	Medium	Low-None	Medium-High	High
Liquefied Biogas)	Low-Medium	High	Low-None	Medium	High
Batteries					
Hybrid (Battery/Diesel)	Low-Medium	Medium-High	Low-None	Medium-High	High
Renewable fuels from non-biological origin (RFNBOs)					
Hydrogen ICE	Low-Medium	Low	Medium*	Low	Low
Combined alternative solutions					
Tri-mode (Catenary/Battery/ Diesel or Biofuels)	Low-None	High	Medium	Medium-High	High
Hybrid (Battery/Biofuels)	Low-None	High	Medium	Medium-High	High
Long-term solutions					
Batteries					
Dual-mode (Catenary/Battery)	Low-None	Medium	Low-Medium	High	High-Medium
Batteries only	Low-None	Medium	Medium	High	High-Medium
Renewable fuels from non-biological origin (RFNBOs)					
Hydrogen Fuel Cell (H_2 FC)	Low-None	Low-medium	Medium*	Medium-Low	Medium
Dual-mode (Catenary/H_2 FC)	Low-None	Low	Medium*	Medium	Medium
Ammonia	Low-None	Low	High	Low	Low

*High in terms of rolling stock but lower in terms of infrastructure, since only the installation of hydrogen refuelling stations is needed.

2.2. Use cases from CER members

2.2.1. France

In France, SNCF is actively involved in many projects aiming for the decarbonisation of its activities.

- **B100 Paris-Grandville**

In April 2021, SNCF launched an experiment: 15 Régiolis trainsets began commercial operation on the Paris-Granville line, powered by B100 biofuel from 100% French rapeseed. Since then, it's more than 9.7 million km travelled with 31,500 tonnes of CO_2 saved.

- **Dual-mode HYBRID REGIOLIS**

SNCF, together with train manufacturers Alstom and CAF, and with the financial support of 4 Regional Transport Authorities, undertook the hybridisation of an existing electric/diesel Multiple Unit (E/DMU) into an electric/diesel/battery Multiple Unit (E/D/BMU). 2 out of the 4 diesel powerpacks were replaced by 2 high-power lithium-ion Energy Storage Systems (ESSs). After more than a year in commercial operation and 70,000 km performed, the hybridisation has far proven to be a technical success by reducing by 20 % its energy consumption. In addition, it can run on its sole batteries for 10 to 20 km in urbanised areas and particularly stations. The dual-mode hybrid REGIOLIS is currently operating around Toulouse (France).

- **Dual-mode AGC – BEMU**

SNCF, together with train manufacturer Alstom, and with the financial support of 5 Regional Transport Authorities, undertook the modification of 5 existing electric/diesel Multiple Units (E/DMU) into electric/Battery Electrical Multiple Units (E/BEMU). The entire diesel traction system is being replaced by lithium ESSs. Charged under overhead lines, the batteries can also recover braking energy and reuse it, for an energy saving of around 20%. On non-electrified lines, they offer a range of at least 80 km. They will enter commercial service in 2026, and their operation will not require any modification to the current infrastructure. However, infrastructure investments will be necessary to enable the deployment of BEMU fleets. This will involve enhancing the current infrastructure, strengthening it (1.5 kV DC), electrifying terminus stations and implementing partial electrification of certain lines with the objective of increasing the time and opportunities for batteries loading.

- **Dual-Mode REGIOLIS H2**

In 2021, 4 Regional Transport Authorities ordered 12 Dual-Mode train with an innovative hydrogen powered traction system. These trains will be in commercial service in 2026 on energy challenging lines with a required autonomy up to 600 km. It should be noted that REGIOLIS H2 carry also batteries, allowing braking recovery and low speed manoeuvre. A hydrogen train project is not only about rolling stock but also infrastructures for maintenance (workshop) and refuelling stations. Their location should be carefully selected depending on several criteria as footprint availability, distance from the usage, local regulations and constraints...

SNCF is investigating different solutions knowing that there is not a unique solution to decarbonise rail transport. By using dedicated simulation tools, SNCF addresses the diversity of line profiles and operating constraints of passenger and freight trains with battery and hydrogen traction to map area of relevance and to define the energy and power requirements. Going forward, both battery and hydrogen technologies have their relevance depending on the technological solutions, infrastructure, and desired transport service.

2.2.2. Belgium

Belgium's SNCB/NMBS is moving towards modernising its regional fleet by prioritising electrification and exploring innovative alternatives for its remaining diesel-operated lines.

- **New EMUs fleet AM30 with dual-mode (catenary/battery) option**

A new fleet of electric multiple units (EMU) labelled AM30 will be operated after 2030, when the existing diesel trains AR41 will be gradually put out of service. As an option, some of those new trains can be equipped with batteries.
As the main network is 90% electrified and the 5 remaining non-electrified lines are relatively short, the longest branch line being up to about 50 km, and mostly single-track, hydrogen trains are not necessary and more expensive to operate, even when hydrogen related infrastructure is already available on the right locations.
To reduce the total cost for the railway sector, a compromise has been reached between infrastructure manager Infrabel and railway undertaking SNCB/NMBS to partly electrify these remaining non-electrified lines and build charging infrastructure in the stations at the end of the branch lines, avoiding complete electrification on the one hand and unnecessary oversized and heavy batteries on the other.
As the main traction power supply system in Belgium is the 3 kV DC system and differs from the ones in the 4 neighbouring countries France & Luxemburg (25 kV AC), Germany (15 kV AC) and the Netherlands (1.5 kV DC), these new battery trains could be more easily used for all cross-border operations than specific multi-system trains for each use case. This of course only holds under a few extra conditions like compatibility with the ETCS onboard the new AM30 trains. The distances on battery mode across the borders shall remain short and not have an impact on the dimensions of the batteries.

For some of the remaining non-electrified lines, electrification remains the preferred and most powerful option, even when foreseen traffic is too low to create a positive business case, because these lines then could serve as alternative routes for conventional electric trains, adding robustness and flexibility to the network.

2.2.3. Italy

In Italy, FS Group is developing solutions to replace its diesel fleet. Apart from their tri-modal regional train, which entered passenger service in 2022 and uses catenary, diesel and battery power, the group is also exploring biofuels to significantly reduce CO_2- and particle emissions during operation.

- **Hydrotreated Vegetable Oil (HVO)**

To achieve its 2030 goals, Trenitalia believes that the use of HVO currently represents one of the best solutions for immediately reducing the environmental impact of diesel traction. Thanks to its compatibility with existing engines and the absence of infrastructure requirements, HVO biofuel presents itself as a strategic resource for the transition phase, while awaiting completely zero-emission mobility.

- **Bio-liquefied natural gas (Bio-LNG)** or liquefied biogas

Fondazione FS, the company within the FS Group who takes care of the historical heritage, unveiled the first two historic railcars powered entirely by bio-LNG in 2025. The conversion of the first two ALn 668 railcars, carried out at Trenitalia's Cycle Maintenance Workshops in Rimini, involved converting them from diesel to LNG, a fuel that significantly reduces polluting emissions of nitrogen oxides, sulfur oxides, and particulate matter, and reduces climate-altering carbon dioxide emissions by 20%. This conversion will also allow the railcars, without any other engine modifications, to also use Bio LNG, a biofuel capable of reducing CO_2 emissions by an average of 80%.

The Italian mobility operator and infrastructure manager, FNM Group, is a pioneer in Europe in the development of hydrogen rail, notably with its involvement in the H2iseO project.

- **H2iseO Hydrogen Valley Project**

The Brescia-Edolo railway is a non-electrified single-track line of approximately 103 km length, passing through Valcamonica, a UNESCO world heritage site in the northern part of Italy. The line features 28 tunnels for a total length of approximately 4,400 m, with a difference in altitude between the two terminus stations of over 500m and it is currently served by a fleet of 14 diesel-powered trains.

In 2019 FNM decide to start a transformation project (H2iseO project) to decarbonise rail traffic on this line, thus considering several alternative options, such as:

- Traditional electrification by over-headline and pantograph;
- Electrification by battery-powered trains;
- Electrification by hydrogen fuel-cell trains.

The option of electrification by over-headline and pantograph was discarded due to the technical complexity related to the size of the tunnels, as reprofiling the tunnels or lowering the rail level would have been necessary in a highly complex geological and morphological context. Furthermore, since the line has no electrification points, not even at the terminal stations, the entire infrastructure would need to be built.
The option of introducing battery-powered trains was discarded due to the plano-altimetric characteristics of the line, and in particular with the fact that a significant part of the height difference of over 500m is concentrated in less than half of the line. As a consequence, trips towards Edolo require significant energy consumption without the possibility of recharging enroute putting the line outside the operating limits (autonomy) of battery trains.
Considering the technology available in 2019, the electrification through hydrogen-powered trains was highlighted as having a comparable autonomy and refuelling time to those of a diesel-powered train. This technology was then selected for the electrification of the line.
To cater for the use of hydrogen trains, as a very limited hydrogen market was and is still available in Italy, the project integrates all the plants and technology for the production of hydrogen and the refuelling of trains.
The H2iseO project thus includes:

- the introduction of 14 hydrogen-powered trains, replacing the entire diesel-powered fleet currently used for the local rail public transport service;
- the construction of 3 renewable hydrogen production plants, directly connected to hydrogen refuelling stations in Brescia, Iseo and Edolo;
- the construction of a new maintenance facility for hydrogen trains only coupled with a hydrogen refuelling station operated through trailers in Rovato.

Train homologation tests and the commissioning of Rovato maintenance facility and hydrogen refuelling station were completed in 2025.
The entry into service of the first batch of 8 trains and of Edolo and Iseo production plants and HRS are expected in 2026.
As the project concept was developed in 2019, in 2020 the company signed a framework agreement and first contract for train procurement (FID) financed through its own resources. Afterwards, the company submitted 3 project proposals under the 1st EU ETS

Innovation Fund Small Scale call for proposals, in order to secure European funding for the 3 renewable hydrogen production plants and refuelling stations. The proposal submitted for the Brescia plant was funded under the EU IFSS, while the one related to the Iseo plant was admitted to the PDA program delivered by EIB on behalf of EC.
Furthermore, in 2021 the hydrogen plants and the HRS of the H2iseO project were included in the Italian NRRP and 97.2M€ allocated accordingly in 2023. In 2022, the Lombardy Region (where the project is located) allocated 86.5M€. The additional public funding provided is thus equal to 183.7 M€.
In 2024, the total cost of the fleet of 14 hydrogen-powered trains (€183.2 million) was funded under the Italian PNRR (84.5 M€), the Italy's Development and Cohesion Fund (68.6 M€) and other national funding schemes (30.1 M€).

2.2.4. Spain

In Spain, Renfe aims to reduce its diesel consumption by 50% between 2023 and 2028 and carbon emissions in traction by 100% by 2030. To achieve their net-zero objective, Renfe is focusing on optimising operations and the use of alternative propulsion systems, including batteries, hydrogen and green biofuels or eFuels. When possible, electrification of tracks is inherently a viable option. ADIF is responsible for constructing, managing, maintaining and modernising the railway network. This includes strategic planning for new lines and overseeing works, such as the electrification of new and existing routes.

- **Potential applications of hydrogen for Renfe**

Renfe is exploring hydrogen as an alternative to diesel for long regional services (over 200km), freight access to branch lines, heritage lines and shunter vehicles. One notable initiative is the FCH2RAIL project (2021–2024), first hydrogen project in the Spanish rail network, which involved retrofitting a Renfe Commuter EMU (Electric Multiple Unit) to operate in dual-mode (catenary/hydrogen), enabling use on both electrified and non-electrified lines.

Overall, Renfe is participating in several Working Parties of Europe's Rail FP4 'Rail4Earth' for the development of alternative propulsion systems. On Hydrogen specifically, the Spanish government has launched an initiative that includes a work line for the use of hydrogen in railways, highlighting both the strategic interest and the emerging business case for its deployment in Spain's railway sector. The Ministry of Transport and Sustainable Mobility recently published a Public Market Consultation to implement sustainable traction as an alternative to electrification. The purpose of this Preliminary Market Consultation is to examine possible alternative and innovative technical solutions and, through a socioeconomic analysis, study the advisability of electrifying a series of lines (or sections of them) or opting for an innovative solution involving the use of trains with alternative traction to diesel, with the ultimate goal of reducing emissions on the national railway network.

2.2.5. Germany

DB Cargo has set itself the target of becoming climate-neutral by 2040 — ten years ahead of the European Green Deal's deadline. To achieve this, the company is working on expanding the share of renewable energies, using alternative technologies and alternative non-fossil fuels such as Hydrated Vegetable Oil (HVO) as well as increasing energy efficiency.

- **Dual-mode (Catenary/Biofuel)**

In 2025, 43 new dual-mode locomotives will be delivered to DB Cargo AG. By the end of 2027, a total of 146 new dual-mode locomotives are expected. These will replace older vehicle types in the shunting diesel locomotive cluster of the 261, 265, and 294 series.

Dual-mode locomotives offer significant advantages in daily use over the diesel locomotives currently in use and are intended to make DB Cargo more efficient and powerful in the future.

- **HVO (Hydrotreated Vegetable Oil)**

DB Cargo's entire diesel locomotive fleet (approximately 1,300 locomotives) has been approved for HVO since the end of 2023. In 2025, DB Cargo plans to further increase HVO quantities to replace fossil diesel in fuelling diesel and hybrid locomotives. For DB Cargo AG, an HVO share of 33% is planned for 2025. As of May 2025, 36% had already been achieved. As a medium-term goal, DB Cargo is pursuing a 50% HVO share in Germany by the end of 2028.

- **Systems designed to reduce energy consumption**
  - Distributed Power System (DPS)

DPS is a locomotive at the rear of a train that can be remotely controlled by the leading locomotive via radio. This not only increases tractive effort by a third, but also doubles the regenerative power and enables heavier and longer trains with only one driver. In March 2025, the project team successfully tested a 3,000-ton DPS train on a five-day test run between Passau and Oberhausen. The system will be in practical use from the second quarter of 2025, and the first steel transports will be converted to DPS mode.

  - Driver assistance system LEADER

The LEADER driver assistance system is currently installed on more than 560 electric locomotives, representing around two thirds of DB Cargo’s electric locomotive fleet. In 2024, its use contributed to a reduction in electricity demand of approximately 12%. As zero- or low-carbon technologies cannot yet be applied on all non-electrified tracks, driver assistance systems provide an interim approach to reducing energy consumption. LEADER has not yet been deployed on diesel-fuelled locomotives, but installation is planned for 2025. The system is being further developed and tested for application on all main-line diesel locomotives. In the first phase, 60 main-line diesel locomotives are scheduled to be equipped in 2025. Expected savings amount to around 4.5% in fuel consumption, equivalent to approximately 307 tons of CO_2 emissions annually for these 60 locomotives.

2.3. Criteria guiding the selection of an alternative propulsion technology

The diversity of approaches to decarbonising the rail sector shows that there is no universal solution.

To ensure progress in the right direction, CER advocates for technology openness, allowing railway undertakings the flexibility to select the technology that best fits their specific needs. This paper enumerates the main selection criteria that must be considered when choosing alternatives to diesel, highlighting the challenges faced by railway undertakings and infrastructure managers, while promoting best practices across the sector.

Several CER members and other stakeholders, such as rail industry, are already leveraging innovative tools, using data analysis, digital twins, or AI-based decision-support systems, to assess these criteria and identify the most appropriate technologies for their unique needs[3].

The characteristics of the use case, such as service type (freight or regional passenger), line topology (gradient, curvature), climate (wind, temperature, humidity, etc.), distance,

[3]Example: Deutsche Bahn. EcoRailSimulator (sustainability initiative).

electrification status, and speed requirements, frame the scope of feasible options. Additional parameters, like maximum operating speed, train tonnage, required acceleration, and traction effort, determine the energy demand and power output needed to ensure reliable service. Each scenario presents unique constraints and opportunities, underscoring the importance of a case-by-case assessment rather than a uniform approach.[4]

To support this assessment, three broad categories of selection criteria must be considered: **technical feasibility, environmental impact,** and **economic viability**.

Technical feasibility involves assessing whether a given technology can meet the specific operational demands. This includes verifying the energy autonomy range (including the necessary studies about the brake regenerative energy, especially important for longer non-electrified routes), the traction power required to handle gradients and heavy loads, and the performance characteristics and ageing profiles of onboard systems such as batteries or hydrogen fuel cells. Infrastructure considerations are equally essential, especially the availability and scalability of recharging or refuelling facilities, as well as the possibility of future electrification. In this context, assessing the technological readiness level (TRL) and the availability of resources is also crucial to ensure that proposed solutions can be effectively implemented and sustained over time.

Environmental impact can be analysed across the full lifecycle of the technology, from raw material extraction and manufacturing to usage and end-of-life. This requires assessing greenhouse gas emissions, local air pollutants, and the environmental burden of constructing and maintaining associated infrastructure.

Finally, economic assessment is crucial to ensuring that the selected solution is not only technically and environmentally sound, but also financially viable. This involves for example calculating the total cost of ownership (TCO), including acquisition, energy consumption and maintenance, as well as infrastructure costs, and evaluating the overall profitability. Additionally, it is important to factor in potential financial support from public institutions, such as subsidies, grants, or tax incentives aimed at promoting decarbonisation.

However, at present, innovative propulsion systems can cost 20% or more per train-kilometre than diesel, depending on the line[5]. Railway operators therefore need support from policymakers, which is why CER outlines key EU-level policy priorities to accelerate rail decarbonisation and enable the deployment of alternative propulsion technologies.

3. Accelerating rail decarbonisation through strong EU policies

To meet the EU's climate objectives and achieve large-scale deployment of alternative propulsion technologies, the rail sector requires a strong and coordinated policy framework. CER identifies two main areas for action: moving from innovation to deployment and anticipating future standardisation and regulatory needs.

3.1. Shifting from innovation to deployment

As explained in this paper, mature solutions exist and are ready for large-scale implementation. The EU is already successfully supporting research and innovation through initiatives such as the four-year FP4-Rail4EARTH project under the Horizon Europe

[4] Belleguie, A. (2023). Energy Transition of Rail Transport: Assessing the competitiveness of decarbonized rail alternatives.
[5] Roland Berger. The future of innovative propulsion in rail (industry report).

funding programme within Europe’s Rail Joint Undertaking. Such projects are essential to developing alternative energy solutions for rolling stock to replace diesel trains. **However, the next step is to shift from innovation to widespread deployment.**

For passenger services, one of the most effective ways to achieve this is by supporting European regions. For instance, French regional authorities have acted as transport organising authorities since 2017 and manage regional rail services (e.g. TER). In Germany, the federal states (*Länder*) have long overseen regional rail operations and are now beginning to deploy battery-electric and hydrogen trains with a mix of federal and regional funding. An example of this are the hydrogen trains implemented since 2018 in Germany by the Lower Saxony federal state and operated by EVB[6]. Regions therefore hold significant decision-making power over railway undertakings and their ability to adopt alternative propulsion technologies. Access to dedicated funding for both the development and long-term implementation of alternative drives across European regions is essential.

For freight operations, deployment efforts should focus on key corridors and terminals where diesel traction remains prevalent. Battery-electric and hydrogen-powered locomotives can offer low-emission alternatives, particularly on last-mile sections. Targeted support is needed to pilot and deploy these technologies in collaboration with freight operators, terminal managers, and infrastructure managers. Development of alternative propulsion technologies in freight will also contribute to achieving the EU’s modal shift and decarbonisation targets. For example, Polish rolling-stock manufacturer PESA is advancing hydrogen-powered solutions such as its SM42-6Dn shunting locomotive prototype, which demonstrates technological progress in low-emission freight operations[7].

To scale up these efforts, European funding instruments are key. The European Regional Development Fund (ERDF) supports investments in sustainable mobility and green infrastructure across EU regions. Additional mechanisms such as the Connecting Europe Facility (CEF Transport), InvestEU, and loans from the European Investment Bank (EIB) offer further opportunities to co-finance rolling stock procurement and supporting infrastructure. Blending these funds with national resources and financing tools like green bonds or public–private partnerships can help accelerate the deployment of alternative propulsion technologies across Europe. In particular, hydrogen projects in rail could be financed through key funding mechanisms under the EU Emissions Trading System (EU ETS), notably the Modernisation Fund and the Innovation Fund.

- The **Innovation Fund** provides substantial grants for pioneering low-carbon technologies, including hydrogen-powered trains and related infrastructure, by covering up to 60% of relevant project costs.
- The **Modernisation Fund**, targeted at lower-income EU Member States, supports the transition to cleaner energy by financing modern energy systems, including hydrogen applications in rail transport.

Both funds are financed through the auctioning of EU ETS allowances, aligning financial support with decarbonisation goals and promoting the deployment of zero-emission mobility solutions across Europe’s rail networks. So far, as presented in the use cases’ section, CER members, such as FNM and Renfe, have benefitted from these funds with (H2iseO Hydrogen Valley Project in Lombardy Italy and FCH2Rail consortium, project in which Spain, Portugal, Germany and Belgium collaborate, thanks to grants).

[6] evb Elbe-Weser (evb). Hydrogen Train (Webpage).
[7] PESA (2023). SM42-6Dn Hydrogen locomotive. (Webpage)

The railway sector as the most sustainable transport mode could provide additional services to the energy sector, keeping electrification and the use of batteries as a long-term objective and a complete electric ecosystem in mind. Until now an often very big and unbalanced load to the public electric grid, increased railway electrification coupled with renewables and future rollout of the alternative battery technologies, for propulsion onboard trains or stationary as new or recycled second life batteries, can help stabilise the public grid, reduce peak demands and even offer additional capacity to supply electric energy to other modes of electric transport when demand from the railway is low. This compatible use of the overall system can further reduce the need for primary energy. Importantly, by positioning itself as an active partner in energy system optimisation, **the rail sector can also benefit from funding synergies with other sectors, particularly the energy sector, tapping into cross-sector financing instruments designed to support renewable integration, grid balancing, and storage solutions.** Such synergies would enable rail projects to access a broader pool of resources strengthening the link between sustainable mobility and clean energy for instance through initiatives such as hydrogen valleys — integrated regional ecosystems that connect hydrogen production, storage, distribution and end-use across sectors, including transport.

In parallel, it is crucial to support the European rail supply industry in expanding production and maintaining technological leadership. Targeted industrial policy can help manufacturers respond to growing demand for zero-emission rolling stock and components. This will ensure that the transition to alternative propulsion technologies also strengthens Europe's industrial base and global competitiveness, like advised in the Draghi report[8].

3.2. Anticipating standardisation and regulation needs

Standardisation is a key enabler for the large-scale deployment of alternative propulsion technologies in the European railway sector. Harmonised standards can reduce costs for railway undertakings, create a volume market for manufacturers, and improve interoperability across borders. While the current priority is to gather feedback from recent use cases, the railway sector must already anticipate future needs for standardisation.

CER supports standardisation and harmonisation efforts led by CEN/CENELEC and EuroSpec and advocates for the development of voluntary technical guidelines instead of mandatory requirements in the Technical Specifications for Interoperability (TSI). This approach preserves flexibility, allows for continuous improvement, and avoids locking in premature choices as alternative propulsion technologies are still evolving. **Minimum essential requirements where consensus can be achieved should still be included in TSIs to avoid diverging solutions, prohibiting interoperability.**

Hydrogen propulsion systems require dedicated safety and interoperability standards adapted to the railway sector. The COG H2 for Rail, a dedicated coordination group within CEN/CENELEC, is leading efforts to align standards for hydrogen trains covering five areas:

- Safe integration of on-board hydrogen storage, propulsion systems, and refuelling infrastructure & processes in road and rail transport.
- Fuel cell systems for propulsion.
- Fuel cell systems for propulsion – performance requirements and test methods.

[8] European Commission. (2024, September 9). The future of European competitiveness: Report by Mario Draghi (the "Draghi report")

- Fuel cell systems for propulsion – hydrogen storage system.
- Rail vehicle hydrogen refuelling equipment.

Any other effect that a hydrogen train may have on the railway network, such as a leak in a tunnel or a side collision at a level crossing.

CER actively supports this initiative, along with the EuroSpec project. In parallel, the International Electrotechnical Commission (IEC) is set to publish hydrogen-specific railway standards in 2025 through IEC TC 105 (Fuel Cell Technologies) and TC 9 (Electrical railway systems). These will complement existing ISO/IEC standards for hydrogen quality, pressure vessels, and fuel cell performance, tailored for use in rolling stock.

Standardisation for battery-powered trains is advancing through initiatives led by IEC and CEN/CENELEC. Committees such as IEC TC 21 / SC 21A and CEN/CLC/TC 9X are working on charging infrastructure with dedicated contact line sections, battery module design, Battery Management Systems (BMS), thermal runaway protection, and performance evaluation. While these initiatives address essential safety and reliability requirements, the sector still faces a lack of harmonised practices. Diverging approaches among manufacturers are creating challenges for infrastructure managers and operators, underscoring the need for convergence on common standards in the near future. Future revisions of the Technical Specifications for Interoperability (TSIs) will be necessary, particularly to address safety considerations and the impact on grid capacity. Preliminary assessments and discussions on these aspects have already been initiated by various stakeholders.

For existing diesel fleets, the use of alternative fuels like biofuels, LNG, and bio-LNG offers an immediate pathway to emissions reduction. Standards such as EN 15940 (paraffinic fuels like HVO) and EN 590 (diesel with up to 7% FAME) are already applicable to railway operations. However, a key gap remains in the standardisation of retrofitting practices. While technical work is underway at national levels and within associations like UIC and UNIFE, there is currently no comprehensive European framework. Moving forward, a coordinated approach under CEN/CENELEC could ensure the safe, interoperable, and efficient integration of retrofitted trains into the EU rail network.

4. Conclusions

4.1. Key messages and CER recommendations

Rail transport already stands out as one of the lowest-carbon modes of transport, yet urgent action is needed to eliminate the remaining diesel-related emissions if the sector is to fully contribute to Europe’s climate ambitions. The transition towards electrification must remain the cornerstone of rail decarbonisation, given its technical superiority and operational efficiency. However, recognising the economic and practical limits of electrification, policy frameworks must equally prioritise the deployment of mature alternative propulsion technologies such as biofuels, batteries, and hydrogen. These solutions are indispensable for areas where electrification is not feasible and must be supported as key enablers of a comprehensive and resilient decarbonisation strategy.

A technology-neutral policy approach is critical to ensure that the most economically viable and context-specific solutions are implemented across diverse rail operations. The European Union must strengthen its commitment through dedicated funding, regulatory incentives, and innovation programmes to accelerate the market uptake of these technologies at scale. Moreover, standardisation bodies such as CEN/CENELEC and EuroSpec should be empowered to develop harmonised technical requirements that safeguard interoperability while maintaining the flexibility necessary to avoid technological lock-in. Premature integration of alternative propulsion technologies into the Technical Specifications for Interoperability should be avoided to preserve innovation and competition.

Addressing regulatory inconsistencies between transport sectors is essential to create a level playing field for decarbonisation technologies, particularly for hydrogen and biofuels. Policy coherence across sectors will enhance market certainty and investment confidence, enabling the sustainable growth of these emerging industries. In this context, policies targeting diesel limitations and the internalisation of CO_2 emission costs could serve as important tools to accelerate decarbonisation.

4.2. For further reflexion: Synergies between alternative propulsion technologies and military mobility

Military logistics require robust, flexible, and autonomous transport solutions that can function in contested or degraded environments, meaning traction solutions must be resilient and capable of operating independently of external power sources. Currently, military operations remain heavily reliant on fossil fuels, particularly diesel, which also necessitates the availability of secure and reliable diesel refuelling stations along operational routes. Meanwhile, the EU rail sector is progressively electrifying. Yet military trains must often circulate on non-electrified routes or last-mile connections to military installations. This divergence presents both a challenge and an opportunity. Dual-mode locomotives, combining electric and diesel traction, can address military needs for flexibility while leveraging the benefits of the electrified rail network when available. These systems are commercially available and could serve as a bridge technology to reinforce both military mobility and the EU's climate objectives. However, the adoption of alternatives to diesel in dual-mode systems, such as batteries or hydrogen, faces technical and logistical constraints, especially given the high-power requirements of freight and military trains and the lack, to this date, of appropriate refuelling infrastructure. Despite these limitations, the potential for synergy remains high if the EU expands its concept of "dual-use" to include rolling stock and traction technologies. Dual-use is a recognised concept under EU law[9] and is applied to rail infrastructure including terminals. The element of additionality can also be applied to rolling stock. While recognising that for military use full diesel locomotives could serve as the baseline solution, dual-mode locomotives offer a compelling alternative, as they can operate efficiently on electrified lines in peacetime (supporting EU objectives of energy efficiency and decarbonisation of transport) while retaining diesel capability to ensure continuity of service during conflict (i.e. electricity supply disruptions), thus simultaneously meeting both civilian and military requirements. Full diesel locomotives (which the EU industry has transitioned from), in theory and if available, new on the market, would imply a lower investment cost (estimated up to 2 to 3m€/unit) than dual-mode solutions with an equivalent capacity and suited for freight haul by rail (estimated from 4 to 5m€/unit). Although retrofitting diesel locomotives into alternative propulsion locomotives (using biofuels, hydrogen or batteries) cannot be excluded as an option, there is no known experience so far with regards locomotives that are fit for the heavier loads military and freight trains imply. In order to create synergies between policy objectives, the EU should consider setting in place the incentives to promote the uptake of dual-mode locomotives, placed new on the market. In this, the EU should set in place a dual-use framework for traction, to enable support from the EU Multiannual Financial Framework and the programs meant to support military mobility, to at least cover the cost difference these assets entail.

[9]Commission Implementing Regulation (EU) 2021/1328 of 10 August 2021

5. Annex – Definitions and complementary information

- Bridge solutions:

Interim technologies or measures that reduce CO_2 emissions compared to traditional diesel trains but still produce some direct carbon emissions during operation. Examples include biofuels and hybrid trains (diesel/battery). These solutions act as transitional steps to lower emissions while allowing time for infrastructure and technology to evolve.

- Long-term solutions:

Sustainable, low- or zero-emission technologies that enable full decarbonisation of rail transport in the future. These solutions are carbon-free during operation, do not rely on fossil fuels, and aim for net-zero CO_2 emissions overall. Examples include hydrogen-powered trains, battery-electric trains, and fully electrified rail systems.

5.1. Bridge solutions

5.1.1. Biofuels

- Fatty Acid Methyl Esthers (FAME) are produced from vegetable oils, animal fats or waste cooking oils by a relatively simple and low-energy process called transesterification. While FAME can be blended with conventional diesel, using it in its pure form (B100) requires minor engine modifications, such as filter checks and elastomers compatibility. FAME offers CO_2 reductions of up to 70% compared to fossil diesel. However, its availability depends on regional feedstock supply, and it poses some challenges in terms of cold-weather performance and long-term storage.
- Hydrotreated Vegetable Oil (HVO) is produced through the hydrotreatment of vegetable oils and animal fats, an energy-intensive process requiring high temperatures, pressures, and hydrogen input. Despite the higher energy demand during production, HVO offers superior fuel quality: it is chemically very similar to fossil diesel and can be used directly in existing diesel engines without any technical modifications, making it a true “drop-in” fuel. HVO can reduce CO_2 emissions by up to 90% during operation, although its production depends on the availability of sustainable feedstocks and access to hydrogen. Typically, the oil used is of recycled origin. However, most used oils are imported from Asia, where concerns have arisen over fraud involving the substitution of used oils with virgin palm oil, a practice currently under investigation by the European Commission. Another consideration is the limited number of producers and the competition for feedstocks with the road transport sector. A key advantage of HVO is its compatibility with existing refuelling infrastructure, allowing continued use of current systems.

FAME and HVO allow to exit from fossil fuels, as they are produced from animal fats, vegetable oils or waste cooking oils.

5.1.2. Liquefied natural gas (LNG) and Bio-LNG or liquefied biogas

Liquefied natural gas (LNG) is natural gas, predominantly methane, converted into liquid form for ease of storage or transport. It is a fuel that makes it possible to greatly reduce polluting emissions of nitrogen oxides, sulphur oxides and particulates (at least 90% reduction), and limit climate-changing emissions of carbon dioxide by 20%. To use LNG, existing rolling stock must be retrofitted, including the addition of LNG tanks and modification of diesel engines to be LNG-compatible. This transformation allows railcars, without any type of engine modification, to also use Bio-LNG, a renewable form of liquefied methane produced from organic waste streams such as agricultural residues, sewage sludge or food waste, capable of reducing CO_2 emissions by an average of 80%.

5.1.3. Hydrogen Internal Combustion Engine (ICE)

Hydrogen ICEs are being explored as an alternative use of hydrogen and a useful bridge solution. These engines burn hydrogen like diesel engines burn fossil fuels without emitting any CO_2, offer lower upfront costs than fuel cells and have similar lifespans to diesel engines, extendable with maintenance. They use few rare earths due to their steel construction but have lower efficiency and higher side-emissions than hydrogen fuel cells. They also remain in the research phase at the moment for railways.

5.2. Long-term solutions

5.2.1. Batteries

Battery-electric trains rely on lithium-ion batteries to store electrical traction energy onboard and are best suited for short and medium non-electrified routes or long but only partially electrified routes. They emit no CO_2 during operation and offer high energy efficiency, although not as high as conventional electric trains without onboard electric traction energy storage. These trains can be charged at stations or along the route and make use of regenerative braking to extend range. However, operational limitations such as autonomy, charging time, weight of the batteries, must be considered, and investment in charging infrastructure is necessary. Battery-electric trains are increasingly used in hybrid or dual-mode configurations (e.g., catenary/battery).

5.2.2. Hydrogen fuel cells

- Hydrogen fuel cell trains generate electricity onboard by converting hydrogen and oxygen into water through an electrochemical process. They emit only water vapor during operation and are a promising solution for long, non-electrified routes. To compensate for the low dynamic reactivity and the non-reversibility of fuel cells, an association/hybridisation with batteries is required. Hydrogen can be produced from renewable electricity through electrolysis, making it a low-carbon or zero-carbon option when sustainably sourced. However, hydrogen’s low volumetric energy density requires storage at high pressure or in liquid form, which presents technical and safety challenges: the consequences are usually the risk of explosion. Existing hydrogen production and storage capacities are adequate to sustain moderate traffic levels.

5.2.3. Other renewable fuels from non-biological origin

- Ammonia is another hydrogen-derived fuel under investigation for rail applications. It is easier to store and transport than hydrogen and has a higher energy density. However, ammonia is toxic, corrosive, and poses significant safety risks in the event of leaks. It can be used in modified combustion engines or fuel cells but is currently at the research and development stage and not yet applied in the rail sector.
- Other RFNBOs, such as synthetic fuels or e-fuels, are still in early stages of research and development for rail. Produced from renewable electricity and captured CO_2, they could eventually power diesel engines with significantly reduced lifecycle emissions, using existing infrastructure and rolling stock with minimal modifications. However, perspectives for railway applications are very limited, partly due to competition with other sectors, particularly the aeronautical industry, for access to what is expected to be a scarce resource.

About CER

The Community of European Railway and Infrastructure Companies (CER) brings together railway undertakings, their national associations as well as infrastructure managers and vehicle leasing companies. The membership is made up of long-established bodies, new entrants and both private and public enterprises, representing 78% of the rail network length, 81% of the rail freight business and about 94% of rail passenger operations in EU, EFTA and EU accession countries. CER represents the interests of its members towards EU policy makers and transport stakeholders, advocating rail as the backbone of a competitive and sustainable transport system in Europe. For more information, visit www.cer.be or follow us on Twitter @CER_railways or LinkedIn.