CER
The Voice of European Railways

Position Paper

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Hydrogen propulsion in the European railway sector

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Summary

With this paper CER formulates the needs of the railway operating community for hydrogen propulsion in terms of regulation and standardisation. The paper also outlines the major elements that shall be taken into account when elaborating Technical Specifications for Interoperability (TS) or European standards (EN).

CER supports that additional functional requirements, that are neither covered in TSIs nor ENs, shall be laid down in EuroSpecs. Specific guidance for the railway operating community concerning railway operations among others shall be harmonised at European level and laid down in International Railway Solutions (IRS).

The paper addresses the railway system from a railway operator's point of view and focusses on the needs of railway undertakings (both passengers and freight) and infrastructure managers.

1. Operational concept: technology, state of the art and ongoing projects in Europe

1.1. Making the case for hydrogen-powered trains

Hydrogen-powered trains can represent a strong alternative for further decarbonisation of the railway sector. Electrification (overhead line) is the standard traditional industry solution for the introduction of electric propulsion to replace diesel traction. Recent technology evolution allows for the introduction of innovative propulsion systems, including the use of hydrogen for on-board energy storage.

Hydrogen-powered trains are not the only available solution, but they can add flexibility in terms of usage across the network, allowing new operational concepts. While a mix of modes of propulsion can be used, hydrogen can be an option when there is a weak business case (or a negative business case) for electrification or when the use of battery-powered trains, at current technology level, is not viable because of a certain distance/power demand.

The introduction of hydrogen-powered trains involves several (complementary or alternative) technologies:

- Fuel cells with batteries (as currently no fuel cells-only options are available);
- ICE (Internal Combustion Engines);
- Hydrogen pressure storage and on-board storage (gas vs. liquid);
- Battery packs;
- Ammonia (and other alternative options).

The first introduction of hydrogen in the railway sector should be technology neutral, allowing the testing of different technologies in operational conditions. While fuel cells are considered the main technology for the use of hydrogen in the rail sector, ICE might play a role in a transition phase, allowing the use of existing diesel-powered fleets, through retrofitting and converting existing diesel engines to the combustion of hydrogen or ammonia and equipping the vehicles themselves with new tank systems.

Nonetheless, another approach to realising CO_2-free vehicle propulsion systems is ammonia. In fact, due to the widespread use of ammonia as a chemical feedstock, the infrastructure for storing, transporting and handling it is already mature with existing standards and the reuse of existing diesel infrastructure for ammonia fuelling could be considered and analysed.

As decarbonisation through the use of alternative fuels (instead of traditional electrification) is ramping-up, technology-openness helps to stay in line with target paths (e.g., emission goals) and, at the same time, to test and identify alternative solutions. Under given regulations, the market (railway companies, suppliers, etc.) will identify the most suitable option for each operational condition.

1.2. Ongoing projects & activities

Numerous projects for the introduction of hydrogen-powered trains are ongoing in Europe and worldwide.

Several train manufacturers are working on delivering hydrogen-powered trains:

- Alstom Coradia (ILint and stream);
- Siemens Mireo +H;
- Staedler Flirt H2;
- PESA Bydgoszcz (shunting locomotive SM42 6Dn);

while other projects are still in the concept phase (both in terms of new rolling stock or retrofitting of existing ones) or were used as a testbed:

- Concept of Dual Fuel engine for freight locomotive developed by ABC Engines – Belgium;
- TALGO Vittal One;
- CAF Retrofit Civia;
- Porterbrook HydroFLEX;
- Locomotive CRRC Datong Co.;
- Conversion of freight locomotives with hydrogen ICE:
  - Belgian loco HLD77 (with BeHydro ICE): concept phase, applying for financial support;
  - HyRail Namibia (with BeHydro ICE): concept phase, granted subsidy from Germany;
  - German Alstom H3 loco (with BeHydro ICE) concept phase, granted subsidy from German government;
  - Alstom hydrogen generator wagon (following this approach, we could introduce hydrogen, substitute diesel, and continue using existing electric locomotives furthermore);
  - Austrian conversion of a former diesel electric rail maintenance vehicle to a fuel cell hydrogen hybrid version and conversion of a diesel hydraulic shunter (ÖBB Class 2068) to full electric operation based on the same modular architecture.

1.3. UIC's ongoing activity for hydrogen technology

UIC is delivering relevant projects and activities related to hydrogen technology:

- UIC IRS [work in progress] project H2TR « Hydrogen technology in the railways »:
  - The objective of our H2TR project is to identify the solutions available on the market for the use of hydrogen in railway operations [2022];
  - the relevant parameters, situations to be considered for a risk assessment and the corresponding methodology [2023];
  - the mitigation measures resulting from the risk assessment and their impact on the business (costs and asset availability);
  - The corresponding IRS will summarise these elements in order to facilitate the specification and assessment of risks by the IM and RUs. NSAs will receive similar approval files. This will simplify the exchange with them;

- UIC Energy & CO_2 Sector's activity:
  - Sharing within the sector about pilot projects for alternative propulsion systems, including hydrogen;
  - Organisation of workshops on the state of art of specific decarbonisation strategies: « Hydrogen trains » online workshop (May 2021 energy efficiency and decarbonisation workshop).

2. Barriers to the introduction of hydrogen-powered trains

Hydrogen-powered trains are a new technological solution based on technologies where the technology readieness level has to be considered from subsystems and the overall system. Key barriers to their introduction on a large scale at European level are mainly of operational nature and do not refer to technical issues, but rather to the full ecosystem for the use of the train itself, across the full value chain:

1. Train technical standards;
2. Safety requirements (rolling stock and infrastructure);
3. Authorisation;
4. Train performance;
5. Refuelling facilities & hydrogen logistics;
6. Business case and financing (capex and opex);
7. Operational phase.

An operational concept for hydrogen propulsion should include considerations of the hydrogen supply chain, especially the aspect of intermodal transport (rail, maritime as well as road).

Hydrogen as a product (chemical substance) as well as all components that are needed to use hydrogen as propulsion energy are embedded in a global technology development and will be embedded in a supply chain that has elements in common with other sectors as well. This is what emerges from the wide range of fields of hydrogen applications. For instance, hydrogen can be used as:

- Propulsion energy for sustainable mobility;
- Raw material for industry;
- Medium for heat and power production to meet the demand of buildings;
- Energy storage.

Therefore, the development of prices, of technological readiness, of reliability, of safety etc. is also strongly influenced by the development in other sectors or even determined almost exclusively by the development in these sectors.

2.1. Train technical standards

The introduction of hydrogen-powered operations requires the definition of new operational concepts, elements and standards.

Key points for the definition of technical standards (also through the delivery of a full risk assessment) include:

- Amount of hydrogen on-board and technical characteristics of tanks (reference standard) and fuel cells or, more generally, hydrogen-related components of the power trains;
- Operational requirements, with specific reference to tunnels;
- Certifications andauthorisation of rolling stock.

The lack of existing common standards is a relevant barrier for the introduction of large-scale hydrogen-based rail operations. Currently, in some cases, for each single project it is necessary to identify specific and local conditions for the use of hydrogen, based on the specific infrastructure and on the specific train.

This lead to long implementing time for the full project, with potential need for case-specific risk and safety assessments and for case-specific design of technical, logical and operational interfaces, leading to potential extra costs and reducing the competitiveness of hydrogen.

2.2. Safety requirements (rolling stock and infrastructure)

Safety levels in the EU rail system are generally high especially when compared to road transport. Railway safety should be generally maintained and, when practicable, continuously improved, taking into account technical and scientific progress, and the development of EU and international law.

Directive (EU) 2016/798 of the European Parliament and of the Council of 11 May 2016 on railway safety lays down provisions to ensure the development and improvement of the safety of the EU rail system.

The Common Safety Methods (CSMs) describe how the safety levels, the achievement of safety targets and compliance with other safety requirements should be fulfilled.

The CSM for risk evaluation and assessment sets out the risk assessment process to be applied in case of technical, operational or organisational changes. Deployment of hydrogen propulsion in the railway sector is to be regarded as a significant change in the railway system and therefore triggers the need for a risk assessment.

Main issue and points to be addressed refer to:

- Storage of hydrogen;
- Leaking of hydrogen;
- Ventilation aspects;
- Limited knowledge in countries where hydrogen propulsion is not yet used.
- Risk assessment of (i) rolling stock and (ii) infrastructure.
- Operational concept

2.3. Authorisation

Vehicle authorisation at European level is regulated by the Directive (EU) 2016/797 of the European Parliament and of the Council of 11 May 2016 on the interoperability of the rail system within the European Union and the Commission Implementing Regulation (EU) 2018/545 of 4 April 2018 establishing practical arrangements for the railway vehicle authorisation and railway vehicle type authorisation process.

For any new vehicle (with hydrogen propulsion or hybrid propulsion including hydrogen fuel cells) the authorisation cases and process in the abovementioned regulations apply.

The authorisation process for hydrogen-based operations is still largely new, with specific reference to hydrogen-related on-board equipment, and in terms of railway infrastructure.

In general, technical specifications are still lacking, leading to laborious overall authorisation processes, with an extra burden on train manufacturers, train operating companies, infrastructure managers and agencies.

Depending on the train, standard authorisation processes apply but the certifying entities have to deal with new components (with specific characteristics and risks, also in terms of risks generated to rail infrastructure) and known or standardised components might present new unknown risks, related to the new on-board components (i.e. topics of shock, vibration, crash, electromagnetic compatibility might generate new hazards due to the presence of hydrogen-related components). Moreover, in this framework, results of the analysis could be component-specific and non-replicable or with general relevance. This also applies to the upgrading or renewal of existing stock with the replacement of the original power source with hydrogen.

Regarding the infrastructure, similar issues apply. Impacts of hydrogen-powered operations are assessed for each single project and in non-standardised conditions. Being carried on for specific projects, results of the analysis could be component-specific and non-replicable or with general relevance.

Nonetheless, in this scenario, some entities might lack specific skills on hydrogen or might be required to bring in new skills and competencies. This could lead to a sort of reluctance in accepting hydrogen-powered trains.

2.4. Train performance

Train performance still limits the use of hydrogen. Key issues relates to:

- Extension of the operational range of the train (at present at around 600km-800km for regional passenger trains, based on actual operational conditions and commercial missions), to enlarge the area of interest of hydrogen-powered trains;
- Introduction of dual mode trains (catenary and hydrogen);
- Increase in the power of fuel cells, to allow freight and shunting operations as well as track construction and track maintenance works.

A distinction should be made between passenger trains and freight locomotives:

- The power requirement of a passenger train is much lower than for a freight train and, in addition, installed power can be distributed over different coaches.
- For a freight train, the required power and energy consumption is much higher and all concentrated on a single locomotive.

Fuel cells, which are a relatively new and developing technology in railway vehicles, still have a significant power limitation and therefore economics and durability are yet to be proven for high power heavy-duty applications such as traction power for locomotives.

At present technology, on the short and medium term, while on the one hand passenger trains can operate with hydrogen fuel cells with traction on each individual car, on the other hand, hydrogen fuel cells might not be able to provide a powerful solution for freight locomotives; on the contrary, hydrogen internal combustion engines (ICE) might provide the required power (as it is now with diesel ICE).

In order to extend the operational range of the train, other options should be evaluated:

- For applications with a rather limited range and/or limited required power (such as shunting locomotives or passenger trains), a solution with on-board compressed hydrogen storage could be sufficient;
- However, for applications with a high range and/or high power, needing a high storage volume of hydrogen (like mainline freight locomotives), a separate tender car behind the locomotive for hydrogen storage may be a solution, also considering the introduction of skids with compressed hydrogen tubes and refuelling by skid swapping;
- Other fuels with a higher density of energy, like e.g. (green) methanol or ammonia, could also be considered.

2.5. Refuelling stations and hydrogen logistics

Refuelling stations and hydrogen logistics can be considered outside the scope of railway operations, despite the potential impact on operations. Similarly, gaps in hydrogen supply chain (still under development and evolution at the European level), including transport, are not specifically railway-related open points. Nonetheless, their impact on regular hydrogen-based operations can be relevant.

Current technical regulations, that may be used in the rail sector, mainly refer to the automotive sector, that has previously faced similar issues in terms of setting up a common framework for hydrogen-based operations.

However, to ensure (i) full interoperability of hydrogen-powered rolling stock or (ii) the use on a specific network of rolling stock from different manufacturers, it is necessary to identify, at least, the conditions that can ensure both full technical compatibility between the train and the hydrogen dispenser irrespective of the specific train and of the specific dispenser and standards (in terms of standards and quality specification) for hydrogen.

2.6. Business case and financing (capex and opex)

An important business consideration is the correlation between the input costs incurred by railway undertakings (RU) and infrastructure managers (IM) when implementing hydrogen technology in their rolling stock and the potential financial benefits over the years of operation.

This issue is undoubtedly an individual matter for each RU and IM, but the demonstration of unified results of the technology's cost-effectiveness in long-distance traffic and not only in regional traffic (as current studies mainly focus on hydrogen propulsion in regional traffic), may contribute to a greater willingness to implement hydrogen, by the largest RUs.

The benefits of no CO2 emissions, no need to electrify lines, etc. are among the undoubtedly positive features of hydrogen propulsion. On the other hand, the issue of capex costs for rolling stock, operating costs or the costs of building additional infrastructure can be raised.

Nonetheless, despite the fact that hydrogen railway systems are already suitable for large-scale production and even though they have reached a high technology readiness level, regarding the fuel cells there is the issue of little practical experience about life cycle behaviour in the context of railway systems. However, a fair comparison between fuel cell systems, hydrogen-based ICE and other technologies should always embrace considerations about the total costs of ownership (TCO). In general, as hydrogen technology has only been in the rail industry for a relatively short time, there is a lack of data covering a long-term representation of the life-cycle costs of such vehicles.

The presentation of a forecasted rate of return on costs or other benefits will allow RUs to better optimise potential investments in terms of planning expenditures and budgets, which may translate into greater commitment on the part of RUs to implement the technology.

Indirectly arising from safety considerations are issues involving the disposal (scrapping) of hydrogen rolling stock at the end of its life or in the case of vehicle disposal after an accident; similar considerations can be taken for hydrogen refuelling stations, which are a relatively new technology in the road sector as well. In fact, hydrogen-powered trains and refuelling stations have components that may require special disposal procedures, e.g. pressure tanks, fuel cells (containing catalysts), etc.. This in turn may increase end-of-life costs.

2.7. Operational phase

The choice on the particular hydrogen technology shall take into account the operational costs, over the entire life of the train, including the handling of hydrogen, maintenance of the refuelling infrastructure and of onboard components, as well as the decommissioning and/or recycle phases. Maintenance costs will depend on the technology, e.g. for the hydrogen tanks (700 bars vs. 300 bars gas tanks, vs. liquid storage vs. metallic hydrides storage).

Long-term resilience of metalling (steel) pipes for hydrogen distribution, especially trackside, must be carefully assessed, taking into account the adsorption effects of hydrogen in the metal crystal structures. The reuse of existing pipes is certainly an interesting option on the financial side, but its technical practicability remains uncertain.

All in all, the railway sector needs to get a better understanding of the current hydrogen technological trends for rolling stock and infrastructure, their current costs (both CAPEX and OPEX) and their possible future evolution, before a clear cost/benefit analysis can be made, to demonstrate a positive business case for the introduction of hydrogen in the rail industry.

The costs for the production of hydrogen and the benefit of its use for the environment depend of course on the type of hydrogen (green hydrogen, blue hydrogen, etc., till brown hydrogen from reforming of carbon fuels); the comparison of costs for hydrogen introduction vs. the costs for a classic electrification of a line is also an important evaluation to be jointly made by IMs and RUs, from a full system perspective.

All other operational aspects of a hydrogen-powered train should not be that different from a normal electric train and "transparent" to the driver; so they should be kept unchanged as far as possible.

The choice of the best technologic solution for hydrogen introduction should evaluate the overall advantages for the whole rail system and not be driven by particular interests of just some parts of it (IM, RUs, suppliers).

Regarding the train, it could be convenient to also have a pantograph on the train together with the hydrogen system to have more flexibility on the mix of lines (electrified and not electrified). The pantograph could be also used to recharge the traction batteries during the normal operation and/or during stand-by and for energy optimisation during regenerative braking.

Going further into the details, operations of hydrogen-powered trains introduce new requirements when compared to standard electric trains (with overhead lines) or diesel trains. In fact, while body/doors, chassis, boogies, engines and safety and control systems are fully comparable to those of a standard electric train, hydrogen-related components (storage, fuel cell, battery) are additional to standard equipment and new-to-the-industry. Moreover, to qualify as an effective operational solution, hydrogen-powered trains should deliver an operational range at least comparable to present diesel trains and availability comparable to diesel or standard electric trains.

Currently, due to the novelty of the technology, key issues relate to:

- Safety aspects strictly connected with the fire and explosion risk prevention: the risks assessment procedures still have to be developed and will strongly depend of the technologies;
- Maintenance costs (no track record for maintenance costs): as on-board hydrogen storage units, fuel cells and batteries are a new technology in railway environment, no track record is available for maintenance costs. This could lead to higher costs when compared to standard electric trains, in particular for capitalised maintenance, for the replacement and/or reconditioning of these components, considering that the technical life of a train is significantly longer than the technical life of the abovementioned components. Nonetheless, no actual data is available also for daily scheduled or unscheduled maintenance (in terms of frequency, required time and costs). Similar issues might apply for ICE-based hydrogen operations, with specific reference to hydrogen storage and piping;
- Range (no track record for efficiency or degradation of fuel cell and/or batteries): degradation of fuel cell performance or degradation of capacity of batteries might have an impact on operational performance, reducing the range between refuelling stops or increasing hydrogen consumption and, consequently, the operating costs; with fuel cell being a relatively new technology, the actual impact in real rail operations (instead of on testbeds) is still to be fully analysed. Similar issues might apply for ICE-based hydrogen operations, with specific reference to the performance of the combustion engine;
- Performance of hydrogen refuelling stations (HRS): HRS in the automotive industry are a consolidated technology; nonetheless, refuelling capacity (and compression capacity) for rail operation might be significantly higher than standard capacity required for road operations; this might lead to potentially higher costs for hydrogen distribution (including energy required in the process)

or maintenance (including nuzzle, piping, compressors, etc.) requirements than for road HRS.

3. Recommendations

The introduction of hydrogen in the railway sector will follow other sectors like the power industry, the manufacturer of road vehicles and large-scale industry because these sectors have a higher pressure to act and in general wider fields of application. Nonetheless, it is important that the railway sector participates in the process of standardisation in the emerging field of hydrogen as soon as possible. In general, standardisation (also with other industries) will help to reduce costs in the entire supply chain significantly.

Within the transport sector, key developments should cover technical, organisational as well as economic interfaces between all sectors and the usability of components in railway applications should be part of the standardisation process from the beginning.

A holistic approach, including aspects like the possibility of regional energy storage, the possibility to deploy hydrogen to fuelling stations for trucks/cars/busses or to local business and industry can tip the scales in favour of hydrogen.

Apart from this, the decision about the implementation of hydrogen will often be dependent on developments in the respective geographic environment. The practical experience in several showcase regions across Europe will show to which extent the synergetic effects matter.

To boost the development and evolution of hydrogen-based operations, some key recommendations can be drafted, for future integration into the full framework, with specific reference to:

1. Technical standards and safety requirements;
2. Authorisation;
3. Train performance, operations and refuelling.

Besides hydrogen transport and hydrogen as an energy source for propulsion of trains, the industry should also focus on topics like auxiliary power, temporary electrical supply for constructions sites or power supply for decentralised point heating systems or for the energy needs of railway buildings as in these areas, emissions are often relatively high. Overall, it makes sense to also use hydrogen knowledge in other applications inside the railway sector, as soon as it is established.

3.1. Technical standards and safety requirements

Standards

Standardisation will help to reduce costs in the entire supply chain significantly, both for fuel cells and ICE applications.

Main standards from related sectors might apply if no specific railway regulations are available, including standards as:

- IEC 63341 and VDE AK 351 on hydrogen storage in rail vehicles should apply to fuel cell rail vehicles in the future. Others such as standards EC 79, UNECE R134, SAE, should cover the area.
- ISO 14687:2019 on minimum quality characteristics of hydrogen fuel as distributed for use in vehicular and stationary applications and should also be valid for railway sector.

Moreover, it is of key relevance that there is the safe integration of hydrogen-specific subsystems within the vehicle, on the basis of the relevant TSIs, and where applicable, national rules, and the CSMs referred to in Article 6 of Directive (EU) 2016/798. Consequently, the topics of shock, vibration, crash, electromagnetic compatibility should be dealt with in a railway-specific manner and mapped accordingly.

UIC work and products

International Railway Solution (IRS) are a structured framework of documents prepared and published by UIC for use within the railway sector. They blend together a range of voluntary solutions to support the design, construction, operation and maintenance of the railway system and the services that the sector provides. CER promotes that IRS in the field of hydrogen publishing shall facilitate defining and compiling the railway operators basic needs beyond regulation and standardisation, i.e. railway operational processes.

EuroSpec

European Specification for Railway Vehicles (EuroSpec) is an initiative of several European railway companies with the aim to develop common, explicit technical specifications for train systems and components. The work program includes doors, parking noise, TCMS, seating comfort and the revision of published specifications. The jointly developed specifications support and facilitate the process of purchasing trains. These specifications are not in the competitive domain. The continued application of the EuroSpec methodology and the developed specifications support the standardisation of trains and lead to higher quality, support the development of vehicle platforms and provide significant cost savings.

The EuroSpec consortium has published a EuroSpec on “Alternative energy supply – Battery driven systems”; CER supports that the hydrogen propulsion topic is addressed by EuroSpec as well.

3.2. Authorisation

In order to smoothen the authorisation process at European level, any actor shall refrain from defining national technical rules or national safety rules for rolling stock with hydrogen propulsion. If not yet covered by European regulation and/or standardisation yet, hydrogen related requirements shall be set at European level (i.e. Technical Specifications for Interoperability (TSI) or European Standard (EN)).

3.3. Train performance, operations and refuelling

Operational issues should clarify in a few years with the introduction of regular and scheduled hydrogen-powered railway services.

Nonetheless, short-term higher costs or short-term lower performance are part of the introduction of new technological solutions. It is relevant that early users can test and introduce new technological solutions to support the identification of industry operational standards and related costs.

To increase the operational range, alternative non-industry-specific technical solutions might be discussed (based on business cases) and implemented, including:

- The use of hydrogen at pressure of 700 bar or liquid hydrogen (following the same evolution proposed for road vehicles);
- Increase in efficiency of fuel cells, including reuse of the heat produced by the fuel cell;
- Limitation of battery charging by the fuel cell to what is necessary, using knowledge of the route and position of the train;
- Evaluation and development of ICE for the retrofitting of existing diesel engines.

Moreover, other improvement with an impact on operational performance might involve the storage of hydrogen on-board. It is of high importance to ensure a technically flawless and thus safe hydrogen storage. In fact, hydrogen storage systems adapted to the installation space could make it possible to store more hydrogen, especially in locomotives, which leads to new applications for hydrogen drives in the cargo sector, in the locomotive-hauled passenger rail transport and for big rail maintenance machines like track renewal machines. In addition, innovative technologies for maintenance (including CBM) should also be considered.

4. Conclusions

CER supports all efforts to decarbonise railway transport. Hydrogen propulsion for the railway sector can be one part of the solution. CER acknowledges the work carried out by the standardisation organisations both at European as well as at international level. National approaches shall be avoided in this respect in order to ensure full interoperability. The European Agency for Railways is encouraged to assess with the sector with the input of Europe's Rail Joint Undertaking (ERJU) if, how and to which extent requirements for hydrogen propulsion may or must be integrated in the set op interoperable requirements in the Technical Specifications for Interoperability (TSI). Functional requirements to facilitate the railway operating community's rolling stock and infrastructure component tendering process may be described in the Europe and operators' specific description of operational process in International railway solutions.

The railway operating community believes in following the technical developments of the other industry and to refrain from developing railway specific solution and technologies. Nonetheless, the railway specific needs need to be properly addressed in regulation and standardisation or sufficient room must be given to have gaps defined by the railway sector. CER recommends to complete the standardisation landscape with a focus on refuelling stations and hydrogen logistics.

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 79% of the rail network length, 77% of the rail freight business and about 90% 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.