ZEFES, Zero Emission flexible vehicle platforms with modular powertrains serving the long-haul Freight EcoSystem

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Abstract

The electrification of Heavy-Duty Vehicles over longer transport distances in Europe is still in its infancy. The EU-funded ZEFES project aims to test the barriers and opportunities for the implementation of Battery Electric Vehicles (BEV) and Fuel Cell Electric Vehicles (FCEV) in daily logistics operations by means of demonstrations. In total, 15 demonstrations across Europe, gathering quick learnings and define concrete measures to be taken prior to scaling the use of ZEVs on European roads and intermodal transport. On top of being the frontrunner in Europe demonstrating collaboration between all stakeholders, building up knowledge and expertise, becoming advisor for other EU member states. The focus within the ZEFES demonstrations is not only the vehicle and charging or fueling. It´s about the right vehicle / the right cargo / the right road, intermodal & combined transport, sustainable freight transport, optimization of energy infrastructure (charging & fueling) along corridors, terminals, and hubs. The outcome will be conclusions and recommendations of measures and actions to be taken to support the scaling of ZEVs by 2030.

Keywords: Resilient Road freight transport systems, Climate change mitigation and adaptation, Policies, pilot projects towards sustainable road freight transport.

Content

1. Introduction

Within the Green Deal, Europe commits itself to be the first CO2 neutral continent, by 2050. To achieve this, a first milestone is defined as an overall CO2 reduction target of 55% by 2030[1]. For the road transport sector, the target is set at 45% less CO2 emissions by 2030, following Regulation (EU) 2019/1242. The regulation requires that manufacturers of heavy-duty (HD) vehicles deliver more efficient vehicles: a reduction of CO2 emissions for the newly produced fleet of 15% in 2025 and 45% in 2030. The use of zero tailpipe emissions vehicles (ZEV) is an important part of achieving the above targets. ZEVs can be battery electric vehicles (BEV), fuel cell electric vehicles (FCEV), electric road systems (ERS) and to a limited extent vehicles with internal combustion engines (ICE) running with hydrogen.
The EU has launched several projects focusing on the development and implementation of ZEV across Europe. They are coordinated by the AEVETO cluster[2]. The ZEFES project is the coordinator of this cluster. Each project covers different aspects
The ZEFES project, *Zero Emission, flexible vehicle platforms with modular powertrains serving the long-haul Freight EcoSystem* focuses on the use of BEV and FCEV vehicles in long-haul cross border freight transport across Europe. Until now, these ZE-vehicles have a **limited range**: this makes it difficult to use them effectively as replacements for vehicles with a Diesel-ICE. In addition, the weight of the batteries in such long-distance vehicles affects the **available payload**. Furthermore, a challenge exists regarding **charging** vehicles. A large-scale switch to electric vehicles for long distance heavy transport requires many charging points. Particularly, if the best use of the driver's rest is to be made. The EU rules on driving times and rest periods[3] prescribe a break of 45 minutes, the perfect moment to recharge the vehicle giving a range of 400 km until the next break. **Energy prices** are having a big impact on the rate of the introduction of ZEVs. Higher diesel fuel prices and lower electricity prices

at the charging point (or a lower hydrogen price), Fuel cells will be a useful part in the fleet electrification process, especially for certain types of heavy transport, when there is a lack of EV-charging points (yet, at the same time, an availability of hydrogen), when there is a low price of hydrogen and when additional requirements are imposed upon the refueling rate. Given the near-term breakthrough of battery electric and fuel cell trucks, three important challenges remain. **Firstly, the efficiency of the vehicles** is a key factor for the rate of the introduction. Lower energy consumption means smaller battery packs, meaning lower investment (less need for raw materials) and more payload. **Secondly, preparing the technology for mass production,** scaling up production will be needed, to reduce prices via volume effects and technical improvements. The modularity, ensuring the right vehicle configuration for each mission, of vehicle components and architectures will be of big help. **Thirdly digitalization**, switching to ZEV raises questions about how these vehicles can be used in the operator's fleets, given the range, charging possibilities and transport demand. Digitalization will support smooth integration of ZEVs and operational efficiency. In the ZEFES project, **relevant stakeholders** work together towards the overall goal demonstrating ZEVs for long distance heavy transport, by focusing on efficiency improvements, mass production capabilities and the use of the technology in daily operations. 15 demonstrations, 11 vehicles a max. GCW up to 64 tons under real operational conditions comparable to the VECTO long haul and regional-national mission profiles, meeting the requirement of 750km un-refueled / 400km un-recharged, over a period of 15 months, covering 1,000,000 kilometers, representing 30,000 hours operational life. The total length of all use cases represents road use of approximately 9,000 km across European corridors and 2.000km rail operation, bringing ZE-HDV adoption in the freight transport ecosystem a big step further.

2. Update of the ZEFES project

The ZEFES project started in January 2023 and is now in its 3rd phase Project Demonstrations. See figure 1. Project demonstration preparation up to Q1 2025 and execution of the demonstration Q2-3 onwards till end Q4 2026.

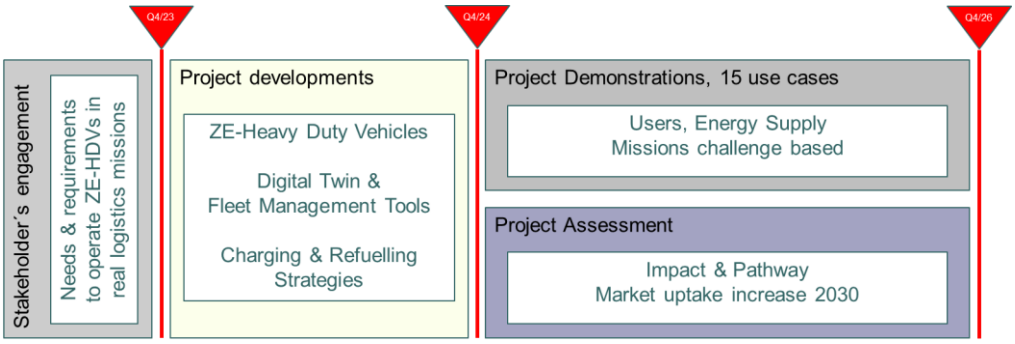

Figure 1 ZEFES project concept

At HVTT17, an overview is given of the project's ambitions, the objectives, the expected outcomes, and first results of the first 9 months. For details, see HVTT17 paper ZEFES 3057.

2.1 First phase of the ZEFES project Stakeholders' engagement Q1 2023 – Q4 2023

Phase 1 is the gathering of the needs & requirements from stakeholder´s perspectives and reported in deliverables. Workshops, surveys, interviews and desk research have resulted in structuring all needs & requirements. The first group is the technical requirements of vehicles (trucks & trailers) and charging & fueling. The second group is about the logistics missions'

part of the ZEFES demonstration in the third phase of the project. The third group focuses on the ZEFES ecosystem specification as the fourth group is about mapping the supply chain and supply chain needs. Phase 1 ended by holding a Symposium end October 2024, a one-day event having a dialog with stakeholders in 4 sessions on supply chain needs, digital platforms, road permits and energy infrastructure. All needs & requirements show a complex dependency, see figure 2, and force all stakeholders to collaborate in achieving the implementation of ZE-HDV on time to achieve the target of 45% less CO_2 emissions by 2030. A huge challenge, the ZEFES project is facing. All information about needs & requirements is available on the www.zefes.eu website under results / expected and achieved results WP1.

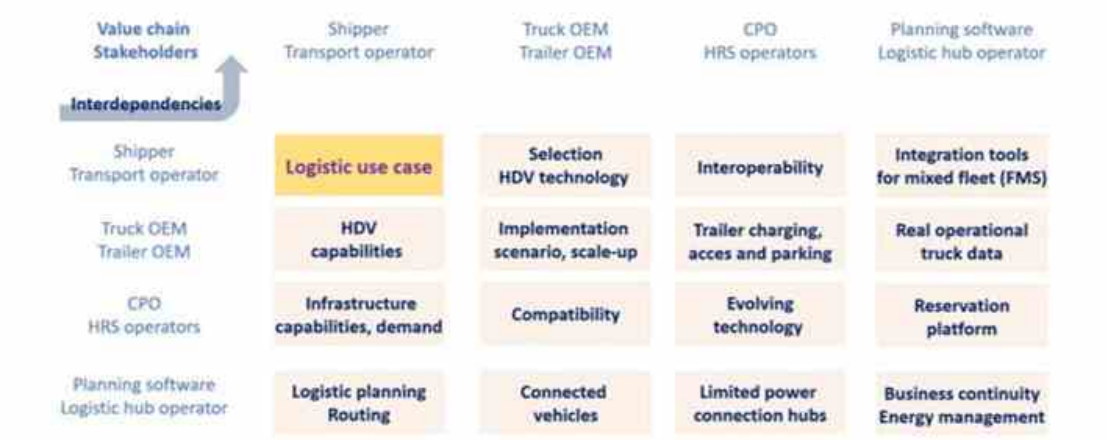

Figure 2 Needs & requirements and depenedcies

2.2 Second phase of the ZEFES project, product developments Q4 2023 – Q1 2025

Phase 2 is about the development of the "hardware and tools", see figure 3.

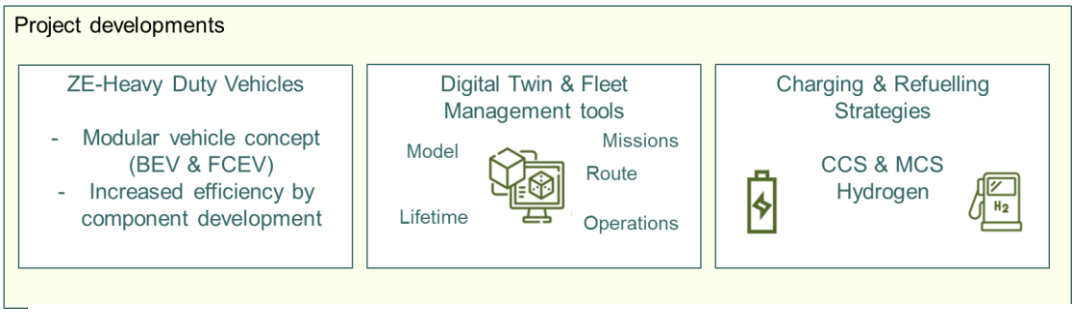

Figure 3 Project developments

The improved ZE-HDV.
Developments of Vehicle Simulation Platforms for ZE-HDV. Simulation models of the different components have been developed, with a focus on modularity and compatibility between technologies, makers and developers. See figure 4.

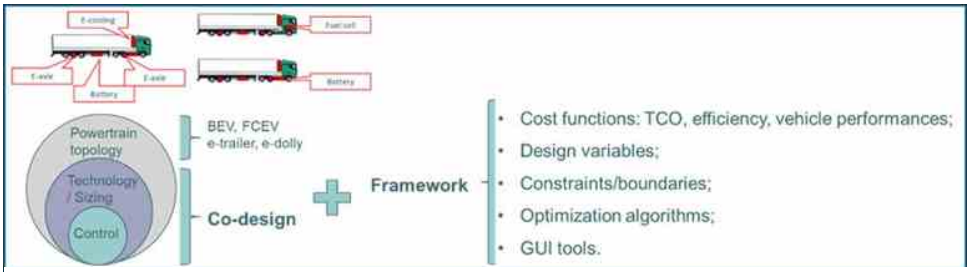

Figure 4 Simulation platform

As a part of the simulation models, a Total Cost of Ownership (TCO) tool has also been developed. This tool calculates the price of a new vehicle considering technology used, country of purchase and use of the vehicle. While both tools are functionally complete, additional work on the models will be encouraged to further improve the quality of the models and validate their coherence with the experimental data obtained in the demonstrators. For details, see the www.zefes.eu website under results / expected and achieved results WP2, 5 and 6.

The demonstrators.

The current stage is that all demonstrators are specified and in production, see figure 5. 9 BE-HDV and 3 FCE-HDV and 2 e-trailers. From the AEROFLEX project, the e-dolly will have a role as well in one of the demonstrations. Commissioning and homologation of all vehicle configurations are planned for Q1-4 2025. All vehicles are specified to meet the requirement of the logistics missions and drive up to 400km between two charges or 750km for FCEV in real-time daily logistics missions. All BEV vehicles will perform an additional conditioned test to meet 750km without charging.

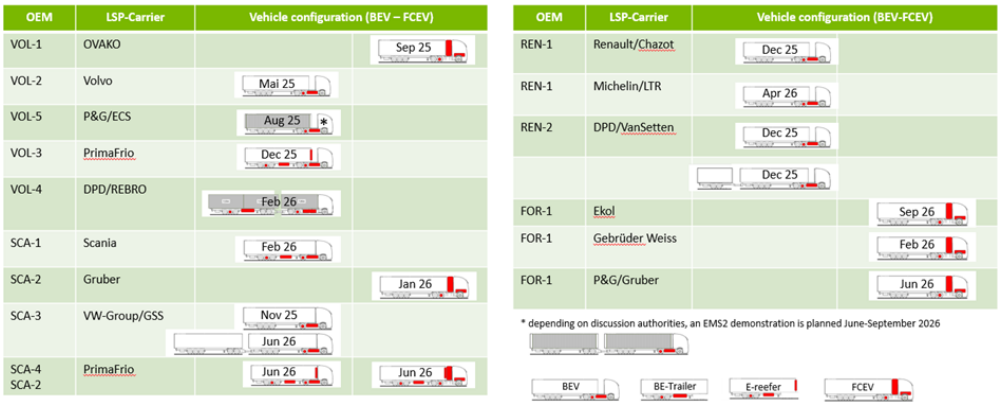

Figure 5 ZEFES demonstrators

The Digital Twin & Fleet Management tools.

Digital twin specifications and architecture. The digital tools are designed and developed to facilitate zero tailpipe emission vehicle integration in fleets, optimize logistical tasks assignments considering routes, infrastructure and refueling/recharging opportunities, and develop predictive maintenance strategies including deployment of diagnostic & prognostic techniques. The platform comprises 5 tools.

1) Buying decision, a platform finding suitable ZE-HDV for certain logistics operations

Figure 6 Buying decision tool

2) Mission planning, a platform optimizing the routing for a certain mission

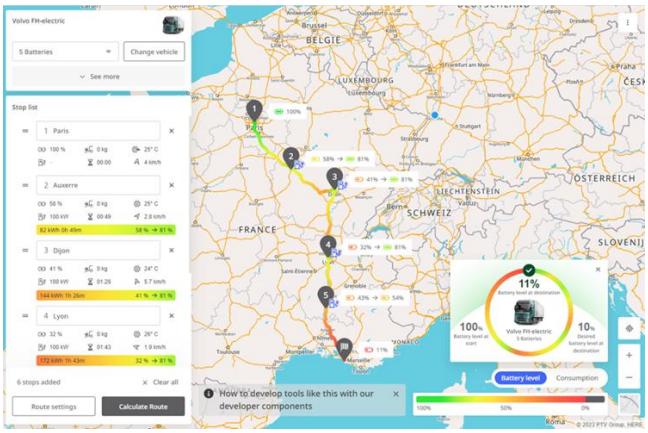

Figure 7 Mission planning tool

3) Right vehicle in right duty

Figure 8 Right vehicle tool

4) Dynamic correlation, not accessed by users, operators of the platform
5) Predictive maintenance, a platform predicting vehicle maintenance needs.

The tools' impact and effectiveness will depend on the breadth of information that will be made available regarding the operation and status of the real-world assets and of the wider eco-system for long haul truck operation. Access to such information will enable the creation of digital twins of the real-world assets and environment. The digital platform is a crucial interaction point with the accent on the security aspects and governance to automate the interoperable solutions based on heterogeneous datasets and models for the Digital Twins. The orchestration and the application of these data and services take place in different

scenarios enabled by ZDTP. Due to the sensibility of data protection, detailed information cannot be published. For details, see the www.zefes.eu website under results / expected and achieved results WP4.

The Charging & Refueling strategies.

The focus is on implementing and demonstrating advanced fast charging concepts (such as Megawatt Charging System (MCS) with its connectivity), mapping the Hydrogen Refueling Stations (HRS) and potential charging on ferry and Rail, enabling efficient charging and HR processes for heavy duty electric trucks both BEVs and FCEVs, respectively.
Charging and fueling is key for the smooth operation of the ZE-HDV in long-haul cross-border freight transport. Mapping the infrastructure is crucial to meet drive and rest schedules under the EU legislation, arriving at ferries, rail terminals, and hubs / warehouses / factories on time keeping the supply chain intact. Several external partners (CPOs, DSO, ESPORG secured parking operators, HRS operators, etc.) were contacted and engaged in technical discussions. Especially Spain showed a need for many interventions as from government side no actions were undertaken yet enabling investing in energy infrastructure for long-haul ZE-HDVs. At this stage, still not all needed infrastructure for the ZEFES demonstration is secured. Nevertheless, mitigation strategies are drafted, ensuring all use cases will be feasible. Specific working country-groups for charging and fueling, search of HRS operators and CPOs and contacts with relevant ZEFES partners, followed by technical and organizational meetings to realize installation and commissioning. A major issue is grid strategies, powerlines & connections. The EU strategy is to have a charging facility at each 60km and each 120km HRS along the motorway (TEN-T). CCS charging (up to 400kW) to supply energy over a longer time (xhr parking and overnight), MCS charging (starting from 850kW) to supply power over a short time (45min rest schedule driver). A standard service station has parking facilities for about 45 trucks. Along a section of 240km, 8 service stations can be expecvted servicing up to 360 trucks. In a combination of CCS and MCS charging, a power quality monitoring of about 160Mw is needed. This needs a strategy design by DSOs and CPOs to ensure future power supply. See figure 9.

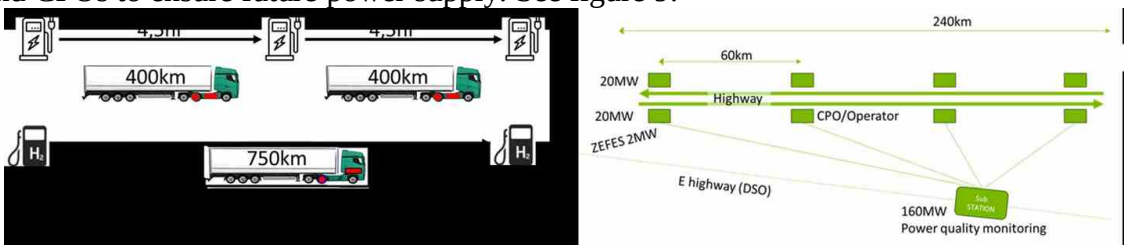

Figure 9 Mapping infrastructure

ZEFES is focusing on the TEN-T corridors[4] covering most of the freight transport and supports intermodal cross border freight transport in Europe.
Regarding the MCS chargers, the project develops efficient and Interoperable-Megawatt-Charging-System (IMCS) concepts, standards and physical power stations providing a high overall charging efficiency higher than 80 % during the battery SoC window of 15%-85% of the BEVs within fast charging process and adaptive local control system thanks to the introduction of recent SiC wide bandgap (WBG) technology and new control systems. This will provide a fast-charging concept enabling a recovery of 400km in 45min. In addition, efficient Multiport MCS (as a fast-charging concept with multiple outputs) with recent SiC RoadPack modules to enable high flexibility and high efficiency > 80% in the charging

process for different heavy-duty vehicles. This will introduce a mobility hub charging concept to minimize the footprint and lower the TCO thanks to also the shared infrastructure. The MCS chargers will be ready for demonstration Q2 2025 and will be seen in the harbor of Zeebrugge Belgium, CFL Intermodal Luxembourg, Vilamalla near Spanish French border, Murcia Spain and at the crossing A1/A25/A255 Hamburg Germany, serving the ZEFES BEV demonstrations. HRS filling stations are allocated in Sweden (Gothenborg and Hofors), Austria (Graz and Vienna), Spain (Tarragona, Murcia), Turkey (Kocaeli factory) serving the ZEFES FCEV demonstrations.
In addition, demonstrations are planned to charge vehicles and/or trailers on rail wagons during rail operations as well as on ferries. On the rail wagon, a Powerbox[5], being a battery-operated charger getting its electricity from a wheel motor attached to a wagon wheel will be used, see figure 10.

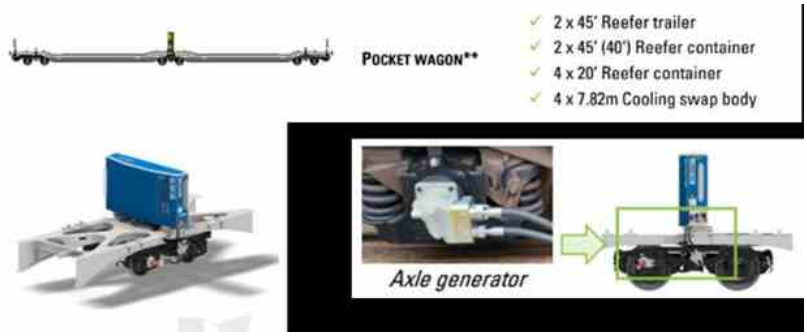

Figure 10 Powerbox on railwagon

On top, three types of reefers will be used during the demonstrations, the traditional ICE-Diesel cooling unit, the electrified cooling unit and a passive liquid nitrogen cooling unit for sensitive freight[6].

The challenge within the ZEFES project is the availability of public charging and fueling stations along all ZEFES corridors as can be seen in figure 9. This implies close collaboration with DSOs (distribution system operators) and CPOs (charge point operator) at strategic locations, see figure 11 – ZEFES charging and fueling

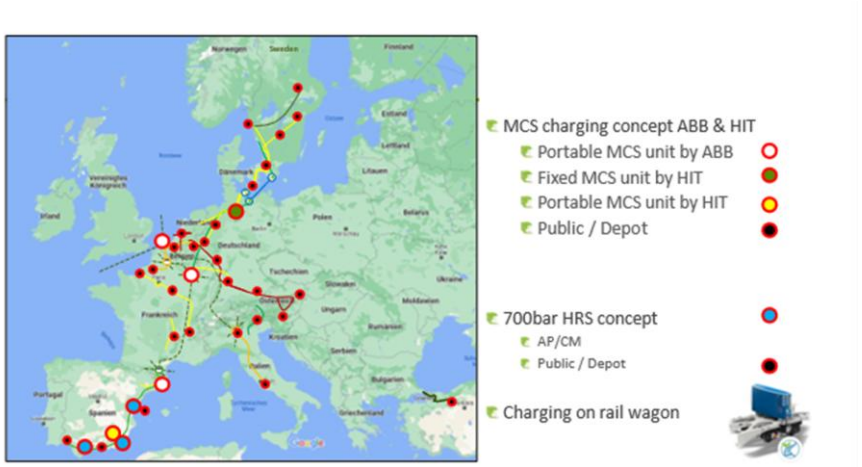

Figure 11 ZEFES charging and fuelling locations

2.3 ZEFES project demonstrations and assessment Q2 2025 – Q4 2026

To prepare the third phase of the ZEFES project, starting Q2 2025, activities are running at high-speed solving challenges and barriers in close collaboration with relevant stakeholders. The demonstrations do represent the major long-haul cross border freight transport in Europe representing the diversity of freight, logistics service providers, shipper-and carriers. Challenges and KPIs enabling the right assessment and validation, see figure 12.

Figure 12 ZEFES demonstrations, challenges and KPIs

A PAN European demonstration of 12 vehicles (9 BEV, 3 FCEV), 2 MCS concepts at 4 different locations, and 2 HRS concepts at 2 locations, supported by the digital platform under real life operational conditions comparable to the VECTO long haul and regional-national mission profiles and meeting the requirements of 750km unrefueled / 400km un-recharged over a period of 15 months, covering 1,000,000 kilometers, representing 30,000 hours operational life.

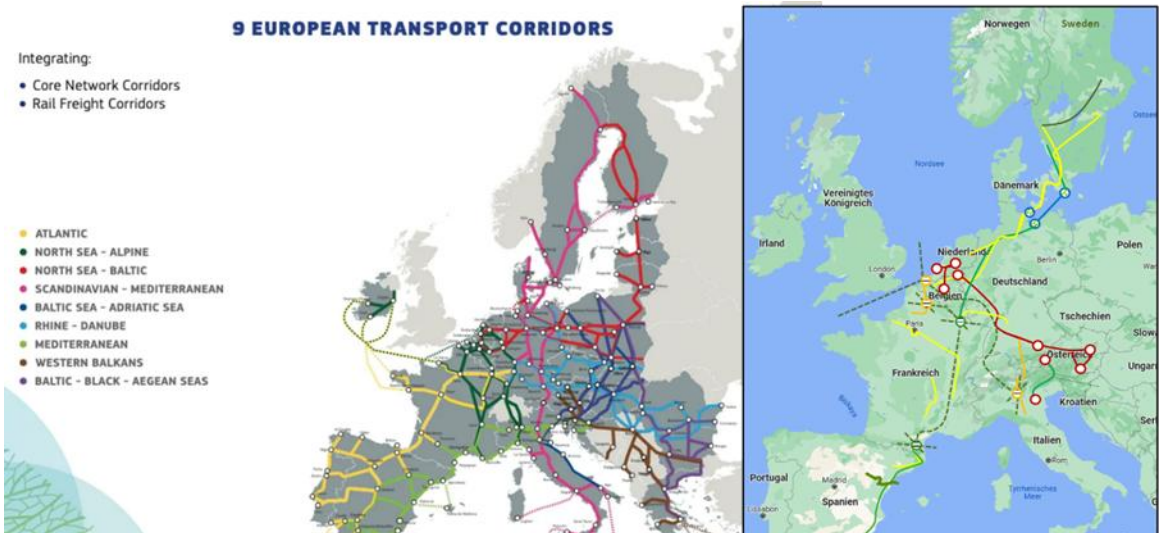

Figure 13 ZEFES & TEN-T corridors

The total length of all use cases represents road use of approximately 9,000km road and 2,000km rail across European corridors. The coverage of the TEN-T corridors is shown in figure 13

The ZEFES use case are running on the corridors,

Atlantic,	Blainville – Bourg en Bress	use case 742
North Sea – Alpine,	Oirschot – Frankfurt being	use case 724,
	Lyon – Dudelange	use case 723-2/733/734
	Amiens – Zeebrugge	use case 723-1
Rhine – Danube,	Frankfurt-Aichach	use case 724
	München-Crailsheim	use case 763
	Heilbronn – Dudelange	use case 734
Mediterranean,	Lepe-Lyon	use case 733/734
Scandinavian – Mediterranean	Dudelange – Gothenburg / Södertälje	use case 722, 723-2, 731
	Milan – Munchen	use case 763

The final demonstration plan will be ready by the end of Q1 2025. The demonstrations will run till Q4 2026.

3. Status and next steps

At this stage, simulations of each demonstration are made using the ZEFES digital platform. Specific challenges and barriers are identified, and measures are taken to mitigate. One major challenge is to transport the same amount of cargo within acceptable timing meeting the demonstration´s specific needs & requirements. An example is the transport of fresh fruits in Spain is shown in figure 14 below. Fresh fruits are collected to a central warehouse. From there it is transported to its destination somewhere in North Europe. Questions raised are how to deal with the extra time for charging / refueling, the loss of payload, the driver's extra cost, and the risk management of unexpected events. Critical questions to be answered before the demonstration can start as it operates in a daily logistics mission under the same terms & conditions as the ICE-HDV.

Fresh fruits pipeline South of Spain and North of Europe. Collecting fruits along corridor ending in Vilamlla close to the French border.

2 drivers	ICE	hr	BEV	hr	FCEV	hr
Start Mo	Murcia	06:00	Murcia	06:00	Murcia	06:00
Stop			Valencia, charging CCS	09:00-10:15		
Stop	Driver change	10:30-10:45			Driver change	10:30-10:45
Stop			Tarragona, charging CCS	13:30-14:45	Tarragona hydrogen	12:15-13:00
Stop	Driver change (Vilamalla)	15:15-15:30	Vilamalla charging MCS	17:45-18:45	Driver change (Vilamalla)	16:00-16:15
Stop	Le Boulou	16:15	Le Boulou	19:30	Le Boulou	17:00
Km	770		770		770	

Figure 14 example Spanish corridor

All demonstrations can be carried out. A result of intensive work by the 4 working groups, operation-energy-permits-digital. The start is Q2 2025, ending Q4 2026.

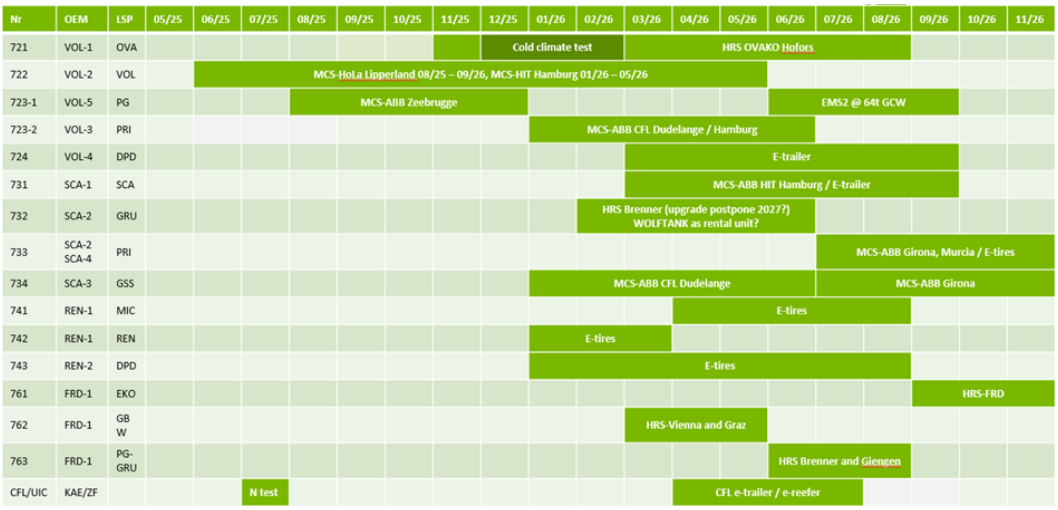

Figure 15 Overview planning ZEFES demonstrations

A detailed report on all demonstrations is available on the website, www.zefes.eu.

The main concerns remain, being the energy infrastructure and the permits for road demonstrations under real-time conditions. On top, the business model is crucial, how to achieve cost neutrality?

3.1 Energy infrastructure.

ZEFES supplies 2 MCS chargers by ABB and HIT, 2 HRS by CM/AP, covering 6 locations. Most of the charging and hydrogen locations needed to execute the ZEFES demonstrations are public and at sides of ZEFES logistics partners.
The main concerns experienced during the past year are,

- Legislative issue regarding drive & rest schedules not aligned with charging vehicles,
- Poor interest of DSOs and governments investing in energy infrastructure,
- Concerns high and medium voltage concepts,
- Leadtime to build charging and hydrogen stations,
- Standards for filling and 700bar filling systems

3.2 Road permits

ZEFES will use demonstrators, developed by the OEMs in line with the revised directive “weight and dimensions” incorporating the new technologies for BE- and FC-EHDVs. The proposed overlength and extra weight is used to build in all innovations making the vehicles technically road worthy.
The main concerns experienced in the past year are,

- Not all EU member states will approve this revised directive,
- Overlength kingpin – front of truck (900mm) not enough to create space for all e-components,
- Extra weight of 2t GCW is not enough to compensate for the extra weight of e-components (batteries and e-axle).

3.3 Business model

The business model is more folded. The CPO needs to make a profit by selling electricity or hydrogen. The carrier driving the ZE-HDV needs to make a profit by selling freight transport. Both are still in competition with the Diesel-ICE HDVs. To scale ZE-HDVs, trust in reliability, cost-efficiency, social acceptance by willing to pay more, policy conformity are important levers.
For the CPOs the utilization of charging points by 15-20% is already sufficient to create a profit. For the carrier, the use of ZE-HDVs needs enabling conditions. Awareness by logistics service providers and shippers willing adapting supply chain processes in line with the capabilities of ZE-HDVs. The OEMs and policy makers must create lower entry barriers to achieve TCO parity at the start of the scaling period towards a solid ZE-HDV fleet percentage. Suggestions were made to use EU funding for scaling projects beyond TRL9 to help the transition process.

4. Outlook and expected outcome

ZEFES is an example of best practice, learning from advantages and drawbacks. It will motivate the industry to commit and to contribute to the decarbonization of road freight transport. Demonstrations will start Q2 2025 and end Q4 2026. The evaluation and impact assessment of the collected data will end Q4 2026 as well as the end report including findings, recommendations and measures for the scaling of ZE-HDVs across Europe. 2 Follow-up projects are already planned to build on these outcomes.
The building of a flexible MegaWatt Charging station to serve charging in a combination of CCS and MCS optimizing the utilization and balancing the energy need.
The second project will focus on large scaling implementing ZE-HDVs and adapting logistics missions by creating interfaces between digital logistics platforms and digital twins as developed within ZEFES.

To do´s managing the ZEFES demonstrations and working on the follow up are

- creating an “A-Team” guiding the demonstrations enabling quick support when unexpected events turn up.
- involvement of demonstration-operators ensuring data of reference vehicles enabling a solid validation and assessment of the new technologies, their pro´s and contra´s leading to clear recommendations beyond the ZEFES project.
- involvement of stakeholders supporting the creation of realistic and concrete recommendations beyond the ZEFES project scaling up the use of ZE-HDVs.

5. References

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6. Figures and tables