Energy Infrastructure for Zero-Emission Heavy-Duty Vehicles

A Summary of the AEVETO Cluster Working Group 3 White Paper

AEVETO Cluster — Working Group 3 (Energy Infrastructure and Barriers)

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Purpose and Scope

This white paper, produced by AEVETO Working Group 3 (Energy Infrastructure and Barriers), consolidates findings from the ten AEVETO cluster projects — EMPOWER, ESCALATE, FLEXMCS, H2Haul, MACBETH, MORELife, NextETRUCK, RealHyFC, ZEFES and BELOGIC — to identify infrastructure gaps and provide recommendations for the large-scale deployment of battery-electric (BE-HDV) and fuel-cell electric (FCE-HDV) heavy-duty vehicles across Europe by 2030–2040. Drawing on demonstration data, stakeholder interviews and a 54-organisation survey conducted under the FLEXMCS project, the paper argues that vehicle deployment, charging and refuelling infrastructure, grid and hydrogen supply, digital tools, business models and regulatory frameworks must mature together. Ten cluster-level recommendations are proposed, spanning demand-driven infrastructure planning, harmonised and backward-compatible standards, corridor-level energy planning, shared infrastructure business models, and coordinated implementation frameworks that translate policy targets into deployed infrastructure.

1. Introduction

The AEVETO (Advanced Electric Vehicles for Efficient and Economic Transport Operations) cluster brings together ten EU-funded research projects under a common vision for the electrification of heavy-duty road transport. This white paper targets transport and logistics stakeholders, energy providers (TSOs and DSOs), operators of charging and refuelling sites, and policymakers. Its central argument is that the transition to zero-emission heavy-duty vehicles (ZE-HDVs) should be supported by a joint development of vehicles, infrastructure, energy supply, digital tools, business models and policy frameworks.

2. Key Findings from AEVETO Projects

Vehicle readiness differs by technology. BE-HDVs are commercially available with steadily improving range, consuming roughly 1–1.8 kWh/km (about 1.3 kWh/km for a fully loaded 40-tonne truck), up to 65% more energy-efficient than diesel per kilometre. FCE-HDVs remain largely prototype-scale, with hydrogen consumption around 8–10 kg per 100 km.

Charging must be layered by usage. Depot, semi-public and public/MCS charging serve distinct operational roles, consistent with the AFIR distinction between private and publicly accessible infrastructure. Uncertainty over availability, cost and accessibility, particularly for long vehicles, remains a central barrier.

Interoperability is not yet guaranteed. ISO 15118-20 and IEC TS 63379 define MCS communication and connector standards, but CCS/MCS coexistence and backward compatibility with legacy assets

remain essential during the transition. For hydrogen, not every 700-bar HRS can serve an HD-FCEV; pressure, nozzle, cooling and protocol compatibility (SAE J2601/5) must be confirmed in advance.

Grid and hydrogen-supply availability are the binding constraints. Connection lead times, limited visibility of grid hosting capacity and peak-demand costs delay charging sites; HRS deployment relies on renewable hydrogen production, distribution and refuelling being planned together.

Business models must share risk. Electric trucks can cost up to 2.5 times a diesel truck, residual values remain uncertain, and public charging can be nearly twice as expensive as depot charging. Shared or semi-public depot access, anchor-user agreements, phased investment and public co-funding recur as proposed mitigations.

Digital tools are emerging but still fragmented. ZEFES has developed a validated vehicle Digital Twin, a total-cost-of-ownership (TCO) model, and fleet-management tools for predictive maintenance, eco-driving and route/charging planning. BELOGIC is developing interoperable route-planning and smart-charging tools, validated across eleven real-world BEV demonstration missions. Charging-reservation functionality exists but is not yet universal or interoperable across charge point operators (CPOs), with the emerging OCPI 2.3 Booking module cited as a likely enabler.

Policy target-setting is ahead of implementation conditions. EU CO_2 standards (a 45% reduction by 2030 and 90% by 2040) and AFIR deployment targets are not yet matched by grid readiness, harmonised permitting or the MCS standards finalized in June 2026; several OEMs report delaying MCS product launches pending protocol implementation finalisation.

3. Challenges

Charging-infrastructure challenges identified across the AEVETO projects are grouped into three levels:

1. **Station level** — space constraints (the footprint required for charging is roughly 25% larger than a standard parking bay), depot layouts not designed to host an entire fleet, conflicts between charging zones and loading operations, and still-immature vehicle-to-everything (V2X) / bidirectional charging, held back by standards, taxation and pricing gaps.
2. **Grid and electricity market level** — lengthy and inflexible grid planning processes (delays often exceeding a year), charging-demand models still calibrated on diesel logistics data, and the risk of peak-period saturation at shared truck/passenger-vehicle sites.
3. **Enabling conditions** — fragmented regulation and permitting, uneven geographic coverage (even relatively well-served regions such as the Nordics and Benelux remain insufficient for AEVETO use cases), and weak early-stage business cases driven by uncertain utilisation and unclear cost-sharing among CPOs, grid operators and logistics users.

For **FCE-HDVs**, six specific barriers are identified:

1. limited technological readiness of both vehicles and stations;
2. scarce renewable (“green”) hydrogen supply;
3. poor accessibility of real-time HRS capability data;

4. gaps in inline hydrogen purity and quality monitoring;
5. weak HRS utilisation and business sustainability, evidenced by station closures such as OMV in Austria and Hynion in Sweden; and
6. uncertain vehicle residual values that expose operators, particularly SMEs, to financial risk.

4. Opportunities

Based on AEVETO projects findings and current challenges, a few opportunities have been identified to ease the deployment of BE- and FCE-HDVs:

- Logistics companies can build "corridor-ready" operations, for example trailer swapping and predictable hub layouts, and exploit hybrid depot/semi-public charging models to control energy costs; fleets consulted target roughly €0.35–€0.45/kWh to reach diesel cost parity.
- Depot owners and operators could unlock value from V2X and bidirectional charging, although dedicated heavy-duty vehicles with this capability are not expected before 2028.
- Infrastructure providers benefit from converging standards such as AFIR in the EU and SAE J3271 in North America that enable scalable, interoperable deployment across regions.
- Grid operators (DSOs and TSOs) can capture strategic value by proactively securing capacity at logistics hubs and freight corridors, evolving from passive connection providers into active energy and flexibility partners.
- For hydrogen, the shift from 350-bar to 700-bar refuelling and AFIR's station density, accessibility and positioning requirements create a clearer framework for scaling HRS at multimodal freight hubs.

5. The Solution Space

AEVETO projects contribute complementary vehicle innovations: ZEFES (optimised regenerative braking, thermal management, electrified trailer axles), NextETRUCK (infrared cabin heating to cut HVAC energy use), ESCALATE (roof-mounted photovoltaics for auxiliary power), EMPOWER (a modular battery/fuel-cell multi-powertrain with improved cab insulation and HMI-based eco-routing), H2Haul and EMPOWER's fuel-cell variant (long-haul FCEV drivetrain validation), MORELife and RealHyFC (fuel-cell stack materials, degradation modelling and durability), and BELOGIC (operational and logistics models testing whether BEV trucks can match diesel costs on long-haul routes).

On infrastructure, FLEXMCS and MACBETH are demonstrating multipoint megawatt charging (MCS) hubs, addressing site layout, grid connection strategy and interoperability. On digital tools, the ZEFES Digital Twin and TCO model, together with BELOGIC's route and smart-charging tools, support fleet planning and dispatch decisions. On regulations, the projects collectively call for aligning AFIR deployment targets with grid readiness and the finalisation of MCS and HRS standards.

6. Recommendations

A stakeholder survey conducted under FLEXMCS, covering 54 organisations, found that fixed-time charging reservations are largely rejected by logistics users as too rigid for unpredictable freight operations; dynamic load forecasting and predictive planning are preferred instead. Proximity to freight corridors, reliable delivery of at least 1 MW for 500–900 kWh truck batteries, MCS/CCS compatibility, transparent energy pricing, and basic driver amenities were consistently prioritised by respondents.

On this basis, the AEVETO cluster puts forward **ten recommendations**:

1. Concentrate **charging and HRS investment** where **freight operation** shows the greatest need, following the **corridor approach** along TEN-T corridors, while keeping AFIR's minimum-spacing requirements as the minimal network baseline.

2. Guarantee **reliable energy delivery** to the ZE-HDV and provide fleet operators with **real-time information** on vehicle, charger/HRS status, availability, pricing and accessibility.

3. Accelerate **harmonised implementation** of MCS and HRS standards, make **interoperability** testing mandatory before deployment, and ensure new standards remain backward-compatible with existing infrastructure.

4. Establish **corridor-level energy planning** that jointly forecasts freight demand, charging and refuelling requirements, grid capacity and renewable hydrogen supply, based on the needs of the electrified ecosystem, not on historical data.

5. Adress barriers on viability of infrastructure sites, involving the full ecosystem, including grid operators and hydrogen providers, permitting authorities and infrastructure developers, with the objective to define the short- and long-term, technical and economic viability early in the planning cycle, before detailed infrastructure design.

6. Mandate standardised, **dynamic infrastructure and vehicle data** integrated into logistics interfaces, such as fleet management and routing tools, so operating ZE-HDVs will not require additional work, compared to diesel vehicles.

7. Promote **shared charging and HRS infrastructure**, anchor-user models and public-private co-funding mechanisms, also for depot and logistics hub infrastructure.

8. Design **new charging and refuelling infrastructure** specifically for **heavy-duty vehicle** operation with drive-through access, safety, parking and driver amenities, rather than adapting passenger-vehicle facilities.

9. Move from deployment targets alone towards **coordinated implementation frameworks** that align permitting, grid readiness, standards and funding mechanisms.

10. Deploy hydrogen refuelling stations at **strategic freight corridors and logistics nodes** based on aggregated demand and coordinated fleet roll-out, while assessing whether gaseous and liquid hydrogen refuelling technologies can coexist.

7. Conclusion

The white paper's central message is that infrastructure deployment targets under AFIR and the EU CO_2 standards will not translate into fleet-level adoption of zero-emission heavy-duty vehicles unless matched by coordinated grid planning, harmonised and backward-compatible technical standards, risk-sharing business models, real-time interoperable data, and site design built around the operational needs of heavy-duty vehicles rather than passenger cars. The AEVETO cluster projects collectively provide the technical, operational and stakeholder evidence base underpinning these recommendations, and their working groups intend this white paper to serve as a support for further coordinated action across the European zero-emission freight ecosystem.