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Zero Emission flexible vehicle platform with modular powertrains serving the long-haul Freight Eco System

ZEFES - Deliverable report

D5.4
Next generation battery-electric trailers

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Publishable Summary

Within the Green Deal, Europe commits itself to be the first CO2 neutral continent by 2050. To achieve this, an overall CO2 reduction target of 55% by 2030 is defined as a first milestone. For the road transport sector, the target is set to 30% less CO2 emissions by 2030 (compares to 1990 emission levels) following Regulation (EU) 2019/1242. The regulation requires that manufacturers of heavy-duty vehicles (HDV) deliver more efficient vehicles to achieve a reduction of CO2 emissions for the newly produced fleet of 15% in 2025 and 30% in 2030. This deliverable presents the process of adaptation and improvement of the electrified trailers (e-trailers) that will be applied in the logistics missions of different ZEFES use cases. Three use cases demonstrate three different vehicle combinations with modular multi-powertrains consisting of three battery-electric towing vehicles, two electrified semitrailers and one electrified converter dolly. Based on the use case definitions and the specific configuration of the vehicle combinations, the requirements for the base vehicles and powertrain components of the e-trailers are derived. The deliverable presents the design and integration of the powertrain components into the trailer chassis along with the commissioning of the powertrain on component and system level. As one of the main results, the e-trailers are built and released for expert operation on public roads.

Finaly, the homologation process and its challenges resulting from the missing regulatory framework within the European Union is described including an outlook on the final validation of the e-trailers and its handover to the use case owners.

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1 Introduction

In the ZEFES work package 5, the modular and flexible battery-electric powertrains are designed and their integration in five demonstrators is realized. These demonstrator vehicle combinations consist of five battery-electric towing vehicles, two electrified semitrailers, and one electrified converter dolly.

The work includes the development of a modular battery-electric powertrain concept for long-haul heavy-duty vehicle combinations, which are adaptable to daily demands of mission profiles in terms of range and power, and flexible in terms of integration of batteries and powertrains in different vehicle units. For this powertrain concept, a functional safety concept is created.

To realize the vehicle units, specific powertrain components, subsystems, control systems and energy & thermal management systems are adapted and integrated in the prime mover battery-electric powertrains. Development and integration efforts are also made to realize the next generation e-trailers serving as range extender integrated in the electric powertrain of the prime mover.

The following list of deliverables shall clarify the context of deliverable D5.4:

D5.1 – System specification for zero-emission modular multi-powertrain concepts: In this deliverable, the system specification of the battery-electric vehicle combinations with a modular multi-powertrain is verified and evaluated. The upgraded vehicle simulation tool IVIsion is used to verify the final design specifications of each targeted BEV demo.

D5.2 – Functional Safety Concept: The deliverable investigated the functional safety concept for the vehicle combinations with a modular multi-powertrain. The concept of an additional powertrain located in a trailer is described in terms of its application area, its functional behaviour on vehicle level, the powertrain functions, and a draft system architecture. Furthermore, the results of the hazard analysis and risk assessment are presented including the derived safety goals and functional safety requirements for the development of the electrified trailers and the application in the ZEFES use cases.

D5.3 – Powertrain components and control systems for next generation battery-electric trucks: Within the deliverable, the innovations and system improvements for the battery-electric towing vehicles developed by SCA, VOL and REN are described. This includes results of the proof of concept.

D5.4 – Next generation battery-electric trailers: The deliverable describes the adaptations and improvements of the e-semitrailer and the e-dolly as part of the modular multi-powertrain vehicle combinations. This includes the improvement of the mechanical design for the trailer chassis, based on the existing ZF e-trailer, and the development efforts regarding the powertrain components, controls, and auxiliary systems.

D5.5 – Commissioning, testing and verification connectivity between BEV demonstrators and digital twin tool: The deliverable briefly describes the results of the commissioning and testing of the data interface between the demonstrator vehicles and the digital twin tool developed in work package 4.

D5.6 – Realization and commissioning of all BEV demonstrators: In this deliverable the commissioning and testing of the six battery-electric demonstrator vehicle combinations is presented including the results of short dry run tests. As a result of the work described in this document, the vehicle combinations can be handed over to WP7 use cases.

The position of deliverable D5.4 within WP5 and the relation to other deliverables and work packages is shown in Figure 1-1.

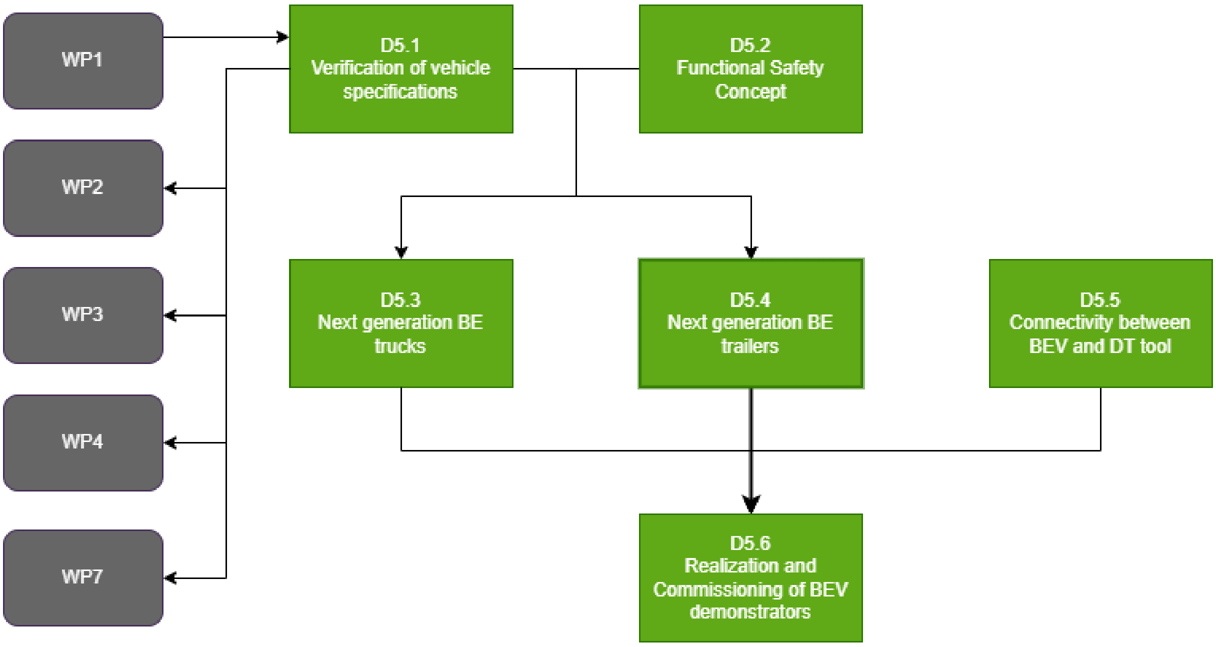


Figure 1-1: Relation of deliverable D5.4 to deliverables of WP5 and other WPs

1 ZEFES e-trailers

1.1 Use case specific requirements to the basic trailers

1.1.1 Container Chassis for UC 7.2.4 / VOL/DPD

The e-trailer is a 3-axle semi-trailer container chassis, suitable for swapbody transport with two 7,15 m swapbodies. In combination with a rigid truck with a 7,45 m swapbody and a gap between the rigid truck and the e-trailer of 1,2 m it enables a total length of the vehicle combination that fits in the 25,25 m that is allowed in most European countries. Under this constraint the EMS1 vehicle combination fulfils the requirements of the Dutch and Scandinavian turning circle with an outer radius of 14,5 m. The vehicle is equipped with the optiturn option to comply with the German turning circle of 12,5 m.

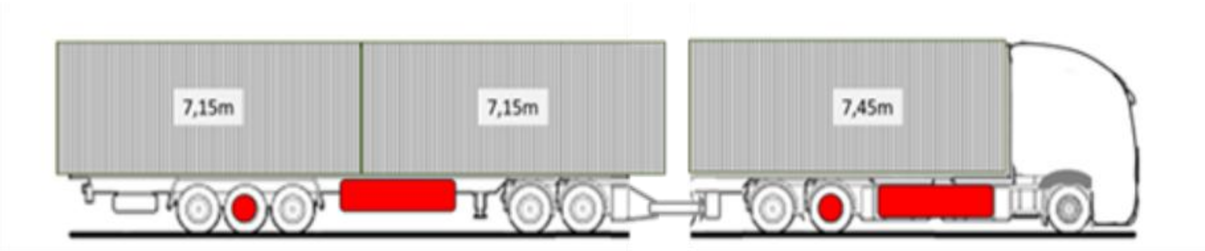


Figure 1-1: Layout of the vehicle combination for UC 7.2.4

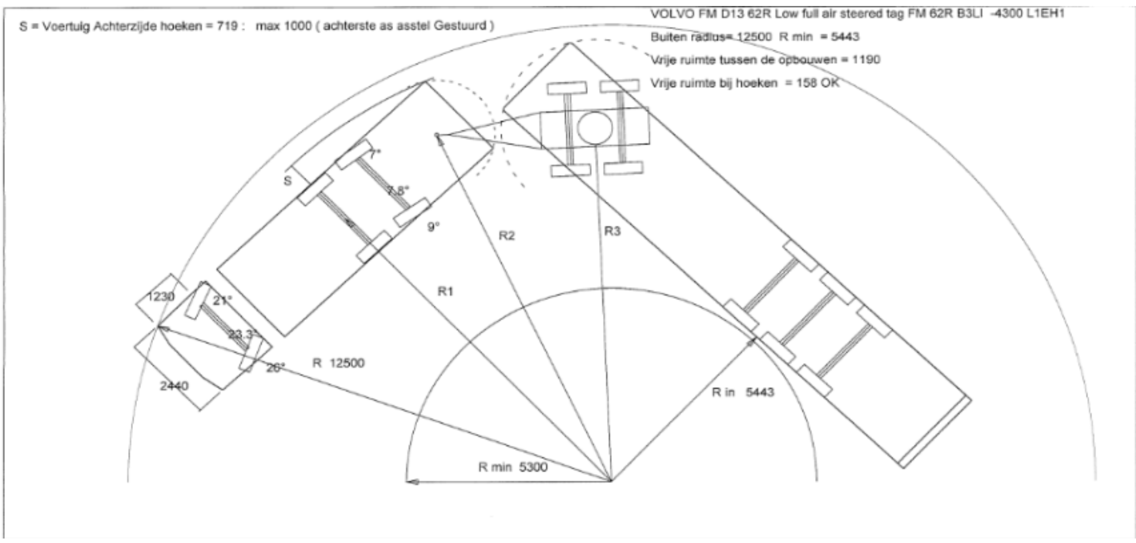


Figure 1-2: Turning circle of the vehicle combination for UC 7.2.4

In the trailer load area, container lock placements were optimized for 2×7,15 m swap body loading in the EMS1 vehicle combination. To accommodate these configurations, the front panel and extendable rear bumper were modified, ensuring compatibility with standard-sized trailers under specific loading conditions.

For safe integration of the TrailTrax system, a bracket was designed for the anti-jackknife belt connection. The 1st and 3rd axles were selected to meet e-axle suspension requirements, considering factors such as brake component compatibility, track width, spring centre distance, and air suspension parameters.
The trailer chassis underwent several adaptations:

- Integration of the e-axle and selected suspensions
- Reinforcement for TrailTrax component mounting
- Battery box mounting enhancements
- Design and installation of an angle sensor in the king-pin area

Finally, infrastructure updates were implemented to meet the electrical and electronic brake system requirements of the TrailTrax system.

Trailer configurations compatible with use case loading conditions and TrailTrax application is defined and applied.

Table 1-1: Vehicle data of the e-tailer chassis for UC 7.2.4

Chassis	• 3 axle semitrailer • 1300 mm frame distance • Truck fifth wheel plate height 1150 mm
Curb weight	7,6 t
Technical weight (GVW)	39 t
Battery-electric powertrain	• 308 kWh energy capacity • CCS compatible charging capability
Axle/tire configuration	• E-axle (2nd axle) • all 3 Axles with pole wheels and Speed sensors • BPW ALII Disc Brake axles • ECAS (Sensor 2nd Axle) • Tire 385/65 R22,5 • Alcoa Dura Breigth ALU Rims
Special equipment	• Anti Jack-Knife-Belt bracket between the landing legs • King Pin with angle sensor • Lash for Ferry • Optiturn cornering system • Container locks locations compatible with containers and swap bodies • Extendible rear bumper
Brake/suspension system	• TEBS E Premium 4S2M / XHZ • Air Reservoirs 2 x ca.80l + 1x60l/80l in steel, painted in black (2xBrake, 1x Air suspension) • Coupling Head red and yellow
Trailer interface	• 15-Pin Light cable

	• Additional ISO7638–2(12Volt) front to the axles • TEBS power cable with ISO7638 Socket with interrupting plug

Due to specific loading conditions of the use case (swap bodies), striping concept applied on underbody area of the trailer in accordance with project requirement were studied.

Figure 1-3: Striping concept for the e-trailer chassis for UC 7.2.4

1.1.2 Curtainsider for UC 7.3.1 SCA/SCA

The e-trailer is a 3-axle semi-trailer curtainsider, suitable for dryfreight transport, especially automotive products. In the trailer's upper structure, interior height, load securing features (lashing points, anti-theft curtains etc.), roof features (roof lifting, roof safety airbags etc.) have been studied and applied according to end user requirements
The bracket design for the anti-jackknife belt connection required for the safe realisation of TrailTrax system development studies was carried out.
1st and 3rd axle type were selected to be compatible with e-axle suspension requirements. While making this selection, compatibility with e-axle brake components, track width, spring centre distance and air suspension parameters were taken into consideration. Adaptation works were carried out on the trailer chassis to connect the e-axle and other selected axles and suspensions. Chassis adaptations were carried out for the safe connection of other components of TrailTrax on the chassis. Necessary reinforcement/adaptation works were carried out in order to safely connect the battery box to the chassis. Design work was carried out for the integration of the angle sensor required by the system in the king-pin area.
Infrastructure updates were made in accordance with the electrical-electronic brake system requirements required by the TrailTrax system.

Table 1-2: Vehicle data of the e-tailer for UC 7.3.1

Chassis	• 3 axle curtainsider semitrailer • 1300 mm frame distance • Truck fifth wheel plate height 1150 mm
Upper body	• Roof Lifting • Roof Safety Air Bag (RSAB) • Anti-Theft Curtain

Curb weight	9,6 t
Technical weight (GVW)	39 t
Battery-electric powertrain	• 200 kWh energy capacity • CCS compatible charging capability
Axle/tire configuration	• E-axle (2nd axle) • 1st & 3rd axle is liftable • all 3 Axles with pole wheels and Speed sensors • BPW ALII Disc Brake axles • ECAS (Sensor 2nd Axle) • Tire 385/65 R22,5 • Alcoa Dura Breigth ALU Rims
Special equipment	• Anti Jack-Knife-Belt bracket between the landing legs • King Pin with angle sensor • Lash for Ferry • Optiturn cornering system • Container locks locations compatible with containers and swap bodies • Extendible rear bumper
Brake/suspension system	• TEBS E Premium… 4S2M / XHZ • Air Reservoirs 2 x ca.80l + 1x60l/80l in steel, painted in black (2xBrake, 1x Air suspension) • Coupling Head red and yellow
Trailer interface	• 15-Pin Light cable • Additional ISO7638–2(12Volt) front to the axles • TEBS power cable with ISO7638 Socket with interrupting plug

Striping concept applied on upper body area of the trailer in accordance with project requirement are studied.

Figure 1-4: ZEFES project striping concept for curtainsider e-trailer

Figure 1-5: ZEFES project striping on the curtainsider e-trailer

1.2 Use case specific requirements to the TrailTrax System

Figure 1-6: Schema of the ZF TrailTrax system and its components

1.2.1 Basic technical description of the TrailTrax system

The ZF electrified trailer solution is made possible by integrating the ZF TrailTrax system into a heavy-duty trailer. The TrailTrax system consists of the trailer version of ZF's AxTrax 2 electric axle with a modular battery system box for recuperation and traction support. Thanks to its ability to recuperate energy from braking, the system can effectively convert a heavy-duty diesel truck into a hybrid vehicle. The trailer also provides benefits for zero-emissions electrified heavy trucks by extending the driving range of the combined vehicle. The latter is used in context of the ZEFES project.

A scalable Battery concept allows installations with 100 kWh, 200 kWh or 300 kWh gross battery capacity. The 100 kWh configuration is used in urban application with high potential for recuperation in stop and go traffic. The 200 kWh version provides a balanced support for recuperation and propulsion in regional environment or for long haul "on demand" support. The 300 kWh configuration allows sufficient support on long haul missions for CO2 saving or for range extension.

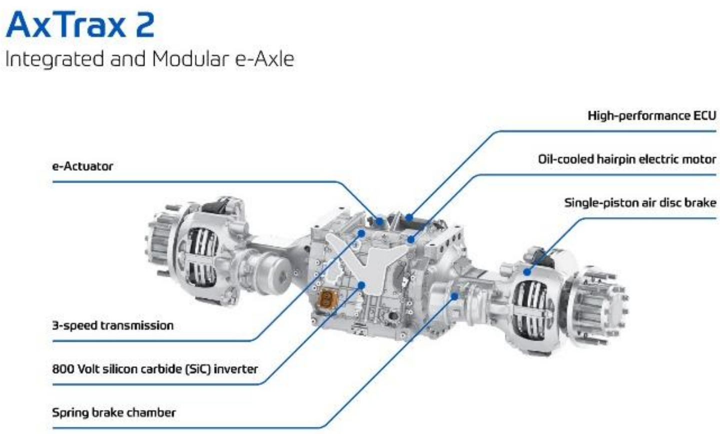


Figure 1-7: Schema of the ZF AxTrax 2 electric axle for trailers

The trailer version of the AxTrax 2 comprises the same drive characteristics as the truck version:

- 210 kW continuous power and 26,000 Nm of peak output torque
- Includes an integrated 800 Volt silicon carbide (SiC) inverter
- Features a 3-speed transmission with an e-actuator for optimized efficiency
- Offers full neutral capability enabling coasting and towing
- Incorporated high-performance ECU
- Easy integration with air disc brake and brake actuation solution

The differences for the trailer solution are related to a modified mechanical interface for integration in a trailer suspension system.
For integration in an e-trailer system, the different operation strategy versus a main drive axle for propulsion must be considered. In a truck or bus application, the drive axle is permanently powered for propulsion or recuperation purposes. The trailer axle is used to support in dedicated driving situations. It supports the driving axle of the truck, without forcing the truck's drive system to an operating point with poor efficiency.

1.2.2 Functional interaction between e-trailer and towing vehicle

The operation mode of the TrailTrax system in the ZEFES e-trailers is called "self-controlled e-trailer". The TrailTrax control system uses data from the trailer EBS system and other available information like axle loads from air suspension system and vehicle speed/acceleration in the trailer, to conclude on the forces between the towing vehicle and the trailer as towed vehicle. By doing so, in the ZF TrailTrax system, it is possible to operate without a dedicated physical measurement of the forces between the vehicles.
The functional controls of the e-trailer can process the on-board generated force information together with supplemental data and information to conclude on the active driver demand (respectively, the demand of a driver assistance system like cruise control). A basic principle of the e-trailer operation is to support the driver demand and not act against it. This is important for reasonable efficient operation as well as for safety reasons. For example, the e-trailer should support the propulsion of a vehicle combination which is accelerating on a flat road. Undoubtedly, the driver

demand is to speed up the vehicle. But going downhill, the e-trailer will not support an acceleration which is just caused by downhill slope forces and not by explicit driver demand.
Especially for range extension with BEV, it can make sense to compensate rolling resistance of the trailer by continuous propulsion support via the e-axle. Nevertheless, as soon as any indication is detected that the driver intends to decelerate the vehicle (e.g., brake lights activated or retarder active), the propulsion of the e-trailer will instantly be deactivated.
In every driving situation, the braking system stays the master for stability control. The propulsion or recuperation in the e-tailer will be deactivated as soon as a stability intervention by truck and/or by trailer is detected.
Finally, the e-trailer activates propulsion or recuperation by itself, following the reliable detected driving state given by the towing vehicle, when not interfering with the operation of stability functions.

The chosen operating strategy leads to the following conclusion

- No dedicated controls for the e-trailer must be implemented in the truck
- No dedicated e-trailer functional interface must be developed between truck and trailer
- The usual ABS/EBS data connection according ISO11992-2:2014 between truck and trailer is mandatory to validate the e-trailer operation for plausibility regarding the driver demand and operational status of the vehicle systems, especially braking system and stability control.

Further information on alternative operating strategies and the conclusion for using “self-controlled e-trailer” in ZEFES can be found in deliverable report “D2.7 Design of the interface between e-trailer and prime mover” [1]. The document also contains more details about the e-tailer operation in different driving situations.

1.2.3 Driver Interface to Towing Vehicle and Driver Display

The above mentioned deliverable D2.7 [1] is also addressing the need for a driver display / interface for ZEFES demonstrations.
The generic e-trailer concept (respectively, the generic concept for ZF TrailTrax) principally comes without the need for a driver information display and without the need for driver intervention. In connection with a diesel truck, the e-trailer harvests kinetic energy by recuperation during brake events. This energy plus energy gained by plug-in charging is used to support propulsion and reduce fuel consumption and CO_2 emission of the diesel truck significantly. When the battery is empty, the vehicle just returns to unsupported operation. With the assumption, that the truck has sufficient fuel in its reservoir, the driver has not to care about re-charging on the transport mission. The e-trailer operation is not relevant for reaching the destination. Regular over-night charging at the depot or opportunity charging on regular stops is sufficient. Consequently, there is in principle no need to take care about the state of charge of the battery by the driver.
The e-trailer is self-supervised and provides no recuperation and no propulsion when internal faults or insufficiencies are detected. Also, in this case, the driver does not have to take actions. Therefore, the driver information is not mandatory. Insufficiencies which could be solved by the driver (e.g., coolant fluid level issues) can be indicated by regular trailer warnings on the truck dashboard.

The e-trailer operation as a range extender for a BEV truck and especially the use of the TrailTrax e-trailers, which are not yet in series status in ZEFES, lead to additional requirements. A driver information display and a push button switch to deactivate e-trailer operation need to be installed in the towing vehicles for the following reasons:
For range extension operation, it is essential for the driver to know about the state of charge of the battery in e-trailer. The energy stored in the battery of the truck and the energy in the battery of the e-trailer are needed to finalize the trip. The driver needs to know both battery charging states to plan and monitor the mission. Therefore, the state of charge of the e-trailer battery is indicated on a driver information display, supported by information on the actual supporting power during driving.
For operation of the e-trailers which are not yet released as a series product, the driver is informed about dedicated system states of the e-trailer. Warnings are indicated if insufficient function appears or measurements in the system exceed limits. As not all self-supervising functions are finally released, the driver has to take action and, e.g., deactivate e-trailer operation temporarily and/or, e.g., refill coolant liquid or initialize maintenance actions.

Before starting the ZEFES demonstration, the drivers will be instructed on how to react on warnings indicated via the driver display and what information should be monitored.

ZF installs the display and necessary connection devices to the BEV trucks. Alternatively, ZF sends the material and an installation instruction to VOL and to SCA for installation. In that case, the plug and cable are pre-installed in the truck by the OEM. If not possible, a retrofit by ZF is possible with guidance by the OEM on best location for wiring inside the cabin.

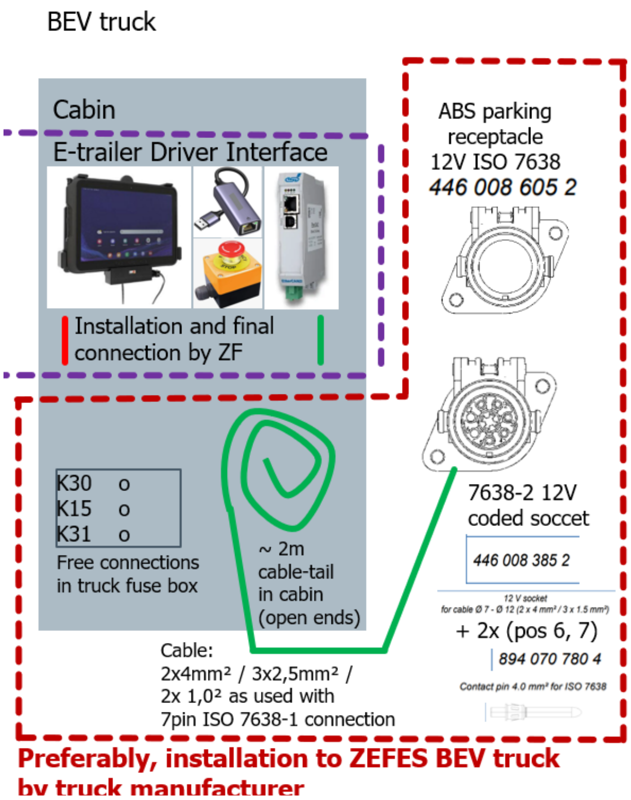


Figure 1-8: Overview on interface between truck and e-trailer for driver information display and a push button switch

The actual physical installation differs from the proposal described in deliverable D2.7 [1]. The first proposal makes use of free pins on the ISO12098-connector to connect driver-display and off-switch in the truck to the e-trailer. Meanwhile, a better solution is found, which is not mixing up standard usage of ISO12098-connector with e-trailer signals. Supplemental to the existing standard ISO12098-connector (for lights and not-running-gear-controls) and to the existing standard ISO7638-1 24V connector (ABS/EBS), a supplemental ISO7638-2 (12V type) Socket on the trailer is used. The e-trailer electrical signals for the driver display and for the emergency-switch are connected there. The towing vehicle should be supplemented by the same connector.
The driver display itself is realised as a standard Android tablet device. A ZF developed application is reading the information on the vehicle interface connection and puts it on the screen. Furthermore, a back channel is realized, for limited functional controls.
As an alternative to the tablet solution, a robust series display from ZEFES partner CPAC was in evaluation. Finally, the ZF tablet-solution was chosen, as the function is already existing. Changing the display would cause additional efforts and need for coordination.

1.2.4 TrailTrax Adaptation to UC 7.2.4 / VOL/DPD

Within the demonstration according ZEFES Description of the Action Subtask 7.2.4, the vehicle combination of Volvo BEV (rigid truck / container transport) + Dolly (conventional) + e-trailer (container chassis) will be operated for 6 months in a DPD transport mission on their Rhine-Alpine corridor. The route leads from Eindhoven (NL) to Aichach (DE) and vice versa. Depending on the best route for the day (influenced by weather conditions, construction work, traffic) the total distance can vary between ~670km and ~750km.

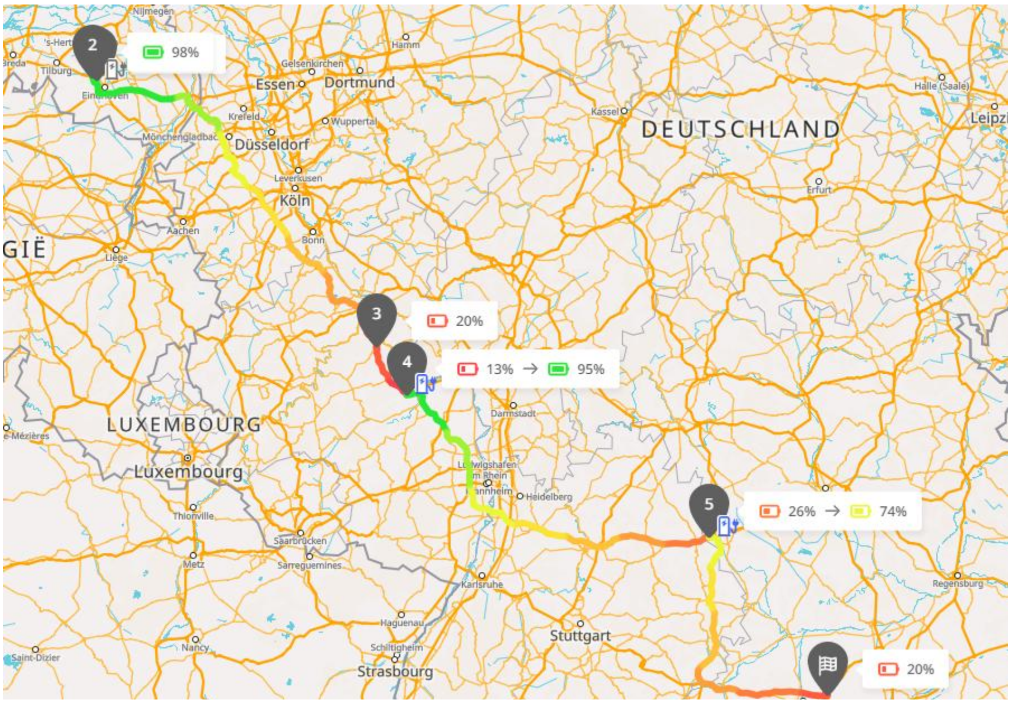


Figure 1-9: Visualization of the simulation results on a draft route for UC 7.2.3 including routing, charging stops and resulting state of charge of the vehicle combination (assuming an energy capacity corresponding to the sum of both energy storage units in the truck and the e-trailer

Figure 1-9 shows a possible route with possible charging stops. A first proposal for the route is provided by PTV via their EV planning tool. The final assumption for a primary route and an additional secondary route (in case the primary route is blocked) will be found in an iterative process. The final routes depend on the charging infrastructure and the driving range of the vehicle combination. The driving range of the vehicle combination is determined by the energy of the batteries at the starting point, on the mass of vehicle and freight and on the topology of the route. The next feasible charging location must be reached within this driving range. DPD will identify the charging stations, that are able to accommodate the ~25m long EMS1 vehicle combination and can provide charging facilities for BEV and e-trailer.

Requirement for the e-trailer to manage the trip is

- A sufficiently large battery configuration and
- An operation strategy, which ensures that the truck is supported efficiently by the e-trailer

Based on a generic e-trailer operation strategy provided by ZF, FHG simulated the energy need separated for BEV and for e-trailer on a possible route segments between Oirschot and Aichach. The results from beginning of 2025 are available in deliverable D5.1. "System specification for ZE modular multi-powertrain concepts" [2]. The chosen route segmentation for the simulation was quite challenging, based on a first route discussion at the beginning of the project. A first segment of ~135 km (Oirschot-Neuss) is followed by ~315 km (Neuss-Wertheim) and concluding with the third segment of ~310 km (Wertheim Aichach).
The outcome of the investigation is presented in deliverable D5.1: With the assumed Battery configuration gross 450kWh BEV and gross 308kWh trailer, the range is below 300km. Thus, the legs >300km cannot be completed. The BEV runs out of energy, while ~30kWh useable energy in the e-tailer is still available.
But considering that the BEV battery capacity is actually 540 kWh, and that the parameters of the real e-trailer operating strategy (software) will be optimized in a preparation phase for best operation with the dedicated BEV and for the final mission routing, even the Oirschot-Neuss-Wertheim-Aichach route seems challenging, but operable.
Finally, the risk to come to a halt in the real transport operation before reaching a charging station is not acceptable, and an alternative primary route and secondary optional routs must be identified to limit the distance between any two charging stops to ~250 km. Thus, the mission trip may be subdivided by two charging stops into 3 legs of the same length.

When starting the demonstrations, the driver of the vehicle combination should get a list of suitable charging stations between Oirschot and Aichach. In addition, the driver gets a primary route which is the preferred one regarding level of available energy in the vehicle considering the charging opportunities. A set of secondary legs gives the driver and operator the opportunity, to take a feasible alternative leg in case of problems on the primary route.

The following steps are taken for preparation of the information for the driver to find a trip without running out of energy on the trip from Oirschot to Aichach:

- Identification of a primary route as well as up to 3 secondary routes with an EV route planning tool (no separate simulation of BEV and e-trailer), considering the driving range of the vehicle combination consisting of the BEV, a standard dolly and the e-trailer resulting from the separate simulation of the drivetrains of BEV truck and e-trailer presented in deliverable D5.1 and considering the list of charging stations which are suitable for commercial vehicles (from WP3).
- Visit of the identified charging stations, to check on site, whether and how the 25,25m long EMS1 combination can be charged there and whether it is possible to charge BEV and e-trailer in parallel.
- Simulation of the combined vehicle with distributed drivetrain at FHG and/or ZF (regarding up-to-date status of the operation strategy for e-trailer) on the proposed primary and secondary legs. Confirm feasibility to manage the trip. Identify the amount of energy to be charged to BEV truck and to e-trailer at the charging stop.
- If needed, within the step before, optimize the e-trailer operation strategy, by tuning the parameters for better balanced support of the truck for the dedicated topology of the trip.
- Determine the time for charging at the stops, considering the conditions at the charging location (power of the chargers, charging for BEV truck and e-trailer in parallel or one after the other)
- Revise the choice of primary and secondary route and legs, modify if needed, highlight the smoothest route and eliminate the legs with risk of run out of energy.
- Finally, before starting the demonstrations, run the combination of BEV and e-trailer on the mission route for final validation of the actual performance of the vehicle combination versus the simulation results and checking the operability at charging stops.

1.2.5 TrailTrax Adaptation to UC 7.3.1 / SCA/SCA

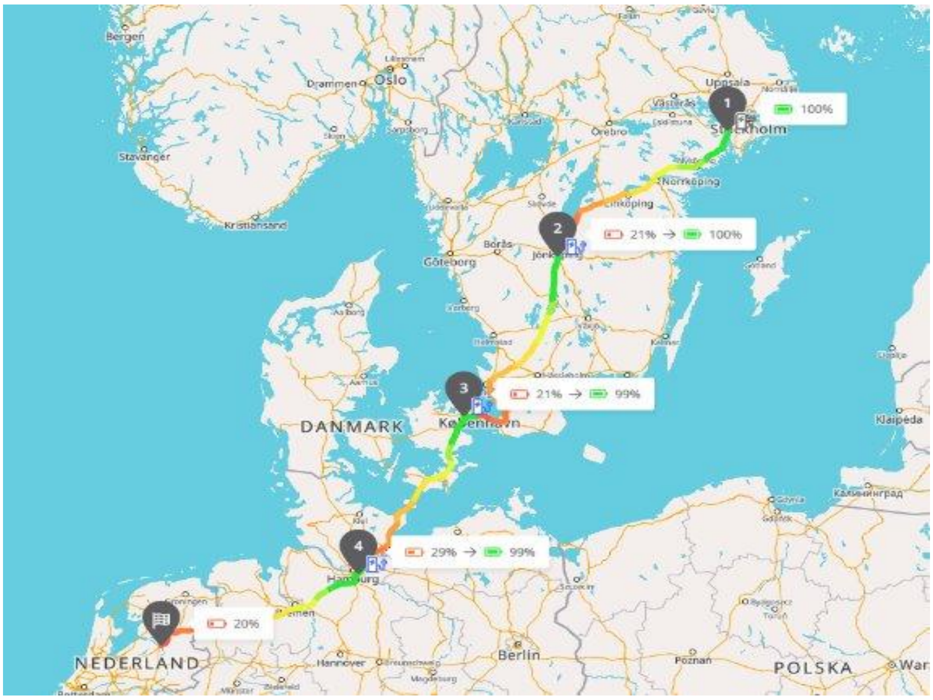


Figure 1-10: Visualization of the simulation results on a draft route for UC 7.3.1 including routing, charging stops and resulting state of charge of the vehicle combination (assuming an energy capacity corresponding to the sum of both energy storage units in the truck and the e-trailer)

Scania will operate the BEV vehicle for 6 months on an existing transport flow of automotive components from Södertälje to Zwolle and back. The return flow to Södertälje contains a limited amount of goods. The trip is around 1325km per direction. Charging Stops between Södertälje and Zwolle are foreseen in Jönköping, Helsingborg and Hamburg. Figure 1-10 still shows the charging stop

in Copenhagen. Meanwhile, passing the Öresund-Bridge from Malmö to Copenhagen with charging there, is replaced by charging in Sweden in Helsingborg before entering the ferry to Helsingor (DK).
The Scania BEV is equipped with a battery gross capacity of 624 kWh. For the e-trailer, the battery configuration is gross 205kWh.
The initial PTV simulation for the route via Copenhagen for an installed battery capacity of 734 kWh shows feasibility to manage the route, if it is acceptable that the battery can be discharged down to 20% and can be re-charged up to 100% state of charge during the trip. As Scania can equip the BEV truck type with up to 728 kWh (7 batteries with 104 kWh each), the route is close to be manageable by the BEV truck alone.
The simulation by FHG, which was presented in deliverable D5.1 [2], also considers the BEV equipped with the large battery configuration, but assumes restricted timing for charging. With the assumption that the truck is not fully charged in Hamburg, the leg Hamburg-Zwolle may not be managed by BEV truck alone.
But the simulation presented in D5.1 calculates a lower power consumption for the trip compared to the PTV simulation with the EV simulation tool. In principle, based on the FHG simulation, even a BEV with 624 kWh gross battery capacity installed, may manage the trip without support by the e-trailer, assuming the BEV is fully charged to almost 100% state of charge at every charging stop.
A reason for the different power consumptions in the FHG simulation and the PTV tool is probably the assumption on environmental temperature and on the driving conditions in summer versus winter season. In fact, the present timeslot for the demonstration starts in summer and ends before winter. Therefore, the actual battery capacity of 624kWh installed gross capacity looks promising to manage the trip without e-trailer. Since charging in Copenhagen is cancelled and replaced by charging in Helsingborg, the leg before reaching Hamburg extended significantly from 297km to 362km. Here, the useable energy of the BEV battery alone is probably not sufficient for the increased distance. Furthermore, using the e-trailer provides an additional degree of freedom, since the battery does not have to be fully charged at every charging stop.
Finally, for some legs of the trip, especially when driving fully loaded from Sweden to Denmark, it is likely, that the e-trailer is needed to support the BEV for reaching the next destination. For this demonstration in UC 7.3.1, the e-trailer is not mandatory for permanent support of the BEV truck for range extension. It is rather a backup support for the BEV truck, in case charging to the maximum state of charge was not possible and/or conditions on the road (weather, detour due to roadblocks, …) demand a higher amount of energy for the trip. As the battery capacity of the BEV is already comfortably high, the 205kWh battery configuration of the e-trailer should be sufficient for that purpose, even though it will not be recharged in parallel to the BEV Truck at every charging stop.
For using the e-trailer on demand as an energy backup, SCA requested the possibility to enable/disable the e-trailer functionality by the driver. This possibility is realized via a back channel from the driver display (tablet) to the e-trailer.
Following steps ensure to identify and to prepare the necessary e-trailer functionality to enable the vehicle combination to meet the requirements of UC 7.3.1:

- Update of the route simulation by PTV with the final battery configuration of truck, the updated charging locations and the resulting length of the legs.
- Identification of the legs, where e-trailer support is needed to reach the destination or to reduce the risk that the battery of the BEV is discharged to a critical level.

- Simulation of the legs with the EV-Route simulation tool considering the additional battery capacity of the e-trailer.
- Identification of the charging stations, where the e-trailer has to be charged. Check the charging means on these locations, whether it is possible to charge the e-trailer in parallel to the BEV-truck.
- Simulation of the vehicle combination with distributed drivetrain by FHG and/or ZF (regarding up-to-date status of the operation strategy for e-trailer) on the proposed primary and secondary legs. Confirm feasibility to manage the trip.
- If needed, within the step before, optimize the e-trailer operation strategy by tuning the parameters for better balanced support of the truck for the dedicated topology of the trip.
- Before starting the demonstrations, run the combination of BEV and e-trailer on the mission route (or on the legs where the e-trailer shall be active) for final validation of the actual performance of the vehicle combination versus the simulation results and check the operability at charging stops.

1.3 Design and Integration of the TrailTrax e-Box

1.3.1 Requirements and Constraints from TrailTrax system

For ease of integration to a heavy-duty semitrailer, the TrailTrax system comes with two main subsystem assemblies: the e-Box compartment and the e-axle as already shown in pictures above.

The e-axle integrates:

- the electric machine, which can act as an electric motor for propulsion and as a generator for recuperation,
- an electrical power inverter, which converts the three phase AC current on the motor side to DC current connected to the battery,
- a transmission (3 gear + neutral) plus a differential gear, which distributes the torque of the electric motor to the wheels,
- internal lubrication system with an oil pump for lubrication of transmission and motor bearings,
- an electronic control unit with sufficient computing power for low level control of the axle as well as for e-trailer TrailTrax operation control functions.

The e-axle replaces the passive middle axle of the regular 3 axle trailer. The integration in the suspension system is described later in this document. The e-axle is equipped with similar brake components as the replaced passive axle.

The e-axle is exclusively connected to the e-box via following connections:

- Electrical DC power supply
- Equipotential bonding connection
- Low voltage connection (Supply and Data connection)
- Tubes, to connect inlet/outlet for fluid cooling of the axle to the thermal management system which is integrated in the e-Box.

The e-box itself comprises the following sub systems and devices

- 1, 2 or 3 high voltage batteries of 102,8 kWh each,
  allowing system configuration of 103 kWh, 206 kWh or 308 kWh,
  (weight per battery: 540 kg; dimensions (L*W*H): 1400mm * 740mm * 390mm),
  battery/system voltage: nominal 659 V , minimal operating 504 V, maximal operating 765 V
- Temperature Management System (TMS) for cooling the power electronics and the batteries inside the box and for cooling circuit through the e-axle outside the e-box.
  For operation of batteries in wintertime, the TMS supports a limited capability of heating.
- High voltage power distribution unit (PDU) and Fuse-Box:
  The box distributes the power connection from the batteries to the different high voltage

consumers. Each HV-output of the box is fused internally. Circuit breakers within the box allow to disconnect the drive axle from HV and to connect the charging input to the battery.

- DC/DC converter to buffer two acid-lead batteries for 24V low voltage system supply.
- All low voltage (LV) connections to the devices are routed to a low voltage connection box.
  Here, the connection to the manifold devices of the TrailTrax system is made for supply, signals and data buses. The box is a central connection point, where also data and signals of the braking system are connected. Data logging, and supervisory system for testing and validation are also connected here.
- On-board charger unit (OBC) and CCS2 connector:
  AC-charging (22 kW) is possible via the on-board charger. The on-board charger also controls the DC-charging process, while the DC-charging pins of the CCS2 connector are directly routed to the PDU. Depending on the battery configuration, ~70kW to ~210kW typical charging power is theoretically feasible (to be practically validated).

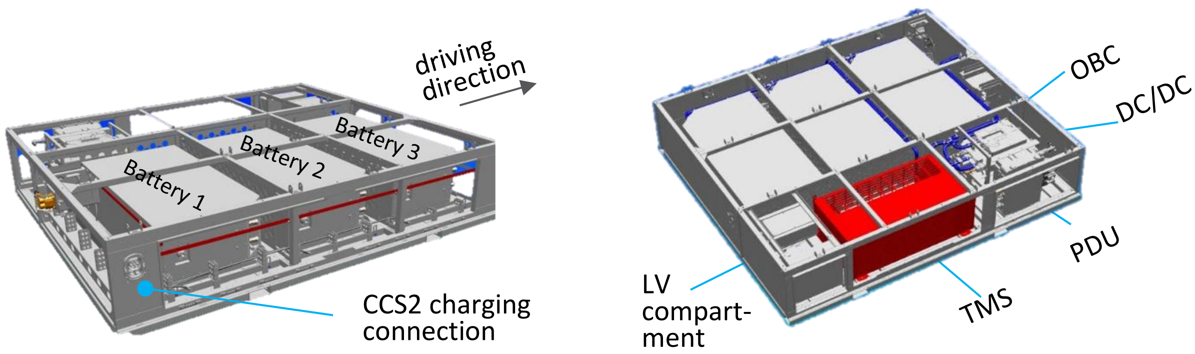


Figure 1-11: Schema of the e-Box with all subsystems and devices

Diverse requirements are coming from the integration of the subsystems and components to the box, which must be considered in the requirements and in the design, to be observed during commissioning and testing and finally to be validated in release for application.
Requirements to be considered are:

- Battery Integration:
  The batteries are the heaviest components of the system. The fixation of the batteries and the entire fixation of the e-Box to the vehicle must ensure proper fixation and mechanical integrity over lifetime.
- Requirements from Regulation R100 regarding installation of batteries:
  The provisions for mounting the batteries to the vehicle shall be suited to protect the batteries, e.g., in crash situations. Even at high accelerations given by R100 and on crash impacts to the box, the batteries shall not lose mechanical integration inside the box.
  (Details on the construction and related tests of the e-Box can be found in sections 1.3.3 and 1.3.4)
- Battery accessibility for maintenance:
  The battery itself is maintenance free, but the battery must be accessible through flaps from the outside for inspection of the high voltage system.
  For low level disconnection of the high voltage system, the Manual Battery Disconnect plugs must be removed from the batteries. For checking equipotential bonding among the high voltage components, the housing of the batteries needs to be accessible with a measurement probe.
- Accessibility of the Power Distribution Box:
  The PDU must be accessible via opening flaps from outside, to exchange fuses in case of service. For High Voltage maintenance. Furthermore, close to the PDU, special contacts can be accessed in a box, where zero voltage on the HV system can be checked, before any work on the high voltage system may start.

- Accessibility of the thermal management system.
  For maintenance, the reservoirs for the cooling fluid for the TMS shall be accessible.
- Ventilation for the TMS.
  The TMS must take thermal energy out of the system. The heat, transported from the components to the TMS via cooling fluid, is transferred via a heat exchanger to an air stream. The e-Box must provide an air inlet and outlet for heat dissipation.
- Low voltage compartment.
  The low voltage compartment must be accessible through a maintenance flap for being able to maintain the low voltage batteries and to connect measurement and control equipment to the system for development and validation.

Finally, not only the components but also their connections have to be integrated in the e-Box:

- Several high voltage cables and wires are quite heavy and bulky. General requirements for installation of high voltage cabling must be followed. E.g., the cables must be fixed to fixation points on their way, and the bending radius of the cables should not be less than 5 times their outer diameter.
  Holders for the cables have been designed for the integration in the box. Of course, the metal box must consider fixation points for the holders.

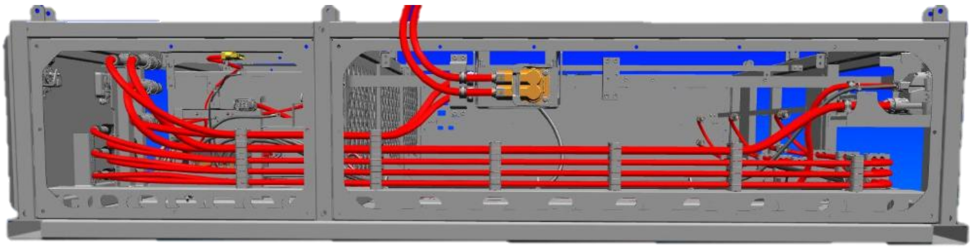


Figure 1-12: Design of the HV wiring concept inside the e-Box

- The tubing for the cooling fluid inside the box poses similar challenges like the cabling. But in addition, for the tubing, accessibility of regulating valves and air escape valves needs to be considered for later filling process of the cooling fluid and for the hydraulic equalization.

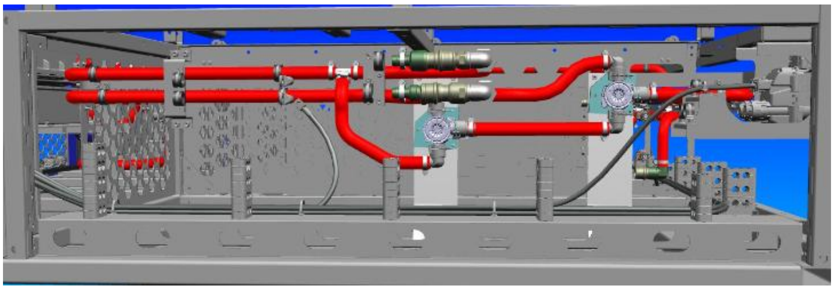


Figure 1-13: Design of the tubing concept inside the e-Box

1.3.2 Requirements and Constraints from Environment

Considering the operating conditions of trailer vehicles, the battery enclosure must withstand vibration and mechanical shocks generated during vehicle movement, acceleration, braking, and traversal of uneven road surfaces. The design process included extensive modal analysis, random vibration analysis, and mechanical shock simulations to ensure structural integrity and component safety. During the first design phase, prototype vibration tests were conducted; however, it was observed that these tests did not provide clear and concrete information regarding the design requirements. In particular, the effect of vehicle dynamics on the e-Box was not accurately represented, and the tests failed to reflect the actual accelerations experienced by the battery enclosure under real-world operating conditions. To address these limitations, accelerometers were installed on the prototype enclosures during field testing over approximately 300 km of real road conditions. These tests included various road types, such as highways, speed bumps, potholes, and uneven surfaces, allowing for accurate recording of vibrations and mechanical shocks. Additionally, hydraulic test benches were used to simulate long-term operational loads. The results confirmed that the battery enclosure maintains structural integrity, secures internal components, and withstands environmental loads without damage. By meeting the environmental requirements defined by KAE/ZF, the battery enclosure ensures both, long-term durability and operational reliability, providing a robust solution capable of performing safely under a wide range of environmental conditions.

1.3.3 Integration to the trailer

To determine trailer compatibility with the e-Box, a comprehensive analysis was conducted across the entire catalogue of standard trailers. The study focused on the spatial dimensions beneath the chassis, specifically the area between the landing gear and the first axle. Based on this evaluation, an approximate volume envelope was established.

Among the vehicle types considered in this analysis were reefer trailers, container chassis, plywood box trailers, and curtain siders. In collaboration with ZF, it was agreed that the dimensions of a standard pallet box—measuring 2750 mm × 2470 mm × 600 mm—aligned with the defined volume envelope and would serve as a reference framework for the design of the battery enclosure. This approach also accounted for the spatial requirements of internal components intended to be housed within the enclosure.

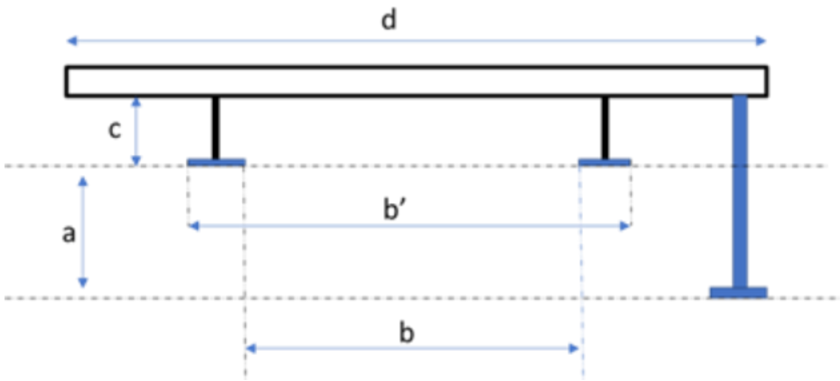


Figure 1-14:Mechanical fixation/mounting (one concept for different dimensions of frame)

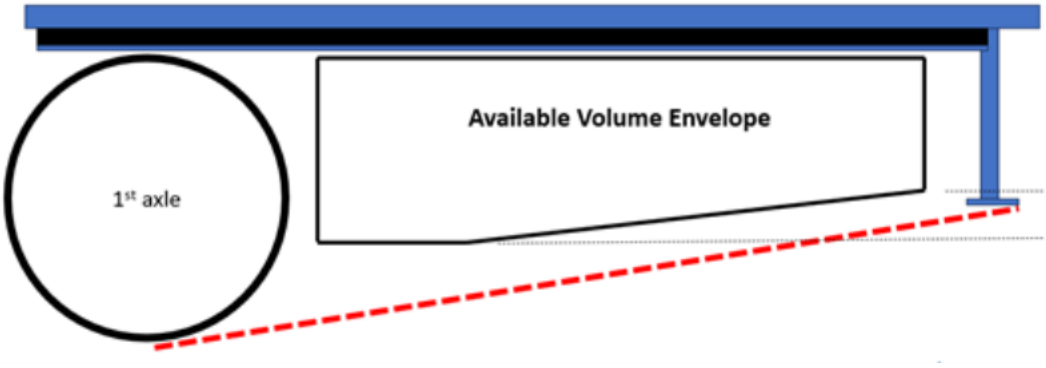


Figure 1-15:Identification of vehicle types which can be equipped with same box

The e-trailer concept is realized through the integration of a battery and an electric axle into the tractor-trailer unified system. In this configuration, the battery is directly mounted onto the chassis, ensuring comprehensive system-level integration. Within this context, the development of a modular and adaptive design approach, compatible with vehicle platforms exhibiting varying longitudinal beam (lonjeron) widths, is of strategic significance. As illustrated in Figure 1-16, the component highlighted in orange is engineered for facile attachment and detachment to the battery enclosure. In instances where the vehicle's longitudinal beam length differs, an alternative component with a corresponding height (h) specification must be produced. Consequently, the existing system can be efficiently and flexibly adapted to diverse vehicle platforms solely through the modification of this component, thereby ensuring rapid deployment and operational versatility.

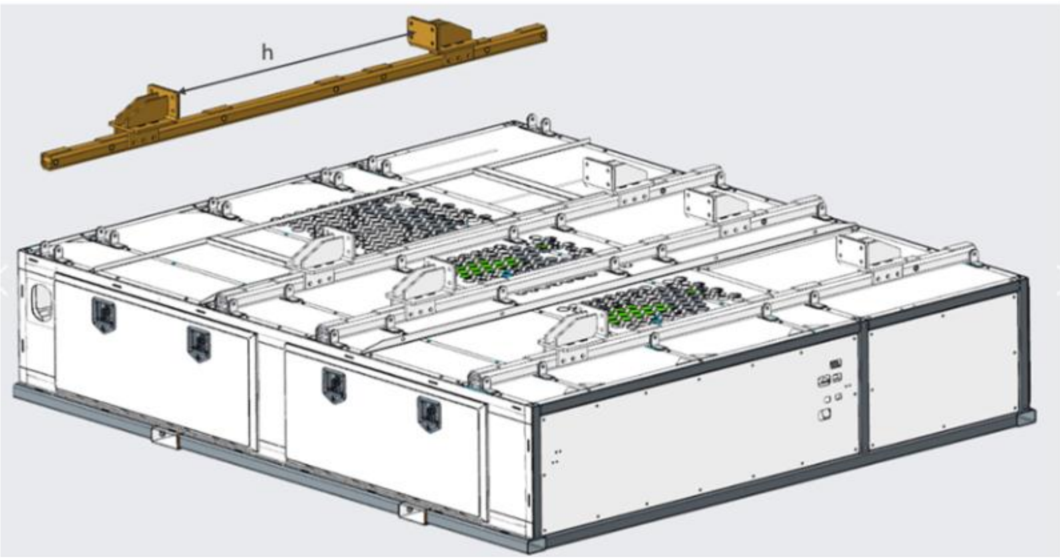


Figure 1-16: Modular concept or integration of the e-Box into the trailer chassis

1.3.4 Design of the box

Within the scope of the ZEFES project, the development of a battery enclosure for use in trailer vehicles, designed to facilitate seamless integration, has been targeted. In accordance with project requirements, the enclosure is intended to accommodate a battery with a maximum power capacity of 400 kW, a decision fully aligned with the operational needs defined for the project. Accordingly, the most suitable location for battery installation was identified as the existing space at the front, lower section of the trailer. This location provides advantages in terms of weight distribution, vehicle dynamic performance, and facilitates maintenance and accessibility. Figure 1-17 shows the curtain sider vehicle with the E-box mounted.

Figure 1-17: curtain sider vehicle with the e-Box mounted

Following the location selection, the battery enclosure design process was initiated. As part of the initial design cycle, a Finite Element Analysis (FEA) model of the enclosure was developed. Detailed analyses of stress and strain distribution were conducted, and it was observed that maximum stresses in certain critical regions could exceed the design criteria. Based on these findings, a series of design iterations were carried out to ensure that the enclosure remained within safety limits, resulting in an optimized structural configuration. Upon completion of the first design cycle, the battery enclosure was mounted to the vehicle, and the analysis process continued. As anticipated, the chassis movements induced changes in the stress distribution on the enclosure. This necessitated additional design iterations using vehicle simulations to ensure compliance with design criteria. During these iterations, both the connection details and structural characteristics of the enclosure were re-evaluated, and necessary improvements were implemented. Figure 1-18 shows the design iteration table which was used for the e-Box design.

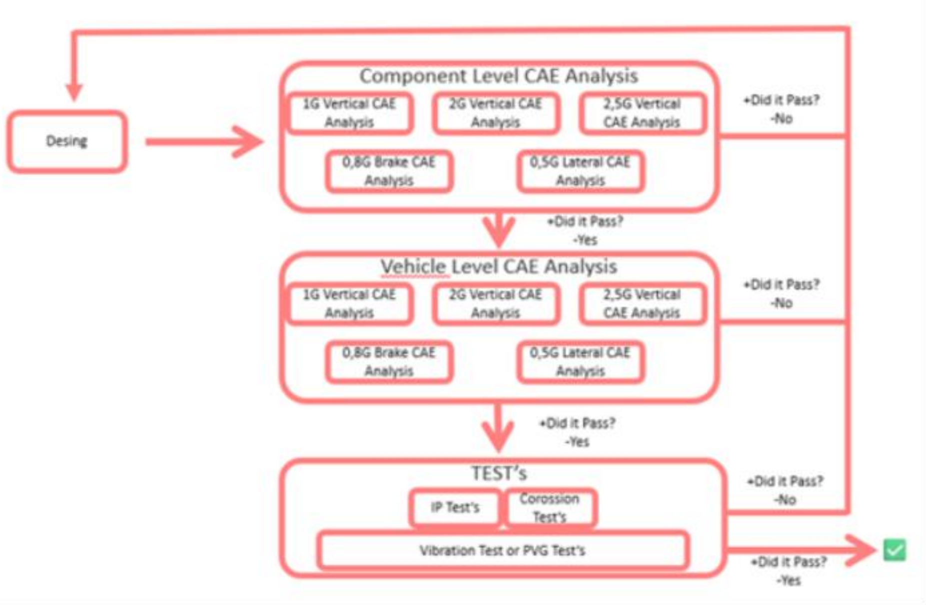
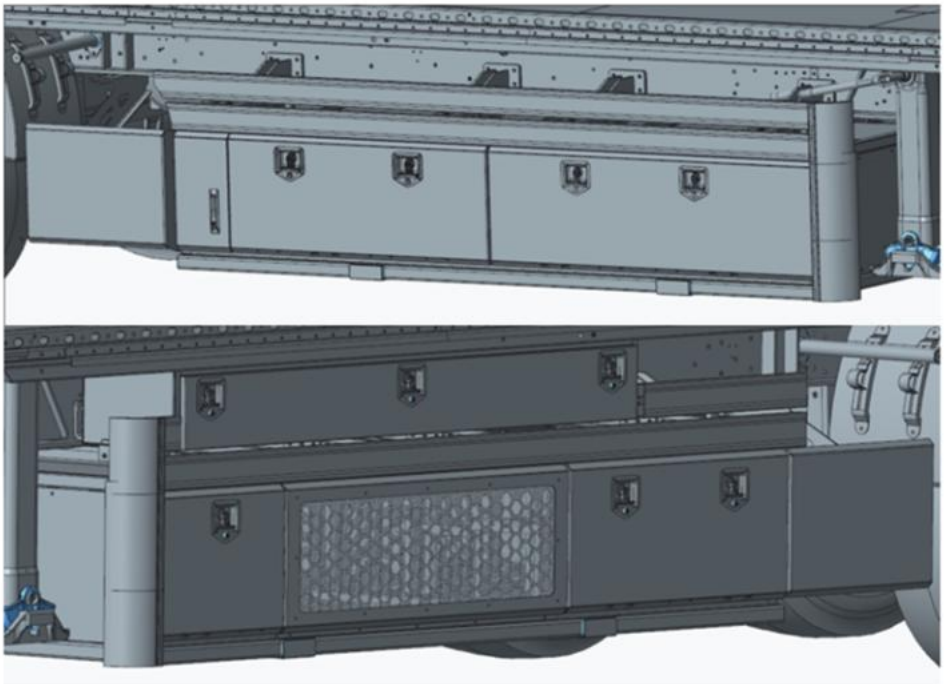


Figure 1-18: design loop of battery enclosure

Subsequently, a prototype of the enclosure was manufactured (see Figure 1-19), and manufacturability tests were performed to assess production feasibility and identify potential issues prior to mass production. The prototype was then installed in the vehicle, and approximately 300 km of field testing was conducted, covering a variety of road conditions including highway asphalt, speed bumps, potholes, and uneven surfaces. During these tests, accelerometers installed on the enclosure recorded the dynamic responses, providing a dataset for evaluating the enclosure's in-field performance and serving as input for accelerated life testing. Following the initial field tests, hydraulic field vibration tests were conducted to evaluate the long-term durability of the battery enclosure under sustained vibration and mechanical shocks. These tests, carried out across various frequency and amplitude ranges, provided insights into potential weak points and validated the

Figure 1-19: Prototype of the battery enclosure installed in the vehicle during field testing, illustrating acceleromenter placement for dynamic response measurement across diverse road conditions and subsequent hydraulic vibration testing for durability

design requirements. During road testing, it was observed that the existing clamp mechanism exposed the battery enclosure to higher vibration levels relative to the trailer. Consequently, the position and configuration of the clamp connection were modified, and additional structural enhancements were applied. Data obtained during the first design cycle served as the basis for establishing the boundary conditions for the second design cycle, resulting in optimized connection



geometry and improved structural stiffness.

Figure 1-20: Final design of the battery enclosure

Due to the initial e-Box dimensions not fitting directly into the corrosion testing chamber, a small-scale sample representing all holes, cutouts, and bend/weld features of the e-Box was produced. This sample underwent corrosion testing, validating the surface durability of the enclosure. A second sample produced from the same design was subjected to an Ingress Protection (IP) test, evaluating the effects of water pressure and temperature on paint integrity and deformation. These tests confirmed the enclosure's resistance to environmental exposure and validated the robustness of the design. Additionally, in accordance with R73 regulation, a crash analysis was performed using LS-DYNA simulation software, examining the enclosure's behaviour under vehicle collision scenarios. The analysis verified that the structural integrity of the enclosure is maintained and that safety requirements are met. Based on the boundary conditions established during the first design cycle, a subsequent design phase was initiated.

The enclosure was evaluated under vertical, lateral, and braking loads in accordance with trailer-specific constraints, ensuring that stresses remained within material endurance limits. Furthermore, modal and random vibration analyses were conducted to prevent resonance, confirming that the natural frequencies of the system do not coincide with operational frequency ranges. At this stage, the enclosure design was deemed ready for validation testing.

Figure 1-21: Optimized battery enclosure undergoing validation tests on the trailer test track, illustrating acceleration measurements and confirmation of compliance with the 250.000 km operational life span requirement

To verify field performance, the optimized design was tested on the trailer test track (see Figure 1-21). The vehicle was tested both in loaded and unloaded conditions, and the accelerations on the battery enclosure were recorded. These measurements completed the final design cycle and facilitated progression to the ultimate validation phase. Upon completion of all analyses, tests, and field trials, it was confirmed that the battery enclosure meets the ZEFES project requirement of a 250.000 km operational lifespan. Through the design iterations, field evaluations, and optimization activities, the battery enclosure has been validated as a solution that fulfils both mechanical performance requirements and long-term durability objectives, rendering it suitable for series production.

1.4 Integration of the e-axle

1.4.1 ZF AxTrax2 (trailer-version)

A basic description and specification of the e-axle can be found in section 1.2.1.

1.4.2 Adaptation of the ZF e-axle to the Suspension of KAE Trailers

The ZF e-axle for trailers is a modified version of the AxTrax2 axle for truck and bus applications. While the middles section of the e-axle (electronics, motor, transmission) keeps unchanged, the axle

arch casings are modified from twin tire application to single tire application and the position of the connection points to the suspension has changed.
The e-axle replaces the standard middle axle in a 3-axle semitrailer.
For design and integration of axle and suspension two major differences must be considered between conventional trailer and e-trailer:

- The e-axle has a higher mass than a regular passive axle
- Besides torque from braking, affecting from the axle to the suspension system, also torque in the other direction caused by propulsion must be countervailed by the rocker arms of the air suspension system.
- The bracket assembly to mount the axle to the rocker arms must be modified for the shape of the e-axle and for the new torque and force requirements.

Therefore, the following steps for design and validation have been processed for integration of the ZF e-axle to the BPW suspension system in the running gear of the KAE trailers.

- Simulation of the forces/torques from the e-axle to the suspension system from a regular trailer to confirm feasibility of integration.
- Design of new bracket subassembly to mount the e-axle to the rocker arms of the suspension
- Adaptation of the shape of the locking dome on the axle to the shape of the bracket assembly.
- Destructive test on test bench at supplier of the suspension to validate robustness of the modifications. Forces and torques up to and above actual limits have been applied to the assembly of axle arch, bracket and suspension arm.
  - → After one improvement loop (reinforcement of the design for the brackets), the tests were passed. → stiffness of axle arch, function and robustness of the bracket solution and stiffness and robustness of the suspension elements are sufficient.
- During commissioning and testing activities, the proper connection between axle and suspension as well as the integrity of axle and suspension elements are monitored.
- An additional test bench test for lifetime robustness of the axle is planned prior to the ZEFES demonstrations.

Finally, even though the axle and its integration to the trailer is not a released series solution yet, the process allows to release the solution for the operation purpose for ZEFES demonstrations.

1.5 Other Equipment / Measurement control Box

Besides the TrailTrax subsystems e-box and e-axle, a measurement control box is installed to the e-trailers (see Figure 1-22). The box is needed to host special devices for operation, measurement and data-access for running engineering investigations and for test and validation during preparation of the ZEFES e-trailers. The ZEFES data loggers are also installed to that box.

Figure 1-22: Measurement control box of the e-trailer

1.6 Mounting of TrailTrax system to the trailers commissioning and validation of basic functionality

1.6.1 Installation procedure,

The following steps have been processed to assemble all devices and subsystems to the e-trailers:

- The metal enclosing for the e-box has been produced by Kässbohrer and shipped to a ZF facility in Alsdorf Germany. All parts and material to be installed to the e-box were procured before, to be available for assembly. The ZF facility was prepared to mount heavy parts to the box. The personnel working on the e-box have the necessary qualifications to take care of the special requirements in high voltage installations.
- After installation of all components to the box, all checks for correct installation which can be done without powering up high voltage have been processed. The high voltage batteries were installed but not electrically activated. The battery main disconnection plugs at the batteries kept unmounted. The cooling fluid had not been filled.
- Then, the box was transported by road transport to ZF Hannover.
- In Hannover, at first a high voltage check is done for the high voltage installation inside the e-Box according ZF standards, following high voltage safety measures given by standards for development (ISO6469-3) and for system/vehicle type approval (UN Regulation 100).
- After the box is released for high voltage operation, the proper operation and controllability of the high voltage system (without connected e-axle) is checked.
- In parallel to the e-box assemblies, the trailers have been prepared. Kässbohrer sent the trailers without installed middle axle to ZF Hannover/Jeversen. Here the axle is mounted to the trailers. The installation is supported by experts from the suspension supplier to ensure and confirm proper installation.
- The e-Box is mounted to the trailer and all connections to the e-axle system are installed.
  With the completed high voltage system, a high voltage check according ZF check protocol is done, to ensure high voltage safety for the remaining testing activities till the ZEFES demonstrations start and for the demonstrations themselves.
- After electrical functionality and safety is proven, the cooling circuit is filled. According to guidelines and instructions of the supplier of the thermal management system, the system is filled with fluid, and the flowrate through all devices with connected cooling (e-axle, batteries, on board charger, DC/DC converter) is balanced to the demanded value.
- Now the e-trailer is principally ready to be operated full functionally within the power capabilities of the e-axle and the batteries. Before the e-trailer is released internally at ZF for drive operation on test track, the ZF workflow foresees an inspection and test report by technical service to confirm that the vehicle can be operated safely with regard to the type approval regulations which are affected by the TrailTrax installation.
  After the positive test report by technical service on high voltage safety (R100), electromagnetic compatibility (R10), side protection (R73) and that the functions of the brake system are not violated by the basic TrailTrax functionality, the e-trailer can be operated on test-track by expert drivers for checking and improving functionality in real driving conditions.

1.6.2 Release for expert operation on public roads

For development of the e-trailer functionality for ZEFES, testing on public roads is essential. The tests can only be done on public road sections, which are similar to the road sections of the ZEFES use cases. Ideally, tests for validation and optimization of the e-trailer functionality are already done with the ZEFES BEV, to ensure the transferability of the results. The test validates the use case related requirements to the e-trailer and ensures expected performance for the demonstrations.

For test execution, the trailers need to be registered to ZF as “vehicle for validation purposes”. On basis of the tests and test reports conducted and prepared by the technical service for operation on test-track, a certificate can be issued, which allows registration at licensing office. Additionally, this allows driving of the vehicles during ZF winter testing in Rovaniemi Finland.

1.7 Preparation of the Vehicles for handover to ZEFES

1.7.1 Homologation for road approval/licensing for cross-border European fleet mission.

Within the scope of the ZEFES project, detailed studies have been conducted on how the homologation process of the e-trailer should be carried out. Since there is currently no defined and enforced approval procedure under the European Union framework, it has been decided to proceed with an individual type approval in Spain.

The process, conducted in collaboration with IDIADA — the technical service authorized by the Spanish approval authority — has involved a thorough evaluation of regulatory requirements, technical validation procedures, and testing activities.

In this context:

- All UN and EU regulations applicable to trailers (O4 category) have been re-examined, and all systems potentially affected by the transition to e-trailer have been identified.
- The requirements, testing, and documentation needs for these systems under Spain’s individual vehicle approval process have been defined.

As a result of the studies, it has been determined that the following key regulations are affected by the e-trailer application and must be verified for compliance:

- **UN R13**: Braking performance, stability control, and functional safety (Annex 18).
- **UN R100**: Electrical safety and battery system validation.
- **UN R10**: Electromagnetic compatibility (EMC).
- **UN R73**: Lateral protection systems.

The procedures required to verify compliance with these regulations have been reviewed and defined in collaboration with IDIADA, ZF, and KAE. For regulations other than R13, compliance will be assessed based on their currently published versions. Since the technical requirements related to e-trailers in R13 have not yet been officially published, the defined guidance from the Spanish authority and IDIADA bases on the proposal by the R13 industry working group which was presented beginning of 2025 at GRVA (UNECE Working party for safety and regulatory issues regarding vehicle type approval process).

The technical requirements are as follows:

- **Req. 1**: Equal distribution of regenerative brake forces across axle wheels.
- **Req. 2**: Prevention of wheel lock-up at speeds above 15 km/h.
- **Req. 3 & 6**: Propulsion cut-off during VSF/ESC intervention.

- **Req. 4**: Compliance with electric control line.
- **Req. 5**: Propulsion cut-off during braking.
- **Req. 7 & 12**: Propulsion force must not exceed total rolling and air resistance and a share of the acceleration forces provided by the towing vehicle to the trailer.
- **Req. 8**: Functional safety documentation.
- **Req. 9 & 10**: Controlled behaviour when communication is lost or active.
- **Req. 11**: E-trailer must not provide propulsion unless the towing vehicle does.
- **Req. 13**: Maximum regenerative brake rate.

As ZF participated in the R13 industry working group, the requirements are well known, and the technical background is understood. ZF proposed tests from product validation process to prove the fulfilment of the requirements.
IDIADA has proposed a comprehensive test plan from the perspective of a technical service to validate the above-mentioned requirements.

Detailed work on the implementation of this test plan is ongoing. The final plan will be established based on the outcomes of these discussions.

Planned tests (proposed by IDIADA):

1. Straight-line and curve driving test (Req. 1)
2. Spiral/J-turn test for VSF activation and propulsion cut-off (Req. 3, 6)
3. Surface transition test (Req. 2)
4. Route test (ascent/descent, braking, acceleration) (Req. 7, 12)
5. CAN communication interruption test (Req. 9, 10)
6. Propulsion test without towing vehicle support (Req. 11)
7. Type 0 braking test comparison (active/passive system) (Req. 13)

To ensure that the above tests are conducted in accordance with IDIADA's quality procedures, an evaluation is underway to determine which data can be obtained from the existing system according to the established processes at ZF and which require new measurement equipment. The final test plan will be shaped based on the results of this evaluation.

The remaining activities are planned according to the following timeline:

- **Testing Phase**: Targeted for completion by mid-April 26
- **Documentation Preparation**: Approximately 3 weeks
- **Vehicle Registration**: Approximately 1 week
- **Approval and Final Registration**: Expected by mid-May 26

1.7.2 Final Validation and Handover of e-trailers

After the e-trailers have received their license plates, they will be transferred to the BEV truck OEMs SCA and VOL as the use case leaders. After final test runs with the BEV trucks at VOL and at SCA the vehicles are handed over to the operators of the demonstrations.

The process and the result of validating the combined operation of e-trailers with the ZEFES BEVs close to the demonstrations but also before, will be described in deliverable D5.6 “Realization and commissioning of all BEV demonstrators”.

2 ZEFES e-dolly

The electrified dolly that is used in the ZEFES project was originally developed in the Aeroflex project. Due to the shift in the scope of application, several adaptations are necessary to enable an independent operation of the e-dolly without the need of being coupled to a towing vehicle over a longer time period.

2.1 Aeroflex e-dolly architecture and design

This section briefly describes the architecture and design of the e-dolly as it is taken over from the Aeroflex project. Further details and information are presented in the Aeroflex Deliverable D2.4 [3]. In the Aeroflex project, the e-dolly was part of a so-called Advanced Energy Management Powertrain (AEMPT) distributed over several units of the vehicle combination. To reduce the fuel consumption of the vehicle combination, a towing vehicle with a conventional internal combustion engine was hybridized by using the e-dolly and/or an electrified semitrailer. Thus, the e-dolly was primarily designed for trailer operation, which means operation within vehicle combinations that are equipped with a centralized powertrain control system located in the towing vehicle. Based on that use case, the capabilities and features of the e-dolly were derived. Its basic architecture follows the concept of a trailer unit with an electric powertrain controlled by a local system management. During trailer

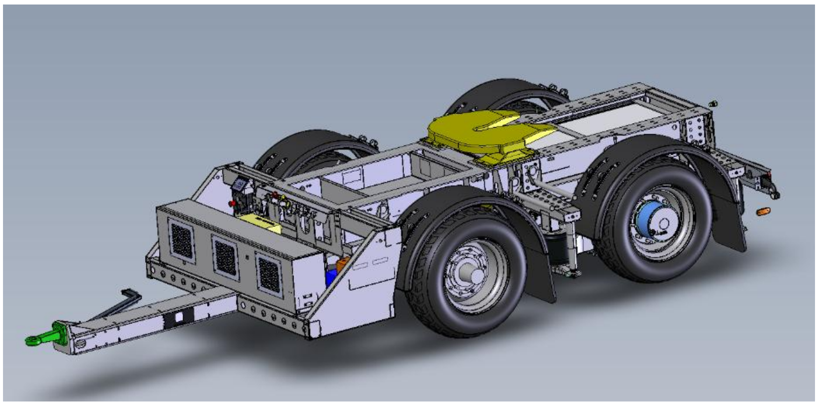


Figure 2-1: Design of the e-dolly incorporating all components of the electric drivetrain and the local system management

operation, this local system management receives force requests to the electric drive from the centralized energy and torque management system.
The functionality was extended to realize an operation scenario that allows the operation of the e-dolly independent from the towing vehicle. The main application area is the operation of a e-dolly – semitrailer vehicle combination with shunting speed at a terminal or depot. During this manual operation the local system management receives force requests from an external remote control. To enable this operation scenario the e-dolly is also equipped with a steering axle that is controlled by the remote control.

2.1.1 Design of the base vehicle

The e-dolly is a double axle dolly with a drawbar at low level to couple under a rigid truck. In combination with a standard semitrailer with a length of 13,6 m and a gap between the rigid truck and the semitrailer of 1,0 m, it enables a total length of the vehicle combination that fits in the 25,25 m that is allowed in most European countries. While the e-dolly is operated in an EMS vehicle

combination, it is assumed to drive as non-steering vehicle. Under this constraint, the EMS1 vehicle combination fulfils the requirements of the Dutch and Scandinavian turning circle with an outer radius of 14,5 m. It cannot cope with the German turning circle of 12,5 m.
The base vehicle was designed considering the rules defining the design space, e.g., clearance around the fifth wheel for required pitch and roll angle of the semitrailer, gap distance between the front side of the semitrailer and back side of the rigid truck and the space behind the fifth wheel that must not be exceeded by the chassis of the semitrailer. Also, the maximum forces on the fifth wheel and the drawbar were considered. This input was used to validate the design of the chassis using a 3D model and FEM analysis. The 3D model provided the basis for integration of all interfaces for axles, battery housing, cooling cabinets etc.

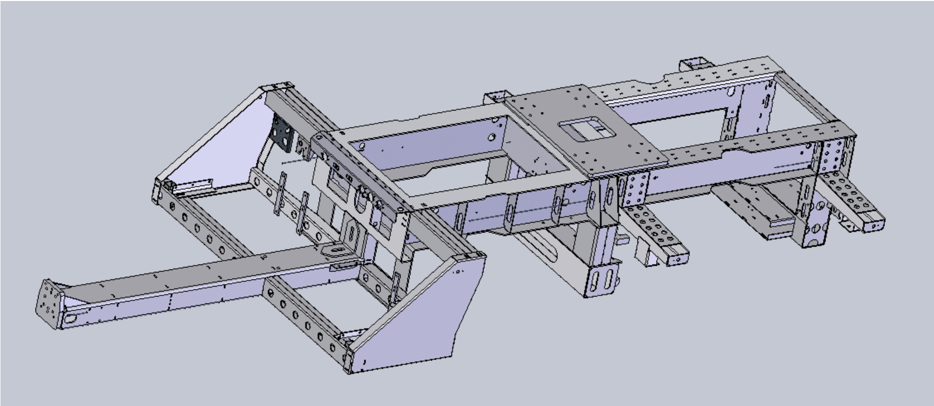


Figure 2-2: Steel chassis frame of the e-dolly as produced by Tirsan

2.1.1.1 Technical description of the e-axle

In the e-dolly an electrical portal axle AVE130-400VAC by ZF Friedrichshafen is installed. The unit

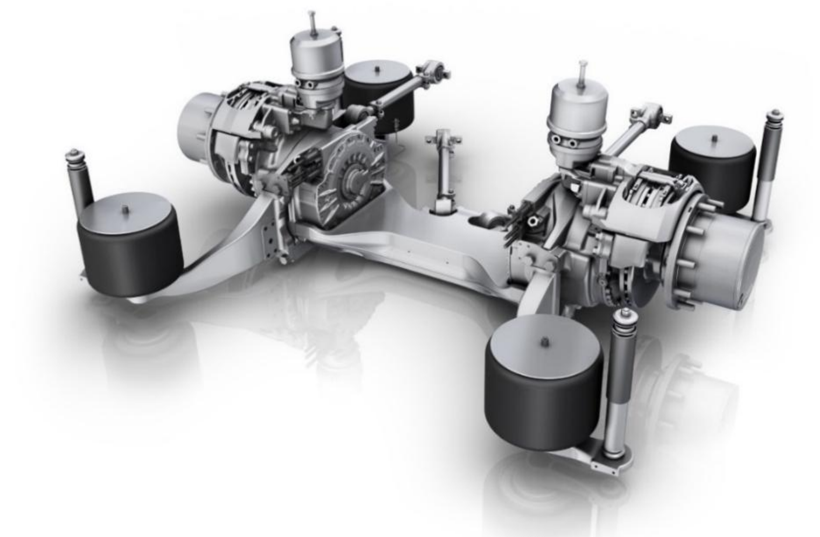


Figure 2-3: 3D view of the ZF e-axle

integrates the EMGs, traction converters and an electronic control unit. Each wheel is driven by a liquid cooled asynchronous motor via an additional gear stage. In total the motors provide a continuous power of 120 kW and a maximum power of 250 kW. Although the EMGs are powered by separate traction converters, torque requests to the driven axle are distributed evenly between the left and right wheel whereby a torque vectoring capability is not provided.

2.1.1.2 Technical description of the high-voltage battery and housing

The e-dolly is powered by three battery tray of type AKASYSTEM 15 OEM 37 PRC by Akasol. Each tray consists of 16 battery modules, while each module contains 12 Lithium-ion nickel manganese cobalt cells (Li-ion NMC). The Energy Storage Unit (ESU) provides an energy capacity of 73,5 kWh and can be discharged with a continuous / maximum power of 150 kW / 450 kW and charged with a continuous / maximum power of 150 kW / 210 kW.

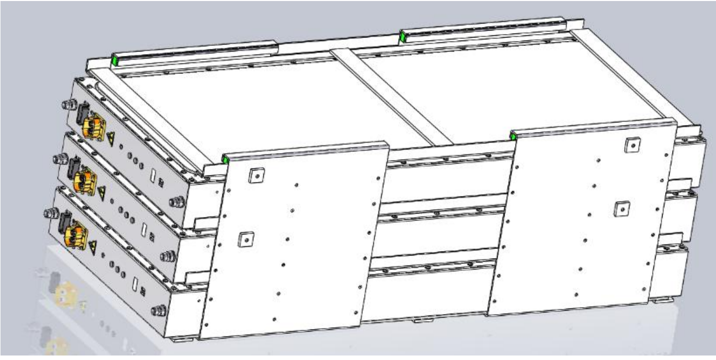


Figure 2-4: Frame with three Akasol battery modules

2.1.1.3 Technical description of the cooling equipment

The e-dolly is equipped with two cooling circuits, which are separated due to their different temperature levels: one for the driven axle, the traction converter and the 24 V inverter and one for the battery system. For maintaining a suitable coolant temperature, both cooling circuits are equipped with heat exchangers. If the coolant temperature reaches a defined upper limit, the DC fans are activated by thermal switches. The pump speed and thus the flow rate of the coolant is controlled by the Local System Management (LSM). All components are powered by the internal 24 V system.

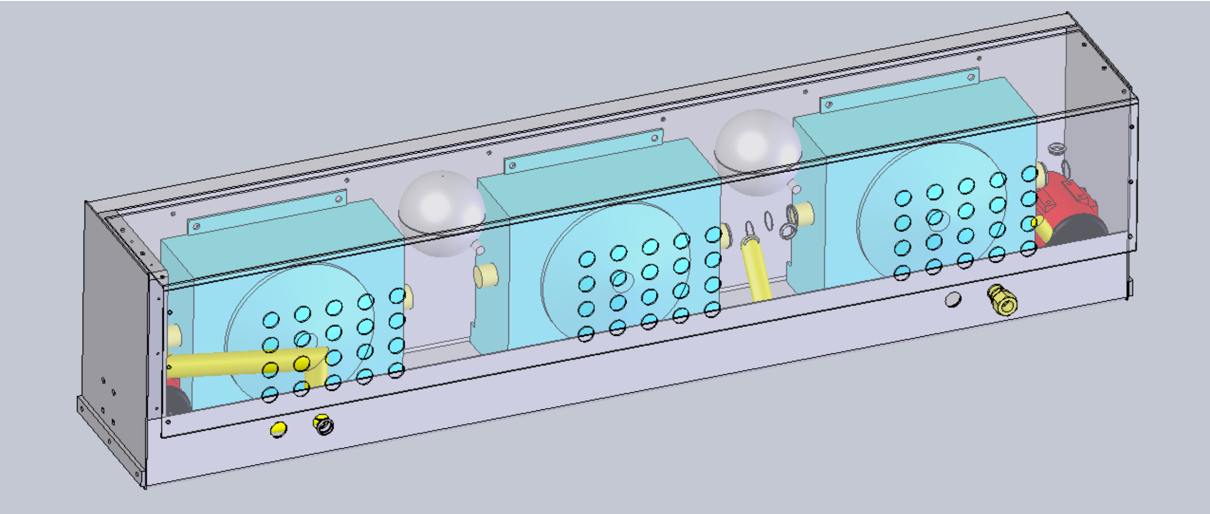


Figure 2-5: cabinet with cooling equipment

2.1.1.4 Technical description of the steering axle

The e-dolly is steered by an electro-hydraulic steering system by V.S.E. Vehicle Engineering B.V installed with a steered axle by BPW Bergische Achsen Kommanditgesellschaft. The steered axle is used in manual operation mode up to vehicle speeds of 12 km/h. While driving in trailer operation, the axle is fixed in centered position. Centering is also activated by the internal ECU of the steering axle, if the vehicle speed exceeds a threshold of 12 km/h.

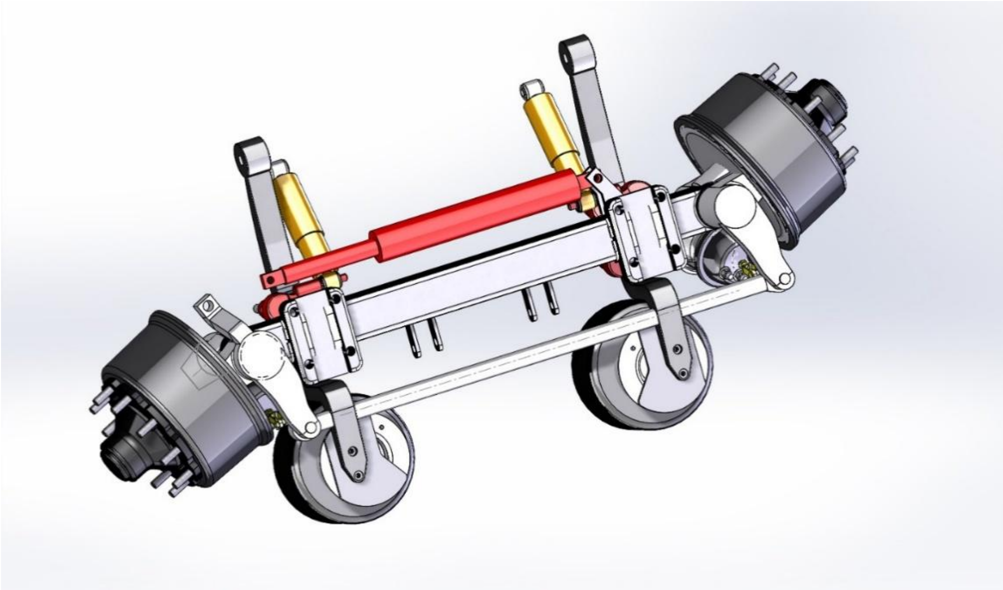


Figure 2-6: BPW axle with steering cylinders

2.1.2 Vehicle architecture

2.1.2.1 System architecture

Figure 2-7 and Figure 2-8 show the overall system architecture of the e-dolly for the trailer-operation mode and the manual operation mode. Beside the series functions and functions provided by external suppliers, depicted in green, the figures highlight the AEMPT functions developed in the Aeroflex project, depicted in yellow, that are necessary to control the electric powertrain. Peripheral systems, such as the 24 V supply or the cooling system of the high voltage battery and the power electronics, are not shown in the figures.

The LSM controls the electric powertrain and communicates with the centralized powertrain management system in the towing unit. In the trailer-operation mode, the e-dolly's powertrain is only enabled if the towing unit provides the appropriate communication interface (GETMS interface). Furthermore, the LSM receives state information from the electric motor (EMG) and the battery (ESU), consolidates this information and reports the current traction and braking capabilities to the centralized powertrain management. Vice versa, the LSM receives force requests to the electric drive from the centralized powertrain management and from the trailer EBS, which must be consolidated. The trailer EBS includes a brake blending function, which can distribute a service brake request between the friction brakes and the electric drives. The service brake request is distributed with the aim of maximizing recuperation of brake energy.

The communication between the LSM and the centralized powertrain management system is realized in a dedicated communication protocol, which is established in addition to the standardized ISO 11992 truck trailer interface. The interface is implemented on the Automotive Ethernet Standard. The Automotive Ethernet router combines both protocols and physically transmits them via the EBS interface. During manual operation mode, the Automotive Ethernet router only forwards the ISO 11992 communication from the LSM to the trailer EBS and the towed vehicle. As the centralized

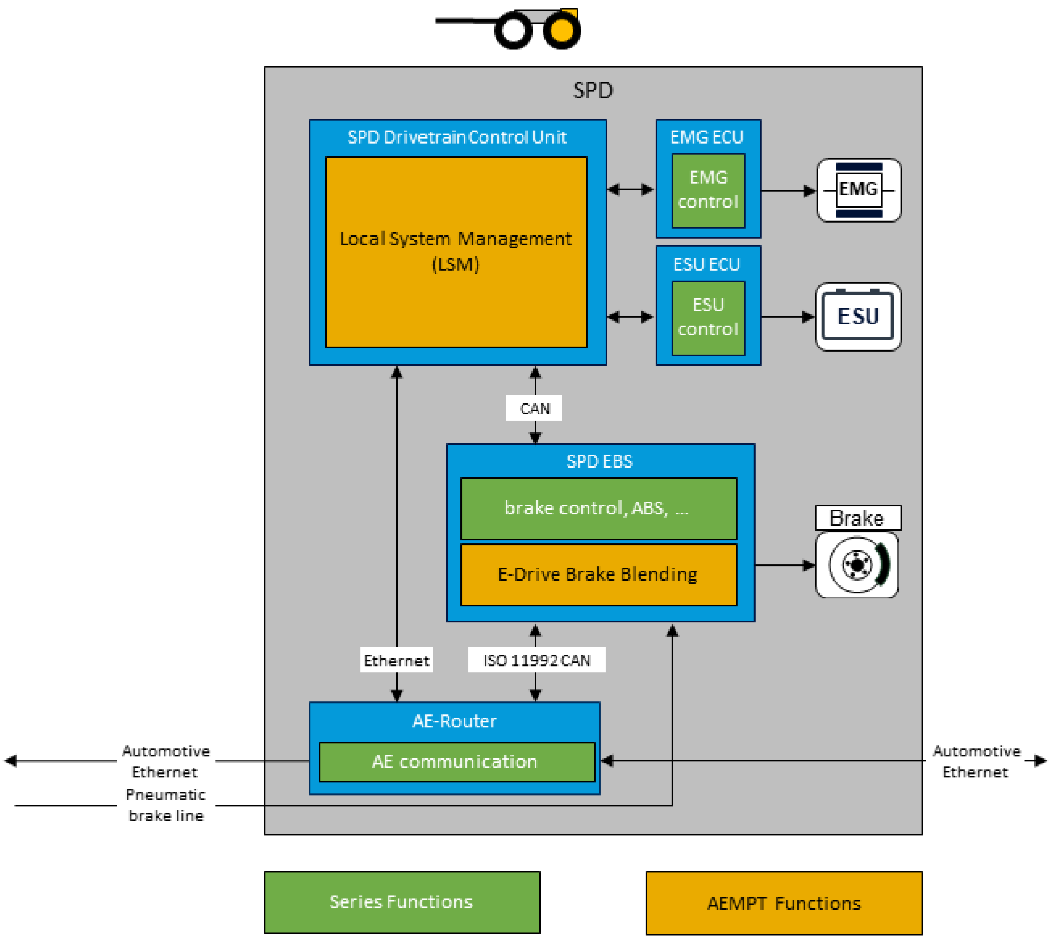


Figure 2-7: System architecture of the e-dolly for trailer-operation mode

powertrain management system is not available in that case, the Aeroflex communication protocol is not used.

To realize the manual operation mode a remote control for industrial applications is integrated. It sends force requests and steering commands to the LSM. The LSM also distributes brake requests between the electric drive and the friction brakes by communicating with the trailer EBS via an additional ISO 11992 CAN connection.

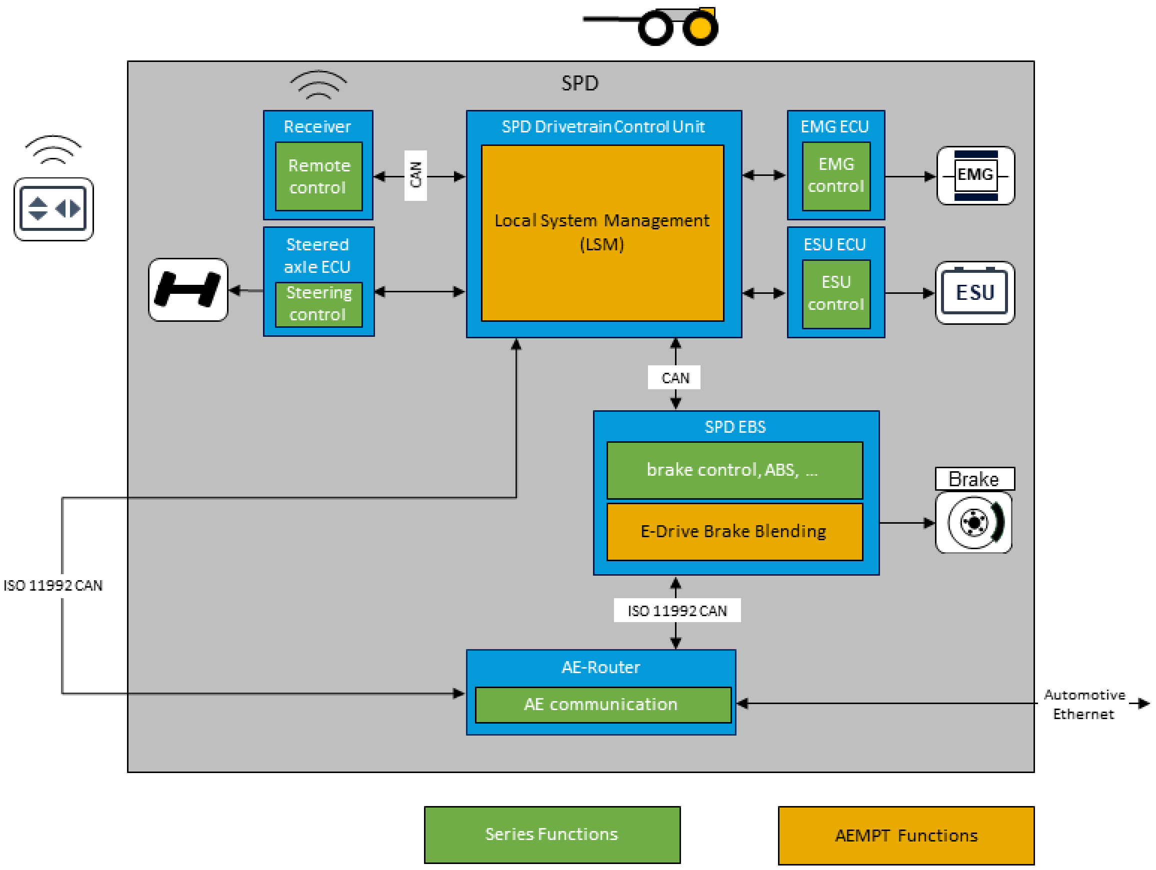


Figure 2-8: System architecture of the e-dolly for manual operation

2.1.2.2 Interfaces

The mechanical and the electrical interfaces including plugs and connectors between the e-dolly and the towing vehicle as well as the e-dolly and the semitrailer remain unchanged.

During manual operation mode, a plug according to standard ISO 7638-1 provides an additional electrical interface to realize the communication between the LSM and the trailer EBS based on standard ISO 11992 CAN.

Beyond others, the following interfaces were defined that are also relevant for the adaptations that are made at the e-dolly in the ZEFES project.

The GETMS interface is the bi-directional interface between the centralized powertrain control system and the LSM. The centralized powertrain control system receives powertrain performance/capability parameters from the LSM and sends driving/recuperation requests to the LSM in return. Details about the communication protocol can be found in the Aeroflex deliverable D2.2 [4].

The remote-control interface is the interface between the LSM and an external control system. During manual operation the LSM receives signals, e.g., from a remote control, to control the steering system and the electric powertrain. The communication protocol is provided by the manufacturer of the remote-control system.

The steering axle interface is the interface between the LSM and the ECU of the steering axle. During manual operation, the LSM controls the steering axle according to the requests received from an external control system via the remote-control interface. The communication protocol is provided by the manufacturer of the steering axle.

2.2 Use case specific requirements to the base vehicle

The adapted use case focusing on the remote-controlled operation of the e-dolly resulted in several requirements. Since the e-dolly was designed to be operated in a vehicle combination, the operation as a stand-alone vehicle required solutions for:

- recharging the e-dolly's energy storage, which was previously done by recuperative braking only or by dragging the e-dolly in a special operational mode,
- filling the air tanks, which was previously done by the towing vehicle via the airline connection.

The secondary operational mode in the Aeroflex project, operating the e-dolly with the remote control, needs to be adapted due to requirements regarding efficient operation and precise control capabilities. This includes solutions for:

- steering to a certain angle that is defined by the operator or an automation system (the previous solution just actuated the steering axle as long as a button is pressed),
- a better controllability of acceleration and braking, which also features a brake blending functionality (the previous solution provided reduced torque and imprecise actuation of the service brake),
- a more sophisticated signaling of the operating state and possible faults to enable troubleshooting by the operator

Additional findings from the Aeroflex project need to be solved to provide a reliable solution. These findings include:

- missing isolation monitoring,
- an uneven leveling of the vehicle with the air suspension of the front and rear axle when the vehicle is operated stand-alone.

Finaly, features implemented during the Aeroflex project in the e-dolly ECU need to be removed to not interfere with the current use case. This includes the dedicated communication between the centralized energy and torque management system that was located in the towing unit and the local system management implemented in the e-dolly ECU.

2.3 Adaptation of levelling control system

In the original Aeroflex configuration, the Wabco height levelling control system of the e-dolly was equipped with a single mechanical height control valve located on the first axle. This configuration allowed the air suspension to adjust the chassis height based solely on the level detected at the first axle. Consequently, when the dolly's overall height was adjusted — either raised or lowered — at the first axle reacted first, while the second axle, which serves as the steering axle, followed passively through the pneumatic interconnection between both circuits.

During operation, it was observed, that this arrangement did not provide sufficient synchronization between the front and rear suspension units. Due to the dolly's comparatively high curb weight and the front-biased center of gravity, the rear section of the chassis tended to remain lifted, resulting in uneven levelling behavior and reduced ride stability, particularly during coupling and decoupling maneuvers.

To resolve this issue, a second height control valve equipped with a level sensor was installed on the steering axle. Both valves were parameterized and synchronized within the Wabco configuration software, ensuring that height corrections are now applied simultaneously to both axles. This modification enables parallel adjustment of the air suspension across the dolly, maintaining a uniform chassis height under varying load and operating conditions. The levelling control can also be managed via the Wabco SmartBoard interface, which allows for real-time monitoring and manual adjustment of suspension height when required. The revised system architecture now ensures balanced pressure distribution between the two axle circuits, smoother levelling transitions, and improved ride comfort.

The commissioning of the updated system was performed together with Wabco service engineers to verify the correct installation, calibration, and parameterization of both height control valves. Initial tests under workshop conditions confirmed electrical and pneumatic integrity as well as proper response to manual commands issued through the SmartBoard. Functional testing on the test track included static height calibration, dynamic levelling cycles, and coupling/decoupling operations with different payloads. The results confirmed full synchronization between both axles and accurate maintenance of the target ride height within ±3 mm deviation. The overall response time of the levelling process was reduced by approximately 25 %, while the chassis demonstrated stable vertical behavior during acceleration, braking, and load transfer.

These results validate the successful adaptation of the levelling control system for the ZEFES e-dolly, ensuring improved stability, smoother operation, and readiness for further integration with automated control and suspension management systems.

2.4 Integration of new components

2.4.1 High-pressure air supply

During the research for suitable air compressor, several requirements are identified, which need to be accomplished to provide the best experience. This comprised a screw compressor type, input voltage of around 750V and the possibility of removing humidity in the compressor. Additionally, the compressor must fit into the limited installation space of the e-dolly and must be suitable for automotive usage.
A MOTEG sAir V60 compressor in combination with a traction inverter model COMBIVERT T6 from KEB Automation KG was chosen. The compressor was installed at the front right side behind the cabinet with the cooling components (see Figure 2-9). The traction inverter was installed in front of the cabinet with the hydraulic components of the steering axle (see Figure 2-10).

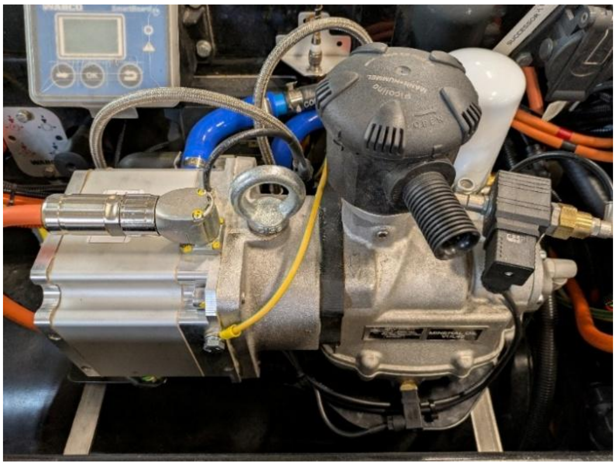


Figure 2-9: Installed MOTEG eAir V60 high-pressure air compressor

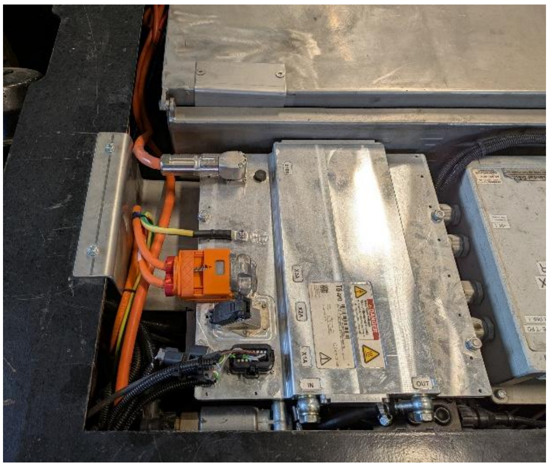


Figure 2-10: installed KEB Combivert T6 inverter module

Table 2-1: Technical specification of the high-pressure air compressor

Type	MOTEG eAir V60 W2
Compressor	Rated air pressure: 12.5 bar Rated / max. flow rate @ 10 bar: 270 / 325 l/min Integrated demand oriented compressor control
Motor	Drive type: Direct Motor type: Permanent magnet synchronous motor output power @ rated speed / 12.5 bar: 3.6 kW rated torque @ 12.5 bar: 11.5 Nm voltage (rated phase to phase): 400 V
Environmental conditions	Ambient temperature: -30 / 80 °C Max. relative humidity: 85% Protection class: IP67 Noise level @ 2.500 rpm: 68 dB(A)
Cooling	Coolant: water/ethylenglycol 50/50 Temperature: < 60 °C Rated flow rate: 6 l/min Max. cooling pressure: 3 bar
LV connection	Supply voltage: 7 … 32 V
HV connection	DC link voltage: > 560 V rated current @ rated speed / 12.5 bar: 7.9 A
Weight & dimensions	28,8 kg 500 / 320 / 350 mm (length / width/ hight)

Table 2-2: Technical specification of the inverter module for the high-pressure air compressor

Type	KEB COMBIVERT T6 APD
Inverter module	Rated power: 7,5 kW
Environmental conditions	Ambient temperature: -30 / 70 °C Protection class: IP6k9k
Cooling	Coolant: water/ethylenglycol 50/50 Temperature: 30 … 65 °C Rated flow rate: 10 l/min Max. cooling pressure: 2 bar
LV connection	Supply voltage: 9 … 32 V 2x CAN communication interface IN and OUT HVIL loop
HV connection	nom./min./max. DC voltage: 565 / 520 / 750 V max. DC current: 120 A (depending on rated power of the inverter module)
Weight & dimensions	8,7 kg 346 / 320 / 125 mm (length / width/ hight)

The commissioning of the compressor is done together with the manufacturer. Beside a check of the basic functionality, it includes a stress test during which the compressor is forced to run over a longer period of time. The compressor passed the test without exceeding certain limits of parameters like motor temperature, oil temperature and temperature of the cooling liquid.

2.4.2 On-board charging system

To provide the full experience of charging an electric vehicle the requirement for charging power is set to at least 22kW AC charging and the possibility of DC charging. For all On-Board-Chargers (OBC) offered by different suppliers an external charging port must be purchased separately. The CCS (type 2) charging was installed at the front right side of the e-dolly (see Figure 2-12). For manual termination of the charging process a button was installed that is also able to indicate the status via different colours of a signal LED. The OBC also must fit in the limited installation spaces of the e-dolly. It was installed in the front behind the cabinet with the cooling components (see Figure 2-11).

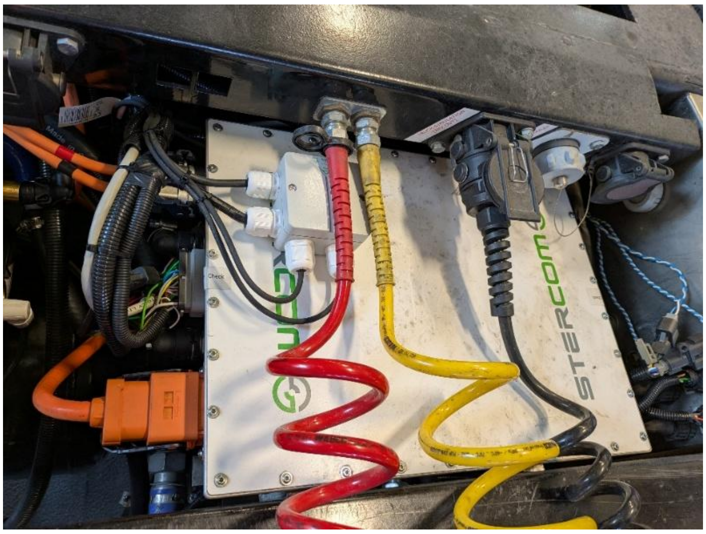


Figure 2-11: Installed Stercom on-board charger


Figure 2-12: CCS vehicle charging inlet, type 2

Table 2-3: Technical description of the on-board charging system

Type	Stercom On-Board Charger OBC_22KW-800
AC input	Voltage range three-phase: 346 … 440 Vrms Voltage range single-phase: 200 … 254 Vrms Max. input current: 32 Arms Input AC frequency: 45 … 65 Hz
DC output	Voltage range: 420 … 800 V Max. charging current @ 3~ input: 40 A Max. charging power @ 3~ input: 22 kW Max. charging current @ 1~ input: 32A Max. charging power @ 1~ input: 6.5 kW Charging mode: CCCV
Environmental conditions	Ambient temperature: -30 / 70 °C Protection class: IP6k9k
Cooling	Coolant: water/ethylenglycol 50/50 Temperature (without power derating): -40 … 50 °C Rated flow rate: 8 l/min Max. cooling pressure: 2 bar
LV connection	Supply voltage: 9 … 30 V 2x CAN communication interface IN and OUT HVIL loop
Weight & dimensions	18 kg 492 / 348 / 95 mm (length / width/ hight)

2.4.3 Isolation monitoring

After commissioning the vehicle during the Aeroflex project, it was noticed, that a live isolation monitoring is not available. The existing insulation monitoring in each of the HV batteries is only active when the batteries are not connected to the high-voltage DC link. This is not sufficient for safe operation. Therefore, it was necessary to install external insulation monitoring.

2.4.4 HV cabling

The components described in the previous sections were integrated into the high voltage (HV) system of the e-dolly. The existing HV connection box did not offer enough space to integrate the additional components. Therefore, a new box was developed, making use of the maximum available installation space. No box from the manufacturers' product range is available that fits in this space. A complete custom design was required. All these components are connected to the HV circuit and were connected to the intermediate circuit using the HV cables required for this application. The installation of additional HV cables and components in an existing vehicle not designed for this purpose led to complex installation situations.

2.4.5 LV cabling

Like the HV cabling, these components were also integrated into the LV circuit. These are control voltage and CAN communication. Furthermore, an additional emergency stop function has been integrated into the remote control for monitored autonomous operation. This allows the operator to stop the e-dolly from a safe distance.

2.4.6 Cooling System

Due to the operating temperature levels of the new components, it is suitable to integrate them into the cooling circuit of the power electronics. The model of the cooling circuits that was designed and implemented in Matlab/Simulink was extended by the new components high-pressure air supply compressor, its motor inverter, and the AC/DC of the on-board charger. It was than simulated using a demanding power profile and characteristic environmental conditions of Central Europe.

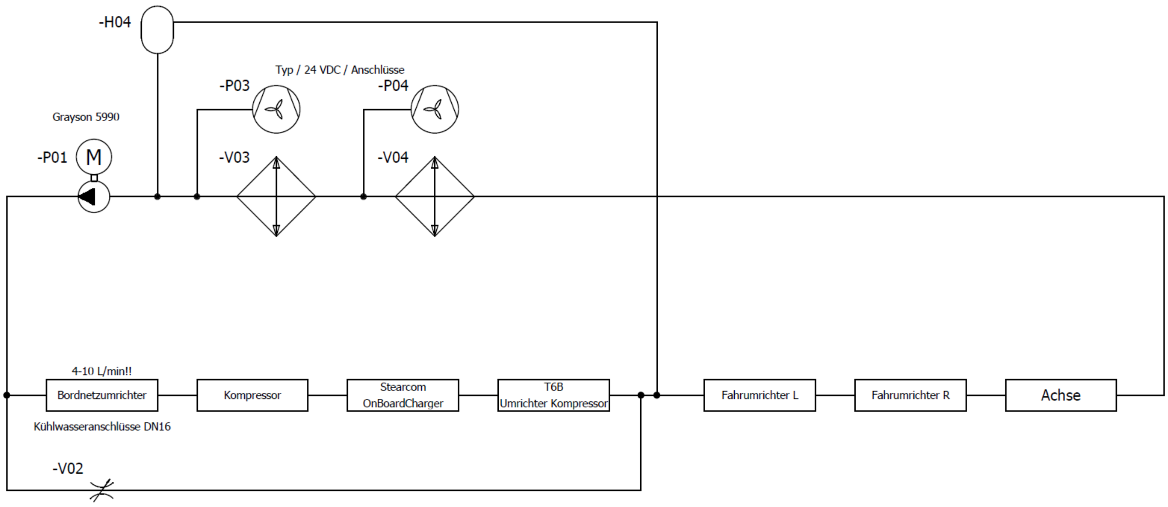


Figure 2-13: Schematic diagram of the cooling circuit for the electric axle, power electronics and the air compressor

The simulation results showed that the cooling power of the existing cooler/fan combinations and pumps are sufficient if the new components are integrated into the part of the cooling circuit with the 24V inverter (see Figure 2-13). Since the cooling circuit had to be opened for integration of the components, the cooling liquid was completely changed to guarantee frost and corrosion protection of the cooling agent.

2.5 Adaptation of the steering system

The actuation of the steering system was realized via a remote control connected to the interface provided by the manufacturer. The steering axle was actuated to the left or right side the related input channel was powered. An additional channel could be used to centre the axle position. With this interface it was not possible to steer to a certain angle, since the axle went back to straight slowly when not powering the channel anymore. This behaviour is not suitable for a fully remote-controlled vehicle, and not compatible with an automated driving. Therefore, an interface was designed that allows for the request of a certain steering angle by the remote control or an automation system. The actual steering angle must also be provided by the steering axle. The interface was implemented by the manufacturer including the realization of the requested steering angle by the axle. The whole implementation was provided by the manufacturer on a new axle ECU, which was then integrated into the vehicle by FHG.

The old interface, based on digital outputs and some relay was removed. The new interface based on CAN needed internal rewiring of the steering system. After installation the steering system was calibrated and commissioned.

First performance requests for verification of the requirements revealed that the delay between the angle request and the realization of the angle was too long. One of the reasons was that the hydraulic pump first must start before a movement is performed. This could be improved when the vehicle is moving, since the pump starts running, when the vehicle is moving. Finally, the steering speed is sufficient for low-speed driving.

2.6 Commissioning of the e-dolly remote control operation

The commissioning is done according to a list of tests for each of the newly integrated components (high pressure system, on-board charger, steering system) and the overall functionality of the e-dolly. The latter includes tests of the basic driving functions as well as tests of the safety functions like the emergency stop functions. An excerpt of the most relevant tests of system functions and foreseeable misuse can be found in Table 2-4.

Table 2-4: Overview of commissioning tests of the e-dolly and its components

Component	Test
Compressed air system	- Realization of system pressure by the compressor - Evolution of component temperature during continuous operation - Support of system pressure during operation of the service brakes
On-board charger	- External AC charging of the HV battery

	- External AC charging of the HV battery between minimum and maximum state of charge - Termination of external AC charging with the OBC at the upper limit of the battery's state of charge - Termination of external AC charging with the OBC by manual operation of the dedicated button next to the charging inlet - Termination of external DC charging with the OBC by manual operation of the dedicated button next to the charging inlet - Behavior of the OBC when button for termination of the charging process is repeatedly pressed
Steering system	- Realization of a target steering angle and repeatability - Manual forward / rearward driving along a straight line - Manual forward / rearward driving along a circular arc - Manual driving of an evasive maneuver
Driving functions	- Basic driving functions - Kickdown acceleration in forward and rearward direction from stand still and while driving - Recuperative braking - Emergency braking - Limitation of driving speed in forward and rearward direction - Behavior of the system management when starting with deactivated remote control - Behavior of the system management when leaving the communication range of the remote control or in case of a failure of the remote control - Foreseeable misuse of the gear switch (forward / neutral / rearward)
Emergency stop	- Test of emergency stop buttons at the e-dolly and the remote control - Behavior of the system management when starting the e-dolly with activated emergency stop button

3 Conclusion and Recommendation

For e-trailer technology, which is not in regular market production yet, the target of the ZEFES project to operate the demonstrations in regular transport operations is challenging. Beside the functionality that must be guaranteed, a significant amount of homologation activities is needed to guaranty safe operation under real-world conditions on public roads. To align these homologation activities with the responsible authorities is a major challenge, especially as the regulations for e-trailers are not ready yet (namely regarding interference with braking functions (R13)). Therefore, it was decided to aim for an individual type approval in Spain. Nevertheless, the procedures required to verify compliance with these proposed regulations (R13) that have been defined in collaboration with the Spanish authorities, IDIADA, ZF, and KAE must be further reviewed. Thus, it must be ensured that the planned tests fulfil all technical requirements within the tight time plan of the ZEFES project.

3.1 Contribution to project (linked) Objectives

The work done in tasks 5.4 and 5.5 and documented in this deliverable contributes reaching several objectives that have been defined in the ZEFES description of action. The preparation of the e-trailers and the e-dolly fulfils

- ZEFES overall objective 1: "improve modular Heavy Duty (HD) Battery Electric Vehicles (BEVs) […]",
- Sub-objective 1.2: "develop a vehicle concept with enhanced energy storage and e-axles (in the prime mover and the trailer)" and
- WP5 objective O5.4 "Adaptation and implementation of specific powertrain components and control systems for next level e-trailer serving as range extender integrated in the electric powertrain of the prime mover".

Thus, it enables the realization and commissioning of battery-electric vehicle demonstrators with a multi-modular distributed powertrain. The preparation of the vehicles and the preparation of their function for range extension in long haul intermodal European transport operation and the handling of long EMS vehicle combinations, will generate valuable insights for future volume operations.

3.2 Contribution to major project exploitable result

The work done in tasks 5.4 and 5.5 and the documentation in this deliverable indirectly contributes to the projects exploitable results. It mainly realizes the targeted optimization and development of vehicles that serve the logistics missions demonstrated in the use cases.

4 Risks and interconnections

4.1 Risks/problems encountered

Risk No.	What is the risk	Probability of risk occurrence[1]	Effect of risk[1]	Solutions to overcome the risk
WP5.5	As described in section 1.7.1, the final homologation procedure is not yet defined. Therefore, it is not clarified yet whether the request of the Spanish authorities on validation of draft requirements worded by R13 industry working group in Jan. 2025 must be tested similar to existing regulations (extra effort) or based on professional ZF system testing procedures (limited efforts).	2	2	The details of the homologation process will further be clarified in close cooperations with the involved partners ZF, KAE, IDI and the Spanish authorities.

1) Probability risk will occur: 1 = high, 2 = medium, 3 = Low

4.2 Interconnections with other deliverables

This deliverable describes the process of adaptation and improvement of the base vehicles and powertrain components as well as the realization of the next-generation e-trailers. The final homologation process based on the concept described in section 1.7.1, its results and the commissioning of the e-trailers with the prime movers will be presented in deliverable D5.6.

5 Deviations from Annex 1

Due to the delays within the preparation process of the e-trailers as well as the challenges in defining the required homologation procedures (see section 1.7.1), this deliverable was postponed from month 22 to month 35. Nonetheless, at the time of releasing this deliverable the e-trailers could not be provided for commissioning with the prime movers according to the defined time plan for WP5, task 5.5. To avoid further delay of publication of this document, the deliverable does not include the results of the homologation process and the commissioning activities. These results will be presented in deliverable D5.6.

6 References

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Project partners:

#	Partner short name	Partner Full Name
1	VUB	VRIJE UNIVERSITEIT BRUSSEL
2	FRD	FORD OTOMOTIV SANAYI ANONIM SIRKETI
3	HYU	HYUNDAI MOTOR EUROPE TECHNICAL CENTER GMBH
4	KAE	KASSBOHRER FAHRZEUGWERKE GMBH
5	REN	RENAULT TRUCKS SAS
6	SCA	SCANIA CV AB
7	VET	VAN ECK TRAILERS BV
8	VOL	VOLVO TECHNOLOGY AB
9	ABB	ABB E-MOBILITY BV
9.1	ABP	ABB E-MOBILITY SPOLKA Z OGRANICZONAODPOWIEDZIALNOSCIA
10	AVL	AVL LIST GMBH
11	CM	SOCIEDAD ESPANOLA DE CARBUROS METALICOS SA
11.1	APG	AIR PRODUCTS GMBH
12	HEPL	HITACHI ENERGY POLAND SPOLKA Z OGRANICZONA ODPOWIEDZIALNOSCIA
13	MIC	MANUFACTURE FRANCAISE DES PNEUMATIQUES MICHELIN
14	POW	PLASTIC OMNIUM NEW ENERGIES WELS GMBH
15	RIC-CZ	RICARDO PRAGUE S.R.O.
15.1	RIC-DE	RICARDO GMBH
16	UNR	UNIRESEARCH BV
17	ZF	ZF CV SYSTEMS HANNOVER GMBH
18	ALI	ALLIANCE FOR LOGISTICS INNOVATION THROUGH COLLABORATION IN EUROPE
19	DPD	DPD (NEDERLAND) B.V.
20	COL	ETABLISSEMENTEN FRANZ COLRUYT NV
21	GRU	GRUBER LOGISTICS S.P.A.
22	GBW	GEBRUEDER WEISS GESELLSCHAFT M.B.H.
23	PG	PROCTER & GAMBLE SERVICES COMPANY NV
23.1	PGP	PROCTER AND GAMBLE POLSKA SPOLKA Z OGRANICZONA ODPOWIEDZIALNOSCIA
23.2	PGA	PROCTER & GAMBLE AMIENS
24	PRI	PRIMAFRIO CORPORACION, S.A.
25	PTV	PTV PLANUNG TRANSPORT VERKEHR GmbH

26	Fraunhofer	FRAUNHOFER GESELLSCHAFT ZUR FORDERUNG DER ANGEWANDTEN FORSCHUNG EV
27	HAN	STICHTING HOGESCHOOL VAN ARNHEM ENNIJMEGEN HAN
28	IDI	IDIADA AUTOMOTIVE TECHNOLOGY SA
29	TNO	NEDERLANDSE ORGANISATIE VOOR TOEGEPAST NATUURWETENSCHAPPELIJK ONDERZOEK TNO
30	UIC	UNION INTERNATIONALE DES CHEMINS DE FER
31	CFL	CFL MULTIMODAL S.A.
32	GSS	Grupo Logistico Sese
33	HIT	Hitachi ABB Power Grids Ltd.
34	IRU	UNION INTERNATIONALE DES TRANSPORTS ROUTIERS (IRU)
35	RIC-UK	RICARDO CONSULTING ENGINEERS LIMITED

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