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

ZEFES - Deliverable report

D5.3 Powertrain components and control systems for next generation zero emission trucks

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Publishable summary

Regarding to the objective of the Green Deal for achieving the CO_2 reduction target of 30% by 2030 for the road transport sector, different strategies and technologies are under study. On the sector of HDV, the vehicles are becoming greener thanks to new fuels and energy resources; also, new technologies will appear, and new combinations of vehicles are starting to be used in order to reduce the tailpipe emissions. Those new technologies will be tested on the ZEFES project with different objectives related with:

- The improvement of the overall vehicle range in different vehicle combinations.
- The adaptation of powertrain architecture and components to a regular platform chassis
- The analysis of tyre wear under varying innovations
- The dimensioning of batteries on different missions and vehicles characteristics.

The OEMs are developing innovations in the field of Battery Electric Vehicles. The aim of this deliverable is to show what are the objectives, characteristics and innovations done on the battery electric trucks for achieving the objectives of each mission profile, focusing on the following aspects:

- Thermal system
- Powertrain
- Charging capability
- Integration of components on modular EV platforms

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Abbreviations & Definitions

Abbreviation	Explanation
HDV	Heavy-Duty Vehicle
ZEV	Zero tailpipe Emission Vehicle
BEV	Battery Electric Vehicle
FCEV	Fuel Cell Electric Vehicle
ICE	Internal Combustion Engine
OEM	Original Equipment Manufacturer
VECTO	Vehicle Energy Consumption Calculation Tool
GCW	Gross Combination Weight
ZE-HDV	Zero tailpipe Emission Heavy Duty Vehicles
WPL	Work Package Leader within ZEFES project
BE-HDV	Battery Electric Heavy-Duty Vehicle
FCE-HDV	Fuel Cell Electric Heavy-Duty Vehicle
HV	High Voltage
ISO	Interchangeable container as defined in the ISO-Norm 668
SWAP	Interchangeable container accommodating Euro-pallets for road and rail transport
Reefer	Loading unit to transport temperature controlled cargo
USP	Unique Selling Proposition (uniqueness of ZEFES use cases)
EMS	European Modular System, HDV carrying standardised loading units for intermodal freight transport
T	Tractor unit
R	Rigid unit
ST	Semi-trailer
TR	Trailer
D	Dolly
e-ST	Electric semi-trailer
e-D	Electric dolly
CCS	Combined Charging System
MCS	Megawatt Charging System
HRS	Hydrogen Refuelling Station
vkm	Vehicle kilometers
tkm	Tonne kilometers
DTP	Digital Twin Platform
DT	Digital Twin
	Abbreviations of project partners, see chapter 8 acknowledgement

1 Introduction

In the ZEFES work package 5 the modular and flexible battery-electric powertrains 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 effort 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 shall clarify the context of deliverable D5.2:

D5.1 - System specification for ZE 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 the OEMs 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 D5.3 within WP5 and the relation to other deliverables and work packages is shown in Figure 1-1.

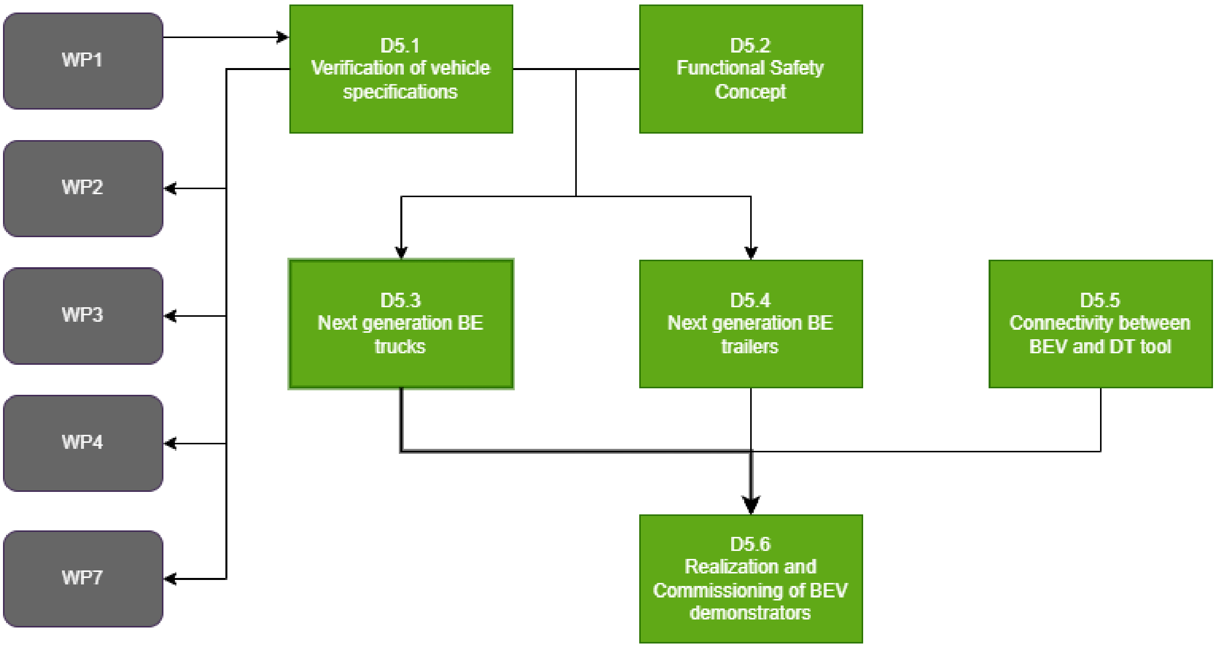

Figure 1-1: Relation of deliverable D5.3 to deliverables of WP5 and other WPs

Chapters 2 of the document presents the innovations and adaptations of the battery-electric powertrain and further components of the modular EV platform developed by OEM 1 and OEM 2 respectively. Both partners describe the innovations developed in the engineering areas of the thermal management system, the powertrain components and the fast-charging capabilities of their vehicles. Furthermore, OEM 3 presents the analysis of the overall energy need of the vehicles depending on the use cases. Special focus is put on the low-liner vehicle and the investigation of its limitations regarding battery size and ground clearance.
Additionally, the integration of the vehicle-to-vehicle interface in the BEVs of OEM 1 and OEM 3 is presented that enables the usage in a vehicle combination with the electrified trailer realized in task 5.4.
In chapter 3 conclusions for the further realization and commissioning of the prime movers in task 5.5 as well as the application in the use case demonstrations in WP8 are drawn.

2 Summary of battery-electric truck innovations

The OEMs efforts within task 5.3 aim to improve their modular EV platform and their flexible battery electric powertrain for long-haul heavy-duty vehicles.

In the ZEFES project one battery-electric truck and six battery-electric tractors from different OEMs will operate in ten different logistics flows.

In use case 7.2.2 a battery-electric tractor will operate in a tractor semitrailer vehicle combination between Gothenburg, Sweden and Ghent, Belgium. In use case 7.2.3-1 a battery electric tractor will operate for Procter & Gamble in an EMS2 vehicle combination between Amiens, France and Dourges, France and in a tractor – semitrailer vehicle combination between Dourges, France and Zeebrugge, Belgium. The same battery-electric tractor will operate in use case 7.2.3-2 for Primafrío in an intermodal long-haul transport from Spain to Sweden. The Primafrio logistics flow is divided into three legs. The trailers with temperature-controlled goods are driven on the road from Spain to France. Operated within ZEFES use case UC 7.3.3 they are crossing France on rail in the second leg. The third leg between Bettembourg, Luxemburg and Halmstad, Sweden is operated with the OEM 1 BEV.

A 6x2 rigid truck will operate in an EMS1 vehicle combination for DPD on their daily Rhine-Alpine corridor to transport parcels between Munich area, Germany and Eindhoven, The Netherlands. The EMS1 vehicle combination will be supported by an e-trailer.

In use case 7.4.1 a battery-electric tractor will operate in a tractor semitrailer vehicle combination between two Michelin manufacturing plants in Blanzy and Blavozy, France. In use case 7.4.2 the same tractor will operate in a tractor-semitrailer vehicle combination between Blainville sur Orne and Bourg en Bresse, France. In use case 7.4.3 a battery-electric tractor with similar vehicle specifications will operate on a DPD logistics flow to transport parcels between Veenendaal, The Netherlands, and Brussels area, Belgium or Rotterdam area, The Netherlands. It will be applied in a tractor-semitrailer vehicle combination or in an EMS1 vehicle combination with a semitrailer and a drawbar trailer.

In use case 7.3.1 a battery-electric tractor will operate in a tractor-semitrailer combination on an existing transport flow of automotive components from Sodertalje, Sweden to Zwolle, The Netherlands and back. The vehicle combination will also contain an e-trailer. In use case 7.3.3 the same tractor will operate on an existing route of temperature-controlled goods between Lepe, Spain and Le Boulou, France.

Finally, in use case 7.3.4 a battery-electric low-liner tractor will operate on two different routes. First it is used in a tractor-semitrailer vehicle combination on an existing transport flow of automotive goods between Heilbronn, Germany and Dudelange, Luxemburg. Second it is used in a EMS2 vehicle combination also in a transport flow of automotive goods between Le Boulou, France and Martorell, Spain.

In 2025 OEM 1 will launch a new long-range version of its existing battery-electric tractor that will be able to reach up to 600 km on one charge. This will allow transport companies to operate electric trucks on interregional and long-distance routes and to drive a full working day without having to recharge. The new BEV will be released for sale during the second half of 2025. The enabler for the 600 km range is a new driveline technology, including a newly developed e-axle, which creates space for significantly more battery capacity onboard. More efficient batteries, a further improved battery management system and overall efficiency of the powertrain also contribute to the extended range.

OEM 2 improved the cooling for the electric system and adapted the powertrain architecture and components to the regular platform chassis. This includes the development of a new e-axle and a new generation of traction batteries that will significantly contribute to the truck range extension and autonomy. The trucks are compliant with the more recent charging systems combined charging system (CCS2, charging power up to 350 kW) and megawatt charging system (draft MCS, charging power up to 720 kW) according to standards DC EIM (DIN 70121 or ISO 15118-2 2013), DC PnC (ISO 15118 - 2 2016) or New ISO 15118-20.
In addition to the vehicle improvements, the tractors will be equipped with tires of Michelin specifically developed for electric heavy-duty vehicles. During the demonstration in the use cases the tire wear under varying conditions will be analysed.

To fulfil the requirements and needs of the use cases the main part of the development work for OEM 3 in the ZEFES project was to dimension the battery in the BEV vehicles. OEM 3 calculated the estimated energy consumption in the different Use Cases. For the use cases 7.3.1 and 7.3.3 the distance between charging points is somewhat more than 300 km. Looking at worst case scenario a useable energy capacity of 550 kWh would be needed to reach the next charging point with an SOC level above 10% under all weather conditions and topography. However, in the Spanish use case (UC 7.3.3) where the long-haulage truck drives from Lepe to Le Boulou it was estimated that an installed energy capacity of 728 kWh (useable energy capacity of 600 kWh) is needed. The standard energy consumption of the vehicle combination is increased due to the hilly terrain.
For the use case between Södertälje and Zwolle (UC 7.3.1) the vehicle combinations includes an e-trailer that adds about 200 kWh to the energy capacity of the tractor. Therefore, a tractor with an energy capacity of 624 kWh would be sufficient. Since for the described use cases the same tractor is used, it will be equipped with 728kWh energy capacity even if it is not needed in UC 7.3.1. The energy storage is installed in a regular 4x2 tractor with 4150mm axle distance. This vehicle will have an MCS main inlet at 750kW and a secondary CCS capable of 375kW.
OEM 3 also develops a lowliner tractor for operation in use case 7.3.4. The lowliner solution was realized by adapting the chassis of the vehicle to enable a fifth wheel hight below 1000 mm. The tractor will first operate in Germany with a Eurotrailer of about 42 ton. As the distance is limited, an installed battery capacity of 624 kWh (useable energy capacity of 520 kWh) is sufficient. In a second stage it will run in an EMS2 vehicle combination with a total weight of about 60 ton. The consumption per km is higher, however the distance driven is shorter, so the chosen battery size is also sufficient for this operation.
As there will only be CCS chargers available at both ends of the routes, only a CCS is installed at the main inlet. This may change if MCS chargers will be available till the start of the demonstration phase.

As a result, seven BEV were developed and prepared for realization in 2025.

Table 2-1: Summary of vehicle specifications

Vehicle type	Summary of vehicle specifications
OEM 1 BE tractor (BEV1)	- Use case 7.2.2 - Range: 600 km - DC charging standards: CCS2 (ISO 15118 - 2 2016), MCS (ISO 15118-20)
OEM 1 BE tractor (BEV2)	- Use case 7.2.3 - Range: 600 km - DC charging standards: CCS2 (ISO 15118 - 2 2016), MCS (ISO 15118-20)
OEM 1 rigid truck (BEV3)	- Use case 7.2.4 - Range w/o e-trailer: 345 km - Range with e-trailer: > 500 km - DC charging standards: CCS2 (ISO 15118 - 2 2016)
OEM 2 BE tractor (BEV1 and BEV2)	- Use case 7.4.1, 7.4.2 & 7.4.3 - Range: 600 km - DC charging standards: CCS2 (ISO 15118 - 2 2016), MCS (ISO 15118-20)
OEM 3 BE tractor (BEV1)	- Use case 7.3.1 & 7.3.3 - Tare weight: 11.000 kg - Battery energy capacity: 728 kWh (installed) - Max. continuous power (mech.): 400 kW - DC charging standards: CCS2 (ISO 15118 - 2 2016), MCS (ISO 15118-20)
OEM 3 lowliner BE tractor (BEV2)	- Use case 7.3.4 - Low chassis to enable trailers with 3m loading hight - Tare weight: 11.138 kg - Battery energy capacity: 624 kWh (installed) - Max. continuous power (mech.): 400 kW - DC charging standards: CCS2 (ISO 15118 - 2 2016)

3 Conclusions and recommendations

3.1 Conclusions

The improvements of powertrain components and control systems were realized by the OEMs. Vehicle configurations were designed according to the requirements and needs of the use case missions and its boundary conditions. Vehicles and components are ready for assembly. Built slots for all vehicles are allocated.
Approval and homologation for OEM 2 trucks will be performed in 2025. The full homologation and certification are expected before October 2025.
The OEM 3 Low Liner is a production vehicle and will have approval from factory. OEM 3 plans to do test runs about one month before the use case starts, but not before the chargers are available. Therefore, there are no test results available at the time this deliverable is submitted.

3.2 Recommendations

For the OEM 1 use case UC 7.2.2 it was originally planned to use an EMS2 vehicle combination. The road permit for this vehicle combination is not yet approved, which will have to be achieved by the shipper supported by IDIADA. To keep the time plan for the use case, it will start with a tractor – semitrailer vehicle combination consisting of the OEM 1 BE tractor (BEV1) and a standard semitrailer.
For the BEV 2 use cases UC 7.4.1, UC 7.4.2 and UC 7.4.3 the test and mission must be adapted according to the availability of charging infrastructure. The tests will heavily contribute to confirm truck autonomy in real logistic usage, in various conditions. The analysis of tyres wear in all these conditions is an expected output for Michelin. The measurement of tyres wear will be planned within each use case.
The OEM 3 use case UC 7.3.1 will demonstrate the battery-electric long-haulage truck in combination with the e-trailer. This vehicle combination will be quite heavy and exceed the regular weight limits. Therefore, the shipper supported by IDIADA will have to achieve the road permit for the extra-weight in the countries where the combination is passing through.

3.3 Contribution to project (linked) Objectives

The work done in task 5.3 and documented in this deliverable contributes reaching several objectives that have been defined in the ZEFES description of action. The adaptation and implementation of specific powertrain components, subsystems, control systems and energy and thermal management systems of the prime mover's battery-electric powertrains are prerequisites for the realization of the vehicles in task 5.5. The improvements contribute directly to objective 1, in particular sub-objective 1.1 "improve the efficiency of electrically powered vehicles". Compliance with the verification criteria defined in the description of action will be proven after the vehicles are built, commissioned and tested by conducting the dry run tests in task 5.5 as well as by monitoring the vehicles during the demonstration and assessment of the collected data in WP7 and WP8 respectively.

3.4 Contribution to major project exploitable result

The work done in task 5.5 and the documentation in this deliverable directly contribute to the projects exploitable results. The improvements of the vehicle components are prerequisite to provide modular battery-electric vehicles from three OEMs that will be suitable for use in selected regional and national long-haul missions of at least 500 km daily, multimodal and cross boarder long-haul missions up to 1.300 km single route. The work results lead to an improved know-how of the OEMs to develop powertrain control strategies to optimize the lifetime and energy consumption of the BEV. The partners developed further know-how in smart energy management control software, optimum operating temperatures of all electric components, modular and scalable battery packs, power electronics, and the integration of interfaces to battery-powered trailers. This will help the OEMs to secure a leading position in the automotive industry.

4 Risks and interconnections

4.1 Risks/problems encountered

There are currently no risks encountered by the partners involved in task 5.3 regarding the availability of the BEVs for the demonstration.

4.2 Interconnections with other deliverables

The deliverable is connected to deliverable D5.6 “Realization and commissioning of all BEV demonstrators”, since the development and improvement of the powertrain components according to the requirements and needs of the use cases is a prerequisite to realize the battery-electric trucks and tractors that will be demonstrated within the ZEFES project.

5 Acknowledgement

Project partners:

#	Partner short name	Partner Full Name
1	VUB	VRIJE UNIVERSITEIT BRUSSEL
2	FRD	FORD OTOMOTIV SANAYI ANONIM SIRKETI
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
8.1	CPA	CPAC SYSTEMS AB
9	ABB	ABB E-MOBILITY BV
9.1	ABP	ABB E-MOBILITY SPOLKA Z OGRANICZONAODPOWIEDZIALNOSCIA
9.2	ABG	ABB E-MOBILITY GMBH
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	OPmobility
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
23.3	PGG	PROCTER & GAMBLE SERVICE GMBH
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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