European COmpetitiveness in Commercial Hybrid and AutoMotive PowertrainS

Final Report

EUROPEAN COMMISSION
Horizon 2020 | GV-4-2014 | Hybrid Light and Heavy Duty Vehicles
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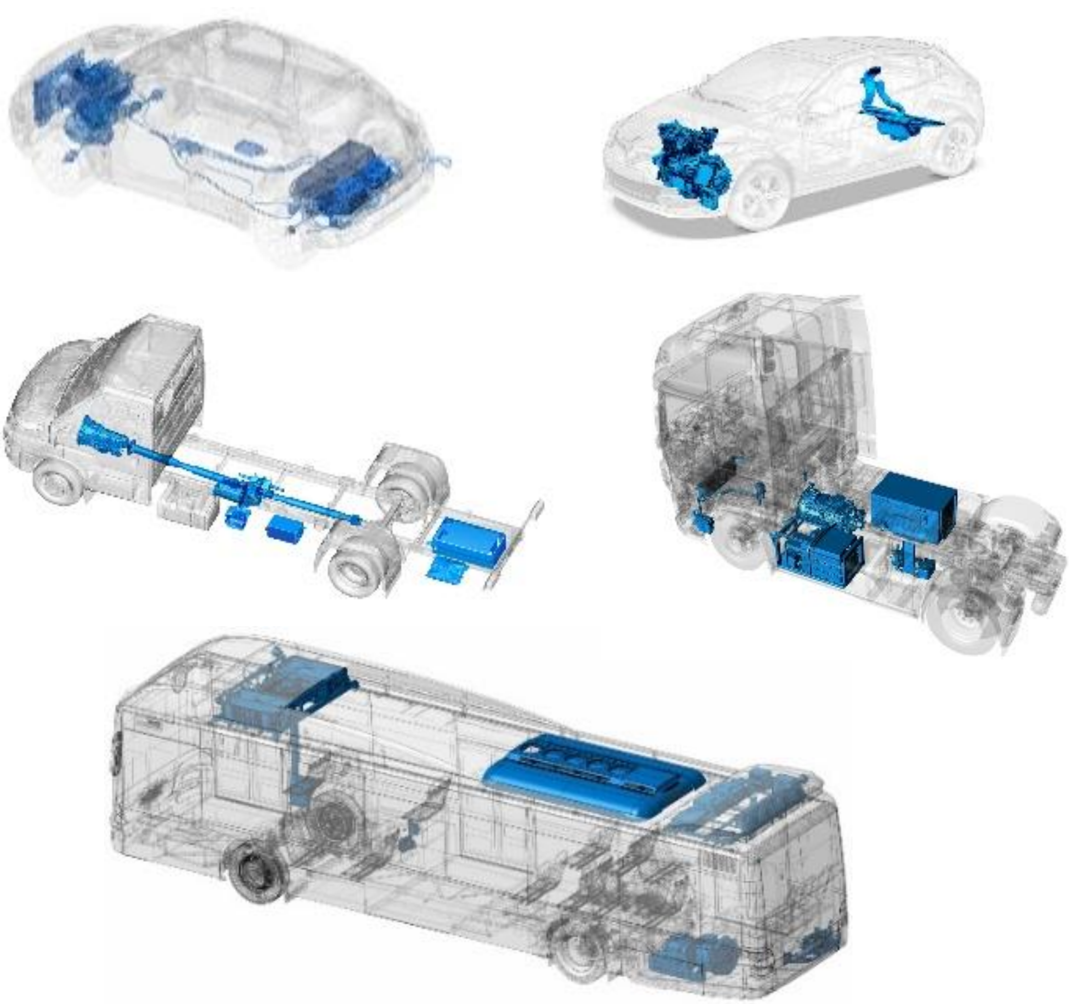


Summary

The innovations from the ECOCHAMPS project have resulted in efficient, compact, low weight and cost-effective hybrid powertrains for both passenger cars and commercial vehicles, which make European road vehicle manufacturers and their suppliers more competitive in hybrid vehicle technology.

The hybrid vehicle demonstrators developed in ECOCHAMPS were targeted to achieve a 20% powertrain efficiency improvement, a 20% powertrain weight and a 20%volume reduction, with respect to the 'best in class' hybrid vehicles on the market in 2013, whilst having a maximum 10% cost premium over the conventional vehicle. It should be noted that specific targets, leading to progress beyond the state-of-the-art, vary per demonstrator vehicle in detail, due to the wide range of vehicles worked on.

End User Requirements (EURs) and Key Performance Indicators (KPIs) have been defined to meet the expectations of the vehicle users for the forthcoming developments and to generate a starting point for the activities within ECOCHAMPS. These requirements ensured the practicability of the developed vehicles. All vehicle evaluations have been supervised by 'Golden Engineers', independent technical experts from Ricardo or the Joint Research Centre (JRC), who assessed the validation methods and the results compared to the targets.

Besides the optimal specification of the demonstrator vehicles based on the EUR's, further cost reduction of the heavy duty vehicles in the project has been achieved by the introduction of the Modular System and Standardization Framework (MSF). The MSF is a modular pre-standard framework that, for the first time, recommends standards for hybrid electric drivetrain components for commercial vehicles. Standardisation requirements have been identified for each hybrid electric component developed in ECOCHAMPS and, in a cooperation between both passenger car and heavy duty vehicle manufacturers and suppliers, this resulted in agreements on system voltage levels, interfaces (electrical, mechanical and communications), lifetime expectations, performance classes etc. The standards resulting from the pre-normative research performed in ECOCHAMPS are a sound basis for official standards to be published by standards organisations, as well as a good starting point for new component developments. For this purpose, the MSF document will be available via the European Council of Automotive R&D (EUCAR), as well as via the ECOCHAMPS project website: www.ecochamps.eu.

The project achievements include the development of six new hybrid electric components based on the MSF and five powertrains, which have been demonstrated in five vehicles at Technology Readiness Level (TRL) 7. The results show that a significant CO_2 reduction is possible, whilst offering valuable additional functionality to the end customer. Examples of results are the proven benefits of plug-in hybrid powertrains across different vehicle segments. For passenger cars, the use of 48V instead of high-voltage components is proven to be a viable alternative. Passenger car-based battery modules and inverters have been applied in heavy duty vehicles, proving their feasibility and unlocking the potential of their volume of scale. And lastly, the ECOCHAMPS proposals for the standardisation of hybrid-electric components (MSF) show a relevant cost reduction potential for hybrid commercial vehicles.

Contents

1 Introduction

1.1 What is ECOCHAMPS?

The ECOCHAMPS project boosts the introduction of hybrid powertrained commercial vehicles and passenger cars. ECOCHAMPS does this by developing technologies that improve vehicle performance, comfort and functionality, lead to less CO_2 emissions and reduce costs at the same time. The project has shown five hybrid powertrains that are applied in five different vehicles, from a small and a medium sized passenger car to a van, a city bus and a heavy duty truck.

For hybrid commercial vehicles, the developed Modular System and Standardization Framework (MSF) is a cornerstone for cost reduction. The MSF is a new pre-standard framework that recommends technical standards for hybrid electric drivetrain components. This provides planning certainty for suppliers, supports competition and scalability, resulting in a significant cost reduction for hybrid components and vehicles.

The consortium comprises three manufactures of passenger cars, four manufacturers of light, medium and heavy duty trucks and busses, the Original Equipment Manufacturers (OEMs) plus nine first tier suppliers of components. The consortium is complemented by four specialised research centres. With these partners, the ECOCHAMPS consortium has the critical mass, skills and commitment to improve European competitiveness in hybrid powertrain technology but also to accelerate the market uptake of hybrid technologies.

1.2 Why do we need a project such as ECOCHAMPS?

1.2.1 Societal needs

Green House Gas emissions (GHG), such as CO_2, and the air quality in cities are major societal challenges. In the context of sustainable mobility, propulsion technology development helps overcome these challenges. The electrification of vehicles is an important step to increased energy security, improved air quality and contributes to global CO_2 emissions reduction.

The further development and introduction of hybrid vehicles will help address these challenges by 2030. Hybrid vehicles reduce CO_2 emissions, improve air quality and reduce transport energy consumption in general. Hybrid vehicles do not have tight range limitations like full electric vehicles, such that hybrid vehicles meet consumer's needs and driving patterns today.

1.2.2 Past approaches

The results of many previous projects formed input into the ECOCHAMPS project. These earlier projects usually focused on a single specific innovation. The ECOCHAMPS project is different from these earlier projects in the sense that it brought these innovations together to demonstrate integrated powertrain concepts at Technology Readiness Level 7 (i.e. system prototype demonstration in operational environment) as well as providing the MSF to the industry.

1.2.3 The project scope

The project is divided into two different types of activities: 'horizontal' and 'vertical'. The horizontal type relate to collaborative activities to realize synergies and achieve the goals of standardisation, evaluation and dissemination; they include the overall project management activities. The vertical type relates to demonstrator development and validation activities at a vehicle level.

Standardisation requirements have been identified for each hybrid electric component developed in ECOCHAMPS: in a cooperation between both passenger car and heavy duty vehicle manufacturers and their suppliers, this resulted in agreements on system voltages, interfaces, lifetime expectations, performance ratings etc. The standards resulting from the research performed in ECOCHAMPS are a sound basis for official standards (as published by national or international standards organisations), as well as a good starting point for new component developments.

The project includes the development of six new hybrid electric vehicle components based on the MSF and five powertrains, all of which are demonstrated in five vehicles. The powertrain developments are based on End User Requirements (EURs) and Key Performance Indicators (KPIs) determined for each of the vehicles.

1.3 How can we increase the market uptake of hybrid vehicles?

1.3.1 What we are addressing:

Whilst hybrid passenger cars are already in production, their market penetration is still relatively low and limited to certain vehicle classes. Extending both the functionality of hybrid vehicles, and minimising their cost premium relative to conventional non-hybridised vehicles, will increase the end user interest in hybrid vehicles of all classes. Hence, increased market penetration is expected and then the overall number of hybrid vehicles in the market should increase. This increase in market size will result in fleet CO_2 and noxious emissions reductions. Therefore, the ECOCHAMPS project concentrates on comparative demonstration of lower cost hybridisation technologies.

Two actions were taken to increase the market uptake of hybrid vehicles (Figure 1-1). Component standardisation will bring cost down, especially since for commercial hybrid vehicles no such standards yet exist. A second way to reduce cost is modularisation, which enables the use of the components over different vehicle types. Another way to increase market uptake is to offer more vehicle functionality through the use of the hybrid technologies.

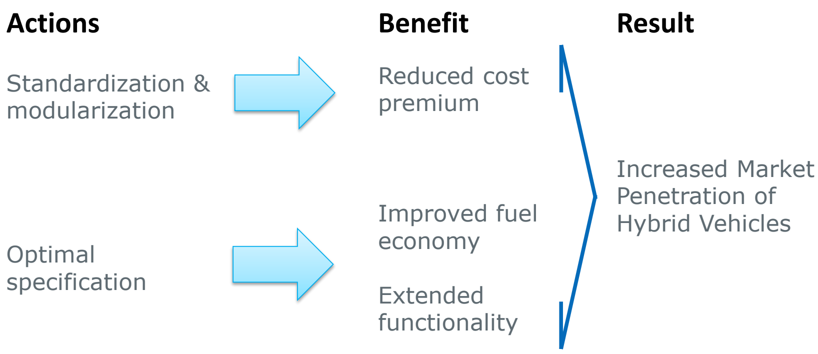


Figure 1-1. The activities in ECOCHAMPS to bring more hybrid vehicles on the road.

1.3.2 Key innovations

The overall objective of the ECOCHAMPS project is to achieve efficient, compact, low weight, robust and cost-effective hybrid powertrains for both passenger cars and commercial vehicles (buses, medium duty and heavy duty trucks), with increased functionality, improved performance, comfort, functional safety and emission levels below Euro 6 or VI.

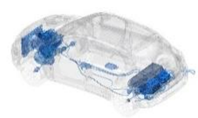
The most important aspect is to achieve commercial viability of the new technologies, to bring hybrid vehicles across the complete vehicle parc. For light duty vehicles, this means keeping the purchase cost premium compared to existing non-hybrid vehicles to a minimum. For hybrid commercial vehicles, this means an attractive payback period for the incremental costs of the hybrid vehicles. In both cases, this will enable OEMs to successfully market their vehicles and, together with their suppliers, to start series production of components and vehicles. Higher production volumes lead to a lowering of the Cost of Goods Sold (COGS), subsequently to the lowering of the incremental vehicle costs. The net effect is a growing increase in production and sales volumes. Since the ECOCHAMPS consortium comprises all stakeholders needed to develop, demonstrate and market the hybrid technology in the different vehicle segments, there is a vested interest in bringing the technologies to production.

2 What did we develop in ECOCHAMPS?

2.1 Vehicles

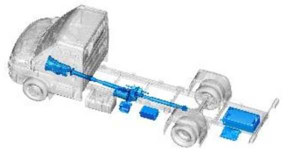
Five demonstrator vehicles were developed in ECOCHAMPS to Technology Readiness Level 7. The TRL is a scale to estimate the maturity of a development (ranging from basic research to a system that is commercially ready): level 7 means a “system prototype demonstration in operational environment”.

The class B vehicle, based on a FIAT 500X, is designed as a plug-in hybrid with an electric range of 25 km. The demonstrator focuses on improving powertrain efficiency and offers additional functionality, such as pure electric and all-wheel drive. A plug-in powertrain is heavier and larger than a mild hybrid solution but is substantially more efficient and gives greater electric range.

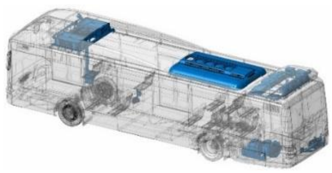


The class C vehicle, based on a Renault Megane, is a 48 V hybrid demonstrator. The aim is to demonstrate a fuel economy comparable to a high voltage hybrid, whilst halving the powertrain costs by using lower voltages. A downsized, turbocharged and friction-optimised combustion engine is combined with a 48 V, 15 kW electric motor. The lightweight 48 V technology helps meet the powertrain weight and volume targets.

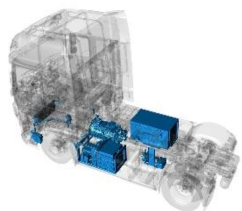
The medium duty vehicle is based on an IVECO Daily. The demonstrator focuses on improving powertrain efficiency and offers additional functionality (such as pure electric driving), whilst not reducing the flexibility of the vehicle. This flexibility is needed in the delivery business. A gearbox connects the high-speed electric motor to the prop-shaft and to the rear axle, giving the vehicle an electric driving range suitable for zero emission driving in city centres.



The city bus demonstrator is based on a MAN Lion bus. It focuses on powertrain efficiency and costs, in equal amounts. The main system components are modular, to have a basic electric bus that can easily be adapted to customer requirements. To explore the possibility of reducing costs, the demonstrator uses powertrain components and battery systems originally developed for passenger cars.



The heavy duty demonstrator is based on a DAF XF truck and has been fitted with a parallel hybrid electric powertrain to reduce CO_2 emissions compared to the conventional vehicle. Similar to the bus, components from the high volume passenger car segment are used in the hybrid truck to reduce costs. This results in the voltage level of 400 V for the electrical architecture.



2.2 Components

Next to the vehicles, several components were developed in ECOCHAMPS. The goal was to take, where possible, advantage of synergies between passenger cars and heavy duty vehicles. Some of the components were developed starting from existing parts, others have been newly designed. In all cases, the components comply with the LV123 agreement (for light duty vehicles) or are based on the ECOCHAMPS Modular System and Standardisation Framework MSF. The hybrid components that have been developed in ECOCHAMPS are shown in Figure 2-1.

Figure 2-1 An overview of the components and the vehicles in which they are applied.

2.3 Modular System and Standardization Framework (MSF)

Light duty components are (relatively) low cost since they are typically produced in large numbers. In comparison, heavy duty vehicles are produced in small numbers. That means that for heavy and medium duty vehicle components, there is room for lowering the cost by increasing the production scale. This can be achieved by introducing standards and norms, so that the components can be used by different OEMs.

Figure 2-2 shows the benefits of standardization using the ISO 4762 standard for screws as an example. When Allen screws and keys were not yet standardized, customers had to specify a range of requirements to the manufacturer when ordering screws. the length of the shank. Now the requirements on the screws are standardized, so that customers only have to specify size (M), length (L) and strength. This is expected to bring the delivery time down from 7 days to 1, and bring down the price from >5€ to <0.5€.

The ECOCHAMPS partners have developed the MSF for the same reasons as for screw standardization. The MSF is a framework proposing the requirements for drivetrain components and electrically driven auxiliaries for heavy duty vehicles. Requirements are, for instance, the voltage level of components. After ECOCHAMPS this standard is expected to bring down development times and costs for hybrid components, making hybrid heavy duty vehicles more attractive for customers.

To establish such a pre-standard framework, the partners identified two types of requirement at the start of the project. Firstly, experts came together in workshops and meetings to select the most beneficial and feasible component requirements to include. Secondly, system level requirements were identified that impact on more than one driveline component. Existing standards were used as far as possible in the process. During the rest of the project, the ECOCHAMPS partners brought in new findings from the component development and their integration into the demonstrator vehicles. Further, feedback from an external mirror group was taken into consideration for the final version of the MSF.

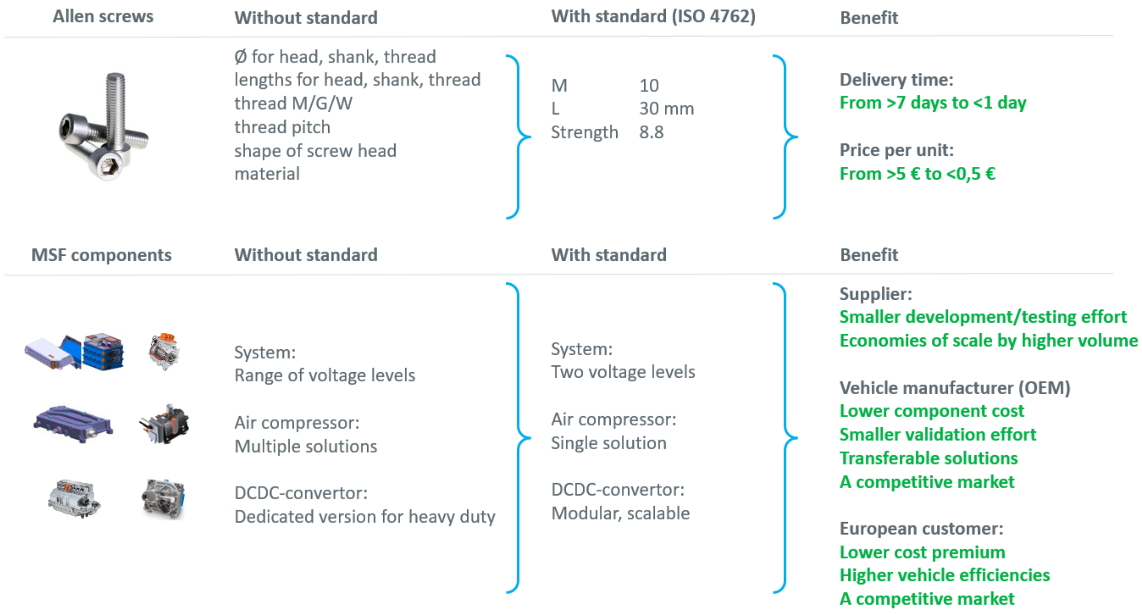


Figure 2-2. Benefits of standardization.

2.4 Method to come to a proposal for new standards

The ECOCHAMPS partners developed a method to come to the standardization proposals and a way to assess the results. This is a development in its own right. Figure 2-3 shows this method, which consists of four steps.

The first step was to create a template with requirements for each component. An expert group defined requirements: the suppliers filled out the templates with the values, ranges, definitions, norms etc. They did this for four different vehicle classes, thus the requirements of different OEMs were discussed anonymously.

In the second step, the potential parameters for standardization/modularization were identified for each component. The most beneficial requirements were marked and plotted in a matrix, considering benefit versus standardization feasibility. The requirements in the matrix were evaluated based on the potential for generalization towards other components and towards modularization.

In the third step, the requirements for standardization were determined and responsible experts were assigned. Subsequently, each expert had to develop a proposal for a standardization of their requirement and discuss the proposal with in-house experts etc. The proposed requirements were combined in a draft MSF document.
Finally, in the fourth step, the standardization proposals of each component were discussed and agreed. After these four steps, the suppliers used the MSF draft for the component development.

To evaluate the cost saving potential of standardization and to provide a guideline for future standardization activities, an assessment method for the proposals was aligned with the OEMs and suppliers. Based on feedback, a template for each component and vehicle was prepared and sent to experts. The component experts provided their assessment results, which were collected, analyzed and shown. In parallel, the draft of the MSF was sent to external reviewers and the mirror group. The feedback from those reviewers was included in the final MSF proposal. The results from the internal assessment and the external reviews were used to enhance the MSF draft. Further, learning from the component development was taken into account.

For more details see also the publicly accessible reports, D2.4 (MSF Creation and the Standardization Proposals) and D2.5 (The Assessment Method).[1]

[1] The MSF report and deliverables are available on the EcoChamps website: www.ecochamps.eu

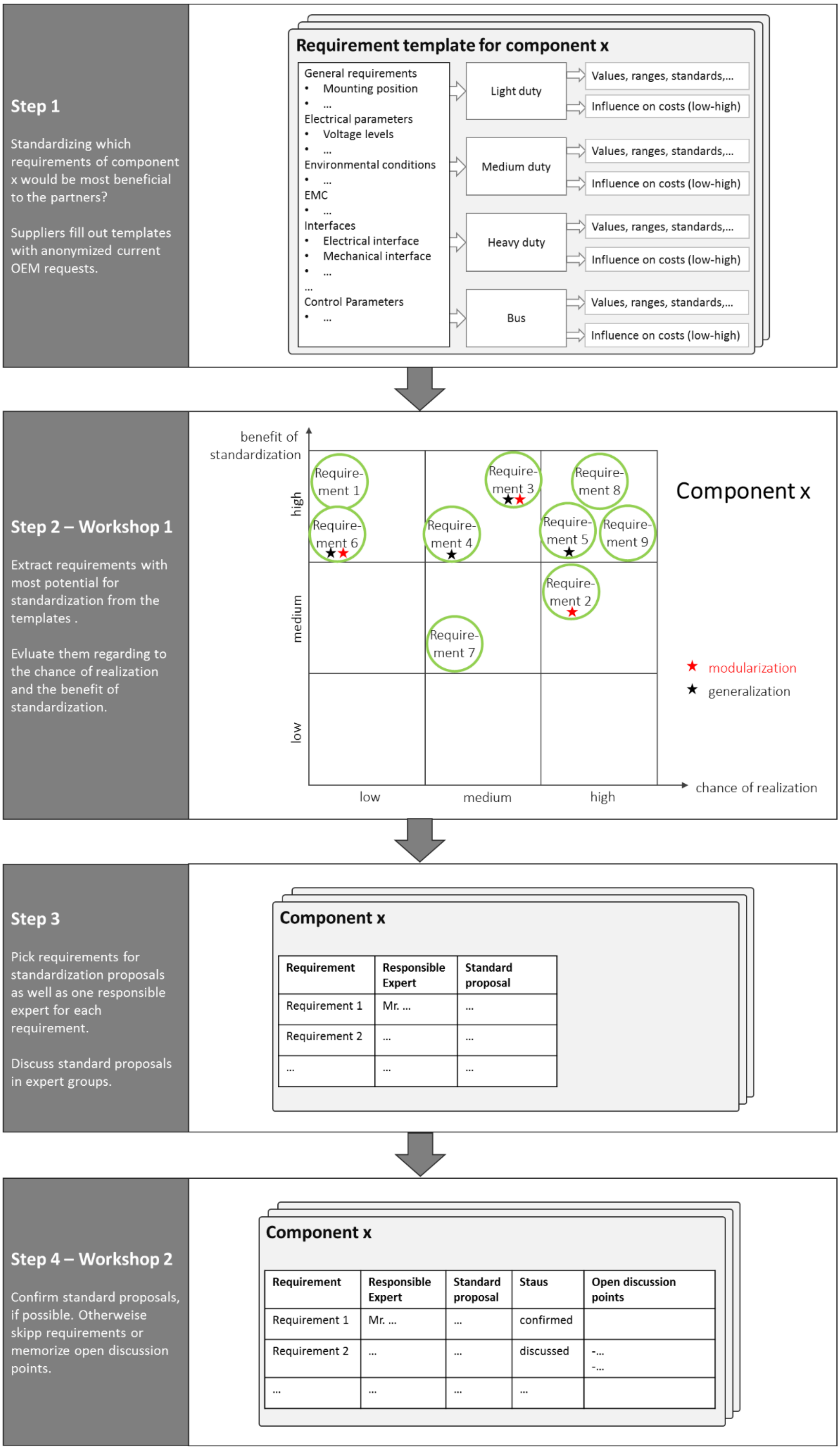


Figure 2-3 The way in which requirements are determined that should be standardized and development of standard proposals.

3 How do we assess the results?

3.1 Independent evaluation

It is not straightforward to share information between companies due to confidentiality. The EU has strict competition laws, for instance OEMs cannot share any cost information. Compliance, i.e. acting conform to the EU competition regulations, makes it a significant challenge to develop new technology and pre-standards together, certainly if these are designed to bring down costs. In addition, it is very important to have an independent evaluation of the demonstrator developments in the ECOCHAMPS project.

In ECOCHAMPS this challenge is met by including a separate horizontal work package, to make sure that the evaluation of the demonstrator vehicles (compared to the project targets) is independent. In this work package, a key role was given to “Golden Engineers”, independent technical experts from Ricardo or the Joint Research Centre (JRC) under the work package lead of Fraunhofer IVI. A Golden Engineer is actually a team of specialists, who were involved in the target setting, tracking and evaluation of the project. The Ricardo engineers were responsible for the two passenger car demonstrators, whereas the JRC engineers evaluated the commercial vehicle demonstrators. Efficiency, emissions, mass and volume figures are made available by the OEMs for inspection by the Golden Engineers, and performance can be assessed by driving the vehicles. The Golden Engineers can see the prototype powertrain costs at a macro-cluster level, and how many vehicles need to be produced to have a successful business case.

The Golden Engineers are not influenced by the commercial relationship between the OEM and supplier. Furthermore, this multi-layer approach ensured confidentiality and compliance within the project. For example, no cost information was shared among the OEMs and suppliers; only the Golden Engineers had direct access to this information. Therefore, the Golden Engineers were able assess all information in more detail than was summarized in the reports. Figure 3-1 shows how the information goes from very detailed to finally very basic in the report. More details on the work of the Golden Engineers is given in the Transport Research Arena (TRA) publication[2], and D1.1 to D1.5[3].

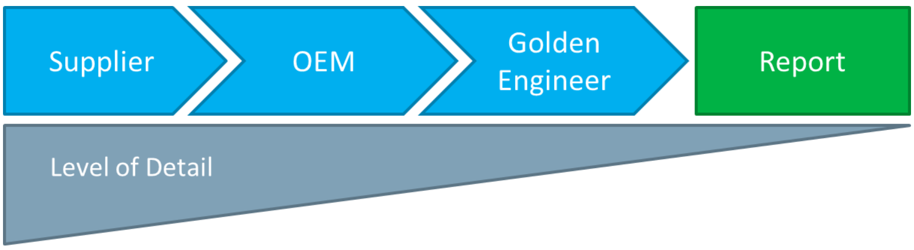


Figure 3-1 Level of detail during the steps of the assessment.

3.2 Setting the targets

When inviting research proposals in 2013, the EU set targets for the to-be-developed hybrid vehicles in the GV-04-2017 call with respect to the best-in-class hybrid vehicle in the market in 2013 or the conventional vehicle on which the demonstrators will be based. The ECOCHAMPS project ambitions were geared to the impact expected by the EU. During the project, the ambitions were refined into three sets of targets:

- End User Requirements (EURs), that represent the consumers’ desires at a mostly qualitative level,
- Key Performance Indicators (KPIs), that are quantified technical targets derived from consumers’ wishes,
- Technical Targets, which are related to the impacts expected by the EC, and the project ambitions.

Since ECOCHAMPS is a large and complex project, each demonstrator has its own target values.

[2] Nitzsche, G., et. al., ECOCHAMPS – Project Targets, their Tracking and the Evaluation of the Demonstrator Vehicles, 7th Transport Research Arena 2018, Vienna, Austria

[3] The public deliverables can be downloaded from http://www.ecochamps.eu/results/.

In the case of Light Duty (passenger car) vehicles, the end users are customers that buy and use the cars, but this could also include fleet management companies. In the case of commercial vehicles, the end users are customers who buy the vehicles for commercial use.

Reference vehicles were necessary to baseline the performance of the to-be-developed demonstrator vehicles. The reference vehicles were carefully selected, to be as close to the call definition as possible whilst enabling a sensible comparison. Sometimes, no best-in-class hybrid vehicle was available in the market in 2013, e.g. for the long haul truck. The Golden Engineers also considered the peculiarities of the different powertrain concepts, when for example comparing a plug-in-hybrid to a conventional hybrid vehicle. The detailed argumentation for the reference vehicle selection is included in D1.2. A summary of the vehicles is provided in Table 3-1 below.

Table 3-1 Reference vehicle selection.

Vehicle	Class B Pass. Car	Class C Pass. Car	Medium duty Truck	City Bus	Heavy duty truck
Reference	Toyota Yaris hybrid, 2013	VW Jetta hybrid, 2014	Daily Electric, 5 tonne, 2014 Daily 170CV, 2014	MAN Lion City Hybrid, 2013	DAF XF FT FP7 CONVENIENT DAF XF FT, 2013
Donor Vehicle	FIAT 500X, 2015	Renault Megane, 2014	Daily 7 tonne 170CV, 2014	MAN Lion City Hybrid, 2016	DAF XF FT, 2017

3.2.1 End User Requirements

As described above, the End User Requirements (EURs) are mostly qualitative customer's desires given in general descriptions, since end users are normally no technical experts. Examples of those requirements are given in Table 3-2. Some requirements, such as reliability, are included to make sure that those topics are considered in the evaluation of the demonstrators. Nevertheless, they are not investigated in detail in this project, because this is not feasible at a demonstrator vehicle level, since this is not as mature as a serial production vehicle.

Table 3-2 Examples of EURs for the different demonstrator vehicles.

EUR	CRF	Renault/Daimler	IVECO	MAN	DAF
Costs	Cost of ownership lower than donor vehicle	Max. 10% premium over donor vehicle (cost of acquisition)	Cost of ownership lower than donor vehicle	Lower than SoA vehicle	Cost of ownership lower than donor vehicle
Fuel Consumption	Lower than SoA	Lower than SoA	Lower than donor vehicle	Lower than SoA	Lower than SoA
Emissions	--------- Below Euro 6b --------		--------------- Below Euro VI ---------------		
Performance	------------------------------ Equal or better than donor vehicle ------------------------------				
Available Capacity	-- Sufficient --				
Reliability	---------------------------- Equal or better than industry practice ----------------------------				

Note: State of the Art (SoA)

3.2.2 Key Performance Indicators

KPIs are defined to quantify EURs, as needed. They provide numbers as targets for the evaluation. Whilst some EURs only needed to be quantified with a specific value to become a KPI, some EURs needed to be split in separate KPIs. E.g. “available capacity” was defined with a value at which the capacity is considered to be sufficient. The “performance” EUR was split into, e.g., maximum speed, acceleration, charging time (where applicable), gradeability and pure electric range (where applicable).

3.2.3 Technical Targets

As mentioned, the starting points for the Technical Targets were the impacts that the EU expected, such as a better powertrain efficiency or a maximum weight increase (hybrid vehicles are typically heavier than their conventional counterpart). When writing the ECOCHAMPS proposal, taking into account the 2013 conventional vehicles and the 2013 Best-in-Class Full Hybrid vehicles (BIC), it became clear that the EU ambitions were well beyond general development trends. The conclusion was that achieving all expected impacts in each of the demonstrators was unachievable. Therefore, each demonstrator focuses on a different sub-set of improvements. Simulations were used during this stage to define realistic targets for the demonstrator vehicles. The resulting Technical Target values are compiled in Table 3-3.

Table 3-3 Overview of the Technical Targets for the five demonstrator vehicles.

Technical target	CRF	Renault/Daimler	IVECO	MAN	DAF
Powertrain Efficiency	+20% vs. SoA	+20% vs. Megane gasoline	+20% vs. Daily Diesel	+10% vs. SoA	+20% vs. DAF XF Diesel
Powertrain Weight/Volume	+5% vs. SoA w/o battery	+5% vs Megane gasoline	-20% vs. Daily Electric	-10% vs. SoA	-5% vs. FP7 Convenient
Hybrid Cost Premium	15-20%	10%	40%	-10% vs. SoA	10%
Emissions	< Euro 6b	< Euro 6b	< Euro VI	< Euro VI	< Euro VI

3.3 Evaluating the end result

The Golden Engineers compiled all data (the targets, their definition and the evaluation method) in an assessment matrix to evaluate the demonstrator vehicles. This matrix served as a guideline through the evaluation process and formed the basis for the public assessment report, D1.5.

The testing of the demonstrator vehicles was performed by the OEMs in the presence of the Golden Engineers. The actual testing was slightly different for each demonstrator vehicle. The individual sections below describe this in more detail. For example, the fuel efficiency tests were handled in different ways. They all were carried out by the OEMs themselves. However, the Golden Engineers witnessed part of the tests and assessed the testing method based on data provided.

In general, the project targets were achieved. The table below summarises the results of the assessment of the Technical Targets and End User Requirements. For all details, please see the assessment report in the public deliverable, D1.5.

Table 3-4 Overview of the assessment results for the Technical Targets and the End User Requirements; Status 28.06.2018.

Ambition	Class B Pass. Car	Class C Pass. Car	Delivery Truck	City Bus	Long Haul Truck
Powertrain Efficiency	+20%* vs. Yaris hybrid	+40% vs. Megane gasoline	+30% vs. Daily Diesel	+18% vs. SoA	+≈17% vs. DAF XF Diesel
Powertrain Mass and Volume	+5% volume +5% weight vs. Fiat 500X gas.	+15% volume +35% weight vs. Megane gasoline	-36% volume -27% weight vs. Daily Electric	+10% volume** +8% weight** vs. SoA	-17% volume -13% weight vs. FP7 Convenient
Noxious Emissions	< Euro 6b*	< Euro 6b	< Euro VI	< Euro VI	Expected < Euro VI
Hybrid Cost Premium	Cost results cannot be shown due to compliance				

* Tested after end of project ** With HD components

EUR	Class B Pass. Car	Class C Pass. Car	Delivery Truck	City Bus	Long Haul Truck
Costs	Cost results cannot be shown due to compliance				
Fuel Consumption & CO_2	*				
Emissions	*				
Safety Standards					
Performance	*				
Ride & Handling					
Comfort					
Noise, Vibration & Harshness					
Available Capacity					
Reliability					
EV Battery Life	n/a				
Ease of Charge		n/a			
HMI					

not assessed Target met Close to target, or target not met without impact Target not met with impact

4 Modular System and Standardization Framework (MSF)

4.1 General motivation

As described in Section 2, part of the ECOCHAMPS project was to propose the MSF, to recommend standards for electric hybrid drivetrain components and auxiliaries including voltage levels, mechanical, electrical and communication interfaces for commercial vehicles. This MSF will provide planning certainty for suppliers, supporting commercial competition and scalability. When implemented, this will significantly reduce the costs of hybrid drivetrain components and vehicles in the mid-term. To demonstrate the synergies between the needs of light and heavy duty vehicles, a set of components was developed to TRL 6 or 7. These components conform to LV123 (LD) or are based on the MSF (HD) and were built into the demonstrator vehicles.

4.2 System level requirements

During the development of the MSF, several requirements have been identified that affect more than just one component. These system level requirements were discussed on a system/cross component level. The system level requirements that have been defined in the MSF are the following: voltage-levels, ASIL-classification, environmental conditions, DV-testing, electromagnetic compatibility (EMC) and noise levels.

4.3 Component level requirements

The component level requirements have been defined in the MSF per component. The requirements are:
High voltage battery system: the specification of power requirements, the specification of energy content, the minimum set of CAN signals, the high voltage testing, the modularity and architecture, the installation space and mounting position, and the high-voltage DC residual ripple.
Electric motor/generator (EMG): the high-voltage testing, the specification of power requirements, the minimum lifetime requirements, and the housing and mechanical interface.
I**nverter EMG:** the minimum lifetime requirements, the cooling system (temperature ranges and durations), the ambient temperature ranges and vibration requirements, the minimum drive cycle/lifetime requirements, the definition of the term “continuous current”, and the high-voltage DC residual ripple.
DC/DC-converter: the operating time/lifetime, the continuous power step down, the cooling system and temperature, the mounting position and humidity, the temperature load spectrum, the mechanical interface and installation space, and the control interface and signals.
Electric air compressor: the rotational speed and air flow, the non-electrical interfaces, the oil intrusion into piping/system, the service intervals and operating intervals between services, the maximum air pressure, the electrical interface, the maximum air flow, the reference cycle, the mechanical shock and maximum acceleration forces, and the inclined mounting position.
Electro-hydraulic power steering: the operating time (mileage), minimum volume flow at given pressures, input/output-signals, basic functional requirements, load spectrum mechanical operation and mechanical shock, low voltage-powernet specification, reference cycle, hydraulic, electric and mechanical interfaces.
A/C-Compressor: the performance classes, the mechanical and the electrical interfaces, the low voltage-powernet specification, the I/O-signals and diagnostic outputs, the lifetime (EU-wide), the DV-testing, and reference cycle.

4.4 Potential impact of the MSF

The potential impact of the MSF is described in the public report, D2.5 in which the partners evaluated the cost saving potential of the standards and provided a guideline for future standardization activities. The potential impact of the MSF was analysed in two different ways. The assessment was separated into a method for component suppliers and a method for vehicle manufacturers. Both methods used the same future scenario to evaluate the potential cost impact when introducing standardized requirements for components in commercial vehicles. The relative cost impact is described for a future fictive production volume and is given in terms of low, medium and high volumes. Due to confidentiality reasons and competition rules, the report does not include the detailed information provided by the ECOCHAMPS project partners to Fraunhofer IVI. Nevertheless, the summaries per component give a recommendation based on the results.

5 Results for the Demonstrator Vehicles

5.1 Class B passenger car

5.1.1 Motivation for the solution

Environmental and social mobility challenges are becoming more relevant. To pave the way to this green, clean and efficient mobility vision towards the long term goal of a sustainable and zero emission future, electrification is one of the most promising solutions. In the short and mid-term, to support a wider diffusion of electrified vehicles, it is essential to find solutions that are able to satisfy the typical customer expectations in terms of costs, higher performance (fun to drive), better driveability and comfort, improved usage flexibility, and new functionalities.

The hybrid architecture selected for the B Class passenger car aims to give an answer to the environmental requests and the private user needs, through a plug-in solution (enabling a pure Electric Vehicle (EV) mode for tens of kilometres), an improved regenerative braking strategy and an electric AWD capability with higher dynamic and efficiency in comparison to a mechanical system, plus a wide impact (not only for zero to near-zero speeds (depannage)).

The Class B passenger car developments performed can be summarised as follows:

- identify the hybrid architecture
- define the hybrid powertrain subsystems and components specification
- design and size the selected new plug-in hybrid architecture with a modular approach and considering its potential scalability to lower and higher size cars and light commercial vehicles
- integrate, at a functional level, the hybrid powertrain in a B Class passenger car demonstrator vehicle
- define and implement the optimised thermal and energy management
- assess through vehicle level test (dyno. bench and track) the developed solution, optimising fuel efficiency as well as driveability and safety (enhanced as result of the electric All Wheel Drive (e-AWD) capability).

Table 5-1. Main technical targets for the city car demonstrator.

Key Target	Specific Target Values	Notes
Powertrain efficiency	+20%	vs. best in class SoA on NEDC cycle (R101 based)
Powertrain Mass	+5%	vs. baseline (w/o Battery System)
Powertrain Volume	+5%	vs. baseline (w/o Battery System)
Noxious emissions	Euro 6b	on dyno bench

where:

- best in class State of the Art (SoA) (HEV for B segment): Toyota Yaris Hybrid 2013
- baseline: FIAT 500X 2015 with 1.4 l MultiAir gasoline engine, ZF AT9 gearbox and GKN mechanical All Wheel Drive (AWD)
- hybrid powertrain: internal combustion engine, mechanical transmissions, front & rear e-machines and power electronics.

Table 5-2. Main targets for the end user requirements for the city car demonstrator.

End User Requirements	Class B Passenger Car
Fuel Consumption & CO_2	Lower than SoA
Noxious Emissions	Below Euro 6b
Safety Standards	Pass all relevant safety standards
Performance	Equal or better than baseline vehicle
Ride & Handling	Acceptable
Comfort	Unchanged to base vehicle
Noise, Vibration & Harshness	Equal or better than industry practice
Available Capacity	Sufficient
Reliability	Equal or better than industry practice
EV Battery Life	Product level target: 10 years or 150.000 km
Ease of Charge	Mode 2 and 3 compliancy
HMI	Pass

5.1.2 Key innovations

The CRF demonstrator is based on a FIAT B/C segment passenger car (donor vehicle) in which the hybridized plug-in powertrain has been installed in place of the current normal production one (Front Wheel Drive (FWD) pure thermal engine based with mechanical AWD capability). The developed architecture additions are:

- high efficiency (engine downsizing and high voltage e-components (included the Li-ion batteries))
- add-on approach for the front axle hybrid powertrain and the integrated rear electric axle (with favourable impact on the costs)
- hybrid architecture able to exploit the advantages of the front dual clutch transmission and compensate its limitations through the hybridization
- wide flexibility in the usage (engine only, parallel (with torque assist), split (with power looping) or series hybrid and pure electric modes)
- pure electric range based on the proper battery sizing
- advanced energy management

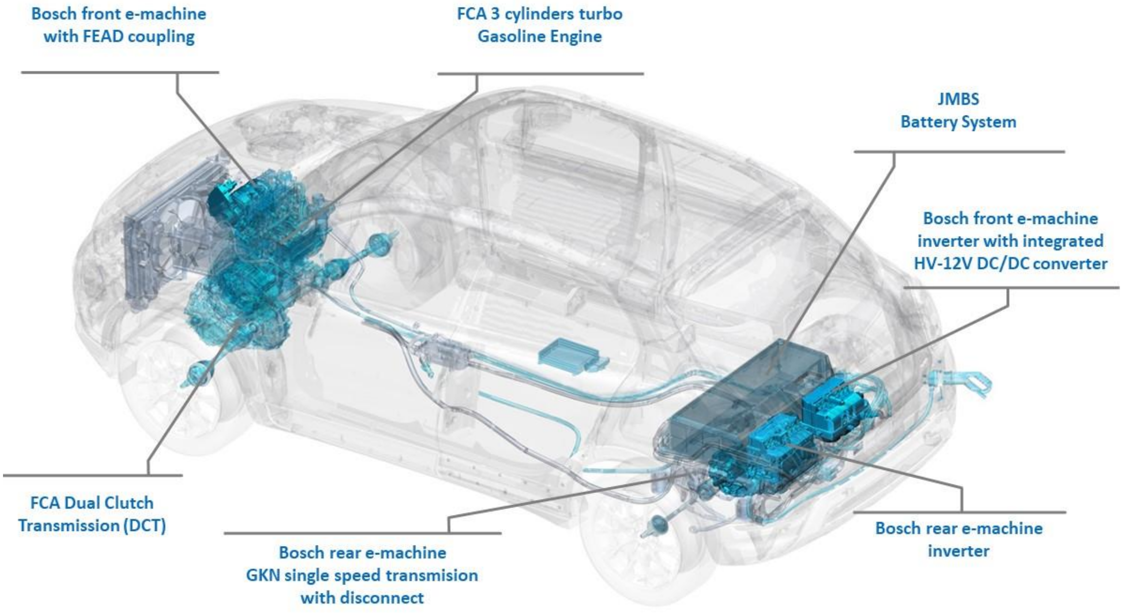


Figure 5-1. Ghost view of the car showing the installation of the hybrid powertrain components

The key components implemented on the demonstrator are:

- the new downsized Fiat Chrysler Automobiles (FCA) gasoline engine (in place of the donor vehicle 1.4 gasoline engine)
- the FCA Dual Clutch Transmission (in place of the donor vehicle Automatic Transmission)
- the Bosch 400V front e-machine (in place of the standard alternator)
- the rear electric axle made of the Bosch 400V e-machine plus the GKN fixed speed transmission with integrated differential and disconnect (in place of the donor vehicle mechanical AWD unit)
- the Bosch 400V inverters with the integrated HV-12V galvanically insulated step-down DC/DC converter
- the 400V Li-ion based Battery System (initially planned by JMBS)
- the Brusa 400 V battery charger (with the charging socket)
- the thermal systems (included an High Voltage (HV) electrical PTC heater and the Denso HV electric air compressor of the passenger air conditioning also in EV mode and the Battery System cooling-heating)
- the HMI devices (tablet display, mode selector, buttons etc)

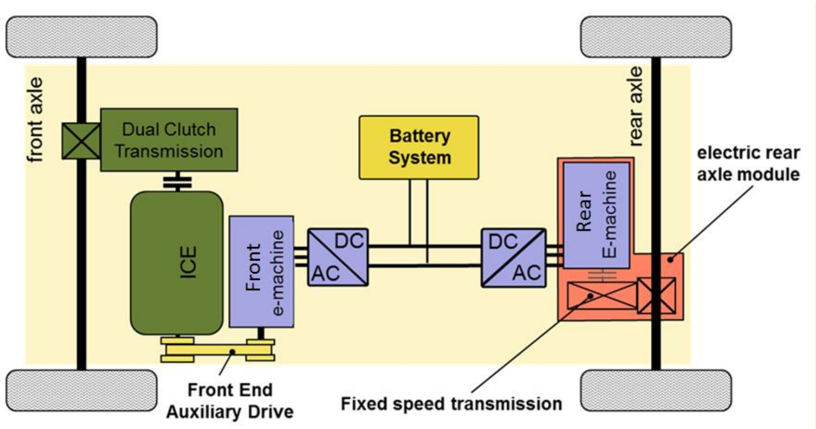


Figure 5-2. E-AWD distributed complex plug-in hybrid architecture.

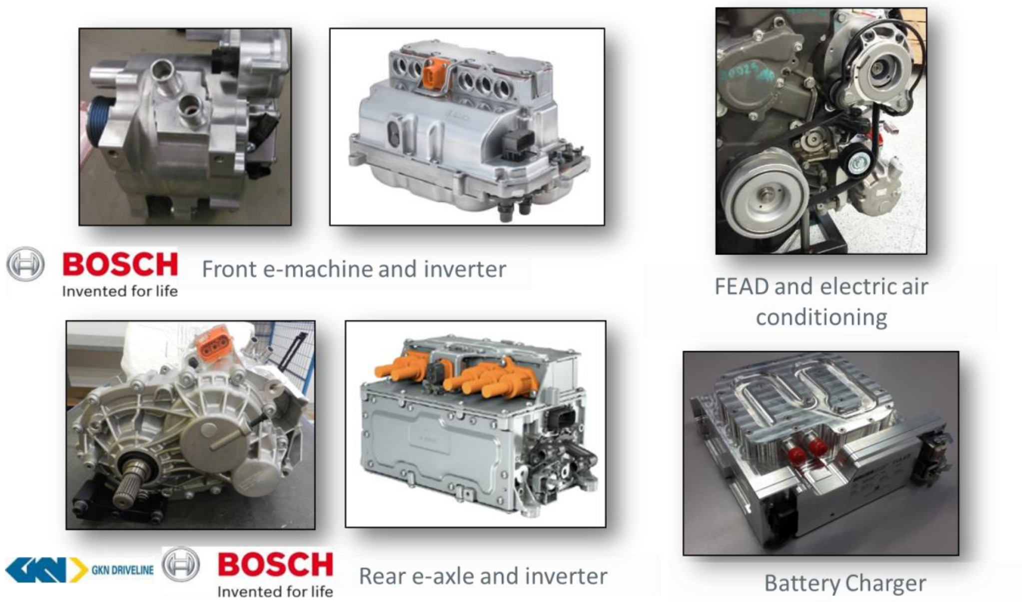


Figure 5-3. Some of the main hybridized powertrain components.

5.1.3 Key results

The plug-in hybrid demonstrator vehicle, based on the FIAT 500X, meets near all the ECOCHAMPS targets despite severe issues with the supply of the JMBS traction battery (in the vehicle validator replaced with a Li-ion A123Systems based solution CRF had to develop in house). Due to the significant delays, CRF had to complete a comprehensive part of the final evaluation after the end of the project (April 30th, 2018). The final assessment was carried out between the second half of March and the end of April 2018 on closed test tracks within FCA facilities in Orbassano (Centro Sicurezza) close to Turin (Italy), partially under the supervision of the Golden Engineer.

Figure 5-4. City car demonstrator.

As reported in the two previous tables, the developed prototype vehicle was assessed against:

- Toyota Yaris Hybrid 2013 for the powertrain efficiency and vehicle consumption/CO_2 emissions
- FIAT 500X gasoline mechanical 4WD for the weight & volume plus delta cost impact and many of the EUR

For noxious emission, the EURO standards have been considered, while for the remaining EURs, standards (for instance for safety) and industry practice, Noise Vibration and Harshness (NVH) and Reliability, have been used. Table 5-3 and Table 5-4 summarize the main results.

Table 5-3. Main technical results for the city car demonstrator.

Ambition	Reference	Target Value	Result
Powertrain Efficiency	Toyota Yaris Hybrid (BIC)	+20%	+20%*
Powertrain Mass	Fiat 500X gasoline	+5% (w/o battery)	+5% (w/o battery)
Powertrain Volume	Fiat 500X gasoline	+5% (w/o battery)	+5% (w/o battery)
Noxious Emissions	none	< EURO 6b	< EURO 6b*
Hybrid Cost Premium	Fiat 500X gasoline	<20%	Yes

* tested after end of project

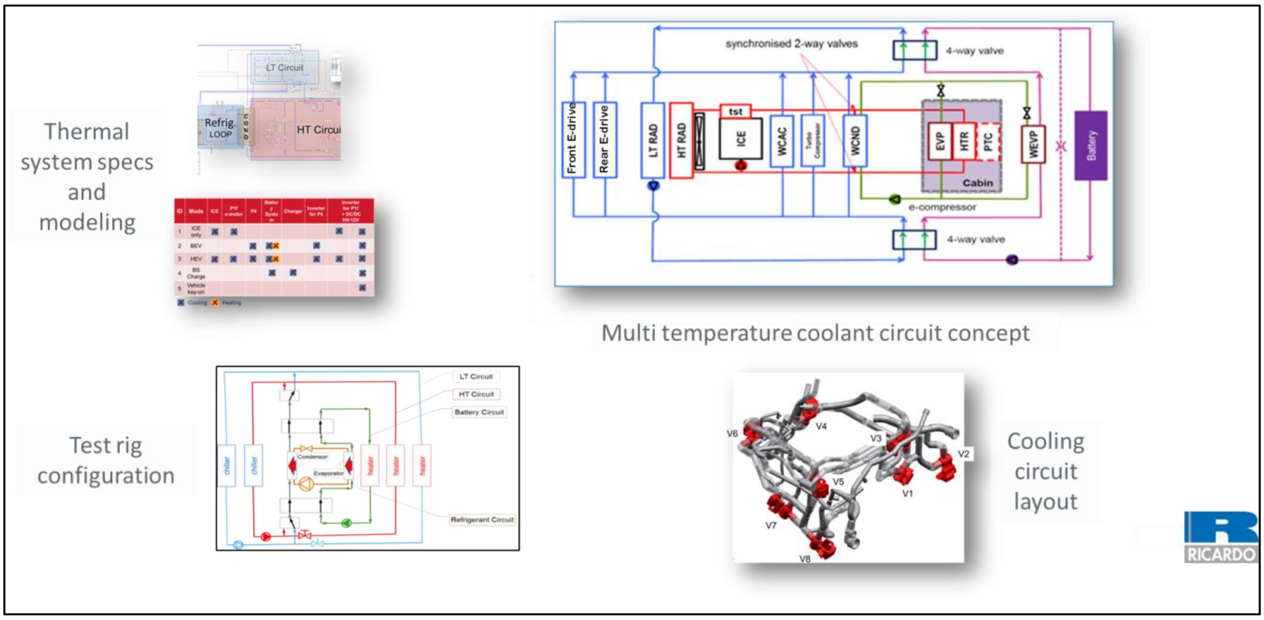
Table 5-4. Main results from the end user requirements for the city car demonstrator.

End User Requirements	Specific vehicle targets	Results
Safety standards	Pass all relevant safety standards	High Voltage managed in line with ISO 6469-3 and R100
Performance	Maximum speed: as baseline vehicle Maximum EV speed: at least 100 km/h Acceleration time: lower than baseline vehicle	Target performance verified* (maximum EV speed: verified on dyno bench)
Ride & Handling	Acceptable (for a proto vehicle)	Verified on track
Comfort	Unchanged to base vehicle	Verified on track
Noise, Vibration & Harshness	Equal or better than industry practice	Verified on track
Available Capacity	Sufficient/< 100 litres	Limited trunk available volume reduction/ 20 litres
Reliability	Equal or better than industry practice	Verified in the test phase (acceptable for a proto vehicle)
Ease of Charge	Mode 1 and 3 (conductive charge) compliancy	Mode 1, 2 and 3 conductive charge (on-board 3.3 kW charger). For Mode 2 and 3 type2-type 2 cable (IEC 61851)
HMI	Pass	Tablet display, mode selector, EV button, Battery System energy saving button

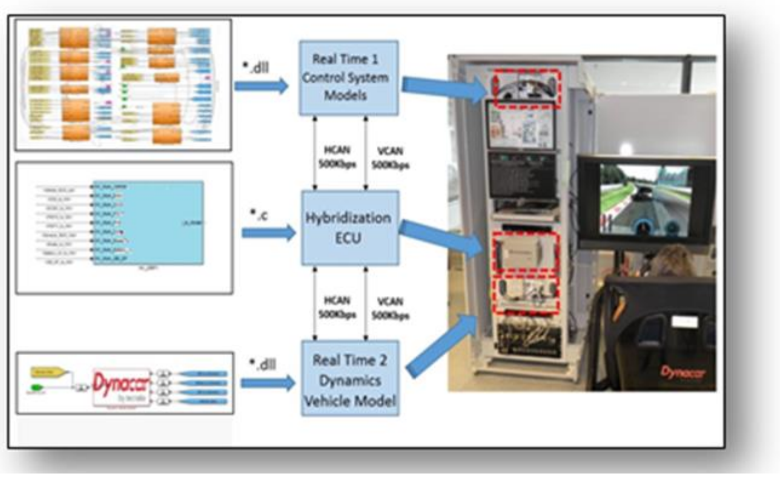
* tested after end of project

The EV Battery Life target has been defined according to the future product (but not verified in the project due to the already mentioned JMBS problems). Moreover, the following results have been achieved through integrated component bench activities combined, where necessary, with 3D CAD virtual installation and calculations:

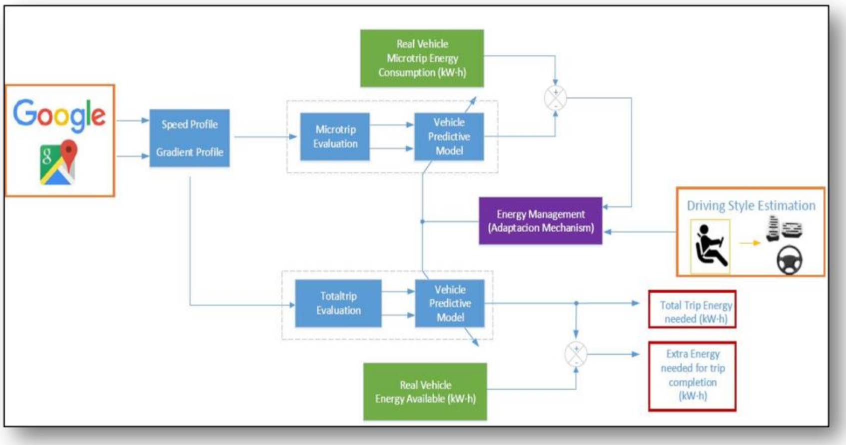
- **Enhanced Thermal Management** through an innovative multi temperature coolant circuit concept to better cope the high efficiency targets with the passenger comfort in the different vehicle modes (engine on and off, pure EV etc) thanks to a 4-way valve and its proper control.



- **Smart Energy Management** (e-horizon based): adaptive-predictive control strategy designed and implemented to pre-calculate the total trip energy needed and the remaing energy needed for the trip.



(Hardware in the Loop Platform)

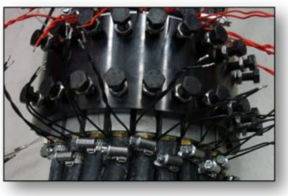


Adaptive predictive backward Quasi-Steady State (QSS) Vehicle model to predict on board the energy consumption of a real trip by using trip information and driving styles.

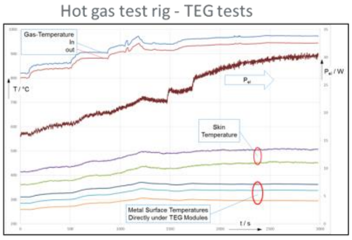
- **Thermo Electric Generator** (TEG) novel solution applied to the engine exhaust pipeline to recover part of the gas' heat and convert it into electric energy (power: 450 W, weight: 4.5 kg and volume: 7.9 litres)

TEG Prototype modules (Bismuth-Telluride)

Hot gas test rig - TEG tests



Proto sample TEG for bench validation (hot gas rig)



Tests at high TEG input Temperature

5.1.4 Further potential

The main improvements to be considered/investigated towards the production level can be summarised as:

- Powertrain Architecture: evaluate for the front e-machine a position between engine and transmission (or inside the transmission) also to avoid limitations in the power transferred to the rear axle

- Traction e-Drives: one unit (integrated e-motor & inverter; for the rear powertrain also the transmission)
- Battery System: different position to increase luggage compartment area and increase safety during crash
- Thermal Management System: simplified 4-way valves layout and battery direct refrigerant cooling
- Engine: replace the standard aftertreatment to include a GPF (Gasoline Particulate Filter)
- Vehicle Control Unit: integration of e-horizon based algorithms
- Charging port: better positioning.

5.2 Class C passenger car

5.2.1 Motivation for the solution

The motivation for developing a 48 V hybrid vehicle is to see if this technology can lead to a cost breakthrough compared to regular (higher voltage) hybrids. Many hybridization solutions are known at high voltage (~200V), which need specific components that are protected against electric hazards, making them relatively expensive.

The benefit of a hybrid vehicle is (mainly) that it can recover energy during vehicle deceleration (i.e. mostly braking). An electric motor working at a lower voltage inherently delivers less peak power and can, consequently, also recover less energy. However, given an efficient energy management, a rather limited electric power does offer the opportunity of significantly reducing the CO_2 emission at lower costs than conventional hybrids. Figure 5-5 shows the percentage of the energy that can be recovered during vehicle deceleration for different drive cycles versus the electric (e-) motor power. The general trend is that more energy can be recovered at higher e-motor powers, but the potential energy that can be recuperated depends on the power rating of the e-motor and the type of drive cycle. At an e-motor power of 15 kW between 80 % (highway) and 95 % (urban) of the total deceleration power can be stored in the battery. A power of 15 kW can likely be achieved with a 48 V system, making it possible to take advantage of low cost 48 V components.

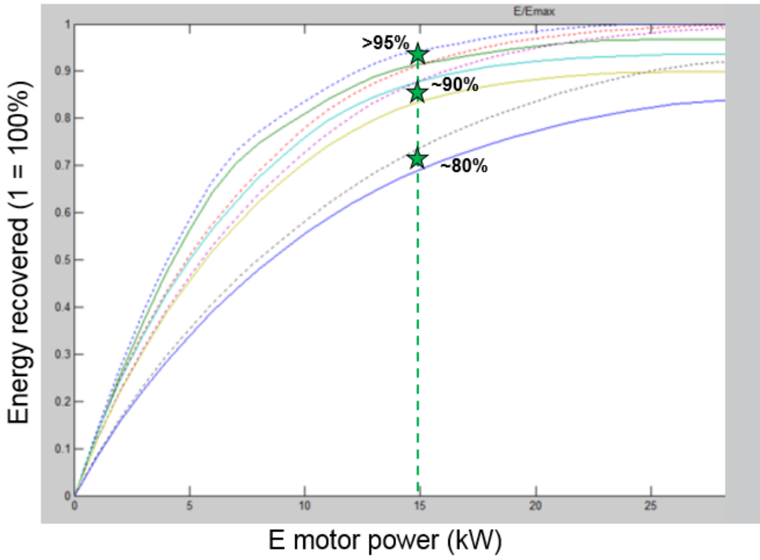


Figure 5-5 Projected energy recovery during deceleration.

The main technical and end user requirements for the 48 V demonstrator are given in Table 5-5 and Table 5-6.

Table 5-5. Main technical targets for the 48 V car demonstrator.

Key Targets	Target value	Reference
Powertrain efficiency	+20%	Base Megane over New European Driving Cycle (NEDC)
Powertrain weight reduction	Max + 5% mass and volume	Base Megane
Powertrain volume reduction	Less than 100 ltr volume loss	Base Megane
Emissions level	Equal or better	Base Megane

Table 5-6. Main targets for the end user requirements for the 48 V car demonstrator.

End User Requirements	Vehicle Specific Target
Vehicle performance	Equal or better than base vehicle
NVH	Equal or better than base vehicle
Safety Standards	Equal or better than base vehicle
Human Machine Interface	Equal or better than base vehicle

5.2.2 Key innovations

The 48 V hybrid passenger car demonstrator is based on a Renault Megane. Figure 5-6 gives an overview of the innovations that have been developed. The innovative architecture is that the powertrain is fitted with an e-motor that is directly coupled to a 7-gear double clutch transmission (DCT). By directly coupling the e-motor to the transmission, energy can be saved, e.g. by regenerative braking, acceleration assistance and limited EV operations. At the same time, this solution fits within the vehicle packaging and is a lower cost solution, which makes a rapid market uptake likely. The powertrain has been developed with a state-of-the-art electrical machine, rated at up to 15 kW when running at 48 V. However, an advanced 25 kW electrical machine and its power electronics are also being developed, targeted to fit the same practical package.

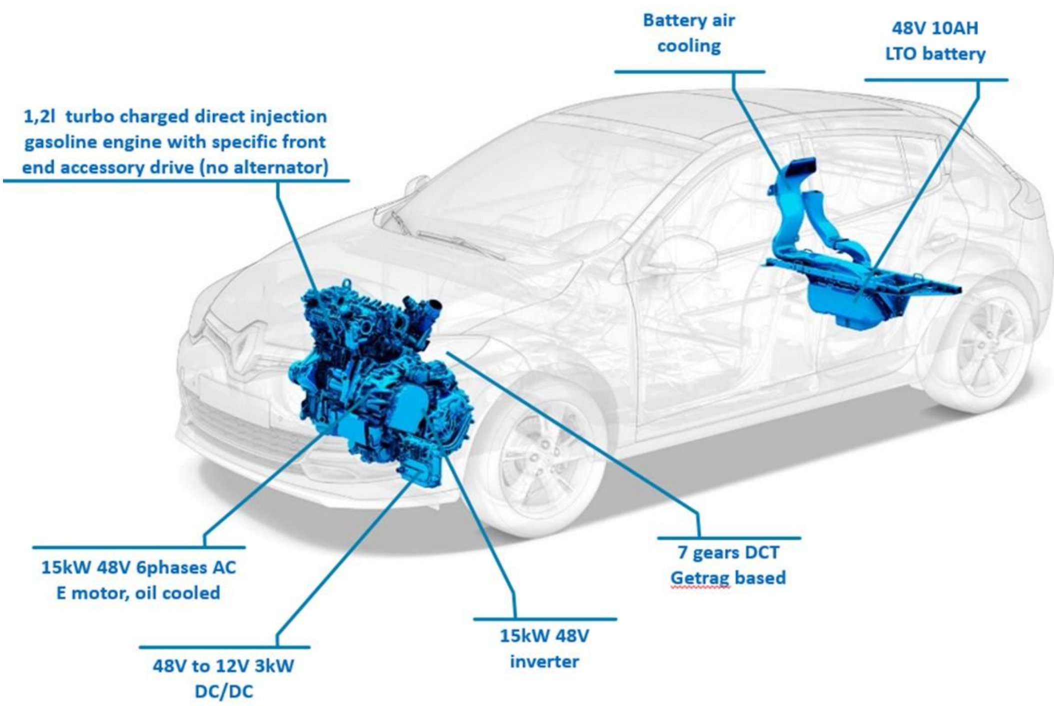


Figure 5-6 Ghost view of the car showing the installation of the hybrid components

The key innovations to achieve the desired cost breakthrough are:

- Using 48 V components
  - Galvanic isolation is not necessary, and a specific crash protection is not needed thanks to the low voltage level.
  - 48 V components are soon to be expected in mass production (components for 48 V belt starter generator, battery, DC-DC converter, plugs, connectors and related controls).
- A hybrid architecture that exploits the advantages of the double clutch transmission
  - No additional component except one extra gear.

- A high speed motor for a small size.
- Internal oil cooling for a high performance.

- Careful sizing of electrical components to keep them as small as possible.

Figure 5-7 shows the electric topology of the demonstrator vehicle. As can be seen, the 48 V battery is integrated in the rear of the vehicle, whilst the DC-DC converter and the vehicle 14 V battery are integrated within the engine room. The inverter for the e-motor, which is integrated within the transmission, is connected directly to a side e-motor.

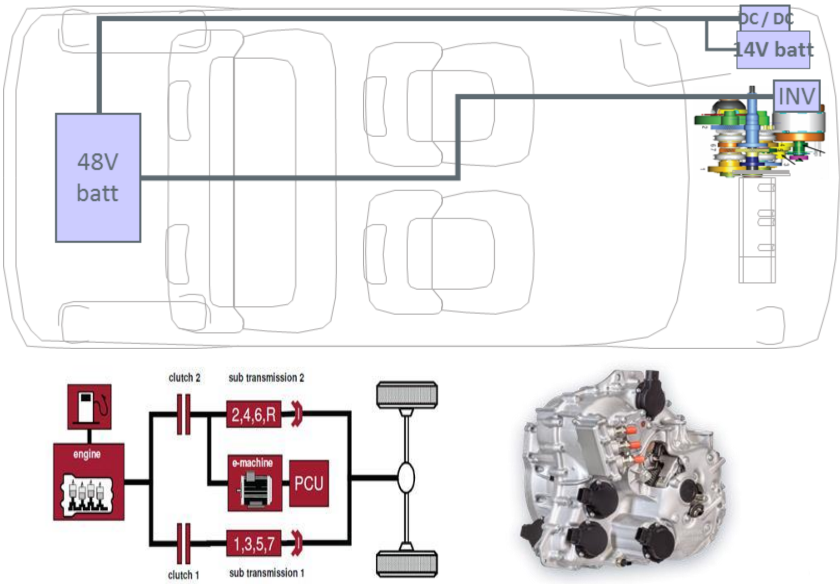


Figure 5-7 Diagram showing the architecture of demonstrator vehicle and the layout of components, with an image of the E-DCT (Source Getrag)

5.2.3 Key results

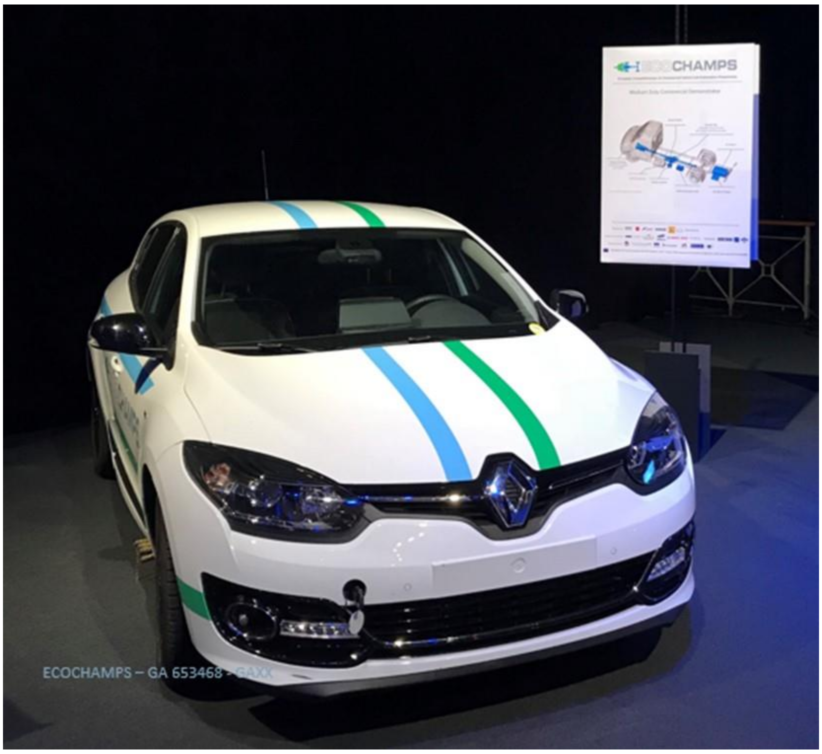
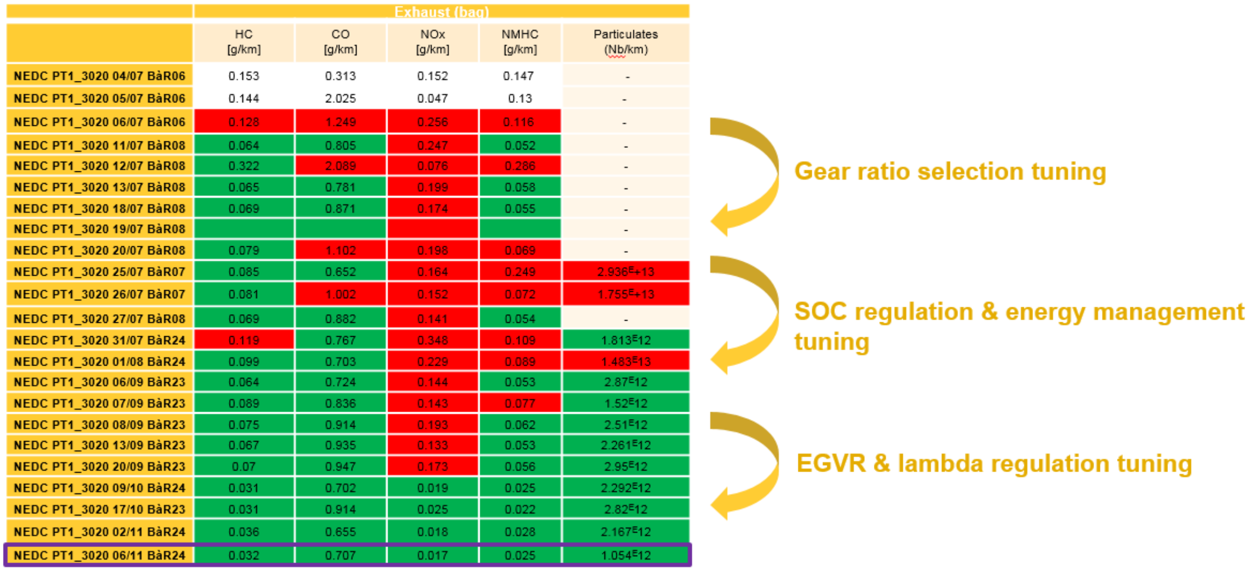


Figure 5-8 Final demonstrator vehicle

The demonstrator car has been built and tested within Renault's facilities: the results are encouraging. Figure 5-9 shows the tuning loops that were necessary to comply with the Euro6b regulation. At the end of these optimization loops, the emissions were below the requested levels. Based on that tuning, the CO_2 measurements were performed. Table 5-7 shows the results. The expected emission, estimated by simulation, was 106.7 gCO_2/km (shown in dark red on the left). The raw result measured on the test bed was 111.1 gCO_2/km (shown in the orange box in the middle). This raw result was corrected with the traction battery state of charge (SOC) variation, the 12 V network consumption deviation and the platform drag deviation. After applying these corrections, the final result was 104.7 gCO_2/km (shown in the light red frame on the right). These CO_2 emissions are slightly better than expected (104.7 gCO_2/km vs. 106.7 gCO_2/km simulated). This result confirms the potential of the 48 V hybridization, at a far lower cost, even if the car performs slightly less than the high voltage solutions.



	Exhaust (bag)				
	HC [g/km]	CO [g/km]	NOx [g/km]	NMHC [g/km]	Particulates (Nb/km)
NEDC PT1_3020 04/07 BàR06	0.153	0.313	0.152	0.147	-
NEDC PT1_3020 05/07 BàR06	0.144	2.025	0.047	0.13	-
NEDC PT1_3020 06/07 BàR06	0.128	1.249	0.256	0.116	-
NEDC PT1_3020 11/07 BàR08	0.064	0.805	0.247	0.052	-
NEDC PT1_3020 12/07 BàR08	0.322	2.089	0.076	0.286	-
NEDC PT1_3020 13/07 BàR08	0.065	0.781	0.199	0.058	-
NEDC PT1_3020 18/07 BàR08	0.069	0.871	0.174	0.055	-
NEDC PT1_3020 19/07 BàR08					-
NEDC PT1_3020 20/07 BàR08	0.079	1.102	0.198	0.069	-
NEDC PT1_3020 25/07 BàR07	0.085	0.652	0.164	0.249	2.936E+13
NEDC PT1_3020 26/07 BàR07	0.081	1.002	0.152	0.072	1.755E+13
NEDC PT1_3020 27/07 BàR08	0.069	0.882	0.141	0.054	-
NEDC PT1_3020 31/07 BàR24	0.119	0.767	0.348	0.109	1.813E12
NEDC PT1_3020 01/08 BàR24	0.099	0.703	0.229	0.089	1.483E13
NEDC PT1_3020 06/09 BàR23	0.064	0.724	0.144	0.053	2.87E12
NEDC PT1_3020 07/09 BàR23	0.089	0.836	0.143	0.077	1.52E12
NEDC PT1_3020 08/09 BàR23	0.075	0.914	0.193	0.062	2.51E12
NEDC PT1_3020 13/09 BàR23	0.067	0.935	0.133	0.053	2.261E12
NEDC PT1_3020 20/09 BàR23	0.07	0.947	0.173	0.056	2.95E12
NEDC PT1_3020 09/10 BàR24	0.031	0.702	0.019	0.025	2.292E12
NEDC PT1_3020 17/10 BàR23	0.031	0.914	0.025	0.022	2.82E12
NEDC PT1_3020 02/11 BàR24	0.036	0.655	0.018	0.028	2.167E12
NEDC PT1_3020 06/11 BàR24	0.032	0.707	0.017	0.025	1.054E12

Figure 5-9 NEDC aftertreatment result after tuning

Table 5-7 CO_2 results at NEDC (framed in red: expected and obtained result)

Measured Parameter		Certified Base Megane	Simulation: Base Megane	Simulation: 48V Hybrid	Measured: 48V Hybrid	Corrected for SOC and 12V supply	Corrected for platform impact
		NEDC	NEDC	NEDC	NEDC	NEDC	NEDC
Energy required to complete cycle	kWh		1.105	1.27	1.14	1.14	1.14
Energy consumed during cycle (fuel)	kWh		5.89	4.79	4.58	4.69	4.32
Energy consumed during cycle (battery)	kWh		0	0	0.41		
Calculated powertrain efficiency			18.8%	26.5%	**24.8%**	24.3%	26.4%
Total fuel consumed	g		472.4	371.4	386	395.4	363.8
Fuel consumption	L/100Km		5.8	4.5	4.96	-	-
Battery SOC at start of test	%		-	80	95	-	-
Battery SOC at end of test	%		-	80	88	-	-
Battery pack usable energy	kWh		-	-	0.25	-	-
Total battery energy consumed	kWh		0	0	0.0175	-	-
Electricity consumption	Wh/km		-	0	1.59	-	-
CO2 emissions	g/Km	136	136	106.7	111.1	113.8	104.7
CO2 delta to baseline		0		-29.3	-24.9	-22.2	-31.3
CO2 percentage improvement		0.0%		-21.5%	-18.3%	-16.3%	-23.0%
Powertrain Efficency Percentage improvement		0.0%		41.3%	32.2%	29.5%	40.8%

Concluding, Renault and Daimler have succeeded in creating a viable 48V hybrid demonstrator vehicle that can compete convincingly with the performance of high voltage hybrid competitors in a similar vehicle class, but at a much lower cost. This being said, the powertrain is larger and heavier than expected. Nonetheless, mass and volume savings in serial production are encouraging and will be much closer to targets, but ultimately the targets set by ECOCHAMPS were unrealistic for these metrics. Still, passenger space is not significantly affected, so there is no direct impact on the final customer. Another deviation is that the NVH of the demonstrator car was little behind the targeted level for a serial car, but this was related to the maturity of the demonstrator and not intrinsic to the concept.

Globally speaking the 48 V concept was considered as valid:

- Compliant with the emission limit
- Giving significant CO_2 savings, less than but close to the levels of a high voltage hybrid
- Providing significant cost potential compared to high voltage hybridization

The technology as demonstrated though the car during the final evaluation event can be considered as TRL7.

Table 5-8. Main technical results for the 48 V demonstrator.

Ambition	Reference	Target Value	Result
Powertrain Efficiency	Renault Megane gasoline	+20%	+40%
Powertrain Mass	Renault Megane gasoline	+5%	+35%
Powertrain Volume	Renault Megane gasoline	+5%	+15%
Noxious Emissions	none	< EURO 6b	< EURO 6b
Hybrid Cost Premium	Renault Megane gasoline	<10%	Yes

5.2.3.1 Further potential

Whilst in the demonstrator car a 48 V 15kW e-motor was implemented, a 25 kW e-motor was developed and built in ECOCHAMPS. As mentioned, an electric motor working at a lower voltage inherently delivers less peak power, can consequently recover less energy, and offers fewer possibilities of improving the fuel efficiency. Therefore, it is worth the effort to study the possibility of a high-power 48 V e-motor. Figure 5-10 (a) shows the benefit in recovered energy.

The targeted power for the high-power e-motor was set at 25 kW. Given the space to integrate the e-motor, the challenge was to fit 25 kW e-motor the same packaging as the 15 kW e-motor. Figure 5-10 (b) shows the maximum dimensions. The prototyping led to the samples shown in Figure 5-10 (c), (d) and (e). The operating envelope was simulated and tested: the bench tests indicated a performance limit of about 22 kW. On that basis, the partners are confident that it is feasible to reach 25 kW, assuming the inverter can be upsized.

The confidence in reaching 25 kW, combined with the 15 kW CO_2 results obtained by test shows that the 48 V system performance can extend the scope of low-voltage hybrids, and is competitive with the high voltage hybridization.

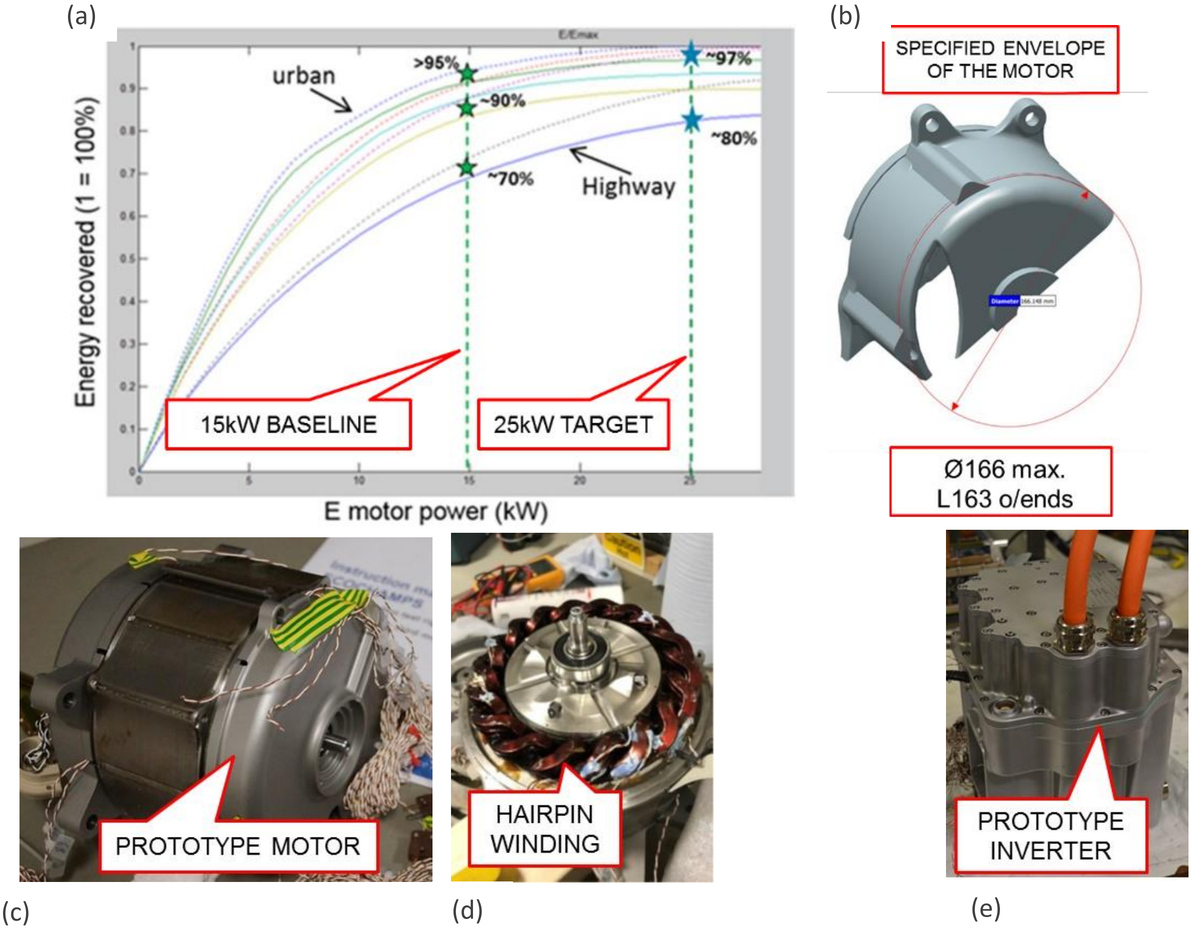


Figure 5-10 (a) Benefit to increase the E-motor power (b). Allocated volume for the E-motor. (c, d) High power E-motor. (e) High power inverter.

5.3 Medium duty truck

5.3.1 Motivation for the solution

IVECO customers confirm that commercial vehicles have different missions every day; itineraries may be urban or extra-urban, with straight or more winding roads, and loads may be different. Based on these requirements, the IVECO demonstrator configuration enabled immediate traction switching, depending on the type of itinerary and conditions, in this way making an important innovation towards environmentally friendly mobility.

The objectives for developing the medium duty truck were the following:

- Design a new plug-in hybrid architecture with a modular approach for components and applications
- Optimize the vehicle layout to limit the vehicle weight increase with respect a diesel version as much as possible (hybrid vehicles are typically heavier than non-hybrids), and to maintain the load capacity
- Introduce new control and sub-systems to ensure the flexibility of the system on the one hand, and to improve the powertrain efficiency with respect the diesel version on the other hand, using the best electrical and thermal management.
- Build a prototype that integrates modular components coming from MSF.
- Assess and test the demonstrator vehicle

Table 5-9. Main technical targets for the medium duty demonstrator.

Key Targets	Specific target Value	Reference
Powertrain efficiency	+20%	vs.Daily Diesel
Powertrain weight reduction	-20%	vs.Daily Electric
Powertrain volume reduction	-20%	vs.Daily Electric
Emissions level	below Euro 6 / VI	below Euro 6 / VI

Table 5-10. Main targets for the end user requirements for the medium duty demonstrator.

End User Requirement and KPIs	Specific Target
Vehicle performances	General Performance equal or better than Base Vehicle
Pure Electric Range	20<x<40 Km
Charging	Easy, Flexible and Fast
NVH	Equal or better than industry practice
Human Machine Interface	Subjective judgement of Golden Engineers

5.3.2 Key innovations

The IVECO demonstrator is a Daily 7t and has a plug–in diesel-electric parallel hybrid architecture. It is designed to reduce fuel consumption and CO_2 emissions compared to the diesel version, to increase the range and to avoid “the range anxiety” that is typical of pure electric vehicles. The ghost view in Figure 5-11 gives an overview of the innovations that have been developed.

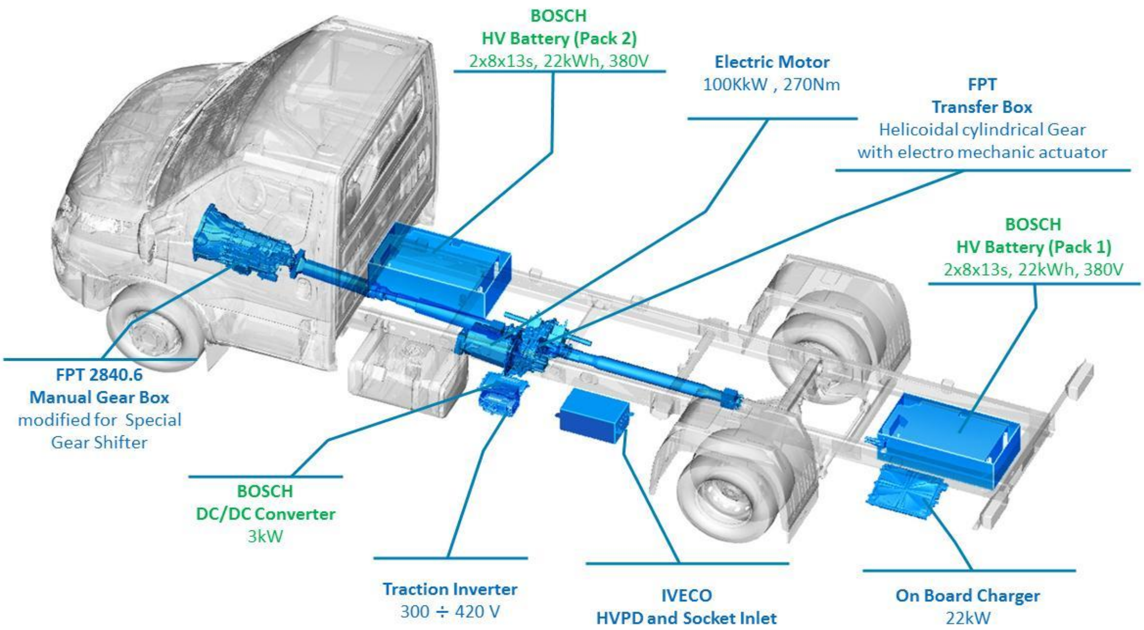


Figure 5-11. Ghost view of the medium duty truck demonstrator, including the components that have been developed

The key innovations implemented on the demonstrator are:

- **Flexible driving -** The demonstrator has extremely flexible technology, capable of switching to the most appropriate source of energy and operative modes depending on the vehicle's mission and system conditions, using a customized hand lever and a specifically designed transfer box. See Figure 5-12(a).
- **Modular** - Some modular components, like the BOSCH HV battery, RESS and the smart DC/DC converter developed according MSF guidelines with the HV high efficiency E-Drive, and a 3-phase Alternating current (AC) charger, have been integrated in the demonstrator. See Figure 5-12(b).
- **Flexible charging** - The system satisfies all customers' requirements, retaining the flexibility of private Mode 1 with CEE type connectors, Mode 3 public charging capability with type 2 AC connectors, and domestic-charging. See Figure 5-12(c).
- **Dedicated human-machine interface (HMI)** - A specific HMI has been developed to have the most "natural & intuitive" approach (see Figure 5-12(d):
    - It is a modular solution, applicable to all ranges and all missions/markets
    - It uses smart & consumer-based technology (Android tablet)
    - The interface is easy and can be configured
    - It has remote connectivity

The vehicle architecture is shown schematically in Figure 5-12(e), where the components developed according the MSF guidelines are highlighted in green.

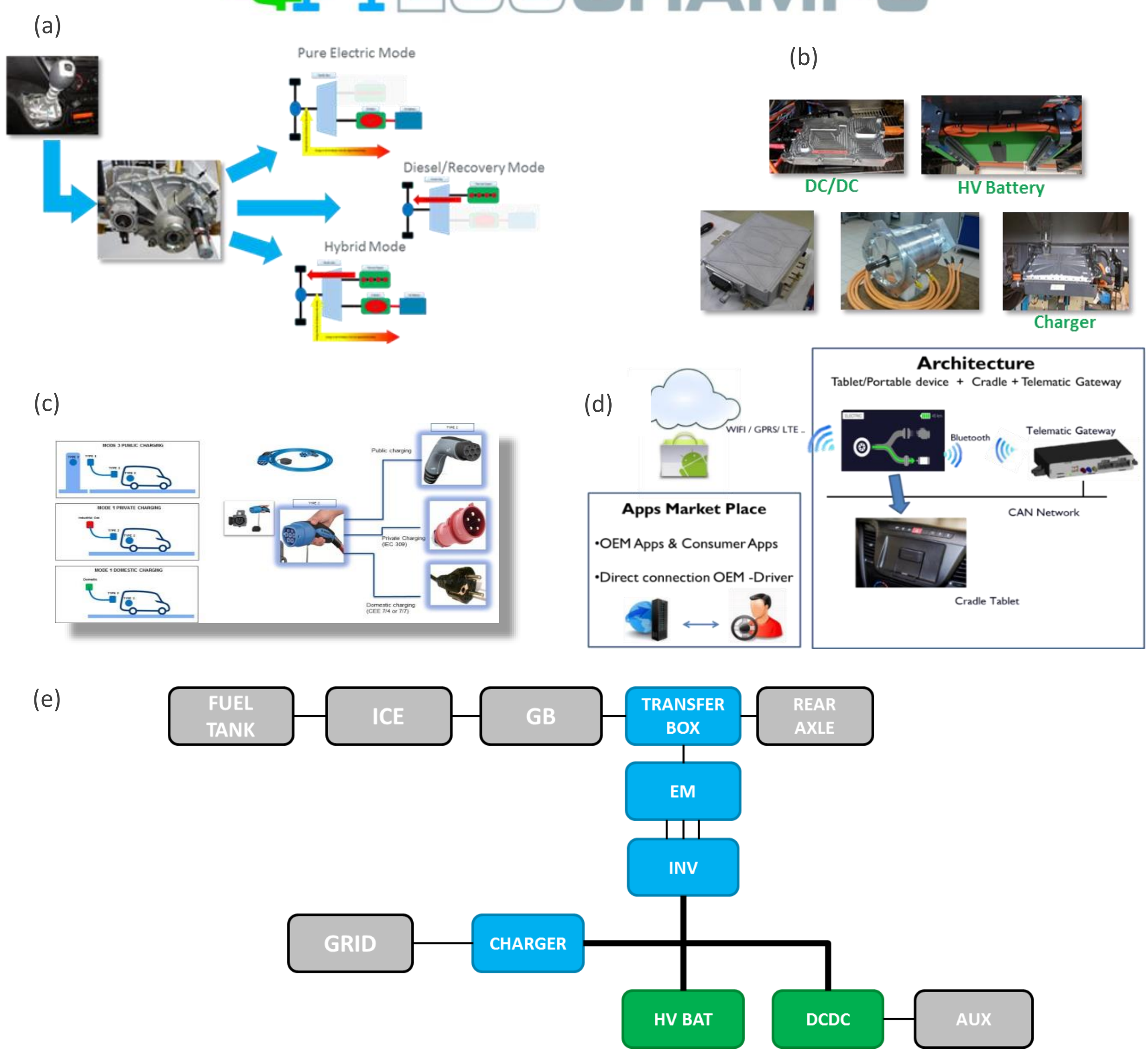
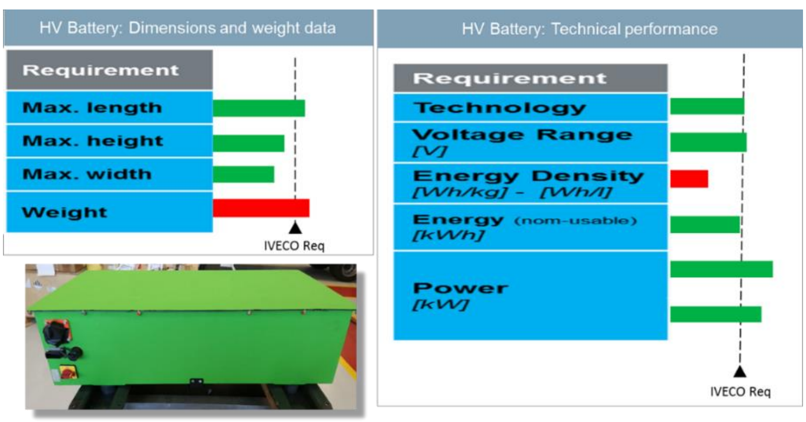


Figure 5-12 (a) Flexible driving. (b) Modular components. (c) Flexible charging. (d) Dedicated human-machine interface. (e) Schematic overview of the vehicle architecture, with the MSF components highlighted in green.

HV Battery

The HV battery system has been designed in order to allow for modular components for multiple batteries. A prototype battery management system (BMS) coordinates the whole system through specific software and is the interface with the IVECO vehicle supervisor. The only negative point is the energy density results in a smaller payload capability. With the 21 kW.h battery all final targets were reached, and almost all the IVECO requirements. The HV battery technical data are given in Table 5-11 with the IVECO requirements as reference.

Table 5-11. The HV battery technical data with the Iveco requirements as references.



DC-DC Converter

The DC-DC converter was also developed to be modular. Figure 5-13(a) shows the concept, which has:

- Scalable/flexible output power, output voltage and input voltage
- Redundancy in power transfer
- Optimized ripple and low load

As Figure 5-13(b) shows, all technical performances meet the IVECO requirements.

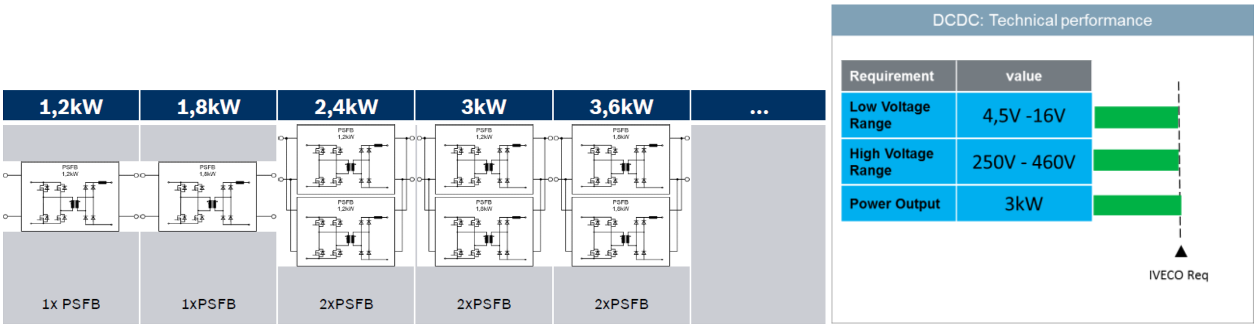


Figure 5-13. (a) The modular concept of the DC-DC converter. (b) Technical performance of the DC-DC converter, including a comparison to the IVECO requirements

Transfer Box

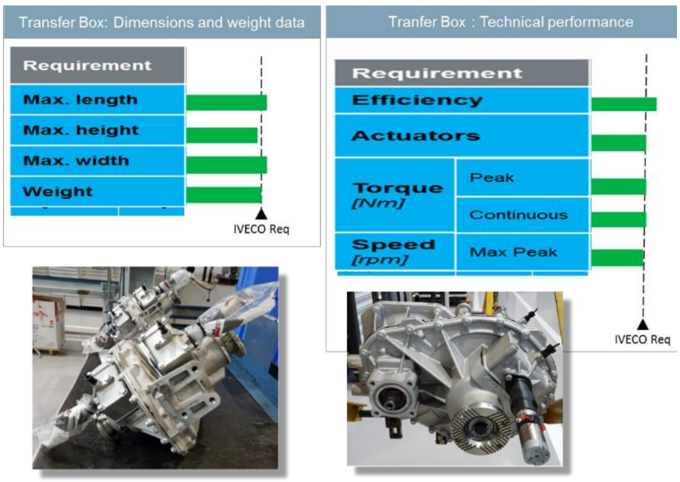
The multimodal transfer box is the core of the system. In the parallel hybrid layout a mechanical power transfer unit is needed to connect the internal combustion engine (ICE) with its gear, the EMG and the final driveline. The driver or by the vehicle control system can decide on the configuration. The selected hybrid architecture makes the system very flexible, the big advantage being that the components in the existing driveline do not have to be changed. At the same time, the ability to disconnect all the mechanical parts makes the solution very efficient.

The transfer box has five basic configurations:

- Traction provided only by ICE
- Traction provided only by EM
- Traction provided by the combination of ICE and electric motor (EM) (hybrid mode)
- Energy recuperation
- Electric power take-off (PTO) (as optional, not implemented in ECOCHAMPS demonstrator)

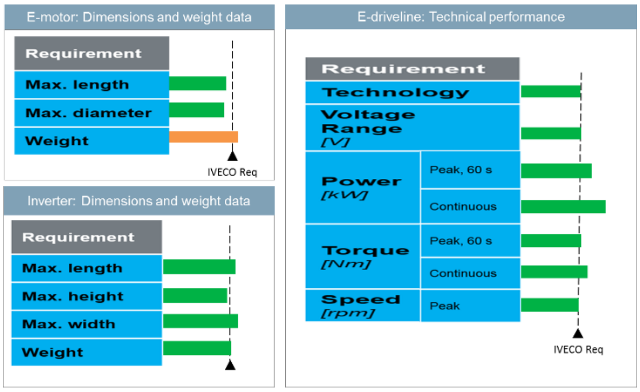
The concept has been designed for maximum simplicity for cost and weight optimization: one stage of reduction, a dog clutch connection and wet sump lubrication. As Table 5-12 shows, the system meets all the IVECO mechanical requirements.

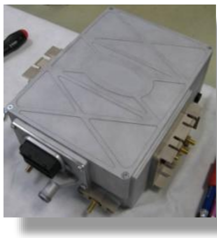
Table 5-12. Transfer box requirements



Driveline

The driveline of the IVECO demonstrator has been designed for optimal performance and to allow the regeneration in most of the vehicle missions. The power density of the system reached a very good level.



5.3.3 Key results

Figure 5-14. The final demonstrator.

The assessment of the IVECO demonstrator has been performed taking into account the targets. The final assessment has been carried out between November 2017 and March 2018 at the CNH-IVECO facilities in Turin (Italy) under the supervision of the Golden Engineer. Table 5-13 and Table 5-14 summarize the main results.

Table 5-13. Main technical results for the medium duty truck demonstrator.

Ambition	Reference	Target Value	Result
Powertrain Efficiency	Daily Diesel	+20%	+30%
Powertrain Mass	Daily Electric	-20%	-27%
Powertrain Volume	Daily Electric	-20%	-36%
Noxious Emissions	None	< EURO VI	< EURO VI
Hybrid Cost Premium	Daily Diesel	<40%	Yes

Table 5-14. Main results from the end user requirements for the medium duty truck demonstrator.

End User Requirements and KPIs	Specific vehicle targets	Results
Vehicle performances	General Performance equal or better than Base Vehicle	Achieved
Pure Electric Range	20<x<40 Km	- City driving (real-world urban) = 32 km - Constant speed at 50 km/h = 29.5 km - Constant speed at 70 km/h = 23 km
NVH	Equal or better than industry practice	Achieved
Charging	Easy, Flexible and Fast	Achieved
Human Machine Interface	Subjective judgement of Golden Engineers	Achieved

The vehicle was assessed against two reference vehicles: (1) a Daily 7.5 ton diesel and (2) a Daily electric 5 ton. Two reference vehicles were needed properly compare the demonstrator against the 2013 SoA across all evaluation categories, which included fuel consumption, plus the weight & volume of the powertrain. A single vehicle was not applicable to benchmark all the assessment criteria, therefore two references were necessary.

The hybrid demonstrator is significantly more fuel efficient than the reference, allowing for an energy consumption reduction measured on the IVECO proprietary test cycle ranging of between 21.7% to 25.5%, equivalent to a powertrain energy efficiency improvement ranging from 27.8% to 34.4% with the vehicle half-loaded (vehicle weight 5.2 tons). The demonstrator emits 7.3% less carbon dioxide per km driven and per kg of payload compared to the reference. The electric part of the hybrid powertrain of the demonstrator is ≈36% smaller in volume and ≈27% lighter than the reference vehicle, doubling the volumetric and gravimetric peak power and torque, and tripling the volumetric and gravimetric continuous power and torque.

The vehicle is fully compliant with EURO VI emissions regulations, verified by Portable emissions measurement system (PEMS) tests and it meets or exceeds all performance parameters, allowing a full recharge in approximately 70 minutes (industrial plug three-phases at 380 V accepting 11 kW constant), satisfactory acceleration and operational performance (both in hybrid and in full electric), and a fully electric range of approximately 30 km in urban driving. Comfort, ride and handling and NVH performance are fully satisfactory being equal or better compared to the reference. The vehicle meets the required safety standards, reliability and durability requirements, it is easy to operate and to recharge and is equipped with a clear and intuitive HMI for feeding the driver with the relevant information on the functioning of the hybrid powertrain.

Due to confidentiality reasons and competition rules, the cost of the demonstrator vehicles cannot be made public.

In conclusion, the result of the assessment is excellent, and the ECOCHAMPS IVECO Daily Hybrid 7.5 tons meets all the targets set for the project, constituting a significant advancement beyond the 2013 state-of-the-art and paving the way for the next generation hybrid medium duty vehicles. The overall TRL of the demonstrator is evaluated at level 7 (system prototype demonstration in operational environment).

5.4 City bus

5.4.1 Motivation for the solution

Whilst the market for electric vehicles is developing quickly, important barriers for introducing electric vehicles more quickly are availability of components as well as infrastructure, costs due to small numbers, and the lifetime of the main components for heavy duty vehicles (components for the traction drive and for electrified auxiliaries). In particular, the market for public transport city busses is driven by costs and (regional) politics. Bus OEMs are asked for many different drive traction systems (e.g. diesel, CNG, diesel hybrid, BEV or fuel cell), resulting in high development effort for a relatively small number of specialized busses.

5.4.2 Key innovations

Coming from this background described above, the following solution should be evaluated to reduce costs:

- Using standardized components, in particular the possibility to define common requirements that components should meet;

From that the key innovation is the development of common requirements of components and partial systems aligned to the requirements of OEMs and deliverer. Mainly auxiliaries' systems can be shared between OEMs of heavy duty applications like:

- Steering pump system
- Air compressor systems,
- Low voltage board net supply from high voltage by DC-DC-converters
- Heating and ventilating air conditioning system (HVAC)

The second solution is

- Using components or derivatives from "high volume production", such as passenger car components;

This leads to key innovation of a battery system for heavy duty application using battery modules from small car batteries., which are combined to a quite bigger system. Also the high speed traction drive concept of small cars will lead to an additional key innovation for heavy duty application, i.e. a gearbox adapts the high speed and low torque to the requirements having low speed for the vehicle by high torque for the traction. Both components, electric machine and power electronics (inverter), from small car production in high volume will be used for cost reduction.

The third solution is especially for the city bus market. The innovation is the creation of a modular concept of all partial systems of the bus like chassis, traction drive and auxiliaries to meet all several customers wishes and will be reached by:

- A definition of a basic E-Bus in a model kit, which can be readily changed from diesel hybrid to fuel cell or a full battery vehicle.

Example of solution implementation will be shown in the following chapter of results.

5.4.3 Key results

The demonstrator bus vehicle itself is based on a modular concept using a "Basic E-Bus-Vehicle" so, that it can be adapted to the kind of energy carrier, that is cost effective for the city or region. On the roof there is enough space for the energy storage (e.g. vessels for hydrogen or compressed biogas, or additional batteries). The bus can be driven by several "Gensets", see the following figure, such as an internal combustion engine with a generator, a fuel cell for hydrogen, or an enhanced battery system for a purely electric bus.

Thanks to the modular concept, these buses can be adapted to the wishes of the customers against acceptable costs, making it a versatile solution.

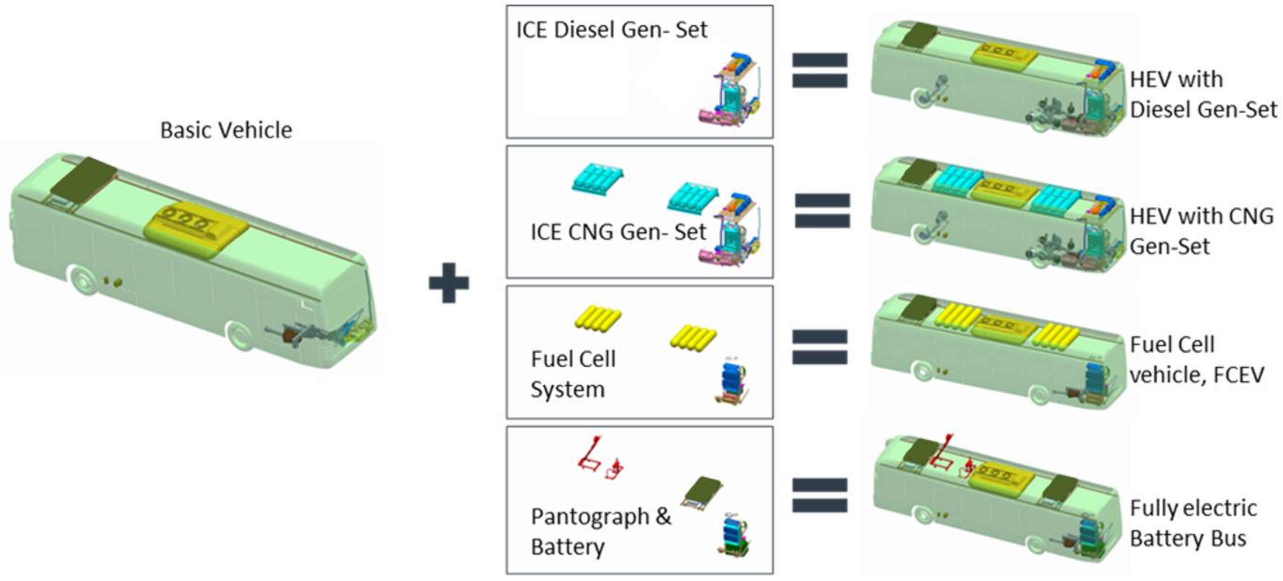


Figure 5-15. Combination of the basic e-bus with several generator systems or batteries

Two main partial systems from the high volume production of components for passenger cars will be adapt for heavy duty application:

- Battery system
- High speed traction drive

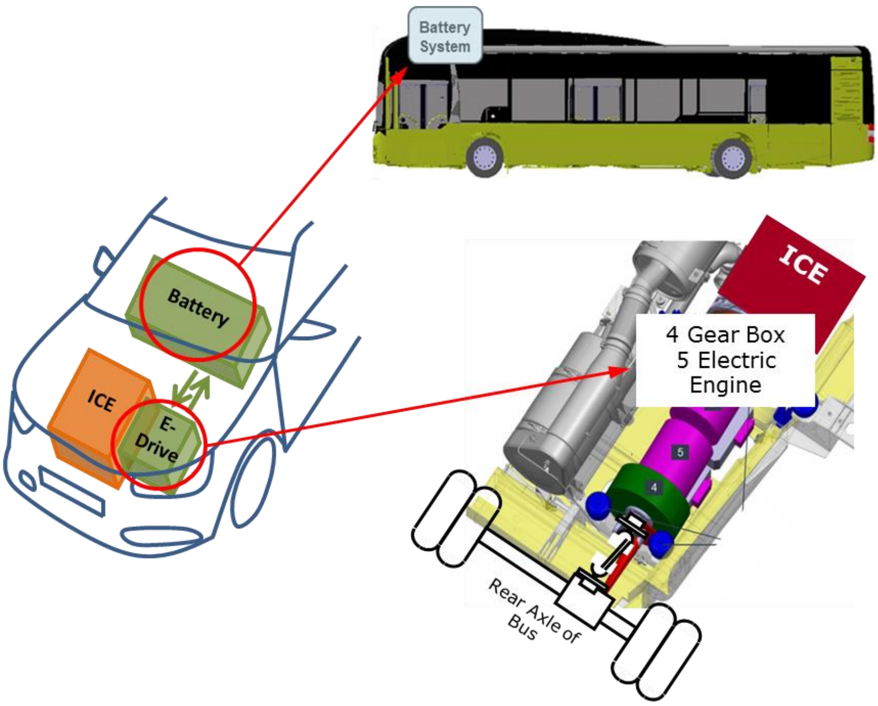
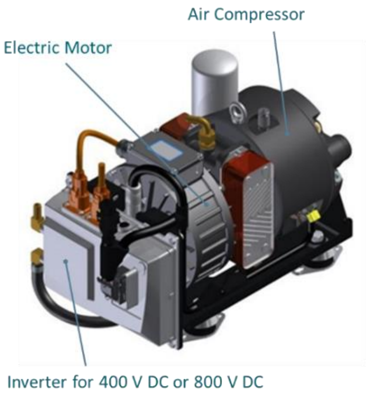


Figure 5-16. Using components or derivatives from “high volume production”

The demonstrator bus vehicle will use two auxiliaries systems, which are shared with the truck demonstrator coming from the standardization of components:

- air compressor systems,
- steering pump system

The partner Gardner Denver has delivered the air compressor system for air supply of the vehicle brake system, which is typical for heavy duty applications.



Property	Unit	Value
Type		rotary vane compressor
Voltage	V DC	240-800
Volume	mm³	310*345*505
Weight	kg	37
Pressure	bar	7-13
Power consumption	kW	4,6
Air Delivery	l/min	450 @ 3000rpm

Figure 5-17. Air compressor system by Gardner Denver and main technical data of the air compressor

The steering pump system could be also shared with the truck application:

Property	Unit	Value
Type		EHPS
Weight	kg	15,5
Volume	mm³	250*190*232
Max. current	A	250 for 10s
Voltage	V DC	24 (16-32)
Max. hydraulic power	kW	3,2
Max. pressure	bar	200
Max. volume flow	l/min	19

Figure 5-18. Steering Pump system by Magna and main technical data of the steering pump system

The additional auxiliaries system, low voltage board net supply from high voltage by DC-DC-converters and heating and ventilating air conditioning system (HVAC) have the potential to share them with truck application and other OEMs too. Therefor the DC-converters need a wide DC-Input of the high voltage side from 400 V DC up to 800 V DC. The HVAC system with heat pump functionality can be also shared among several Bus OEMs according to their common standard requirements.

All three main solutions will be shown by the demonstrator bus vehicle. The following figure, the ghost view, gives an overview of the innovations that have been developed. The bus uses standard components according to the MSF of the ECOCHAMPS project. The battery is an example of a derivative from a "high volume production" component from passenger cars. "High volume production" components for the traction drive are currently under development. Therefore, with respect to the time frame of the project, a high efficiency traction drive for heavy duty application has been used.

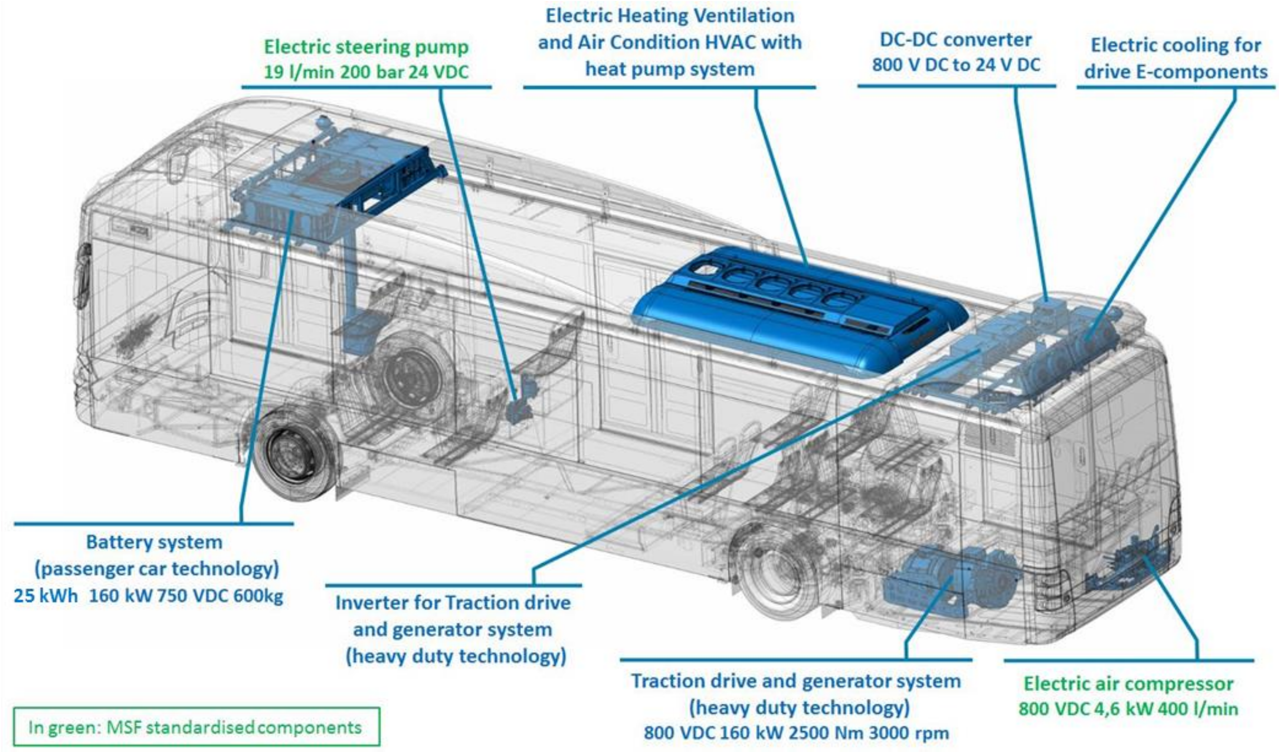


Figure 5-19. . Ghost view of demonstrator vehicle

The demonstrator is assessed against one-reference vehicle: the MAN Lion's City Hybrid SHS A37 MY2013. The following table summarize the main technical results from the assessment.

Table 5-15. Main technical results for the city bus demonstrator.

Ambition	Reference	Target Value	Result
Powertrain Efficiency	MAN Lion's City Hybrid, 2013	+10%	+18%
Powertrain Mass	MAN Lion's City Hybrid, 2013	-10%	+8%*
Powertrain Volume	MAN Lion's City Hybrid, 2013	-10%	+10%*
Noxious Emissions	None	< EURO VI	< EURO VI

*with Heavy Duty (HD) components

The ECOCHAMPS MAN Lion's City Hybrid 18 tons provides significant benefits in terms of fuel efficiency compared to the reference, allowing for a fuel consumption reduction measured on three MAN proprietary test cycles (heavy urban, urban and suburban) ranging from 11% to 20% (hybrid driving mode, i.e. excluding the plug-in mode which brings further advantage. Measurement data show that the tank-to-wheel powertrain efficiency improvement of the demonstrator compared to the reference ranges from 18 to 28% with the vehicle half-loaded (weight 14.6 tons). This is calculated with the bus capable of the same passenger capacity, i.e. 78 passengers, and averaged across different repetitions of the test cycles.

Based on the test results, the demonstrator exceeds the absolute targets set by ECOCHAMPS at the 10% and the assessment is fully satisfactorily. The test results highlighted that the shift from a low-speed to a high-speed machine, which is not done yet in hardware, but with simulation, will have the same high efficiency perspective, as it was demonstrated in the ECOCHAMPS MAN City Hybrid Bus with current heavy duty components. But in addition, it brings advantages in terms of cost decrease.

Overall CO_2 emission reduction has been also estimated, highlighting that the demonstrator is capable of emitting on average from 11-to-20% less carbon dioxide per km driven compared to the reference. The electric part of the hybrid powertrain of the demonstrator has a volume and weight comparable to the reference, bringing approximately 10% improvement in terms power density performance for the low-speed machine, and 40% improvement in terms power density performance for the high-speed machine. These improvements allows for reducing the cost of acquisition of the bus.

The demonstrator meets or exceed all the performance parameters, allowing for satisfactory acceleration time from 0 to 60 km/h in less than 17 seconds at partial load (14,6 tons) and satisfactory grading ability at the speed of 30 km/h at 7% of hill climb at full load (18 tons). The demonstrator, a PlugIn Hybrid Bus, has a fully electric range of approximately 18-to-22 km in MAN testing conditions with comfort, ride, handling and NVH performance, which are fully satisfactory and equal or better compared to the reference. The demonstrator meets required safety standards, reliability and durability requirements, it is easy to operate and recharge and is equipped with a clear and intuitive HMI for providing the driver with the relevant information of the hybrid powertrain.

The tests also highlighted areas of possible further improvements, which are: (1) integration on the demonstrator of high-speed electric machine to improve its cost reduction performance, and (2) improvement of the weight and volume reduction of the electric powertrain and (3) conclude the EURO VI certification.

The final assessment of the hybrid city bus has been carried out between Sept. 2017 and Mar. 2018 at the MAN facilities in München (Germany). In conclusion, the result of the assessment is very good, and the ECOCHAMPS WP6 MAN Lion's City Hybrid 18 tons meets most of the targets set for the project, constituting a significant advancement beyond the SotA 2013 and shows the way for the next generation of hybrid bus.

Figure 5-20. Demonstrator vehicle prepared for the final event

The overall TRL of the demonstrator is evaluated at level 7 (system prototype demonstration in operational environment). MAN will use the ECOCHAMPS bus as an advanced platform to develop the next family hybrid and fully electric buses.

5.5 Heavy duty truck

5.5.1 Motivation for the solution

The customers in the heavy duty vehicle market are asking for low fuel consumption, as it is one of the key factors in the vehicle Total Cost of Ownership. On top of that, the European Commission has set challenging targets on the CO_2 emissions of Heavy Duty Vehicles in 2025 and 2030. For these reasons, the heavy duty truck demonstrator is focusing on a significant driveline efficiency improvement with minimized cost increase.

To address these challenges, the heavy duty truck demonstrator has a parallel hybrid powertrain and a combined waste heat recovery system. Increased powertrain efficiency is gained from downsizing of the combustion engine and the hybrid electric components. The energy management system optimizes the trade-off between using the combustion engine, auxiliaries and electric motor, minimizing the overall energy losses.

The combination of a waste heat recovery system with the hybrid system offers freedom to store the generated energy from otherwise wasted heat. This enables the hybrid system to use the stored energy at a later moment or to use it directly for auxiliary power supply, resulting in an improvement of the overall fuel economy. A delay in response time of thermodynamic systems, such as the waste heat recovery system, results in a delay in the availability of thermal energy that is converted to drive power, reducing the potential of the waste heat recovery system.

The cost reduction is addressed by applying standardized, modular hybrid components that were as well originally developed as high volume passenger car components, and based on the established 400 V technology. The main targets of the demonstrator are listed in the tables below.

Table 5-16. Main technical targets for the heavy duty demonstrator.

Key Targets	Target value	Reference
Powertrain efficiency	+ 20%	DAF XF FT Super Space Cab, MX-13 340kW
Powertrain weight reduction	- 5%	DAF XF FT FP7 Convenient demonstrator
Powertrain volume reduction	- 5%	DAF XF FT FP7 Convenient demonstrator
Emissions level	+ 0 %	Compliant to EU6 emission norm

Table 5-17. Main targets for the end user requirements for the heavy duty demonstrator

End User Requirements	Vehicle Specific Target
Vehicle performance	General Performance equal or better than Base Vehicle
NVH	Equal or better than industry practice
Safety Standards	Safe demonstrator vehicle, pass all relevant safety standards
Human Machine Interface	Subjective judgement of Golden Engineers

5.5.2 Key innovations

The DAF XF demonstrator is based on a DAF XF tractor unit and has a parallel hybrid architecture. The powertrain is optimized by using hybrid driveline components, the thermal energy of the waste heat recovery, the electrified auxiliaries and the optimized energy manager.

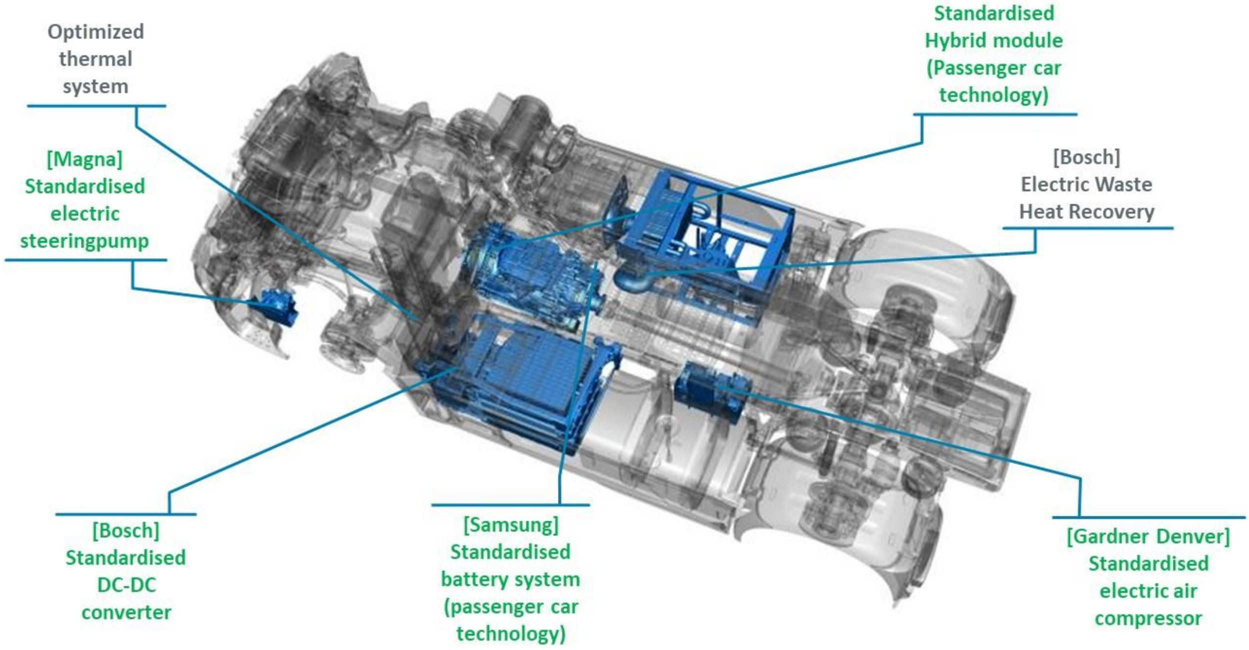


Figure 5-21 WP7 DAF demonstrator key innovations

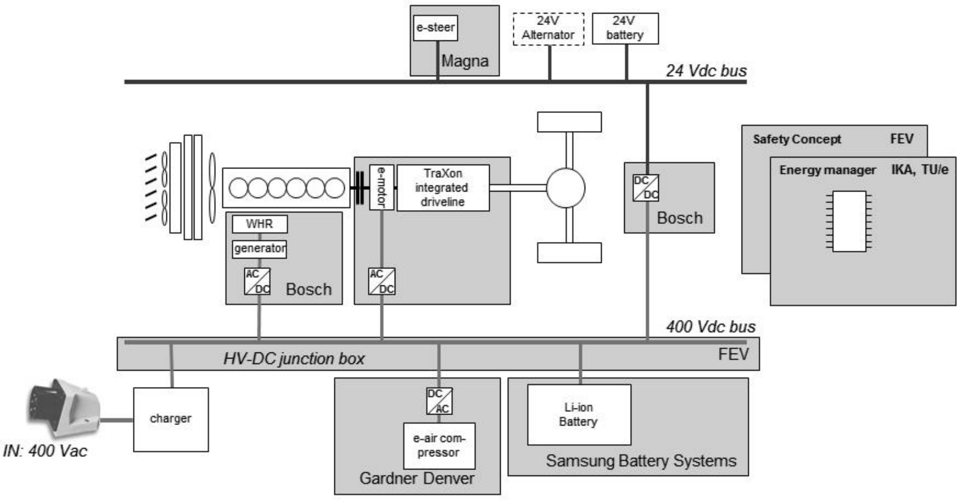


Figure 5-22 DAF demonstrator vehicle layout

HV Battery

The Samsung HV battery is a key feature of the hybrid powertrain. The battery pack consists of several modules and can easily be extended, making it consistent with the MSF modularization concept. The pack consists of LiPF6 battery cells, each with a with capacity of 28 Ah. The battery can deliver a useable energy of 16 kWh at a nominal voltage level of 300 V (the voltage range is 250 – 350 V). The battery can only deliver power to electric components if they are in the voltage range of the battery pack. When the high voltage system was designed and integrated, the proposed voltage levels appeared to be partially outside this range. For that reason, the voltage levels of the different components needed alignment. Hence, the battery pack has been tuned to a level where all components align with this setting.

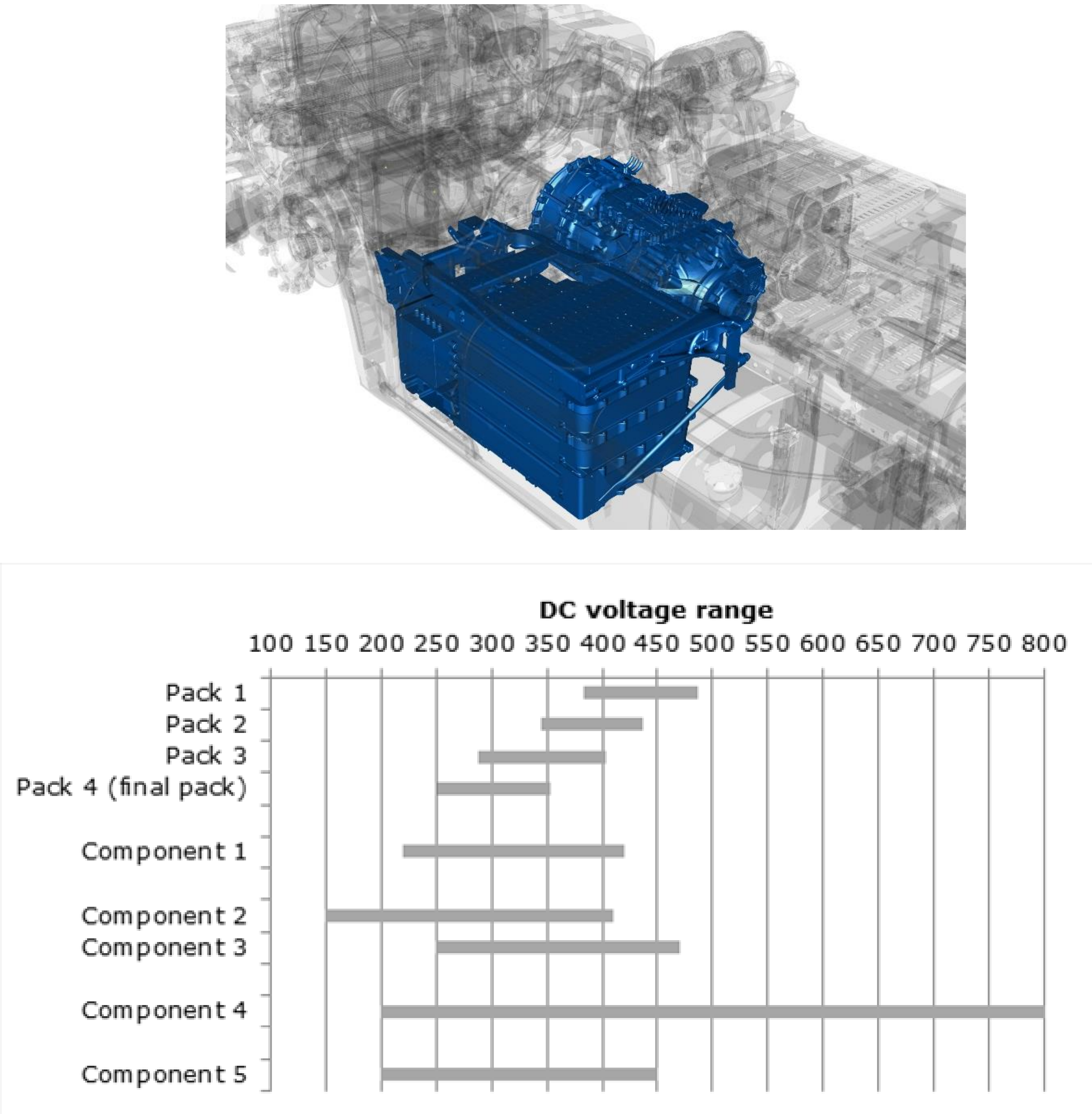


Figure 5-23 (a) HV battery box and E-machine (b) Voltage level alignment

Electric motor

The electric motor is developed outside the ECOCHAMPS project. Nonetheless, the E-machine and the dedicated inverter have been developed with the ECOCHAMPS philosophy to be compliant with the overall goals, using standardized components of the passenger car industry. The electric motor is a permanent magnet synchronous machine, with a mechanical peak power of 100 kW, a peak torque of 250 Nm and an integrated reduction transmission bringing the peak torque at 750 Nm. The e-motor is strong enough to fully drive the heavy duty truck, without support from the internal combustion engine. As the e-motor was designed for passenger cars, the peak output currents from the inverter is too low for a heavy duty vehicle to drive-off fully electric from standstill, and therefore it needs the internal combustion engine to assist. During high way use-cases the vehicle is able to stop the internal combustion engine and fully drive on the E-machine thereby eliminating the internal friction from the engine and thus saving additional fuel.

E-Waste Heat Recovery (WHR)

The electric Waste Heat Recovery (e-WHR) converts the heat from the vehicle exhaust system into electrical energy, and so helps to improve the efficiency. The e-WHR is based on the Rankine Cycle and uses an evaporator to heat a fluid with the heat from the vehicle exhaust gas. The heated fluid is then fed into the expander unit, where a generator converts the thermal energy into AC electrical energy. An inverter converts the AC power into

DC power, after which it is stored in the HV battery system. The energy can then be used for powering the E-machine or the air compressor.

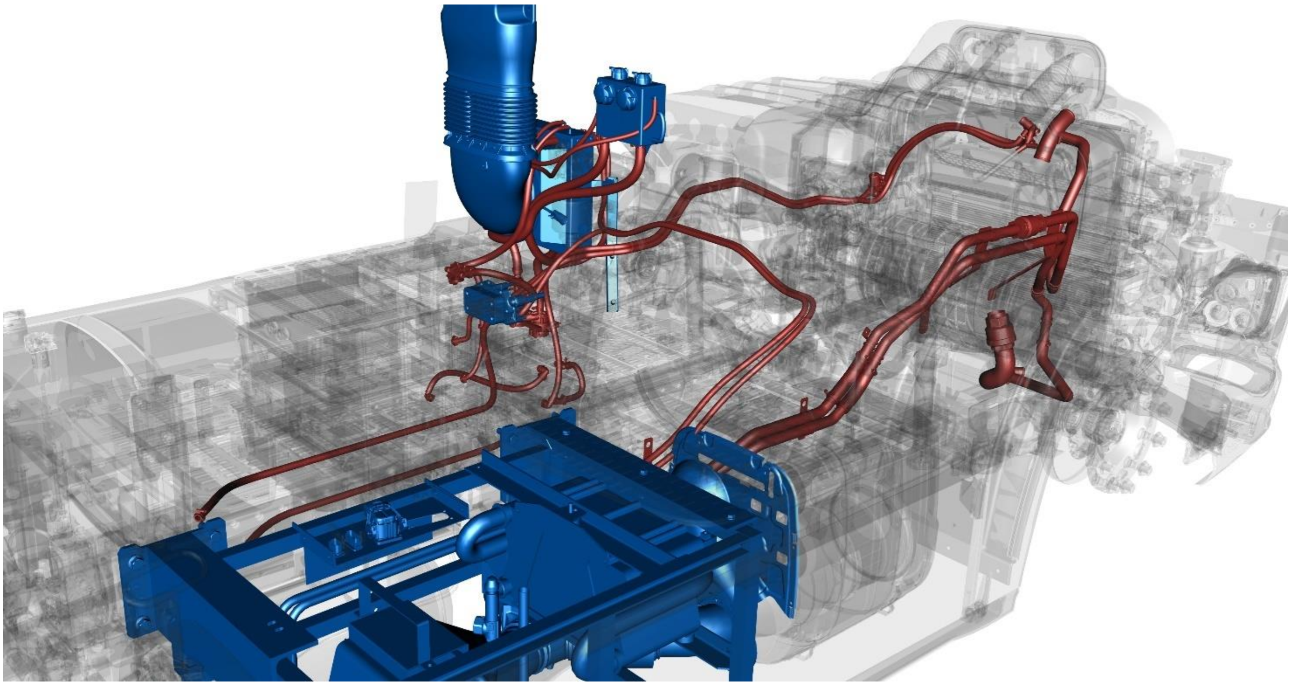


Figure 5-24 e-WHR and thermal systems

Electrified auxiliaries

On heavy duty vehicles, the air compressor provides pressurized air to operate the brakes. Conventional air compressors are driven by the internal combustion engine. To enable pure electric driving, an electric air compressor is needed. Therefore, in ECOCHAMPS an optimized electric air compressor has been developed and is used both for the bus and for the truck. The ECOCHAMPS e-motor and controller are 50 % and 75 % lighter compared to the original e-motor and controller, respectively.

Similar to the air compressor, a conventional hydraulic steering pump normally driven by the combustion engine. In ECOCHAMPS, an electro hydraulic steering pump (EHSP) has been developed. The EHSP unit is connected to the 24 V DC boardnet as the required DC current is relatively low.

The DC/DC converter was developed to convert the 300 V DC from the high voltage battery to a 24 V DC (low voltage) level to supply the board net with electrical power. This converter avoids to use of an alternator and is able to convert a maximum of 3 kW electrical power from the high voltage to the low voltage boardnet on a higher efficiency.

Energy manager

The energy management for the hybrid truck has a generic, modular approach, so it can be used for various powertrain topologies with differently dimensioned components. This solution is demonstrated for the first time in the ECOCHAMPS hybrid truck. The generic energy management can use preview information (available road/route information) as well as historical data to optimize the overall powertrain efficiency.

5.5.3 Key results

Figure 5-25. The final demonstrator.

The ECOCHAMPS DAF-XF-FT Super Space Cab was assessed in March 2018 at the DAF facilities in Eindhoven (The Netherlands) under the supervision of the Golden Engineer. Table 5-18 and Table 5-19 summarize the main results.

Table 5-18. Main technical results for the heavy duty truck demonstrator

Key Targets	Specific vehicle target	Results
Powertrain efficiency	+ 20%	+ 17.4 %, detailed validation ongoing
Powertrain weight reduction	- 5%	- 13 %
Powertrain volume reduction	- 5%	- 17 %
Emissions level	+ 0 %	Within emissions legislation, last validation tests ongoing.

Table 5-19. Main results from the end user requirements for the heavy duty truck demonstrator

End User Requirements	Vehicle Specific Target
Vehicle performance	Equal performance as reference vehicle (exception: full electric 85 km/h)
NVH	Better then Reference vehicle
Safety Standards	Safety concept implemented and tested.
Human Machine Interface	Integrated in DAF HMI

In 2013 there were no hybrid long haul trucks available in the market, so several vehicles were used to compare the demonstrator to the 2013 state-of-the-art. The DAF-XF-FT Super Space Cab MX-11 320 kW MY2017 was used as a base vehicle, the DAF-XF-FT Super Space Cab MX-13 340 kW MY2013 was used as a reference for powertrain efficiency and the DAF XF-FT Convenient demonstrator was used as a reference for the hybrid powertrain.

The ECOCHAMPS DAF-XF-FT Super Space Cab is significantly more fuel efficient than the reference, consuming about 14.5 % less energy (simulated on the DAF proprietary test cycle), which is equivalent to a powertrain energy efficiency improvement of about 17.4 % with a loaded vehicle (average loading factor).

The electric part of the hybrid powertrain of the demonstrator is 37.7 % smaller (volume) and 43.7 % lighter (weight) than the reference vehicle, increasing the volumetric and gravimetric peak power and torque by 40 %.

Overall CO_2 emissions are expected to be reduced, consistent with the lower fuel consumption. Furthermore, compliance with in-force EURO VI emissions regulation is expected. The demonstrator meets or exceeds part of the performance parameters, can maintain a cruise speed of 85 km/h in four traction configurations (i.e. 16 tons/40 tons, ICE and hybrid-powered configurations), accelerates satisfactory and has an electric range of 14 km (at a constant speed at 50 km/h). Comfort, ride, handling and NVH performance are fully satisfactory, being equal to or better than the reference.

The demonstrator meets required safety standards, reliability and durability requirements, is easy to operate and recharge, and is equipped with a clear and intuitive interface to give the driver relevant information on the functioning of the hybrid powertrain. The tests also highlighted areas of possible further improvements, e.g. a fully functioning WHR system, to further improve the fuel efficiency.

In conclusion, the assessment is positive. The DAF-XF-FT Super Space Cab meets most of the targets set for the project, and is an advancement beyond the 2013 state of the art. The overall TRL of the demonstrator is evaluated at TRL 7 (system prototype demonstration in operational environment), with exception of the WHR system, which is evaluated at TRL 6 (technology demonstrated in relevant environment).

6 The legacy of ECOCHAMPS: how does it carry on?

This chapter describes the EcoChamps results and how it will be carried over to the exploitation phase, to bring it into market entry. The section will not provide detailed market prospects or business plans, only a glimpse of the potential of the different aspects of the results from the project.

6.1 Vehicles

During the ECOCHAMPS project, the partners have summarised the exploitable results in graphical overviews per demonstrator vehicles. Please note that, for the sake of clarity, the overviews are extensive but not exhaustive.

Class B demonstrator
The investigated architecture (HV eAWD P-HEV) is a candidate solution for the FCA B/C segment applications of the coming years. Thanks to its modularity and flexibility, it is under investigation for possible extension also to other vehicle segments (such as Light Commercial Vehicles up to 3.5 ton and, in a simplified layout, for small urban vehicles (i.e. P1f only at lower voltage).

All the e-powertrain components (Bosch e-motors and power electronics and GKN transmissions) can be applied not only in the investigated hybrid architecture, but also in other hybrid configurations and also in pure EV application (the P4 e-axle). The TEG, having a lower TRL, needs a longer pathway to complete its feasibility loop before to evaluate its sustainability at cost level for a production applicability in the automotive field.

The main risk for the class B vehicle exploitation is the extra cost/price acceptance (why should the customer pay more than for an HEV?). Today the P-HEVs appeal (in Europe) is limited due to a “long” payback time, charging issues and limited access areas not so widely diffused. Potential countermeasures are to enable an extended AWD capability, to identify an architecture with important communalities with conventional powertrains (ICE, front transmission), modularly applicable and allowing synergies for the e-components with other solutions (to reduce their cost with the volumes). Another possible countermeasure is to introduce wireless charging (to be evaluated).

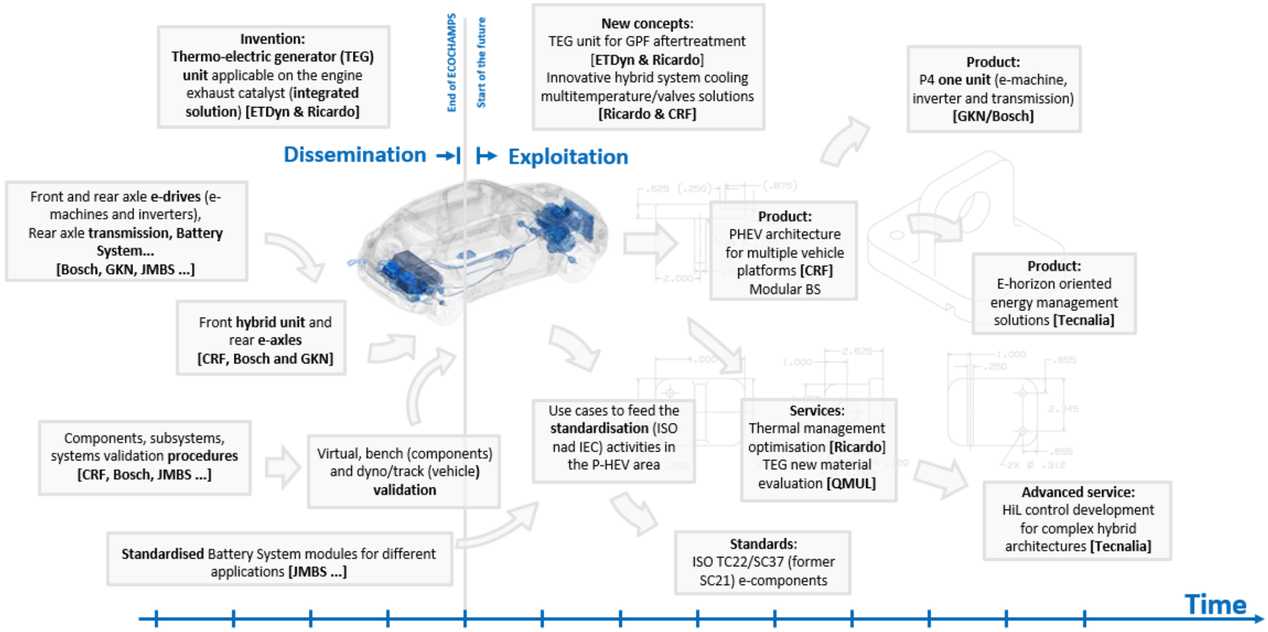


Figure 6-1 Route to market for the class B developments.

Class C demonstrator

Beyond its specific hybrid application, several 48 V additional developments can be foreseen related to:

- 48V board net new functions (comfort, active chassis control, emission control etc)
- New mobility devices (micro-car emerging market in China, 2 wheelers)

The 15kW 48V efficient dual clutch transmission (EDCT) will take advantage of the next coming massive 48V components developments (48V BSG, 48V network).

The main risk for this hybridisation concept is related to the driveability. Even if the current transition time between E-drive and hybrid drive is judge acceptable for light commercial vehicles (LCV), it must be estimated for passenger cars. In case of insufficient driving comfort for passenger cars, countermeasures such as an electrical motor power increase (inside ECOCHAMPS study) or an additional fast starting device (48V BSG) can be applied.

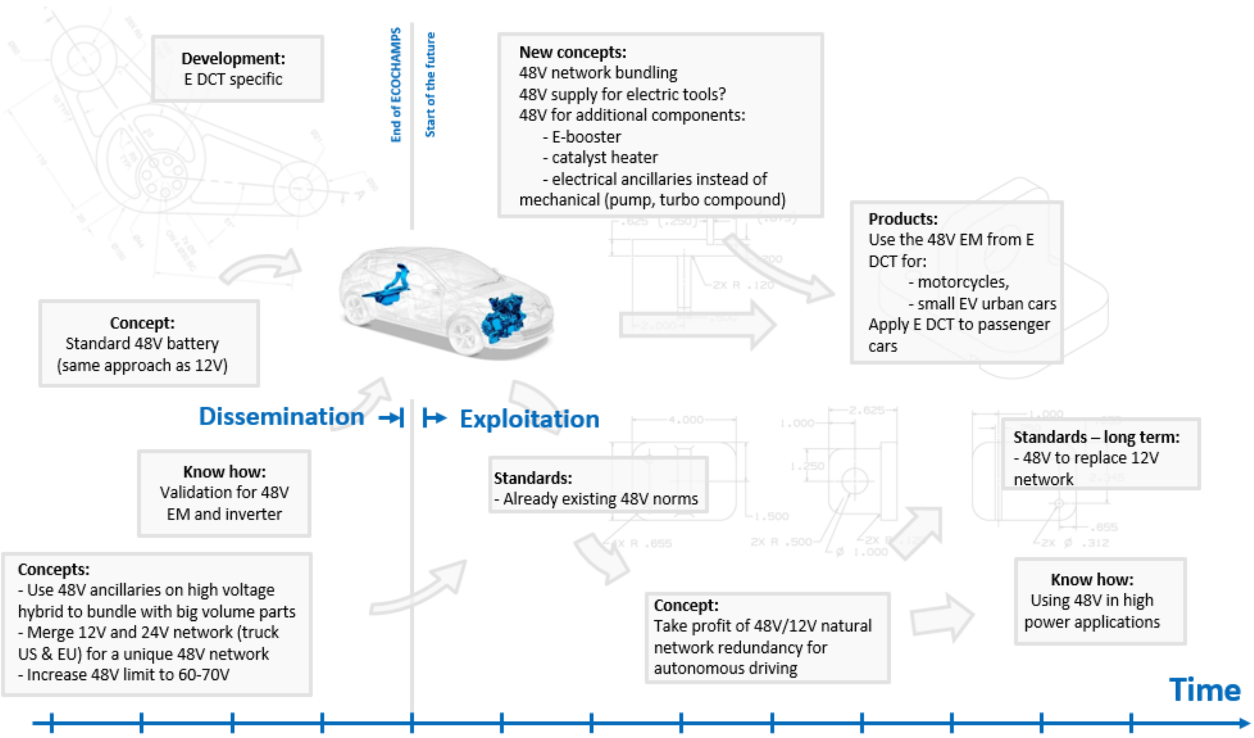


Figure 6-2 Route to market for the class C demonstrator developments.

Medium duty truck
A second generation PHEV MCV concept is expected in 2025 if it shows a viable business case.

The main exploitation risks for PHEV MCV after the project end are related to the following issues. Political decisions (taxation and city fees exemptions, traffic ban exclusions) still not totally in favour of PHEV MCV. Expected volume too low due to main subsystem low production volume. HV Battery Cost, Energy cost (at charging station) and fuel cost: if the cost of the electricity will be not considerably lower with respect to the fuel cost and the battery cost (at system level) will not decrease significantly, the Total Cost of Ownership (TCO) for a hybrid/electric vehicle could be not competitive with respect to the diesel version. Furthermore, another additional brake on the spread of electric vehicles could be the high investment cost/cycle-ability/lifetime/energy throughput of the HV battery itself.

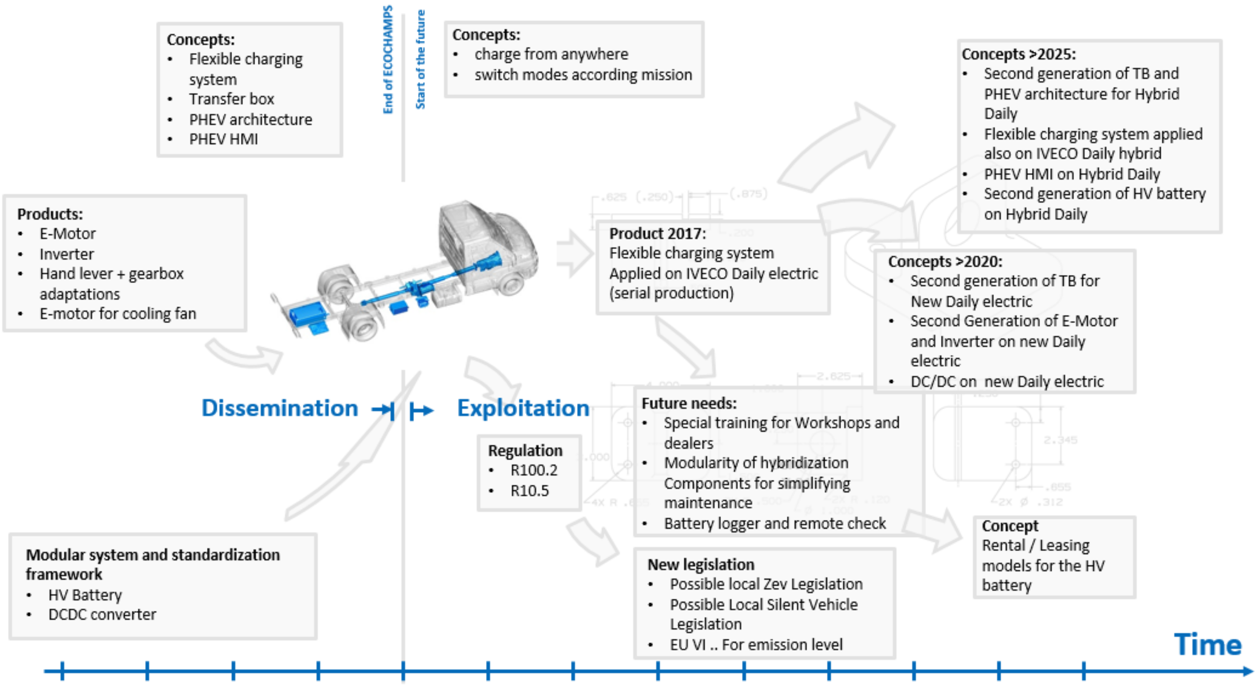


Figure 6-3 Route to market for the medium duty van developments.

City bus demonstrator

The main exploitation potential on vehicle level is that the main auxiliaries can be shared between bus and truck, such as the steering pump, air compressor, DC-DC-converter for 12 V or 24 V DC Board net supply, battery systems (sharable in the VW company only), electric machines with integrated inverter. The main exploitation potential on component level is a high voltage level in a wide operation range of 400 to 800 VDC according to L123 Standard (i.e. modularisation of power front end of the inverter, adapted cooling concept, control unit is “always the same”).

The main exploitation risks are the following. The lifetime of the “high volume product components” is not sufficient for bus applications, i.e. 6000 h vs. 30000 h for long haul applications and 50000 h for bus applications. The lifetime of the “high speed electric drive” from high volume production (passenger cars), such as the bearing, power electronic, magnetic remanence of PSM, is not sufficient. The lifetime of “High Voltage Battery system” from high volume production (pass. cars), such as the electric capacity over time, insulation, power performance, is not sufficient.

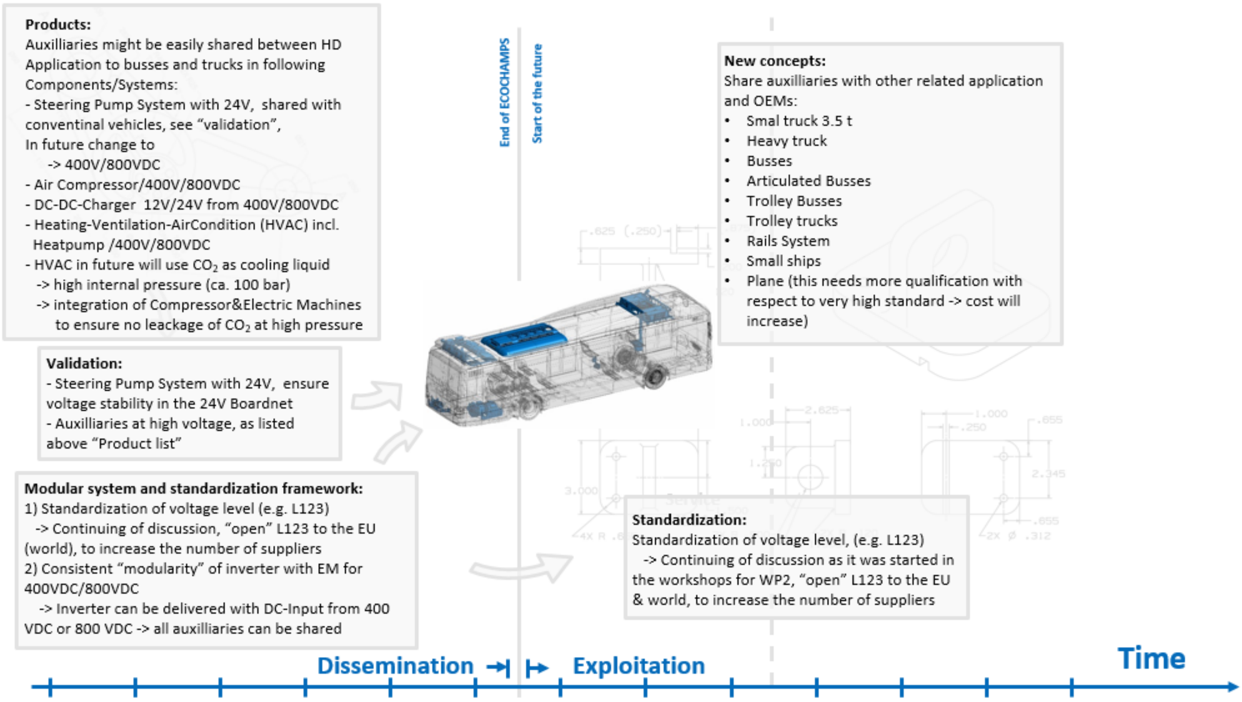


Figure 6-4 Route to market for the city bus developments.

Heavy duty truck

Cross application usage of standardized components, for example auxiliaries, between medium duty and heavy duty applications, battery pack and DC/DC converter all vehicle applications. Or usage of components outside vehicle applications, for example modular battery architecture for household applications. Exploitation potential on component level: cost reduction due to limited platform differences, development focus due to standardized voltage levels proposal, vehicle integration knowledge to be used for design optimization.

Risks related to implementation are the following. Integration of Heavy Duty (HD) vehicles requirements in Light Duty (LD) vehicles components: it should be avoided that HD requirements will impact the development of the LDV components. The standardization requirements of the MSF should be incorporated in a larger perspective, for example, a standardization framework: necessary to increase the impact of the standardization proposals. The TCO of the integrated driveline might be too high.

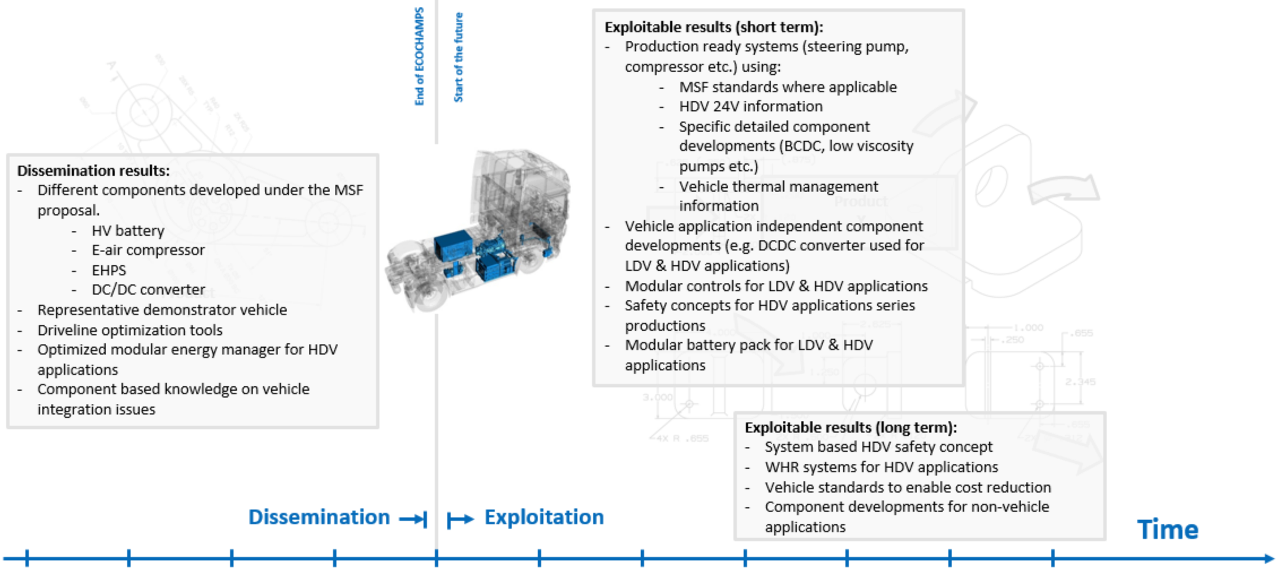


Figure 6-5 Route to market for the heavy duty truck developments.

6.2 Standardization

What is the route to market?

- Proposed standards can be used in the national standardization bodies as the basis for actual standards
- The MSF document can be a start for new developments for suppliers, enabling to know what the technical requirements are per component
- The procedure can be used by others
- To use the MSF as a basis for future European projects on hybrid vehicles/components

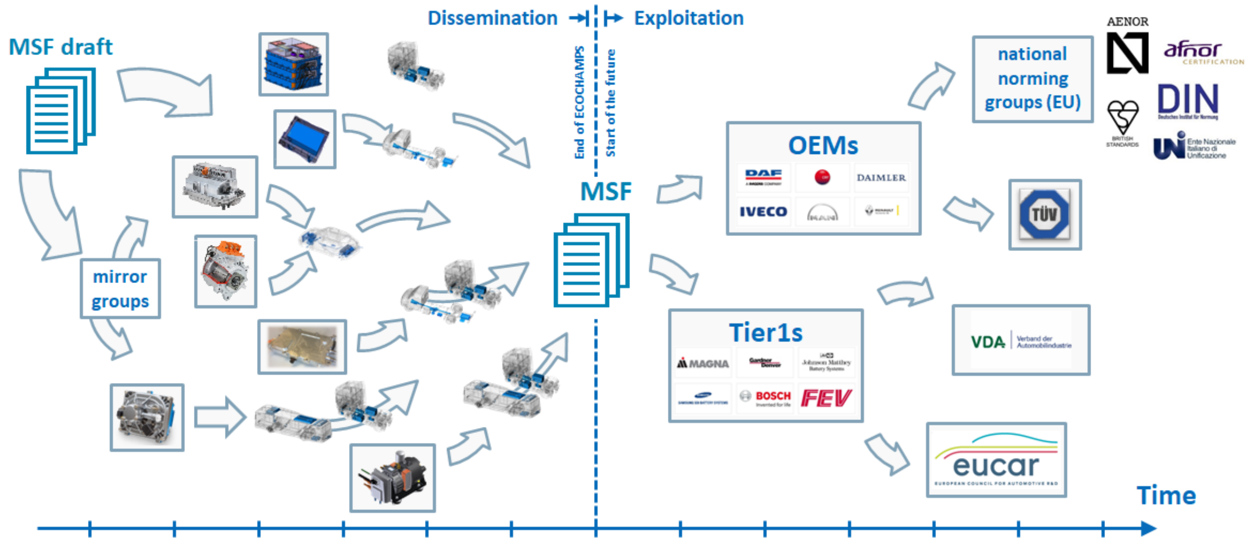


Figure 6-6 Route to market for the efforts on standardization.

6.3 Overview of current and future CO_2 declaration methods for HD vehicles

One third of the CO_2 emissions in the transport sector comes from HD vehicles (European Commission, 2015), representing 9.2 % of total inland surface passenger transport and 74.9 % of total inland surface freight transport. Recent data shows that over the last years the energy demand and CO_2 emissions of the HD vehicle sector increased, possibly overtaking LD vehicles in the next decade (Fontaras, et al., 2016). In order to move towards a sustainable transportation system, more efficient technologies need to be developed. Hybrid powertrains (hybrid-electric, plug-in hybrid-electric etc) are one step in this direction, and may help to significantly reduce the carbon footprint of the commercial vehicle fleet in the future.

Emissions can be reduced by introducing regulations, if there is a clear criterium for the regulation. For instance, for light duty vehicles (passenger cars) regulations are based on the emissions mass per driven distance (g CO_2/km). However, regulating the emission of commercial powertrains is far from straightforward. In contrast to passenger cars, there are many vehicle sizes, configurations and in-use duty cycles. Current regulations for conventional powertrains circumvent this issue by focusing on engine test procedures and prescribing the allowable mass of emissions per unit of engine work (g CO_2/kW.h).

Hybrid powertrains introduce even more diversity, by adding an energy source and extra interactions between the conventional engine and the hybrid components. Thus, solutions for defining carbon emissions adopted for conventional fuel vehicles may not be representative for hybrid powertrains. Therefore, an alternative method for defining CO_2 emissions, i.e. the CO_2 declaration, is necessary.

In ECOCHAMPS the JRC embarked on a preliminary technical screening of possible methods to enhance CO_2 declaration of hybrid heavy duty vehicles. This activity has been carried out in parallel with the study commissioned by DG CLIMA to the Technical University of Graz (TUG), i.e. “Feasibility assessment regarding the development of Vehicle Energy Consumption Calculation Tool (VECTO) for hybrid heavy duty vehicles”, and considered the input from the simulation approaches used by ECOCHAMPS partners. These two contributions are acknowledged, although the results of this technical screening presented below constitute the JRC's independent opinion on the subject. Within this task, three groups of methods for CO_2 declaration for Hybrid Heavy Commercial Vehicles have been identified:

- virtual methods, i.e. crediting scheme, VECTO (stand-alone) and VECTO enhanced with Software in the loop (SILS) and Hardware in the loop (HILS);
- physical tests (on the bench), i.e. engine and powertrain in-the-loop;
- full-vehicle tests, i.e. chassis-dyno and on-road testing.

The results of the technical screening carried out at the JRC are summarised in Table 6-1. Here qualitative ratings have been assigned to each criteria, with "+" meaning "low" and "+++++" meaning "high". Note that "low" and "high" might assume a positive or negative meaning depending on the context, therefore this information is enriched with colours according to the legend below the table.

Table 6-1 Results of the JRC technical screening of possible methods for enhancing CO_2 declaration methods for Hybrid Heavy Commercial Vehicles

	Method	Simulation-based	Hybrid part simulated	Effort for development of certification procedure	Capital investment for test facilities	Effort for certification test	Expected accuracy
Virtual Methods	Crediting scheme	yes	no	+++	+	+	++
	VECTO (stand-alone)	yes	yes	+++	+	++	++++
	VECTO with Software-in-the-Loop (SILS)	yes	yes	++++	++	+++	+++++
	VECTO with Controllers-in-the-Loop (HILS)	yes	yes	++++	++	+++	+++++
Physical Tests (on-the-bench)	Engine-in-the-Loop	mixed	Depends on architecture	+++++	+++	++++	++++
	Powertrain-in-the-Loop	mixed	no	++++	++++	++++	++++
Full Vehicle Tests	Chassis dyno testing	no	no	++	+++++	+++++	+++++
	On-road testing	no	no	++	++	++++	+++++

Legend

negative	negative-to-neutral	neutral	neutral-to-positive	positive

The results indicate that the virtual methods might be a valuable candidate for CO_2 declaration purposes of hybrid heavy duty vehicles, with increasing accuracy from VECTO stand-alone to VECTO enhanced with SILS/HILS, despite an increase in effort for development and execution of the certification tests. Software-In-the-Loop testing (SILS) is, in particular, a very promising method, implying the use of a tool for full vehicle simulation that allows for the inclusion of OEMs-proprietary software. This software can be provided by the OEM under a non-disclosure agreement for the type-approval test. Hence SILS can be, ultimately, more desirable than HILS, allowing for a leaner procedure which does not include major hardware components. On the other hand, physical tests on the bench demand high efforts for development and certification, thus resulting less attractive. These, in fact, are not viable due to limited time available for their implementation, high effort needed for the development of the testing procedure and small benefit to the accuracy of the method in comparison to other solutions. Moreover, in the case of Engine-in-the-Loop testing, some engines will be type-approved equipped together with their hybrid components while some others are not, depending on the architecture of the hybrid system. This would make this option the least desirable. Additionally, full vehicle tests require relatively low efforts for development, higher efforts for certification and good accuracy too. The on-road testing is, in general, more desirable than chassis-dyno due to the lower capital investment, and it can be a valuable candidate for the validation of the virtual methods, although some scattering of the results can be expected due to the variability of the on-road conditions.

Therefore, based on the analysed data, the best solution for CO_2 declaration points in the direction of VECTO enhanced with SILS/HILS combined with full vehicle on-road testing for validation of the simulation results and for in-service conformity check purposes. Noticeably both methods could be used together, each of them does not exclude the other. VECTO enhanced with SILS/HILS can be used in tandem with on-road full vehicle testing for vehicle certification, while on-road full vehicle testing can be sufficient for in-service conformity checks.

Note that the contents of this report are purely explorative: they are not intended to be considered conclusive, neither as an indication nor a position from the JRC, on the methods that need to be applied in future certification of Hybrid HD vehicles. However, they aim at informing future regulatory processes on the subject, in view of supporting the development of future hybrid heavy duty market. More details are provided in the full report, (Tansini, Grigoratos, & De Gennaro, 2017).

7 Conclusions and recommendations

The innovations demonstrated in ECOCHAMPS have shown an improvement beyond the state-of-the-art for hybrid powertrains in terms of the cost/benefit ratio. The technology is proven to have a strong impact on CO_2 reduction for road transport and, at the same time, have a positive effect on the air quality in densely populated areas due to the zero emission driving capabilities. The hybrid powertrains proposed for the various vehicle classes, based on a set of End User Requirements, are concluded to be attractive solutions for their end-customers. Based on the cooperation between passenger car and heavy duty vehicle manufacturers, it has been concluded that there is a clear benefit from the use of technology from the light-duty into the heavy duty sector.

The Modular System and Standardization Framework (MSF) developed in the ECOCHAMPS project recommends, for the first time, standards for hybrid electric powertrain components for commercial vehicles. These pre-standards are a sound basis for the official standards that are to be published by the national and international Standards Organisations. The fact that all information provided in the MSF is publically available makes it a unique document compared to other standards in the industry that are often created by and available for a limited group of manufacturers. With the MSF, ECOCHAMPS has made a start on a standardization process with respect to heavy duty hybrid vehicles, a first step that was hardly possible to achieve without EU funding. The MSF document has been made available by the consortium to all relevant organisations in the automotive industry, as well as well as to the public domain via the project website on www.ecochamps.eu.

Hybrid technology will play an important role in achieving the 2030 industry CO_2 targets and contribute to a competitive and resource efficient transport system as targeted in the European Transport Policy White Paper (2011). The hybrid vehicle technology demonstrated in ECOCHAMPS is, next to full electric vehicle technology, essential to meet the targets for a resource efficient transport system, and to improve air quality as well as reduce noise emissions, for commercial vehicles in particular, allowing a greater portion of freight transport within the urban areas to take place at night time, easing the problem of road congestion during peak hours.

Due to the size of the consortium, a full representation of the automotive industry could be involved, thereby gaining the critical mass necessary to enable adoption of the benefits of the project. Utilizing the know-how gained in the project will contribute in strengthening the European technological leadership in hybrid powertrain technology and system optimization. As a result, the competitiveness of EU vehicle manufacturers and suppliers will be increased, securing European jobs as one of the major results. As the ECOCHAMPS technologies are developed at TRL 7, the following logical step is a market introduction of the hybrid powertrains the near future.

Continuing research within Horizon2020 and succeeding EU framework programmes will remain necessary to gain the know how required to meet 2030 and 2050 CO_2 targets for the transport sector. Further reduction in component costs, mainly of high voltage batteries and the resulting required production facilities in Europe should be major focal points for these future projects.

8 Acknowledgement

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Project partners:

#	Type	Partner	Partner Full Name
1	HD	DAF	DAF Truck NV
2	LD	CRF	Centro Richerche Fiat S.C.p.A.
3	HD	DAIMLER	DAIMLER AG
4	HD	FPT	FPT Industrial S.p.A.
5	HD	IVECO	IVECO
6	HD	MAN	MAN Truck & Bus AG
7	LD	RENAULT	Renault
8	HD	BOSCH	Robert Bosch GmbH, DS/CV/PJ-HEV
9	HD	ECS	Magna Powertrain
10	LD	GKN	GKN Driveline International
11	HD	GEVEKE	Geveke Compressed Air & Gas Technology
12	LD	JMBS	Johnson Matthey Battery Systems
13	HD	SSBS	SAMSUNG SDI Battery Systems GmbH
14	HD	ZF	ZF Friederichshafen AG
15	LD	ETL	European Thermodynamics Ltd
16	HD	AVL	AVL List GmbH
17	HD	FEV	FEV GmbH
18	LD	RIC	Ricardo UK Ltd
19	LD	TEC	TECNALIA
20	HD	UNR	Uniresearch
21	HD	FHG	Fraunhofer IVI
22	LD	IKA	Institut fur Kraftfahrzeuge - RWTH Aachen University
23	HD	JRC	Joint Research Centre
24	HD	VIF	Virtual Vehicle Research Center
25	LD	QMUL	Queen Mary University of London
26	HD	TUE	Technische Universiteit Eindhoven
27	HD	HYDRO	Gardner Denver Ltd

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9 Abbreviations / Nomenclature

Abreviation	Explanation
AC	Alternating current
AWD	All Wheel Drive
BMS	Battery management system
COGS	Cost of Goods Sold
DCT	Double clutch transmission
EDCT	Efficient dual clutch transmission
EHSP	Electro hydraulic steering pump
EM	Electric motor
EMC	Electromagnetic compatibility
EMG	Electric motor/generator
EUR	End User Requirements
EV	Electric Vehicle
FCA	Fiat Chrysler Automobiles
FWD	Front Wheel Drive
GHG	Green House Gas
GPF	Gasoline Particulate Filter
HD	Heavy Duty
HMI	Human-machine interface
HV	High Voltage
HVAC	Heating and ventilating air conditioning
ICE	Internal combustion engine
JRC	Joint Research Centre
KPI	Key Performance Indicators
LCV	Light commercial vehicles
LD	Light Duty
MSF	Modular System and Standardization Framework
NEDC	New European Driving Cycle
NVH	Noise Vibration and Harshness
OEM	Original Equipment Manufacturers
PEMS	Portable emissions measurement system
PTO	Power take-off
SILS	Software in the loop
SoA	State of the Art
SOC	State of charge
TCO	Total Cost of Ownership
TEG	Thermo Electric Generator
TRA	Transport Research Arena
TRL	Technology Readiness Level
VECTO	Vehicle Energy Consumption Calculation Tool