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CONVENIENT – complete vehicle energy saving technologies for heavy trucks

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Abstract

This article presents an overview of the interim results achieved in the FP7 project CONVENIENT "Complete Vehicle Energy Saving Technologies for Heavy Trucks" (No.312314) which started in November 2012 and concludes April 2016.
From the customer viewpoint, fuel efficiency is top priority because of its significant impact in terms of cost (in the EU, fuel represents about 30% of the Total Operating Costs for a 40-ton tractor-semitrailer combination). Correspondingly, the CONVENIENT project targets a 30% reduction of fuel consumption in vehicles for long-distance freight transport by developing innovative heavy-trucks featuring a suite of innovative energy-saving technologies and solutions by adopting a holistic approach to on-board energy management, considering the tractor, semi-trailer, driver and the mission as a whole.
The objective has been to achieve complete vehicle energy management by proposing highly innovative solutions for improved efficiency and enhanced integration of components currently designed independently, integrated and evaluated directly on validator vehicles including energy efficient sub-systems, energy harvesting and active/passive aerodynamics devices.
The CONVENIENT Consortium comprises three major EU truck manufacturers, ten Tier 1/2 suppliers, and a network of nine research centres and Universities, representing European excellence in the field of long distance transport R&D.

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1. Introduction

The CONVENIENT project (www.convenient-project.eu) targets a 30% reduction of fuel consumption on long-haul heavy-trucks by developing a suite of innovative energy-saving technologies and solutions.

The focus of the project is to leverage on a holistic approach to energy management of complete vehicle, considering the truck, the semi-trailer, the driver and the mission as a whole.

Over the course of the project, three heavy-trucks are being developed by CONVENIENT Consortium, which comprises 3 major EU truck manufacturers (IVECO, VOLVO, DAF), 10 suppliers Tier1/Tier2 and a network of 9 research centres and Universities (see Figure 1), with the common aim of demonstrating and validating the fuel-saving solutions adopted on validator vehicles, featuring:

- energy efficient systems, including: hybrid transmission, electrified auxiliaries, dual level cooling system;
- parking HVAC;
- energy harvesting devices, like photovoltaic solar roof for truck and semitrailer;
- advanced active and passive aerodynamics devices for the truck and for the semitrailer;
- Holistic Energy Management system at vehicle level;
- Predictive Driver Support to maximize the energy saving benefits;
- novel Hydraulic Kinetic Energy Recovery System for the semitrailer.


The overall target is to achieve 30% fuel-saving improvement on the reference vehicle, thanks to the adoption of new technologies, adopted both on the trucks and also on the semitrailer.

Fig. 1. Locations of Partners for CONVENIENT project.

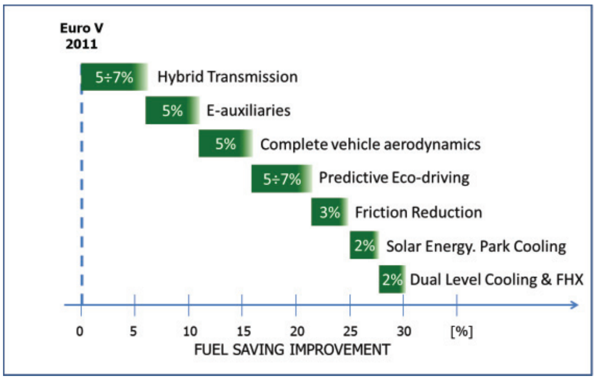

Fig. 2. Deployment of fuel economy target in CONVENIENT project.

2. Background

Long distance freight transport plays today and, according to the future scenario, will play in the next decades a central role for the European economy and its plans for growth. Indeed long-distance road transport system is an irreplaceable cornerstone of European mobility and transportation, and for the coming decades more efficient transport solutions with reduced environmental impact, reduced oil and energy consumption will need to mitigate the environmental impact and at the same time enable a further increase in EU competitiveness with respect to the rest of the world. All future development of the European mobility and transportation system must be entirely sustainable and affordable, a challenge that can be faced only with the contribution of all the stakeholders sharing the same aim within an integrated approach.

From the customer view point, fuel efficiency is one of the main priorities for long-haulage heavy-trucks due to its major impact on the Total Operating Costs. It has been estimated that in Europe the cost of fuel is about 30% of the Total Operating Costs for a 40-tonne tractor-semitrailer combination. Therefore European goods transport on roads, which is characterized by high fuel prices, together with high weights and volumes and relatively long distances, will greatly benefit from a significant improvement infuel efficiency.

Correspondingly, as part of its mission, the EU Commission promotes policy for mobility and transportation that is efficient, safe, secure and has low environmental impact. In this context, the development of a new generation of efficient and affordable vehicles for road transport which incorporate complete vehicle energy management solutions, which is the goal of the CONVENIENT project, is an enabler for achieving significant reduction levels of fuel consumption and pollutant emissions achieved only through intensive collaborative research, developing innovative solutions for improved vehicle efficiency and the optimized integration of components which are currently developed independently.

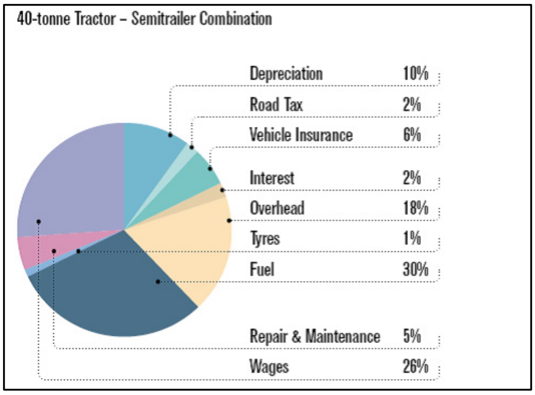

Fig. 3. Fuel efficiency is a first priority for Customers of long--haul trucks, because of its major impact (30%) on the Total Operating Costs.

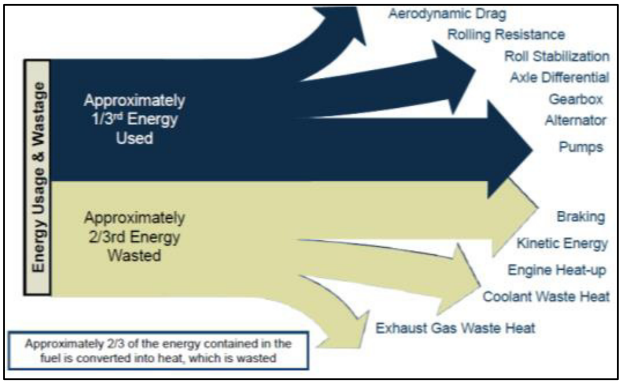

Fig. 4. The efficiency of a heavy duty vehicle can be improved in a various ways by operating on both the tractor and the semitrailer.

3. Overall strategy and general description

The approach of CONVENIENT, which is illustrated schematically in Figure 3, has been to address directly the development of the prototype vehicles in three main Sub-Projects (named A1, A2 and A3) conducted by the truck manufacturers, namely IVECO, VOLVO and DAF respectively, and covering a range of different approaches with regard to the adoption of fuel-saving technologies on each.

These core activities are supported by the close collaboration with two transversal subprojects B1 and B2, led by MERITOR and CRF respectively, focusing on the development of common technologies, i.e. Friction Reduction and Holistic Energy Management & Fuel-saving Systems, respectively, for adoption and integration into the vehicles.

A bridging sub-project A4 was also included to ensure knowledge and technology transfer from all sub-projects into a common task, for numerical simulations and final experimental assessment of the fuel economy targets. At the beginning of the project, sub-project A4 focused on defining the reference fuel-consumption testing protocol and baseline values, to be compared in the final phase, when the demonstrator trucks are tested to evaluate their contribution to the overall achievement of fuel-saving targets. Successively, a methodology to assess the different technologies was defined according to the specific needs, e.g. by including bench-testing of hybrid powertrain solutions and realistic usage conditions; the experimental results from the three vehicle-related sub-projects were evaluated and compared with regard to each specific application; furthermore, an attempt to merge the contributions among the different solutions was proposed via simulation, with the aim to define the future road-map for the most effective approach to fuel-saving on heavy-trucks.

Sub-project C1 is devoted to project management issues by the SP leaders led by the project coordinator.

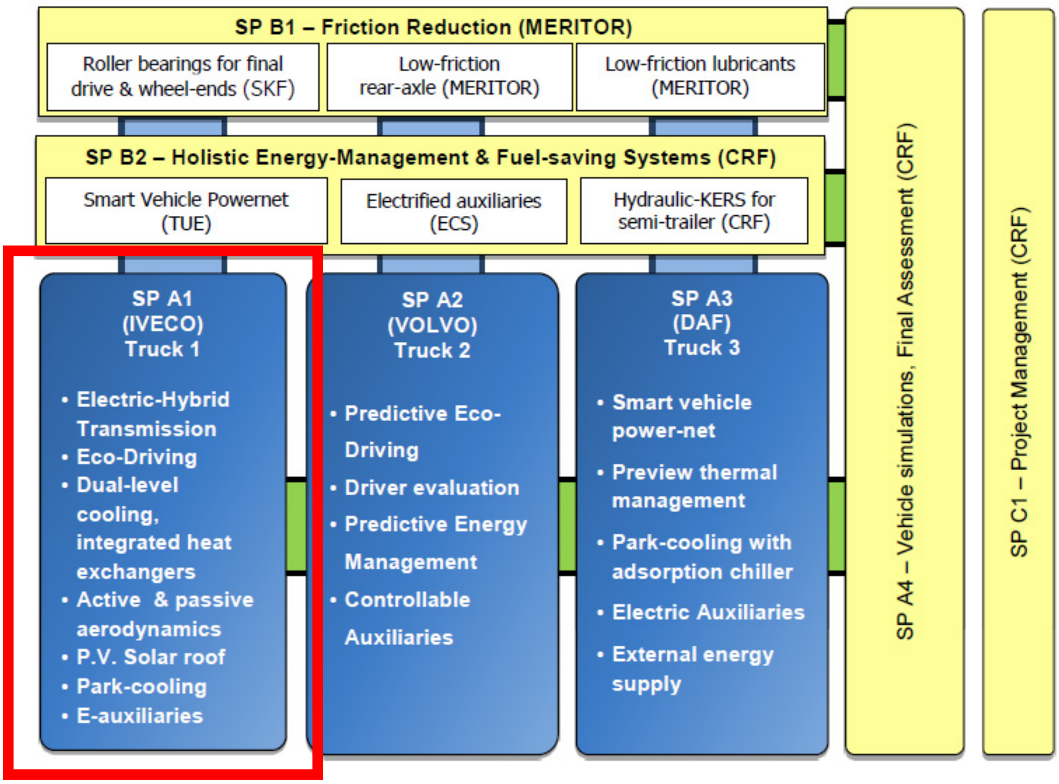

Fig. 5. Key technologies/approaches of the project.

4. Project objectives and major achievements currently achieved

The scientific objectives and the major results achieved in the first two years of the project are summarized below for each Sub-Project.

4.1. SP A1: Prototype Truck 1 (IVECO)

The main objective of SP A1, led by IVECO, was to develop the IVECO long-haul truck prototype capable of achieving the challenging target of 30% fuel-saving by means of the following main energy-saving technologies:

- Hybridization of the transmission. The partners involved performed the concept analysis and simulations phase, which includes the concept study and CAD installation analysis for integrating an Electric-Hybrid transmission on the validator truck. IVECO, CRF and ZF carried out the integration of the Electric Hybrid Transmission on the Stralis truck, with a full CAD packaging study being undertaken and the electric/electronic architecture defined. A prototype hybrid transmission was also realized by ZF.
- Electrification of auxiliaries. The on-board integration of electrified auxiliaries was undertaken with ECS developing the Electro-Hydraulic Power-Steering system (EHPS) and MATTEI realising the electric-driven brake air-compressor with support from Univ. Aquila.
- Passive and active aerodynamic solutions. Aerodynamic CFD simulations were conducted in order to define the appropriate active and passive aerodynamic solutions to be adopted on the IVECO truck. The main focus has been on Active Grill Shutters combined with novel devices for wheel-arch flow-control on the tractor, together with purpose-designed aerodynamic fairings (including side-wings, boat-tails and spoilers) on the semi-trailer. Simulation results have shown a significant potential improvement of drag-resistance for the truck-semitrailer combination by adopting an appropriate aerodynamic kit.
- Dual-Level Cooling system. The system architecture of a Dual Level Cooling system has been defined, with a corresponding simulation model being developed.
- Predictive eco-driving HMI. The technical specifications of Eco-Driving system for IVECO truck demonstrator have been defined by CRF, the main focus being on developing a Predictive Cruise Control system. After developing the e-Horizon telematics platform (in SP B2), CONTI integrated this system also on IVECO demonstrator truck, with CRF and IVECO collaborating to update and refine the algorithms already developed inside the simulation tool for the Predictive Eco-driving HMI.

4.2. SP A2: Prototype Truck 2 (VOLVO)

The main objective of SP A2, led by VOLVO, was to develop advanced predictive energy management control strategies for a long-haul truck prototype including the cohesive control of cooling systems, propulsion systems and adaptive aerodynamics (by means of controllable air-deflectors) applied to a tractor semi-trailer combination. Correspondingly, in order to encompass the new highly integrated control strategies, both the electrical architecture and the electrical power supply had to be further developed. Moreover, controllable electrified auxiliaries have been used in the prototype truck: Specifically an electrically-driven cooling pump and an electro-hydraulic power--steering pump are incorporated to reduce the energy demand, with both components contributing to improve the vehicle fuel efficiency in a different way depending on the operating conditions.

In particular VOLVO has performed the following activities:

- Build-up of a complete vehicle model of the prototype truck, used primarily for control development and fuel saving assessment. The work has focused on specifying the prototype truck, collecting correct physical parameters and validations model data, collecting measurements for validation, and building up the simulation model itself.
- Preparation the VOLVO prototype truck: The main challenges have been the packaging of the electrical actuators and sizing the electrical systems (batteries, generators, etc.) for higher electrical power consumption. The chosen electrical architecture has been tested in the simulation model developed.
- Integration of the eHorizon system on the prototype truck: VOLVO received a prototype hardware from Continental in order to collects GPS data and map data and performed the integration tests.
- Development of the Human Machine Interface (HMI): It is believed that a good communication between the control system, the driver and the back-office reduces the fuel consumption. Driver use-cases and HMI strategies have been developed. Volvo received a full dynamic instrument-cluster from the partner Continental, which has been programmed according to the developed strategies. The prototype HMI includes a full digital cluster unit, which is used to develop the graphical user interfaces and the signal converter provided by CONTI, which converts DVI signals to LVDS and makes it possible to transfer the graphical interfaces from a desktop computer to the full digital cluster itself. This prototype “HMI System for Driver evaluation and coaching” has been completed by VOLVO.

- Development of the Predictive Energy Management system, used to control the electrified auxiliaries: A series of activities, including literature survey, set-up of the control structure and decision on approaches, were undertaken. Moreover, a thermal system model has been developed and optimized for on-board controllers. Improved aerodynamics using adaptable air deflectors was assessed with IDIADA analysing the optimal air deflector angles by means of CFD simulation while Volvo developed the adaptable deflectors.

The fuel consumption gain is shown by simulation. The purpose of the real prototype truck, shown in Figure 6, is to solve implementation problems and to prove functionality in a real application.

Fig. 6. The CONVENIENT prototype truck.

4.3. SP A3: Prototype Truck 3 (DAF)

The main results for this Sub-project, led by DAF, include:

- The formulation of the vehicle requirements and the definition of the vehicle mission.
- The development of a complete simulation model for the SP-A3 proto truck was carried out. Since not all vehicle parameters are available, some assumptions will be done and preliminary simulations are performed. After building up the proto truck, the parameters based on assumptions were updated and final simulations are performed with final assessment for the three prototype trucks.
- The ICT system has been developed. The quantitative layout study was performed with the final results.
- The development of the aerodynamic package for the SP-A3 proto truck with semi-trailer is in progress. The final aero-concept with active shutters and active mirror flow guides are mounted on the tractor. The semi-trailer will be equipped with Side Wings and a boat tail.
- The aerodynamic devices are investigated and the final hardware prototypes were built (shutters, mirror flow guides and boat tail). The aerodynamic hardware was assemble on the proto truck and the aerodynamic measurements are scheduled.
- The development of the OVMP (Open Vehicle Management Platform) was carried out. The communication mapping was defined and a database was constructed to host all CAN and Flexray messages used by the OVMP. The OVMP has been designed and a prototype was built. Testing of the prototype was performed.
- The smart vehicle powernet was developed and its communication protocol was defined. The smart powernet controls were developed for each programmable auxiliary present in the SP-A3 proto truck. The universal algorithms from smart vehicle powernet were mapped onto the OVMP. Initial simulations have been done for a limited set of auxiliaries and then will be extended to all auxiliaries.

Fig. 7. OVMP prototype.

- The development of an engine and after treatment previewer model was performed. The fit-tools, which estimate the model parameters according to measurement data, were developed. The models and fit-tools were validated by performing engine tests on a dynamometer (DAF MX-11 engine) and the previewer was developed. The first part of this previewer estimates the future vehicle speed and corresponding torque demand from e-horizon map data. The second part of the previewer contains the fast numerical models for the engine and after treatment to calculate the fuel consumption and emissions for the upcoming period. This information delivers input signals for the smart powernet.
- Building up the SP-A3 proto truck and a layout study were done. A redesign was needed because the envisioned high voltage battery was no longer available and the implementation of shutters in combination with extra radiators for the hybrid powertrain leads to cooling system packaging problems in the engine bay.
- The commissioning of the proto truck and static calibration were performed. More specifically, the OVMP and the individual auxiliaries (i.e. shutters, electric steering pump, electric air compressor, reefer trailer and plug-in charger) were tested separately to check their communication and set them into action.

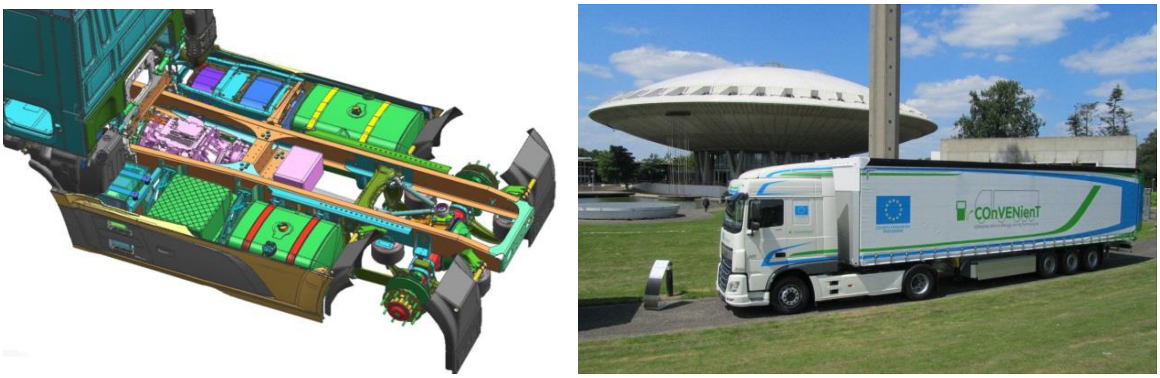

Fig. 8. CAD layout and realisation of DAF prototype truck.

4.4. SP A4: Vehicle Simulations and Final assessment (CRF)

The main objective of SP A4, led by CRF, has been to evaluate the enhancement of proposed technologies in terms of fuel efficiency at complete vehicle level, by means of the selected simulation tools, namely CRF-PERFECTS and AVL-Cruise respectively, both well-established tools for such fuel-consumption evaluations. In this context, one fundamental goal was to define the scope of the simulation by identifying appropriate reference missions to be used for the simulation activities. The activity performed led to the definition of the reference assessment criteria to be used to simulate the average fuel-consumption of a complete heavy-duty vehicle (truck-semitrailer combination), hence enabling also the validation of such simulations during the successive developing phases of the project.

During this activity, the interested partners of CONVENIENT have agreed that the reference missions should be coherent with the activities underway in the Working Group “Heavy-Duty Vehicles” of ACEA (www.acea.be). In particular, it was decided that the reference assessment mission in CONVENIENT will be the “Standard ACEA Regional Delivery cycle”, together with a modified version named ‘Legal ACEA Regional Delivery cycle’, coherent with the speed limitation in force in different European countries including Italy. These reference cycles are reasonably well correlated with the available experimental data-base related to IVECO Stralis long-haul trucks, the compliancy with real-user missions of the IVECO fleet having also been verified.

Moreover, in addition to the ACEA “Regional Delivery” cycle, other real-usage missions have been used during the course of project, with the aim to evaluate deeply some solutions under specific usage conditions, eg. the ACEA “Urban Delivery” cycle has been adopted for the evaluation of fuel-efficiency improvements related to hybrid transmission, while on-highway missions have been used for an overall comparison against real-usage data extracted from IVECO testing Data-base.

4.5. SP B1: Friction Reduction (MERITOR)

The main objective of SP B1, led by MERITOR, was the reduction of friction generated by rear-axle bearings and lubricating oil in the differential case, the principal result being a novel rear-axle prototype for integration on both the IVECO truck and DAF truck respectively. In particular, the following activities have been performed:

- MERITOR realized and tested the prototype axles for DAF and IVECO.
- The prototypes were developed integrating the pinion, differential and wheel end bearing provided by SKF.
- SKF developed the models of the specific bearing design and friction model with detailed knowledge of the sources of friction (bearing friction, gear friction, lubrication splash losses) on the rear-axle.
- MERITOR worked on the estimation of the drag reduction due to the new solution implemented.
- During the test campaign MERITOR tested some of the new oil specifications in order to verify any improvement on efficiency. In the meantime, SKF developed the low friction bearings.
- MERITOR performed a design study with DAF to integrate the new axle in the DAF demonstrator.

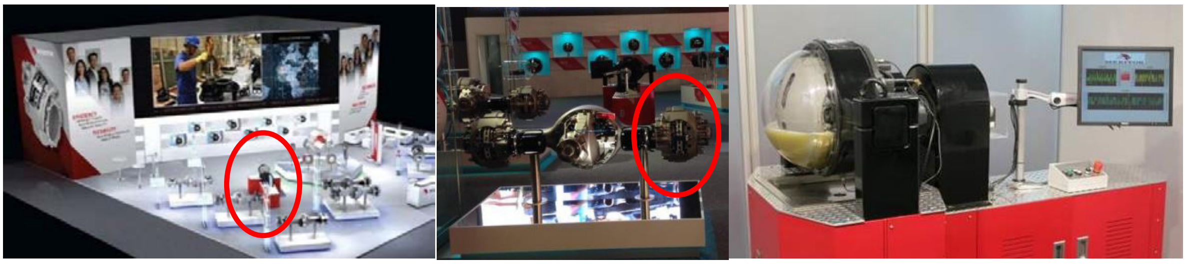

Fig. 9. Demo-bench with oil level control system in the differential.

The Demo bench with the new Friction Reduction Lubrication System was showed during the IAA exhibition (Hannover, October 2014). During the exhibition MERITOR demonstrated the differential oil level control system.

4.6. SP B2: Holistic Energy Management & Fuel-Saving Systems (CRF)

The Sub-Project B2, led by CRF, was a cluster of activities aiming to develop several technologies to be transversally used in the ‘vertical’ SPs A1, A2 and A3. The main results for this Sub-project include:

- The development of a Holistic Energy Management system. The partner Eindhoven of Technology (TUE) prepared a Roadmap of on-board energy management for heavy-trucks. This concept for smart vehicle powernet will be implemented in the DAF prototype vehicle in SP-A3.
- The development of a realistic simulation model for the electro-hydraulic power steering (EHPS) in MATLAB Simulink. This energetic model of the EHPS power-pack, based on the characteristics of the e-motor and the

hydraulic pump, has been developed by MAGNA ECS and provided to AVL and Fraunhofer Institute for the integration into a complete vehicle simulation model.

- The development of electrified auxiliaries prototypes. MAGNA ECS was involved in the development and testing of a functional prototype of a 24V Electro-Hydraulic Power Steering unit. The first samples available in hardware had been tested on a hydraulic test bench and on a truck at MAGNA ECS. The EHPS unit is a fully integrated power pack containing vane-pump, e-motor and power electronics in a single housing. The prototypes were sent to the three OEMs.
- MAGNA ECS was also developing an Electrified Water Pump (EWP), based on the requirements of VOLVO, using the same 24V electrical architecture of the EHPS. In this case, the power electronics for driving the EWP is separated from the EWP housing in a passive cooled external box to avoid the thermal impact of the hot cooling water. The EWP prototypes were tested on a pump test-bench.

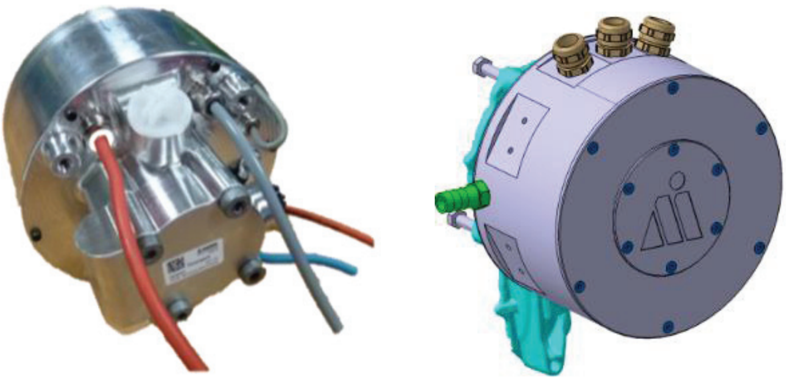

Fig. 10. Electro-hydraulic power steering (EHPS) and Electrified water pump (EWP).

5. Conclusions

The main technical objectives useful for the completion of the activities have been finalized on time with reference to the project plan and the consortium has achieved most of its objectives and technical goals.

In particular, the main specifications for the three prototype vehicles were defined by IVECO, VOLVO and DAF at the start of their respective sub-projects. Additionally, several key components have been developed by supplier partners, e.g. the electric-hybrid transmission by ZF and the low-friction rear-axle by MERITOR. Additionally, several important ‘building blocks’ of the project have been developed, e.g. the electrified water-pump and the electro-hydraulic steering-pump by ECS. Also the Low-Friction Rear-Axle Prototype issued by MERITOR is an important system for both IVECO and DAF demonstrators.

To fully achieve the challenging target of 30% fuel-saving, it will be also necessary to adopt additional energy--saving technologies, e.g. low-rolling resistance tires. Moreover the consortium will evaluate the possibility to further improve the fuel-saving of CONVENIENT prototypes, by gathering the outcomes of EU project as NoWASTE project (dealing with exhaust-heat recovery) and CORE project (regarding improved engine technologies) in accordance with the holistic approach to fuel-saving adopted in CONVENIENT project.

The CONVENIENT web-site (www.convenient-project.eu) has been activated since April 2013 and contains a detailed description of the project objectives, the carried out technical activities and the references to dissemination actions.

Acknowledgements

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