SEVENTH FRAMEWORK PROGRAMME

Switching the Gears for Innovative Diesel Propulsion The CleanER-D Project

Rail Diesel in Europe at a glance

The environmental benefit that rail carries over other modes of transport is a vital precondition in ensuring social and political support for this mode of transport. Although air pollutant emissions from the railways only contribute to a small proportion of total emissions from the transport sector, rail diesel exhaust emissions are increasingly attracting the attention of the public and authorities alike.

Nevertheless, the European railway sector is prepared to meet these challenges and the stricter environmental frameworks set by the European Union. The European railways have committed to "reduce their total exhaust emissions of NOx and PM10 by 40% in absolute terms even with projected traffic growth compared to base year 2005"[1]. CleanER-D will help the sector to reach these targets.

Approximately 80% of total transport volume is hauled on the electrified part of the network. Nevertheless, diesel traction plays an important role in providing rail services and serves as the backbone of railway operation in countries with little electrification, such as the UK, the Baltic states of Estonia, Latvia and Lithuania, as well as Ireland and Greece. Diesel locomotives have key importance for freight transportation and the liberalization of the freight market.

In 2004, the European Commission amended the Non-Road Mobile Machinery Directive (NRMM). This amendment (2004/26/EC) put railway engines in the scope of the Directive, from which they had been excluded previously. The step change from stage IIIA to stage IIIB, 3 years only after the implementation of IIIA as far as locomotives are concerned, represents a major step in terms of engine and after-treatment technology. Due in particular to limitations of weight and space inherent to railways vehicles, advanced technical adaptations will be necessary. Although some EU stage IIIB engines are available in time before the new emission legislation comes into effect in 2012, it has become clear that its integration into the vehicles still requires in-service experience before being considered as proven systems, guaranteeing the high reliability demanded in rail applications.

CleaneER-D (Clean European Rail-Diesel) is a research project partly funded by the European Commission under the 7th Framework Programme that started in June 2009. This 4 year project (budget: 13.6 M€ of which 8 M€ is funded by the European Commission) aims at developing, improving and integrating emissions reduction technologies for diesel locomotives and railcars.

A collaborative project to face the challenges

With the newly established emission level limits set by the European Directive 2004/26/EC soon coming into force, the ClearER-D project was launched to find technical solutions to the challenges faced in complying with this new regulation framework. The project also anticipates that further regulation is likely and seeks to provide the sector with dynamic and innovative solutions for future applications should new limits be introduced. Keeping this in mind, the project will analyse hybrid technologies and their contribution to the reduction of energy consumption and CO_2 emissions. In order to reach the goal of "greening" diesel vehicles, the consortium's 25 partners from across Europe are putting forth a strong, collaborative effort.

The project's main goal is to demonstrate the feasibility and reliability in service of railway rolling stock powered with diesel engines which are compliant with the requirements of state IIIB of the NRMM Directive. To ensure the achievement of the project objective(s), three operational projects have been established, two of which focus on re-powering existing diesel vehicles – a railcar and a locomotive – through a low-emission engine.

[1] *Moving towards Sustainable Mobility: European Rail Sector Strategy 2030 and beyond, UIC/ CER (2010)*

System requirement subproject

This sub-project provides a platform to engine and vehicle manufactures as well as operators to collect, monitor and evaluate the results delivered by the demonstration sub-projects. In addition to the coordination activity, the sub-project is responsible for developing the FMEA (Failure Mode and Effects Analysis) and the LCC (Life Cycle Cost) model to achieve a common understanding on the availability, reliability, safety and cost details.

In order to ensure successful monitoring, this sub-project organizes periodic workshops where experts from each stakeholder and the leaders of the 3 demonstration projects are invited. The representatives of the demonstration projects provide details of the latest stage of their developments which are discussed and analyzed by the expert group.

As a first step a generic system requirement specification for the different vehicle types was drafted based on the input of each demonstration project. This was followed by the analysis of the design and development phase of the rail vehicle developments. This phase was divided into 3 main milestones:

- Finalise emission technology
- Finalise consept design
- Freeze engine and vehicle package

The first phase focused on the engine technology path followed by the engine manufactures and explained the in-engine technology and new aftertreatment systems which had to be specifically developed for each individual vehicle due to the low emissions limit set by the stage IIIB requirements.

In the project, two different ways of lowering exhaust emissions were implemented; while all engines use a Diesel Particulate Filter (DPF), some reduce NOx emissions inside the engine by means of Exhaust Gas Recirculation (EGR) and others have opted for reducing NOx using Selective Catalytic Reduction (SCR) exhaust after-treatment.

Due to its larger NOx emission reduction capability, SCR has been the option for the smaller railcar engines, which have to comply with a 2.0 g/kWh NOx limit, but also for the US market, for the larger engines complying with EPA Tier4. This technology requires the vehicle to carry an additional consumable fluid (aqueous urea solution) as a reagent for the NOx reduction.

On the other hand, EGR has been the option for the larger locomotive engines which have to comply with a 4.0 g/kWh NOx limit. Although this path does not provide potential for much further emission reductions, it avoids the need for a second consumable fluid in the vehicle, and thus allows for a larger operational flexibility of the locomotives and does not require operators to special investments make in infrastructure for distribution and supply of such second fluid.

The next phase was in charge of the monitoring of the design and the design modifications to install the emission reducing engine and its aftertreatment systems. The main emphases were on the engine compartment, the cooling system and other vehicle interfaces with the engine.

Due to the new engine package, each vehicle builder faced weight and space constrains. These challenges were solved by modified vehicle design and by using practical solutions for the cooling system or for the space restrictions. In some cases the original parts were replaced by compatible but lighter or smaller components.

The third phase is the verification of the vehicle adaptation during the engine installation stage. It examines whether the originally planned modifications are sufficient or other modifications have to be made during the real installation work. During this period the vehicles builders and operators should make sure that the diesel vehicles are homologated and can be run on the field test.

The future work will focus on the evaluation of the test bed results and of the valid emission measurement data which will be carried out by each demonstration sub-project.

Railcar subproject

This sub-project aims at refurbishing a class 842 railcar with a new power-pack which complies with stage IIIB requirements. The objective of this exercise is also to deliver valuable information on local emission reduction for diesel railcars. The main partners in this sub-project are:

Czech Railways is responsible for integrating the engine into a diesel railcar

TEDOM delivers the stage IIIB compliant engine package

Consiglio Nazionale delle Ricerche is in charge of the emission measurement campaign on the vehicle

ATOC will ensure at the end of the project that the results of this sub-project can be implemented also for the UK vehicles which are known to have limited gauge restrictions.

The target of this re-powering exercise is to replace an almost 20 year old engine with an IIIB engine. In parallel, the Czech Railways are equipping the same Class 842 diesel railcars with IIIA engines. This work will allow the CleanER-D project to receive comparable data on emission and technical performance of IIIA and IIIB compliant engines.

This refurbishment project is unique in the CleanER-D project since it focuses on railcars, another vehicle type compared to the other demonstration project. And as mentioned in the system requirement sub-project, the specificity of this refurbishment is that in addition to the DPF system, a different emission reduction technology, called Selective Catalytic Reduction (SCR), is chosen.

To meet the emission limits EU IIIB, TEDOM has improved the engine type TD 242 series for railway application. To meet the new EU IIIB limits the following technologies has been developed and will be tested for the first time for rail application in the CleanER-D project:

- Selective Catalitic Reduction system to reduce NOx emissions
- injection system with higher injection pressure
- new piston design for low emission combustion
- closed wall-flow diesel particulate filter with active electrical regeneration system.

Currently, the engine test on the test bench was fulfilled, proving to meet IIIB exhaust limit values, and the engine is available to be installed in the railcar.

The feasibility analysis and customer requirement specification regarding the new engine installation contains preliminary technical, dimensional and operational inquiry for the development and operation of the IIIB engine TEDOM in the 842 railcars. During these tasks, the main concern was to find sufficient available under-floor space for the aqueous urea solution required for the SCR aftertreament system.

The next step is to carry out the engine installation work and get the homologation approval by the beginning of 2012. The railcar is planned to be operated on the Czech network. During this period, the reliability and emission performance will be investigated by the demonstration partners.

Heavy Haul subproject

The second demonstration sub-project – Heavy Haul – involves the installation of a new-generation *C-175* series engine manufactured by Caterpillar. The 16 cylinder rail engine is designed to comply with the stringent stage IIIB emission limits. In autumn 2011, the engine will be integrated in the newly designed Vossloh diesel-electric locomotive *EURO Light*. Once the installation is completed, exhaust gas emissions measurements will be carried out on the locomotive by the research center CMT Motores Térmicos of Universidad Politécnica de Valencia. Finally the prototype locomotive will be operated, performing revenue service under a special monitoring program.

This Heavy Haul sub-project has the special challenge of weight, mounting a 2800 kW power Stage IIIB diesel engine in a typical European four axle locomotive configuration, while not exceeding the maximum axle load restrictions with the addition of the new emission reduction components.

According to the requirements specifications defined at the beginning of the project, the selected emission reduction systems for the diesel engine were EGR (Exhaust Gas Recirculation) technology plus particulate aftertreatment, DPF (diesel particulate filter). This solution allows stage IIIB limits to be adhered to without using a second fluid (urea).

The EGR technology will reduce the Nitrogen Oxides (NOx). The DPF will reduce the particulates (soot and ash) and it will also replace the locomotive silencer. In order to remove the soot accumulated in the DPF at lower exhaust temperatures a pre-oxidation catalyst (DOC) is installed. This avoids the use of burners for active regeneration, and reduces maintenance.

The engine prototype has completed the required lab-tests at Caterpillars test bed facilities in the USA during early 2011. Currently, both engine and DPF aftertreatment are being installed in the locomotive at Vossloh's factory.

The new components allowing the locomotive engine to comply with the Stage IIIB exhaust emission limits also involve additional weight and installation constraints requiring vehicle modifications for their integration. The modifications have affected mainly: the cooling plant, locomotive roof hatches and air intake filters.

To maintain the same high power output of 2800 kW and at the same time keep the low axle load, weight reductions in other areas of the locomotive have also been necessary.

With the aim to minimise operational costs, the DPF installation design allows performing maintenance tasks on the aftertreatment without having to disassemble it from the locomotive.

Before the end of 2011, the locomotive will undergo the defined commissioning audits in order to validate the installation of the new engine package. The tests to be carried out include among others: vehicle noise, cooling and thermal tests, exhaust backpressure and engine pollutant emissions measurements.

The locomotive is planned to be placed into service in the first quarter of 2012 and operate under a special field-follow program. During this period, the partners will focus on the reliability and maintenance aspects of the new low-emission components in order to optimise and validate their performance under real operating conditions.

Light Weight subproject

The Light Weight subproject has two objectives to accomplish during the project duration. The heart of the subproject is to carry out a field trial with a modified freight locomotive from Deutsche Bahn AG (DB AG) which meets the Stage IIIB emissions requirements. In addition, the subproject focuses on monitoring the performance of the SNCF locomotive Type BB69419.

The following companies are involved in this sub-project:

- MTU Friedrichshafen GmbH, leading the Light Weight sub-project, provides a prototype engine with diesel particulate filter (DPF) which complies with EU Stage IIIB emissions legislation.
- Deutsche Bahn AG installs the Stage IIIB-compliant drive system in an existing freight locomotive (BR225 008-2) and operates the prototype in normal service.
- Voith AG provides the project team with support on transmission and cooling system technology.
- SNCF contributes expertise gathered from its experience with DPF systems in shunting locomotives.
- The research laboratory APTL/CERTH conducts measurements in the locomotive.

The project team has equipped the locomotive with a prototype 12V4000 engine with exhaust aftertreatment technology for a 14-month period of field trials under realistic working conditions. The data gathered during the trials will make a significant contribution to the development of environmentally-friendly locomotives and multiple unit trains.

The prototype 12V4000 engine produces 1800 kW at 1800 rpm. The engine is a further development stage of the current engine of Series 4000R43. To meet the emission regulation IIIB, the engine is equipped with new technologies:

- Cooled Exhaust Gas Recirculation
- Two-stage Turbocharging with Intercoolers
- Enhanced low emission combustion system
- Injection system "LEAD²" with higher injection pressure

In Addition, a diesel particulate filter (DPF) is attached to the engine. This exhaust aftertreatment system incorporates a passive regeneration DPF dimensioned and designed by engineers at MTU Friedrichshafen GmbH.

New MTU series 12V4000R84 with EU stage IIIB certificate

In spring 2011, the calibration of the prototype engine and DPF-system was finalized on a test bench by MTU specialists. The aim of meeting all emission and vehicle requirements, while keeping in mind the need for high fuel efficiency – was achieved.

During the summer, Deutsche Bahn AG has installed the prototype system into the Type 225 locomotive. This freight locomotive was originally powered by a 12V 956T B10 engine dating from 1971. Therefore, modifications to the engine bed, gearbox, cooling system and other assemblies were needed, in order to adapt the locomotive for the new engine which is designed for future needs.

The German Federal Railway Authority (EBA) has accepted the undertakings so that there are no obstacles to the homologation of the locomotive.

Deutsche Bahn AG and MTU Friedrichshafen GmbH are working closely together with the other partners involved in Sub-project 4. This intensive cooperation between all participants has facilitated the development of an extremely promising concept.

By autumn 2011, the integration of the engine and its auxiliaries into the locomotive will be completed. After commissioning and completion of all relevant checks, the locomotive will be handed over to DB Schenker and operated in regular service for 14 months. The engine and exhaust aftertreatment system will undergo a comprehensive program of inspections and measurements in order to gain information on how the system performs.

Integration of the MTU prototype engine into the Type 225 008-2 locomotive at the DB AG workshop in Bremen in April 2011.

The locomotive BB69419 from SNCF is equipped with a commercially available DPF-system. The fourth subproject has installed a data logging system on this locomotive. SNCF operates the locomotive during common service. Different temperature- and pressure-sensors give an indication, how the system performs.

The experience and information gathered throughout all the phases of the project will provide an invaluable basis for the development of future, environmentally-friendly rail vehicles.

Sustainability & Integration

The total worldwide emissions from rail diesel traction are very low today; compared to the whole transport sector less than 2.5% (NOx) and 4.5% (PM) are emitted from rail diesel traction. The emissions of NOx and PM have already decreased by ~ 35 % from 1990 to 2008 and calculations by the CleanER- D consortium suggest a further decrease of NOx by more than 30% and more than 40% for PM from 2008 to 2020. The reasons for this significantly better performance are mainly:

- The introduction of cleaner engine technologies and limit values (stage IIIB) into the European vehicle fleet,
- A smaller diesel traction fleet and lower total mileage of vehicles with old engines,
- Electrification of railway lines and,
- More efficient operation of diesel locomotives and Diesel Multiple Units (DMU) due to higher load factors and occupancy rates.

The CleanER-D project has been strongly focusing on the socio-economic and green aspects of rail diesel applications. Rail is proven to be the most environmentally-friendly mode of transport. Special attention must be devoted to improve the emission performance of diesel-powered vehicles which still constitute about 20 % of European rail traffic volume. The calculation of life cycle costs and the development of a methodology for cost/benefit analysis are core elements of the "Sustainability & Integration" sub-project in order to assess the impact of the introduction of clean diesel technologies for rail. Finally, optimisation of technical solutions and possible trade-offs will be studied and identified.

The first study developed by the sub-project is called, "Sustainability Study". It tackles the major factors that influence the European rail diesel vehicle fleet and related future diesel exhaust emissions. The baseline of this work was the "Rail Diesel Study"[1] from 2006. This data has been updated with information coming from latest studies and results of a questionnaire survey among European operators of rail diesel vehicles. For the first time, the inquiry included the number of replacement engines and average mileage per vehicle type, power class and age. An overview of existing legislation and the comparison of specific emissions of rail compared to other modes are part of the Sustainability Study as well.

Together with an assessment of future emission reduction technologies, the findings of the Sustainability Study will be completed in a Sustainability Impact Assessment which will include the social, economical and environmental impacts of the future diesel fleet. Finally, the Sustainability and Innovation sub-project will aiming at providing sector-wide agreed recommendations on future emission reduction approaches and strategies of rail diesel traction in Europe.

[1] Rail Diesel Study, UIC/ UNIFE (2006)

Emerging Technologies

The emerging technologies work is focused on identifying the state-of-the-art on low emission technologies (after-treatment systems) suitable for railway application; benchmarking such technologies applied to other transport modes; assessing the impact and feasibility of using innovative low-emission technologies on engine and rail vehicle performance and integration; and finally providing recommendations on existing and alternative solutions for emission reduction of diesel railway vehicles based on potential scenarios beyond stage IIIB.

The state-of-the-art and benchmarking exercise has provided a clear indication on the path that technology is likely to follow. Automotive applications are currently at the forefront in terms of development and they are likely to be the future candidate solutions for railway application, albeit with the necessary modifications.

At the core of the research activities of this sub-project is the analysis of the impact that current and future innovations, in terms of after-treatment systems are likely to have. To achieve this, numerical models are being developed to perform an SCR v EGR (Selective Catalytic Reduction v Exhaust Gas Recirculation) analysis as well as to optimise SCR-EGR-DPF designs and strategies. Other key activities include a strong focus given to the influence of fuel type and quality on emissions, evaluating DPF (Diesel Particle Filter) regeneration strategies, and assessing emerging after-treatment technologies using stage IIIB emissions levels as a baseline, but also researching the suitability of these solutions beyond IIIB. Numerical simulation tools, including computing fluid dynamics are being developed to complete these tasks.

Specifically, a V8 560kW engine model has been developed. This model will be used in conjunction with other numerical tools to perform the work described above. Starting from a current state-of-the-art solution to meet Stage IIIB emission levels (engine with EGR plus DPF v engine with SCR) the work will assess increasingly tighter emission levels that would require an optimised solution involving engine with EGR plus DPF and SCR. The effects on factors such as BSFC (Brake Specific Fuel Consumption), emissions and urea consumption will be assessed. To complete this phase, technologies in the research domain, such as those currently being developed to meet automotive's Euro VI legislation will be also evaluated to understand the potential limitations in railway applications.

The main outcome of SP6 will be an understanding of the capability and limitations of potential after-treatment solutions that could be applied to rail vehicles reducing the emission levels beyond current requirements.

The results of this sub-project will be evaluated from a technical feasibility perspective, feeding back to the Sustainability and Integration sub-project where a deeper cost-benefit analysis will be performed.

Hybrid Solutions

This subproject is evaluating the energy saving potential of onboard energy storage systems (ESS) for diesel-driven rail vehicles. The use of the so-called hybrid drive systems ensures a higher energy efficiency and therefore reduces fuel consumption and minimizes both CO_2 and pollutant emissions. Normally, a conventional diesel-driven train mainly dissipates the braking energy into heat by the braking resistor.

Technologies of hybrid drive systems and their influence on reduction of fuel consumption and emissions based on definition of "standard duty cycles" for different rail vehicles types will be investigated.

The state of the art hybrid technologies highlight different technologies for onboard ESS, such as flywheel, hydrostatic accumulator, double-layer capacitors and batteries. Recent innovations were described for urban rail vehicles, trams and metros but also for mainline rail vehicles and shunters. A potential technology transfer from developments made in road transport and stationary applications seem possible.

The review has identified a high potential for energy storage technologies in rail applications. This is particularly relevant for urban and suburban rolling stock as duty cycles involve frequent stops. Based on these, battery technology and double layer capacitors appear to be the preferred solution.

Duty cycles for different diesel powered rail vehicles – suburban Diesel Multiple Unit (DMU), regional DMU, high speed DMU, intercity locomotive, freight mainline locomotive and shunter – were defined to determine the energy performance and the emissions. Furthermore, comparable data for rolling stock were collected to define standardised duty cycles which can allow comparisons.

Parameters of typical diesel vehicles including fuel and emission mapping charts from existing UIC II and IIIA compliant engines, as well as three transmission types (hydrodynamic, hydromechanic and diesel-electric), efficiencies, etc. were described. These will be used for virtual synthetic vehicles to simulate the potential fuel and/or emission savings by hybrid systems.

A detailed analysis for different energy storage technologies were realized to define the most appropriate architecture for train integration. A common basis was agreed in order to provide data for the global modelling, see Figure 1.

On the most demanding identified duty cycle – regional train with altitude – a detailed analysis was elaborated for each ESS technology to validate the fitting within constraints allowing possible field integration. Redistribution of the recovered energy during braking was considered to allow stopping the motor at turn points and supporting acceleration with the remaining energy. Corresponding parameters for the global model were provided as a basis for upcoming tasks to refine on-board energy management strategies.

A ranking of system architectures has been done. First simulations in the backward mode identify that fuel savings of up to 30 % can be achieved when comparing the same system architecture with and without ESS. Verification of results has been done with other simulation tools, showing that the simulation approach is giving reasonable results, see Figure 2.

All defined parameters, elaborated results and the created model library (tool box) will be used to simulate different system architectures and different ESS technologies. The standard duty cycles and the different "synthetic" rail vehicles will be the base to compare the simulation results for emissions and fuel consumptions.

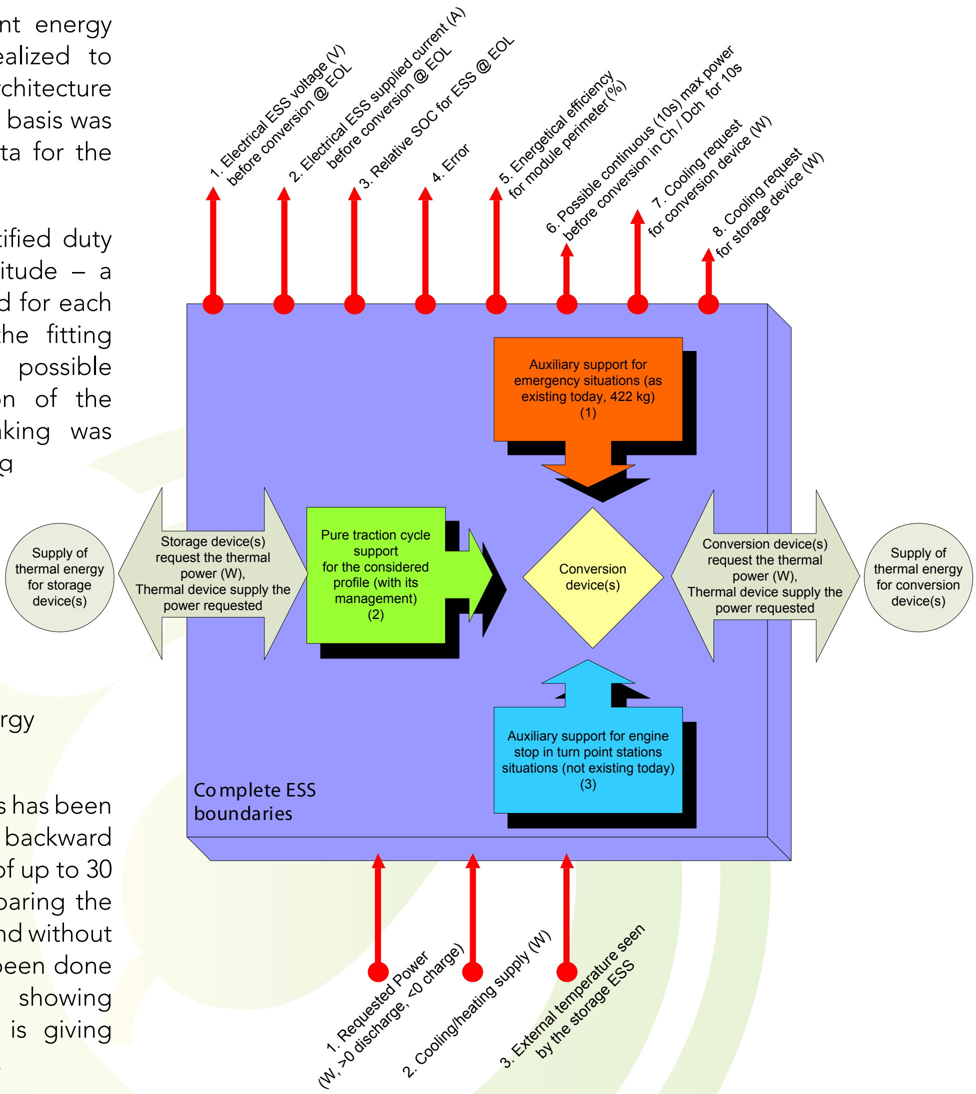

Figure 1: Common model interfacing for ESS technologies

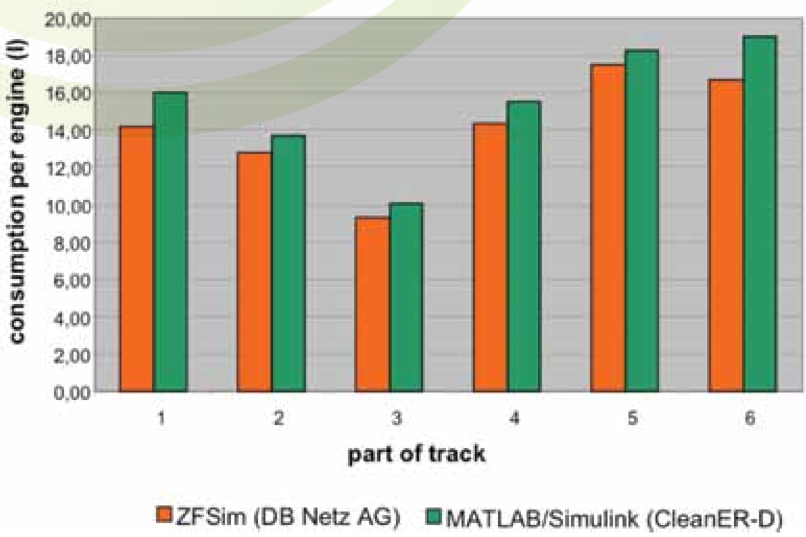

Figure 2: Comparison of results between the ZFSim-tool from DB and the SP7-tool for a 170 km track divided in 6 parts: fuel consumption per engine

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