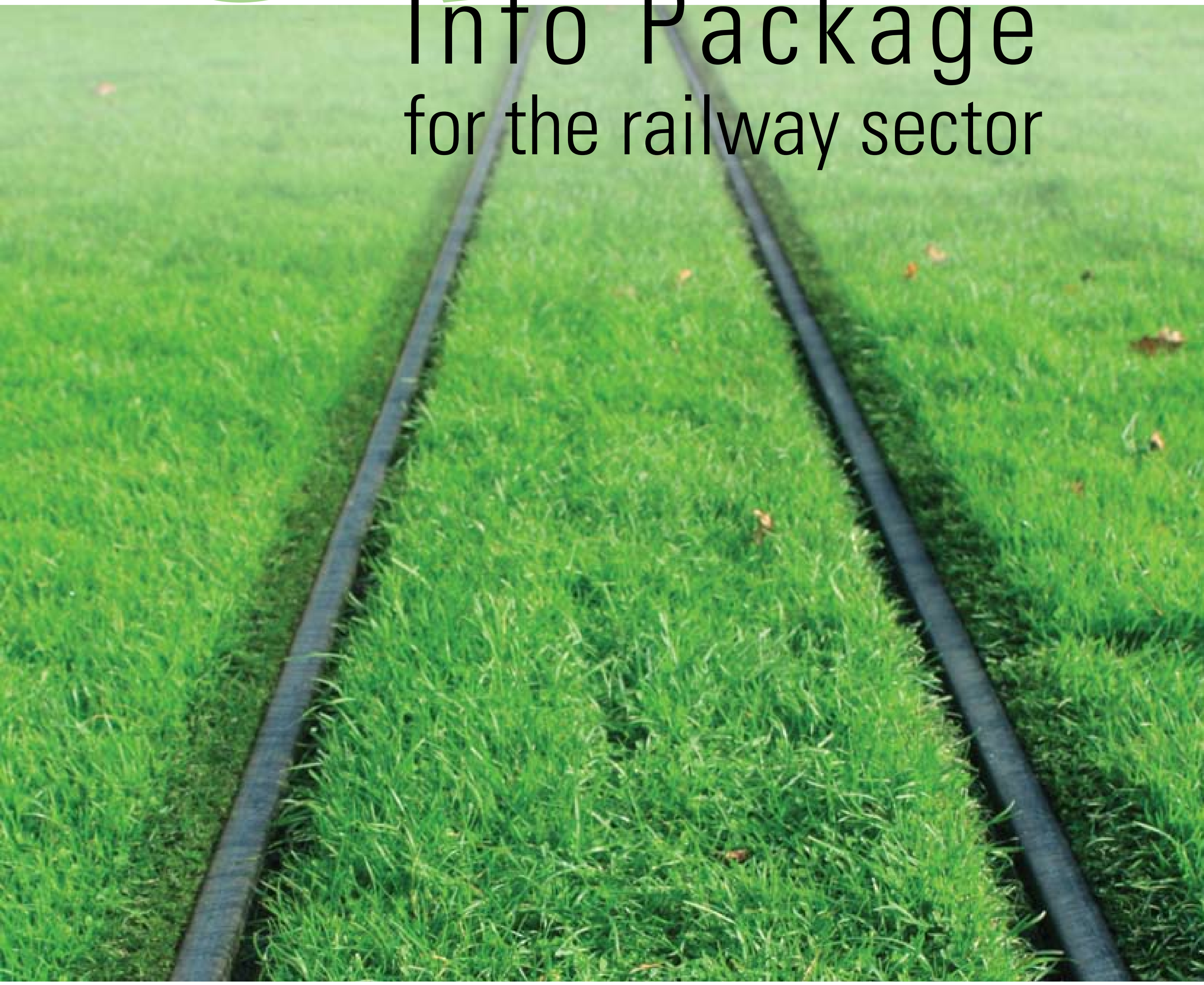
SIXTH FRAMEWORK PROGRAMME

GREEN Info Package for the railway sector



UNIFE
The European Railway Industries

UIC

GREEN

GREen heavy duty ENgine

Final report for the rail sector

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Project summary

The main objective of GREEN was to develop an intelligent flexible Heavy Duty (HD) engine system able to achieve maximum fuel conversion efficiency, while complying with a zero-impact emission level. As fallout of the achieved knowledge and realised technologies of such an integrated combustion system, innovative HD diesel and gas prototype engines were developed. These technologies will allow Europe to maintain the leadership in the production of internal combustion engines in the years 2012 – 2016, while allowing the completion of the integrated combustion system in an innovative powertrain.

The future GREEN engine consists of:

- Flexible components
- A new combustion process
- Closed loop emissions control
- High power density
- Suitability for renewable fuels
- Integrated exhaust after-treatment system

In the GREEN project, the main focus is on on-highway engines and is represented by the big road engine manufacturers and component suppliers Volvo, Iveco, Ford, Daimler Chrysler, FIAT, Deutz, Bosch, etc. The railway sector is represented by UIC, UNIFE and MTU.

UIC, UNIFE and MTU examined the possibility of transferring new on-highway technologies for in-cylinder reduction of exhaust gas emissions to railway applications, responding to the demand of minor emissions from diesel locomotives. Based on the undertaken research it is to be stated that the GREEN Heavy Duty engine can be transferred to the railway sector.

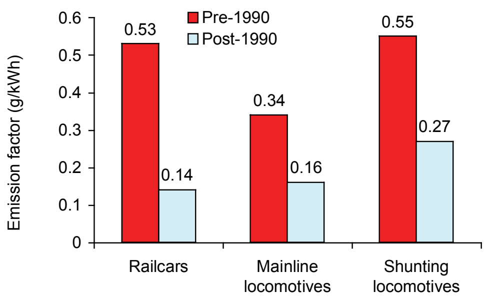
Diesel Engines and Emissions

Among surface transport modes, road transport and international waterway navigation produce the largest fraction of the pollutant emissions (NOx, PM) in this group. Due to an increase in transport by waterway navigation, emissions increased between 1990 and 2001, whilst road transport emissions decreased.

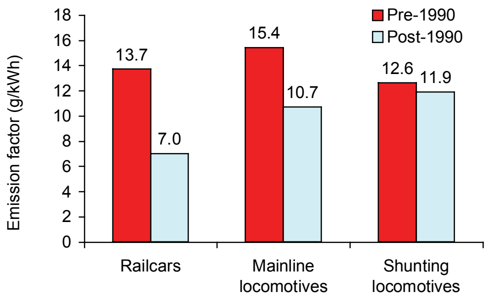
Rail's share of emissions is comparably small (1-3%), but emissions generated locally by individual diesel vehicles may be highly perceived by the population living nearby. This is to be particularly considered since increasing attention on air quality is paid by the public and authorities, and it seems that often air quality limits are being exceeded in various European hot spots.

The European Parliament and the Council agreed on amendments to the Non-Road Mobile Machinery (NRMM) Directive 97/68/EC. The Directive was reviewed and the revised version was published as Directive 2004/26/EC. The scope of the Directive has been extended to cover all new diesel engines for railway vehicles. This means that emission limits for new engines for railway use are provided by legislation at European level. Stage IIIA limits for NOx and PM emissions came into force at the beginning of 2006 for railcars and will come into force by 2009 for all types of locomotives. Stage IIIB limits will come into force in 2012 for railcars and locomotives and particularly tightens PM limits by around 90% relative to Stage IIIA.

PM emissions of European Diesel fleet



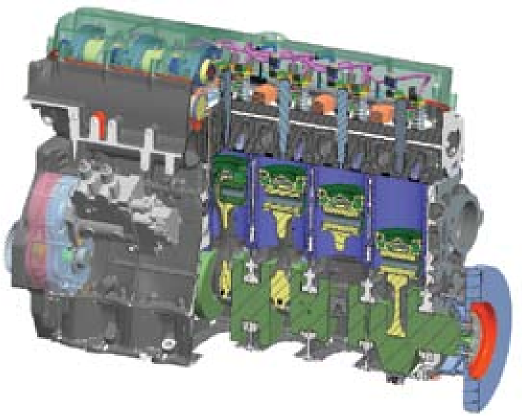
NOx emissions of European Diesel fleet



Source: UIC Diesel Study Group

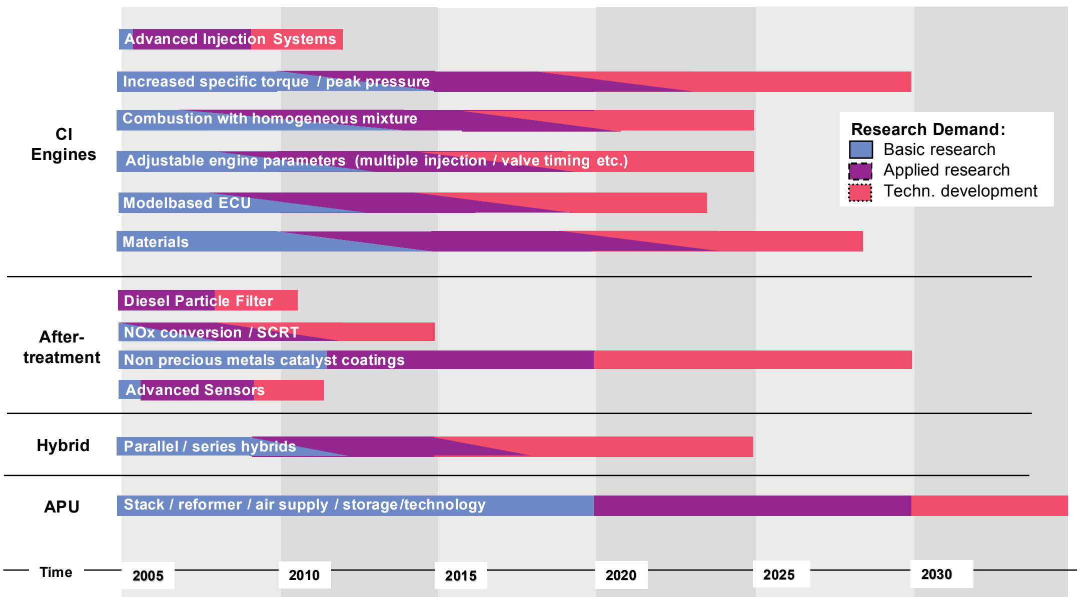
The GREEN vision

The impact of Transport systems on environment as well as the reduction of the worldwide energy resources motivates the improvement of internal combustion (IC) engines in terms of efficiency and emissions reduction. Regarding the real input on environment, IC engines with liquid hydrocarbons will continue to dominate in the future. Alternative propulsion systems will achieve significant market-share and contribute to the security of energy-supply. Future on- and off-highway heavy-duty engines will have to fulfill strict regulations for emissions (including noise) as well as for greenhouse gas emissions and in particular CO_2. It is therefore necessary to develop powertrain systems that, being cost effective, are able to face the medium-long term challenge of the global market and in the meantime are multivariable to prepare the transition to the technology available after 2020.



The need for high specific engine output and optimized well-to-wheel efficiency of HD diesel engines based on hydrocarbon fuels will continue to be a driving factor. However, the expected reduction capacity of noxious exhaust gas emissions and particulates, beyond Euro 5, are much more difficult and risky in terms of cost and energy. For delivery trucks and busses also gas engines with efficiency close to today's Diesel engines provide high potential for emission reduction in urban areas. Key issues in this field are new combustion developments with best air utilization, homogeneous mixture, high in-cylinder peak pressure engines, including flexible components and advanced emission and after-treatment systems, connected with model based closed loop control systems to fulfill simultaneously the objectives of extremely low CO_2 and zero-impact emissions during transient conditions as well as noise.

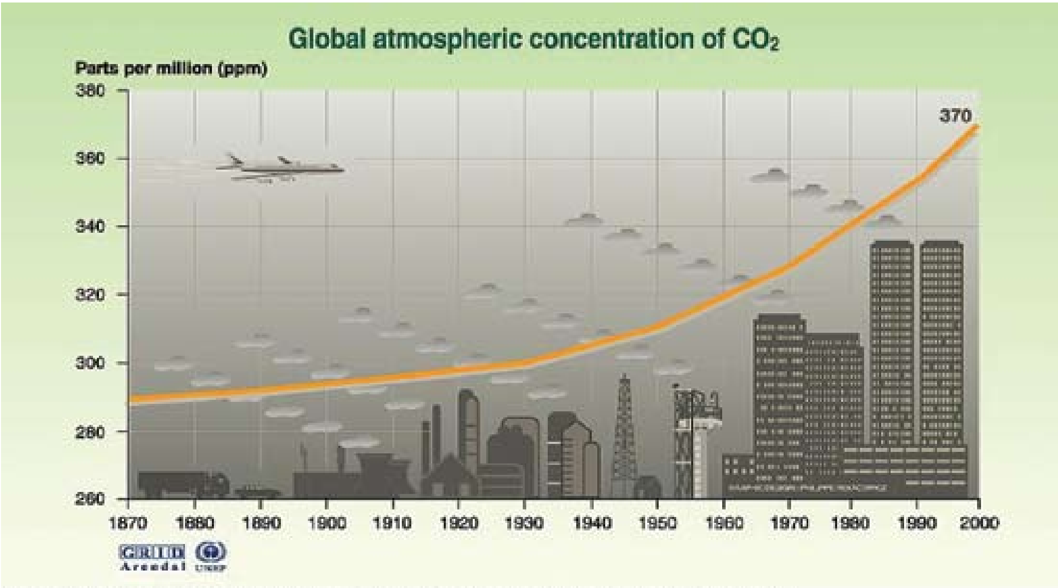
Heavy Duty Vehicle Powertrain Road Map



Source: UIC Diesel Study Group

The vision for future heavy-duty engines is a 'green' engine technology, which combines highest efficiency from well-to-wheel with zero-impact emissions and significant reductions of CO_2. It will be characterised by an advanced integrated combustion process and the integration of an advanced after-treatment system to a single unit. Both combustion process and after-treatment will interact by a modelbased control system, as today's sensor reaction times are too slow for transient operation. Flexible engine components offer potential for fuel-consumption reduction and optimised control integration of combustion and exhaust after-treatment.

The operation with modified liquid hydrocarbon-based fuels (pure and blended diesel) and gaseous fuels offers the cost/benefit optimum for HD diesel engines in the future. For buses and delivery trucks in urban areas, gas engines with efficiency close to today's HD diesel engines, taking into account near-zero-emission targets, will be an issue.

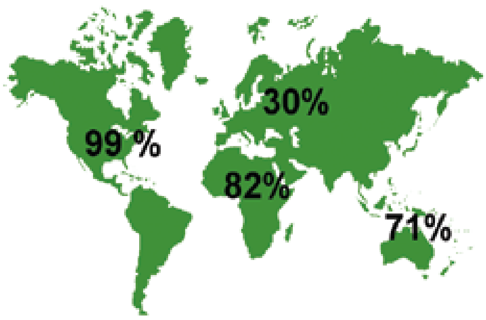


Sources: TP Whorf Scripps, Mauna Loa Observatory, Hawaii, Institution of oceanography (SIO), university of California La Jolla, California, United States, 1999

Diesel traction in the World

The European railway network is the most dense in the world and features the highest percentage of electrification totalling almost 70%. On the electrified part of the network about 80% of the total transport volume (Passenger + Freight) is hauled. The main lines in Western Europe that have been or will be partly turned into high-speed lines are operated by electric traction exclusively. For lines in rural areas and in the Eastern European countries Diesel traction still plays an important role. Further use of diesel locomotives hauling freight trains avoids time-consuming traction changes at the national borders.

Diesel traction in Europe hauls only approx 15-20% of the railway transport volume whereas diesel traction in North America covers more than 90% of the total railway transport volume. In North America the market share of the total freight transport volume hauled by rail is approx 40% whereas in Europe it less than 15%.



The percentage non-electrified networks on the countries

The Asian continent and Oceania are very inhomogeneous covering the percentage of electrification. Although generally only one third of the entire "network" is electrified some countries like Japan, Taiwan and Azerbaijan with 60% electrified network stick out. Only a few countries such as Japan and Korea operate a high speed network. The majority of Asian and Oceanian freight and passenger trains are hauled by diesel locomotives.

In Africa the electrification of railway lines is limited to the every northern part of the continent (Egypt, Morocco and Tunisia) and South Africa with 42% electrification. The majority of trains on the African network are hauled by diesel propulsion.

Number of Diesel locomotives and DMUs in the world:

	Locomotives	DMU
Europe	16 153	10 007
Africa	3 950	133
America (UIC members only)	23 808	6
Asia and Oceania	20 617	2 476

The average age for locomotives in Europe is 27 years and 16 years for DMUs. It has to be underlined that the Diesel rail fleet is not a homogeneous entity. Some vehicles are intensively used whereas especially older ones are just used supplementary.

Transferring GREEN to the railway sector

UIC, UNIFE and MTU aim to apply technologies for the near zero emissions HD diesel engine, under development by the GREEN project, to locomotives on non-electrified tracks for the railway sector.

List of rail specifications

In order to apply the HD diesel engine technologies to diesel locomotives and multiple units UIC & UNIFE have drafted a list of rail specifications:

- **Fitment space engine + periphery < 110%**
  Path 1: EGR-concept: 110% is possible from today's point of view
  Path 2: SCR-concept: only with considerable development effort achievable

- **Weight of engine + periphery < 110%**
  Path 1: EGR-concept: 110% is possible from today's point of view
  Path 2: SCR-concept: ca. 115% is achievable from today's point of view

- **Purchase cost of all traction equipment incl. engine + periphery and transmission < 110%**

- **Purchase cost of the engine incl. additional components, cooling equipment, auxiliary equipment and exhaust post-emission treatment < 120%**

  No exact quantitation possible. From today's point of view engines with exhaust gas after-treatment will become significantly more expensive than today's engines without after-treatment.

- **Operating costs incl. maintenance < 105%**

- **Costs of operating substances (fuel, oil, coolant, reducing agent, etc.) < 100%**

  No exact quantification possible. To achieve these values is the target of the MTU development strategy.

- **Engine + periphery overhaul intervals (DMU traction unit < 600kW) > 800 ton km**

- **Engine + periphery overhaul intervals (locomotive traction > 600 kW) > 1.2 million km It is expected, that the same standard as today will be reached.**

- **Transmission overhaul intervals (DMU traction unit < 350kW) > 800 ton km**

- **Transmission overhaul intervals (DMU traction unit > 350kW) > 1.6 million km**

- **Transmission overhaul intervals (locomotive traction > 600kW) > 2.4 million km There will be no change in the required specifications of the transmission due to the emission concept.**

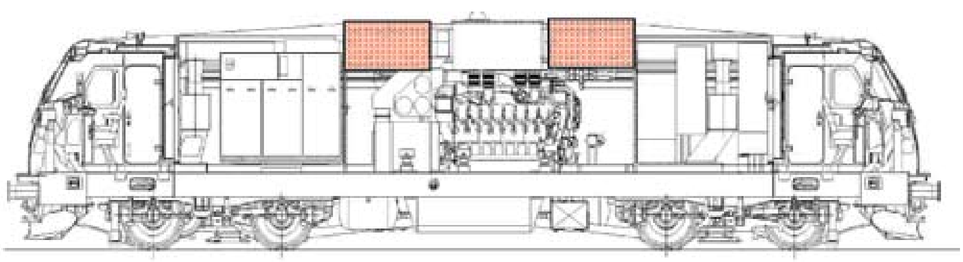
- No second operational fluid In the case of SCR an additional fluid is necessary.
- No restrictions regarding suitability for rail sector use (idling, non-stationary load profiles, ambient temperatures, vibrations, etc.)
- Approval in accordance with UIC Leaflet 623 “Approval procedures for diesel engines of motive power units“

Vehicle characteristics – space, mass & length

Diesel rail vehicles are usually classified into Diesel locomotives and Diesel railcars (DMU). Both vehicle types are mainly used in Europe on non electrified branch lines, which are characterized by a limited allowable axle load (max. 18t/axle) and small tunnel profiles (Tunnel profiles in UK are the smallest in Europe. The maximum allowable height of rail vehicle built for UK is almost 30 cm lower than for the rest of Europe. They are designed for a service life of 30 years.

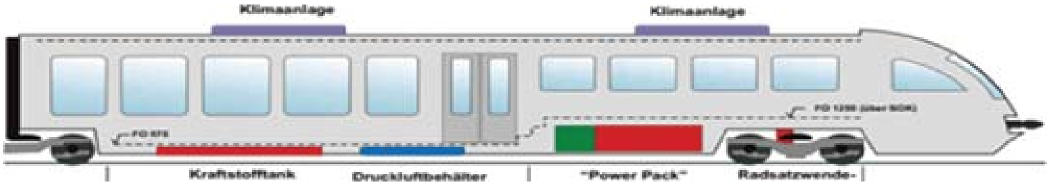
Diesel locomotives

European Diesel locomotives are normally powered by one high-performance engine (>560 kW- 3000 kW derived from marine, mining or stationary engines) and are used for passenger and freight services. The power equipment is installed in a special machine room inside the locomotive’s body. A typical European 4-axle locomotive is shown in figure 1.



Diesel railcars

Diesel railcars (or DMU) are designed for passenger service only, are either single coaches or fixed coupled consisting of 2 or max. 3 power cars. Normally, each unit is driven by one medium power engine (250kW < 560kW), which is often a derivate of off-highway industrial or on-highway truck engine. The power equipment is installed under floor, e.g. below the passenger cabins. For a typical Diesel railcar refer to figure 2.



Common aspects for locomotives and railcars

In contrast to electrical rolling stock both diesel driven vehicle types have to carry their own energy source onboard (1-2 tons fuel for railcars/ 2-8 tons for locomotives).

Today, both the general requirements caused by the rail infrastructure (tunnel profiles, max. axle load) and the functional requirement to carry the locomotive's own energy supply onboard force the manufacturer to utilise all available space in, under or above the vehicle (refer to figure 1 and 2).

Latest investigations of the European rolling stock manufacturers show that meeting the new Stage IIIB emission limits of 2004/ 26/EC will require voluminous additional equipment to be installed in rail vehicles. "Stage IIIB" will require the following additional external equipment:

- Exhaust gas after-treatment systems for NOx reduction (SCR, with urea tank, heated piping and NOx catalyst) and particulate filter (DPF) require additional space and weight.
- As cooled exhaust gas for the modified combustion cycle is required, a larger engine cooling system is the consequence.
- Space for additional auxiliary power needed (e.g. for larger cooling fans).
- Engine weight increase
- When the lengths of the locomotives increase to package all the above mentioned additional components the body has to be strengthened too, this causes an additional increase in axle load.

  Realistic assumptions show a weight increase of 3 to 4 tons for a 4-axle locomotive and about 0.5 – 1 ton for railcars.

  Even modern existing 6-axle locomotives, which are the largest and most powerful used in Europe, have axle loads of more than 21 metric tons today. This limits its use to high capacity main lines.

  Facing the general arrangements of modern diesel rail vehicles it must be stated that today's locomotives/ railcars have already reached their regulated size and weight limits.

  Consequences of increased weight and space, due to additional equipment for Stage III B equipment:

Locomotives:

- Restricted use of 4-axle locomotive on branch lines (due to weight), and into customer's terminus (shunting).
- There is a risk that locomotives may no longer be allowed on non-electrified branch lines and in rural areas; this threatens rail freight as cost-intensive electrification as an alternative is questionable.
- Limited space and weight may be counteracted by integrating a smaller and lighter engine with reduced power but this increases the number of locos necessary for rail service thus higher transport cost
- When axle load must be increased to allow heavier equipment and vehicles must be longer, rail infrastructure must be improved. very high cost
- Avoid a Modal Shift from rail to road. (One 2000kW locomotive hauls the same freight volume as 50 trucks with 400kW each.)

Railcars:

- Loss of passenger capacity due to additional space requirement for After-treatment device

Re-engining and in-use experience aspects

Re-engining meaning the installation of this additional equipment in an existing railcar/ locomotive structure- is impossible for the majority of vehicles.

By far the largest application of particulate filtration to rail vehicles to date is on 73 locomotives built for SBB (Cargo and Infrastructure Division), 3 Locomotives G-1700 for BLS and 3 Locomotives G-1700 for Sersa and the re-powering of 5 SNCF shunting locomotives. Furthermore the SBB Infrastructure Division started in 2007 to equip all of their traction equipment and motorised vehicles (for example self propelled platform cars) with particulate filters. This counts for several hundred units. SBB has also equipped the DE-6400 locomotives from

Eurotunnel with particulate filters. It is, however, premature to attempt to extrapolate the experience gained on those locomotives to general rail operation. Swiss line haul rail service is currently being entirely electrified and the SNCF equipment only started in late 2006.

In order to verify the operational constraints associated with the use of particle filters, SNCF has, for example, just equipped a number of locomotives powered by new generation engines with a very good emission performance. Feedback is already highlighting a number of constraints linked to the reliability of certain parts which were not designed for railway use, as well as issues linked with the need to clean the ceramics on a regular basis (aspiration of ash, for example).

Even though the increase in fuel consumption can be considered reasonable, we should not forget the additional fuel consumption generated by particle filters and their temperature control devices.

For re-engining the design is not flexible and the space is not always sufficient to accommodate the systems in question.

HD engine development and test

MTU aimed to develop a new combustion concept for diesel rail engines which allows fulfilling future emissions legislation (2012 and later). The technologies used for HD truck engines offer possibilities to be transferred to rail engines. However, it is important to pay attention to the different operating conditions in rail applications. Engines for railcar application with power output less than 560 kW are usually derived from HD engines, and the transfer of technologies is relatively easy to realise. "Locomotive" engines with power output of typically 1000 kW to 3000 kW are not derived from HD engines. The transfer of HD technologies to these engines is much more difficult to achieve and for this reason, the investigations of task 0.3.2 are concentrated on locomotive engines. Here, the focus is on the in-cylinder reduction of NOx-emissions in order to be able to fulfil future NOx-emission legislation without after-treatment. Regarding the particulate emissions, a DPF might be possible.

In a first step the possible in-cylinder measures (from on-highway heavy duty applications) for the reduction of engine-out NOx raw emissions in locomotive applications have been described and evaluated. The study has shown that technologies like EGR (Exhaust Gas Recirculation), homogeneous combustion and variable valve actuation are the most promising ones for rail application.

For this reason, in a second step a new combined combustion process (conventional combustion with EGR + HCCI) has been thoroughly examined on a single cylinder engine. Altogether this combined combustion has given promising results. However, it has been shown that the benefits of this combustion can only be exploited at part load and that at full load the necessary EGR rate can not be reduced, compared to a pure heterogeneous combustion. Hence, the full load point will be operated in pure heterogeneous combustion with EGR (this is also a new HD-technology that has been transferred from on-road to rail application in task 0.3.2), and the desired reduction of the necessary cooler size in the locomotive can not be realized. This result impacts the cooling system of IIIB-compliant diesel locomotives since either the efficiency of the cooling system or the dimensions of the coolers has to be increased.

In a third step, the new EGR-concept has been examined on a multi-cylinder demonstrator engine (prototype).

Altogether, the outcome of the research is a combustion process which meets the EU-stage-IIIB limits. Based on these results, an EU-stage-IIIB compliant diesel engine is currently developed at MTU. Emissions of nitrogen oxides are reduced by an EGR combustion process and the emissions of particulates are reduced by a diesel particulate filter (DPF). Within the scope of the CleanER-D project, that was submitted to the European Commission under the EU 7th Framework Programme 2nd call, the first prototype-engines will be intensively tested in different rail applications – in a mainline locomotive and in a shunting locomotive. Therefore it can be concluded that the results of the GREEN project provide important input to the CleanER-D project.

Consortium members

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Advanced Combustion GmbH (ACDE) (D)

Robert Bosch GmbH (D)

Chalmers University of Technology (S)

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C.R.F. Società Consortile per Azioni (I)

DaimlerChrysler AG (D)

Deutz AG (D)

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Holset Engineering Co. Ltd (UK)

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Universidad Politécnica de Valencia (E)

Volvo Powertrain Aktiebolag (S)

List of abbreviations

de Diesel-electric drive

dh Diesel-hydraulic drive

dm Diesel-mechanical drive

DMU Diesel multiple unit

SCR Selective catalytic redaction

DPF Diesel particulate filter

NOx Nitrous oxide emissions

PM Particulate matter

pme Effective mean pressure

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