Rail Diesel Study
Work Package 2

Final Report

Technical and operational measures to improve the emissions performance of diesel rail

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1 Introduction

The environmental benefit demonstrated by the railways over other modes of transport is a vital precondition to ensuring social and political support for this mode of transport. The railways have shown that on specific consumption of resources and specific emissions of carbon dioxide their values are lower than those obtained by their main competitors on the road (in particular due to the higher passenger densities achieved on the railways). Apart from the depletion of resources and climate change effects, the impact of traffic on the environment in the form of local air pollution is also important. Although road transport is considered to be the main polluter, the emissions from diesel-powered locomotives and railcars, despite their small numbers, are increasingly attracting the attention of public and authorities alike – not just on a local level, but also on a European scale.

The European Parliament and the Council agreed Directive 2004/26/EC on amendments to the Non-Road Mobile Machinery (NRMM) Directive 97/68/EC. The scope of the Directive has been extended to cover all new diesel engines for railway vehicles; this means that limit values for new engines for railway use are provided by legislation at European level. Stage IIIA limit values (see Annex 1) are foreseen to come into force in 2006 for railcars and 2009 for locomotives. Stage IIIB will come into force in 2012 for railcars and locomotives and particularly tightens particulate limits by around 90% relative to stage IIIA. The IIIB limit values are subject to a review by the end of 2007. In particular this review will examine the progress made in developing reliable technology to meet the Stage IIIB limits on all NRMM applications and if necessary propose exemptions or derogations.

In addition to the new limits provided for in the NRMM Directive, the European Commission (DG Energy and Transport), in direct contact with the CER, called for initiatives from the railways in the field of diesel exhaust emissions, with particular emphasis on the existing railway fleet. As a result, the International Union of Railways (UIC) Technical and Research Commission (CTR - Commission Technique et de Recherche) decided in October 2003 to produce the UIC Diesel Action Plan advocating pro-active measures to reduce diesel exhaust emissions.

Following the success of a pre-study by UIC into technical and operational possibilities, it was decided to follow up with a more detailed multi-partner “Rail Diesel Study”, co-ordinated by UIC and running from January to December 2005. Project partners also include the Community of European Railways (CER), the Union of European Railway Industries (UNIFE) and The European Association of Internal Combustion Engine Manufacturers (Euromot), with AEA Technology Environment as sub contractor/consultant to UIC. This cross industry input and support for the work is essential for the study’s success and for the authority of outputs.

This draft report constitutes a summary of activities and results of Work Package 2 of the Rail Diesel Study, which concerns the assessment of the technological and operational possibilities for emissions reductions. It is important to note at this stage what the report can and cannot provide.

The work ***can*** provide a snapshot of the status of technologies and operational measures in order to provide:

- the basis for a more detailed examination of the technical possibilities for the review of NRMM Stage IIIB limit values;
- an indication of the measures that could be applied to parts of the current rail fleet and indications on their costs and effectiveness;
- Information on the barriers/restrictions that might preclude their use in some situations, based on current experience and knowledge.

Although the study has examined possible options that could be used to enable the rail sector to achieve the NRMM Stage IIIB limit values, and the outputs from this study will be used to support the technical review of the of these limit values, it must be recognised that further work, outside of this study, will be required to provide more in-depth information and analysis that would allow firm conclusions on whether or not the Stage IIIB limit values can be achieved by the rail sector. Some of the reasons why this study on its own cannot provide all of the necessary information required for the technical review of the Stage IIIB limit values are as follows:

- The timeframe for the work is relatively short compared to that needed for a detailed analysis applicable across the whole European rail sector;
- Many of the technical measures expected to be utilised to achieve emission control limits set out in the NRMM Directive are at an early stage of development. The reason is that the adaptation of on-highway technologies for NRMM applications has proven to require, in most of the cases, significant development work. This is due to the broad range of NRMM applications and the low volume/niche product characteristics of the NRMM markets. Therefore performance and costs are expected to change rapidly;
- It takes significant time to develop the new technologies for application in rail vehicles.

However, the outputs from this study will still provide useful information to support the technical review process.

The following introductory sections provide a summary/overview of the Rail Diesel Study and more details on the specific activities carried out under Work Package 2 (WP2).

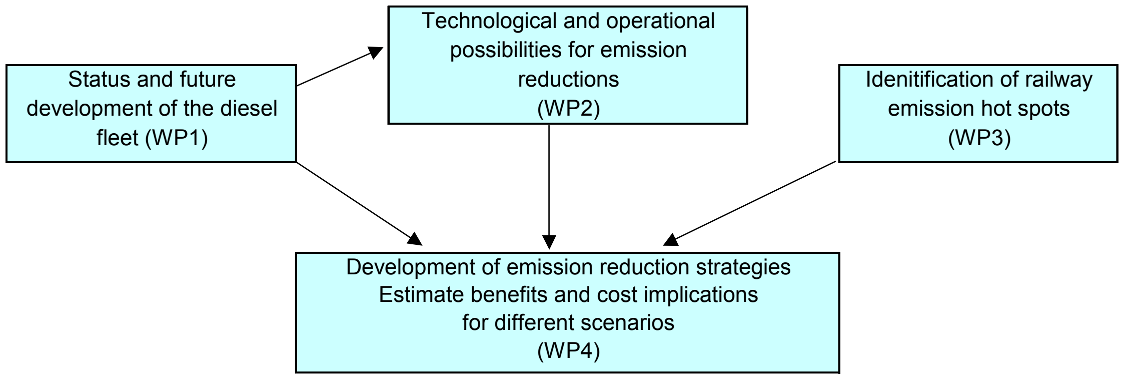
1.1 Overview of Rail Diesel Study

The scope of the study includes all diesel fuelled traction units (new and existing) running in service by UIC members in the "UIC EU 27 Railways" (the 23 railways from the EU25 Member States + Norway, Switzerland, Bulgaria and Romania). The purpose of this project is therefore to:

1. Investigate the possibilities of using technical and operational measures for reducing diesel exhaust emissions (including the use of renewable energy sources) by sharing knowledge and experiences (technical, economical, etc.) with the aim to prepare for implementation;
2. Support the technical review of the NRMM Directive (2004/26/EC). This review is due to be completed at the latest by the end of 2007 (technical feasibility of limit values in 2012) for new rail vehicles, and the work carried out as part of this study will feed into the review process; it should, however, be noted that additional work outside of this study will be required in order that detailed analysis can be carried out for the technical review.
3. Assess the status, performance and need for (technical and operational) emission reduction measures for the existing fleet, using a cost-benefit analysis approach, whilst also taking into account the practical feasibility of applying each option.

The project consists of four main work packages with interactions indicated in Figure 1.1.

Figure 1.1: Interrelation between work packages



1.2 WP2 overview, purpose and activities

Work Package 2, running from February to September 2005, forms the primary focus for the Rail Diesel Study work and is central to its intended outputs and formation of conclusions and recommendations. The work package is led by AEA Technology, but with the majority of the technical input coming from Euromot, UNIFE and UIC.

Since the inception of the project the structure and responsibilities for work on Work Package 2 has been refined. A full flow chart for Work Package 2 tasks and responsibilities is provided in Figure 1.2, however the activities carried out may be summarised as follows:

- Preliminary identification (for screening) and definition of technical and operational measures that could be used reduce pollutant emissions from the diesel fleet for screening [AEAT]
- Selection of representative traction units for more detailed analysis of technical options [UIC /UNIFE /Euromot].
- Collection of data on train operators' experience of measures first through a survey/questionnaire and second through follow-up with interviews with individual operators [AEAT/UIC].
- Analysis of the costs and emissions benefits associated with each finally selected option and reporting on results [UIC /UNIFE /Euromot].
- Final WP2 Reporting [AEAT]
- Third party assessment of results [Technical University of Denmark]

As discussed already, assessment of technical measures in WP2 is closely related to the preparation for the review of the amended NRMM Directive (97/68/EC) for new engines, as well as for possible reduction measures on the existing fleet. This assessment was carried out according to the following steps:

1. Identification of possible measures, drawing on experience from the road transport and stationary power sectors, but bearing in mind that these options may not be suitable for retrofitting to rail vehicles;
2. Investigation to identify if and how widely the identified options have already been used in the rail sector;
3. Narrowing down the range of options to focus on only those which are feasible for rail;
4. For new and future vehicles a more general assessment of technical measures has been performed based on typical types of vehicles with reference to the limit values for Stage IIIA and IIIB of the NRMM Directive;

5. For the current fleet, detailed analysis of the costs and benefits of applying technical options to specific representative traction units, taking into account the practicalities of trying to retrofit emissions abatement equipment to existing vehicles (e.g. space, weight and operational conditions, such as engine performance and exhaust characteristics);
6. Operational measures have not been assessed using the same life-cycle cost analysis techniques, as they are also dependent on particular site and/or route conditions. Therefore their assessment was based on a case study approach utilising existing experiences from operators. This was collected through a questionnaire survey (Annex 2) and individual operator interviews.

As part of the work an independent 3rd-party assessment of the whole WP2 results and report is to be carried out by Spencer Sorenson (Department of Mechanical Engineering, Technical University of Denmark), an expert in rail emissions and engine emission control technologies. This assessment will be provided in a separate report.

1.3 Report structure

The following gives an overview of the structure of this report:

Section 2 provides detailed information on the various methodologies that have been used in the approach to achieving Work Package 2 objectives.

Section 3 summarises the range of technical measures for emissions reductions initially identified for consideration for potential rail application. Subsections provide short descriptions of the measures and a summary of issues identified with regards to possible application in rail vehicles, drawing on any rail experiences in their utilisation, where available. At this stage the technologies are also screened for their applicability to the current fleet and new vehicles detailed analyses (with further information in Section 5).

Section 4 summarises the methodology and results for the detailed analysis work (carried out by UIC, with input from Euromot at UNIFE) for potential application of technical measures to the current rail fleet. It provides a summary of the results by representative vehicle and technology, together with descriptions of:

- the selection of representative traction units for the life cycle analysis.
- the methodology/framework for the assessment, including the lifecycle cost and emissions analysis;

Section 5 summarises the methodology and results for the detailed analysis work assessing the potential application of technical measures for new and future rail vehicles (carried out by Euromot with input from UNIFE and UIC).

Section 6 provides details on the (new and existing) operational measures initially identified as potentially useful in reducing emissions from diesel rail. Subsections provide short descriptions of the measures and a summary of issues identified with regards to possible application by European railway operators, drawing on any experiences in their utilisation, where available. At this stage the measures have not yet been screened for their suitability for detailed case study analyses.

Section 7 summarises the results of the operational measures assessment. It also provides an overview of the reasoning behind the approach taken to assessing operational measures utilising case studies and the selection of particular measures for the more detailed analysis.

Section 8 provides a summary and conclusions from the WP2 results.

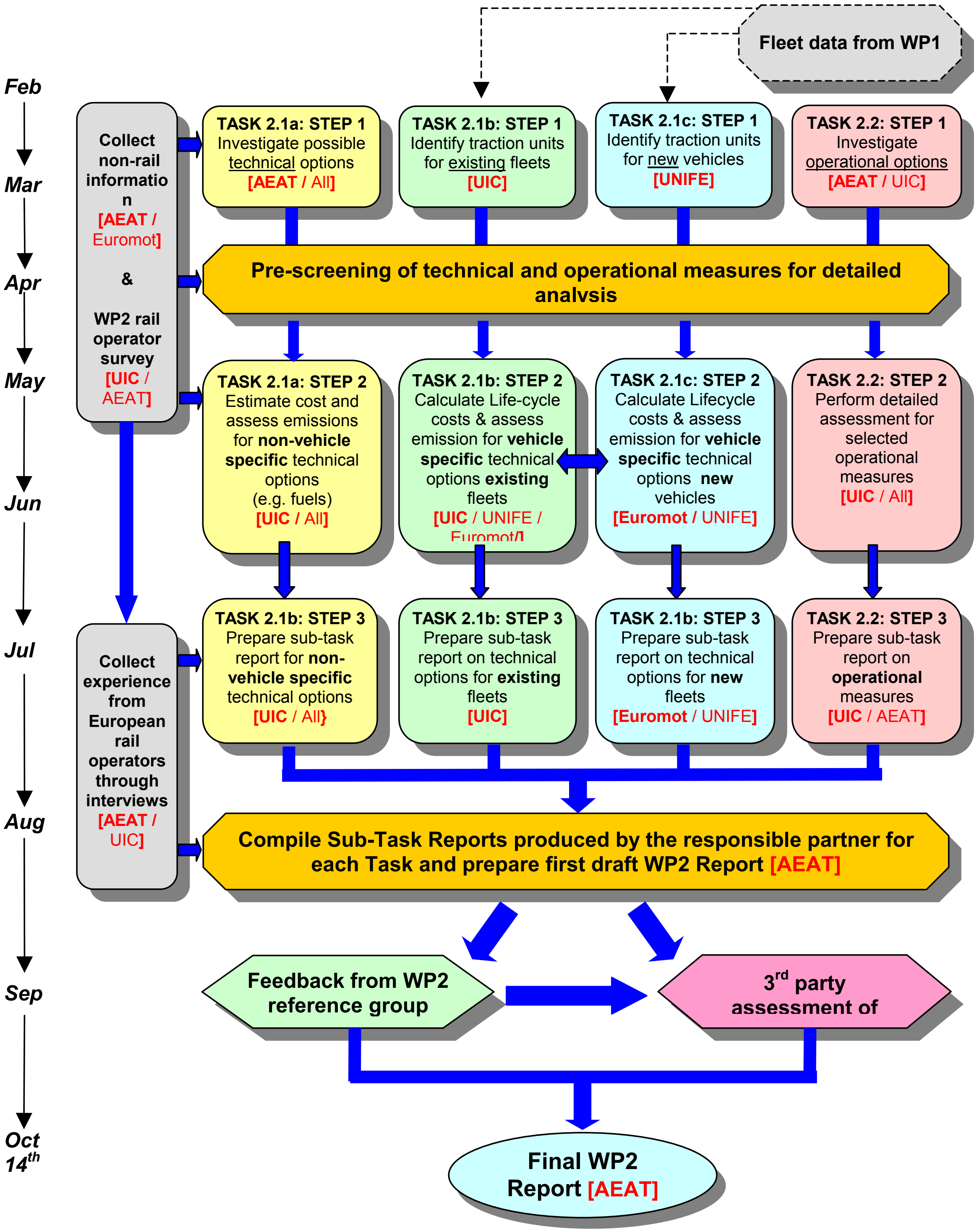


Figure 1.2: Flow chart of Work Package 2 Tasks

2 Study methodology

The purpose of this section is to provide an overview of the methodology used to achieve the objectives of Work Package 2. The challenge was to take a wide range of technical and operational possibilities as the starting point, with the aim of sifting/sorting these and evaluating which options could potentially be used with the current fleet or future rail vehicles, and then assessing the resulting costs and benefits of their use. The processes used to achieve this are briefly outlined in the following sections, and include:

- Preliminary identification of technical and operational measures;
- Collection of rail experience and case studies related to the use of the identified technical and operational measures;
- Selection of representative traction units;
- Screening of options:
  - Technical measures;
  - Operational measures.
- Detailed analysis of technical and operational measures, consisting of:
  - Technical measures for the current fleet;
  - Technical measures for future rail vehicles;
  - Operational measures case study approach.
- Discussion and conclusions;
- Third party assessment.

Most of the activity for the work package involved technical work carried out by UIC partners (DB AG, ČD and SNCF), Euromot and UNIFE. AEA Technology's role was to lead the work package, co-ordinate input, carry out detailed consultations with selected rail operators around Europe, and collate and prepare the final report.

2.1 Preliminary identification of technical and operational measures

A preliminary list of technical measures was drawn up mainly on the basis of technology used for road vehicles and stationary units, and also previous work by AEA Technology on the UK rail sector. This was supplemented by additional information and experiences provided by the other core work package partners and from UIC members through a survey and interviews (discussed the following section). The preliminary list and information on operational measures was also drawn up on a similar basis. Details on the initially identified technical and operational measures are provided in sections 3 and 6.

2.2 Collection of rail experience and case studies

Information on rail operator experience with technical and operational measures was collected firstly from existing UIC and other partners' sources and second via a questionnaire survey sent to UIC members at the beginning of the work package (see Annex 2). The questionnaire helped to identify which rail operators had experience with which technical and operational measures and was followed up with face-to-face interviews were additional detailed information on their experiences was available. Summary information on the results of the questionnaire survey is provided in section 3.4 for technical measures and section 6.8 for operational measures, with information on the interviews provided in section 7.1.

2.3 Selection of representative traction units

It was not feasible or practical within the resources of the study to carry out compatibility and life-cycle analyses on technical measures for a large variety of different rail vehicles. It was therefore necessary to select a range of "representative traction units" for the current and future European fleet, taking into account parameters such as the numbers of vehicles of particular types currently in operation, vehicle power, emissions, age, traction type and usage (in terms of both annual tonne-kilometre and also type of use, e.g. commuter, long-distance passenger, freight or shunting). This work was carried out by DB AG, ČD and SNCF, in consultation with UIC members (and using data provided in the WP1 Questionnaire) for the current fleet, and by Euromot and UNIFE for future rail vehicles. Details of the selection process are provided in section 3.5.1 for the current fleet and section 5.3 for future rail vehicles.

2.4 Screening of options

2.4.1 Technical measures

The initial list of technical measures was screened/filtered in two stages in consultation with rail industry experts:

(i) *Initial pre-screening of measures* that are/are not applicable for application to the current fleet (e.g. hybrid drive-trains and energy storage) or to future rail vehicles (e.g. re-engining).

(ii) *Screening measures for practicality prior to life-cycle cost analysis*: Consultation with equipment manufacturers and utilisation of engineering expertise to determine whether measures could be applied on the basis of the available space, weight limitations or engine/exhaust characteristics.

Further details of the screening process for technical measures are found in section 3.5 for the current fleet and section 5 for future rail vehicles.

2.4.2 Operational measures

The initial list of operational measures identified was screened/filtered in consultation with UIC member experts to take into account both the level of current application across the European rail sector and the degree of possibility for application. Further details on the screening process are provided in section 7.2.

2.5 Detailed analysis

The objective of the detailed analysis was to calculate unit annual costs (capital and operational) and the level of emissions abatement for the selected technical measures where applicable for each representative traction unit. These costs include capital expenditure on equipment and installation/modification of the engine or vehicle annualised over the lifetime of the measure/equipment, plus the resulting change in maintenance, additive (where applicable) and fuel costs.

For the current fleet, the detailed analysis was based on information collected by DB AG from equipment manufacturers and suppliers mainly in Germany, Austria and Switzerland. Details of the analysis and results are provided in section 4.

For future rail vehicles the detailed analysis was carried out via a consultative process with Euromot and UNIFE members to develop estimates for likely application of technical measures, associated costs and potential emissions reduction performance for future engines and vehicles. Details of the analysis and results are provided in section 5.

2.5.1 Operational measures case study approach

As mentioned previously, operational measures cannot be assessed using the same vehicle specific basis used for the assessment of technical measures, and are dependent on particular site and/or route conditions. Therefore it was decided to base their assessment on a case study approach utilising existing experiences from operators, collected through a questionnaire survey and individual operator interviews. This approach utilised a combination of qualitative and quantitative analysis, utilising data on costs and emissions performance where available and taking into account any additional benefits or barriers to implementation. Details of the case study analysis and results are provided in section 7.

2.6 Discussion and conclusions

A summary and conclusions from the WP2 results are provided in section 8.

2.7 Third party assessment

In drawing up the specification for Work Package 2 it was acknowledged that it would be desirable for an independent expert to carry out an assessment of the methodology and results to provide independent verification. AEA Technology has arranged for this assessment to be carried out by Spencer Sorenson from the Department of Energy Engineering at the Technical University of Denmark (an internationally recognised expert in the field of rail emissions). This independent third party assessment will be provided as a separate report in due course.

3 Identification of technical measures for screening

This section summarises the range of technical measures for reducing emissions initially identified for consideration for potential rail application. **The inclusion of options does NOT imply they can be fitted to rail vehicles.** In fact, the range of measures identified has been drawn from mainly road and stationary applications, as there has been little experience to date in the rail sector. The technical measures can be broadly placed in three categories:

1. Emissions abatement equipment and engine design modifications;
2. Vehicle replacement and re-engining options;
3. Non-vehicle specific measures.

The following subsections provide short descriptions of the measures and a summary of issues identified with regards to possible application in rail vehicles, drawing on any rail experiences in their utilisation, where available. Unless otherwise stated, cost and emissions performance information has been drawn from mainly road and stationary applications, and therefore does not take into account specific operating characteristics of rail vehicle diesel engines and costs for vehicle modifications. Detailed, rail-specific analysis of the costs and emissions benefits associated with particular technical measures can be found in Section 4 and 5.

Rail operator experience with measures was identified through consultation with UIC members and rail diesel experts from UIC, Euromot and UNIFE. A questionnaire survey was also sent out to UIC members (Annex 2), followed up with interviews with individual rail operators, where additional information from experiences was available. However, it should be noted that the bulk of the research and in-service experience for the technical measures comes from the road sector. Whilst the systems for the road and rail sectors will be similar the duty cycles will differ significantly. Consequently, comprehensive research is required to assess the failure modes and durability of the systems in a rail context.

3.1 Emissions abatement equipment and engine design modifications

3.1.1 Diesel Particulate Filters (DPFs)

Diesel particulate filters (DPFs) remove particulate matter from the exhaust stream. Periodically, PM captured by the filter must be removed to prevent the filter from blocking (this process is often referred to as "regeneration"). This filter regeneration is the key to an effective emissions control system. There are several types of particulate filter, differentiated by their method of regeneration[1]. The first type uses an electrical heater to raise the temperature inside the filter to burn away the PM. This is used when equipment runs on higher sulphur fuel and when low engine speeds/loads give rise to low exhaust temperatures. The second type utilises a fuel additive metered into the diesel fuel that acts as a catalyst, oxidising the PM trapped in the filter. This type is used when equipment runs on higher sulphur fuel and duty cycles give high exhaust temperatures. These types of DPFs typically lead to reductions in particulate emissions over 95% and are examples of closed-channel DPFs. Another type of DPF includes filters that are combined with an up-stream oxidation catalyst[2] (such as in Continuously Regenerating Traps - CRT®) to oxidise nitric oxide in the exhaust stream to nitrogen dioxide (NO_2). The NO_2 then reacts with the trapped particulate matter to regenerate the filter. Such systems, which do not rely on the use of heaters or fuel to regenerate the trap, are passive systems and can also achieve efficiencies of over 95%. In open channel systems the ends of the filter channels are open, which only cause exhaust-

[1] Johnson Matthey – 'Diesel Particle Filter Systems for Off-Road Applications'

[2] Continuously Regenerating Traps consist of a DPF with up-stream oxidation catalyst to oxidise nitric oxide in the exhaust stream to nitrogen dioxide (NO_2).

gas backpressure and fuel consumption to rise negligibly. Regeneration occurs continuously despite there no sensors or electronics, no additives and no additional fuel injection being involved. In the case of automotive diesel engines the emission of particulate matter falls relative to the initial value by approx. 30-40%.

DPFs can be very bulky, and there are a number of questions over how feasibly such systems can be retrofitted to vehicles in the existing rail fleet. More detailed descriptions of different types of DPFs can be found in Annex 4.

3.1.2 Combined Particulate Oxidation Catalyst (POC)

Combined Particulate Oxidation Catalyst (POC) use a single catalyst that combines the functions of particulate removal and oxidation of CO and HC emissions to CO_2 and water respectively. The principal advantage of these catalysts over systems employing separate DPFs and oxidation catalysts (such as the CRT®) is a substantial reduction in cost, size, and complexity. The size issue is particularly important given that this is a major issue when attempting installation of retrofit abatement equipment on diesel railcars/multiple units (DMUs). POC systems have been extensively tested on trucks, generator sets and power stations. The system brings about large reductions in the levels of carbon monoxide and hydrocarbons (typically 85%), with more modest reductions in the level of particulates (around 30%). The system does not require regular maintenance, but can only be used with ultra low sulphur diesel (<50ppm sulphur).

The combined POC is a relatively simple, low cost solution with fewer of the drawbacks in terms of space constraints that some of the other retrofit technologies have. Although it does not have any effect on NO_x emissions, it has a significant effect on CO, PM, and hydrocarbon (HC) emissions. The lower capital costs, weight and volume associated with these types of catalysts, compared to CRT® systems, is a further advantage. However, no rail experience with the technology has been identified.

3.1.3 NO_x Adsorber Catalyst (NAC)

NO_x Adsorber catalysts (NAC) use a combination of base metal oxide (e.g. Barium oxide) and precious metal coatings to affect control of NO_x by storage on the surface of the catalyst. When the available storage sites are occupied, the catalyst is operated briefly under fuel rich and low oxygen exhaust gas conditions, using the diesel fuel to convert the stored NO_x to nitrogen gas and CO_2. NACs are capable of converting more than 90% of NO_x emissions to nitrogen over much of their operating range.

The NAC process utilises diesel fuel for the regeneration process, and hence there is a negative impact on fuel economy. This process requires precise control of the engine and catalyst together as a system to determine exactly when regeneration is needed, and to control the exhaust parameters during regeneration itself. The system is therefore primarily aimed at integration with new engines and not suitable for retrofitting to older engines. In addition the adsorber catalyst is sensitive to sulphur and requires the use of sulphur free diesel (<10 ppm sulphur). NACs are still in the development phase and are expected to appear first in the light duty automotive applications, with heavy-duty applications unlikely before 2010. There is therefore also no rail experience with these types of systems.

3.1.4 Lean-NO_x Catalyst

Lean-NO_x catalysts work by using unburned hydrocarbons (i.e. fuel) to chemically reduce NO_x over a catalyst (containing precious metals such as platinum or other material such as zeolite). Successful operation requires continuous injection of fuel upstream of the catalyst. NO_x conversion efficiencies are much lower than for NAC systems (10%-25% in use in practical duty cycles)[3], however are seen as potentially a very good option for retrofit as they

[3] Source: ‘ Mobile Off-Highway Emissions - Choosing the Right Technology’, Cummins.

are relatively easy to install and integrate with existing engine and equipment systems (no core engine modifications are needed). However, like NACs, lean-NO_x catalysts are still in the development phase, with challenges including the need for higher performance catalysts, higher durability and higher selectivity to lower their fuel penalty. There is therefore also no rail experience with these types of systems.

3.1.5 Selective Catalytic Reduction (SCR & SCRT)

The SCR (selective catalytic reduction) method of reducing nitrogen oxides has proved very effective in various stationary applications. A large number of commercial vehicle builders are engaged in testing and implementing this method. Selective Catalytic Reduction (SCR) systems work by injecting ammonia or urea into an engine's exhaust stream to chemically reduce NO_x emissions to Nitrogen. Trials on heavy-duty road vehicles have shown reductions in NO_x emissions of between 60% and 90%[4]. Compared to Exhaust Gas Recirculation (EGR, discussed in the following section), SCR will provide a larger NO_x reduction in a well-developed system, but does require replenishment of the reducing agent (ammonia or urea) whereas EGR is a "fit-and-forget" technology. SCR (and EGR) technology requires the use of low-sulphur diesel fuel (<50 ppm).

As SCR catalysts mainly treat the NO_x exhaust component, typically an oxidation catalyst would also be included in the system to reduce emissions of carbon monoxide and hydrocarbons, and specifically, to minimise the risk of ammonia emissions being released to the atmosphere. SCR catalysts may also lead to up to 30% reduction in emissions of soluble particulate matter. To improve the abatement of particulate emissions, SCR systems can be used in conjunction with DPFs including Continuously Regenerating Traps (CRT®) (see section 3.1.1) – the use of an SCR system with a CRT® gives a combined system known as an SCRT® system. SCRT technology is a combination of oxidation, reduction and filtration processes. It has the greatest potential for reducing all pollutant constituents subject to limit values. Rates of reduction are between 80 and 98 % of the respective initial values. Of the systems covered so far it represents the most involved procedure with the most complex technology.

Unlike EGR systems, SCR technology can potentially be fitted to vehicles equipped with engines that do not meet the Euro II emissions regulations, however SCR and SCRT® systems are very bulky, both in their requirements for the system and the catalyst. The size of the SCR catalyst itself is approximately twice the capacity of the engine – therefore a 19 litre DMU engine will require a 40 litre catalyst. In addition, space is also required for additional hardware that forms part of an SCR system, including smaller oxidation catalysts and the tank for storing urea or ammonia. This puts severe restrictions on its potential for use as a retrofit item to rail vehicles, where spare space and weight availability is limited.

For an SCR or SCRT® system using ammonia as the reducing agent, ammonia consumption is between 1% and 2.5% of diesel fuel consumption. For systems that use urea, urea consumption is between 2.5% and 6.0% of diesel fuel consumption[5]. The engine manufacturer Cummins has carried out some feasibility work with regard to fitting this system to the QSK19 engines found in a number of DMU traction units. Whilst this may be a workable option for the engine, space limitations on DMU rail vehicles might rule out the use of this technology for some types of railcars/DMUs.

SCR systems are one of the technologies that are likely to enable rail traction units to meet the Stage IIIB emissions limits in the Non-Road Mobile Machinery (NRMM) Directive. SCRT technology is a possible option whose further consideration ought nevertheless to await

[4] Source: Energy Savings Trust, and personal communications with representatives from Cummins Engines and Dinex Exhausts Limited,
[5] Source: Personal communication with representatives from Cummins Engines

examination of other technical options given its complexity and current state of development. More detailed descriptions of SCR and SCRT systems can be found in Annex 4.

3.1.6 Exhaust Gas Recirculation (EGR)

Exhaust Gas Recirculation (EGR) has been fitted to all light duty diesel-engined road vehicles in Western Europe for some years. EGR operates on the principle that recirculation of the exhaust air into the combustion chamber reduces the amount of oxygen available for NO_x formation. The package consists of a valve (under electronic control) that utilises the exhaust back-pressure to allow flow back to the inlet manifold in a normally aspirated engine, or to the compressor inlet in a turbocharged engine. Additional cooling of the exhaust gases is needed for optimum performance.

Retrofit EGR is only suitable for vehicles fitted with engines that, as a minimum, meet the Euro II emissions standard, and hence older rolling stock could not be fitted with this equipment. Retrofitting EGR involves removing the vehicle's engine so that it can be remapped (reprogramming the engine electronic control unit(s)) and may involve upgrading the cooling system of the vehicle. In addition to the minimum Euro II requirement, EGR also needs to be used in conjunction with a particulate filter, and the engine must run on low sulphur diesel (<50 ppm sulphur content). Consultation with technical experts[6] suggest that the cooling systems on many rail vehicles are already close to capacity and that an EGR system will require additional cooling equipment to be fitted, with additional cost and space requirements.

EGR is typically used in conjunction with a particulate filter and oil cleaner in HGV applications, and this combination can result in up to a 40-55% reduction in NO_x emissions, a 70-90% reduction in PM_{10}, and a 70-90% reduction in CO emissions. Similar levels of reduction are theoretically possible with rail vehicles if additional cooling systems were installed. Tests carried out without cooling have only achieved much lower levels of emission reduction (around 10%). Retrofit EGR systems can be relatively expensive to install; as a consequence, retrofit EGR is only financially viable if large numbers of identical vehicles are fitted with the same equipment. The technology may be suitable for Railway Operators that operate large numbers of DMUs or locomotives with the same engine specification where the economies of scale could make this approach more economically viable.

Although EGR can give very significant emissions benefits, for rail applications the scope for applying the technology is limited by the minimum requirement for vehicles to be fitted with Euro II engines. Furthermore, as it may not be possible to fit EGR equipment to many classes of trains due to space restrictions (particularly with regards to the cooling required), and a potentially large proportion of vehicles fitted with Euro II engines could also not benefit from this technology. It should also be noted that EGR fitment leads to increases in fuel consumption. Information from EGR equipment manufacturers indicates that fuel consumption increases by approximately 4%[7], with the obvious knock-on effects on operating costs. More detailed descriptions of EGR systems can be found in Annex 4.

3.1.7 Internal engine design measures

Advanced engine design can be used to optimise the combustion process in order to reduce pollutant emissions. Improvements to cylinder design, fuel systems, and electronic control systems can all be used to minimise emissions. Such measures are usually only applied to new engine designs, and therefore would only be used for new or re-engined rail vehicles. In some cases, older engines can be modified to improve emissions. Examples of internal engine design measures include the following:

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[6] Personal communication with representatives from Dinex Exhausts Ltd and STT Emtec.
[7] Source: Dinex Exhausts Limited. 4% increase in fuel consumption is based on heavy truck applications

- Variable valve timing;
- Supercharging;
- Improved after-cooling systems;
- Diesel Water Injection systems;
- Low Emission Idle systems.

More detail on specific examples of internal engine design measures can be found in Section A.4 of the Annex to this report.

3.2 Vehicle replacement and re-engining options

3.2.1 Re-engining trains

Exchanging the engine on a diesel motive power unit constitutes an effective means of reducing emissions as long as the new engine is technically state-of-the-art. Rail engines generally receive a complete overhaul every 3 years and the entire engine may be replaced a number of times within the life of the train. The engines are usually replaced with the same model – often a reconditioned unit. In order to obtain an emissions benefit from re-engining, it is necessary to replace the original engine with a more modern unit with improved emissions performance. There are other examples of re-engining programmes where new engine designs have replaced older units. Costs and emissions reductions depend on specific cases. Recent examples of European re-engining programmes include:

- Re-engining of SNCF (France) shunting locomotives and mainline locomotives in the Paris area has achieved significant reductions in emissions (see section 7.3.2.1).
- The Paxman RP200L Valenta engines from approximately 15 UK Class 43 HST locomotive power cars have been replaced with the Paxman VP185 engine.
- The conversion programme from UK Class 47 to Class 57 involved replacing the original Sulzer engine with a new General Motors engine;
- SZ (Slovenia) has replaced engines and turbochargers on 40 shunting diesel locomotives at a cost of around €14 million for the new engines and €1.5 million for the new turbochargers (around €400,000 per locomotive total). Reductions in emissions and fuel consumption have been estimated at 10%.
- LDZ’s (Latvia) replacement of their M756 DMU engines with new MTU engines will result in significant fuel and oil savings, see Annex 4.
- At DB AG in total 740 shunting and mainline locomotives have been re-engined with cleaner engines since 1998 - meaning around 100 locomotives per year.

Details of specific examples of the emissions benefits associated with specific re-engining programmes can be found in Annex 4.

At this time there are perceived to be some limitations for re-engining possibilities as result of the NRMM Directive, which will require new engines to be compliant with the Stage IIIA emission limit values from 2006. An example of this impact can be found in relation to vehicles operated by the railway company DSB (Denmark) (see Annex 4 for details).

3.2.2 Fleet replacement

The environmental performance of diesel rail could be improved by accelerating the rate of vehicle fleet replacement. By encouraging railway operating companies to invest in new rolling stock to replace older, poorer performing stock, emissions from trains could be significantly reduced. This can be seen if the emissions performance of selected newer classes of trains are compared with equivalent older classes. An example from the UK of the differences in emission factors between old and equivalent new vehicles is given in Table 3.1. There are constraints on what can be achieved, however, as there are no modern equivalents for some classes.

Table 3.1: Comparison of emissions per train kilometre for Class 43 HST and Class 180 Adelante trains

				Emissions (grams per train kilometre)[8]				
Class/ Type	**Power source**	**Configur-ation**	**Power consump-tion**	**NOx**	**CO**	**HC**	**PM_{10}**	**CO_2**
Class 43/ High Speed Train (HST)	Diesel	2 power car locomotives + 8 carriages	17.50 kWh per km[9]	196.93	58.47	21.88	5.08	14860
Class 180/ Alstom Adelante	Diesel	8 car DMU*	16.86 kWh per km[10]	88.05	50.25	13.83	1.86	11142
Percentage change in emissions (Adelante replacing HST)				**55.3% decrease**	**14.1% decrease**	**36.8% decrease**	**63.5% decrease**	**25.0% decrease**

*Note: Adelantes do not currently run in an 8-car configuration, but for direct comparison purposes (in terms of overall passenger capacity), this configuration has been assumed

As can be seen from the tables, large reductions in emissions of NO_x and PM_{10} could be achieved by replacing older stock with more modern, equivalent trains. However, CO and hydrocarbon emissions from some new replacements are higher than they are from the older DMUs.

Whilst accelerating the rate of fleet replacement can have large emissions benefits, the costs associated with this measure are not insignificant. Capital costs associated with new DMU vehicles are of the order of €1.5 million per DMU power car, and the capital lost by early replacement of the older vehicles would also needs to be taken into account in a full assessment.

In Europe, SNCF is operating an accelerated locomotive replacement programme as part of its strategy to improve its environmental impact and reduce emissions. The replacement of locomotive driven trains by modern train sets together with re-engining programs (see section 3.2.1) are main reasons for the achieved reduction of the overall particle emission of DB’s diesel traction by 80 % compared to 1990.

3.2.3 Hybrid and energy storage concepts

Hybrid systems and energy storage concepts for regenerative braking are only really practicable for new rail vehicles. Hybrid diesel-electric railway vehicles use a diesel engine in conjunction with an electric motor, power controller and battery (or other form of energy storage). The battery may also store power generated during “regenerative braking”, when the engine is driven by the momentum of the vehicle and used as a generator to send power to the battery. Regenerative braking allows trains to recover energy during braking by the use of kinetic brakes that in electric trains feed electrical power back to the overhead lines. For electrical multiple units operating on frequent stop services, savings of around 25% are thought to be attainable in regular service. This energy would otherwise be lost as heat with the use of friction brakes. For use in diesel railway vehicles the captured energy can be stored for later use either to supplement motive power (in a hybrid vehicle) and/or auxiliary power requirements.

[8] Emissions for Class 43 HST and Alstom Adelante trains calculated from emission factors supplied by a UK train operating company.
[9] Class 43 HST power consumption data based on power data obtained from Scientifics Report “Exhaust Emission Measurements on the HST”, January 1995, and information on HST operating characteristics supplied by First Great Western for the London Paddington to Bristol route.
[10] Alstom Adelante power consumption data supplied by AEA Technology Rail from test measurements recorded on the London Paddington to Bristol route, March 2004.

Hybrid technology can lead to very large reductions in NO_x and PM emissions in road applications; up to 90% reduction in NO_x, CO and hydrocarbons is claimed for the Toyota Prius. In the rail sector, the Japanese railway operator JR East is developing/demonstrating a prototype hybrid railcar (known as the "NE Train") and is aiming to achieve 50% reductions in NO_x and PM levels in the exhaust gases. Savings of 80-90% in NO_x/PM emissions have been achieved by Railpower's Green Goat hybrid shunting/switcher locomotives (370 to 1500 kW). Reductions in fuel consumption mean that there are also CO_2 emissions benefits to be achieved from hybrid vehicles. Savings of around 20% have already been achieved on commuter lines by the JR East prototype series-hybrid railcar in Japan (equivalent performance characteristics). Savings of 40-60% on CO_2 emissions have been claimed for Railpower's Green Goat locomotive (depending on duty cycle). Information from the automotive sector indicates that hybrids may be optimised for CO_2/fuel consumption or NO_x/PM emissions. Hybrid buses optimised for low NO_x/PM show no CO_2/fuel savings, but may reduce NO_x by up to 80% and PM by up to 90%. Conversely, hybrid buses optimised for CO_2 are expected to be 30% more fuel-efficient and give up to 30% reduction in NO_x/PM emissions. In Europe, Trenitalia is currently running a collaborative project developing hybrid railcar concepts, see Annex 5.

Hybrid technology can also potentially contribute to reducing noise if the engine switches off when the vehicle is stationary (at stations, for example), with auxiliary power provided from the energy storage medium. Furthermore, hybrid vehicles that can be driven in fully electric mode are, in this mode of operation, zero-emissions vehicles (at point of use) and are significantly quieter than conventional internal combustion engine (ICE) vehicles. The ability to switch to a mode of operation with zero emissions at point of use means that such vehicles, if used extensively in urban areas/stations, could lead to significant reductions in emissions of regulated pollutants including NO_x and particulate matter. Further technical information on hybrids is provided in Annex 4.

3.2.4 Multi-engine concepts

Multi Engine Concepts mean downsizing of a combustion engine as singular propulsion system to different smaller engines (e.g. using four 500 kW units instead of a single 2000 kW engine), and/or covering a separate auxiliary power supply (small combustion engine or potentially fuel cell in the future). Depending on the demand for power output the single engines can be switched on or off. Possible Advantages in relation to exhaust emissions result out of the enhanced overall efficiency factor when operating in part load or idling operational ranges. The potential for emission reduction, however, is limited. This propulsion system also demands an enhanced effort concerning control and design of the engine peripheral equipment (gears, air and exhaust gas return). (Source: DB, department of drive and energy engineering). The possibility of applying multi-engine concepts to diesel-electric traction units is limited by the fact that such vehicles do not have hydraulic or mechanical transmissions or gearboxes that would enable multiple power inputs to be handled. It should also be noted that design concepts of this nature are likely to require additional space over that required by a single power unit; furthermore, there are likely to be increases in vehicle mass and life-cycle costs compared to a conventional vehicle.

A more attractive prospect could be provision of an auxiliary power unit (APU) as an alternative to shore power supply of auxiliary power at stations. This would allow the larger main engines to be switched off (rather than idling), significantly reducing all pollutant emissions at stations and improving fuel consumption. At the moment and emerging technologies for the provision of auxiliary power in heavy duty vehicles is a solid oxide fuel cell (SOFC) plus reformer, which can use diesel fuel to provide electrical power at much higher efficiencies than internal combustion engines (ICEs) and without emissions of NO_x, CO, HC and PM. The first HGV (5kW) prototype units are expected to be available from suppliers such as Delphi by the end of 2005, with estimated costs around $500/kW. The EC scalability of fuel cells means that larger power rated versions could also become available for other applications (such as rail) in the near future.

The French State Railways (SNCF) use separate engine/generator aggregates in modern multiple units exclusively to supply energy for the air-conditioning systems. These were built in from new and not retrofitted. In practice the auxiliary engines run at a constant 1500 rpm when the train is stationary and are consequently very noisy, frequently attracting complaints from customers. Three other railways, the Austrian State Railways (ÖBB), the Czech Railways (ČD) and the Railways of the Slovak Republic (ŽSR) have studied past experience with the use of auxiliary diesel engines or their recent use.

Case studies of ČD experience and ÖBB experience are provided in Annex 5. ZSSK have 14 diesel locomotives equipped with the multi-engine concept. The concept consists of a Caterpillar diesel engine for providing traction (1.2 MW) combined with an auxiliary engine (80 kW). The auxiliary engine provides a 400 V AC output for supplying the air compressor for the brake system. Originally, these locomotives were all intended for use on passenger trains, but in practice they are all owned by the freight company. The auxiliary engine is use for short movements and for downhill running, as well as for idle operation. ZSSK have found this system useful, and would specify it again on future trains. They do not have any noise problems associated with this measure.

3.2.5 Compressed Natural Gas (CNG) and Liquefied Natural Gas (LNG) vehicles

Natural gas (consisting mainly of methane) is a very clean-burning fuel, with virtually no particulate emissions and NO_x levels up to 80 or 90% lower than diesel vehicles. Natural gas vehicles have spark ignition engines, although many standard road vehicle diesel engines can be converted to run on a mixture of diesel and up to 90% natural gas. The gas is carried either compressed (in CNG vehicles) or liquefied (in LNG vehicles) in heavily insulated tanks. Both systems are relatively heavy and bulky, and therefore road vehicles suffer reduced range. Natural gas is normally stored on board the vehicle in high-pressure send at about 200-250 bar (CNG). The weight of fuel and tank can typically be about four times heavier than the equivalent diesel storage tank filled with fuel in automotive applications. LNG tanks are lighter and the fuel has a higher energy density, so the vehicle range can be around three times that of CNG for the same volume of tank (but still significantly less than a diesel vehicle)[11]. Also, liquefaction removes many of the impurities present in natural gas, allowing better fuel combustion. However, LNG can be lost from LNG vehicles through boil-off if stored for more than a few days, and there are other handling problems. Natural gas engines are less noisy than diesel engines, as it involves switch from compression engine to spark ignition engine, resulting in a noise reduction.

Connection to existing distribution networks should be possible. However, refuelling infrastructure is very expensive, typically costing €375,000 to €750,000 for a fast-fill CNG refuelling station for road vehicles (refuelling time comparable to diesel), and €150,000 to €450,000 for LNG[11]. Availability of suitable engines is also uncertain for rail applications.

In contrast to the diesel engine sector, the supply of gas-powered engines for non-stationary operation is very limited. Gas-powered engines with ratings <200kW are predominantly used as stationary motors in block-type thermal power stations at present. In the UK, CNG and LNG are generally used for heavy vehicles – trucks, buses and waste collection vehicles. Cummins also offer CNG conversions for HGVs. CNG buses have been demonstrated widely in other countries in Europe, although there are still concerns over their reliability and high capital costs. Available natural gas engines can also only cover the lower end of power classes needed for railway applications. More powerful engines (500-2000 kW) mainly exist

[11] Transport Energy (2003), *The Route to Cleaner Buses*

for stationary applications[12]. A recent example of a natural gas powered rail vehicle is the Swedish biogas powered railcar; a short case study based on this example is found in Annex 5. Additionally, in the United States, the Boise Locomotive company built two MK1200G LNG-powered locomotives fitted with 1000 BkW V16 spark-ignition engines. These locomotives were used as LNG demonstration projects by the Union Pacific Railroad and the Atchison, Topeka and Santa Fe Railway (now part of the Burlington Northern Santa Fe Railway).

It should also be noted that shifting to alternative fuels such as CNG or LNG might lead to some conflicts with the likely long-term shift to hydrogen-based road transport. If operators make large investments in natural gas vehicles and refuelling infrastructure, it may not be economically viable to shift to hydrogen in the medium-term. A further factor with a particular bearing on the issue of running locomotives on natural gas is the fuel's comparatively low energy density compared with diesel fuel (1:5 at 200 bar).

For NG powered vehicles it is necessary to carry out comprehensive modifications to the engine's carburetion in order to harness its potential in respect of pollutant emissions. A further disadvantage for LNG concerns the high input that liquefaction entails and the elaborate infrastructure required to supply the fuel. Its storage at fuelling points requires it to be cooled using liquid nitrogen. Vehicle tanks have to be vacuum-insulated so as to keep waste steam losses due to heat entry down to acceptable levels.

3.2.6 Liquefied Petroleum Gas (LPG) vehicles

No information has been identified on rail applications; however, Liquefied Petroleum Gas (LPG) has become a relatively popular choice as an alternative fuel for passenger cars, light vans and heavy duty vehicles, both for companies concerned with their environmental impact and for those keen to make cost savings. LPG in the UK consists mainly of propane, and can be burnt in spark ignition engines. Petrol engines can be converted to run on LPG fairly easily, but for diesel engines, conversion is more complex as it involves changing the compression ignition system of the diesel engine into a spark ignition system. Better emissions savings and performance are obtainable for dedicated LPG engines, however availability of suitable engines is uncertain.

Emissions of NO_x and PM from LPG-powered vehicles can be up to 90% lower than from equivalent diesel powered vehicles. However, the actual emissions performance can vary considerably between different LPG vehicles. Compared to diesel vehicles, LPG vehicles also have much lower levels of engine noise. CO_2 emissions are very similar to diesel-engined vehicles. As for natural gas vehicles shifting to LPG may lead to some conflicts with the likely long-term shift to hydrogen-based road transport. If operators make large investments in LPG vehicles and refuelling infrastructure, it may not be economically viable to shift to hydrogen in the medium-term.

3.3 Non-vehicle specific measures

3.3.1 Overview

This section provides a review of additional measures that could potentially contribute to reducing emissions from rail vehicles. The options reviewed in this section have been considered as non-vehicle specific measures in that they would be applied across a whole rail network or to a range of vehicles, rather than on a vehicle-by-vehicle basis. The non-vehicle specific measures covered in this section include:

- Low sulphur diesel
- Biofuels
- Water Diesel Emulsion fuel

[12] http://www.railway-energy.org/tfee/index.php?TECHNOLOGYID=56&ID=220&SEL=210

- Fuel Additives
- Track electrification

3.3.2 Low sulphur fuels

Where used, current rail gas oil may have a sulphur content of up to 2000 ppm, although in practice it is likely to be lower than this and most European railways use the same diesel fuel supplied to road transport (limited to a sulphur content of <50 ppm (ULSD) from 2005 and moving to <10 ppm in 2009). Gas oil supplied to the rail industry is unlikely to have a higher sulphur content than 2000 ppm due to restrictions on sulphur levels in gas oil for other industry sectors. Reducing the level of sulphur in railway gas oil or diesel would not only result in an immediate reduction in sulphur dioxide (SO_2) emissions, but would also pave the way for the introduction of retrofit abatement equipment unable to tolerate to high sulphur fuels. Such equipment includes technologies such as Exhaust Gas Recirculation, Selective Catalytic Reduction, and oxidation catalysts amongst others.

The Swedish Railways have converted all their trains to run on diesel fuel with <10 ppm sulphur content (commonly referred to as sulphur-free diesel - SFD), as have DB AG in Germany, without any significant problems. Member States are required to introduce SFD from the start of 2005 for road vehicles (from 2009 all fuel for road vehicles must have a sulphur content of <10 ppm). Any move to low sulphur fuels for the rail industry should therefore take this factor into account, as in the near future it may be difficult for oil companies to supply and store <50 ppm ULSD as well as <10 ppm sulphur-free diesel. At current pre-duty prices, ULSD is around €0.02 to €0.03 per litre (1.5 to 2.0 pence per litre) more expensive than gas oil in the UK[13]. A similar differential is expected between ULSD and sulphur-free fuels. Differentials in price may vary in other countries depending on fuel availability and tax levels.

For rail vehicles, use of sulphur-free diesel is likely to result in an increase in fuel consumption, of between 2.5% and 3.0% due to the lower density of sulphur-free diesel compared to gas oil[14]. In addition, the findings from a recent ATOC study suggest there is likely to be a drop in engine power output of up to 2.67%, depending on the engine type.

A move to low sulphur fuels from gas oil is likely to require lubricity additives in order to replace the lubrication properties currently provided by the sulphur in gas oil. With such additives, even older engines might be operated on ULSD or sulphur-free diesel, however a risk analysis carried out by ATOC investigating the possibility of moving to sulphur-free fuel identified that high pressure seals on the fuel inlet system may also need replacing on engines over 10 years old where nitrile rubber seals are used. They are also recommending the use of fuel filters, however the total amount of modification work is currently estimated to be quite small (a minimum of an hour per engine on average). Newer diesel multiple units and freight locomotives may not even require additives, but the mix of vehicles across fleets would require all fuel to be supplied with these additives. Apart from the additional costs, there may be other barriers to the introduction of low sulphur fuels for the railways. However, The Euromot position paper as part of NRMM review[15] states in its summary of requirements for non-road diesel fuel quality:

> *"**1. The fuel sulfur level shall be restricted to 350 mg/kg by 2006***
> *The future sulfur level of heating oil (0.1 %) is not suitable for safe EGR operation under all ambient conditions (potential off-cycle emissions procedure) and in terms*

[13] Source: UK Petroleum Industry Association (UKPIA)
[14] Source: Environmental Performance of Rail: Cost Effectiveness of Measures to Improve the Emissions Performance of Rail, Sujith Kollamthodi and Sam Cross, June 2005.
[15] 'Considerations on diesel fuel quality required for nonroad mobile machinery', Euromot, May 2005

of durability. Sulfur levels above 500 mg/kg will cause condensation problems with Sulfuric Acid in EGR coolers or intake manifolds and excessive corrosion and engine wear. Furthermore lowering Sulfur levels will immediately lower PM levels of machines already operating in the field.

2. The fuel sulfur level shall be restricted to 10 mg/kg by 2009
To enable use of aftertreatment technologies like oxidation catalysts, soot filters and NO_x traps and to be able to meet the 2010 PM standard in use, Sulfur fuel levels must not exceed 10 mg/kg. Higher levels result in irreversible poisoning and blockage of catalysts over lifetime, i.e. reduced durability and in-use compliance."

For the few European railways still using gas oil (such as Italy and the UK) moving to ULSD represents a significant cost increase because of both the additional fuel consumption (around 4.5% on the basis of relative density and energy content of gas oil and ULSD/SFD) and higher cost of the fuel (currently around 2-3 €c/litre in the UK). However, benefits include up to 97.5% reduction in SO_2 emissions and also a reduction in CO_2 emissions of 2.8% (because of the relative carbon content and energy densities between the fuels).

Euromot has also stated that sulphur-free diesel (SFD) should be available 2 years before the introduction of new engines and after-treatment technologies (to meet IIIB emission limits in 2012) requiring its use. In addition, there is a European drive towards harmonisation of road and non-road fuel qualities; this would mean that rail fuel may need to use <10 ppm sulphur by around 2009 – the date currently set for a mandatory limit at this level for road fuels under Directive 98/70/EC (as amended by 2003/17/EC). For this reason many European rail operators are investigating the transition to sulphur-free diesel (such as in the UK), or have already switched to the fuel (such as DB AG in Germany). On the basis of an estimated 2 €c/litre cost differential between ULSD and SFD (actual cost will vary depending on specific country supplies and taxation policy), the cost of switching all European railways to SFD is estimated at €66 million per annum (using 2002 fuel consumption data supplied to UNFCCC).

3.3.3 Liquid biofuels

Biofuel is a term that covers vegetable oil, biogas, bioethanol, Biomass-to-Liquid (BtL) diesel and biodiesel (such as rapeseed methyl ester, RME). Biogas can be used in gas-powered engines, whilst bioethanol is used in spark ignition engines.

The EU Biofuels Directive aims for biofuels to make up 2% of the energy content of all fuels used for transport by the end 2005, 5.75% by 2010, and 8% towards 2020. The main benefit of biofuels is their contribution to the reduction of CO_2 emissions. In principle, the EC regards biofuels as CO_2 neutral, because the amount of CO_2 that is released during their combustion is equal to the amount that was assimilated from the atmosphere during growth. However in practice the actual savings are estimated to range from 30%-80% (for RME from oilseed rape) depending on the production methods and transport routes.

Rapeseed methyl ester is obtained by altering the chemistry of rapeseed oil with the aid of methyl alcohol (methanol). In the process, the fatty acids in the rapeseed oil are separated from the glycerine the oil also contains, and are esterified with methanol instead. The resulting RME has physical properties that allow it to be used in conventional diesel engines. Most greenhouse gas emissions from biodiesel derived from oilseed rape occur during the cultivation of the crop, which requires the use of agricultural machinery and the application of fertilisers and pesticides. Biodiesel is the most developed of the liquid biofuels, but other vehicle fuels can be obtained from biomass sources including biomethanol and bioethanol. Biodiesel can be produced from a range of vegetable oils, including rapeseed, palm, sunflower and Soya bean oils. Around 700,000 tonnes of biodiesel are produced each year in Europe, mainly in Austria, France, Germany, Italy and Spain. Biodiesel can also be sourced from waste vegetable oils, which provide a useful outlet for this material that may otherwise be disposed of at landfill sites. However, the waste oils have to be collected and cleaned before they are esterified into biodiesel and this imposes an additional cost.

Biofuels are often used in a blended form, where a relatively small proportion of biofuel is mixed with a much greater amount of conventional fossil fuel. Many engine manufacturers do not recommend the use of biofuel blends with a biofuel content that exceeds 5%. This is due to the possibility that blends with a higher biofuel content may cause damage to some types of engines. Blending is common in France and Germany where 5% blends are used, but unblended biodiesel can be used in some older existing rail engines, after slight modifications have been made to the engine. The Euromot position paper as part of NRMM review[16] states:

> *"Biofuels shall be used only as a blend with conventional fuel. The amount of FAME shall not exceed 5 % by volume. For diesel engines, concentrations of Fatty-Acid Methyl Esters (FAME) beyond 5% by volume can have an adverse effect on the engine's performance and the fuel system's integrity or durability. Areas of concern are low-temperature operability (filter plugging), heat content (poor fuel economy) and storage/thermal stability (filter plugging, injector deposits, microbial decomposition). Higher volume blends can only be accepted for BTL (Biomass-to Liquid) due to its superior quality (this applies also for GTL (Gas-to-liquid) though it is not a Biofuel)."*

In light of these comments it would be advisable to undertake some comprehensive research to assess the impact on the engine's performance and the fuel systems' durability and integrity prior to the rolling out of blends with a FAME content of greater than 5%.

It is estimated that a 5% greater volume of biodiesel is needed to maintain vehicle performance and range relative to diesel since the energy density of biodiesel is lower. There may be odour problems associated with biodiesel combustion from some sources, such as vegetable oils. Prices for biodiesel have been estimated to be 20-25% more than for diesel. Other drawbacks arise due to the aggressive behaviour of RME, which results in all materials that come into contact with the fuel having to be RME-resistant. Fuel hoses and rubber joints, for instance, swell and become brittle if they come into contact with RME. Before a vehicle can run on pure RME or high percentage blends of RME with diesel, therefore, it is necessary to replace any "at-risk" components with ones that are RME-proof. This has to be checked in each individual instance. The engine manufacturer MAN, for example, issues RME clearance for all new engines delivered, whereas Cummins and Caterpillar are categorically opposed to their engines running on RME.

With respect to CO_2 emissions, using biodiesel (RME) can result in reductions of up to 60% in CO_2 emissions when taking into account the full fuel cycle and combustion of the fuel (according to the recent EC JRC Well-To-Wheels study, 2004). The range represents both variations in production-distribution route maps, and also a degree of uncertainty in estimates. Use of blends of biodiesel greater than 5% by rail vehicles has now been ruled out. However, if all the European railways switched to 5% blends of diesel with biodiesel this could potentially lead to CO_2 reductions in the range of 43-125 ktonnes CO_2 per annum (estimated on the basis of 2002 fuel consumption data supplied to UNFCCC). On the basis of a 2.4 €c/litre differential in the base cost of biodiesel relative to ULSD (estimated on the basis of JRC WTW study, 2004) the accompanying minimum cost to the industry could be around €3.3 million per annum (equating to 26-76 €/tonne CO_2 abated). This figure is obviously dependant on the assumptions on relative costs of biodiesel and regular rail diesel and accompanying individual tax regimes in different countries.

[16] 'Considerations on diesel fuel quality required for nonroad mobile machinery', May 2005

While biodiesel can play an important part in reducing CO_2 emissions, its effects on NO_x and PM are less clear-cut; NO_x emissions from vehicles can be higher when using biodiesel. Emissions of particulate matter are difficult to evaluate, but the available data does not show much difference between biofuels and conventional fuels as regards emissions of particulate matter.[17] The best current estimates assume that biofuels would not lead to any reductions in NO_x or PM_{10} emissions[18] compared to conventional diesel. Tests run by SNCF on biodiesel blends confirm this (see Annex 5). The effects of biofuels on CO_2 emissions are important however, and given the measures already in place to increase market share, awareness of related impacts on air quality is important. In addition, the pollutant sulphur dioxide (SO_2) may be reduced where the introduction of biofuels replaces fuel with a high sulphur content.

Gas-to-Liquid (GtL) diesel is a mature technology producing synthetic diesel by Fischer-Tropsch synthesis of natural gas. When a similar process is carried out using gas derived from gasification of biomass it is referred to as Biomass-to-Liquid (BtL) diesel, also known as 'SunFuel' or 'SunDiesel'[19]. This fuel can generally be used in all diesel engines, as the make-up and especially the purity of the synthesis gas is able to meet the highest quality standards. It also has the potential to reduce net greenhouse gas emissions by up to around 90%[20]. However, the BtL technology is in an earlier stage of development at the moment, compared to relatively mature biodiesel/RME production.

3.3.4 Water Diesel Emulsion (WDE) fuels

Recent advances in fuel technology have led to the development of diesel fuels that can reduce the level of NO_x emissions from road vehicles. A specific technology now on the market is a fuel that consists of an emulsified mixture of diesel, water, and additives that are blended to produce a stable mixture. This technology, generically referred to as Water-Diesel Emulsion (WDE) fuel, has been developed by the Lubrizol Corporation, and has been licensed to a number of different global oil companies. The NO_x abatement performance of this fuel is directly related to the proportion of water in the mixture. WDE fuel marketed in the UK by BP (the fuel is known as "Aspira") consists of 13% (by weight) water held in an emulsified mixture, and NO_x emissions from vehicles using this fuel are approximately 12 to 16% lower when compared to conventional diesel fuels. The percentage NO_x abatement performance does not vary with emissions standard, but the absolute magnitude of the abatement does differ. Emissions of PM are also reduced significantly, by up to 25%.

Water-diesel emulsions have mainly been developed with heavy-duty road vehicle applications, such as trucks and buses, in mind, so might be suitable for rail applications also. Low operating temperatures should not be a problem as trials on London buses have been successful. Although fuel consumption increases due to the water content, this is proportional to the amount of water in the fuel, therefore leading to a reduction in CO_2. Net CO_2 emissions are expected to be approximately neutral as a maximum.

The current pricing structure for these types of fuel is complex and depends on the tax structure of the fuel. WDE fuel costs around €0.06 per litre more to produce than ULSD. However, in the UK BP is exempted from paying tax on the water content of the fuel (around 10%). It is estimated that the retail price of the fuel in the UK is currently around 3 pence (€0.05) more per litre than conventional ULSD. No additional capital costs are incurred by switching to this fuel (fuel storage and dispensing infrastructure is identical to standard diesel fuel).

[17] Gerie Jonk, *European Environmental Bureau (EEB) background paper: On the use of biofuels for transport* (18 March 2002): http://www.eeb.org/publication/EEB-Biofuels-background-18-03-02.pdf
[18] AEA Technology Environment, National Atmospheric Emissions Inventory
[19] As developed by CHOREN Industries, see http://www.choren.com/en/
[20] VW Mobility and Sustainability report - http://www.mobility-and-sustainability.com/

There is relatively little experience in the sector of water Diesel emulsion fuels although DB AG (Germany) FS/Trenitalia (Italy) and SNCF (France) have run tests on their effectiveness. Experience from DB AG was mainly in using systems combining the diesel and water on-board, where NO_x emissions can be reduced by ca. 50-60% by using an injection of a diesel-water emulsion, in which the water amounts to up to 60% of the fuel mass. In addition, a clear reduction in PM emissions was observed. The high water proportions are only achievable for high loads, as when running at low loads the water amounts must be reduced, otherwise the combustion can be put out. Although, SNCF experience with test on premixed WDE were not positive (see Annex 5), FS has run some more successful tests, achieving reductions in NO_x and PM of 18% and 17% over the F-cycle, see Table 3.2, although emissions of particulates were slightly higher at idle and medium speeds. WDE is now currently in use all over Sardinia for rail application.

Table 3.2: Results of tests run by Trenitalia on WDE fuel

	Fuel consumption, kg/h	Emissions, g/kWh			
		CO	HC	NO_x	PM
Gas oil (<2000 ppm sulphur)	187.2	8.2	4	46.9	0.23
Gecam (WDE, 12-15%m/m water, <310 ppm sulphur)	207.3	8.7	4.4	38.4	0.19
Percentage change using WDE	**+10.7%**	**+6.1%**	**+10.0%**	**-18.1%**	**-17.4%**

It should be noted that both SNCF and DB have found that the use of WDE fuel leads to a reduction in power output consistent with the percentage of water in the fuel emulsion.

3.3.5 Fuel additives

Diesel combustion performance can be modified by introducing additives to the fuel or motor oil. This may improve fuel economy and/or reduce pollutant emissions. The use of 5-20% levels of oxygenates (e.g. dimethyl ether (DME), diglyme, ethanol, etc.) in diesel fuels have been shown to be able to reduce emissions. The main impact of oxygenates is a strong reduction in soot emissions, with little influence on NO_x. Biodiesels using diesel/vegetable oil blends are also oxygenated fuels as the vegetable oils contain oxygen-carrying compounds, as is ethanol when manufactured from farm crops. Biofuels are being encouraged as they are considered to be greenhouse gas neutral (discussed further in section 3.3.3). Their use generally depends on the taxation status of the diesel and the oxygenates, as most oxygenates cost more to produce than diesel. From 15% ethanol blended with diesel, PM emissions can be reduced by up to 75% and NO_x emissions by up to 84% at engine loads of around 50% have been reported (for a 1.9 litre VW diesel engine)[21]. This region (high loads at low speeds) is of greatest interest for heavy-duty engines, and therefore may be transferable to some degree to rail applications.

Other additives used in the automotive sector can also, in principle, be applied on rail vehicles, however experiences cannot be directly transferred to railways because of the higher power requirements. Cleaner Diesel Technologies' Platinum Plus diesel fuel catalyst products[22] claim improvements on fuel economy for locomotive engines. They also claim 15-30% particulate reduction, up to 5% NO_x reduction and improvements to oxidation catalyst and particulate filter performances. Claims by ORYXE for their OR-LED additive product include >5% reduction in NO_x, >20% reduction in hydrocarbons and up to 10% reduction in CO[23]. There is some doubt about the effects on fuel economy cited by manufacturers of

[21] Argonne National Laboratory: http://www.transportation.anl.gov/publications/transforum/v3n2/ethanol additive.html
[22] Clean Diesel Technologies Inc: http://www.cdti.com/
[23] ORYXE website: http://www.oryxe-energy.com/

additives, however. The Platinum Plus additive cost is in the range of €0.04 to €0.08 per litre.

Rail experience with additives for emissions reductions is limited, with tests run by SNCF concluding there were no net benefits (see Annex 5). Given the uncertain benefits and significant extra cost there is currently not much enthusiasm for additives in the European rail sector.

3.3.6 Track electrification/reduction of diesel traction utilisation

Across Europe, there is great variability in the proportion of track infrastructure that has been electrified, and consequently in the proportion of vehicle kilometres travelled by electric and diesel rail vehicles. In a number of Eastern European countries (e.g. Lithuania, Estonia, and Latvia), and some other countries such as Ireland, there is either no electric traction, or the proportion of electric traction is less than 10%. By contrast, there are other countries where the proportion of *diesel* traction is below 10% (Poland, Hungary, Italy, Switzerland, and Austria). Electric traction offers a number of advantages in terms of emissions performance. Firstly, there are no pollutant emissions at the point of use; this is particularly important for rail vehicles that operate in urban, or densely populated areas, as air quality is only an issue in such areas. There are still pollutant emissions associated with electrically powered rail vehicles, but these emissions are released at the point of power production – i.e. at power stations, and in the main these tend to be located in rural areas away from large centres of population. Furthermore, in most cases, emissions of local pollutants per passenger kilometre tend to be lower from electric traction when compared to diesel traction. Recent analysis of the situation in the UK has allowed us to provide a comparison of the average emissions performance for a typical DMU and a very similar EMU. These data are presented below in Table 3.3.

Table 3.3: Comparing the environmental performance of a modern DMU with a modern EMU

				Emissions (grams per train kilometre)				
Class / Type	**Power source**	**Configuration**	**Power consumption**	**NOx**	**CO**	**VOCs**	**PM_{10}**	**CO_2**
Bombardier Turbostar	Diesel	1 x 4 car set	9.32 kWh per km	58.90	9.60	2.53	1.21	5990
Bombardier Electrostar	Electric	1 x 4 car set	10.54 kWh per km	10.96	2.05	0.001	0.28	4554
Percentage reduction in emissions (moving from diesel to electric)				**81.4%**	**71.6%**	**99.9%**	**76.8%**	**24.0%**

Note: electric train emissions are the emissions associated with generating electricity at power stations (based on DTI data on the fuel source mix used for electricity generation in 2002).

As can be seen from the Table, emissions of NO_x, PM_{10}, volatile organic compounds (VOCs), carbon monoxide (CO), and carbon dioxide (CO_2) are all significantly lower from electric traction. Data from the EcoTransIT project[24] demonstrates similarly large reductions more widely for rail cargo transport within Europe (see table below), although it is clear from these data that SO_2 emissions from electric traction are higher than for diesel traction.

[24] EcoTransIT: Ecological Transport Information Tool, "Environmental Methodology And Data - Update", IFEU Heidelberg, July 2005. Commissioned by DB Cargo (Germany), Green Cargo AB (Sweden), SBB Switzerland, SNCF (France) and Trenitalia (Italy).

Table 3.4: Average emission factors for rail cargo transport within Europe (based on the EU25 energy split), IFEU Heidelberg 2005

	Energy consumption (kJ/tkm)	CO_2, g/tkm	NO_x, mg/tkm	SO_2, mg/tkm	NMHC, mg/tkm	Dust, mg/tkm
Average diesel train	473	35	544	20	54	15
Average electric train	392	18	29	52	2	13
Percentage reduction *	**-17.1%**	**-48.6%**	**-94.7%**	**160%**	**-96.3%**	**-13.3%**

*Moving from diesel to electric

It should also be noted that emissions from electric traction would improve in further years without the need for further action from the rail industry. The fuel mix used for electricity supply at power stations will change in future years, moving away from coal, and in favour of renewable energy sources. This will have automatic knock-on benefits to the rail sector in the shape of reduced pollutant and greenhouse gas emissions for electric traction.

3.4 Summary of WP2 survey and experience with other measures

As mentioned in the introduction to this chapter, a questionnaire survey was sent out to UIC members (see Annex 2), and followed up with interviews with individual rail operators, where additional information from experiences was available. Figure 3.1 summarise the responses to the questionnaire with regards to experience with technical measures. Details on the specific operators with experience of individual measures is provided in Annex 3.

Whilst there is little experience with retrofit after treatment technology, not surprisingly, there is considerable experience with re-engining and replacing old vehicles with cleaner new ones. Furthermore, almost 70% of the responding train operating companies (TOCs) also had low sulphur diesel fuels (ULSD or sulphur free diesel) in regular service. The use of these fuels is also a prerequisite for many of the advanced emission control measures, so this is a positive result.

A few cases of additional case-specific technical measures were also identified; these are summarised in Annex 5 and include use of modern mechanical transmissions in DMUs by DSB to improve fuel efficiency and ZSSK experience with locomotive modernisation and battery-electric operation.

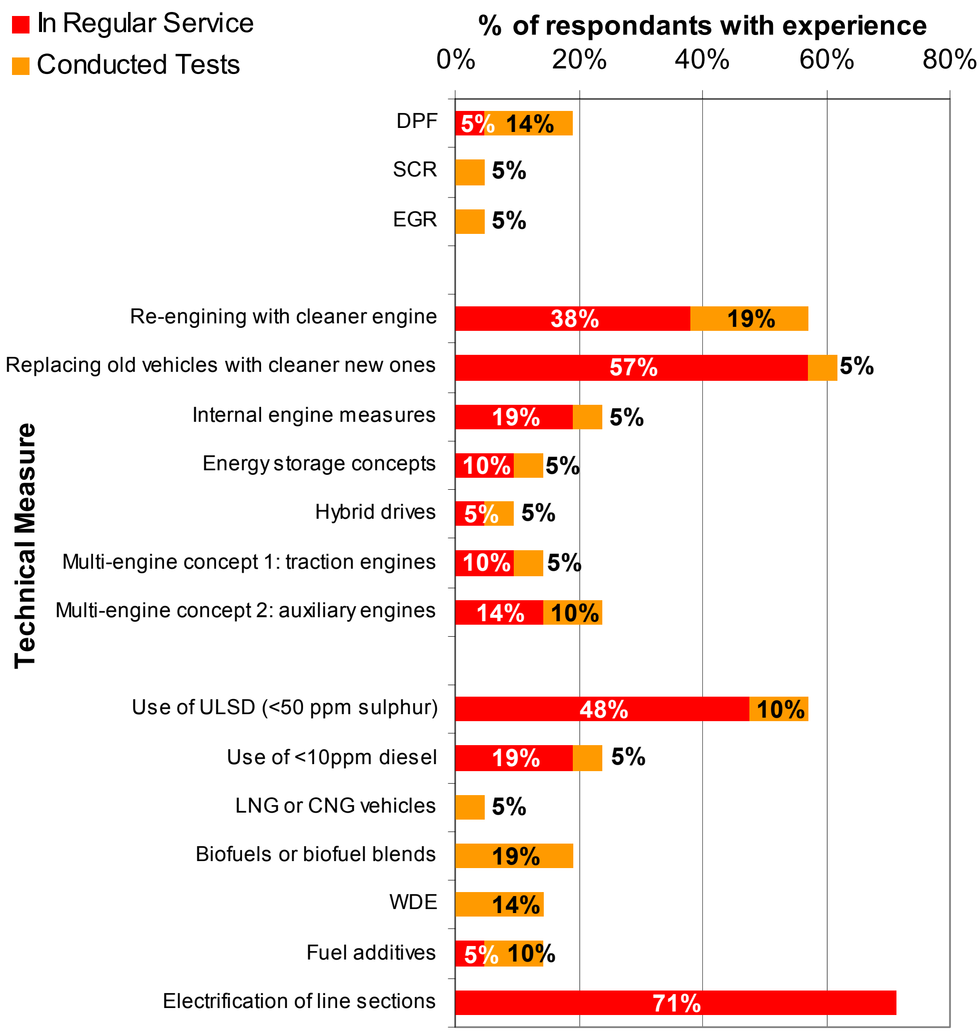


Figure 3.1: Summary of survey responses on experience with technical measures (21 respondents)

3.5 Discussion and summary

There exist a great many potential technical options for improving the environmental performance of diesel rail in Europe. However, some of these options are more suitable for the current fleet, whilst others are more suitable for future rail vehicles. Furthermore in some cases either the benefits are not proven, or the technologies are still in their development phase, with further research and improvements necessary before application will be possible.

The information provided in this section of the report should be treated as the starting point for the more detailed investigation of the costs and emissions benefits of introducing technical options for reducing emissions from diesel traction, although where possible rail-specific case studies on the use of particular technical options have been included in Annex 4. In many cases, current information is based on experiences from application in heavy-duty road vehicles. Detailed life-cycle cost assessments carried out by UIC, UNIFE, and Euromot in sections 4 and 5 of this report use rail-specific data on the anticipated emissions abatement performance of technical options, and initial estimates of vehicle modification costs, where this is available, or rail specific estimations for the future. In particular, attention has been paid to the issue of whether retrofit equipment can actually be fitted to the specific representative traction units chosen for the study.

3.5.1 Selection of measures for detailed analysis for the current fleet

The technological options selected for detailed analysis for the current fleet include:

- DPF (open or closed channels);
- SCR;
- POC;
- SCRT;
- EGR;
- Re-engining.

These have been selected on the basis of realistic potential for application to the current fleet and potential for reduction of NO_x and PM. Methods of aftertreatment for exhaust gases differ both in the way they act and the degree to which they reduce the pollutants contained in diesel engine exhaust gases (see Table 3.4).

Table 3.4: Types of exhaust after-treatment

Method	Action	Name	Constituents*
Oxidation	Catalysis	Oxidation catalyst	HC, CO
Filtration	Precipitation	Particulate filter	PM
Reduction	Catalysis	SCR system	HC, NO_x, PM
Oxidation + Filtration	Catalysis + Precipitation	POC/CRT® system	HC, CO, PM
Oxidation + Reduction + Filtration	Catalysis + Precipitation	SCRT® system	HC, CO, NO_x, PM

HC = hydrocarbons, CO = carbon monoxide, NO_x = nitrogen oxides, PM = particulate matter

Options are not investigated further within this study for the following reasons:

- NO_x adsorber or lean-NO_x catalysts are not known as possible application for retrofitting in railway applications at the moment.
- A detailed analysis of hybrid drive, energy storage and multiengine concept would be much beyond the scope of this study and more suited to new vehicles.
- In its present state of development, CNG technology is not suitable for attaining the requisite distances with existing rolling stock and will not, therefore, be dealt with further as part of this study.
- Given that it is not possible to install LNG tanks plus their peripherals on existing rolling stock in dimensions that would be practicable, LNG propulsion shall also not be gone into in any further depth in this study.
- Use of water diesel emulsions or fuel additives has been ruled out on the basis of unfavourable results of trials carried out for rail applications (discussed in sections 3.3.4 and 3.3.5).

The possibilities for use of low sulphur diesel fuels and biofuels are discussed more generally in the following section 3.5.2, and summarises their potential for use on the railways and the resulting potential impacts on emissions and costs. .

3.5.2 Low sulphur diesel fuels and biofuels

As already discussed earlier in section 3.3.2, there is theoretically no difficulty for rail vehicles moving from <50 ppm sulphur diesel fuel (often referred to as Ultra Low Sulphur Diesel, (ULSD)) used by most European railways to <10 ppm diesel fuel (often referred to as sulphur-free diesel, (SFD)). However, there are potentially problems for vehicles currently operating on gas oil (up to 2000 ppm sulphur) moving to either ULSD or SFD. These include the need for lubricity additives, increased fuel consumption (due to the relative energy content between gas oil and ULSD/SFD) and replacement of nitrile rubber seals on engines over 10 years old (according to a UK ATOC risk analysis).

The implications of the move to ULSD or SFD have been discussed in more detail earlier (section 3.3.2), however with harmonisation of road and non-road fuel quality standards likely on an EU scale, many operators are already investigating a switch to SFD, because the road sector will have moved completely to sulphur-free fuels by 2009 and Euromot have indicated this fuel will also be required for future technologies to meet the envisaged NRMM Directive Stage IIIB limit values.

With regards to biodiesel, it is the general position of diesel engine manufacturers (represented by Euromot) that biodiesel should not be used in blends with regular rail diesel at greater than 5% by volume, as for new advanced engines there are also additional problems for RME use, already discussed earlier in section 3.3.3. With respect to emissions of air pollutants, using RME only yields mixed results from only a small reduction in the various constituents, to increases in emissions in some cases. In rig tests conducted on a multiple-unit engine (Cummins QSK 19), NO_x emissions fell by approx. 10 % in the ISO F cycle, HC and CO emissions by approx. 30 % and emissions of particulates remained constant. This is offset by an increase in fuel consumption of approx. 15 %. However, tests carried out by SNCF for 10-20% biodiesel blend with regular diesel on a DMU engine actually lead to a 3% increase in NO_x emissions. The UK biodiesel provider Green*ergy* has also indicated poor (100% biodiesel) to neutral (5% biodiesel) NO_x emissions performance in rail applications[25]. For these reasons, no further consideration has been given in this study to using biodiesel or biodiesel blends. The implications of moving the European fleet to a 5% blend have been discussed in more detail earlier (section 3.3.3), but could potentially lead to CO_2 reductions in the range of 43-125 ktonnes CO_2 per annum at a cost of 26-76 €/tonne CO_2 abated. This figure is obviously dependant on the assumptions on relative costs of biodiesel and regular rail diesel and accompanying individual tax regimes in different countries.

3.5.3 Overall summary

Table 3.5 overleaf summarises the potential performance and the status of the technical options identified. Many of the technical emissions abatement measures discussed in the previous sections rely on the use of low sulphur fuels with a maximum sulphur content of 50 ppm. Not only do low sulphur fuels open the door for a range of other technologies, but on their own they also can also lead to very large reductions in SO_2 (and possibly PM emissions). It is clear that in order for any significant emissions benefits to be realised, low sulphur fuels would have to replace the higher sulphur fuels currently still used on part of the European rail network. However, before such a decision is made, the cost implications should be understood and care should be taken to ensure the market is able to supply the requisite quantities of low sulphur or ultra low sulphur fuel.

[25] Presentation by Green*ergy* on Biodiesel to the UK Strategic Rail Authority (SRA), May 2004.

Table 3.5: Summary of status of technical options and whether they are taken forward for more detailed analysis

Measure	Primary emissions benefits	Status	Additional requirements	Considered further in detailed analysis	
				Current	Future
Vehicle Specific Options					
After treatment / modification					
Oxidation Catalyst	CO, HC	- Experience mainly in on-highway sector	ULSD	No	Section 5
Diesel Particulate Filter (DPF)	PM	- Experience mainly in on-highway sector	ULSD	Section 4	Section 5
Continuously Regenerating Trap (CRT®)	CO, HC, PM	- Development needed for rail	ULSD	Section 4	Section 5
Combined Particulate Oxidation Catalyst (POC)	CO, HC, PM	- Experience mainly in on-highway sector - Development needed for rail	ULSD	Section 4	Section 5
NO_x Adsorber Catalyst (NAC)	NO_x	- Technology still in development	SFD	No	Section 5
Lean-NO_x Catalyst	NO_x	- Technology still in development	ULSD	No	Section 5
Selective Catalytic Reduction (SCR)	NO_x	- Experience mainly in on-highway sector	ULSD, urea and urea infrastructure	Section 4	Section 5
SCRT® (Combined SCR+CRT®)	NO_x, CO, HC, PM	- Development needed for rail		Section 4	Section 5
Exhaust Gas Recirculation (EGR)	NO_x, (HC, CO)	- Experience mainly in on-highway sector - Some experience for rail	ULSD, additional cooling	Section 4	Section 5
Internal Engine measures	Varied	- Some experience for rail		Section 4	Section 5
New engines / new vehicles		-			
Re-engining	All	- Good experience in the rail sector - Limited by engine availability		Section 4	N/A
Fleet replacement	All	- Some experience as part of overall strategies		No	N/A
Hybrid drive and energy storage concepts	All	- Technologies in development - Some rail development projects		No	No
Multi-engine concept (twin main engine or additional auxiliary engine)	All	- Some experiences for specific applications	More frequent maintenance	No	No
Compressed Natural Gas (CNG)	All	- Very limited engine availability - Very low vehicle range due to difficulties in storing sufficient fuel on-board	CNG, new refuelling infrastructure	No	No

Measure	**Primary emissions benefits**	**Status**	**Additional requirements**	**Considered further in detailed analysis**	
				Current	**Future**
Liquefied Natural Gas (LNG)	All	- Very limited engine availability Very low vehicle range due to difficulties in storing sufficient fuel on-board	LNG, new refuelling infrastructure	No	No
Liquefied Petroleum Gas (LPG)	NO_x, CO, HC, PM	- Very limited engine availability Very low vehicle range due to difficulties in storing sufficient fuel on-board	LPG, new refuelling infrastructure	No	No
Non-Vehicle Specific Options					
Fuels					
Ultra-Low Sulphur Diesel (ULSD)	SO_2, (PM)	- Most European fleets already use this type of fuel	Potential replacement of certain seals for engines currently using gas oil (such as in Italy and UK)	No*	No*
Sulphur-free diesel (SFD)	SO_2, (PM)	- Some European rail fleets already using - Likely to be required by 2009		No*	No*
Biofuels	CO_2, (PM)	- Only blends up to 5% guaranteed by engine suppliers		No	No
Water Diesel Emulsion (WDE) fuels	NO_x, PM, (CO_2)	- Unfavourable results of trials for rail ⇒ corrosion of fuel injection elements	Separate/new refuelling infrastructure	No	No
Fuel additives	NO_x, PM	- Unfavourable results of trials for rail		No	No
Other options					
Line electrification	All	- Well understood, with practicalities of developments dependant on varying government policies, relative costs and industry organisation in different countries		No	No

Notes:
ULSD = <50ppm sulphur) diesel, SFD = <10ppm sulphur diesel
* Required for many engine and aftertreatment technologies and already being implemented. Detailed LCA assessment is not appropriate.

4 Technical Measures Assessment for Current Fleet

In this section the methodology and results of the detailed assessment of technical measures for the current fleet are presented. Some of the measures selected for more detailed analysis are characterised on a more general level within the following sections. For the others, such as different exhaust after-treatment measures as well as Exhaust Gas Recirculation (EGR) and re-engining vehicles, specific analyses are performed and displayed in section 4.3.

4.1 Selection of representative traction units

The concept developed for the detailed analysis work of technical emission abatement measures was to model typical traction units on a single vehicle basis. This was to be carried out on the basis of offers from industry (vehicle and engine builders, suppliers of exhaust after-treatment systems, vehicle refurbishing works, suppliers of suitable fuels, etc.), taking the requirements for railway applications into consideration. Subsequently, the reduction of exhaust emissions were to be set against the necessary investment costs, and the effects on the Life Cycle Cost assessed.

It was not feasible or practical within the resources of the study to carry out compatibility and life-cycle analyses on technical measures for a large variety of different diesel locomotives and railcars. It was therefore necessary to select a range of "representative traction units" for the current European fleet, taking into account parameters such as:

- The numbers of vehicles of particular types currently in operation;
- Vehicle power;
- Emissions;
- Vehicle age;
- Traction type;
- Engine mounting conditions, and
- Usage (in terms of both annual tonne-kilometre and also type of use, e.g. commuter, long-distance passenger, freight or shunting).

Furthermore, it was necessary to consider whether the chosen vehicle would be able to contribute to reducing emissions at possible air quality hot spots. For example, traction units primarily used on rural lines are unlikely to be contributors to hot spots and hence it is unlikely to be cost effective to choose such vehicles, whereas vehicles used on commuter or main lines are more likely to be suitable.

The work was carried out by Deutsche Bahn (DB) AG, Česke Drahy (ČD) and SNCF, using test objects for the current fleet selected from the list of vehicles constituting the diesel fleet in Europe developed in work package 1 (using data provided in the WP1 Questionnaire) in consultation with UIC members. Selection of representative vehicles was made according to the following steps:

4.1.1 Step 1: Definition of categories

In consultation with the UIC diesel expert group B 208 it was agreed to define a typical diesel railcar, main line locomotive and shunting locomotive for two different age categories “engines built before 1990” and “engines built after 1990”.

Table 4.1: Categories of vehicles for the selection of representative traction units

Typical existing traction unit	
Engine age category A (< 1990)	**Engine age category B (>= 1990)**
• Typical railcar • Typical main line locomotive • Typical shunting locomotive	• Typical railcar • Typical main line locomotive • Typical shunting locomotive

The main arguments for these age categories are:

- From 1990 onwards a lot of low-floor railcars that have very limited space available for exhaust gas after-treatment devices to be fitted came onto the market.
- Electronic control for engines is more common from 1990 onwards, which is prerequisite for certain types of emission abatement technology.
- A further age category for very old vehicles does not seem to be reasonable to meet the objectives of the study as such vehicles are more likely to be decommissioned in the near future than be equipped with emission abatement technology.

4.1.2 Step 2: Identification of countries/companies with a large number of diesel traction units

As part of the surveys carried out for Work Package 1, UIC member railways were asked in February 2005 for the number of railcars and locomotives in different power and age categories (see WP 1 report, chapter 2.2.3. and annex 4.5, question A1).

An overview of the age distribution for all traction units (see Figure 4.1) shows that generally, a high percentage of the engines identified are used by DB (Germany), SNCF (France), ATOC (UK), FS (Italy) and ČD (Czech Republic) and PKP (Poland). Especially for the DB and ATOC fleets, a relatively high number of younger engines built from 1990 onwards can be seen. Representative vehicles from these fleets are more likely to also reflect the wider European fleet.

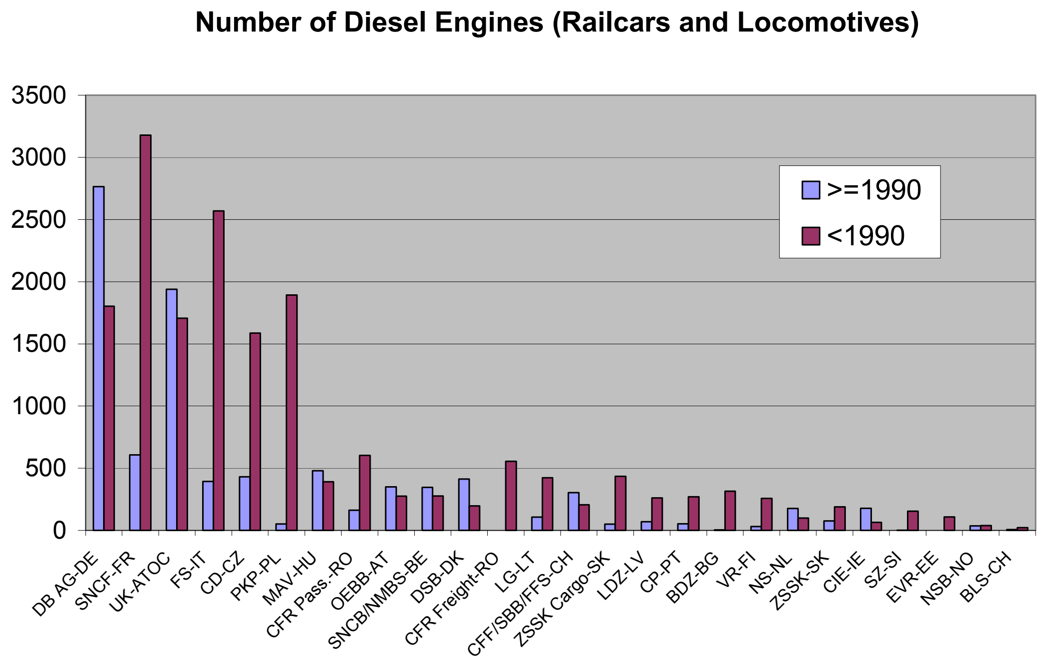


Figure 4.1: Diesel engines before and after 1990 in use at European Railways

4.1.3 Step 3: Evaluation of named representative vehicles in the UIC questionnaire

As part of the survey process carried out in WP1, each of the railway operators surveyed was asked to provide details of railcars, mainline locomotives, and shunting locomotives that they thought were representative of vehicles in their fleets. This data was used to help select a set of traction units (railcars, mainline locomotives and shunting locomotives) that could be thought of as representative of the European fleet. Details of the responses provided by each operator can be found in Annex 4.5 of the WP1 report. Operators were also asked to supply information on average fuel consumption, NO_X and PM_{10} emission factors for their representative traction units, and total tonne kilometres travelled per year for these representative vehicles. It should be noted that the data supplied was not complete in all cases – this was particularly the case for data on tonne kilometres travelled per year. This meant that for each country it was not necessarily possible to categorically identify the most representative traction units. Nevertheless, it is thought that the information supplied by each operator provides a relatively robust indication of which classes of traction units are representative of the wider fleet in each country.

The representative traction units selected by each operator as part of the survey process were then compared with traction units from the fleets in each of the railway operators that were part of the core WP2 project team (DB, ČD, and SNCF). It was decided that the traction units that should be used as representative of the whole European fleet should be taken from fleets of these three operators. There were a number of reasons for using this approach. Firstly, these operators have a very large selection of different types of traction units in their respective fleets, and it was reasoned that it should therefore be possible to identify vehicles that are representative of the wider European fleet. Secondly, as DB, ČD, and SNCF were part of the core working team, it would be more straightforward to obtain detailed technical data on each of the different traction units eventually selected. The type of data required for each traction unit is given in Table 4.2 below:

Table 4.2: Detailed technical data required for the traction units chosen as representative of the wider European fleet

At the different load points of the test cycle the following information was needed:

Engine:
- Performance (kW)
- Rotation (U/min)
- CO (g/kWh), HC (g/kWh), NO_x (g/kWh), PM (g/kWh)
- Exhaust temperature (°C)
- Flow of exhaust (kg/h) and (m3/h)
- Back pressure of exhaust (mbar)
- Fuel consumption (g/kWh)
- Scheduled maintenance
- Oil consumption, kind of oil
- RME suitability (y/n)

Locomotive / railcar:
- Weights and measures of silencer
- Clearance for after-treatment
- Length between end of Turbocharger end silencer
- Mechanical Strength of framework of the locomotive
- Potential Fixation of after-treatment
- Restriction for heat radiation
- Kind of control unit
- Drawings of engine, silencer, exhaust pipes
- Data about operational cost (LCC)

Through reviewing the data on traction units obtained from each UIC member company, a set of railcars, mainline locomotives and shunting locomotives that are representative of the wider European fleet were selected from the DB, ČD, and SNCF diesel fleets. The vehicles chosen are shown in Table 4.3, as follows.

Table 4.3: Chosen representative vehicles for more detailed analysis

	Railcars			**Mainline locomotive**		**Shunting locomotive**	
	< 1990	**>= 1990** ~300 kW	**>= 1990** ~600 kW	**< 1990**	**>= 1990**	**< 1990**	**>= 1990**
Company	ČD	DB AG	DB AG	DB AG	DB AG	ČD	DB AG
Type of vehicle	810	642	612	232	218	742	290 / 294.5-294.9
Type & name of engine	LIAZ ML 634	MTU 6R 183 TD13 H	Cummins QSK 19	Kolomna 5D 49M	MTU 4000 16V R41	K 6 S 230 DR	MTU 4000 8V
Engine power [kW]	155	2 x 275	2 x 559	2226	2100	883	1 x 1000
Type of power transmission	diesel-hydro-mechanical	diesel-hydraulic	diesel-hydraulic	diesel-electric	diesel-hydraulic	diesel-electric	diesel-hydraulic
Diesel consumption [g/kWh]	235.9	220	212	230	214	228	219

	Railcars			Mainline locomotive		Shunting locomotive	
	< 1990	**>= 1990** ~300 kW	**>= 1990** ~600 kW	**< 1990**	**>= 1990**	**< 1990**	**>= 1990**
CO emissions factor [g/kWh]	2.5	0.50	1.07	5.30	0.59	2.82	0.8
HC emissions factor [g/kWh]	1.25	0.34	0.61	1.20	0.43	0.79	0.6
NO_x emissions factor [g/kWh]	17.29	7.0	8.74	17.6	9.10	15.1	11.6
PM emissions factor [g/kWh]	0.45	0.14	0.16	0.25	0.152	0.6	0.16
Test cycle	ISO-13 points	ISO-F	ISO-F	ISO-F	ISO-F	ISO-F	ISO-F

For comparison purposes, Figure 9.7, Figure 9.8 and Figure 9.9 in Annex 6 of the report show the Europe-wide average NO_x and PM emission factors in g/kWh for railcars, mainline locomotives, and shunting locomotives. The charts also show the emissions factors for the proposed representative traction units.

In addition to the traction units that were finally chosen, the SNCF BB 67000 was originally proposed for inclusion as one of the representative mainline locomotives, and the SNCF BB800 was also originally proposed as one of the shunting locomotives. However, these vehicles were, in the end, not included in the list of representative traction units as their emission factors were found to be much lower than the European averages for pre-1990 locomotives. Nonetheless, SNCF undertook some preliminary work (see section 4.5) to determine the applicability of the technical measures to the BB 67000 and BB800. The analysis was not intended to be as detailed as that carried out by DB but does provide a good initial indication of the feasibility of the technical measures. Furthermore, additional analysis relating to the possibility of applying technical measures to the widely used (especially in the UK) Class 66 locomotive can be found in Annex 5.

4.2 Methodology/framework for assessment

For the various different types of traction unit, **re-engining** with a an engine with improved emissions performance has been investigated as an option. When re-engining is being considered as an option, there is a need to ensure that the interfaces between the new engine and the vehicle are compatible, including the following parameters:

- size of engine,
- engine mounting points
- location of the engine's centre of gravity,
- direction of rotation,
- location of engine power shaft output in relation to gearbox position
- compatibility of engine speed with the existing gearbox
- position of components such as the turbocharger and cooler
- engine torque characteristics

It also has to be taken into account that very old engines often do not have any intercooler at all or they have an internal intercooler. By contrast, for new engines an external intercooler is typically necessary, which leads to requirements for additional space.

Future engines that are used for re-engining purposes will have to fulfil the limit values of the NRMM Directive 97/68/EC (Stage IIIA and Stage IIIB limits). To meet the Stage IIIA limits, a variety of concepts exist for future engines. In consequence there will be significant changes in the engine design, e.g. different turbo charging concepts with larger intercoolers, an external cooling system, or the use of EGR. In some cases, this may mean that re-engining will not be possible due to the additional size and weight associated with these replacement engines.

Taking all of the above factors into account, initial market research was carried out to identify whether it would be possible to re-engine the representative vehicles included in this study. Where no appropriate replacement engines were identified, this has been stated and no additional analysis was undertaken with regard to re-engining. Further work to identify possible modifications that could be made to potential replacement engines so that they fit the representative vehicles would have been beyond the scope of this study.

For the purpose of producing **exhaust after-treatment** concepts for the existing fleet, tenders were requested from a number of suppliers of exhaust gas aftertreatment systems.
Bids were to be made for different variants on the basis of the technical data for the reference vehicles and the parameters for installation.

Variant A:
Taking account of fitting conditions, tenders were to be submitted for systems to reduce emissions of NO_x and particulates as well as for systems to simultaneously reduce all pollutant constituents subject to limit values (CO, HC, NO_x, PM).

Variant B:
Tenders were to be submitted for systems permitting conformity with stage IIIB of Directive 97/68/EC without taking account of fitting conditions on the vehicle. In the case of this latter variant, its basic feasibility was examined and the refitting input required assessed.

Hitherto, the manufacturers of exhaust after-treatment systems for internal combustion engines have primarily been active in the power station sector as regards stationary applications and, in the mobile sphere, have focused on ships, road vehicles and construction plant. Very little experience of the specific requirements of railway operations has been gained in the field of rolling stock. The spectrum of deployment scenarios on the railway, involving a high proportion of empty running as it does, poses a particular challenge. The equipment is required to function over a broad range of temperatures (exhaust gas temperatures from 100-500°C) and to withstand the mechanical and thermal loadings common in rolling stock. The large engines on diesel locomotives only tolerate low exhaust gas back-pressures, meaning that the system must be dimensioned accordingly and the substrate for the catalyst and filter appropriately specified. These engines are in use for far longer periods than in other applications; hence the systems need to remain fit for function for a suitably long period as well as having a low failure rate. Additional working materials necessitate additional investment in the relevant infrastructure. Tenders were requested from the following companies:

Table 4.4: Companies requested to provide tenders for exhaust after-treatment systems

ARGILLON GmbH
HJS Fahrzeugtechnik GmbH & Co KG
PUREM
Arvin Meritor
ATH CleanAir GmbH
Robert Bosch GmbH
Friedrich Boysen GmbH & Co. KG
J. Eberspächer GmbH & Co. KG
Energietechnik Bremen GmbH
HUG Engineering GmbH
Johnson Matthey

The responses to our enquiry varied greatly. Some manufacturers indicated a complete disinterest in developing and manufacturing exhaust gas after-treatment units for railway vehicles or else have capacity problems due to high demand in the road vehicle sector. Particular mention should be made of diesel particulate filters for motor cars, which are currently tying up a great deal of development capacity. The tenders submitted do however allow initial pronouncements to be made regarding feasibility, system dimensions and weight, investment costs and consequences for the cost of operating the stock.

The following approach was adopted to determine costs:

1. Life Cycle Costs (LCC) comprising fixed and variable costs.
2. The fixed costs are defined by the procurement price and the cost of developing, integrating and fitting the exhaust-gas aftertreatment equipment.
3. The calculated rate of interest of 10% represents the additional annual costs incurred during the 8-year service life assumed for the exhaust-gas aftertreatment equipment.
4. The variable costs consist of the annual operating costs for the exhaust-gas after-treatment equipment (i.e. reducing agent consumed, outlay for preventative maintenance) and any costs associated with additional fuel consumption.
5. Account also needs to be taken of outlay for infrastructure and logistics where the use of a reducing agent is concerned.

The procurement price was established on the basis of quotes by the potential suppliers of exhaust after-treatment systems. A unit volume of 100 systems was posited (the number of traction units of the same type varies between 10 and about 400 per design series). Where there were several bids that met the technical requirements and where the abatement performance values were comparable, the more economical supplier was chosen for costing purposes. The cost of developing the exhaust after-treatment equipment was either detailed separately or else formed part of the procurement price. Integration costs were related to outlay for the engineering involved in adding the exhaust-gas aftertreatment equipment to the vehicle and creating the interfaces to the diesel engine; these costs are extrapolated for a fleet of 100 vehicles. Fitting costs take account of the outlay needed to adapt the vehicle and fit the system.

Additional operating costs (including additional fuel consumption, etc) were determined on the basis of annual mileage or period in service. Outlay for preventative maintenance relates to the replacement of worn parts as well the servicing of systems and associated diagnostic equipment. Additional consumption of fuel is due to an increase in exhaust-gas back pressure and, in particulate filters with active fuel-based filter regeneration, because fuel is used as the means of regenerating the filter.

In SCR systems, reducing emissions of nitrogen oxides necessitates using a reducing agent. An aqueous urea solution is now commonly used for this purpose in the case of commercial vehicles. This is taken on at the refuelling point along with the diesel fuel. For this particular technology, the cost of retrofitting train refuelling points is cited as a one-off item. Logistics costs are included in the price of the reducing agent.

4.3 Results (by Vehicle/Technology)

In this section the results of the analysis of different emission abatement measures for each chosen representative vehicle are presented.

4.3.1 Railcar (DMU) < 1990: Class 810

Figure 4.2: Photo of the Class 810

The figure shows the layout of the engine and exhaust-gas unit components on the VT 810.

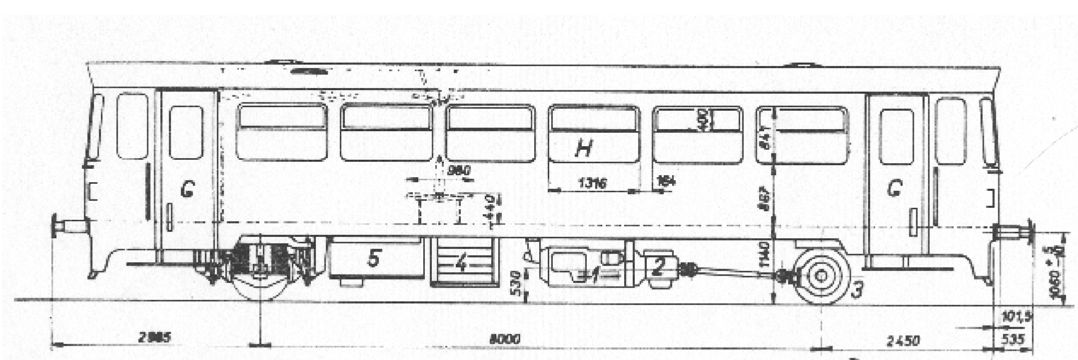


Figure 4.3: Sectional drawing of the Class 810

ČD's VT 810 serves as the older (pre-1990) internal combustion engined railcar (DMU) for the purposes of the study. The layout is typical of older internal combustion engined railcars (DMUs). The engine is fastened to the body. Transmissions, cooling plant and exhaust-gas unit are individually located beneath the vehicle and connected to the body. This mode of design allows individual components to be replaced and flexibly adapted to given fitting conditions but generally entails a large gap between the engine's exhaust gas outlet and the silencer. This causes the exhaust gas to cool down to a greater or lesser degree depending on the point of operation of the engine, which impacts adversely on the efficiency of catalysts or the regeneration of particulate filters.

The parameters cited yield the following options for the various exhaust-gas aftertreatment technologies (the full detailed analysis is provided in Annex 6). A diesel particulate filter with open channels can be integrated into the space available on the DMU by replacing the existing exhaust silencer. Particulate emissions abatement performance of approximately 30-40 % can be achieved in this way (a precondition being that particulate size distribution is comparable to that with automotive diesel engines). A DPF system with closed channels and active regeneration takes up too much space. An SCR system could be accommodated on the vehicle given some modification work. However, this would require the transfer of data from the engine control system for the purpose of regulating the volume of reducing agent, but these are not available. The emission factors for the LIAZ ML 634 engine fitted to the VT810 railcar are far higher than those for modern diesel engines (NO_x: factor 2-3 times greater than the average for a modern engine, particulates: factor 4-5 times greater than for a modern engine). Accordingly, re-engining would be the most suitable means of improving exhaust gas values on the VT 810. This presupposes the availability of a compatible engine, which cannot necessarily be guaranteed.

The additional costs associated with possible options for the VT810 railcar are presented in Table 4.5 below.

Table 4.5: Change in capital and operating costs associated with emissions abatement options for the VT810 railcar

	Retrofit open channel DPF	Re-engining
Total additional capital/fixed costs	€ 11,000	€ 87,500
Total change in annual operating and maintenance costs	€ 510	-€ 2,785

Summary of VT 810 analysis

The analysis reveals the limits to the feasibility of adding exhaust after-treatment units to existing internal combustion engined railcars as well as the limits to the abatement performance for pollutant emissions achievable with their aid. The exhaust emission factors for older diesel railcars are far higher than those with modern diesel engines. It is impossible even with complex and expensive exhaust gas after-treatment technology to adhere to the limit values prescribed for stage IIIB.

Moreover, it is also frequently the case that the after-treatment regulating variables required by the vehicle and engine control systems are not available, thus rendering integration an arduous if not impossible undertaking. The permissible exhaust-gas back pressure for rail diesel engines is generally far lower than the values for motor cars or commercial vehicles. The increase in back pressure induced by positioning a catalyst or filter downstream is one that cannot be coped with by the engine in many cases.

Where older internal combustion engined railcars (built before 1990) are concerned, therefore, re-engining constitutes the most sensible way of lastingly improving exhaust-gas emissions. The availability of compatible engines has a crucial bearing on the feasibility of this course of action and is not something that can always be guaranteed.

4.3.2 Railcar (DMU) >1990: Class 612

Figure 4.4: Photo of the VT 612

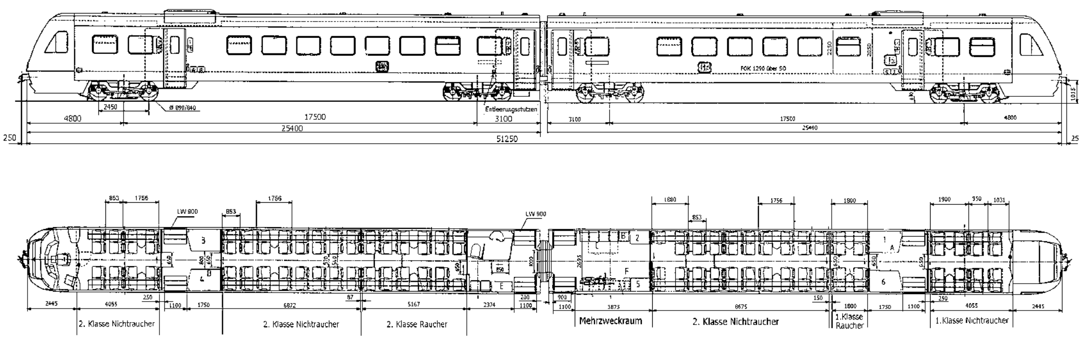


Figure 4.5: Sectional drawing of the VT 612

The VT 612 (560 kW) (and VT 642, 275kW) vehicles were chosen to represent newer DMUs. The layout of the engine and exhaust system components on the VT 612 is typical of internal combustion engined railcars with higher-output diesel engines (>500kW) and no low-floor sections. The drive components (engine, transmission /generator, cooling system, exhaust gas unit) are individually attached to the body and are comparatively easily accessible. On the latest designs of internal combustion engined railcars, these components are grouped together in what are known as power packs with differing degrees of integration depending on their output category (cf. VT 642, VT 644). The exhaust silencer on the VT 612 is located beneath the floor.

The exhaust system comprises a front and rear silencer plus piping. There is comparatively little space in the immediate proximity of the exhaust system in which to integrate any additional components. It is not possible to integrate exhaust after-treatment components in the area around the front silencer. Where the rear silencer is replaced by a catalyst or filter, it is necessary to ensure that the required thermal insulation is provided. The only additional space available to fit after-treatment components is in the area of the rear silencer (approximately 140 litres).

The parameters cited yield the following options for the various exhaust after-treatment technologies (the full detailed analysis is provided in Annex 6). The VT 612 has space for a DPF with active regeneration, enabling it to meet the particulate limit value prescribed for stage IIIB. LCC costs rise by 9.2 eurocents per kilometre (€ct/km). It is possible to add either an SCR or a POC system, or else a combination of a DPF and an SCR system to the vehicle once modifications have been made. The latter option allows emissions of NO_x, HC and particulates to be cut by 50-70%. However, incorporating these additional components may lead to excessive loading on the body or on the axles. Checks need to be made to determine whether the vehicle body can withstand the additional loading in its present form, whether a counterweight may be necessary between the two sides of the vehicle (to counteract uneven loading), and whether the vehicle's licence is still valid given the additional loading on the axles. Should the additional weight not pose an insurmountable problem, the additional costs associated with emissions abatement options for the VT612 railcar are as presented in Table 4.6 below (based on annual distance travelled of 200,000 km per railcar):

Table 4.6: Change in capital and operating costs associated with emissions abatement options for the VT612 railcar

	Open channel DPF	Retrofit SCR system	Retrofit SCR + DPF system
Total additional capital/fixed costs	€ 62,000	€ 58,500	€ 96,000
Total change in annual operating and maintenance costs	€ 6,750	€ 5,700	€ 10,950

These costs can also be quoted in terms of additional costs per train kilometre travelled. These costs are as follows:

Open channel DPF (POC): 9.2 €ct/km
SCR: 8.3 €ct/km
SCR+DPF: 14.5 €ct/km.

Summary of VT 612 analysis

Given the emission values for the engine on the VT612, there is no technology available at present time that would permit adherence to the limit values prescribed for stage IIIB. That said, combining SCR with a diesel particulate filter would allow pollutant emissions to be considerably reduced. However, these improvements would have a significant impact on the operating costs for the rolling stock, which would increase by 14.5 eurocents (€c) per km.

4.3.3 Railcar (DMU) >1990: Class 642

Figure 4.6: Photo of the VT 642 railcar

The VT 642 (275kW) (and VT 612, 560 kW) vehicles (shown in Figure 4.6) were chosen to represent newer DMUs. The VT 642 features a high degree of integration of the drive system in what are known as power packs and has the on-board components positioned beneath the floor, which is typical of a modern internal combustion engined railcar (DMU). This makes optimum use of the envelope by leaving little free space in the under-floor area but maximising the space available for passengers whilst also guaranteeing low boarding heights. The exhaust silencer on the VT 642 is housed in a control cabinet in the passenger accommodation area and the exhaust piping runs from the diesel engine through the vehicle body and passenger accommodation area to the vehicle's roof.

The parameters cited yield the following options for the various exhaust-gas aftertreatment technologies (the full detailed analysis is provided in Annex 6). The systems referred to with regards to the VT 612 (DPF, SCR, POC, DPF+SCR) in section 4.3.2 can only be housed on the VT 642 if comprehensive modifications are carried out that would result in reduced passenger capacity. For instance, two seats would have to be removed from the passenger accommodation area to make way for an SCR regeneration container. Furthermore, the weight problem is even more acute than with the VT 612. The increase in LCC costs per kilometre are the same as for the VT 612 (i.e. DPF: 9.2€ct/km, SCR: 8.3 €ct/km, POC: 9.2 €ct/km, DPF+SCR: 14.5 €ct/km). Table 4.7 presents estimates for the additional total capital costs and additional annual operating and maintenance costs associated with open channel DPFs and a combined SCR with closed channel DPF for the VT612 railcar. The operating cost estimates in this table are based on an annual average distances travelled of 120,000 km per railcar.

Table 4.7: Change in capital and operating costs associated with emissions abatement options for the VT642 railcar

	Retrofit open channel DPF	Retrofit SCR + DPF systems
Total additional capital/fixed costs	€ 24,000	€ 56,000
Total change in annual operating and maintenance costs	€ 2,800	€ 6,756

Summary of VT 642 analysis
The VT 642 is configured in a manner typical of modern internal combustion engined railcars. Its low-floor design greatly limits the options for integrating additional items into the existing layout. Extensive conversion measures are required to create sufficient space for exhaust gas aftertreatment systems. The additional weight is likely to lead to a restriction on the number of passengers permissible. Improvements in exhaust-gas emissions have a significant impact on the cost of operating the stock.

4.3.4 Mainline locomotive < 1990: Class 232

Figure 4.7: Class 232 mainline locomotive

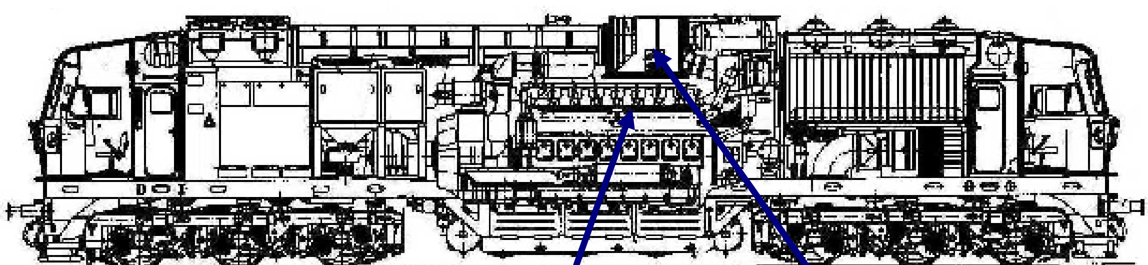


Figure 4.8: Class 232 sectional drawing engine exhaust silencer

The Class 232 vehicle (Figure 4.7) is a typical example of an older mainline locomotive. The sectional drawing (Figure 4.8) shows the locomotive's architecture and how its components are laid out. The principal subassembly consists of the diesel engine and the exhaust silencer. The exhaust silencer is flexibly connected to the engine and fastened to the locomotive roof. There isn't space to fit any other equipment around the exhaust silencer, which is a reflection of a broader trend throughout the locomotive where there is little free space available. It is also worth noting the area to the side of the engine has to be kept clear to allow operating staff to pass.

The factors cited in the previous paragraph yield the following options for the various exhaust-gas after-treatment technologies (the full detailed analysis is provided in Annex 6). The findings of the analysis highlight the problems involved in retrofitting exhaust gas after-treatment units. The systems are to varying degrees significantly larger and heavier than the vehicle's exhaust silencer and generate higher levels of back pressure than the engine can cope with. As with the VT 810 railcar, it is possible to integrate a DPF with a PM_{10} abatement performance of only 30-40 %. This measure would cause costs per kilometre to rise by 54.2 eurocents per kilometre. It is not possible to retrofit the vehicle with systems that offer a higher particulate abatement performance and active regeneration, whilst simultaneously having a positive effect on NO_x (and HC) emissions even if conversion work is undertaken. Firstly, the scope for extending the space available for after-treatment equipment is severely limited due to the position of the engine and due to the maximum loading gauge. Furthermore, the additional weight of such exhaust gas after-treatment equipment would cause the maximum permissible locomotive weight to be exceeded. The vehicle would also no longer comply with Route Availability CE (Class 232 axle-load to 21.3t), thereby rendering this option infeasible in operational terms.

The findings for the exhaust gas after-treatment equipment are also applicable for other examples of this vehicle category such as Class 66 stock. As with older railcars, it is possible to exert a far more positive influence on the pollution record of older mainline locomotives through re-engining. An example of this is can be seen from the re-enginging programme that was carried out on Sixty-four Class 232 locomotives were fitted with the Kolomna 12D 49M successor engine. This yielded the following improvements: NO_x: 40 % reduction, PM: 50 % reduction, HC: 25 % reduction, CO: 40 % reduction. CO_2 emissions and operating costs were also reduced.

The total additional capital costs and total additional annual operating costs associated with integrating a DPF and re-engining are presented below in Table 4.8 below. Additional annual operating costs are based on the average annual distance travelled of 47,500 km per year.

Table 4.8: Change in capital and operating costs associated with emissions abatement options for the Class 232 mainline locomotive

	Retrofit open channel DPF	Re-engining
Total additional capital/fixed costs	€ 97,500	€ 437,500
Total change in annual operating and maintenance costs	€ 7,494	-€ 14,969

Summary of Class 232 analysis

There are clearly limits to the feasibility of fitting exhaust gas after-treatment units on older designs of mainline locomotives. Large, heavy engines with a high throughput of air require corresponding cross sections and system dimensions. It is only possible to fit Class 232 stock with particulate filters with an abatement performance of between 30 and 40 %. Complex systems such as SCR or combinations of SCR and particulate filters are not feasible because they take up too much space and are too heavy. The best course of action would be to fit a new engine that reduces all pollutant constituents subject to legislation whilst simultaneously cutting emissions of CO_2.

4.3.5 Mainline locomotive >1990: Class 218

Figure 4.9: Class 218 mainline locomotive

The Class 218 vehicle was selected as representative of more recent designs of mainline locomotive. These vehicles have already been re-engined, receiving an MTU 4000 16V engine instead of its original MTU 12V 956 TB 10 or 11 models, and hence the issue of fitting space is less critical than with the Class 232 vehicle.

The silencer is flexibly connected to the engine and fastened to the locomotive roof. The only additional fitting space available around the exhaust silencer is to the side and beneath it (between engine and exhaust silencer). This would, however, require making modifications to the engine/exhaust gas unit interface and the means of attachment. Modifications would also need to be made to the locomotive roof and side walls in order to accommodate the additional weight.

The factors cited yield the following options for the various exhaust-gas after-treatment technologies (the full detailed analysis is provided in Annex 6). If the additional weight is not an insurmountable hurdle, it would be possible to add a DPF with closed channels and active regeneration or else a combination of a DPF and an SCR system to the locomotive once the relevant modifications have been made.

Though the limit values prescribed for stage IIIB are not entirely adhered to, emissions of NO_x, HC and particulates are reduced by a sizeable degree with the latter system. Consideration also needs to be given here to the engine's permissible exhaust-gas back-pressure. Any exceedance results in reduced boost pressure, hotter exhaust gases, higher smoke levels and higher fuel consumption. Given the level of exhaust-gas back pressure demanded by a DPF system, it needs to be checked whether the increase in back pressure can be coped with by adopting relief measures elsewhere (such as restricting height working, reducing the max. permissible ambient temperature, lowering output, etc) or whether hardware modifications to the supercharging, exhaust gas piping etc. are required. The input this entails is considerable. The additional LCC costs amount to 30.8 €ct/km for the DPF and 41.9 €ct/km for the dual system. It remains to be seen whether the successor to the present MTU 4000 16V engine achieves the aforementioned improvements without the drastic rise in LCC costs indicated. The total additional capital costs and additional annual operating costs associated with options for the Class 218 locomotive are presented below in Table 4.9.

Table 4.9: Change in capital and operating costs associated with emissions abatement options for the Class 218 mainline locomotive

	Retrofit closed channel DPF	Retrofit SCR + DPF
Total additional capital/fixed costs	€ 128,500	€ 175,000
Total change in annual operating and maintenance costs	€ 14,375	€ 19,531

Summary of Class 218 analysis

There are clearly limits to the feasibility of adding exhaust gas aftertreatment units to newer designs of mainline locomotive, largely because no thought was given to fitting exhaust gas after-treatment systems when the locomotive layout was conceived and configured. Factors limiting the system's feasibility are the fitting space required, high additional loadings and the increase in exhaust-gas back pressure. Modification measures would create sufficient space to integrate a particulate filter system inclusive of regeneration facility or else a combination of SCR system and particulate filter on Class 218 stock. This is, however, conditional upon the weight problem being resolved. (cf. Subsection DPF). It remains to be seen whether the successor to the MTU 4000 16V R40 engine can deliver significant improvements regarding emissions of NO_x and particulates without any form of exhaust gas after-treatment. The rise in LCC costs would be less drastic in that instance.

4.3.6 Shunting locomotive < 1990: Class 742

Figure 4.10: Class 742 shunting locomotive

The Class 742 vehicle (Figure 4.10) was selected to represent older shunting locomotives. The exhaust silencer is located to the rear of the engine and could be enlarged. A DPF with closed channels can be added to this locomotive as a means of improving its particulate emissions, as can a DPF/SCR-system combination if modifications are made. This is, however, dependent upon there being sufficient room for manoeuvre with regard to the locomotive's overall weight and maximum exhaust-gas back pressure. The latter system allows NO_x and particulate emissions to be improved by approx. 50-70 % (particulates possibly >70 %). The LCC costs for the locomotive would rise by about €9 per hour assuming 2,500 hours in operation over the year.

Given the vehicle's initial level of particulate emissions of 0.6 g/kWh, which is 5 to 8 times as high as that for more modern diesel engines, re-engining is the most realistic means of cutting emissions for Class 742 stock. The potential for adding exhaust after-treatment systems to older designs of traction stock depends on the additional weight, the increase in back-pressure and the system control interfaces, all of which need to be evaluated for each type of shunting locomotive on an individual basis. However, it should be noted that the limit values prescribed for Stage IIIB would not be achieved by any of the proposed after treatment systems. The total additional capital costs and annual additional operating costs associated with options for the Class 742 locomotive are presented below. The annual operating costs have been calculated on the basis of 2500 hours average annual operating performance.

Table 4.10: Change in capital and operating costs associated with emissions abatement options for the Class 742 shunting locomotive

	Retrofit closed channel DPF	Retrofit SCR + DPF	Re-engining
Total additional capital/fixed costs	€ 53,500	€ 84,000	€ 210,000
Total change in annual operating and maintenance costs	€ 5,813	€ 6,813	-€ 5,063

Summary of Class 742 analysis

Modification measures would create sufficient space to integrate a particulate filter system inclusive of regeneration facility or else a combination of SCR system and particulate filter on Class 742 stock. However, this is conditional upon the weight and back pressure issues being resolved – a course of action that must be undertaken separately for each type of shunting locomotive. (cf. Subsection DPF). As with the representative older mainline locomotive (Class 232), fitting a modern diesel engine appears to be the most effective means of reducing NO_x and PM emissions. Whilst this option would also reduce CO_2 levels and operating costs it does depend on a suitable engine being available, which cannot always be guaranteed.

4.3.7 Shunting locomotive >1990: Class 290

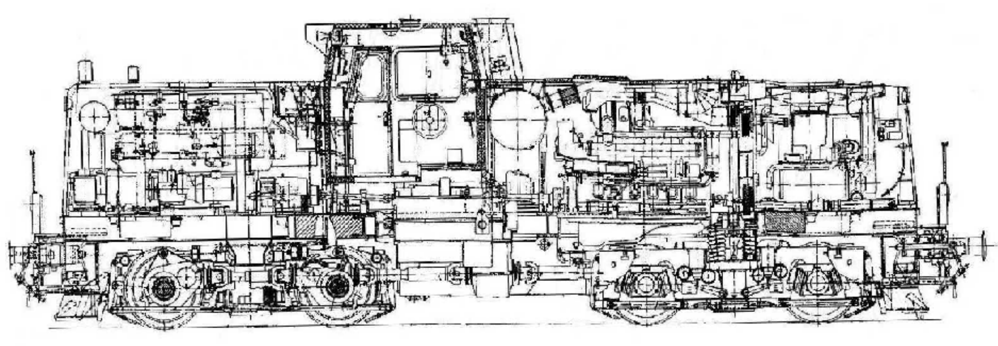


Figure 4.11: Cross sectional drawing of Class 290 vehicle

The Class 290 vehicle was selected as a newer design of shunting locomotive. As with the representatives of the other locomotive categories, the space available for after-treatment equipment, weight and exhaust gas back-pressure constitute the key limiting factors for system integration. The schematic diagram,shows the configuration of the locomotive and the layout of components. The exhaust silencer is located to the rear of the engine and could be enlarged. There is also utilisable space above the engine.

The factors cited yield the following options for the various exhaust-gas aftertreatment technologies (the full detailed analysis is provided in Annex 6). Assuming adjustments are made and the weight and back pressure problems are resolved (they would need to be evaluated for each type of shunting locomotive), it is possible to accommodate either a DPF or an SCR system or a combination of the two on Class 290 stock. This respectively enables particulate emissions (+HC), NO_x emissions, or NO_x, HC and PM to be reduced. However, it should be noted that the increases in LCC costs per hour of operation would be as follows:

DPF: 5.78 €/h
SCR: 4.65 €/h
DPF+SCR: 8.42 €/h.

As with the Class 218 vehicle, it remains to be seen whether the successor to the current MTU 4000 8V engine can achieve these improvements without such a drastic increase in LCC costs.

The total additional capital costs and the annual additional operating costs associated with options for the Class 290 locomotive are presented below. The annual operating costs have been calculated on the basis of 3500 hours average annual operating performance for the Class 290.

Table 4.11: Change in capital and operating costs associated with emissions abatement options for the Class 290 shunting locomotive

	Retrofit closed channel DPF	Retrofit SCR	Retrofit SCR + DPF
Total additional capital/fixed costs	€ 64,000	€ 59,500	€ 102,000
Total change in annual operating and maintenance costs	€ 8,250	€ 5,100	€ 10,350

Summary of Class 290 analysis
Modification measures would create sufficient space to integrate a particulate filter system inclusive of regeneration facility or else a combination of SCR system and particulate filter on Class 290 stock. However, this is conditional upon the weight and back-pressure issues being resolved separately for each type of shunting locomotive. It remains to be seen whether the successor to the MTU 4000 8V engine can deliver significant improvements in NO_x and particulate emissions without any form of exhaust gas after-treatment. The rise in LCC costs would be less drastic in that instance.

4.4 Infrastructure implications for additives

Where use is made of SCR, SCRT or a combination of DPF and SCR technology, attention needs to be paid not only to the LCC costs for the vehicles but also to investment and operating costs incurred in respect of the infrastructure for the supply of the urea reducing agent (commercially known as Ad Blue). In the case of DB AG's refuelling network, for instance, investment costs of approx. €3-5 million are estimated to be required. The following is a summary of the main issues:

- The reducing agent storage container needs to include heating.

- The operating costs for heating are a function of annual temperature curves.
- The Supply of small amounts of Ad Blue may be problematic.
- Ad Blue has a limited life (approx. 6 months), which necessitates tight resource management and the use of level detectors.
- As an alternative, distribution in packaged form (10 or 15 litre drums) would be feasible. However, this procedure is wholly unsuitable for the supply of mainline locomotives since they would have an Ad Blue capacity of approximately 300 litres.

4.5 Applicability of technical measures for SNCF vehicles

As mentioned earlier, detailed analysis of the applicability of technical options for SNCF railcars and locomotives has not been carried out due to the NO_x and PM_{10} emission factors for potential SNCF vehicles being substantially different from the European averages. However, less detailed analysis has been carried out to assess the possibility of using technical options for reducing emissions. For each type of representative vehicle for the SNCF fleet (Figure 4.12 and Table 4.12), the possibility of integrating a exhaust after-treatment system has been examined. Costs were based on road technology, and therefore may differ substantially from actual costs necessary for full application to railway vehicles. The conclusions reached must therefore be thought of only as initial results, and therefore where it is indicated that a technical solution could be used, it will be necessary:

- To ask for the equipment manufacturers to carry out a complete study of feasibility and integration;
- To carry out tests in order to know the actual efficiency of the systems in reducing emissions.

X 73500 **BB 67000** **Y 8000**

Figure 4.12: Representative SNCF rail vehicles

Table 4.12: Technical data of representative SNCF rail vehicles

	Railcars	Mainline locomotives	Shunting locomotives
Type of vehicle	X 73500	BB 67000	Y 8000
Type and name of engine	MAN D 2866 LUH 21	PIELSTICK 16 PA4 185	RVI MIDR 06 20 45
Engine power [kW]	2 x 257	1765	220
Type of power transmission	Diesel hydraulic	Diesel electric	Diesel hydraulic
Diesel consumption [g/kWh]	2 x 240	270	230
CO emissions factor [g/kWh]	2 x 0,67	2,25	0,66
HC emissions factor [g/kWh]	2 x 0,41	0,23	0,40
NOx emissions factor [g/kWh]	2 x 7,69	6,66	6,20
PM emissions factor [g/kWh]	2 x 0,16	0,22	0,12
Test cycle	ISO 8178 F	ISO 8178 F	ISO 8178 F

The results of the analysis carried out by SNCF for representative vehicles in their fleet are broadly in line with the results and conclusions reached from the more detailed analysis carried out by DB AG (the full analysis is provided in Annex 6). It is important to note that the much less detailed SNCF analysis does not take into account all the important aspects, such as maximum axle loads or maximum track section loads. A summary of the results is presented in Table 4.13.

Table 4.13: Summary of assessment of technical solutions for SNCF rail vehicles

	X 73500	**BB 67000**	**Y8000**
Oxidation Catalyst	Potentially possible	Potentially possible	Potentially possible
Diesel Particulate Filter (DPF)	Insufficient space	Critical axle load	Potentially possible
Closed channel DPF / CRT	Insufficient space	Critical axle load	Potentially possible
Selective Catalytic Reduction (SCR)	Possible with reductions to fuel tank capacity in order to integrate a urea tank (weight may still be a critical issue)		
SCRT (SCR + CRT)	Insufficient space	Insufficient space	Potentially possible
Exhaust Gas Recirculation (EGR)	Not possible without significant modifications to the cooling system at prohibitive cost		
Re-engining	Potentially possible with important modifications		
Convert/replace engine to run on CNG or LNG	Only possible with important modifications and a significant decrease in autonomy/operating range		
Biodiesel	Test results for NO_x / PM emissions reductions are not positive		
Diesel-Water Emulsion	Test results for NO_x / PM emissions reductions are not positive		
Fuel Additives	Test results for NO_x / PM emissions reductions are not positive		

4.6 Summary of results

This section of the study has analysed in detail the possibility for using technical options to reduce pollutant emissions from existing railway vehicles. It becomes clear that conversion to alternative fuels (other than low sulphur fuels and up to 5% biodiesel blends) is either impossible to put into practice or else does not improve emissions of exhaust gases.

Several exhaust after-treatment technologies that already have applications in the automotive and stationary power sectors were examined to establish their feasibility and suitability for application in the rail sector.

The aforementioned technologies were examined in greater detail on the basis of feasibility studies conducted on representative vehicles. These vehicles were selected from the European diesel vehicle fleet on the basis of their running performance, unit volume and exhaust gas values and divided into 2 classes:

A. Older pre-1990 stock that is for the most part equipped with mechanically regulated diesel engines and whose drive-system components are individually incorporated onto the vehicle;

B. More recent post-1990 stock with modern, electronically regulated, direct-injection diesel engines and on which the drive components are often grouped into modules (see Section 4.1).

A summary of the main results and conclusions from the analysis provided in Table 4.14 and Table 4.15.

Table 4.14: Conclusions drawn from the analysis of technical options for the current fleet

Conclusions drawn from the analysis of technical options for the current rail fleet
• The main barriers for integrating exhaust gas after-treatment systems in existing vehicles are the required space for retrofitting, the additional weight and the increase in exhaust gas back-pressure.
• Direct application of on-highway systems is not possible (mainly because on-highway engines allow for higher back-pressure)
• For older vehicles re-engining is a much more effective means of reducing emissions than exhaust gas after-treatment technologies. In many cases the requisite space is available, or could be made available through modifications, but the additional weight and back pressure may prove insurmountable barriers. Each vehicle must be assessed separately to determine the significance of those issues.
• For modern diesel railcars an integration of exhaust after-treatment systems is only possible with comprehensive modifications of vehicle configurations (e.g. removal of seats). Checks need to be made on each vehicle type to ascertain whether the vehicle license is still valid given the additional load on the axles.
• For most mainline locomotives it is not possible to retrofit complex systems that reduce several pollutants. Critical factors are the allowable exhaust gas back-pressure, required fitting space and additional weight.
• A Retrofitted exhaust gas after-treatment systems may be the best option for newer shunting locomotives. However, each vehicle must be assessed separately to determine whether the additional weight and greater back pressure would be significant issues. For older shunting locomotives the preferred option is often to completely re-engine the locomotive although that depends on the availability of a suitable engine, which cannot always be guaranteed.
• Even when more recent designs of diesel traction stock are retrofitted with exhaust gas after-treatment equipment they are only able to adhere to one or other of the limit values prescribed for stage IIIB (particulates or NOx) at any one time.

Table 4.15: Summary of results of detailed technical analysis for current rail fleet

	Catalytic Oxidation	**DPF open channels**	**DPF closed channels**	**SCR**	**POC**	**SCR + DPF**	**SCRT**	**EGR**	**Re-engining**	**Remark**
Reduction in % (based on supplier offers)	PM: 0 HC: 80 CO: 90 NO_x: 0	PM: 30 HC: 70 CO: 70 NO_x: 0	PM: >90 HC: 80 CO: 80 NO_x: 0	PM: 20 HC: 80 CO: 0 NO_x: 80	PM: >90 HC: 80 CO: 80 NO_x: 0	PM: >90 HC: 80 CO: 0 NO_x: 70	PM: >90 HC: 80 CO: 80 NO_x: 80	NO_x: 60	All compo-nents 20 to 50	
Railcars										
810		0.048 €/km	No	No	No	No	No	No	?	
612		0.05 €/km	0.092 €/km	0.083 €/km	0.092 €/km	0.145 €/km	No	No	Today no	Critical axle load
642		0.061 €/km	No	No	No	0.144 €/km	No	No	Powerpack	Critical axle load
X73500	0.69 €/km	No	No	0.07 €/km	No	No	No	No*	Yes**	* Prohibitive cost ** Important modifications
Mainline Locomotives										
218		0.21 €/km	0.31 €/km	No	0.31 €/km	0.42 €/km	No	No	Today no	Critical axle load
232		0.54 €/km	No	No	No	No	No	No	Best results	Critical axle load
BB67000	0.19 €/km	0.15 €/km	0.28 €/km	0.20 €/km	0.28 €/km	No	No	No*	Yes**	Critical axle load * Prohibitive cost ** Important modifications
Shunting Locomotives										
742		3.50 €/h	6.30 €/h	No	6.30 €/h	9.03 €/h	No	No	?	
290		3.00 €/h	5.78 €/h	4.65 €/h	5.78 €/h	8.42 €/h	No	New engine	Today no	Critical axle load
Y8000	1.40 €/h	1.00 €/h	1.92 €/h	1.05 €/h	1.92 €/h	1.64 €/h	1.28 €/h	No*	Yes	* Prohibitive cost

5 Technical Measures Assessment for Future Rail Vehicles

5.1 Methodology/Framework Adopted for Assessment

The methodology employed by Euromot for the LCC analysis involved a consultation process with its members. As part of this process Euromot member companies agreed on submitting a spreadsheet of data as follows:

- Companies provided ranges of values and typical engine data, rather than engine specific data;
- Typical power categories;
- Separation of fast and slow speed engines;
- Input from both Euromot and EMA (Engine Manufacturers Association) was included;
- Separate categories for railcars and locomotives according to the categories in the NRMM Directive were included;
- Input was made anonymous;
- Each line represented the complete input from one company;
- Options indicated various scenarios for the same class of traction unit;
- All assumptions on costs, space and mass requirements were given in terms of percentages relative to typical actual numbers (typical current data on costs, space and mass were set to 100%);
- UNIFE included their estimates for whole vehicle costs;

All information was based on former and ongoing development activities. A significant proportion of the findings have been collected from research carried out the field of heavy-duty on-highway applications. For trucks and buses the development work for low-emission engines and after-treatment equipment is considerably more advanced than for the railway sector, because the legal requirements (i.e. Euro IV and V emission standards) have been defined and come into force respectively much earlier than the NRMM Stage IIIA and IIIB limits. In this chapter, the applicability of all currently known measures to reduce the emissions of diesel engines for rail vehicles has been investigated based on Euromot’s present-day findings.

Engine manufacturers, represented by Euromot, are taking the lead in developing engines in accordance to the new EC requirements. They are also responsible for obtaining the necessary certification, which is a basis upon which to implement the new engines in rail cars and locomotives. Based on Euromot’s information about estimated volumes, weights and costs for engine-related measures and after-treatment systems to achieve the Stage IIIA and Stage IIIB limits, UNIFE determined the additional development and cost impacts for future railcars and locomotives. It should be mentioned, that even within individual categories of rail vehicles, significant differences in additional costs can be observed, depending on the specific design differences of the various traction units.

5.2 Selection of Measures for Detailed Analysis

5.2.1 Fundamental Remarks

5.2.1.1 Future emission limits for diesel Engines

- The exhaust emission reduction of diesel engines for locomotives and railcars is regulated by the EU NRMM Directive. Diesel engines will be necessary as propulsion units for rail vehicles also in future. Therefore the engine manufacturers will have to deliver engines that meet the limit values set out in the Directive if they plan to continue supplying engines to the EU railway market. Based on these requirements, the focus of diesel engine manufacturers is on optimisation of engine technologies and the development of suitable exhaust after-treatment systems.

- Fulfilling the requirements of Directive 97/68/EC and 2004/26/EC requires significant resource input from the development teams of engine manufacturers. Investigations concerning alternative fuels and emission reducing operation will therefore have secondary priority.

- Multi-Engine Concepts will possibly be useful in the case of small engines for auxiliary power generation. The development of emission reduction technologies for these types of engines is also foreseen. High-speed engines show good behaviour in terms of starting and part load operation.

- In this chapter we are therefore focussing on the assessment of those measures which are based on the further development of diesel engine technologies to reach the emission limits set out for Stages IIIA and IIIB of the NRMM Directive. Other measures such as hybrid drives, multi-engine concepts and alternative fuels will not be assessed in this study. Please refer to chapter 3 for an overview of these other measures. Assessments of these additional measures may be necessary in the future.

5.2.1.2 Development of emission reduction measures:

Over the last several years, there has been significant public and Governmental attention focused on the effects of pollutant emissions on human health, crops, ecosystems and buildings, and various emission reduction measures for internal engine combustion engines have been developed. Due to the large number of engines and their very significant environmental impacts, stricter emission requirements were first demanded for on-highway motor vehicles. Accordingly emission reduction measures have been (and still are) developed primarily for this application. EGR has been used on light-duty road vehicles for a number of years, but for SCR there is still no considerable experience in the road sector, with the exception of special projects (usually with incentives).

5.2.1.3 Transfer of emission reduction measures to rail engines

The emission reduction measures were examined with regard to their suitability for rail applications and - if positively done so - transferred to these normally significantly bigger engines. It is to be noted that apart from the engine size also the operating conditions, the installation circumstances, the load profile (rail engines are idling between 50% and 90% of their operational time), the vehicle life span (potentially over 30 years) and the maintenance requirements differ very significantly from heavy duty road vehicles.

5.2.1.4 Costs

In general it must be assumed, that the costs of applying emission reduction measures are not negligible for either Stage IIIA or Stage IIIB. These additional costs include both initial investment costs and operational costs. However, in most cases it is difficult at this stage to give concrete values, because the appropriate measures and engines are still in development. The costs quoted in this section of the report refer to typical average engines for each vehicle category (railcars, mainline locomotives and shunting locomotives) according to the state of the art (2005, UIC II). **It must be stressed that the costs quoted are rough, initial estimates**, and that further work will be required outside of this project to quantify these costs in more detail. Possible cost reductions due to advances in technology and associated with volume production have already been envisaged. Compared with the costs for on-highway motor vehicles, the increased application expenditure must be considered, which results from the fact that rail vehicles are manufactured only in small numbers and an exhaust after-treatment facility must be adapted to different vehicles again in each case.

5.2.1.5 Estimation of the attainable emission level.

In the following tables (Table 5.1 and Table 5.2), values for the “emission reduction capability” of each potential option are indicated, which refer to the state of the art (2005, UIC II). These data are rough estimated values, which are based on experience from on-highway applications, and sometimes on initial results from off-highway test data. In practice, very different emissions abatement performance values could occur for rail vehicles, compared to those quoted in the tables overleaf. In addition, it may be that although a particular measure would enable the upcoming NRMM limit values to be met, the impacts on operating conditions and operating costs may restrict or rule out its use. It should also be noted that the data presented in the following tables may not correlate exactly with that provided in Chapters 3 and 4. This is because those data refer mainly to experience from the automotive sector, and to initial field tests carried out in the past. The data presented in this chapter considers actual studies carried out by engine manufacturers that specifically aim for the future application of technical emission abatement options in railway vehicles.

5.2.2 Assessment of possible future measures and their technical and economic impacts

5.2.2.1 Internal engine measures

Table 5.1 below provides details of the assessment of internal engine measures for reducing pollutant emissions. Emission reduction capacity means possible reduction based on the emissions performance of a current UIC Stage II engine.

Table 5.1: Engine internal measures

	Measure	Emission reduction capability	Ability to meet NRMM emission limits		Effects on engine	Estimated additional engine costs	Operational effects	Evaluation
			Stage IIIA	Stage IIIB				
1	**Optimisation on the basis of today's Off Highway combustion systems**	**NOx:** 20% reduction **or;** **PM:** 50% reduction	Yes	Only with addition of de-NO_x catalyst and DPF	Improved combustion (higher Pmax), further developed engine control, supercharging, injection technology	> 5 %	1. Large fuel consumption increase 2. Increased heat rejection 3. Increased main-tenance requirements	NO_x vs PM trade-off: improved NO_x level leads to higher PM emissions and vice versa. Fuel consumption increase (NO_x is the trade-off). ot useful as single measure for stage IIIA. Not sufficient to meet Stage IIIB.
2	**Miller-Cycle**	**NOx:** 30% reduction. **PM:** increase possible	Yes	Only with addition of de-NO_x catalyst and DPF	Improved supercharging and charge air cooling necessary	> 10 %	slight fuel consumption increase for Stage IIIA. Higher heat rejection – may need additional engine cooling	Restricted operation in higher altitudes possible. Higher charge air pressure necessary.
3	**Exhaust Gas Recirculation (EGR)**	**NOx:** 50-70% reduction **PM**: increase possible	Yes	Not known	Supercharging and exhaust gas cooling	15 %	Slight fuel consumption-increase for Stage IIIA. Additional engine cooling required. Low sulphur fuel required.	Increased maintenance requirements. Not known whether EGR will enable the Stage IIIB NOx limits to be met.
4	**Homogeneous Charge Compression Ignition (HCCI)**	**NO_x:** 80% reduction **PM**: 80% reduction. Increase in CO and HC possible	No	Not known	Highly sophisticated combustion control, injection technology, EGR, cooling, fuel mixture swirl improvements	> 15 %	Increase in fuel consumption. Increased maintenance requirements.	Probably not available until 2012. High development costs Not known whether the technology will meet Stage IIIB NOx limits. Not sufficient as a single measure for meeting Stage IIIB.

5.2.2.2 Additional technical information on the engine internal measures included in the assessment

1) Engine optimisation/combustion system development: Optimisation is carried out on the basis of the existing engine technology with the aim of reducing pollutant emissions. Some options lead to increases in fuel consumption. For some options, NO_x emissions can increase whilst PM emissions decrease, and vice versa. There is therefore a trade-off between achieving reductions in NO_x or PM emissions for some measures. Progress in the areas of combustion (higher ignition pressure), electronics and injection technology contribute to the process of engine optimisation.

2) Miller-cycle engines: Closing the intake valve before or after piston Bottom-Dead Centre (BDC) leads to lower compression pressures. Thus the charge temperature and the corresponding fuel-burn temperature are lowered. This decreases the amount of NO_x formed during the combustion process. To use this measure without incurring reductions in power output, a higher charge air pressure is necessary. This could restrict operations in higher altitudes.

3) Exhaust Gas Recirculation (EGR): Recirculated exhaust gas increases the inert gas part of the charge thereby reduces the combustion temperature. This decreases the amount of NO_x formed during the combustion process. However cooling of the recirculated exhaust gas is necessary, and hence the amount of heat energy dissipated by the engine increases.

4) Homogeneous Charge Compression Ignition (HCCI): Engines that use HCCI technology emit very little NO_x or PM. At present, this technology is still at the research stage.

5.2.2.3 Exhaust after-treatment technology

Table 5.2 below provides details of the assessment of various exhaust after-treatment technologies for reducing pollutant emissions. As with internal engine measures, the figures quoted for emissions reduction capability are relative to the emissions performance of a current UIC Stage II engine.

Table 5.2: After-treatment technologies

	Measure	Emission reduction capability	Ability to meet NRMM emission limits		Effects on engine	Estimated additional engine costs	Operational effects	Evaluation
			Stage IIIA	Stage IIIB				
5	**Oxi-cat**	**CO:** 90% reduction **HC:** 80% reduction **PM:** 20% reduction	May be useful as an additional measure		Limited	5%	Low sulphur fuels required	Only useful as an additional measure in conjunction with other equipment
6	**PM-cat**	**PM:** 50-70% reduction **CO:** 90% reduction **HC**: 80% reduction	No	Not known	Exhaust back pressure 70 to 100 millibar	> 20 %	Low sulphur fuels required	Increased volume and weight. Smoke blast possible
7	**Diesel Particulate Filter (DPF)**	**PM:** 90 % (with CRT®, can also achieve reductions in CO and HC emissions as follows: **CO:** 90% reduction **HC:** 80% reduction)	No	Yes, with additional $DeNO_x$ catalyst	Exhaust back pressure ranges from 50 to 250 millibar	> 25 %	Low sulphur fuels may be required. Depending on trap regeneration mechanism, there may be a slight increase in fuel consumption.	Increased volume and weight. Increased exhaust back-pressure (depends on regeneration strategy). Increased maintenance requirements.
8	**Selective Catalytic Reduction (SCR)**	**NO_x:** 80% reduction **CO:** 90% reduction **HC:** 30% reduction **PM:** 10% reduction	Yes	Yes, with additional DPF	Slight exhaust back-pressure increase	> 25 %	Urea required in order for the SCR catalyst to operate.	Increased volume and weight. Increased maintenance requirements. Logistical implications of ensuring urea supply need to be examined.
9	**SCR with DPF**	**NO_x:** 80% reduction **PM:** - 90% reduction **CO:** - 90% reduction **HC:** - 90% reduction	No	yes	exhaust back pressure > 50 … 250 mbar	> 35 %	Urea required in order for the SCR catalyst to operate.	Increased volume and weight increased maintenance requirements
10	**Lean NO_x trap/ NO_x Adsorber Catalyst (NAC)**	NO_x - 90 %	No	?	Engine control, Injection, supercharging, regeneration cycles	> 30 %	Low sulphur fuel required. Regeneration cycles	Probably unsuitable for rail applications

5.2.2.4 Additional technical information on the exhaust after-treatment technologies included in the assessment

5) Oxidation catalysts: the oxidation catalyst decreases emissions of carbon monoxide (CO) and unburned hydrocarbons (HC). Normally these pollutants are not the most significant problems in the exhaust of a diesel engine, however also the PM emission decreases with unburned hydrocarbons. The oxidation catalyst is cheap in comparison to other after-treatment technologies. A condition is the use of low sulphur fuel or better sulphur-free fuel, since otherwise by the sulphate formation increased corrosion in the exhaust gas system may occur. By the oxidation of unburned HC the exhaust gas temperature rises. This effect supports the regeneration of a particle filter.

6) Particulate Matter (PM) Catalysts: this technology consists of metal substrate block of corrugated steel foil. Particles are deviated from the exhaust flow and trapped in a porous metal fleece. It's an open system and no blocking can occur. The temporarily trapped particles are subsequently oxidized.. Due to the oxidation stage also CO and HC are oxidized (HC-oxidation contributes to the reduction of the PM mass, too).

7) Diesel particulate filter (DPF) with ceramic or sintered metal filter bodies. Different regeneration strategies are used, possibly with significant larger space and mass requirement than a muffler. Only if in the load cycle of the engine sufficient portions with high exhaust gas temperatures appears, it works without active regeneration. The CRT® (Continuously Regenerating Trap) is a particle filter (usually ceramic) with an upstream oxidation catalyst. Using this oxidation catalyst, the nitric oxide (NO) in the exhaust gas is oxidized to NO_2. This NO_2 again serves then as oxidizing agent for the particles held back in the particle filter. In the oxidation catalyst also CO and HC are oxidized (HC-oxidation contributes to the reduction of the PM mass, too).

8) Selective catalytic reduction (SCR) systems reduce NO and NO_2 to nitrogen with the help of the reducing agent ammonia or urea, whereby in mobile applications urea is preferred. Usually an additional oxidation catalyst is used to convert surplus ammonia downstream the SCR catalyst to nitrogen. Thus also the CO and the HC emissions are decreased and also a small positive effect on the particle emission arises.

9) Combination of SCR and DPF consisting typically of an oxidation catalyst, particle filter, SCR catalyst and downstream oxidation catalyst. Complex but highly effective, both with NO_x and PM.

10) In the engine operation with excess air (lean operation, the normal operation of the diesel engine) NO_x is stored in the Barium or Sodium containing coating of the catalyst. If this is satisfied, the engine must be operated under fat conditions for regeneration of the catalyst. Sulphur-free fuel is conditional, since otherwise SO_2 occupies the NO_x storage locations.

5.3 Selection of Representative Traction Units

Railcars and locomotives are capital goods with a lifespan of 30 years or more. The numbers of rail vehicles sold, market behaviour, and customer's intentions and requirements are totally different in comparison to on-road vehicles. That results in very much longer technology development times when compared to passenger cars and heavy-duty road vehicles. For the purposes of this assessment, and to avoid confusion, the different types of representative traction units (i.e. railcars and locomotives) have been divided into sub-categories. These are described in the following sections.

5.3.1 Railcars

Future **rail cars** will be very similar to new railcars in production today. For the purposes of this assessment, two categories of future railcars have been considered, and these are described below.

Category I: "low speed" (maximum speed less than or equal to 120 km/h; diesel engines with power output ranging from 315 to 382 kW).

These types of railcars have limited performance and comfort, are light-weight, have a reasonable number of seats, and are used for regional or rural services for transporting people to main lines. Such vehicles are typically used on older lines, or for commuting within larger urban areas where the distances between stations are short. The majority of railcars fall into this category.

Category II: "high speed" (maximum speed ranges from 160 to 200 km/h; diesel engines with power output ranging from 500 to 662 kW).

High-speed railcars are characterised by having high levels of performance and comfort, and are usually used for inter-city traffic on main lines that do not have overhead electrical power.

5.3.2 Locomotives

Future diesel locomotives will be very similar to today's new build locomotives. Two categories have been considered for this assessment, and these are described below.

Category I: shunting locomotives

Future shunting locomotives will typically include both three-axle and four-axle locomotives, and have a maximum speed of 100 km/h. They will be used in shunting yards and for feeder services, and will typically be fitted with engines with power outputs that range from 400 kW to 1500 kW.

Category II: mainline locomotives

Mainline locomotives are used for both passenger and freight services. Future traction units of this type will include both four-axle and six-axle locomotives, and for the purposes of this assessment, traction units with a maximum speed ranging from 100 to 160 km/h have been considered, with maximum engine power output ranging from 2000 to 3000 kW.

5.4 Assessment Results

5.4.1 Overview

The following sections discuss the potential for applying the technical measures listed in Tables 5.1 and 5.2 to the various representative future traction units, and also include a discussion of the development work that would need to be carried out to incorporate these measures in future rail vehicles. The results of the consultation process on anticipated life-cycle costs (LCC) are presented in Table 5.3 and Table 5.4.

5.4.2 Engine Internal Measures

Optimisation of today's combustion processes based on currently available technologies would enable the NRMM Stage IIIA emission limits to be met, but would not be appropriate in terms of the negative impacts that would be incurred on vehicle fuel consumption. Engines equipped with Miller Cycle technology are already used in some off-highway applications (e.g. marine engines), but at the moment the technology is not used in railway engines because operation at high altitudes might be restricted.

EGR is a technology that is already in use on diesel-engine road vehicles. There is no experience with large off-highway engines, and no production applications currently exist in the railway market. There is also no experience with the corresponding duty cycles for off-highway and rail engines. In order to apply this technology to the railway sector, suitable exhaust gas heat exchangers must be developed and optimised in terms of costs and operating lifetime. It should be noted that vehicles fitted with EGR must use low sulphur fuel.

Homogenous Charge Compression Ignition (HCCI) is a combustion technology that still needs a large amount of further research work, even for automotive applications. The challenge lies in accurately controlling the combustion process, an issue which has not been solved for multi-cylinder engines. This technology will not be available for off-highway engines for several years.

5.4.3 After-treatment Technologies

Many after-treatment technologies are in the process of being introduced to production road vehicles, including both passenger cars and heavy-duty vehicles such as trucks and buses. Currently, there is only very limited experience of applying exhaust after-treatment to railway vehicles (e.g. particulate filters have been used in a very small number of diesel locomotives). These are typically special-purpose applications and are not optimised in terms of weight, space, lifetime and cost.

Estimates of the initial costs of these technologies need to consider the fact that there are likely to be significant decreases in costs in future years for application in railway vehicles. Reductions in costs will be dependent on advances in the various technologies, and the economies of scale due to higher production volumes. For the assessment of each technology carried out as part of this study, the potential reductions in costs have been estimated.

5.4.3.1 Diesel Particulate Filters (DPFs) and Continuously Regenerating Traps (CRT®)

Particulate filters have been used in some diesel passenger cars for several years, and there has been much progress in the development of improved filter technology for road applications. For all particulate filters, one of the main challenges is the method for regeneration of the filtered particulate matter. Active regeneration is used for some types of DPF, whilst passive regeneration is used in other types. The duty cycle of the engine, can to a certain extent, determine whether active regeneration must be used.

The second challenge is the ash deposit that remains in the filter after regeneration has taken place. Cleaning intervals must be defined to clean the filter elements. The cleaning intervals currently required are not suitable for the economic use of DPFs in traction units.

Particulate filters suitable for rail vehicles are heavy and need a significant amount of space. A significant challenge is the application of such filters within the design space envelope of current exhaust silencers/mufflers. The development of filter technology for rail traction units must take into account the specific needs and limitations associated with railway applications.

5.4.3.2 SCR and SCRT

SCR technology is part of the European on-highway heavy-duty vehicle strategy for ensuring that vehicles meet Euro V emissions standards. SCR catalysts are in development and already being used in field tests. In order to operate on a vehicle, SCR technology needs the vehicle to be equipped with an on-board supply of urea solution, and hence if the technology is to be used on rail vehicles, traction units would need to be fitted with urea tanks and the logistical issues associated with supplying urea to the railway sector would need to be resolved. A solution of urea has a freezing point just below 0°C. For this reason, heating technology would need to be installed to avoid the solution freezing.

In order to fit SCR equipment on a traction units, a significant amount of additional space is required. Furthermore, fitting SCR equipment adds additional weight to traction units. It Combined SCR and particulate filter units are not ensured to fit in the space currently available on modern traction units for exhaust silencer equipment. The use of SCR would increase the necessary investment costs required for exhaust after-treatment. A comparison of engine internal measures with SCR for reducing NO_x emissions has been carried out in order to assess the best technology mix in terms of both technical and economic aspects.

5.4.3.3 Lean NO_x traps and NO_x Adsorber Catalysts

Lean NO_x traps and NO_x Adsorber Catalysts (NAC) are still in development for the automotive sector. At this point in time, the technology does not seem to be appropriate for large off-highway engines because of the large amount of exhaust gases and the special duty cycles associated with these types of engines.

5.4.4 Summary

All of the measures described above (both internal engine design measures and after-treatment technology) will have an economic impact on the products that they are fitted to in terms of initial and life cycle costs. For some options, if rail vehicles were to be equipped with after-treatment technology, there would be a significant increase in vehicle weight and in the space required for the after-treatment equipment itself. For some of the new combustion technologies, and for EGR, there would also be an increase in the amount of heat dissipated by the vehicle's engine(s), leading to a requirement for bigger and heavier radiators. Again, this would have a considerable impact on vehicle weight and the space required for this additional equipment.

Several options from those discussed above could potentially allow future rail exhaust gas emission limits to be achieved. Based on current knowledge from on-highway and off-highway experiences with these options, there still remain a number of detailed technical and economic questions with regard to the use of emissions abatement options cannot be answered at this point in time. Additional research work is necessary to be able to give a clear view on the possibilities and their impacts.

5.4.5 Basic diesel engine development strategy

5.4.5.1 Stage IIIA emission limits:

Based on experiences with on-highway diesel engines and other recent developments, it is thought very likely that Stage IIIA emissions limits will be achieved mainly by using internal engine design measures, rather than by using exhaust after-treatment. It is envisaged that the use of modern diesel combustion technology, improved injection and charging technology, optimised air-cooling, and possible EGR will be the main methods by which the Stage IIIA limit values will be achieved. Low sulphur fuel will be required. The most significant consequences will be increased engine purchase costs and increased expenditure on maintenance. An increase in fuel consumption of up to 5% is also expected. There is the anticipation that there will be a requirement to increase the amount of engine cooling, but significant increases to the weight and volume of the engine are not expected. Alternative strategies, such as the use of exhaust after-treatment equipment for meeting the emissions limits whilst avoiding increases in fuel consumption are not to be expected because of disadvantages in costs, volume and weight.

5.4.5.2 *Stage IIIB:*

In terms of meeting the PM_{10} emission limits specified for Stage IIIB of the NRMM Directive, diesel particulate filters will be essential. In order to achieve the NO_x limit values without the use of after-treatment, it will be necessary to develop internal engine design measures much further to achieve even greater reductions in NOx emissions. An additional increase in fuel consumption is considered a likely outcome. Alternatively, exhaust after-treatment technology such as SCR must be used. The decision with regard to which NO_x reduction technology should be used must be based on developments and experience in the automotive sector, and the preferences that railway operators have. Technical and commercial benchmarks of the specific technologies will be necessary to finally decide which route is the most appropriate way to proceed. This benchmark is not yet possible because the necessary investigations are not complete at this point in time.

The following tables (Table 5.3 and Table 5.4) provide initial quantified estimates of impacts associated with the different technologies that could be used for meeting the Stage IIIB limits. The impacts considered include the effects of each technology on investment and operating costs, fuel consumption, the use of additives, vehicle and equipment mass, and the space required for after-treatment equipment. All estimates have been quoted in percentage terms relative to the baseline scenario of modern traction units that meet the UIC II regulations. The data used for the baseline scenario are based on actual engines and technologies that meet the UIC II regulations. For all parameters, vehicle from the existing fleet that meet the UIC II regulations have been assigned values of 100%. If, for example, a specific technology required to meet Stage IIIA or Stage IIIB leads to an engine investment cost that is 10% greater than the UIC II baseline, then this is quoted as 110% in the table.

Table 5.3: Rail Diesel Study - Euromot estimates of Life-Cycle Costs and additional impacts for Future Rail Engines

	Engine Type	Engine Output (approx.) kW	Max. Speed	Emissions				Future necessary emission reduction measures				Investment cost: engine (***)	Investment cost: loco/railcar (****)	Fuel Cons. in cycle	Additive cons.* (as a % of fuel consumption)	Engine maint. costs (2)
			< 1300 rpm or > 1300 rpm	NOx g/kWh	CO g/kWh	HC g/kWh	PM g/kWh	Internal engine	NOx a/treat	PM-Filter	Vehicle appl'n issues	%	%	%		%
Existing fleet UIC II																
Railcar	Euromot	130-560	>1300	5.5	0.4	0.2	0.05	--- (1)	---	---	---	100	100	100	0	100
Locomotive	Euromot	700	< 1300	8.9	0.7	0.2	0.1	---	---	---	---	100	n/a			
	Euromot	700	> 1300	8.9	1.1	0.1	0.11	---	---	---	---	100	n/a			
	Euromot	1000	> 1300	9	0.9	0.3	0.13	---	---	---	---	100	100			
	Euromot	1500	> 1300	9	1.1	0.3	0.12	---	---	---	---	100	100			
	Euromot	2000	> 1300	9.1	1.2	0.3	0.12	---	---	---	---	100	100	100	0	100
	Euromot	2500	> 1300	9.89	0.21	0.17	0.1	---	---	---	---	100	100	100	0	100
New vehicles EU IIIA																
Railcar	Euromot	130-560	> 1300	Fulfil Emission Limits Stage IIIA				Yes	No	No	radiator	110 to 115	103 to 107	> 100	0	100 to 105
Locomotive	Euromot	700	< 1300					Yes	No	No	radiator	110 to 115	n/a			105 to 110
	Euromot	700	> 1300					Yes	No	No	radiator	110 to 115	n/a			105 to 110
	Euromot	1000	> 1300					Yes	No	No	radiator	110 to 115	103	106	0	105 to 110
	Euromot	1500	> 1300	Fulfil Emission Limits Stage IIIA				Yes	No	No	radiator	110 to 115	104			105 to 110
	Euromot	2000	> 1300					Yes	No	No	radiator	110 to 115	105 to 110	106	0	105 to 110
	Euromot	2500	> 1300					Yes	No	No	radiator	110 to 115	107 to 111	104	0	105 to 110
	Euromot	3000	> 1300					Yes	No	No	radiator	110 to 115	110 to 115	106	0	105 to 110
	Euromot	3000	< 1300					Yes	No	No	radiator	110 to 115	n/a	104	0	105 to 110
New vehicles EU IIIB (**)																
Railcar	Euromot Option 1	130-560	> 1300	Fulfil Emission Limits Stage IIIB				Yes	Yes	Yes	urea tank	145 to 155	109	100	2 to 3%	110 to 115
	Euromot Option 2	130-560	> 1300					Yes	No	Yes	radiator	135 to 145	108	105	0%	105 to 110
Locomotive	Euromot	1000	> 1300					Yes	Yes	No	urea / electronics	145 to 155	108	95	4%	110 to 115
	Euromot Option 1	2000	> 1300					Yes	Yes	No	urea / electronics	145 to 155	110 to 115	95	4%	110 to 115
	Euromot Option 2	2000	> 1300	Fulfil Emission Limits Stage IIIB				Yes	No	Yes	radiator	135 to 145	110 to 115	103	0%	105 to 110
	Euromot Option 3	2000	> 1300					Yes	Yes	Yes	rad. + urea tank	145 to 155	115 to 120	100	3%	110 to 115
	Euromot	2500	> 1300					Yes	Not sure	Yes	Space, Weight	145 to 155	not sure	109	0%	110 to 115
	Euromot	3000	> 1300					Yes	Yes	No	urea / electronics	145 to 155	115 to 120	95	4%	110 to 115
	Euromot	3000	< 1300					Yes	Not sure	Yes	Space, Weight	145 to 155	n/a	109	0%	110 to 115

* Urea costs = 0,5 €/l (**) low-sulphur fuel (< 10 ppm S) to be available 2 yr in advance (***) Costs on basis 2005, no dynamics

(****) Cost on basis 2005 & worst case no. from engine builder, % Range for Locos= low : DH-, high: DE - Locos, no dynamics. One-off costs spread over basis of typical locomotive contract volume of 20. For railcar one-off costs were spread over typical contract volumes of 50 powerpacks.

(1) Existing measures (2) Engine + aftertreatment, no data for aftertreatment maintenance costs available

Table 5.4: Rail Diesel Study - Euromot estimates of Life-Cycle Costs and additional impacts for Future Rail Engines (continued…)

	Engine Type	Engine Output (approx.) kW	Max. Speed < 1300 rpm or > 1300 rpm rpm	Engine life (TBO) Hours	Additonal engine space required %	Additonal engine mass %	Additional after-treatment space required * compared to silencer %	Additional after-treatment mass required * compared to silencer %
Existing fleet UIC II								
Railcar	Euromot	130-560	>1300	18,000	100	100	100	100
Locomotive	Euromot	700	< 1300					
	Euromot	700	> 1300					
	Euromot	1000	> 1300					
	Euromot	1500	> 1300					
	Euromot	2000	> 1300	24,000	100	100	100	100
	Euromot	2500	< 1300	42,000	100	100	100	100
New vehicles EU IIIA								
Railcar	Euromot	130-560	> 1300	18,000	100	100	100	100
Locomotive	Euromot	700	< 1300	30,000			100	100
	Euromot	700	> 1300				100	100
	Euromot	1000	> 1300	24,000	100 to 105	100 to 105	100	100
	Euromot	1500	> 1300		100 to 105	100 to 105	100	100
	Euromot	2000	> 1300	24,000	100 to 105	100 to 105	100	100
	Euromot	2500	< 1300	42,000	100 to 105	100 to 105	100	100
	Euromot	3000	> 1300	24000	100 to 105	100 to 105	100	100
	Euromot	3000	< 1300	42,000	100 to 105	100 to 105	100	100
New vehicles EU IIIB (**)								
Railcar	Euromot Option 1	130-560	> 1300	18,000	100 to 105	100 to 105	100 to 120	150 to 200
	Euromot Option 2	130-560	> 1300	18,000	100 to 105	100 to 105	100	140 to 160
Locomotive	Euromot	1000	> 1300	30,000	100 to 105	100 to 105	100	150 to 200
	Euromot Option 1	2000	> 1300	30,000	100 to 105	100 to 105	100	150 to 200
	Euromot Option 2	2000	> 1300	24,000	100 to 105	100 to 105	100	140 to 160
	Euromot Option 3	2000	> 1300	24,000	100 to 105	100 to 105	100 to 120	150 to 200
	Euromot	2500	< 1300	42,000	100 to 105	100 to 105	150	150 to 200
	Euromot	3000	> 1300	30,000	100 to 105	100 to 105	100	150 to 200
	Euromot	3000	< 1300	42,000	100 to 105	100 to 105	150	150 to 200

* only equipment that will probably replace the silencer, no other additional equipment (e.g. urea tank) considered (**) low-sulphur fuel (< 10 ppm S) to be available 2 yr in advance

5.4.6 Possible effects on railcars and locomotives

Diesel engines and other components such as gearboxes, cooling equipment and other auxiliaries, are mounted within the main vehicle body for locomotives, and underneath the vehicle body structure for rail cars. Fuel tanks (approximately 1000 – 2000 litres for each rail car engine and approximately 5000 litres per locomotive) are located underneath the vehicles. Due to limited axle loads and the aim to maximise the low floor area in railcars, the available space for fitting diesel engines is very limited. This means that each re-design of the vehicle body or repackaging of the under frame equipment of a railcar, due to changes in the size and equipment fitted to diesel engines will have a large impact on the overall cost of the rail vehicle.

Additional engine heat dissipation, due to either new internal engine design measures or additional exhaust after-treatment options (see tables above) will lead to a requirement to redesign the engine's cooling system. For railcars the result could be a new roof mounted cooling solution instead of an existing under frame system, because of lack of space, There are likely to be considerable additional costs associated with designing and fitting new cooling system in such situations.

Some emissions abatement options lead to additional fuel consumption when compared to the baseline scenario. Additional fuel consumption not only has environmental impacts (e.g. increased CO_2 emissions), but also leads to increased operational costs. In such a situation, if it is not possible to increase the volume of the fuel tank, the operating range of the traction unit will be reduced.

Diesel powered railcars and locomotives are often used on secondary lines within Europe, and there are major limitations in terms of maximum allowed axle loads and clearance gauges in particular. In addition the future Technical Specifications for Interoperability (TSI) requirements for noise and crashworthiness also have to be met. The additional space and weight available for emissions abatement equipment will also be limited by these requirements.

Engine development to achieve the Stage IIIA and Stage IIIB limits will introduce significantly more complex components in and around the diesel engines fitted to traction units. Very sensitive injection systems and fuel distribution components (common rail) require higher fuel quality and adapted tank designs. The use of alternative fuels will no longer be allowed with these new systems without careful investigation. All of this could lead to additional maintenance requirements and a reduction in vehicle reliability.

5.4.7 Specific requirements for railcars

The tendency for low-floor designs in railcars will increase, and this limits the available space envelope for additional diesel traction equipment underneath the vehicles. Each change in size, design and heat dissipation requirements for Stage IIIA engines leads to a redesign of the entire traction system (power pack). Modifications to the railcar body, cooling system and fuel tank could be needed as well. Due to the fact that railcar engines are very similar to diesel engines for on-road applications, emission abatement solutions for meeting Stage IIIB limits using a NO_x-reduction system with additional urea tank (Option 1 in the table above) seem to be the most likely option. Using this option will lead to further restrictions on the critical space available underneath railcar body structures.

5.4.8 Specific requirements for locomotives

Due to their much higher power ranges, diesel engines for mainline locomotives are not based on on-road engine technology. For these engines, it is currently not completely clear whether a NO_x-reduction system, based on SCR-technology with additional urea tanks, will be needed to meet the Stage IIIB emissions limits. This situation means that it is difficult to make a final judgement on the additional space requirements, weight implications, and the additional costs associated with operation and maintenance. However, if there is a need for an additional urea tank, the fuel tank capacity of the locomotive will have to be reduced, in order to ensure that maximum axle loads are not exceeded.

In specific cases, it could be necessary to increase the length of the locomotive in order to fit the additional after-treatment equipment, assuming that there is enough reserve in space and weight and that the network gauge profile will allow it.

5.5 Conclusions

Chapter 5 provides an overview of the technical measures for reducing NOx and PM_{10} emissions that have the potential to be used in future rail vehicles, from the position of engine and vehicle manufacturers. Alternative propulsion concepts and alternative fuels have not been assessed because for the most part, they will only be solutions in a minority of cases – for example, they might be used in locations where there are specific tax incentives in critical or sensitive regions.

The NRMM Directive Stages IIIA and Stage IIIB emissions limits are probably achievable for future rail vehicles by the dates which these limits are due to come into force. However, it should be noted that the technical and economic impacts associated with achieving these limit values will be very significant. It needs to be taken into account that in order to achieve Stage IIIA limits, it is probable that exhaust after-treatment technologies **will not** need to be fitted to traction units. However, the capital purchase costs associated with diesel engines will increase due to the fact that engines that meet the Stage IIIA limit values will need to be equipped with more complex combustion, injection, and charging technology. Furthermore, operational costs will also increase due to higher fuel consumption associated with these technologies, and increased maintenance requirements. Stage IIIB limits will not be achievable without the use of exhaust after-treatment technology. This will increase investment costs significantly once more and will have a very significant influence on the design and engineering of rail vehicles.

It should be noted that the findings from this assessment of the implications on rail vehicles of the Stage IIIA and Stage IIIB limit values should be treated as preliminary, initial findings. Further research and development work is necessary in order to be able to make firm conclusions on specific solutions and their technical and economic impacts. The relevant industry sectors are currently actively working on these issues.

6 Identification of Operational Measures for Screening

6.1 Overview

This section summarises the range of railway operational measures initially identified for consideration that could be used to reduce pollutant emissions. Most of the options are not new and many are being utilised to different degrees across the European rail network. For some measures there is therefore more scope for improved utilisation and emissions savings than others. A summary list of the options considered is provided in Table 6.1.

The following subsections provide short descriptions of the measures and a summary of issues identified with regard to the possible application of each measure on the European rail network, drawing on any rail experiences in their utilisation, where this is available.

Any rail operator experience with measures was identified through consultation with UIC members and rail diesel experts from UIC, Euromot and UNIFE. A questionnaire survey was also sent out to UIC members (see Annex 2) to gather specific information, and where additional information was available, this was followed up with face-to-face interviews with representatives from individual rail operators.

Table 6.1: Preliminary list of operational measures

Operational measure	Description
Engine-idling	
(a) No idling at standstill	Enforced engine switch-off at stations, shunting yards, and depots ("no-idling" policy)
(b) Idling time limits	Time limits on engine idling at stations (particularly important at rail termini)
(c) Fit APU	Fit small auxiliary engine/generator for supplying auxiliary power at stations
(d) Reduced DMU engine use	For DMUs, where engine idling is unavoidable, the number of train engines left in operation should be reduced, where possible.
Work planning of diesel traction units	E.g. modern low emission units could be used in areas with high pollutant exposure. When timetables and schedules are developed, short-termed stops for example in underground stations with restricted air exchange should be achieved.
DMU configuration optimisation	Optimisation of DMU configurations - reducing the number of units when passenger numbers are low
Energy efficient driving strategies and training	Driver training in fuel-efficient driving techniques and strategies
Energy efficient timetabling / speed restrictions	Timetabling to maximise efficiency and/or incorporating speed restrictions
Reduce diesel traction on electrified lines	Reduce operation of diesel powered traction units on electrified lines
Other measures	E.g. the battery driven motion of diesel electric locomotives meeting from maintenance bases to open-air; or calibration/optimising of engine settings in diagnostic station as part of regular maintenance

In the following sections, an overview of each of the possible operational measures is provided with brief discussion of applicability and potential limitations.

6.2 Engine-idling at standstill

Pollutant emissions at stations are not significant in terms of their total mass when compared to emissions from trains that are in motion (a few percent). However, whilst the order of magnitude of these emissions is low, there may be an issue regarding population exposure levels – in particular, this is related to the effect that emissions from idling trains have on local air quality in and around terminal stations, and the effect that they have on overall station ambience. Whilst total emissions from a train over the length of a route will be much higher than emissions from a train idling in a station for a certain time period, the emissions from a moving train are dispersed over a much larger area than stationary emissions and any people exposed are typically further away from the emissions source than for emissions from trains idling in terminal stations. Furthermore, if one takes into account that in a major station, a number of trains can be sat at platforms with their engines at idle at the same time, it becomes clear that the problem may be of a larger scale than the figures would immediately suggest.

Based on all of this information, there might be significant potential to reduce emissions at stations simply through enforcing maximum idle running times. However, it might be considered that this should be done according to the type of train – different trains have different characteristics with regards their ability to power on-board auxiliary electrical equipment whilst the engines are off. There are also different operational restrictions at different rail termini or depots.

For local areas of concern, a “no idling policy” (or reduced engine idling) – if not in place already - could be a relatively simple but effective way of reducing pollutant emissions without making expensive technical improvements to engines or fitting exhaust after-treatment equipment. There is also the additional advantage that turning off engines would reduce the total hours of engine operation. Practically, the measure includes enforcing engine switch-off at rail termini and the use of shore electricity supply or on-board auxiliary power supply. However, such measures could also include significant costs if this requires expensive changes to the planning of the fuelling infrastructure, or costs incurred in installing shore power supply, auxiliary power units (on vehicles) or engine preheating equipment, etc. Additional staff for connecting and disconnecting the shore supply may also be needed.

Leaving diesel engines in idle operation is a widespread practice at many rail termini, usually because of technical or practical considerations. The primary reasons to leave the engine's idling include:

1. Pre-heating/keeping the engines warm, or at operating temperatures. This is necessary as a train leaving a station under high load conditions when the engine is cold can lead to engine damage/increased wear. (Certain locomotive engines are also sensitive to frequent stop-start cycles.)
2. Providing power for the air compressors for the safety brakes;
3. Providing power for heating/cooling of the driver’s cabin and passenger carriages.

Secondary reasons include:

4. Providing power for lights, on-board cleaning and other auxiliaries;
5. The need to maintain power supply to the catering vehicle.

However, in many cases such secondary power requirements can be provided, at least for a short period, adequately from the rail vehicle’s battery supply.

There are a number of possible options suggested for reducing idling emissions at stations. The first is simply to implement a no idling policy rule requiring that engines are switched off and use of shore supply (platform-based power supply) for auxiliary power requirements, and/or engine preheating equipment where necessary. The second variation is a rule requiring that engines be switched off if the scheduled turnaround time is greater that a certain period, potentially in conjunction with a shore power supply/preheating equipment. Two further options to reduce station idle emissions would be to fit auxiliary engines to provide on-board train power supply, and, in the case of multiple units, only to keep one engine, or a reduced number of engines running to power on-board equipment, rather than the engine in every carriage. The following section provides an assessment of the implications of these options.

6.2.1 Option (a): No idling policy

This option would involve enforcing a no idling policy in combination with using a shore supply (platform-based power supply) and/or preheating equipment (i.e. electric or oil burner). Shore power supply and preheating equipment would incur additional capital costs for installation, when not already present. A cost allowance is also needed for the provision of a trained person to disconnect and connect the shore supply to and from stationary trains. This task could potentially be combined with the duties of the train driver (e.g. as part of vehicle checks), or a standby mechanic, and so it is argued that the equivalent expenditure would constitute the equivalent of two full time employees to cover a full day's operation. Use of shore supply is recognised as a problematic option due to the need to ensure that an individual is available to connect and disconnect the supply. There are also health and safety issues relating to trailing wires on the platform. The process of connecting and disconnecting the supply cannot be performed by "commercial" staff who are readily available on the platform due to the fact that the supply sockets are below platform level, at each end of the train, and can only be accessed from the track level (therefore requiring suitable clothing).

The task of connecting and disconnecting the shore supply may work best as one of the duties of the driver; where the incoming driver would connect the train to the supply and the outgoing driver would disconnect the supply. In such cases the socket should be located above platform level (on future trains where not already the case) so that this could be an option. In such a scenario, a trained member of the "commercial" staff might also carry out the task. It should be noted that for relatively short train turnaround times (e.g. less than 25 minutes), it may not be practical to use shore power supply at terminal stations.

6.2.2 Option (b): Enforce maximum engine running time rule

Variations on the possible time period are envisaged for this option. For example, enforced engine switched off for idling of more than 25 minutes could allow 10 minutes for passengers to disembark and for train cleaning and 15 minutes boarding time, during which it might be required that air conditioning should be supplied for passenger comfort (but retained heat in winter months could mean this time could be shorter in the winter). Alternatively it may be desirable to enforce a shorter maximum period of engine running (e.g. 10 minutes) in combination with using a shore supply (platform-based power supply), and/or preheating equipment (i.e. electric or oil burner) and therefore the capital and operational costs already identified for this in section 6.2.1.

6.2.3 Option (c): Fit auxiliary engines for train supply at stations

Given the problems of using shore supply during short turnaround times, one possible alternative option is to fit small auxiliary engines to trains for use during long station idle periods. Such engines are commercially available for providing train supply. It is difficult to quantify the benefits of this approach due to the wide range of different engines and generators available.

It is important to match load requirements carefully to the auxiliary engines, making finding a suitably sized engine for retrofit more difficult than if included in the original vehicle specification. Irish Railways have very good experience of using auxiliary engines; these were included as part of the original new vehicle specification, and they have been used extensively and have been found to have a good lifetime and operational characteristics. Technical issues regarding the installation and use of diesel auxiliary power units (such as space, noise and weight limitations) have also already been discussed in Section 3.2.4 of this report, with some experiences from SNCF (France), ČD (Czech Republic), ÖBB (Austria), MAV (Hungary) and ZSSK (Slovakia).

At the moment an emerging technology for the provision of auxiliary power in heavy duty vehicles is a solid oxide fuel cell (SOFC) plus reformer, which can use diesel fuel to provide electrical power at much higher efficiencies than ICEs (internal combustion engines) and without emissions of NO_x, CO, HC and PM. The first HGV (5kW) prototype units are expected to be available from suppliers such as Delphi and Webasto by the end of 2005, with estimated costs around $500/kW. Fuel cell stacks are modular, and hence the size and power output of individual units could be scaled up in the future to meet the auxiliary power requirements of railway vehicles. A typical railway coach requires a power supply of between 35 and 40 kW for heating, air conditioning, and other auxiliary equipment. Although units capable of providing this amount of power are not currently available, it is probably that in the next five years such units will become available. Such a technology could be considered in the future as a possible option for retrofitting to existing rail vehicles, but at this stage as the technology is not currently available for rail vehicles, it has not been considered any further.

6.2.4 Option (d): Provision of auxiliary power by a reduced number of engines on DMUs

Current practice at terminal stations is for operators to leave all engines on DMU train sets in idle operation during turnarounds. Reductions in pollutant emissions could be achieved by switching off some of the engines, or where possible, all engines except one. Most diesel multiple units have through wiring between carriages to allow one engine to power auxiliary loads in other coaches (although there are some notable exceptions). For example, in theory one engine could provide auxiliary power to five carriages, although in practice this may not be possible for some classes of DMU. This characteristic could be exploited during station turnarounds as the power supply to a train's auxiliary equipment could be maintained whilst giving emissions benefits without the need for shore supply. However, although many diesel multiple units have through wiring between carriages, substantial modification (and therefore cost) would still be required to enable selective individual engine shutdown where this is not already possible (it is currently possible only in a few specific cases).

Where individual engine shutdown is already possible, or modifications allowing it have been carried out, two possible operating procedures are envisaged. The first would be to implement a rule limiting the number of DMU engines in idle operation per train set, with no maximum time limit for idling. The second variant would add an idling time limit to this policy, potentially necessitating the use of a shore power supply for cleaning, etc.

6.3 Work planning of diesel traction units

The emissions performance of different traction units can be taken into account when carrying out work planning, e.g. by using modern, low emission units in sensitive areas (i.e. densely populated areas). When timetables and schedules are developed, limited-duration stops, for example in underground stations with restricted air exchange, should be planned for. However, this may reduce train operator flexibility to move traction units from one part of the rail network to another. In addition, in most cases, newer and cleaner vehicles are already being operated on the busiest routes, such as commuter lines running through urban areas, which are typically the most sensitive areas. In special cases, such as Gare de l'Est in Paris and Norreport station in Denmark, particular concerns have been addressed with reference to both the traction units, as well as other mitigating measures. These cases are discussed in more detail in Section 7.

6.4 DMU configuration optimisation

Using data on fluctuations in passenger numbers for different services, rail operators are able to estimate their capacity needs, potentially enabling a reduction in the numbers of DMU railcars used when passenger numbers are low, thereby minimising emissions (as well as running costs). Planning is complicated by the need to ensure that availability of sufficient numbers of multiple units on certain services is not compromised by reducing numbers on other services, i.e. if a multiple unit is left at location X, but then needed at location Y for another service. Such DMU configuration optimisation therefore needs to take into account a degree of flexibility/contingency in its application. Because of the cost implications of running unnecessary numbers of DMU units, most European rail operators already take into account capacity needs in their operational planning. In addition, particularly for private operators, the number of spare DMUs may also limit flexibility, as unused stock is an additional cost. There may not therefore be a great deal of scope for further improvement across the European rail network.

An example of the possible savings in fuel and motor oil from DMU configuration optimisation has been provided by LDZ (Latvia). These figures are presented in Table 6.2.

Table 6.2: Comparison of indicators of DMUs consisting of 4 and 6 units

Specific fuel consumption (Litres per 10,000 gross tonne-km)		Fuel consumption (Litres per 100 km)		Motor oil consumption (as a percentage of fuel consumption)		Compressor oil consumption (as a percentage of fuel consumption)	
6 units	4 units	6 units	4 units	6 units	4 units	6 units	4 units
62.73	58.47	205.11	152.58	2.52%	1.17%	0.084%	0.056%

6.5 Energy efficient driving strategies and training[26]

Studies have shown that if drivers modify the way in which they drive trains, significant reductions in the fuel consumption of trains can be achieved. The driving pattern, i.e. the speed over time diagram, has a considerable influence on the energy consumed by a train

[26] Based upon information and reporting on the 'EVENT' project of UIC, DB AG IZT (Institute for Futures Studies and Technology Assessment) and 'Join and Share' (a German company specialising in web database development). See: http://www.railway-energy.org/tfee/index.php

on a given trip. For given restrictions (timetable, stops, speed restrictions on particular routes, and installed traction power) a shortest time driving strategy can be determined, which is basically given by:

- Full acceleration up to maximum speed given either by speed limit or by maximum traction power;
- Speed holding at maximum speed until train has to start braking;
- Braking at the latest possible point in order to come to a stop when reaching the station.

A typical timetable does however allow for a more energy efficient driving style. Additionally, lower exhaust emissions can be achieved by promoting an improved driving technique. Training and the use of driver information systems can help to reduce fuel consumption and to lower exhaust emissions. Whilst CO_2 emissions are directly related to fuel use, NO_x, CO, HC, and PM_{10} emissions cannot be quantified in this manner. It is therefore difficult to provide quantified estimates for how fuel efficiency improvements would affect emissions of these pollutants, but in general, improving fuel efficiency by changing driver behaviour leads to reductions in these pollutants as well.

A significant disadvantage of fuel-efficient driving is that journey times may be increased. Barriers to train operator implementation may therefore include the need for operators to meet punctuality targets to avoid incurring financial penalties. However, changing driving style to reduce fuel and power consumption could be more workable for off-peak trains and rural lines, where journey times are less important. Therefore, although fuel efficiency training is a method that is worth considering, care needs to be taken, particularly where passengers are already frustrated by perceived delays. Some savings could be achieved without increases in journey time as timetables often include a recovery time added to the minimal running time to allow for short delays. This recovery time is normally between 5% and 12% of the minimal running time and can allow application of different driving strategies, which save energy in comparison with the shortest time driving strategy. There are several possible driving strategies:

1. Reduced maximum speed: train accelerates to an operating speed below the actual speed limit.
2. Reduced acceleration rate: Train accelerates to maximum speed using less acceleration power (i.e. at a slower rate of acceleration).
3. Coasting: Train shuts off traction as early as possible before station in order to reach station without braking.

These strategies are illustrated in Figure 6.1 for a simple service (constant speed limit between station 1 and 2). Of course, any combination of these strategies can, in theory, be used as well. Each of these strategies increases the overall journey time. This does not pose any problem as long as time buffers provided by the timetable are exploited. For a given timetable efficient driving strategies can be realised in two ways:

a. Instruction and training of drivers and/or use of special internal timetables indicating to the driver when to shut off traction or what maximum speed to use
b. Driving Advice Systems (DAS)

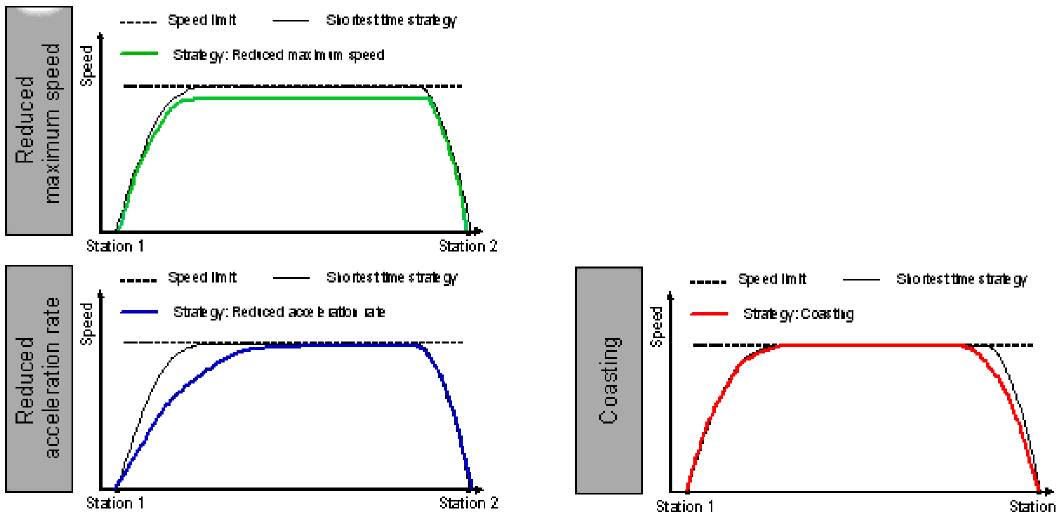


Figure 6.1: Energy efficient driving strategies

Depending on their experience and skill, many drivers have always used timetable buffers to apply a more energy efficient driving style. Today, Driving Advice Systems (DAS) exist that can calculate (and continuously update) the optimum driving strategy much more exactly than any driver could. They are based on train positioning (GPS, the forthcoming Galileo satellite system, or other systems), train, track and timetable data as well as algorithms to calculate driving recommendations.

6.5.1 Driver training

In order to exploit the maximum potential for energy efficient driving without DAS, three factors are essential:

i) *General speed and coasting recommendations:* In order for drivers to be able to exploit the existing potential, they have to be given recommendations or guidelines on what to do. This can include additional timetables specifically for drivers telling them when to coast etc., signs along the way indicating optimum points of coasting (provided the train is ahead of time)

ii) *Training programmes:* Drivers have to be familiarised with these measures and instructed in how to use them via a dedicated training programme.

iii) *Incentives for drivers:* Drivers have to be motivated to adhere to the recommendations given. Monetary incentives may not always be possible from an operational; point of view. However, other incentives such as driving competitions for energy efficient driving have proven effective at DB AG and may be a promising method to raise interest in such measures.

6.5.2 Driving Advice systems (DAS)

Driving Advice Systems (DAS) are on-board tools giving recommendations to drivers for a more energy efficient driving style. In main line operation, rather sophisticated algorithms taking into account a number of track and vehicle characteristics exist to continuously calculate the optimum driving pattern for the remaining route. Various European railways have tested DAS tools, including DB AG (Germany) and NS (Netherlands). In suburban operation the main strategy for reducing fuel consumption is coasting, i.e. switching off traction as early as possible before stations.

6.5.2.1 Non-environmental benefits of DAS tools:

- *Punctuality:* in-service testing of different systems has shown clear improvements in punctuality.
- *Capacity:* DAS could help drivers to stay inside their infrastructure slot at all times. This would improve slot management and thus increase capacity.
- *Wear:* coasting instead of braking reduces the wear of the brakes especially if electric braking is not possible.
- *Passenger comfort:* small improvements in passenger comfort can be achieved through smoother driving. In addition, early train arrival often leading to trains waiting outside stations before reaching the final platform (a situation hardly comprehensible for passengers) is ruled out by DAS.

6.5.2.2 Barriers

The main barriers to the uptake of DAS tools are as follows:

- *Availability of digital infrastructure data*
- *The need to update track information*
- *Delayed trains*
- *Unexpected stops*
- *Computing power*

6.5.2.3 Summary

Driving Advice Systems for main line operation exist and have proven to be operable in in-service testing in several countries. Energy savings are lower than theoretically predicted but are still high. Many operators are currently considering a system-wide introduction of DAS tools. The main technical barrier is the compilation of digital track data. Other obstacles are scepticism about the effectiveness of the system and the length of time that would be taken to recoup the initial investment costs through reductions in expenditure on fuel, as well as uncertainties about the acceptance of such systems by drivers.

6.6 Energy efficient timetabling and speed restrictions

Despite the significant constraints on timetable design, many timetables offer some degree of freedom that can be used for reducing the amount of energy consumed by trains. By fixing the average speed between stops, the timetable has a decisive influence on energy consumption. The design of the timetable underlies rigid requirements imposed by

- *Technology:* installed power
- *Safety:* speed limits
- *Service quality:* fast transportation, short travelling time, punctuality
- *Capacity and mixed operation:* no interference with other trains running on the same line.

Within this rigid framework, some degrees of freedom remain which can be exploited to optimise the timetable for energy efficiency:

1. The length of the buffer times included in a given timetable is of crucial relevance for implementing energy efficient driving strategies. Elasticity of the average energy consumption with respect to buffer times is very high, i.e. slightly increased buffer times lead to large reductions in energy consumption, especially if the original buffer times were low (<5% with respect to shortest time driving strategy). Buffer times are also a key factor for punctuality, and surveys demonstrate that most passengers give higher importance to punctuality than to minimum reductions in travel time. As a

consequence, there is optimisation potential for both energy efficiency and service quality.

2. On some lines there exist low-speed sections that might be removed without major costs. This would not only reduce travel time but also reduce energy consumption, since the deceleration and subsequent acceleration caused by speed limits on short parts of the line usually overcompensate the energetic effect of reduced air drag in speed limit sections.

3. Average energy consumption can often be reduced by reassigning journey times between intermediate stations while keeping the journey time between main stations constant. This option allows the strategy of purposely delaying some trains to be pursued, or the alternative strategy of aiming for a homogeneous distribution of buffer times across the different parts of the line. Due to the non-linear dependence of energy efficiency potential on buffer times, a reassignment of the available time surplus will often have beneficial results. However, the effect of this measure is expected to be rather limited.

Depending on the optimisation strategy chosen, certain “win-win” situations can occur:
- Increased buffer times increase journey time only slightly but may improve overall punctuality considerably.
- The elimination of low-speed sections reduces journey time.

However, timetable design is a highly complex task in which numerous restrictions and constraints have to be taken into account. Energy efficiency and emissions reductions obviously have a low priority to operators in this context and it is difficult to assess the extent to which optimisation has already been achieved by European rail operators.

Certain areas, such as densely populated urban areas, are also particularly sensitive to emissions of air pollutants, so some speed restrictions may be beneficial. The objective for speed-restricted areas could be to ensure engine operation in ranges with lowest specific exhaust emissions in areas of most benefit. However, a significant disadvantage is that journey times may be increased. There is also the difficulty of potentially significant different optimum speeds for different vehicles (e.g. high-speed locomotive services versus local/commuter DMU services), which might necessitate variable limits/guidelines depending on vehicle type.

6.7 Reducing the amount of diesel traction that runs on electrified lines

There is significant variability across Europe in the proportion of track infrastructure that has been electrified, and consequently in the proportion of vehicle kilometres travelled by electric and diesel rail vehicles. This has already been discussed in an earlier section of this report (Section 3.3.6).

In the UK, only 30% of the 16,397 km of track infrastructure is electrified. The low proportion of electrified track has led to the situation where some train operating companies (TOCs) are running diesel-powered trains on electrified track for some of their services. In some cases TOCs operate diesel trains on these lines because part of the journey is on a section of non-electrified track. Diesel trains offer operators greater flexibility as they can be run on both electrified and non-electrified track, and they can be moved from one part of the network to another without problems, if necessary. Situations where diesel vehicles are used on electrified track also arise in other European countries for similar reasons, although to a lesser extent. In the UK, the problem of large numbers of diesel traction units running on electrified track is, in general, one of the consequences of the privatisation of the railway service in that country.

Electric traction offers a number of advantages in terms of emissions performance that have already been discussed in Section 3.3.6 of this report. To reduce the amount of diesel traction operating on electrified lines either requires better use to be made of currently available electric traction rail stock, or alternatively new electric traction units must be purchased. The capital costs of purchasing electric multiple units (EMUs) tends to be higher than for equivalent DMUs, however there are exceptions, e.g. for an Electrostar EMU costing in the region of €1.2 million (£800,000) as opposed to up to €1.6 million (£1.1 million) for Turbostar DMUs[27]. However, the maintenance costs associated with EMUs are usually much lower, thereby making the overall lifecycle costs more favourable for these types of traction units; it should also be noted that emissions from electric traction would improve in further years without the need for further action from the rail industry. This is because the fuel mix used for electricity supply at power stations will change in future years, moving away from coal, and in favour of renewable energy sources. This will have automatic knock-on benefits to the rail sector in the shape of further reductions in the pollutant and greenhouse gas emissions associated with electric traction. The cost balance for the different fuels (electricity vs diesel) depends on the relative prices of oil and electricity (both of which have risen substantially in recent times) and country-specific situations with regard to taxation.

However, as already mentioned, if operators plan to move trains from one part of the network to another, diesel trains offer far greater flexibility; furthermore it is more economically favourable for (mainly private) operators to maintain only one type of vehicle stock. In addition, in cases where there are non-electrified sections of track it is easier to run diesel vehicles for continuity of service, rather than switching to different vehicles for different stages of the journey.

One of the most appropriate ways to start trying to resolve the issue of diesel traction units operating on electrified track would be to first address the sections of track where in-fill electrification is required to provide a continuous electrified route from point to point, and in the longer term, significantly increase the amount of electrified track. However, it is acknowledged that the costs of electrifying large stretches of track are likely to be very large – and in some cases (particularly for many private operators) the track/infrastructure is owned and maintained by a separate organisation, which therefore sets its own policy.

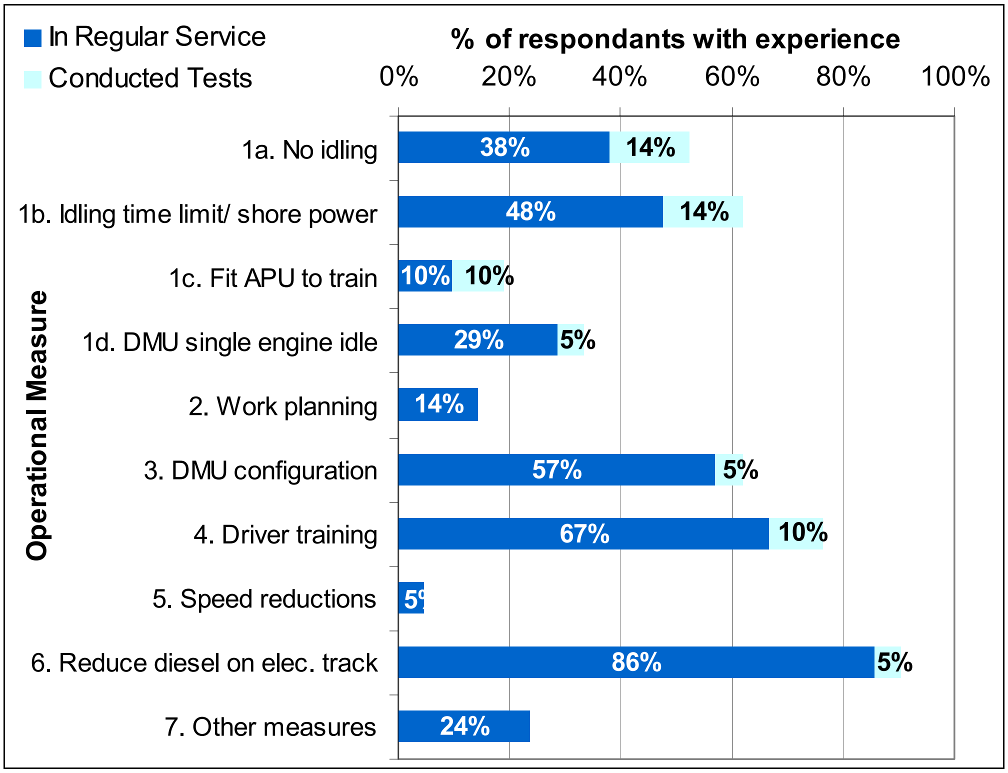
Other solutions to this problem include the use of combinations of DMU and EMU in tandem (DSB, Denmark); utilising diesel and electric locomotives (ČD, Czech Republic) or vehicles equipped with both electric and diesel traction systems (ČD, Czech Republic; SNCF, France).

6.8 Summary of WP2 survey and operator experiences with other measures

As mentioned in the introduction to this chapter, a questionnaire survey was sent out to UIC members (see Annex 2), and followed up with interviews with individual rail operators, where additional information from experiences was available.
summarises the responses to the questionnaire with regard to experience with operational measures. Details on the specific operators with experience of individual measures is provided in Annex 3.

[27] Source: Railway Forum New Build Fact Sheet, October 2003

Figure 6.2: Summary of survey responses on experience with operational measures (21 respondents)



It can be seen from the Figure that European rail operators have extensive experience in applying engine idling limits and the associated necessary equipment (i.e. auto-engine shutdown systems, engine preheating equipment, shore power supply and auxiliary power units). A number of operators also have in their fleets some types of DMU that allow single engine operation at idle, although these appear to be features of the original vehicle design, rather than retrofit.

Not surprisingly there is also considerable experience with DMU configuration optimisation, driver training and reducing/minimising diesel traction use on electrified stretches of track. The latter seems to be more of an issue for private rail operators, rather than large national rail operators, because it is less expensive to operate only one type of stock and diesel vehicles are more flexible (as is the case in the UK). Although driver training to improve energy efficiency was a measure utilised by the majority of respondents, there appeared to be considerable variation in its degree of application and whether additional aids, such as driving advice systems (DAS), or additional equipment/policies to reduce idling were utilised.

Other possible measures identified in the survey and interviews included:

- Battery-driven motion of diesel-electric rail vehicles when moving from enclosed maintenance bays to open-air;
- Calibration and optimisation of engine settings in diagnostic stations as part of regular maintenance for more modern vehicles. (This option also provides the possibility to improve reliability and keep fuel consumption low.)
- The use of rail/road locomotives (with tyres) to replace large locomotives for small shunting operations (and thereby reduce emissions);

- Running only a single power car on non-passenger trains, or switching off the trailing locomotive's engine at low power demand for freight or passenger trains where there are two locomotives in the train-set;
- Capacity allocation strategies, especially with regards to (heavy) freight train operations;
- Infrastructure charge as a cost driver for train operating companies (differentiated by tonnage/km for freight).

6.9 Discussion and summary

It is clear that due to the local effects of diesel exhaust emissions on air quality, operational measures could be just as important as technical measures for reducing pollutant emissions. There are a number of operational measures identified for potentially improving the environmental performance of diesel rail in Europe, many of which are already used to a greater or lesser extent by rail operators.

European rail operators have experience in applying many operational measures already, as they often bring cost savings. However, there are significant operational and technical barriers to the use of some measures that need to be taken into account, depending on circumstances related to the vehicle type, the station, depot, or route conditions. These barriers may be overcome in some cases, although potentially at significant cost.

A more detailed investigation of the costs and emissions benefits of introducing operational measures for reducing emissions from diesel traction of has been carried out by some of the UIC member railway operators (see Section 7). This utilises a case study approach to assess the effectiveness of different operational options, and takes into account any other issues associated with implementing these measures.

7 Assessment of operational measures

7.1 Methodology/framework adopted for assessment

Operational measures cannot be assessed in a similar fashion to the vehicle specific methodology employed in the analysis of technical measures. This is because they are dependent on particular site and/or route conditions, in addition to particular technical limitations of vehicles being utilised. Therefore it was decided to base their assessment on a case study approach utilising existing experiences from operators, collected through a questionnaire survey and individual operator interviews. This approach was intended to use a combination of qualitative and quantitative analysis, utilising data on costs and emissions performance where available and taking into account any additional benefits or barriers to implementation. The objective was to provide some quantitative and qualitative indications of the benefits and disbenefits (in terms of economics, emissions, or others) of some of the most promising operational measures as applied in particular cases, plus any other drivers for their application.

An initial analysis of the survey responses indicated that a number of operators already had experience of using some of the operational measures proposed for this part of the study. To help in the development of the case studies, it was therefore useful to collect additional information from the operators on their experiences. This approach included interviewing some of the operators identified as having experience in the questionnaire (see Table 7.1), following pre-screening by telephone/email. Investigations were aimed at assessing the likely costs, emissions abatement performance and any restrictions that might limit the application of operational measures.

Table 7.1: Details of European rail operator interviews

Operator	Date of Interview
DB AG (Germany)	13th May
Railion (Netherlands)	8th June
DSB (Denmark)	13th June
ČD (Czech Republic)	1st July
SNCF (France)	7th July
ZSS Passenger & ZSSK Cargo (Slovakia)	8th July
BLS (Switzerland)	15th July
FS (Italy)	18th July
ATOC (United Kingdom)	20th July (Seminar)
MAV (Hungary)	26th July

The following types of information were considered necessary for a full quantitative assessment of the operational measures:

- Specific case study situations;
- Applicability and technical feasibility for representative traction units;
- Capital costs associated with specific measures (e.g. costs of installing shore power supply, installation of auxiliary power units (APUs) to vehicles, or modification of DMU train-sets to allow selective engine shut-down to reduce idling emissions)
- Operational costs (e.g. additional maintenance, fuel cost/savings, etc);
- Emissions reductions and fuel savings for particular cases.

However, in practice, analysis was limited to the identification of case study examples and the availability of data relating to these examples. In many cases, much of the necessary data was not available from the rail operators, necessitating a more qualitative approach to the evaluation of operational measures.

7.2 Selection of Measures for Detailed Analysis

The operational measures identified initially were discussed in detail both with the European rail operators interviewed and with diesel rail experts from the UIC B208 Working Group. Responses from the questionnaire survey, summarised in
, provided an early indication of the level of experience of European rail operators with operational measures. This helped focus further investigations through interviews by telephone or through face-to-face meetings, and an initial list for follow-up was constructed (Table 7.2). This allowed identification of particular case studies for evaluation, and collection of relevant information that was to be utilised in the analysis.

Table 7.2: Initial contacts for operational measure experience follow-up

	Measure	**Operators that have carried out tests**	**Operators that use the measure in regular service**
1a	No idling	FS	DB AG, DSB, SZ
1b	Idling time limit/ shore power	FS, SZ	DB AG, ČD, DSB, SNCF
1c	Fit APU to train	ČD, ZSSK Cargo	MAV, SNCF
1d	DMU single engine idle	FS	DB AG, DSB, SNCF, ATOC
2	Work planning		DSB, SZ
3	DMU configuration optimisation	FS, LDZ	DB AG, DSB, SZ
4	Driver training	FS	DB AG, SZ, SNCF
5	Speed reductions		DSB
6	Reduce diesel traction on electric track	FS	DB AG, ČD, DSB, SNCF
7	Other measures	-	ÖBB, ČD, NSB, ZSSK Cargo

As a result of the discussion and evaluation process it was decided to focus the detailed analysis of operational measures into the following areas that were deemed to have the most promise for significant reductions in emissions and potential for greater/more effective application, and are considered in subsequent sections of this chapter:

- Engine idling during standstill;
- Work planning;
- Energy efficiency improvements and driver training;
- Reduce diesel traction on electric track.

The reason other operational measures were excluded from more detailed evaluation were as follows:

DMU configuration optimisation is already very widely applied across the European rail network, primarily because of the strong economic advantages in minimising running costs, and maximising use of stock. This latter in influence is also a barrier to increased optimisation in some cases, where it does not make financial sense to have unused DMU stock held in reserve in order to ensure longer configurations can be utilised, where and when needed for increased passenger demand. This is particularly important for private operators with smaller fleets and therefore less flexibility. A more detailed analysis was therefore not deemed valuable.

Speed restrictions were also initially identified as a potential method for reducing rail vehicle emissions. However, it appears to be the case that this measure may not be of significant benefit for two reasons and no further analysis was deemed useful:

- The most sensitive areas are usually in urban areas, which contain bottlenecks where operational considerations take precedence;
- Rail vehicle engines may not be optimised for emissions performance at lower speeds/power.

The other possible measures identified in the survey and interviews included:

- Battery driven motion of diesel-electric rail vehicles when moving from enclosed maintenance bays to open-air;
- Calibration and optimising of engine settings in diagnostic stations as part of regular maintenance for more modern vehicles. (This option also provides the possibility to improve reliability and keep fuel consumption low.)
- The use of rail-road locomotives (with tyres) to replace large locomotives for small shunting operations (and thereby reduce emissions);
- Running only a single power car on non-passenger trains, or switching off the trailing locomotive's engine at low power demand for freight or passenger services using 2 locomotives
- Capacity allocation strategies, especially with regards to (heavy) freight train operations;
- Infra-charge as a cost driver for train operating companies (differentiated to tonnage/km for freight).

The first three of these measures were not considered likely to lead to significant emissions reductions across Europe, but could have useful application in specific circumstances. Detailed information on their application was also not available for case studies. The fourth option is considered under the area of energy efficiency improvements and driver training. For the final two options no operator experience was identified on their utilisation, nor estimates on their potential effectiveness, thereby preventing detailed analysis.

The results and conclusions from the case study evaluation are presented in the following sections.

7.3 Results

7.3.1 Engine idling whilst trains are stationary

7.3.1.1 SNCF case study: engine idling

Reducing the amount of idling time is not always possible, as there is a need to provide power to the air compressor is in order that safety systems such as brakes are operational. This is particularly true for freight trains, where the pressure losses between wagons are much higher than with passenger trains and the pressure in the main brake pipe needs to be maintained. SNCF operates a "20 minutes" rule, whereby if the train is to be stopped from more than 20 minutes the driver has to stop the engine (e.g. Gare de l'Est discussed later). This rule is not applied widely across the network as it involves substantial operating constraints, for example the engine has to be running when auxiliary power is needed for air conditioning, and/or the air compressors for brakes..

Preheating equipment

Diesel powered preheating equipment (for main engines only) is currently installed on all new locomotives. At the present time, SNCF have only 20 locomotives equipped with a pre-heating system, but there is currently a rapid renewal of the locomotive fleet, so the number of vehicles equipped with the preheating equipment is increasing rapidly. Retrofit to older vehicles was considered, but SNCF decided against that course of action in view of the cost, remaining service life of vehicles and complex nature of the procedure.

It is possible to start the engine when the temperature is above 0°C. At this point, the pre-heating equipment can be turned off. The preheating equipment and computer control does not allow the main engine to be switched on until it has reached a sufficient temperature. This is usually a fairly short time period, although it can take up to 20 minutes if ambient temperatures area as low as -20°C. The preheating equipment switches on automatically when the engine start-up switch is pressed, and is not on a temperature or time based automatic setting.

SNCF has not calculated the impact of pre-heating equipment on exhaust gas emissions or fuel consumption. However, the reduction in idling has been estimated at 100 hours per year.

Auxiliary engines

Some SNCF railcars also have an auxiliary engine and generator set that is designed to provide power and heating for the passenger carriages, as well as engine preheating, thus allowing the main engine to be used less intensively. This system was installed from new and not retrofitted. In service, the auxiliary engines run at a constant 1500 rpm when the train is stationary and consequently are very noisy, frequently attracting complaints from customers. Each generator is designed to supply double the auxiliary power demand from each railcar - built-in redundancy so that if a generator fails, another can supply auxiliary power to two railcars simultaneously. However, in practice, SNCF have found that rather than using the dedicated auxiliary engines and generator sets, it is preferable to draw the auxiliary power from the main engines (the approach used on other types of railcars) because the maintenance costs are lower. For locomotives, a different situation exists as the auxiliary power system can easily be assimilated into the pre-heating equipment.

Through employing an auxiliary engine the reduction in main engine idling/pre-heating undertaken by the main engine itself is estimated to reduce main engine use by 180 hours per year. The associated reductions in exhaust emissions are as follows:

- CO: 8 kg/year;
- Hydrocarbons: 8 kg/year;
- NO_x: 65 kg/year;
- Fuel consumption: 965 kg/year.

Provision of Shore Power Supply
Shore supply is already installed and in use in some stations (1500 V power supply), but it is not also always possible to utilise shore supply with all classes of train. Provision for nine vehicles (three train sets) in a station costs in the region of €300,000. Safety requirements are a significant part of the installation costs. There are also local regulations as to when shore power supply can be used.

In a station, for a single trainset consisting of a BB 67000 and nine coaches, the reduction in exhaust gas emissions would be as follows:

- CO: 60 kg/year;
- Hydrocarbons: 7 kg/year;
- NOx: 590 kg/year;
- Particulates: 16 kg/year;
- Fuel consumption: 21250 kg/year.

7.3.1.2 Deutsche Bahn (DB) case study: reducing consumption for pre-heating during stabling
The reductions in energy consumption and emissions achievable when preheating diesel engines during stabling were investigated as part of a pilot project run at DB Regio AG. The project and its findings are set out below.

Background
The cooling-water circuits on diesel traction units are generally preheated prior to starting the engine (a cold start is either impossible with many engine types or the cause of a great deal of wear). In winter, preheating additionally acts to protect the interiors of multiple unit trains against frost or provide them with an initial degree of warmth. Preheating is effected by means of an oil heater whose consumption is significant when running at full power. Evaluations of test results with operating hour counters (time meters) revealed that typically about 3% of annual fuel consumption is attributable to preheating. It was established that too many vehicles are currently stabled warm over long periods. Some of the reasons for this are as follows:

- So as to provide an “iron-clad” guarantee that the stock will be deployable under all circumstances, locomotive managers order an excess of permanent warm stabling.
- The timer switches on pre-heaters are not made use of consistently.
- It is feared that frequently cooling and heating the cooling water system may give rise to leaks.

Analysis
With a view to keeping preheating times down to an operationally necessary level, the following analyses were carried out:

- Observation by the Vehicle Engineering department that frequent cooling and heating of the cooling system does not lead to any significant increase in leaks and that straightforward action can in any case be taken to prevent these occurring (regular checking of hoses and band clamps).

- Specification as to how many vehicles have to be permanently kept ready to run at each location.
- Examine how vehicles are stabled during and after visits to the depot.
- Examine whether all users are familiar with the operation of timer switches on the preheating devices and whether precise times/dates for return to service are cited in communications between train drivers and locomotive managers.
- Examine whether there are reasons for keeping stock warm despite this not appearing to be operationally necessary (e.g. inoperative frost warning systems, difficulties encountered when draining pipes prior to cold stabling, no means of releasing condensation from the compressed air unit, operation of timer switches overly complicated).

Objectives

Assuming that more frequent cold stabling does not significantly increase wear, orders, instructions, training material, plans and rosters etc, need to be adapted accordingly:

- Details of vehicles that need to be kept permanently warm must be included in rolling stock rosters and stabling plans;
- With regard to the remaining stock, communications between train drivers and locomotive managers must be designed in such a way that train drivers are apprised of the exact time by which a vehicle is required to be ready to run;
- So as to ensure that, for the duration of the investigation, all staff involved in stabling (locomotive managers, train drivers, locomotive shunters, depot staff, etc), are familiar with the documentary material and the correct procedures, short-notice familiarisation sessions are required.

Results

The following results were achieved through the measures adopted:

- The locomotive manager has been notified of the locomotives on which the heating can be programmed and those on which it cannot;
- Rumours regarding technical faults in timer switches have been dispelled;
- Clarification has been achieved by means of a list detailing the locomotives concerned;
- A request has been made to the locomotive manager to keep a critical eye on the number of locomotives in reserve (2-5 will usually be sufficient);
- Information has been disseminated at regular further training sessions;
- Given that only a small number of staff are engaged in the stabling process (locomotive provisioning officers), these have been individually familiarised;
- Since the stabling changes were effected independently of ES, there was no opportunity to conduct a zero measurement and there are no figures for the improvement achieved.

Assessment:

- Knowledge about stabling has improved;
- The moment the locomotive manager fails to provide information on programming the timer switch, the train driver now makes enquiries;
- The procedure/programming are being adhered to;

- Random samples (evening checks) show that a great deal more vehicles are now stabled “properly”.

Further steps mooted:

- Check whether preheating times as a function of the outdoor temperature can be introduced, i.e. train drivers or resource managers receive tables giving details of time setting “x” to be programmed into the preheating devices so as to achieve readiness to run at time “y” given an outdoor temperature of “z” °C.

7.3.1.3 Česke Drahy (ČD) case study: reducing engine idling through the use of preheating equipment, shore power supply and auxiliary engines

The ČD diesel powered fleet size is approximately 833 railcars and 1183 locomotives. Aside from the effect on fuel consumption and emissions, wear and tear on the engines and yields an estimated 400 000 hours/year in reduction of operating time through use of oil burners and electric preheating equipment (in combination with shore power) to reduce idling.

The three principal reasons for engine idling in the ČD fleet are:

- Preheating of the engine and cooling system;
- Preheating of the drivers cabin;
- Powering the air compressors for the brakes.

Power for cleaning is usually provided directly from the platform. Lights and doors are operated directly from the battery (powered by the alternator via the main engines during operation) when stationary. ČD has experience in three related solutions to reduce idling from its passenger and freight operations:

- Installation of oil burner for preheating the engine and the cooling system;
- Installation of electric preheating equipment (powered by a shore power supply) for preheating the engine and cooling system.
- Installation of a smaller auxiliary engine for preheating the engine and the cooling system, plus providing power for the air compressor/brakes.

Where installed these systems save an average of 2.5 hours of idling per day (for preheating and cleaning), where the main brakes do not need to be on (handbrake applied when stationary). Around 50% of all railcars are fitted with an oil burner (30% of Class 810 railcars, 37 Class 842, 31 Class 843, 36 Class 854) or electric preheating equipment (30% of Class 810, railcars and 11 Class 850) fitted, and 13% of locomotives. Only two locomotives are fitted with an auxiliary engine. Even so, engine idling from the remainder of the fleet accounts for some 100,000 operating hours per year (estimated). ČD is in the process of retrofitting oil burners/electric preheating systems to the remainder of its fleet.

Oil Burners

Oil burners are small auxiliary heating generators (35 kW and meeting UIC 1 emission limits) powered by diesel (same supply to the main engines) costing in the region of €3000 for both locomotives and railcars. One unit is fitted per railcar or locomotive and ČD has been using these for over 14 years.

The oil burners are compact (120 cm x 35 cm x 35 cm), relatively easily retrofitted into the engine compartment or under the cooling system of locomotives or under the main frame of railcars. They are also significantly quieter than running the main engines.

Besides reduction of emissions, benefits include reduction in driver time (the units switch on automatically once the main engine is switched off), reduction in engine hours , and reduction in fuel consumption. The reduction in fuel consumption is particularly significant for locomotives where idling consumption is higher; diesel locos have an average consumption of 25 to 30 litres/hour when idling, whilst for diesel railcars the figures are 3.6 to 15 litres/hour when idling. The fuel consumption of oil burners is approximately 2 litres/hour.

Electric preheating system and shore power supply

An alternative to the oil burner is an electric preheating system, powered by external shore power supply from the stand in the locomotive shed or station. The electric preheating units cost around €600 per locomotive/railcar.

The units are relatively easily retrofitted, in a similar fashion to the oil burners, and have similar advantages, with the added advantage of completely eliminating local emissions at standstill once the main engines are turned off. The driver is responsible for connecting the shore power supply to the rail vehicle.

Auxiliary Engine

ČD also has two locomotives fitted with auxiliary engines (40 kW) and electric generators to move the vehicle at low speeds and over very short distances, drive the compressor, charge the battery, and preheat the cooling system and drivers cabin. These are tractor engines and are much larger in size and therefore more difficult to retrofit compared to the oil burners (or electric pre-heaters).

The advantages include providing power for the air compressors that control the main brakes (particularly for freight locomotives), which enables the main engine to be switched off sooner, reducing emissions, reducing fuel consumption and reducing the operating hours and maintenance for the main engine. The disadvantages include cost (where the costs are six to eight times that of oil burners to purchase and fit), significant space requirements and additional complexity. This concept was not extended further due to the magnitude of the investment costs required on what are essentially ‘old’ locomotives.

Shunting operations

There are 15 main shunting yards in the ČD network (freight shunting yards), which each has three to five shunting locomotives - usually a mixture of diesel and electric. There are also around 60 minor yards (for freight and passenger trains), and most of these have only one shunting locomotive each, with a ratio of diesel to electric of about 2:1. There are around 106 electric shunting locomotives and greater than 300 diesel shunting locomotives in total. Electric shunters are, in most cases, utilised at passenger stations (which is a very effective means of minimising emissions), with diesel shunters usually equipped with oil burners to reduce idling.

7.3.1.4 London Paddington Idling Case Study

London Paddington rail terminus is a large enclosed station with 14 platforms (the majority of which cater for diesel traction units only) and as such, the station may sometimes suffers from poor air quality, particularly when several diesel powered traction units are left idling between journeys. Whilst total emissions from a train over the length of a route will be much higher than emissions from a train idling in a station, the emissions from a moving train are dispersed over a much larger area than stationary emissions and hence there is a potential for air quality problems to arise at large terminal stations that operate predominantly or exclusively diesel traction units.

There are a variety of reasons given by the Train Operating Companies (TOCs) for allowing trains to idle at platforms but perhaps the most pertinent reason is to maintain the power supply for services such as lighting, air-conditioning and refrigeration, which are drawn directly from the traction engine. In order to combat this problem a 'shore power supply' was installed on every platform at London Paddington. It was hoped this would allow train operating companies to minimise the time spent idling, and hence reduce the air quality impact, by using the shore power supply to deliver power to trains for lighting, air-conditioning and refrigeration.

The shore supply system was used at Paddington until the number of train services leaving this station significantly increased. The effect of increasing the number of services was that the average turnaround time (i.e. the time that a train spends at the station between consecutive journeys) dropped very significantly, making it impractical to use the shore supply to provide auxiliary power. For example, the train operator First Great Western now has average turnaround times at Paddington of only 25 minutes. For Class 43 HST locomotives, which make up a significant proportion of FGW's fleet, the engine must be re-started 10 minutes before departure to power up the compressors and ensure the cab is at a comfortable temperature for the driver. If the time for passengers to disembark and the time for connecting/disconnecting the shore power supply are factored in, the period for which the shore power would actually be connected is a matter of just a few minutes and as such is not deemed to be a practical solution by the train operator.

An assessment has been carried out of theoretical emissions benefits that could be achieved at Paddington by implementing a 10 minute limit on idling, and enforcing the use of shore supply. It must be stressed that this analysis has been carried out purely to assess the hypothetical emissions benefits associated with such a measure, and it is not recommended that this measure should be implemented. The results of this analysis are presented in the tables below.

Table 7.3: Estimated annual emissions benefits of enforcing a 10 minute maximum engine running time at Paddington Station (based only on First Great Western HST and Adelante vehicles)

	Annual emissions abated (Tonnes)				**Information sources / assumptions**
	NO_x	**CO**	**HC**	**PM_{10}**	
Estimated emissions abatement due to initiating a 10-minute maximum engine idling policy	11.37	3.70	1.32	0.29	Emission factors for Class 43 and Class 180 obtained from First Great Western

Table 7.4: Initial estimates of the cost effectiveness of implementing a 10 minute maximum engine running time limit

	Annual cost per tonne of pollutant abated (€/tonne abated)			
	NO_x	**CO**	**HC**	**PM_{10}**
10 minute maximum engine idling policy	€10,552	€32,457	€91,091	€417,215

The use of shore power supply at London Paddington has also suffered from the added complications that not all train types are able to accept it, and that specially trained staff are required to connect/disconnect the 'plug' to the train. This task could be combined with the duties of a standby mechanic, and so it is argued that expenditure on this option would consist of the costs of two full time employees (in the region of €120,000 per year in total including non-salary costs) to cover a full day's operation. The process of connecting and disconnecting the supply cannot be performed by "commercial" staff who are readily available on the platform due to the fact that the supply sockets are below platform level, at each end of the train, and can only be accessed from the track level (therefore requiring suitable clothing).

Whilst a shore power supply in its current guise may not be practical in the climate of reduced turnaround times at terminal stations, there are other concepts such as providing electrical power at terminal stations platforms via an overhead pantograph or a track-level 'shoe gear' that may enable TOCs to significantly reduce idling times. A pantograph is a spring-loaded arm-like structure that extends from the roof of a train or tram. It pushes a contact shoe up against the electrified contact wire to draw down electricity, which in this context could be for lighting, air-conditioning and refrigeration. Overhead power would have to be available or provided in order for such a system to operate. The shoe gear concept works on a similar principle except that the electricity is drawn from a third electrified rail that runs beneath the train. Retractable versions of either of these concepts could potentially be developed so as only to come into contact with the electrified wire/rail when they were deployed whilst the train was stationary at the platform.

7.3.1.5 ZSSK Cargo – Železnicná (Bèná spoloènos) Cargo Slovakia, a.s: no idling policy and pre-heating

Since the early 1990s, ZSSK Cargo has been striving to reduce fuel consumption in an effort to minimise operating costs. One aspect of this drive has been the introduction of engine pre-heating equipment and associated no-idling policies.

ZSSK Cargo introduced pre-heating equipment in 1996/97 with the aim of reducing engine warm-up times and in turn reducing fuel consumption. ZSSK Cargo's pre-heating equipment uses around 2.5 litres of fuel per hour, whereas if the engine is left to warm itself up, fuel consumption is around 8 to 10 litres per hour. Pre-heating systems typically cost in the region of €4500 (180,000 Koruny) per system. ZSSK Cargo has estimated that it takes around 3.6 years to recoup this investment through reduced fuel consumption.

An alternative type of pre-heating system consists of fitting an electrical resistor to the coolant system, in conjunction with an electronic regulator. The cost of this equipment is approximately €100 (4,000 Koruny) for the equipment, and a further €375 (15,000 Koruny) for the staff time to fit this equipment.

Drivers in ZSSK Passenger and ZSSK Cargo are trained to stop the engines when power is unnecessary. Typically, if a vehicle is stationary for more than ten minutes, drivers will turn the engine(s) off. Most mainline stations in Slovakia operate with electric traction, and hence at such locations, idling policies are not relevant. However, at smaller terminal stations away from the main corridor routes, diesel traction is used in much more significant proportions. The majority of these terminal stations are already equipped with shore power supply and this is regularly used to provide auxiliary power for train heating and lights during station turnarounds. ZSSK Cargo indicated that the cost of equipping a station with shore power supply falls in the range €225,000 to €375,000 (9 million to 15 million Koruny). For DMUs, the policy is to switch off the engine and use the battery to provide lights and heating. The vast majority of ZSSK Passenger DMU railcars are single motor car units that do not operate as multiple units. This means that it is not possible to reduce the number of engines used for providing auxiliary power.

7.3.1.6 Summary

Based on the presented case studies and further information from the questionnaire survey and interviews the reasons for engines being kept running during standstills can be summarised as shown in the following tables.

Table 7.5: Reasons why engines are kept running whilst passenger trains are stationary

Reason for engine running whilst the traction unit is stationary: *Energy needs of **passenger** trains have to be provided*		
Specific energy needs	**Explanations/examples**	**Possible avoidance measures**
Air conditioning Ventilation Heating Lighting Catering equipment / food and drink machines	Large energy requirements for modern railcars with large, fixed windows and automatic doors. Energy consumption for cooling in summer often greater than winter heating requirements – exhaust heat sometimes used for heating.	Provide technical prerequisites (e.g. air conditioning with shore power supply, air conditioning with enough power, auxiliary engines, possibility to keep door open manually for better ventilation): • in specifications for new purchases • retrofit / install in existing vehicles or infrastructure Process optimisations (securing use of e.g. shore power supply)

Table 7.6: Reasons why engines are kept running whilst freight trains are stationary

Reason for engine running whilst the traction unit is stationary: *Energy needs of **freight** trains have to be provided*		
Specific energy needs	**Explanations/examples**	**Possible avoidance measures**
Maintaining power to air compressor system for brakes	In standstills the engine has to run to provide enough air pressure for brakes (depending on needs of train configuration)	Provision and use of stationary air compressors (e.g. for brake test) Process optimisation (e.g. better information of driver about foreseen departure or drive on time)

Table 7.7: Reasons why engines are kept running for preheating

Reasons for engine running whilst the traction unit is stationary: *Preheating of engine and cooling system*		
Specific energy needs	**Explanations/examples**	**Possible avoidance measures**
Engine left on to ensure that it remains at suitable operating temperatures prior to use	Preheating of engine and cooling system can be achieved by: • Running engine • Extra oil burner • Electric preheating equipment • Auxiliary power engine Compared to leaving the main engine running the use of pre-heating equipment in general saves fuel and emissions, but be assess on a case be case basis. Oil consumption of burner: • ZSSK Cargo -example: 2.5 litres per hour, • ČD-example: 2 litres per hour • Example of DB class 642: around 4 litres per hour. 2 burner for 2 hours = 16 Litres per night	Installation and use of automatic burners, which operates depending on outside temperature or programming of starting time dependent on foreseen departure time of traction unit and outside temperature Avoidance of engine/ burner running all time:

Table 7.8: Reasons why engines are kept running to avoid technical problems

Reason for engine running whilst the traction unit is stationary: *Some vehicles have or have had technical problems when starting the engine.*		
Specific energy needs	**Explanations/examples**	**Possible avoidance measures**
Engine kept running to minimise potential delays	Driver fears problems and keeps engine running. (e.g. after software update problems)	Technology to start traction unit has to be reliable and information should be provided to drivers to raise awareness

The emission reductions that can be achieved by reducing engine idling when trains are stationary are assessed as follows. Table 7.9 gives an overview of the typical fuel consumption and emission factors for engines during unloaded idling phases. The values vary significantly depending on engine power and rating. For loaded conditions additional fuel is needed, e.g. for providing energy for air conditioning. The ČD example gives values for diesel locomotives of 25 to 30 litres/hour (21 to 25 kg/hour) when idling, and for diesel railcars values of 3.6 to 15 litres/hour (3 to 13.5 kg/hour) when idling. A comparison of fuel consumption and emissions for idling with typical values for driving shows the following results:

- Fuel consumption and NO_x emissions for one hour of idling is equivalent to the fuel consumption and emissions associated with one, or just a few kilometres of driving.

- PM emissions during idling are due to incomplete fuel combustion and are comparably higher when idling: during one hour of idle operation, and engine will emit PM emissions approximately equivalent to the PM emissions produced more than 10 km of driving.

CO_2 is a global pollutant – i.e. its impacts are essentially independent of the location of the emissions. NO_x and PM are, conversely, local pollutants and their impacts are determined more by the location and concentrations of their emissions, and the impacts are reduced with dilution. It must therefore also be taken into account that the emissions of NO_x and PM when driving are spread over the distance travelled, and are therefore diffuse, whilst emissions occurring when idling and stationary are emitted over a much smaller area. The impacts of idling emissions could possibly be much higher than when the vehicle is travelling between stops.

For example, using the data presented in Table 7.9, a railcar travelling at an average of 100 km/hour will emit PM at a rate of up to 70 g/h, so up to 70 grams of PM in a 1 hour journey; however, the 70 grams of particulate matter would be emitted over a distance of 100 km. The figures in the table indicated that up to the same mass PM emissions could be emitted from a traction unit idling at a station/depot for an hour, but in a local area in the order of 100 m. This constitutes potentially 3 orders of magnitude greater concentration of PM in a given area. Furthermore, at least some of the PM emissions for a journey will probably be released into the rural environment, where human population density (and hence likely population exposure) is much lower than near to major stations/depots located in urban areas.

Table 7.9: Typical fuel consumption and emission for unloaded idling and comparison values

	Typical engine fuel consumption and emission values for idling (g/h)	**For comparison: Typical values for driving (g/km)**	
		Locomotive	**Railcar**
Fuel consumption	2000 – 11000	3000	1000
NO_x emissions	75 – 800	150	50
PM emissions	10 – 70	4	0.7

Source: DB AG, Railway Environmental Center

7.3.2 Work planning

7.3.2.1 SNCF (France) case study: Gare de l'Est (Paris)

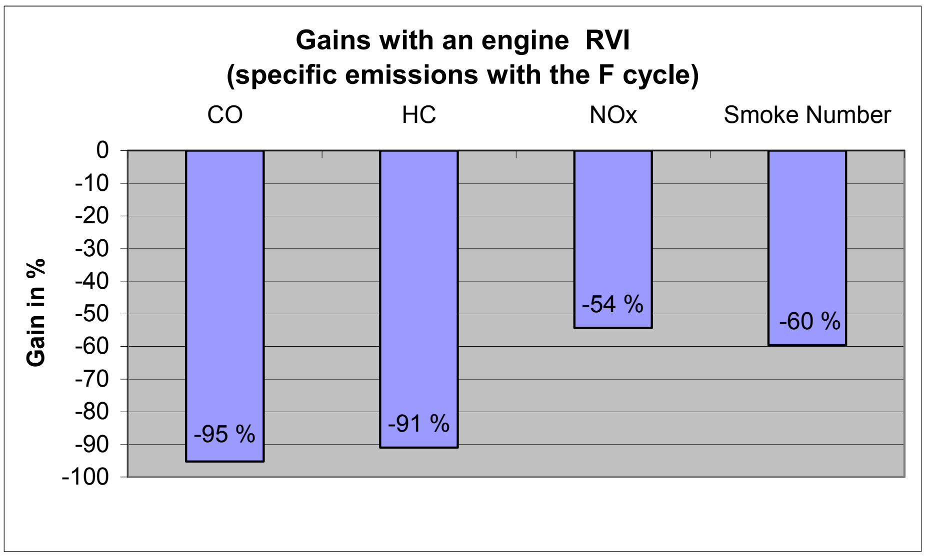
This is a unique situation, where due to the particular local conditions and vehicles utilised, emission problems were particularly acute. The station is on a main line non-electrified route and has many of the largest, oldest and most powerful diesel locomotives in SNCF's fleet stopping at it. A number of measures were implemented at Gare de l'Est and more widely in Paris and the surrounding area to reduce emissions:

1. Accelerated re-engining programme for locomotives;
2. Engine modifications to some of the existing locomotives;
3. Low sulphur (<50 ppm) diesel fuel (from 2003);
4. Additional smoke outlets/air ventilation for buildings;
5. Reductions to engine idling emissions, including:
   (a) A 20 minute idling policy (discussed earlier);
   (b) Locomotive engines are heated up outside the main station (at l'Ourcq, 5 km away) and are pulled into the station with electric locomotives;

More details on the implementation of measures are as follows:

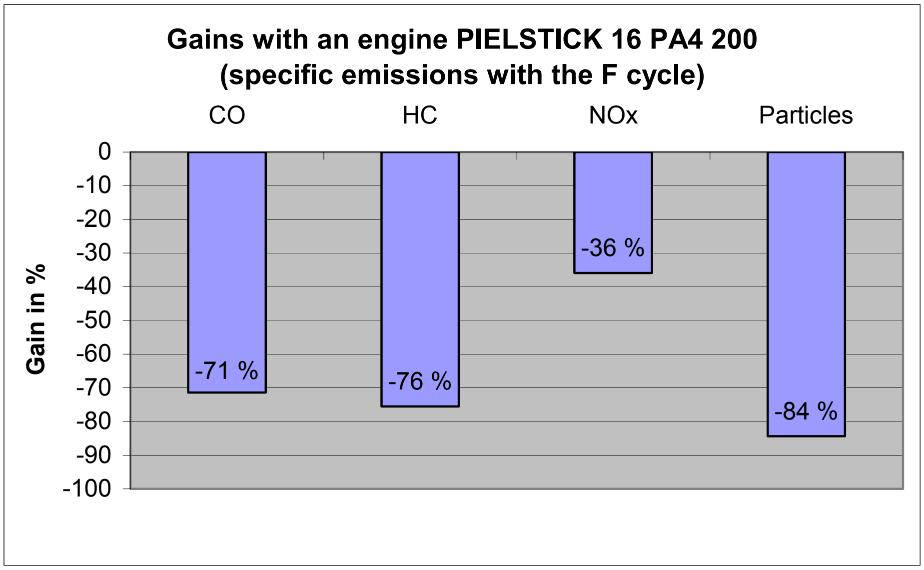
***Re-engining of shunting locomotives (Y8000) and mainline locomotives (CC 72000)**:*
(a) *Impact on the emissions from shunting locomotives (Y8000):*
The re-engining of 85 Y8000 shunting locomotives that are used in Paris and the surrounding area was completed in 2003 at a cost of around €2.13 million. The fuel consumption has been reduced by 18% (based on the ISO F-cycle) and the impact on emissions is shown in Figure 7.1.

Figure 7.1: Emissions reductions resulting from re-engining of Y 8000 shunting locomotives



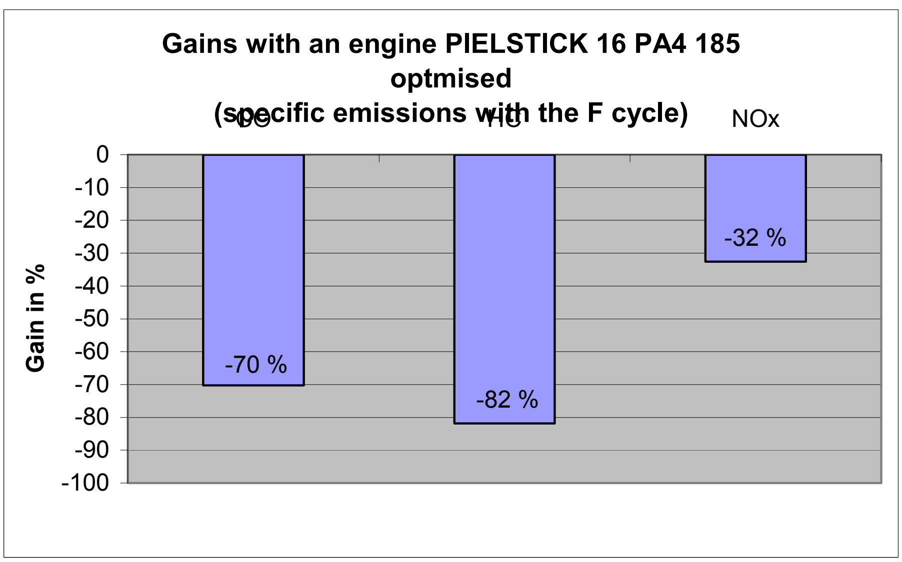
(b) *Impact on the emissions from mainline locomotives (CC 72000):*
The re-engining of 30 CC 72000 mainline locomotives that are used in Paris and the surrounding area was completed in 2004 at a cost of around €15 million. There was no change in fuel consumption (ISO F-cycle) and the impact on emissions is shown in Figure 7.2 below.

Figure 7.2: Emissions reductions resulting from re-engining of CC 72000 mainline locomotives



Engine internal modifications for the second type of mainline locomotives (BB 67400):
BB 67400 locomotives will not be re-engined. In 2000, 15 BB 67400 locomotives operating in Paris and the surrounding area were equipped with engines optimised to reduce the exhaust gas emissions at a total cost of around €80000. The modifications were made to the combustion chamber and resulted in a 15% reduction in fuel consumption (F Cycle). The effects on emissions are shown in Figure 7.3.

Figure 7.3: Emissions reductions resulting from re-engining of Y 8000 shunting locomotives



Use of low sulphur diesel (<50 ppm)
Ultra Low Sulphur Diesel has been used in Paris and its agglomeration since 2003.

Building of an exhaust after-treatment system at l'Ourcq
The mainline locomotives are prepared at l'Ourcq (engine started, braking system tested, refuelled with diesel, and coolant and oil topped up as appropriate, etc) and their emissions are treated with an after-treatment system. CO, HC, NO_x and particulate emissions have been reduced. The cost of this work was approximately €610000.

Reducing engine idling
- *After engine starting:* Since 2002, the time to prepare a diesel locomotive for operation has been reduced from 45 minutes to 20 minutes.
- *Before the departure:* After the preparation at l'Ourcq, the mainline locomotive is integrated into the train and stopped. An electric locomotive tows the train between l'Ourcq and the station and conditions the train. The diesel locomotive is started 5 minutes before the departure and takes the place of the electrical locomotive.
- *After the arrival:* As soon as the train is alongside the platform, the engine is stopped. The train is then towed between the station and l'Ourcq by an electrical locomotive.

- *When the external temperature is low:* Since 2002, the rules governing engine start-up procedures have stipulated that the engine should be started when the external temperature is minus 8°C instead of 0°C.

The global effects of these measures for Paris and its agglomeration were:
- CO (ton/ year): 44% reduction;
- HC (ton / year): 40 % reduction;
- NO_x (ton / year): 23% reduction.

7.3.2.2 Norreport Station (Copenhagen) – DSB, Denmark
Norreport Station is one of three main stations in Copenhagen and is serviced primarily by diesel trains because large parts of the Danish network are not electrified. Since Norreport Station is underground, exhaust gas emissions from the diesel trains become trapped and rapidly accumulate. In the late 1980s this led to significant air quality problems, particularly with PM exhaust emissions, and to a lesser extent NO_x exhaust emissions.

The solutions to the air quality problem proposed by the various Copenhagen municipality authority departments fell into 2 categories:

1. Reduce the emissions from the trains
2. Improve the ventilation at the station

After much debate a ventilation system was installed that involves fresh air being blown in through pillars in the station and vacuums near the staircases extracting air. This was complicated by the fact that the MFA trainsets that pass through the station (and consist of several DMUs) emit exhaust fumes all the way along the train rather than at one or two points, as would be the case with a locomotive powered trainset. The Danish Infrastructure Management Company, who now own Norreport station, are currently looking at ways of increasing the air flow via the pillars since whilst the vacuums are working well it is felt the inward air flow is insufficient.

In addition to the aforementioned ventilation systems, the Copenhagen Environmental Control Agency (ECA) has stipulated that they will only allow trains that meet Euro III standards or better to operate in Norreport station after 2007. Furthermore, regulations have been put in place to ensure ME locomotives accelerate away from Norreport on no higher than notch 4 (8 is the maximum) to minimise emissions.

As part of a general drive by DSB to reduce auxiliary power use, modifications have been made to traction units that also happen to operate in Norreport station. For instance, ME locomotives operate with double deck stock, which has been adapted such that the auxiliary loads (e.g. lighting and air conditioning) can be reduced when required. ME powered trainsets that are stationary in Norreport station exploit this mode.

7.3.3 Energy efficiency improvements & driver training

7.3.3.1 The "EnergieSparen" project being run by Deutsche Bahn AG

A series of energy efficiency projects being run by the passenger and freight transport divisions at Deutsche Bahn AG are revealing great scope for savings and hence financial rehabilitation. Saving energy is helping Deutsche Bahn to cut costs and achieve its climate protection targets. With its Climate Protection 2020 initiative, Deutsche Bahn is continuing with its commitment to reduce emissions of CO_2 by a further 15 per cent by 2020.

Saving energy during train running reduces emissions not only of the greenhouse gas CO_2 but also air pollutants such as oxides of nitrogen and particulate matter. This is of particular relevance for the direct exhaust-gas emissions produced by diesel-propelled rail traffic. It is possible, therefore, to estimate the emission reductions achieved by the projects on the basis of the energy savings set out below.

Passenger Transport - Description of the EnergySparen project and targets for the project

A total of around €27 million was invested in saving energy between 2001 and year-end 2004. The aim is to cut specific energy consumption for traction in passenger transport by 10 % over 2002 (over 2003 in local transport) by the end of 2005. DB's 14,000 train drivers underwent qualification for this from October 2002 to April 2004. Suitable evaluation tools were additionally developed as a means of channelling the economies made. These include supply meters and assistance systems in cabs that display data such as current consumption to the driver or else calculate when recommendations to switch off the traction power should be made so as to optimise energy consumption. It was possible to save a total of 32 million euros in passenger transport during the life of the EnergieSparen project (2001-2004).

Underlying principle: energy-efficient driving (EED)

There are physical laws that help to save energy on the railway: once a train has reached its desired top speed, it can coast over long sections without losing speed significantly. This is an ideal condition for reducing energy consumption while driving, without sacrificing punctuality in the process. The timetable for ICE services only needs to contain a running time reserve of one minute. The train driver can then cut energy consumption by around 8% on a typical section of line between two stations by switching the power off early and coasting for lengthy periods. A running time buffer of a few seconds is sufficient in the case of urban rapid transit and regional services owing to the correspondingly shorter distances between stops. If the train is running to schedule, the minimal running time reserves contained in the timetable can be made good use of for energy saving purposes. Further driving strategies consist of reducing the top speed or stepping down the regulating notch.

Scheme: motivating staff to protect the climate

Around 14,000 passenger train drivers participated in a three-tier training scheme. The principles of energy-efficient driving were presented, along with test findings, at theory seminars at which driving strategies were also addressed and concrete steps for the drivers' own lines discussed. Once the basic principles have been taught, training in the simulator commences. Following the first training run, drivers are given tips on how to economise on energy by, for instance, coasting. Finally, the results of the two runs with and without guidance are compared. A software package computes energy consumption and the economies made. Using the simulator, the best performers produce energy consumption figures for a fictitious route that are 40% below the average for all training runs. By way of conclusion, drivers are given handy tips about routes by experienced coaches accompanying them in the cab.

Energy-efficient driving in internal-combustion-engined (diesel) traction: allowing diesel stock to coast can serve the cause of energy-efficient driving (EED) to a degree: In the case of diesel traction units with **diesel-hydraulic transmission**, the flow converters/hydraulic couplings are emptied once the traction power is set at zero. The frictional connection between the engine and transmission is interrupted and the vehicle is able to coast. Coasting is also possible with **diesel-electric transmissions**, as the electric traction motors are no longer supplied with power then.

It is not possible to practise energy-efficient driving through coasting with all diesel stock, however. Where it is not possible, it may be necessary to resort to reducing the top speed or stepping down the regulating notch. This is the case with Class 642, 643, 648 and 650 stock incorporating **diesel-mechanical transmission**. Here, transmission continues to be by means of frictional connection even when the traction power is set at zero, thus inducing an engine braking event and accordingly rendering coasting impossible.

Evaluating diesel fuel consumption in the Energy Information System (EIS) creates a new level of transparency
Developing metering devices for diesel fuel consumption is more difficult than is the case for electric traction. Thus, it is not as yet possible to evaluate the energy consumed by diesel stock during train movements on a movement-by-movement basis. For the purposes of assessing diesel consumption, it was necessary to examine the vehicles' refuelling data, these being allocated proportionately to the individual movements. The year-on-year economies made in passenger services in 2004 amounted to 24.6 million litres of diesel fuel.

Experience gained in developing an internal diesel meter
Metering systems from three different manufacturers were trialled on three Class 218 locomotives and three Class 628 multiple unit train-sets over a 6-month period. It was not possible to develop a production-status device in this respect. Representatives from the companies concerned, as well as from DB itself managed to pinpoint and remedy a number of shortcomings in the course of the tests. The accuracy of metering was particularly low where the multiple units were concerned. For these reasons, the development of an internal diesel fuel meter will no longer be carried forward. The principal problem was that diesel fuel consumption cannot be directly measured. Fuel flows are what are involved in the direct metering process, which is performed using high-precision meters that establish the flow of diesel going into the engine (forward stroke) and coming back out of it. The diesel consumed is the difference between the two readings. Given that the forward and return flows are significantly higher than actual consumption, it is necessary to determine a small variable taking the difference between two large amounts. Even slight measurement inaccuracies when determining forward and return flow volumes give rise to major inaccuracies in respect of consumption. It is necessary, furthermore, for the metering process to cover the entire range between idling and full load, thereby involving frequent changes of load. High pressure surges occur under certain circumstances in the fuel pipes. It is even possible for the direction of flow to be reversed briefly.

Consumption display for diesel fuel successfully developed
The trialling of direct consumption metering using flowmeters was discontinued at the end of 2003 due to the low measuring accuracy and susceptibility to faults of the meters. In 2004,

therefore, studies were conducted to determine the Classes of traction stock in respect of which it would be possible to obtain and display consumption data from the electronic governor, as is done with modern motor cars. The intention in the process is to display consumption as from the start of a given movement or since the last setting-back by the train driver. A detailed pre-study was jointly drawn up with Bombardier. In tandem with this, it was demonstrated by means of measurement runs that the degree of inaccuracy of indirect metering is less than 2 % for Class 612 stock. Owing to all the requisite preconditions having been met in the case of Class 612 stock, it is intended fitting all vehicles of this type with a diesel fuel display in the summer of 2005.

Further technical assistance system: the EED EBuLa function

The EBuLa on-board unit is connected to a positioning system that continuously determines the vehicle's current position. This enables the current vehicle position to be displayed on the cab timetable display as well as allowing precise computations to be carried out there of the train's scheduled position and the optimum pattern of running for energy consumption purposes and also allowing coasting recommendations to be made to the driver. Of the diesel fleet, Classes 218 and 628 are to be fitted with EED EBuLa in 2007.

Further types of action: deployment of more energy-efficient stock

Deploying new, more energy-efficient stock, notably by replacing locomotive-hauled trains with modern multiple units, will enable DB Regio to make year-on-year savings of 10 % on the cost of energy for diesel traction in 2005.

Extending the project to freight transport

The intention with this project is to identify and harness the scope for saving energy as a function of driving styles, which undeniably exists in the sphere of traction, at Railion Deutschland AG too. This necessitates providing train drivers with suitable means of assistance – including of a technical nature – to enable them to keep energy consumption per train movement as low as possible by taking the appropriate action. Factors that can contribute to this occurring include a foresighted mode of driving, the exploitation of running time reserves and topographical features for the purpose of reducing speeds, giving consideration to operating events as a whole and active communication by the driver and the operation control by the infrastructure provider DB Netz. Whether the potential for savings of 10 % identified for passenger transport can likewise be achieved in the case of Railion is being clarified as part of the EnergieSparen project by means of a series of analyses of potential.

To this end, 2004 was given over to identifying the potential for savings, which involved a total of 174 train drivers being specially coached in energy-efficient driving. With the aid of an earlier zero measurement and the ensuing driving trials as well as of statistical comparisons with the energy consumption figures for the same employees prior to coaching, it was possible to identify potential for saving up to 12 % in electric traction and up to 15 % in diesel traction at Railion. Based on this results the EnergieSparen Project was also launched at Railion Deutschland AG.

The trialling of the supporting system "mobile EED EBuLa" commenced in parallel. This satellite-based computing system gives the driver concrete driving recommendations reflecting the topography of the line, the train's scheduled position and the train's configuration. As a means of establishing the scope for implementing the system and creating the potential for further savings with it at Railion, initial recording and test runs have already been conducted for the purpose. A third strand of activity has seen an Energy Information System (EIS) developed by passenger division and adopted to the needs of freight traffic. The EIS can also be used to systematically track any energy economies achieved so due to information and monitoring they will be of a lasting nature.

Activities planned specifically for diesel traction are as follows:

In 2005:

- Coaching of train drivers in EED for diesel traction too. Constituting the main levers for change are modes of driving, knowing when to switch the traction motor off, and, in winter, knowing how to operate the preheater properly. We have additionally conducted an analysis of stabling consumption figures which we are currently assessing.
- Improvement of collaboration with the infrastructure provider DB Netz with a view to taking account and analysing of energy consumption aspects in operating control.

In 2006:

- Examine the marshalling process and draw up simple energy saving measures (process and behaviour only).

7.3.3.2 The "Fuel Efficient Project" of Railion Nederland

Overview

In the project "*Fuel Efficient*" it is the driver that plays the major role. The project "*Fuel Efficient*" has identified some of the key issues that are necessary to make operational measures to improve the emissions performance of diesel rail by controlling fuel consumption successful. Aside from the effect on fuel consumption and emissions, wear and tear on the 120 engines and other moving parts (brake pads) yields between 7.000 en 12.250 hours in reduction of operating time. There is no further data on this subject as of yet.

By implementing the fuel efficient strategy it is estimated that Railion Nederland will achieve a **fuel reduction of 20%** within the ore and coal transportation market, with a maximum of 1.750.000 litres per year, given a fleet of 120 diesel locomotives hauling 3.500 trains with a maximum hauling distance of 200 km/single trip.

Achievements based on comparison between trial results indicate that this strategy of restricting demand for power and a fuel efficient driving attitude will have an identical effect on all other trains.

Introduction

The aim of the project "*Fuel Efficient*" is to research, develop and implement all necessary means to enable train drivers to drive trains in the most fuel efficient way as possible. The project hence contains both a technical (supportive) component as well as a behavioural (conditioning) component. No matter the technical solutions, the key success factor is the behavioural component as it is the driver that handles the brakes and the throttle.

The project focussed on a balanced mix of "*no idling policy*", "*maximum engine running time*", "*DMU configuration optimisation"* and "*speed reductions"* dynamically controlled by the driver.

Between April 2003 and September 2003 trials were held to determine the effects on fuel consumption. All trials were held with trains carrying iron ore, listed as 48109/48111 from Rotterdam to the Dutch/German border (Venlo) and the (empty) return shuttles 49114/49116. These trains where deliberately chosen because they have a stable and regular schedule and they run a stable standard route of 200 km each way.

The train configuration is also stable: 3 diesel locomotives DE 6400 with a standard set of cars. The trains also carry a stable and regular load (mass). Trials were held on 22-4-2002, 6-5-2002, 3-10-2002,29-8-2003 and 15-9-2003. During the operational trials the different driving techniques and driving strategies where monitored and compared to quality parameters such as compliance with the timetable during transport, timely arrival and the, as such, achieved fuel efficiency. The trials consisted of two approaches:

a. Low intensity acceleration and moderate freewheeling;
b. Forceful acceleration aimed at maximum freewheeling time

Trial evaluations where discussed with experts from Railion's rolling stock department and lead to the conclusion that approach a) low intensity acceleration and moderate freewheeling is the most fuel-efficient strategy. This conclusion also validated conclusions of a trial held on October 3rd in 2002.

Information on fuel consumption during the trials
Parameters: Upon arrival trains were on time and allocated arrival tracks without delay.

- ***Trial 1 strategy: "to maintain the timetable as strictly as possible without paying any attention to fuel-efficient driving".***

  From Rotterdam to Venlo:
  A **loaded** train carrying ore 3 X DE-6400 engines switched on.

  From Venlo to Rotterdam
  The **unloaded** train 3 X DE-6400 engines switched on.

  Fuel consumption: **2559 litres** round-trip.

- ***Trial 2 strategy: "to maintain the timetable as strictly as possible without paying any attention to fuel-efficient driving".***

  From Rotterdam to Venlo:
  A **loaded** train carrying ore 3 X DE-6400 engines switched on.

  From Venlo to Rotterdam
  The **unloaded** train 2 X DE-6400 engines switched on + 1 X DE-6400 engine switched off

  Fuel consumption: 2304 litres round-trip.

  The switching off of one diesel locomotive yielded a savings of 255 litres roundtrip (including a reduction of wear and tear of 3 ½ hours). The unloaded train (1500 metric tons) was able to sufficiently maintain the "prescribed" timetable.

- ***Trial 3: Strategy: "to maintain the timetable as strictly as possible with paying full attention to fuel efficient driving":***
  - Timely adjustments of power demand;
  - Low intensity acceleration;
  - Freewheeling bearing in mind articulations of the track (slopes);
  - Defensive attitude towards signalling mitigating application of the brakes.

Trial 3 added the restriction that power demand on the diesel-generator by the train driver was restricted to 70% of the available capacity of 100%.

Fuel consumption: **2056 litres** roundtrip.

Table 7.10: Summary of fuel consumption results for the different trials

Trial	Outward journey	Return journey	Fuel consumption
1	3 x DE 6400 0-100 %	3 x DE 6400 0-100%	2559 litre
2	3 x DE 6400 0-100%	2 x DE 6400 0-100 %	2304 litre
3	3 x DE 6400 0-70 %	2 x DE 6400 0-70 %	2056 litre

Achievements based on comparison between the results of Trial 1 and Trial 3 (Table 7.10) amount to 20% improvement in fuel efficiency. Identical trials with trains carrying less mass indicate that the strategy of restricting demand for power and a fuel-efficient driving attitude lead to identical results.

Table 7.11: Summary of estimated savings per year in litres and Euros for (O)re & (C)oal trains

Ore and Coal trains/year.	100 litres (L) / train	200 litres (L) / train	300 litres (L) / train	400 litres (L) / train	500 litres (L) / train
2000	200,000 L € 60,000	400,000 L € 120,000	600,000 L € 180,000	800,000 L € 240,000	1,000,000 L € 300,000
2500	250,000 L € 75,000	500,000 L € 150,000	750,000 L € 225,000	1,000,000 L € 300,000	1,200,000 L €360,000
3000	300,000 L € 90,000	600,000 L € 180,000	900,000 L € 270,000	1,200,000 L € 360,000	1,500,000 L € 450,000
3500	350,000 L € 105,000	700,000 L € 210,000	1,050,000 L € 315,000	1,400,000 L € 420,000	1,750,000 L € 525,000

Savings per year in litres and Euros for Ore and Coal trains differentiated into savings of 100 up to 500 litres of fuel per/train. The price of one litre of diesel fuel is set to be € 0.30
The number of trains per year in this market is set to be on average between 2000 and 3500 trains. In addition to this the reduction of wear and tear as a result of the switching off of diesel locomotives may have a beneficial effect on the quality of the combustion, if maintenance intervals remain the same. A summary id presented in Table 7.11.

For the O&C market this would yield between 7000 en 12250 hours operating time. There is no further data on this subject as of yet.

Awareness of maximum engine running time rule
Although the project has not looked at idling time rules during train preparations before departure this is another operations process that may yield substantial reductions of fuel consumption.

During the preparation of the line haul process prior to departure, diesel locomotives are placed and coupled with the train they will haul. The lead-time towards the start of the train run, results in idling of the engines before departure. This lead-time is used to execute safety-testing procedures such as the mandatory testing of the airbrakes and the airbrake system. It is now standard procedure to have the engines of the diesel locomotives running during these procedures. If the driver wanted to stop the diesel engine during these procedures he would also have to get into the external hull of the locomotive to manually turn off pneumatic valves, likewise when the locomotive is taken out of service and parked. If the driver does not turn the manual valves then the electrical circuits will detect the shutdown of the diesel engine in and follow this shutdown in such a way that 10 minutes after the shut down of the diesel engine all electrical installations will be switched off. This also results in the release of failsafe pressure valves, opening the emergency brake valves rendering an emergency brake pressure on the brake pads. This would disturb the on going safety procedures. Hence drivers do not switch off the engines during these procedures. It has been estimated that the application of a switch that can override the cut off of power during safety procedures at stand still will add up to 25 litres/hour idling/locomotive saving of fuel. It is estimated that each locomotive has at least one hour of idling time under these conditions per 24 hours. This adds up to a lot of (wasted) fuel. A change request for the retrofitting of such an override switch has already been executed. Based on a rough estimate calculation it was decided that the savings in terms of fuel consumption during idling were estimated high enough to skip a cost/benefit analyses on the retrofitting of the desired switch.

Driver Training

All technical measures and add-ons only serve one cause, and that is to enable - even enforce - an alternative, conservative way of handling the brake and throttle controls by the train drivers.

The illustrative examples put forward by both the trial reports as well as the empowering managerial approach of the company point out that fuel saving has a tremendous impact on the balance of cost and profit. This has resulted in affirmative action inside the company. A budget of €325,000 has been allocated to equip rolling stock with control tools to monitor fuel consumption per trip by using GPS and data exchange on fuel levels and “black box” information (braking and acceleration) and to finance a campaign inside the company to bring the issue to the attention of all personnel.

Driver training in fuel efficient driving has been incorporated in the basic training modules and is now also part of periodical on board coaching of the drivers.
The computer aided refreshment training that each drivers has to attend every year, has been extended with a module on fuel-efficient driving. It is stressed that the impact of fuel savings is so considerable that the data of the “black boxes” on board the locomotives will in the coming year be linked to GPS equipment such that fuel consumption under standard and stable conditions on line haul services can be monitored in detail. On top of that he made it clear that drivers will be confronted with their “results” and that the results of the confrontation will have consequences for their periodical work evaluation; either it being a pat on the shoulder or a swift kick in the butt.

Discussion and summary

There are a number of operational measures that have been identified for potentially improving the environmental performance of diesel rail in Europe. The information provided by this interview shows that the incentive of “cost drivers analysis” can be a basis on which environmentally significant operational measures can be achieved.

Railion Nederland has decided to go “live” to invest, train and enforce. On the side associated resource needs are the push towards driver awareness and enforcement of the policies. Beyond that it is necessary that timetables allow for fuel-efficient driving. On the business executive level, directors of the boards of Railion and ProRail (the Dutch Infrastructure Manager) now address this issue on a regular basis partly as a result of the results of this project.

Timeframes associated with implementation of the option(s) are as follows:

- Trials in September 2004;
- Implementation January 2005;
- First evaluation of true operational results October 2005.

7.3.3.3 ZSSK (Slovakia) case study: fuel-efficient driver training

In the early 1990s ZSSK (which has since split into ZSSK Passenger and ZSSK Cargo) identified the need to reduce their expenditure on fuel. Consequently, from 1992/93 onwards they began to place greater emphasis on fuel-efficient driving during driving training.

Before drivers are allowed to operate trains for ZSSK Passenger or ZSSK Cargo they must attend a training course, which includes fuel-efficient driving techniques, and pass an exam. In addition, each driver has a total of 20 hours of classroom-based training per year. This is made up of 10 hours on transport issues, and 10 hours on technical innovations that are mainly aimed at improving fuel efficiency.

The pay rate for train drivers in both ZSSK Cargo and ZSSK Passenger is 308 SKr per hour/€8 per hour, which means the cost of the annual driver training equates to approximately €161,600 for ZSSK Cargo and €104,000 for ZSSK passenger. 1% of ZSS/ZSSK drivers are themselves trainers and run some of the courses for training other drivers in fuel efficient driving techniques.

ZSSK Passenger has carried out tests using a fuel meter fitted to a locomotive. The tests have indicated that fuel efficient driving techniques can lead to a 17% reduction in fuel consumption where there is a $17^{0}/_{00}$ downhill gradient. This is due to the use of 'coasting', where the train's engine is temporarily disconnected from the rest of the drive train and its own momentum is used to propel the train forward. Across all the routes covered by ZSSK Passenger there has been a 7% reduction in fuel consumption due to fuel-efficient driving techniques and fleet optimisation.

7.3.3.4 SNCF (France) case study: energy-efficient driver training and measures

SNCF is currently reintroducing energy-saving targets and measures, such as eco-driving, fuel efficiency/consumption measurement equipment for vehicle cabins and procedures to reduce idling when stationary. The decision was made last year to restart measures previously utilised, but fallen into disuse. These will be incorporated into a strategic plan for 2006-8. There are currently no specific targets as assessments are still being performed on what might be possible. In addition they are currently rewriting economic driving procedures (previously updated in the early 1970s). The aim is for wide scale introduction of measures, however work is still in its only stages at the moment.

7.3.4 Reduced Diesel Traction on Electrified Lines

It is known that a number of railway operators use diesel traction units on electrified lines, thereby allowing them greater flexibility with respect to vehicle fleet utilisation. However, a rail operator's emissions performance could be improved by only using electric trains on electrified track.

The first question to be addressed is determining how widespread the use of diesel traction units on electrified track really is across the whole of Europe. Whilst it is a common practice in the UK, only 3 respondents to the WP1 survey questionnaires using diesel traction on electrified track indicated they did not already make active attempts to minimise this in regular services. It appears from the additional information gathered from following up on the questionnaire responses (18 usually utilising it, mainly for service continuity) that it is not a significant problem in most of the (mainly national) railways. Without additional infill electrification or dedicated vehicles, there appears to be low scope for significant reduction, other than in the UK, where the privatised network and separate infrastructure responsibilities (Network Rail) means that cost constraints disfavour reduction in diesel traction use on certain parts of the electrified track network.

Even so the following brief case studies show that in certain cases alternative solutions to in-fill electrification can be utilised to reduce diesel traction use on electrified sections.

7.3.4.1 DSB experience in reducing diesel traction on electrified lines
A solution utilised by DSB (Denmark) is to operate a combination of EMU and DMU coupled together (Figure 7.4). The control systems of the related train sets have been upgraded for this purpose, and are widely used on a particular part of the network. Except for differences in wheel diameters, or switched off traction units, the load is shared equally between coupled train sets. This setup was implemented to maximise the use of existing in new stock after there was the decision to halt further network electrification. The disadvantage is that for non-electrified sections for diesel powered DMU cars are pulling the additional EMU carriages without power, which would potentially impact on the service performance.

Figure 7.4: EMU (IR4) and DMU IC3 are coupled and running together (IC3now in new DSB colours).

7.3.4.2 ČD experience in reducing diesel traction on electrified lines
There is only a very small amount of diesel traction running on electrified track on the ČD network. This is mainly limited to through trains on mixed sections, or for short additional stretches at tail end or start of a journey. Freight trains and shunters are generally diesel as not all stations are electrified.

In only few cases where a mixture of diesel and electrified track covers a route (stations), one diesel locomotive and one electric locomotive are used in tandem to cover the respective segments. ČD is currently also operating a project to build a prototype electric locomotive (800kW) with an auxiliary diesel engine (350kW) that can be used for traction in non-electrified sections for shunting and small freight.

7.3.4.3 SNCF duel powered multiple units
In some areas it is not possible to provide electrified track, e.g. for freight unloading, and diesel powered units are also much more flexible. Interoperability issues such as this are important. One solution being implemented by SNCF is buying 80 two system hybrid railcars for regional services that can either take power for traction from overhead lines when available, or utilise diesel traction when not available.

7.4 Summary

The main quality of the operational measures is that they can be applied within a relatively short time horizon at normally very little investment costs compared to the technical measures. However, these two advantages are not necessarily enough to initiate the needed change of procedures. The complexity of involving the various groups of staff (planning, operation, maintenance, etc.) is one of the barriers for the implementation. Therefore, it is important to identify and initiate the right mix of incentives as well.

The presented case studies give an impression of the current possibilities for the available operational measures to reduce diesel exhaust emission. In many cases the measures mainly aim at saving costs like for energy efficiency improvements and driver training. Emission reductions are additional positive side effects of fuel savings. At present hardly any detailed values for emission savings exist, they have to be estimated based on fuel saved, and this way of estimation is not very accurate due to the lack of information on engine load. As cost savings and fuel reductions go in line, these measures are favourable for railway operators, but nevertheless not always enough to constitute the proper incentive.

The example of Gare de l'Est in Paris shows that in certain areas, with special air quality requirements, dedicated measures to reduce emissions are also performed by the concerned railways. Investments like in re-engining or technical exhaust gas treatment systems or mayor changes in operational procedures like pulling the diesel trains in the station with electric locomotives were needed. The additional costs have been justified here with the special need for emission reductions in the surrounding area of the station. Restricted air exchange and the magnitude of emission sources resulted in critical urban air quality.

The diversity of the case studies makes clear that no standard solution can be applied fitting every situation. The following factors should be taken into account and will also impact on the effectiveness of the potential solutions in each situation, including:

- Different kind of rolling stock (e.g. equipped with automatic pre-heating devices, auxiliary engines, air conditioning, etc.);
- Different administration / legislation in different countries (e.g. public ordered transports with different environmental specifications);
- Different production schemes (e.g. turn round times at stations);
- Different organisational structure of the rail sector and rail companies (e.g. integrated companies or completely separated operator and infrastructure companies could have different decision processes when, for example, investments in installation of shore power supply equipment are considered);
- Different need for action (e.g. possible contribution of railways to critical air quality levels depends highly on the magnitude of rail diesel traffic as well as on existing other emission sources; see Work Package 3 of this study);
- Different impacts and different costs of operational measures depending on where and how they are implemented.

Therefore each situation has to be looked at individually. The described case studies could be used as a basket of potential options that have to be checked against each situation to find the most (cost-) effective measures. In addition to this, the appropriate mix of incentives has to be identified and executed.

8 WP2 Summary and Conclusions

8.1 Overview

The “Rail Diesel Study”, funded by EC DG TREN and the International Union of Railways (UIC), was set up at the end of 2004 and co-ordinated by UIC, with support from industry partners[28]. The main aim of the study was to investigate the possible technical and operational measures that could be used to reduce pollutant emissions from diesel rail fleets across the EU Railway 27 countries. Work Package 2 was concerned with carrying out detailed assessment of the various technical and operational measures that could be used to reduce emissions, and hence forms the primary focus for the work carried out for the Rail Diesel Study. The assessment of technical measures in WP2 will contribute to the preparation for a review (due by the end of 2007) of the amended NRMM Directive for new engines, and has provided important information on the possible emission reduction measures that could be applied to the existing diesel fleet. This work package included the following activities:

1. Identification of possible technical and operational measures, drawing on experience from the road transport and stationary power sectors, but bearing in mind that these options may not always be suitable for retrofitting to rail vehicles;
2. Investigation to identify if, and how widely the identified options have already been used in the rail sector;
3. Narrowing down the range of options to focus on only those which are feasible for application to rail vehicles;
4. For the current fleet, detailed analysis of the costs and benefits of applying technical options to specific representative traction units. This took into account the practicalities of trying to retrofit emissions abatement equipment to existing vehicles (e.g. space, weight and operational conditions, such as engine performance and exhaust characteristics).
5. For new and future vehicles a more general assessment of technical measures has been performed based on typical types of vehicles with reference to the limit values for Stage IIIA and IIIB of the NRMM Directive;
6. Operational measures have not been assessed using the same life-cycle cost analysis techniques, as they are also dependent on particular site and/or route conditions. Therefore the assessment of these types of measures was based on a case study approach drawing on the existing experience of operators. This was collected through questionnaire surveys and face-to-face interviews with representatives from selected railway operators.

The purpose of the analyses carried out for this study was firstly to analyse possible technical and operational strategies for reducing emissions from **existing** rail vehicles across Europe, and secondly it was also necessary to examine the possible options for **future** vehicles. The approach taken in WP2 to meet the objectives set out included three important elements:

[28] Project partners included UIC, the Community of European Railways (CER), the Union of European Railway Industries (UNIFE), The European Association of Internal Combustion Engine Manufacturers (Euromot), and with AEA Technology Environment as sub contractor/consultant to UIC

1. Exchange of knowledge between railway companies (via UIC), system integrators (via UNIFE) and engine manufacturers (via Euromot) in a sector-wide approach.
2. Creation of a snapshot, summary analysis of the status of technical and operational measures that could potentially be used to reduce pollutant emissions from diesel rail traction units. For technical measures, this has included an assessment of the life-cycle cost implications associated with each measure. A robust, detailed analysis was beyond the time-frame available for this study.
3. Identification of barriers and possibilities for technical and operational measures. This includes a discussion of the technical issues associated with using many of the measures on rail vehicles.

The following sections summarise the results and conclusions of the work carried out in this part of the study.

8.2 Assessment of technical measures for the existing rail fleet

8.2.1 Screening of technical measures for further assessment

A large range of technical measures was initially identified, based on experience from other industry sectors. Screening of this list was carried out to identify the measures that were likely to be most suitable for use on existing rail vehicles. The main findings from the screening process were as follows:

- Most of the exhaust after-treatment options were taken forward for further assessment as there is experience of using these options in the road sector. The main exceptions to this were NOx adsorber catalysts and lean NOx catalysts, both of which are technologies that are still in development. For this reason, these options were excluded from further assessment for the existing fleet.
- Hybrid drive, energy storage concepts, and multi-engine concepts are technologies that are still in development and hence were also excluded from being taken forward for further assessment.
- Engines that run on natural gas, dimethyl ether (DME), methanol, or ethanol were not taken forward for further assessment as the availability of suitable engines for rail vehicles is very limited. Additionally, for current rolling stock, these engines would not provide trains with an adequate journey range due to difficulties in storing sufficient fuel on board the vehicle. The energy content values of these fuels are lower than for diesel, and hence a greater volume of fuel would be needed to travel a given distance. This in turn would mean that larger fuel tanks would be required, and for many traction units there are significant limitations in the amount of space available for larger tanks.
- Biodiesel was not examined further, as previous research has indicated that there are either no NOx and PM_{10} benefits associated with using such fuels, or if there are benefits, they are very limited. Using biodiesel does, however, lead to net CO_2 benefits. Further research into the impacts of biodiesel blends with a Fatty Acid Methyl Ester (FAME) content greater than 5%, on engine performance and fuel system durability is needed prior to the widespread adoption of these fuels;

The table below provides details of the options that passed through this screening process for further analysis.

Table 8.1: Technical options that passed through the screening process that were assessed for use on the existing diesel fleet

Options for reducing pollutant emissions that passed through the screening process	Pollutants that the option affects
Diesel Particulate Filter (DPF)	PM
Continuously Regenerating Trap (CRT®)	CO, HC, PM
Combined Particulate Oxidation Catalyst (POC)	CO, HC, PM
Selective Catalytic Reduction (SCR)	NO_x
SCRT® (Combined SCR+CRT®)	NO_x, CO, HC, PM
Exhaust Gas Recirculation (EGR)	NO_x, (HC, CO)
Internal Engine measures	Varies, depending on the specific measure
Re-engining	NO_x, CO, HC, PM

8.2.2 Detailed assessment of technical measures for the existing fleet

The technical measures carried forward from the pre-screening process were examined in greater detail on the basis of feasibility studies conducted on a selection of representative existing traction units. These representative traction units were selected from the European diesel vehicle fleet on the basis of operating performance, numbers of vehicles in operation across Europe, and pollutant emission factors. Railcars, mainline locomotives and shunting locomotives were included in the set of representative vehicles, and two vehicles were chosen for each of these three vehicle types: one dating from before 1990, and another from after 1990.

The purpose of the analysis was to determine whether each of the technical options could be applied to the various representative traction units, and where possible to estimate the life-cycle costs and technical implications associated with each of the options. The main results and conclusions drawn from the analysis are summarised below:

- There is very little experience in the railway sector of using technical measures for reducing pollutant emissions from diesel engines. Hence relatively little is known about the applicability, costs, and reliability of such measures. Although in most cases, it is very difficult to retrofit exhaust after-treatment equipment to existing rail vehicles, there are some possibilities, and these are detailed below;
- For **pre-1990 railcars, open channel Diesel Particulate Filters (DPFs)** could be fitted to reduce PM_{10} emissions. However, such DPFs only reduce PM_{10} emissions by around 30-40%. It has been estimated that the capital cost of equipping pre-1990 railcars with open channel DPFs would be approximately €11,000 per engine, with additional annual operating costs of €510 per engine per year. A more effective option for reducing NOx and PM emissions from these types of traction units would be **re-engining** (i.e. replacing the original engine with one with improved emissions performance). In addition to reductions in pollutant emissions, there are also additional benefits associated with re-engining, including reduced fuel consumption and reduced maintenance costs. It has been estimated that the capital cost of re-

engining a pre-1990 railcar would be approximately €87,500, and that there would be reductions in operating and maintenance costs of around €2,785 per year.

- For **post-1990 railcars**, a combination of **Selective Catalytic Reduction (SCR) with a closed channel DPF** could be used to control NOx and PM emissions. However, it must be stressed that integration of this type of exhaust after-treatment system is only possible if comprehensive modifications to vehicle configurations (e.g. removal of seats) are carried out. Checks need to be made on each vehicle type to ascertain whether the vehicle licence is still valid given the additional load on the axles. The capital costs associated with this option are thought to be in the region of €28,000 to €48,000 per engine, with annual additional operating costs of €3,380 to €5,475 per engine per year. Additional operating costs include the cost of the urea additive required for SCR systems.

- For **pre-1990 mainline locomotives**, open channel DPFs could be fitted to reduce PM_{10} emissions. These types of filters only reduce PM_{10} emissions by between 30% and 40%. The capital cost associated with this option has been estimated to be €97,500 per engine, with annual additional operating and maintenance costs of approximately €7,500 per engine. Complex exhaust after-treatment systems such as SCR or SCR in combination with a DPF are not feasible as there is a lack of space and they are too heavy to be fitted without maximum axle loads being exceeded. The most cost-effective option for these types of traction units is **re-engining**. Re-engining has been estimated to have a capital cost of around €437,500, with annual reductions in operating and maintenance costs of approximately €15,000 per year.

- For **post-1990 mainline locomotives,** it could, in theory be possible to modify such traction units in order to be able to fit **closed channel DPFs**, or a **combined SCR + DPF system**. However, retrofitting such equipment would require very significant modifications to be made to vehicles as such equipment may lead to maximum axle loadings being exceeded. Increases in exhaust back-pressure may also limit the application of such options. The capital costs of equipping such a a locomotive with a closed channel DPF has been estimated to be €128,500, with additional annual operating costs of €14,375 per year. The capital costs for a combined SCR + DPF system have been estimated to be €175,000, with additional annual operating costs of approximately €19,500 per year.

- For **pre-1990 shunting locomotives**, it may be possible to fit a **closed channel DPF** to control PM_{10} emissions, or a **combined SCR + DPF system** to control both NOx and PM_{10} emissions. However, these options are conditional upon weight and exhaust back-pressure issues being resolved. The capital cost associated with equipping these types of shunting locomotives with a closed channel DPF has been estimated to be €53,500, with annual additional operating and maintenance costs of €5,800 per year. For a combined SCR + DPF system, the capital costs would be €84,000, with annual additional operating and maintenance costs of €6,800 per year. The analysis has identified that the most cost-effective option for pre-1990 shunting locomotives would be **re-engining**. The capital costs associated with this option have been estimated to be €210,000, with annual reductions in operating and maintenance costs of €5,000 per year.

- For **post-1990 shunting locomotives**, as with pre-1990 shunting locomotives, it may be possible to fit a **closed channel DPF** to control PM emissions, or a **combined SCR + DPF system** to control both NOx and PM_{10} emissions. Again, these options are conditional upon weight and exhaust back-pressure issues being resolved. The capital costs associated with equipping these types of locomotives with closed channel DPFs have been estimated to be in the region of €64,000 per engine, with additional annual operating costs of €8,250 per year. The capital costs associated with a combined SCR + DPF systems have been estimated as being ion the region of €102,000 per engine, with additional annual operating costs of €10,350 per year.

- It must be stressed that in each case where significant vehicle modifications are required to fit exhaust after-treatment equipment, there will be large increases in life-cycle costs

8.3 Assessment of technical measures for new and future rail vehicles

8.3.1 Screening of technical measures for further assessment

As for the existing fleet, the large range of technical measures initially identified was screened to create a shorter list of options that might be suitable for use on new and future rail vehicles. The main findings from the screening process for the new and future fleet are as follows:

- As with the existing fleet, the majority of exhaust after-treatment options identified were selected for further, more detailed assessment. However, for the new and future fleet, it was thought likely that both NOx adsorber catalysts and lean NOx catalysts should be included in the detailed assessment, as these technologies are likely to be available on the market in the next few years.
- Hybrid drive, energy storage concepts, multi-engine concepts, biodiesel, and natural gas engines were all excluded from further assessment for the same reasons given for the existing fleet

The table below provides details of the options that were selected for further assessment following this screening process.

Table 8.2: Technical options that passed through the screening process that were assessed for use on the new and future diesel fleet

Options for reducing pollutant emissions that passed through the screening process	Pollutants that the option affects
Oxidation Catalysts	CO, HC
Diesel Particulate Filter (DPF)	PM
Continuously Regenerating Trap (CRT®)	CO, HC, PM
Combined Particulate Oxidation Catalyst (POC)	CO, HC, PM
NO_x Adsorber Catalyst (NAC)	NO_x
Lean-NO_x Catalyst	NO_x
Selective Catalytic Reduction (SCR)	NO_x
SCRT® (Combined SCR+CRT®)	NO_x, CO, HC, PM
Exhaust Gas Recirculation (EGR)	NO_x, (HC, CO)
Internal Engine measures	Varies, depending on the specific measure

8.3.2 Detailed assessment of technical measures for the future fleet

The assessment of possible technical options that could be used to reduce pollutant emissions from future rail vehicles utilised an approach based on the general expected characteristics of future engines and of whole rail vehicles. The main results and conclusions drawn from the analysis are summarised as follows:

- The tendency for railcars to have low floors will continue in the future and this design requirement limits the available space envelope for fitting emissions abatement equipment underneath the railcar body structure.
- Diesel locomotive units are often used on secondary lines within Europe, which means there are major limitations in terms of maximum allowed axle loads and clearance gauges in particular. In addition rail vehicle manufacturers have to fulfil the future Technical Specifications for Interoperability (TSI) requirements for noise and crashworthiness; these requirements also increase the average weight of rail vehicles, and mean that there is likely to be less available space for emissions abatement technology to be accommodated.

8.3.2.1 Meeting the Stage IIIA limits

- Information from the engine and vehicle manufacturers indicates that the **NRMM Stage IIIA limits** will be achieved using **internal engine measures**; low sulphur (<50 ppm sulphur) fuel will be required, but it is thought that **exhaust after-treatment options will not be necessary to meet the Stage IIIA limit values**.
- It is thought that using internal engine design measures to meet the Stage IIIA limits will lead to increases in vehicle capital costs of between 3% and 15%, and increases in maintenance costs of between 5% and 10%. Fuel consumption is expected to increase by between 4% and 6%.

8.3.2.2 Meeting the Stage IIIB limits

- **Diesel Particulate Filters** will be required in order to meet the **Stage IIIB PM_{10} limit value**s.
- Currently it is not certain whether the **Stage IIIB NOx limits** will need SCR after-treatment systems, or whether the limit values can be met using internal engine measures. Further work, outside of the scope of this study, is required in order to understand which of these options would be the most suitable for complying with the Stage IIIB limits.
- Sulphur-free (<10 ppm sulphur) or Ultra Low Sulphur Diesel (ULSD) fuel (<50 ppm sulphur) will be required regardless of whether SCR systems are fitted to engines since many of the technical measures rely on exhaust after-treatment systems that cannot tolerate a higher sulphur content. As a necessary pre-requisite, the use of sulphur-free diesel or ULSD by railway operators across the whole of Europe will be required in order to facilitate the reduction in pollutant emissions from diesel rail vehicles.
- Where after-treatment is incorporated into existing designs, its application is restricted by space and weight limitations; this is consistent with the findings for vehicles in the existing fleet. For existing designs, the vehicle body, engine compartment, cooling compartment and fuel tank have to be re-designed, in order to fit the necessary additional emissions abatement equipment.

- When a completely new design is developed, such adaptation is more easily accommodated; however the rail sector design cycles for new models are much longer than for on-highway vehicles and there may still be some significant obstacles.
- At this point in time, there is only limited practical experience of using exhaust after-treatment systems on rail vehicles, and hence at this stage, it is only possible to obtain initial information about the costs and performance associated with such systems. The best current estimates of the additional costs of meeting Stage IIIB are as follows: vehicle capital costs are anticipated to rise by between 8% and 20%, whilst maintenance costs are expected to increase by between 5% and 15%. For fuel costs, the picture is more complex; for some options, fuel costs could decrease by up to 5%, whilst for other options, fuel costs could increase by up to 9%. Where SCR is used, there would be additional costs associated with the need for the urea additive. These additional costs have been estimated to be around 4% of total fuel consumption costs.
- When using internal engine design measures to reduce pollutant emissions, there is typically an increase in the amount of heat dissipated by the engine, with a corresponding need for additional engine cooling. This may manifest itself as a need for larger, or a greater number of cooling radiators, which require additional space and incur additional weight penalties.
- To remain below axle load limits, the fuel tank capacity of locomotives may have to be reduced if emissions abatement equipment is fitted to the vehicle. Sometimes it could be necessary to increase the length of the locomotive in order to fit after-treatment equipment, assuming there is enough space on the vehicle body, and that by fitting the equipment, maximum axle loads are not exceeded. Additionally, it would be necessary to ensure that the network gauge profile can accommodate such a modification.
- Some of the emissions abatement technologies assessed during this study are still under development (especially for rail applications), and it is therefore premature to draw definitive conclusions with regard to the possibility of using them in future rail applications. Changes in the costs and performance of many options are anticipated, especially to achieve the Stage IIIB limit values.
- The Stage IIIA and Stage IIIB emission limits bring more complexity to the diesel engines fitted to rail vehicles. This complexity includes the need for very sensitive injection systems and fuel distribution systems (e.g. common rail), particulate filters, larger cooling equipment, catalytic converters, new interfaces between the engine and control systems. This additional complexity raises concerns with regard to a potential reduction in the reliability of vehicles. It is also possible that the use of alternative fuels may no longer be feasible with these systems in place without careful investigation of the impacts.

8.4 Assessment of operational measures

It was not possible to carry out the same type of detailed analysis of the life-cycle costs associated with the use of operational measures to reduce pollutant emissions from rail vehicles, as operational measures are very dependent on route and vehicle specific parameters. Responses obtained from railway operators as part of the survey process carried out during Work Package 1 provided an initial list of operational measures that have been trialled or that are already used by some operators. This initial list was then discussed with UIC members to decide which operational measures should be investigated in more detail. The results of these discussions were that the following measures were selected for more detailed investigation using a case study approach:

- Engine idling during standstill;
- Work planning;
- Energy efficiency improvements and driver training;
- Reduce diesel traction on electric track

Representatives from individual operators were interviewed in order to gather information on their experiences of using these types of measures. Where available, information on the costs and emissions benefits associated with these types of operational measures was also collated, although in practice it was found that such data was not readily available for all of the types of measures that were examined. It must be stressed that operational measures are very site-specific, and hence any data presented in this report on the costs and benefits of operational measures relate only to the location in question, and it is not possible to assume that the values quoted here would be the same for other railway operations in other locations.

The main findings from the assessment of operational measures are as follows:

- Operational measures for reducing pollutant emissions can normally be applied within a relatively short time and with lower investment costs than technical measures. However, there are significant barriers, such as the complexity of involving various groups of staff (planning, operations, maintenance, etc). Therefore the right mix of incentives is needed.

- The primary objective of some operational measures is to reduce fuel consumption, and hence reduce operational costs. Such measures include driver training for energy efficient driving, and reductions in the amount of engine idle time at terminal stations. For these types of measures, reductions in NOx and PM emissions are additional effects.

- In certain areas with special air quality requirements, dedicated measures to reduce emissions are already used by some railways (e.g. Gare de l'Est, Paris). Investments or major changes in operational procedures are needed in such cases.

- The diversity of the case studies examined makes it clear that no standard solution can be applied that fits every situation. The case studies discussed in this report could be thought of as a basket of potential options that have to be assessed against each individual situation to find the most cost-effective solutions. In addition to this, the appropriate mix of incentives has to be identified and implemented in order to help ensure that the chosen measures work in practice.

Examples of some of the costs and benefits associated with specific operational measures are presented in the following sections.

8.4.1 Measures to reduce engine idling

SNCF has implemented measures to reduce idling at terminal stations. Auxiliary engines and generator sets are fitted to some SNCF railcars to reduce the need for traction engine idling. It has been estimated that this measure reduces emissions in the following manner:

- CO: reduction of 8 kg per engine per year

- Hydrocarbons: reduction of 8 kg per engine per year

- NOx: reduction of 65 kg per engine per year
- Fuel consumption: reduction of 965 kg per engine per year

Whilst these auxiliary engines have led to reductions in pollutant emissions, SNCF are unlikely to use this option more widely as there have been significant problems with high noise levels from these engines. It should, however, be noted that other railway operators have equipped vehicles with auxiliary engines and have not had problems with excessive noise levels.

SNCF has also equipped some stations with shore power supply, which can also be used to reduce idling at terminal stations. Provision of shore supply for three trainsets in a terminal stations costs in the region of €300,000. The estimated reductions in emissions for a single trainsets (BB67000 with nine coaches) are as follows:

- CO: reduction of 60 kg per year
- Hydrocarbons: reduction of 7 kg per year
- NOx: reduction of 590 kg per year
- PM_{10}: reduction of 16 kg per year
- Fuel consumption: reduction of 21250 kg per year

ZSSK in Slovakia have also equipped some of their stations with shore power supply. They have estimated that the cost for equipping a station in Slovakia with shore supply falls in the range €225,000 to €375,000. They have not made estimates of the possible reductions in emissions due to implementing shore supply.

8.4.2 Driver training and measures to improve energy efficiency

Deutsche Bahn has undertaken a series of energy efficiency projects ("EnergieSparen") in recent years, and invested a total of around €27 million into this topic area between 2001 and 2004. All of DB's 14,000 drivers have been trained in fuel efficient driving techniques, and a range of other measures were evaluated over the course of this study. In total, it was possible to save €32 million over the course of the EnergieSparen project due to reductions in fuel consumption.

Railion in the Netherlands has also implemented a project on fuel efficiency. The aim of this project is to develop and implement measures that will help drivers operate trains in the most fuel efficient manner. The objective is to reduce total fuel consumption in the ore and coal transportation market by 20%. The results of trials carried out as part of this project have indicated that it is possible to achieve a 20% reduction in consumption.

Fuel efficient driving trials carried out by ZSSK Passenger railway company in Slovakia have indicated that fuel consumption can be reduced by up to 7% across all routes in modified driving techniques are adopted.

8.5 Summary

Based on the results of the work carried out, it is thought that Stage IIIA limit values could be achieved by using internal engine design measures (without the need for exhaust after-treatment), whilst exhaust after-treatment technologies would probably be required to meet the Stage IIIB limit values. The study has indicated that many of the possible operational measures for reducing pollutant emissions are already being used by railway operators as they make their operations more efficient and reduce costs.

The study has highlighted the fact that the rail sector currently has very little experience of using technical measures to improve emissions performance, and that many of the possible technical measures for reducing rail emissions are based on automotive technology that has not yet been developed or optimised for the rail sector. On top of this, there are very significant limitations with regard to the technologies that can actually be applied in practice to rail vehicles. This is particularly the case for the existing fleet where space and weight limitations would currently rule out many of the potential exhaust after-treatment options; re-engining appears to be the most suitable option for reducing emissions from existing vehicles. For future vehicles, there is more scope to apply both internal engine design measures and exhaust after-treatment equipment, but the issues of space and weight limitations still exist. It must be reiterated that a number of the technical options for reducing emissions are still being developed or optimised, and it can be anticipated that in future years, the cost, weight, and space requirements associated with emissions abatement equipment may decrease, whilst the performance of the equipment may improve. Hence, at this stage, it is far too soon to draw firm conclusions on whether specific technologies definitely can or cannot be used on rail vehicles.

It is clear from this study, that further, more detailed research is required to understand the possibilities and limitations associated with the various options assessed during this study. The outputs from this work should be considered as preliminary findings that will help guide future research activities, and that will contribute to the information necessary to carry out the technical review of the Stage IIIB limit values before the end of 2007. The study has shown that most of the experience with emissions abatement equipment is based on experience from the automotive sector. Whilst the technology may, in principle, be transferable to the rail sector, the durability and reliability requirements of the two sectors are very different. Comprehensive research is therefore required to assess the failure modes and durability of these types of equipment when applied to rail vehicles.

9 Annexes

Annex 1: Rail Limit values according to NRMM Directive

Future diesel exhaust emission standards for rail applications are regulated by the Non-Road Mobile Machinery Directive (amended by Directive 2004/26/EC) The amended Directive will regulate the limit values for new engines in diesel traction units (railcars and locomotives) as listed in the following table:

Limit values according to NRMM Directive										
Stage	Category Net Power (P) (kW)		Pro-pulsion by	Limit values in force		**CO**	**HC**	**NO_x**	**PM**	**Test cycle** (ISO 8178-4)
				Type approval from	Placing on the market from	g/kWh	g/kWh	g/kWh	g/kWh	
IIIA	RC A	P > 130 kW	Railcar	*01.07.2005*	01.01.2006	3.5	4.0		0.2	C1
	RL A	130 kW < P < 560 kW	Loco-motives	*01.01.2006*	01.01.2007	3.5	4.0		0.2	F
	RH A	P > 560 kW	Loco-motives	*01.01.2008*	01.01.2009	3.5	0.5	6.0	0.2	F
	RH A	P > 2000 kW and SV> 5l/cyl	Loco-motives	*01.01.2008*	01.01.2009	3.5	0.4	7.4	0.2	F
IIIB	RC B	P > 130 kW	Railcar	*01.01.2011*	01.01.2012	3.5	0.19	2.0	0.025	C1
	R B	P > 130 kW	Loco-motives	*01.01.2011*	01.01.2012	3.5	4.0		0.025	F

Table A1: Limit values according to the amended Non-Road Mobile Machinery Directive (2004/26/EC)

Annex 2: Work Package 2 Questionnaire to UIC Members

INTERNATIONAL UNION OF RAILWAYS	**UIC Diesel Action Plan** **Rail Diesel Study**

Rail Diesel Study Questionnaire B – Emission reduction measures relating to diesel rail operations

This is Part B and second part of the questionnaire for the UIC Rail Diesel Study. The study aims to develop strategies for reducing pollutant emissions from diesel rail in Europe. This survey covers air quality problems relating to diesel rail operations.

Section	Description	Target group (principal respondents)	No. of questions	Deadline
B	Emissions Reduction	Diesel and rolling stock experts, environmental co-ordinators	4	24 March 2005 (distribution 01 March)

We kindly ask you to fill out the data forms or to forward them to the competent person(s) in the respective field and to return the completed questionnaire sections, preferably in electronic form, to the project co-ordinator, Markus Halder, whose address you can find below.
The expectations of the outputs from this study from the European Commission and outside parties are high. Completing this questionnaire would therefore need a certain workload from your side - in terms of data input and your expertise. The UIC is aware of this request for help and we are grateful for all your assistance in this Rail Diesel Study. The UIC is determined to deliver usable study results and at the same time support our members in this field.

Contact information:

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Phone: +49-30-297-56532
Fax: +49-30-297-56505

Mailing address: Markus Halder
Deutsche Bahn AG
Bahn-Umwelt-Zentrum
Caroline-Michaelis-Str. 5-11
10115 Berlin
Germany

Please return this questionnaire section at the latest on March 24th 2005.

Thank you in advance for your support.

RAIL DIESEL STUDY QUESTIONNAIRE
SECTION B: EMISSION REDUCTION MEASURES

Your contact information:

Railway Company:	Your name:
Position:	E-mail address:
Telephone No:	Fax No:

QUESTION B1: EMISSIONS REDUCTION STRATEGY

B1.1: Does your company have an <u>emissions reduction strategy</u> with clearly defined goals, reduction measures and communicational efforts?
(Please mark "X" in the appropriate box below)

YES, we already have an emissions reduction strategy ☐

NO, we do not currently have an emissions reduction strategy ☐

If you answered YES, please provide details in the space below.

If you answered NO, does your company plan to introduce an emissions strategy in the future?

YES, we plan to introduce an emissions strategy ☐

☐

QUESTION B2: EMISSIONS REDUCTION MEASURES

B2.1: Has your company introduced OPERATIONAL measures to reduce pollutant emissions?
(Please mark "X" in the appropriate boxes below)

	No experience	Have run tests	In regular service
"No-idling" policy and engine auto-shutdown systems for stations and depots			
Where idling is unavoidable, only one DMU engine is left on			
Work planning, e.g. using low emissions vehicles in known emissions hot spots			
Driver training in fuel efficiency			

B2.1: Has your company introduced OPERATIONAL measures to reduce pollutant emissions? *(Please mark "X" in the appropriate boxes below)*			
	No experience	**Have run tests**	**In regular service**
Speed reductions in sensitive areas			
Efforts to avoid or reduce the amount of diesel traction units used on electrified sections of track			
Optimisation of DMU configurations (reducing the number of units when passenger numbers are low)			
Supplying auxiliary power at stations through a feeder cable (shore power supply) to avoid diesel engines running.			
Other operational measures (please specify below)			
1)			
2)			
3)			
4)			

B2.2: Please describe in the box below your experiences (both positive and negative) of using/testing the above measures? In particular, it will be useful to obtain information on the costs, benefits, and any problems (e.g. reliability issues) associated with each measure.

B2.3: Has your company introduced TECHNICAL measures to reduce pollutant emissions? *(Please mark "X" in the appropriate boxes below)*			
2.3a: Retrofit emissions abatement equipment	**No experience**	**Have run tests**	**In regular service**
1) Retrofit particulate filters			
2) Retrofit Selective Catalytic Reduction (SCR)			
3) Retrofit Exhaust Gas Recirculation (EGR)			
2.3b: Re-engining or replacement of older traction units	**No experience**	**Have run tests**	**In regular service**

B2.3: Has your company introduced TECHNICAL measures to reduce pollutant emissions? *(Please mark "X" in the appropriate boxes below)*			
1) Replacing engines in traction units with newer, lower emission engines of a different design			
2) Replacement of old locomotives/DMUs with new locomotives or DMUs with lower emission (please give details below especially when emission abatement equipment is used)			
3) Electrification of line sections			
2.3c: Fuels	**No experience**	**Have run tests**	**In regular service**
1) Use of Ultra Low Sulphur Diesel (less than 50 ppm Sulphur content)			
2) Use of Sulphur-Free Diesel (less than 10 ppm Sulphur content)			
3) Use of Liquefied Natural Gas (LNG) or Compressed Natural Gas (CNG) instead of diesel			
4) Use of Biofuels or biofuel blends (including Rape Methyl Ester (RME) or Fatty-Acid Methyl Ester (FAME)).			
5) Use of Water Diesel Emulsion fuels			
6) Use of fuel additives to reduce emissions			
7) Other technical measures (please give details below)			
2.3d: New technologies	**No experience**	**Have run tests**	**In regular service**
1) Internal engine measures			
2) Energy storage concepts			
3) Hybrid drive			
4) Multi-engine concept 1: Several traction engines, of which only the necessary number is running			
5) Multi-engine concept 2: Traction engines plus auxiliary engine(s), so that traction engines only run when necessary			
2.3e: Other technical measures (PLEASE ADD OTHER MEASURES BELOW)	**No experience**	**Have run tests**	**In regular service**
1)			
2)			
3)			
4)			

B2.4: Please describe in the box below your experiences (both positive and negative) of using/testing the above measures? In particular, it will be useful to obtain information on the costs, benefits, and any problems (e.g. reliability issues) associated with each measure. It will also be useful to know which types of vehicles the measures were tested on. **If you have plans to introduce further technical measures, please also give details in the box below.**

QUESTION B3: FUTURE PLANS FOR ELECTRIFICATION

B3.1: Is your company planning to reduce the use of diesel traction by introducing or expanding electrified service?
(Please mark "X" in the appropriate box below)

***YES**, we plan to increase the amount of electrified services or tracks*		**NO**, we do not plan to increase the amount of electrified services or tracks	

B3.2: If you answered "YES" to the above question, please provide an estimate for the length of additional track that will be electrified, and the time-scale by which this will be achieved.

Estimated Length of additional track to be electrified		**kms**	Year by which this will be achieved	

B3.3: If you answered "NO" to Question B3.1, please indicate why you do not plan to increase the amount of electrified services or tracks
(Please provide information in the space below)

B3.4: Does your company operate diesel trains on electrified sections of track?
(Please mark "X" in the appropriate box below)

YES		**NO**	

B3.5: If you answered "YES" to Question B3.5, please indicate why you operate diesel trains on electrified tracks
(Please provide information in the space below)

B3.3: Please provide information on the typical costs of electrifying sections of EXISTING track?
(Please provide answers in the appropriate boxes below)

Estimated cost of electrifying existing track (cost per km)		**Per km (PLEASE INCLUDE CURRENCY – Euro, Krone, Pounds, etc)**	Year that this estimate was made	

Please indicate what type of electrified systems the above cost estimate refers to (e.g. 3kV DC, 25 kV AC 50 Hz, etc)	

B3.4: For electric traction units, does your company currently use regenerative braking to feed power back to the electricity grid?
(Please mark "X" in the appropriate box below)

***YES**, we use regenerative braking*	☐	**NO**, we do not use regenerative braking	☐

If you answered YES, what proportion of electric services use regenerative braking? ☐ **%**

Comment : Within few years 100%
The older S-trains (urban trains) do not have the facility and will be replaced in a few years.
The regenerated energy is returned to the caternary and that way to other trains – it is not returned to the public grid.

If you answered NO, do you plan to introduce regenerative braking in the near future?

YES, we plan to introduce regenerative braking in the near future	☐	**NO**, we do not plan to introduce regenerative braking	☐

QUESTION B4: ADDITIONAL INFORMATION

B4.1: If you have additional information, a comment or a personal opinion on the subject of emissions from railway diesel vehicles and emissions control, please feel free to add it here. Any contribution is welcome!

Many thanks for your support.

Annex 3: Summary of UIC Member Experience with Technical and Operational Measures

The following abbreviations/codes have been used in the summary tables for the received WP2 questionnaire responses (20).

Key:

Country Code	Acronym	Name
AT	**ÖBB**	Österreichische Bundesbahnen
BE	**SNCB/NMBS**	Société Nationale des Chemins de fer Belges
BG	**BDZ**	Bulgarian railways
CH	**BLS**	BLS Lötschbergbahn AG
CZ	**ČD**	České drahy
DE	**DB AG**	Deutsche Bahn AG
DK	**DSB**	Danske Statsbaner
FI	**VR**	VR-Group Ltd
FR	**SNCF**	Société Nationale des Chemins de fer Français
GB	**ATOC**	Association of Train Operating Companies
HU	**MAV**	Magyar Allamvasutak Rt.
IT	**FS**	Ferrovie dello Stato SpA
LV	**LDZ**	Valsts Akciju Sabiedriba "Latvijas Dzelzcels"
NL	**NS**	N.V. Nederlandse Spoorwegen
NO	**NSB**	Norges Statsbaner BA
PL	**PKP**	Polskie Koleje Panstwowe S.A.
PT	**CP**	Caminhos de Ferro Portugueses, E.P
RO	**CFR**	Societatea Nationala a Cailor Ferate Române
SI	**SZ**	Slovenske Zeleznice d.d.
SK1	**ZSSK**	Železnicá spolocnost', a.s.
SK2	**ZSSK Cargo**	Železnicá (Bèná Spolocnost) Cargo Slovakia, a.s

B2.1: Has your company introduced OPERATIONAL measures to reduce pollutant emissions?						
	None	**Have run tests**	**In regular service**	**No. Test**	**IRS**	**% None**
“No-idling” policy and engine auto-shutdown systems for stations and depots	9	It, Lv, Sk1	At, De, Dk, No, Fi, Si, Cz, UK	3	8	43%
Supplying auxiliary power at stations through a feeder cable (shore power supply) to avoid diesel engines running.	8	It, Ro, Si	De, Cz, (Dk), Bg, Fr, No, Hu, Nl, Sk1, UK	3	10	38%
5) Multi-engine concept 2: Traction engines plus auxiliary engine(s), so that traction engines only run when necessary	19	Cz, Sk2	At, Hu, Fr	2	2	90%
Where idling is unavoidable, only one DMU engine is left on	14	It	De, Dk, Fr, Si, Cz, UK	1	6	67%
Work planning, e.g. using low emissions vehicles in known emissions hot spots	16		Fr, Dk, Sk	0	3	76%
Optimisation of DMU configurations (reducing the number of units when passenger numbers are low)	8	It	Cz, De, Dk, Lv, Pt, Hu, Nl, Ro, Si, Sk1, Be, UK	1	12	38%
Driver training in fuel efficiency	4	It, Fi	Cz, Fr, Lv, Bg, Sk2, De, Pt, Hu, Nl, Ro, Si, Sk1, Be, UK, At	2	14	19%
Speed reductions in sensitive areas	20		Dk	0	1	95%
Efforts to avoid or reduce the amount of diesel traction units used on electrified sections of track	2	It	Cz, De, Dk, Fr, Bg, Sk2, Ch, Pt, Hu, Nl, Fi, Ro, Si, Sk1, Pl, Be, UK, At	1	18	10%
Other operational measures (please specify below)	16			0	5	76%
1) Calibration/optimisation of engine performance using diagnostic stations as part of regular maintenance	17		No	0	1	81%
2) Use of diesel-electric locomotives in battery operation when moving in/out of maintenance bays	16		Cz, Sk2	0	2	76%
3) Electric and fuel preheating of cooling system	16		Cz, De	0	2	76%
4) In winter seasons the vehicles stand off in heated halls	18		Sk1	0	1	86%

B2.3: Has your company introduced TECHNICAL measures to reduce pollutant emissions?						
2.3a: Retrofit emissions abatement equipment	**No exp.**	**Have run tests**	**In regular service**	**No. Test**	**IRS**	**% None**
1) Retrofit particulate filters	17	Dk, Fr, Ro	Ch	3	1	81%
2) Retrofit Selective Catalytic Reduction (SCR)	20	De		1		95%
3) Retrofit Exhaust Gas Recirculation (EGR)	20	De		1		95%
2.3b: Re-engining or replacement of older traction units	**No exp.**	**Have run tests**	**In regular service**			
1) Replacing engines in traction units with newer, lower emission engines of a different design	9	Dk, Sk2, Si, UK	Cz, Fr, It, Lv, De, Pt, Hu, Sk1	4	8	43%
2) Replacement of old locomotives/DMUs with new locomotives or DMUs with lower emission (please give details below especially when emission abatement equipment is used)	7	Bg	Cz, Dk, Fr, It, Ch, De, Hu, Fi, Ro, Sk1, Be, UK, At	1	12	33%
3) Electrification of line sections	6		Cz, De, Dk, Fr, It, Bg, Sk2, Ch, Pt, Hu, Nl, Fi, Sk1, Pl, Be		15	29%
2.3c: Fuels	**No exp.**	**Have run tests**	**In regular service**			
1) Use of Ultra Low Sulphur Diesel (less than 50 ppm Sulphur content)	8	Bg, UK	Cz, Dk, Fr, Lv, Sk2, Nl, Ro, Si, Sk1, Be, At	2	10	38%
2) Use of Sulphur-Free Diesel (less than 10 ppm Sulphur content)	16	UK	Dk, Sk2, De, Hu	1	4	76%
3) Use of Liquefied Natural Gas (LNG) or Compressed Natural Gas (CNG) instead of diesel	20	De		1	0	95%
4) Use of Biofuels or biofuel blends (including Rape Methyl Ester (RME) or Fatty-Acid Methyl Ester (FAME)).	17	Cz, De, Fr, Pt		4		81%
5) Use of Water Diesel Emulsion fuels	18	It, De, Fr		3		86%
6) Use of fuel additives to reduce emissions	18	De, Fr	Hu	2	1	86%
7) Other technical measures (please give details below)	21					100%

B2.3: Has your company introduced TECHNICAL measures to reduce pollutant emissions?						
2.3d: New technologies	**No exp.**	**Have run tests**	**In regular service**			
1) Internal engine measures	16	Sk2	Cz, De, Fr, Pt	1	4	76%
2) Energy storage concepts	18	Sk2	De, Si	1	2	86%
3) Hybrid drive	19	It	Cz	1	1	90%
4) Multi-engine concept 1: Several traction engines, of which only the necessary number is running	18	Sk1	Cz, Dk	1	2	86%
5) Multi-engine concept 2: Traction engines plus auxiliary engine(s), so that traction engines only run when necessary	16	Cz, Sk2	At, Hu, Fr	2	3	76%

Annex 4: Detailed descriptions of technical measures

9.1 A4.1 Diesel Particulate Filters

Diesel particulate filters (DPFs) remove particulate matter from the exhaust stream. Periodically, PM captured by the filter must be removed to prevent the filter from blocking (this process is often referred to as “regeneration”). This filter regeneration is the key to an effective emissions control system. There are essentially three types of particulate filter, differentiated by their method of regeneration[29]. The first type uses an electrical heater to raise the temperature inside the filter to burn away the PM. This is used when equipment runs on higher sulphur fuel and when low engine speeds/loads give rise to low exhaust temperatures. The second type utilises a fuel additive metered into the diesel fuel that acts as a catalyst, oxidising the PM trapped in the filter. This type is used when equipment runs on higher sulphur fuel and duty cycles give high exhaust temperatures. Other types of DPF include filters combined with oxidation catalysts (such as Continuously Regenerating Traps (CRTs)) that use the oxidation catalyst to oxidise nitric oxide in the exhaust stream to nitrogen dioxide (NO_2). The NO_2 then reacts with the trapped particulate matter to regenerate the filter. Such systems that do not rely on the use of heaters or fuel to regenerate the trap are known as passive systems.

Systems with closed channels

Filtering exhaust gases does not constitute a fundamental problem - materials exist that permit efficiency factors of over 95 %. It is more important here for the filter substrates to be sufficiently long-lived, especially where regeneration processes are involved. Diverse materials are employed as filter substrates:

- For motor cars primarily silicon carbide (SiC) or codierite honeycomb structures;
- Sintered metal particulate filters are amongst the solutions being developed for vans;
- Glass fibre is mainly used on ships and stationary facilities.

The materials have differing surface-to-volume ratios (spatial requirement), precipitation levels, thermal constancies, degrees to which they can integrated into existing geometries, servicing intervals and costs. It is not possible to state which is the more favourable for railway applications.

[29] Johnson Matthey – ‘Diesel Particle Filter Systems for Off-Road Applications’

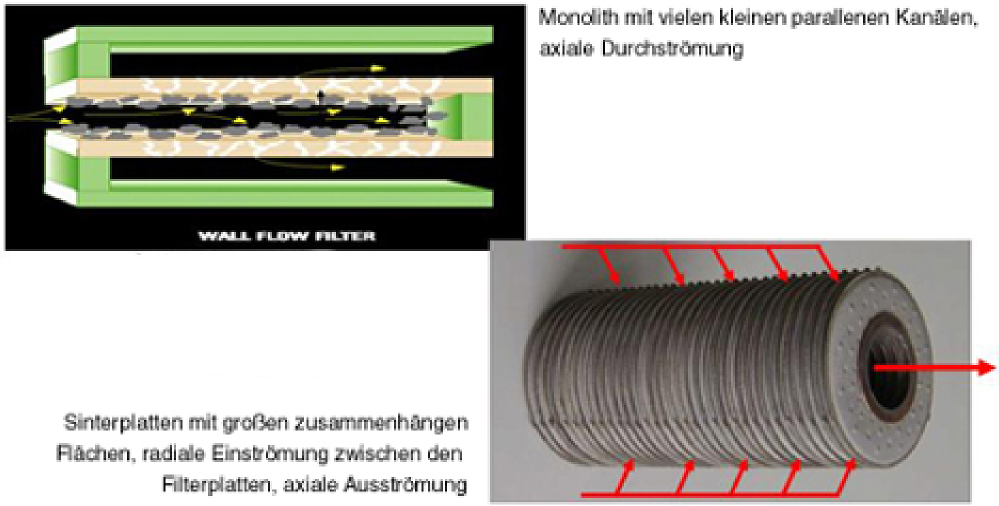


Figure 9.1: Designs of filters for reducing particulates

Precipitation of particulates on the filter material causes flow resistance and back pressure to rise. The soot needs to be removed from the filter at regular intervals. Temperatures of approx. 600°C are required to burn off the soot. These are not generated by the rail diesel engines in use. The minimum temperature required can be reduced to approx. 350°C through the use of additives. The drawback with this method concerns the level of engineering involved to accommodate an additional tank and automated dosing equipment. The additive leads to an additional amount of ash entering the filter, furthermore, meaning that the latter has to be cleaned at regular intervals.

The catalytic soot filter is similarly a passive means of regeneration whose coating causes the regeneration temperature to be reduced to 300-350°C when new. It needs to be ensured that the maximum temperature peaks occurring in the substrate do not exceed 800°C, since there is a danger otherwise of the catalytic action surface being damaged. Lengthy periods of operation with exhaust gas temperatures < 300°C cannot be ruled out in rail applications. It is necessary, therefore, to adopt active regeneration measures to burn off soot. Electric heating elements in the filter material or separate burners would be suitable in principle. Combining either of them with a catalytic coating on the filter raises the level of efficiency.

Leading-edge particulate filter technology has still to be tried and tested on rail vehicles. Posing a particular challenge for engine builders developing the system are the issues of filter regeneration and limiting the maximum level of back pressure. The weight of an exhaust gas unit increases quite considerably when a particulate filter system is added. On locomotives, the exhaust silencer is generally rigidly attached to the vehicle roof. The locomotive needs to be designed in such a manner as to be able to cope with the additional loading. The permissible axle loads need to be borne in mind too.

Systems with open channels

In a most recent development, a new technical variant of particulate precipitation has materialised in conjunction with the retrofitting of motorcars. The channels at the ends of the filter are not closed but open. The particulate precipitation system comprises two layers and is wound very much like a standard metal-carrier catalyst. Shovel-type recesses in a corrugated foil allow some of the exhaust gas to be channelled into a section of sintered metal fleece. Particulates in the exhaust gas flowing by are precipitated in the microstructure of the fibrous fleece. The remaining exhaust gas flows into the layer above or below and can be channelled into the next fleece by dint of the shovel feature. Precipitated particulates are continuously degraded through the oxidation of carbon with nitrogen dioxide ($N0_2$). At temperatures of approx. 250-300°C upwards, NO_2 is formed from nitrogen oxide (NO), which is in any case present in the exhaust gas, in the catalytically coated soot filter converter.

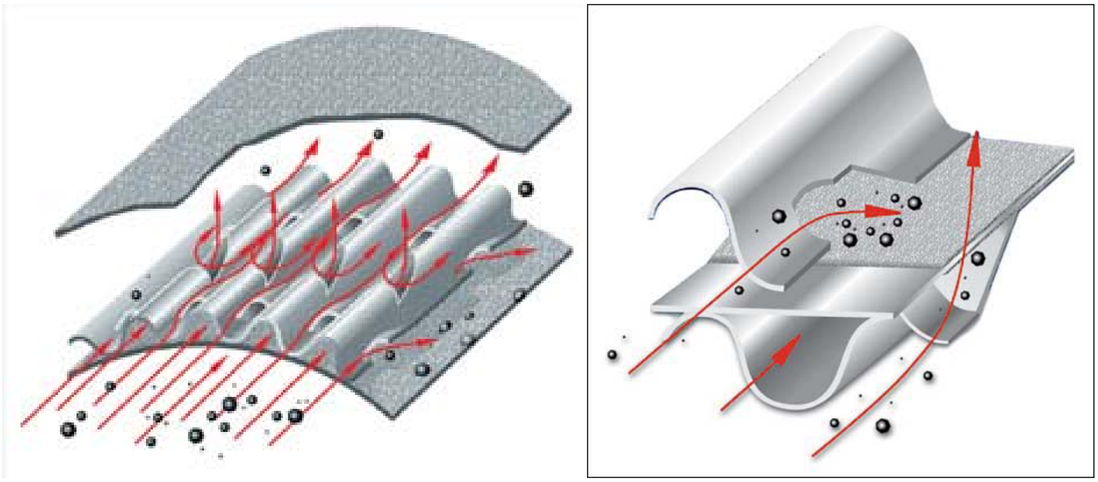


Figure 9.2: Open-channel particulate precipitation system

Unlike soot filter systems with closed channels, this system only causes exhaust-gas back pressure and fuel consumption to rise negligibly. Regeneration occurs continuously despite there no sensors or electronics, no additives and no additional fuel injection being involved. The emission of particulate matter falls relative to the initial value by approx. 30-40 % in the case of automotive diesel engines (as a function of particulate size distribution). It cannot currently be stated with any certainty whether these values also hold true for rail diesel engines. To find out it would be necessary to take readings of particulate size distribution.

DPFs are often used in combination with Exhaust Gas Recirculation (EGR) or Selective Catalytic Reduction (SCR) systems, or with oxidation catalysts to enhance particle removal and typically achieve removal of >90% particulates from the exhaust stream. More compact systems combining oxidation catalysts and DPFs into a single unit are also available, such as the Continuously Regenerating Trap (CRT®) and combined particulate oxidation catalyst (POC) systems discussed in subsequent sections. Most DPFs require ULSD, as higher sulphur fuels will cause them to block more frequently. There can also be a fuel consumption penalty associated with the use of DPFs systems (usually only a few %).

DPF systems have been widely applied in the automotive sector in retrofit programmes as well as new vehicles. However, they are bulky and so space restrictions are an important factor in determining whether they can be retrofitted to rail vehicles. In addition, DPF systems are considerably heavier than existing silencing equipment, potentially leading to additional weight problems, such as for locomotives where axle loading is often already close to maximum weight limits. Structural reinforcement may also be necessary at the area where the DPF system is attached.

There is some experience in the rail sector of using DPF systems, mainly through testing (DSB, SNCF and CFR), although BLS (Switzerland) and has successfully retrofitted DPFs to some of its track/overhead line maintenance and shunting locomotives, where space was not a particular limitation. A case study of the BLS experience is presented in Annex 5.

A Continuously Regenerating Trap (CRT®) system is a type of particulate filter system consisting of an oxidation catalyst followed by a particulate filter. This is a passive system that has been recommended as more suitable for use on trains rather than a stand-alone diesel particulate trap (DPF). The oxidation catalyst that is a part of the system oxidises CO and HC, and also oxidises some of the nitric oxide (NO) in the exhaust system to nitrogen dioxide (NO_2). The NO_2 then reacts with the PM trapped in the filter to regenerate the trap[30]. Hydrocarbons (i.e. fuel) are not used to regenerate the trap unlike some other ‘active’ DPF systems. In automotive applications CRT® systems achieve around 90% reduction of CO, HC and particulate matter (PM).

There are no significant issues with regard to the space required to fit oxidation catalysts onto trains, but the particulate trap is a more bulky and heavy item. As with other DPF systems, CRT® systems are therefore likely to encounter greater difficulties for their application in the rail sector, particularly for retrofit, where existing weight and space limitations are present. The size (and weight) of the CRT® system largely depends on the size/power and allowed exhaust backpressure of the engine for which it is intended. The system has not been tested in locomotive type engines, but is already extensively used in buses with similar engines to DMUs. As for oxidation catalysts, a CRT® must be used with low sulphur diesel (< 50ppm sulphur content).

There some experience the rail sector of the use of CRT® systems, such as successful in-service testing on DMU in Sweden since 1997. A short case study of the experiences provided in Annex 5.

9.2 A4.2 Selective Catalytic Reduction (SCR & SCRT)

A4.2.1 SCR

The SCR (selective catalytic reduction) method of reducing nitrogen oxides has proved very effective in various stationary applications. A large number of commercial vehicle builders are engaged in testing and implementing this method.

The engine is designed to deliver optimum combustion with low emissions of particulates and minimised fuel consumption, whilst nitrogen oxides (NO_x) are reduced downstream of the engine by reaction with a reducing agent (in this case ammonia) in the presence of a catalyst. The NO_x are then converted into nitrogen and water. When adopting this method on vehicles, the reducing agent, ammonia, is indirectly derived from an aqueous urea solution injected into the exhaust gas. Urea, known by the chemical formula $(NH_2)_2CO$, is present as an aqueous solution (32.5 %) and decomposes to form ammonia, NH3, at temperatures above approx. 200°C.

[30] see: http://ect.jmcatalysts.com/technologies-diesel-crt.htm

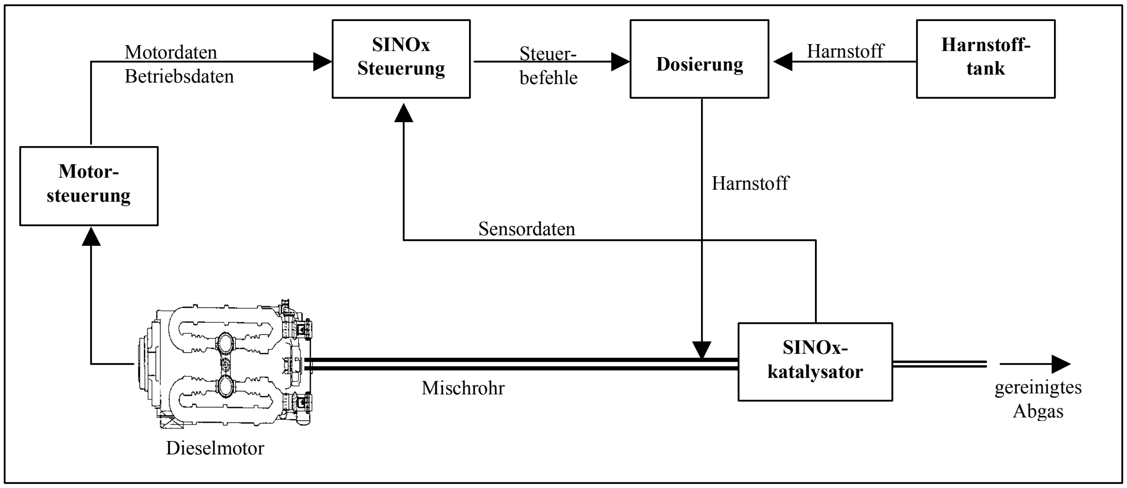


Figure 9.3: SCR system

As SCR catalysts mainly treat the NO_x exhaust component, typically an oxidation catalyst would also be included in the system to reduce emissions of carbon monoxide and hydrocarbons, and specifically, to minimise the risk of ammonia emissions being released to the atmosphere. SCR catalysts may also lead to up to 30% reduction in emissions of soluble particulate matter. To improve the abatement of particulate emissions, SCR systems can be used in conjunction with DPFs including Continuously Regenerating Traps (CRT®) (see previous section) – the use of an SCR system with a CRT gives a combined system known as an SCRT® system.

The reducing agent used in SCR and SCRT® systems can either be ammonia that is directly injected into the exhaust stream, or it can be in the form of solid urea or a urea solution. Information from Dinex Exhausts has indicated that SCR/SCRT systems that use solid urea or a urea solution require a minimum temperature of 200-240^{o}C before the reducing agent can be injected into the exhaust stream. This is because it is necessary for the urea to be converted to a gaseous form prior to injection. Systems that use gaseous anhydrous ammonia do not suffer from this problem, and in such cases the ammonia reducing agent can be injected into the exhaust system from 150^{o}C upwards. However, these are not favoured as ammonia is a hazardous substance, causing severe respiratory damage if inhaled.

Unlike EGR systems, SCR technology can potentially be fitted to vehicles equipped with engines that do not meet the Euro II emissions regulations, however SCR and SCRT® systems are very bulky, both in their requirements for the system and the catalyst. The size of the SCR catalyst itself is approximately twice the capacity of the engine – therefore a 19 litre DMU engine will require a 40 litre catalyst. In addition, space is also required for additional hardware that forms part of an SCR system, including smaller oxidation catalysts and the tank for storing urea or ammonia. This puts severe restrictions on its potential for use as a retrofit item to rail vehicles, where spare space and weight availability is limited.

For an SCR or SCRT® system using ammonia as the reducing agent, ammonia consumption is between 1% and 2.5% of diesel fuel consumption. For systems that use urea, urea consumption is between 2.5% and 6.0% of diesel fuel consumption[31]. Where installed on rail vehicles, it is necessary to accommodate a tank for the reducing agent plus the dosing

[31] Source: Personal communication with representatives from Cummins Engines

equipment and control gear as well as the actual catalyst. There is an additional need to exchange parameters with the engine control gear. Furthermore, it is necessary as with the DPF to take account of back pressure and system mass. SCR systems work by injecting ammonia or urea into an engine’s exhaust stream to chemically reduce NO_x emissions to Nitrogen. Trials on heavy-duty road vehicles have shown reductions in NO_x emissions of between 60% and 90%[32]. Compared to Exhaust Gas Recirculation (EGR, discussed in the following section), SCR will provide a larger NO_x reduction in a well-developed system, but does require replenishment of the reducing agent (ammonia or urea) whereas EGR is a "fit-and-forget" technology.

SCR systems are one of the technologies that are likely to enable rail traction units to meet the Stage IIIB emissions limits in the Non-Road Mobile Machinery (NRMM) Directive. The engine manufacturer Cummins has carried out some feasibility work with regard to fitting this system to the QSK19 engines found in a number of DMU traction units. Whilst this may be a workable option for the engine, space limitations on DMU rail vehicles might rule out the use of this technology for some types of railcars/DMUs.

A4.2.2 SCRT

SCRT technology is a combination of oxidation, reduction and filtration processes. It has the greatest potential for reducing all pollutant constituents subject to limit values. Rates of reduction are between 80 and 98 % of the respective initial values. Of the systems covered so far it represents the most involved procedure with the most complex technology.

The SCRT system comprises an oxidation catalyst, a soot filter fitted downstream, an SCR catalyst and a second oxidation catalyst to conclude. The exhaust gases from the diesel engine initially flow into the oxidation catalyst. There, the pollutants CO and HC are oxidised into water and CO_2. Additionally, NO is oxidised into NO_2. The reducing agent is injected downstream of the first oxidation catalyst and takes the form of ammonium carbamate ($CO_2N_2H_6$). An ammonia generator produces ammonia (NH_3) from the ammonium carbamate, which is then added to the exhaust gas stream in doses through a valve. Implementation is effected by introducing heat (at least 60°C) via the engine’s cooling water circuit. The reducing agent is introduced upstream of the soot filter, allowing the additional section to be used to thoroughly blend the exhaust gas with the reducing agent. Moreover, an SCR-active coating on the soot filter already acts to produce NO_x at this early stage, meaning that the subsequent SCR catalyst can be downscaled.

Soot from the exhaust gas collects in the subsequent soot filter. The nitrogen dioxide is used as an oxidising agent to allow particulates to be continuously burnt off. This obviates the need for any additional working materials with which to regenerate the filter. The reduction catalyst downstream from the soot filter turns a considerable proportion of the nitrogen oxides in the exhaust gas into molecular nitrogen and water with the aid of ammonia. NOx transformation is significantly speeded up, as approx. 40 % of the NOx has already been oxidised into NO_2 in the first oxidation catalyst. To prevent any undesirable ammonia creep, there is a second oxidation catalyst downstream from the assembly that can convert any excess NH_3 into water and nitrogen.

[32] Source: Energy Savings Trust, and personal communications with representatives from Cummins Engines and Dinex Exhausts Limited,

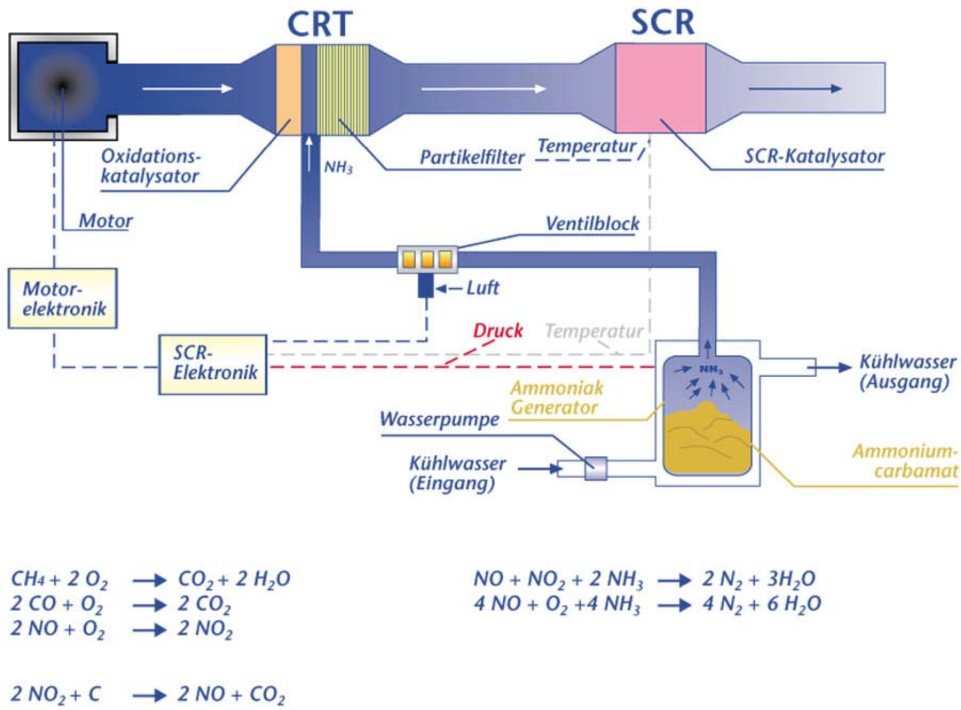


Figure 9.4: SCRT system

SCRT technology requires the use of low-sulphur diesel fuel (< 50 ppm). Regarding conformity to future limit values for rail diesel engines, it can be stated that SCRT technology is a possible option whose further consideration ought nevertheless to await examination of other technical options given its complexity and current state of development.

9.3 A4.3 Exhaust Gas Recirculation (EGR)

Cooled EGR enables NOx emissions to be reduced without significantly increasing the space taken up by the engine and without any additional working materials. The recirculated exhaust gases cause the rate at which nitrogen oxides are formed to fall by reducing local temperature peaks in the flame front. They additionally result in the fuel conversion rate falling, which leads to the maximum conversion rate with EGR being lower than without it and to outburn or full combustion being slower. The key moment in the combustion process is thus delayed. Such factors likewise help cut back emissions of NO_x.

The increase in fuel consumption is due to the effect of exhaust gas recuperation on fuel conversion rates. The combustion process is being developed with the aim of minimising disadvantages in terms of fuel consumption. Unless the combustion process is optimised, cooled EGR is likely to produce emissions of particulates up to three times higher than in the initial state. One precondition for optimisation is a diesel injection system operating at a very high pressure (approx. 1,800 bar/Second Generation Common Rail) as well as adequate means of modelling the injection process (pre/post-injection, ramp, boot, ...). The effects of sulphuric acid corrosion must not be overlooked when designing an engine with cooled exhaust gas recuperation.

Any sizeable amounts of corrosive acid are only condensed out at temperatures lower than the dew point of water. It needs to be ensured by controlling the temperature accordingly that no condensation of sulphuric acid and water forms in the EGR cooler and charge air pipes, through which a mixture of recuperated exhaust gas and charge air flows. The defining parameters for the dew-point temperature are boost pressure, air ratio and EGR rate. This issue only becomes a problem where there are high concentrations of sulphur in the diesel fuel however (>50 ppm). This value is exceeded in some parts of Eastern Europe and for countries still using gas oil (such as Italy and the UK).

The heat obtained from the cooled exhaust gas leads to the overall amount of heat needing to be processed being greater. The extra strain placed on the cooling system depends on the volume of exhaust gas recuperated and the temperature aimed for at the cylinder. The cooling surface needs to be enlarged as a function of the cooling capacity required (up to approx. 30 %). It is essential that this be borne in mind when designing the vehicle as a whole; it is a point that seriously complicates the fitting of EGR in heritage rail stock.

9.4 A4.4 Internal engine design measures

CD (the Czech railway operator) experience included supercharging and valve timing improvements via the engine management computer, plus some changes to the mechanical drive/camshaft. They found this was only a little less costly than full re-engining, but with smaller benefits. Improvements also resulted in reductions to fuel consumption of 5-8%. A case study on ZSSK Passenger experience with engine modifications is provided in Annex 5. Replacement of existing engines with newer lower emission engine models will usually lead to greater emission reductions, however modifications to existing engines are a useful alternative option where suitable compatible new engines are not available. Other measures that could be employed in new engines include more effective after-cooling systems, diesel water injection systems (DWI), and Low Emission Idle systems (these allow the engine to run on only half its cylinders under low load conditions).

It is known that there is an inverse relationship between NO_x emissions and specific fuel consumption when an engine is tuned. Improved engine combustion processes usually lead either to better consumption rates and lower particulate emissions, or to low NO_x emissions. Fuel consumption is an important criterion where railway engines are concerned, since this has a direct impact on operating costs. It is anticipated that optimised combustion processes through advanced engine design will play a significant part in enabling new rail engines to meet Stage IIIA emissions limits, as laid down in the NRMM Directive.

Diesel/water emulsions have been developed for NO_x emissions reductions (discussed in section 3.3.4). In-engine systems for steam / water injection (DWI) into the inlet port for NO_x and PM reduction have also been developed. By utilising the air and cylinder cooling and exhaust heat to generate steam, the method is expected to increase energy efficiency and thus fuel economy (5%-10% estimated), while the same time reducing NO_x production. Direct in-cylinder water injection has been cited as achieving up to 90% NO_x reduction.

Energy Conversions Incorporated’s (ECI) patented Low Emissions Idle (LEI) system is supplementary hardware designed to fit General Motors’ EMD engines to reduce unburned hydrocarbons and particulate emissions under low load conditions. LEI is an electronically controlled linkage that powers left and right cylinder banks alternately while the engine runs at low speeds. A LEI system runs the engine on half of its cylinders when the engine is operating in modes of low engine specific power output (at idle or low RPM). The additional load the non-firing cylinders place on the engine cause the firing cylinders to burn diesel fuel more efficiently. This results in fuel savings, and a significant reduction in the level of unburned hydrocarbons and the emission opacity in the exhaust[33].

9.5 A4.5 Vehicle replacement and re-engining options

A4.5.1 Examples of re-engining programmes

Re-engining has been, and still is being performed on DB AG Class 218, Class 232, Class 290 and Class 360 diesel locomotives. As well as improving exhaust gas emissions, modern replacement engines also significantly reduce operating costs by cutting consumption of fuel and lubricants and making for more cost-effective maintenance. The following Figure 9.5 demonstrates how emissions of nitrogen oxides and particulates have improved for various Classes of locomotives operated by DB AG.

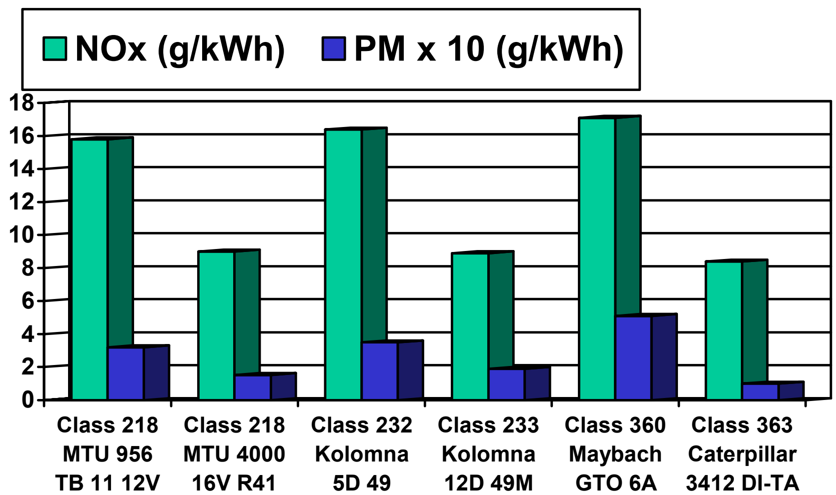


Figure 9.5: Comparison of NOx and particulate emissions pre/post re-engining

The graph shows very clearly the progress made in diesel engine development as regards the principal noxious constituents of exhaust gas. It has been possible to virtually halve the emission of nitrogen oxides and to reduce that of particulates fourfold in some cases.

The Latvian train operator LDZ is also carrying out an extensive re-engining programme for its DMUs that are currently equipped with M756 engines. The re-engining programme will see these engines replaced with new MTU engines, resulting in significant reductions in fuel consumption. The table below gives details of the anticipated improvements in fuel and oil consumption.

[33] Energy Conversions Inc website: http://www.energyconversions.com/lei1.htm

Table 9.1: Fuel and oil savings from LDZ re-engining programme

Specific fuel consumption		Fuel consumption		Motor oil consumption		Compressor oil consumption	
Liters/10^4 gross tkm		Liters/100 km		% fuel consumption		% fuel consumption	
New MTU engine	Old M756 engine	New MTU engine	Old M756 engine	New MTU engine	Old M756 engine	New MTU engine	Old M756 engine
53.41	57.79	95.12	103.11	0.2	2	0.018	0.06

A4.5.2 Case study example of problems with a planned re-engining programme (DSB – Denmark)

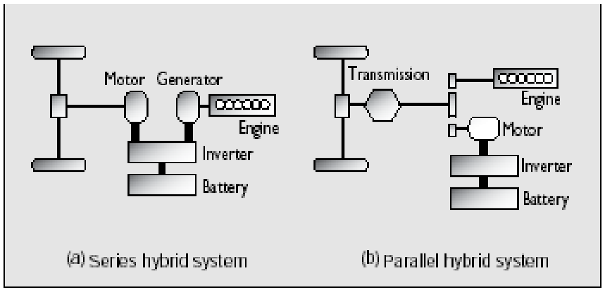
DSB proposed to change all the IC3 trains from the original Deutz engines to Euro III-compliant engines. Another Deutz engine was chosen and Bombardier built a prototype (Deutz BM6 2015 MW However, for this engine to meet Stage 3A limit values, additional equipment to reduce emissions is required. Retrofit EGR was investigated as a possible solution to this problem, but it was found that additional cooling equipment was required in order for this technology to enable the engine to meet the emission limit values. There is no space on the engine frame for the additional cooling equipment, and hence the re-engining programme has stalled. Environmental concerns were part of the reason for the re-engining, but there is also a positive business case for reducing maintenance costs. With the incoming IC4 trains, the IC3 trains will move to more regional services, covering only 200,000 km/yr by 2008 (but engine hours will be similar)

9.6 A4.6 Hybrid and Energy Storage Concepts

Hybrid systems and energy storage concepts for regenerative braking are only really practicable for new rail vehicles. Hybrid diesel-electric railway vehicles use a diesel engine in conjunction with an electric motor, power controller and battery (or other form of energy storage). There are two main types of hybrid configuration (see schematic in Figure 9.6):

- “Series hybrids” in which the vehicle is driven by the electric motor, and the engine drives a generator that produces electricity for storage in a battery, which powers the motor. The engine runs at a constant load, for maximum efficiency.
- “Parallel hybrids”, in which both the electric motor and the engine are connected to the wheels or drive-train. When rapid acceleration is required, the engine drives the wheels. The vehicle can switch to battery-only mode in environmentally sensitive areas, or in stop-start traffic. During phases of faster driving elsewhere on the journey, the engine provides the power to drive the electric motor, which in turn drives the wheels, and surplus power is used to recharge the batteries.

Figure 9.6: Hybrid system configurations (JR East, 2004)



The battery may also store power generated during "regenerative braking", when the engine is driven by the momentum of the vehicle and used as a generator to send power to the battery. Regenerative braking allows trains to recover energy during braking by the use of kinetic brakes that in electric trains feed electrical power back to the overhead lines. For electrical multiple units operating on frequent stop services, savings of around 25% are thought to be attainable in regular service. This energy would otherwise be lost as heat with the use of friction brakes. For use in diesel railway vehicles the captured energy can be stored for later use either to supplement motive power (in a hybrid vehicle) and/or auxiliary power requirements.

Hybrid technology can lead to very large reductions in NO_x and PM emissions in road applications; up to 90% reduction in NO_x, CO and hydrocarbons is claimed for the Toyota Prius. In the rail sector, the Japanese railway operator JR East is developing/demonstrating a prototype hybrid railcar (known as the "NE Train") and is aiming to achieve 50% reductions in NO_x and PM levels in the exhaust gases. Savings of 80-90% in NO_x/PM emissions have been achieved by Railpower's Green Goat hybrid shunting/switcher locomotives (370 to 1500 kW). Reductions in fuel consumption mean that there are also CO_2 emissions benefits to be achieved from hybrid vehicles. Savings of around 20% have already been achieved on commuter lines by the JR East prototype series-hybrid railcar in Japan (equivalent performance characteristics). Savings of 40-60% on CO_2 emissions have been claimed for Railpower's Green Goat locomotive (depending on duty cycle). Information from the automotive sector indicates that hybrids may be optimised for CO_2/fuel consumption or NO_x/PM emissions. Hybrid buses optimised for low NO_x/PM show no CO_2/fuel savings, but may reduce NO_x by up to 80% and PM by up to 90%. Conversely, hybrid buses optimised for CO_2 are expected to be 30% more fuel-efficient and give up to 30% reduction in NO_x/PM emissions. In Europe, Trenitalia is currently running a collaborative project developing hybrid railcar concepts, see Annex 5.

Hybrid technology can also potentially contribute to reducing noise if the engine switches off when the vehicle is stationary (at stations, for example), with auxiliary power provided from the energy storage medium. Furthermore, hybrid vehicles that can be driven in fully electric mode are, in this mode of operation, zero-emissions vehicles (at point of use) and are significantly quieter than conventional internal combustion engine (ICE) vehicles. The ability to switch to a mode of operation with zero emissions at point of use means that such vehicles, if used extensively in urban areas/stations, could lead to significant reductions in emissions of regulated pollutants including NO_x and particulate matter.

There are number of possible energy storage options for regenerative braking/hybrid railway vehicles; the main three types being:

- battery storage (lead acid, lithium ion, etc);
- flywheel storage;
- ultra-capacitors.

Batteries: the main types of rechargeable battery technologies include lithium ion, lithium ion polymer, nickel metal hydride, lead acid and nickel cadmium. Li-ion and Li-ion polymer batteries are the most promising due to their high cycle life, high energy and power densities and flexibility, which would allow them to fill otherwise redundant space in the locomotive or DMU (e.g. application in JR East’s hybrid railcar - NE Train). The main disadvantages of batteries for rail applications are: limited cycle life, relatively lengthy recharge times and the fact that the most promising technologies (Li-ion and Li-ion polymer) are still relatively unproven and expensive.

Flywheels: In a flywheel, electrical energy that is applied to a motor is converted to, and stored as rotational kinetic energy. As the flywheel is discharged and spun down, the stored rotational energy is transferred back into electrical energy by the motor — now reversed to work as a generator — and creates electricity to supply power where it is needed. Unlike most batteries, flywheels can be used over and over again, have a very fast recharge time and very high energy density (42 kJ/kg for the CEM flywheel compared to 2 kJ/kg for ultra-capacitors). In particular the high energy density means they would be suitable for providing a boost to power as trains leave stations. Flywheel systems require essentially no maintenance and are expected have working lives in excess of 20 years. London Underground already plans an installation on one of its busiest lines.

Ultra-capacitors: A capacitor is an electrostatic device that stores electrical energy. A capacitor stores its charge on two layers of conductive material separated by an insulator. The size, shape and materials all play a role, but in general, the greater the surface area of the conductors, and the closer they are to each other without touching, the greater the charge that can be stored and returned. The amount of energy that can be stored is called its capacitance. An ultra-capacitor has a surface area that is several orders of magnitude greater than conventional types, and the separation is less than 10 angstroms (one angstrom is one ten-billionth of a meter). Capacitors deliver unlimited charge/discharge cycles (unlike batteries) and much greater instantaneous power and also do not require maintenance. However their energy density is poor and only provide a short burst of power, therefore they could only ever be an ancillary power source (perhaps to provide motive power for trains pulling out of stations).

Annex 5: Technical Measures Case Studies

Box 1: Application of retrofit DPFs to diesel rail maintenance vehicles by BLS

Background

All of the mainline passenger and freight operations are electrified in Switzerland (this has been the case since the 1930s). This is as a result of the situation in Switzerland in World War I and World War II, where because the country has no natural resources of oil and coal it made sense to develop an electrified rail network, taking advantage of the hydroelectricity resource. Since then the electric network has expanded and now it is not allowed by law to use diesel traction on mainline operations. Diesel traction is therefore only used for emergency vehicles, track/overhead line maintenance vehicles and shunting operations where electrification is not practical.

Recent Swiss legislation mandates that all diesel engines running in tunnels must utilise particulate filters (with the exception of safety/emergency vehicles). This resulted in a BLS strategy to retrofit its diesel vehicle fleet with particulate filters; recently it has been decided to replace the older vehicles with new vehicles, as this is more cost-effective than retrofitting filters.

Application

The BLS diesel powered fleet size consists of approximately 25 vehicles comprising shunting and track/overhead wire maintenance vehicles (this compares with over 500 vehicles for CFF/SBB/FFS in Switzerland). The original BLS strategy was to retrofit particulate filters to all of its track/overhead line maintenance vehicles and diesel shunters. To this end scoping/costing studies were followed by an implementation programme for particulate filter retrofitting.

The vehicles concerned were grouped into four categories depending on vehicle type and age, comprising of:

1. 150-200 kW overhead line and track maintenance locomotives
2. 175 kW track maintenance locomotives
3. 350 kW shunting locomotives
4. 550-700 kW overhead line maintenance vehicles and shunting locomotives.

Costs estimates associated with the retrofit programme (contracted to Hug-Engineering AG) are summarised in Table 1. Mechanical pre-preparation included in some cases structural reinforcement of the roofs of vehicles to take into account the additional weight of the DPFs.

Table 1: An estimate of the range of costs associated with retrofit of DPFs diesel to locomotives in the BLS fleet

	Engineering Design	DPF Material	Other Materials	Mechanical and Electrical Preparation	Mechanical and Electrical Installation	Training /Education	Total Cost per Vehicle
Low	€ 1,795	€19,279	€12,759	€ 8,206	€ 11,284	€ 6,155	**€ 59,478**
High	€ 10,963	€56,888	€14,490	€ 19,362	€ 32,570	€ 9,681	**€ 143,954**

Figure 1. BLS track maintenance diesel locomotive with retrofit DPF (roof of vehicle).

Previously the diesel-powered maintenance vehicles were stored overnight at the nearest station to their use the following morning. However, the current strategy is to centralise storage and maintenance and focus expertise in one location. The impact of this is to increase the distances that vehicles travel to their places of work, favouring higher velocity vehicles with greater power to carry heavier loads than currently.

Since 2005 the strategy with regards to the DPF retrofit programme has therefore been modified as a result of the move to centralised storage. A decision has been taken to decommission 16 of the older vehicles at the end of 2005 and replace them with 9 new ones of greater power and speed. This is also more cost-effective taking into account the remaining service life of the older vehicles - due for replacement in 2007-2012 anyway. The retrofit programme is proceeding with the remaining 9 in-service vehicles and the 9 new vehicles will come fitted with DPFs (although not originally designed with them). To date 5 vehicles have been retrofitted with DPFs (including 3 of the older vehicles), with 4 more in progress.

Box 2: Application of CRT® to DMUs in Sweden

Background

In 1996, Environmental Zones (E-Zones) were established in three Swedish cities: Stockholm, Gothenburg and Malmo. Their aim was to improve air quality by reducing transport emissions, especially particulate matter (PM), from vehicles with large diesel engines such as buses, trucks and trains. The three main elements of the programme were:

- The introduction of cleaner fuels such as 'sulphur-free' diesel (less than 10 ppm).
- Encouraging the take-up of newer vehicles (which have a better emissions performance due to domestic and European regulations) by putting limits on the age of vehicles.
- Encouraging or enforcing the use of exhaust after treatments.

Between 1996 and 1997 Swedish rail company, SJ Rail, purchased eight new IC3 ADtranz (now Bombardier Transportation) Flexliner DMUs that were due operate in the E-Zones. The IC3's, which subsequently became known as Y2 trains in Sweden, are three-car sets with 2 Cummins NTAA855

R7 (310kW/416bhp) or Deutz BF8L513C (265kW/355bhp) engines in each of the end cars. SJ Rail commissioned Eminox to design CRT® technology to be fitted in each traction unit in order to minimise PM emissions. The specification was for the CRT® assembly to fit within the existing space envelope for the normal vertically mounted silencer. In considering this the task almost became a retrofit design project, however the CRTs were in the end actually line-fitted to new IC3 (now Y2) trains of an existing design. The CRT® units were designed in such a way that each unit will service both engines on each IC3 DMU.

An evaluation of the CRT® system performance was performed by the DTI’s Energy group, in April 1997: "Measurement of fuel consumption and emissions from a Cummins engine for IC3 Flexliner". The study showed that the CRT® system was removing 95% of particulate matter (PM), carbon monoxide (CO) and hydrocarbons (HC) from the exhaust gas with no impact on fuel consumption.

The CRT® units require routine cleaning amounting to 10 hours work per train, every 300,000km. The catalysts and filters must also be replaced every 1,200,000 kilometres as planned maintenance. These activities result in running costs per train of approximately €12 per 1000 km.

Since their introduction, the trains have travelled nearly 10,000,000 kilometres in total without a CRT® system failure. One CRT® system performance was evaluated after 600,000km (approximately 3 years) and its performance measured on an engine bench. This test showed that there had been no deterioration in its operating performance over this time and it was still removing over 90% of the particulate matter, hydrocarbons and carbon monoxide from the exhaust.

Box 3: ZSSK (Slovakia) experience in engine modifications to reduce emissions

Variable valve timing (VVT)/variable fuel injection timing

In order to decrease NO_x emissions, it is necessary to deliver the fuel as late as possible. 27 degrees of pre-injection is the optimum value for reducing NO_x emissions. However, the angle of pre-injection should be decreased at low speeds to improve NO_x emissions at low engine speeds. However, at high speeds, this leads to increases in PM, CO, and fuel consumption. Therefore, there is a need to vary the angle of pre-injection from between 26 degrees and 32 degrees.

Before this engine modification was introduced, the UIC NO_x emission limits could not be met by the engine. Adding variable valve timing has allowed the emissions limits to be met and has also led to approximately a 4% reduction in fuel consumption. A pump is used to change the angle and the duration of fuel delivery to the combustion chamber. This modification also means that oscillations in fuel delivery are also minimised, thereby leading to improved fuel consumption performance (see Figure 1).

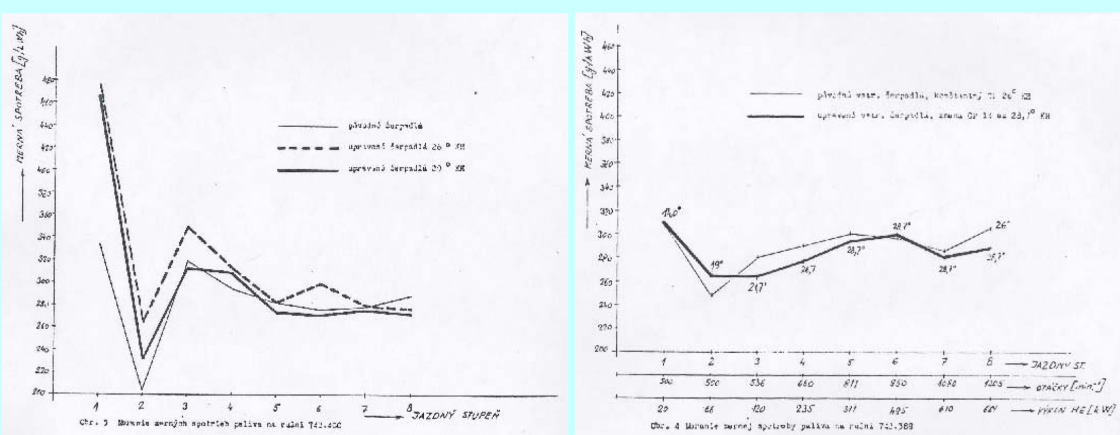


Figure 1: Oscillations in fuel delivery before and after VTT engine modifications

A new type of fuel injector (with lower mass) was used for the variable valve timing equipment. Also, the seals were modified, and the stroke of the injection nozzle was reduced. This led to a more even pressure distribution, and hence smoother fuel delivery. The old engine fitted with the new injector unit now meets UIC 624 and ISO Test Cycle F emissions performance. The new injector unit with variable injection timing is now used in 83 Class 742 locomotives and 11 Class 731 locomotives. These modifications were carried out in 1994, and at that point in time, the costs were as follows:

Cost for modifying 1 cylinder: €5,000 (20,000 Koruny, 1994)
Cost for modifying a 6 cylinder engine: €30,000 (120,000 Koruny, 1994)

These cost estimates include both equipment and staff costs for fitting the equipment. There were no additional maintenance costs associated with this measure – in fact maintenance costs were reduced due to improved reliability and reduced carbonisation.

2) Reduction in temperature variation

To improve efficiency, it is important to reduce variation in engine temperature. Previously, for some engines, there was an oscillation in engine temperature ranging from 80˚C to 90˚C, as shown below.

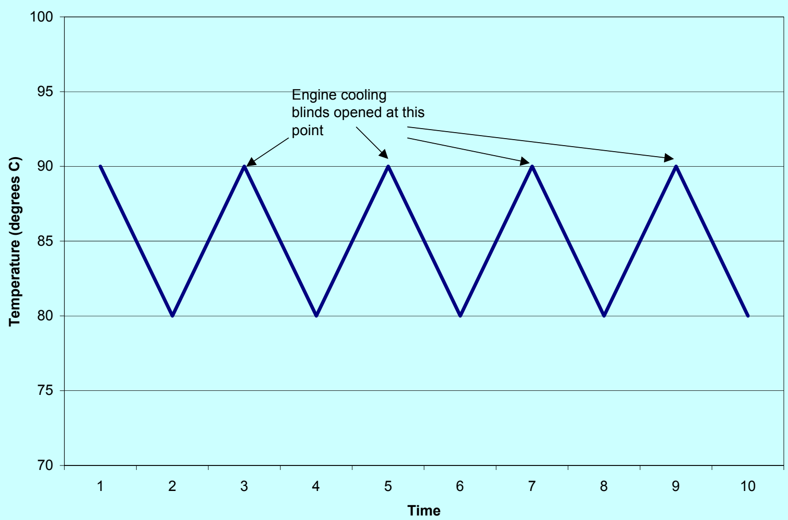


Figure 2: Temperature variation before new electronic thermostat control incorporated

Better control of the engine temperature was achieved using an electronic thermostat, which led to a much smaller variation in engine temperature (variation from 89˚C to 90˚C). This reduction in temperature variation led to a 4% reduction in fuel consumption. ZSSK did not take measurements of any changes in pollutant emissions.

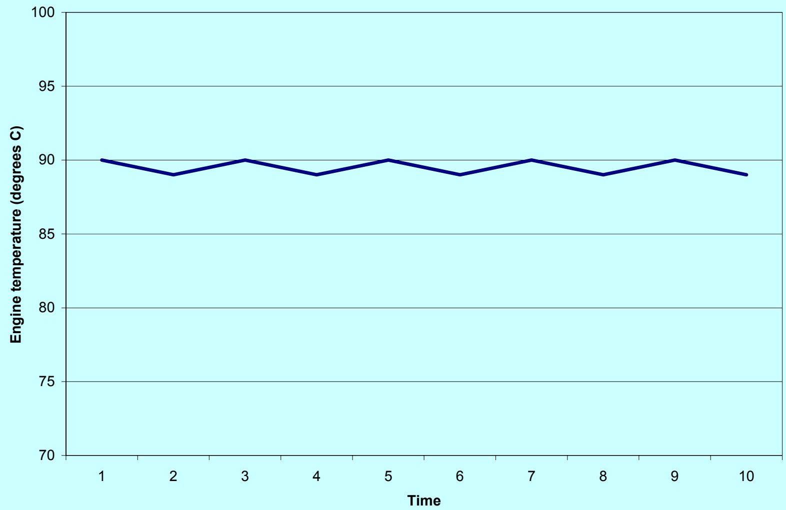


Figure 3: Temperature variation after new electronic thermostat control incorporated

The cost of incorporating better control mechanisms for improved temperature control is 10,000 Koruny (€250) per locomotive. Approximately 40 locomotives have been equipped with this type of electronic control. No measurements of changes in pollutant emissions due to this measure have been made.

Box 4: Class 66 Locomotive Emissions Reduction Measures

There are two general versions of the Electro-Motive Class 66 (JT42CWR) locomotive. Earlier locomotives, which make up the bulk of the population of over 400 units, were built without conformity to emissions limit values and incorporate charge air cooling by jacket water. Later locomotives were built to conform to UIC II limit values and incorporate a separate cooling circuit for charge air. Class 66 locomotives to be constructed in the future will be built primarily to the latter configuration.

For the earlier locomotives, it is feasible to reduce NOx emissions to approximate UIC I levels (per UIC Leaflet 624) by the application of a retrofit kit similar to that used on locomotives in the United States, costing $24,100 (€20,000). With development, it would be feasible to reduce particulate emissions approximately to the UIC II level by application of the oil-consumption reduction technology used to achieve UIC II certification on the later locomotives. This requires new power assemblies and injectors and would need to be done at overhaul, costing approximately $30,000 (€25,000) over standard overhaul cost.

Locomotives conforming to UIC II started to be put into service in 2003. These locomotives met the UIC II limits with the particulate emissions exception. Locomotives meeting the standards without the exception are going into service in 2005. These locomotives have separate circuit charge air-cooling. With engine modification and adjustment, it would be feasible to meet EU Stage IIIA (RH A) limit values with these locomotives. This would require new power assemblies, injectors, and software, and on some locomotives, new charge air coolers. Done at overhaul it would cost approximately $40,000 (€33,250) over standard overhaul cost.

The Stage IIIB limits are aftertreatment-forcing for engines of the size used in these locomotives. The applicability of aftertreatment technologies to Class 66 locomotives is limited by space and weight constraints. European locomotives are limited to a weight of 21 metric tons per axle; for this six-axel locomotive, the weight limit is 126,000 kg. The weight of this locomotive, with fuel and oil supplies, is already 125,992 kg. Thus there is no additional weight allowance available for an aftertreatment device for either NOx or particulates, or for the structure to support it. Even were the space now occupied by the exhaust silencer to be used for an aftertreatment device, assuming that one could be designed to function in that space, the weight constraints would prevent it. The silencer weighs approximately 300 kg; a particulate filter of the same size, for example, would weigh 1300 or 1400 kg, which would by itself result in exceedances of the weight limit.

In summary, reductions in exhaust emissions, depending upon the original locomotive configuration, are possible by internal engine measures. Retrofit of exhaust aftertreatment devices to Class 66 locomotives, or application of them in newly constructed locomotives, is prevented by space and weight constraints.

Box 5: Hybrid Drive Case Study – Trenitalia, Italy

Background

At the beginning of 2005 Trenitalia began a collaborative study with a University to establish the emissions from their existing diesel fleet and assess the feasibility of a number of emissions reductions measures. Once the feasibility phase of the study was completed, Trenitalia commissioned prototypes for the most promising options. These included two series hybrid drive concepts for the Aln668 railcar, which operates as a regional train making frequent stops:

(a) 2 x 150kW diesel-electric generation units and a ‘Zebra’ battery ($Na\text{-}NiCl_2$) energy storage system. The Batteries power 2 AC motors that ultimately drive the wheels.
(b) 1 x 150kW diesel-electric generation unit, 1 x 75 kW hydrogen fuel-cell electric generation units and a ‘Zebra’ battery energy storage system. The fuel cells are supplied by Hydrogen tanks and the batteries power 2 AC electric units that ultimately drive the wheels.

The existing Aln668 railcar is powered by two 150kW diesel engines, one mounted on each of its two bogies but operating as a single drive train. Both these engines will be replaced using the hybridisation of the prototypes. The railcars will be able to run in pure electric mode (from the energy storage/battery) as well as with the ICE + electric generator active. This function is seen as useful in urban centres and at stations.

Figure 1: The Aln668 railcar (3100 series)

Objectives

Through designing and building the prototypes Trenitalia hope to maximise the Aln668 propulsion system's efficiency and minimise its pollutant emissions.

Methodology

The project team began by mapping the speed vs time cycle in order to allow them to accurately estimate the fuel consumption and hence the emissions savings from the hybrid railcars. Through undertaking this process several sections of the cycle were identified where battery only operation would be feasible. The next stage of the design process was to specify the drive train according to the speed vs time profile, the torque required at the wheels, emissions performance and the weight constraints. Once these criteria were met a lifecycle cost analysis was undertaken assuming a 20 year life of the modified railcars.

The final stage of the design phase of the project was to plan the layout of the bogies in order to verify whether there was sufficient space to accommodate all the necessary equipment.

Results

The design phase of the project has been completed and the fully modified prototypes should be completed by 2007. Total capital cost for the modification of the 2xICE hybrid is calculated at €700k with an estimated operating & maintenance cost of €100k/year. The figures for the ICE/fuel cell hybrid were €1900k, with a similar annual operating and maintenance cost. The data presented in this section has been compiled from manufacturer's figures and modelling, with results in Table 1.

Table 1: Pollutant emissions and fuel consumption

Hybrid Type	**2 x ICE**		**ICE + Fuel Cell**	
(* = Estimated)	**[g/km]**	**[g/kWh]**	**[g/km]**	**[g/kWh]**
PM	0.23	0.1	0.11	0.1
NO_x	11.8	5.2	5.8	5.2
HC	0.09	0.04	0.04	0.04
CO	1.3	0.58	0.66	0.59
CO_2	1500	666*	750	696*
Diesel consumption	475	211*	237	220*
Hydrogen consumption	-	-	70	?

Box 6: ČD experience with multi-engine railcars and locomotives

ČD does not have DMU type rail vehicles as they utilise a single powered railcar in combination with up to 2 trailing non-powered carriages (with longer configurations adding an additional powered railcar or utilising locomotives instead). Some of ČD's railcars (68 = 31 Class 843 diesel electric and 37 Class 842 diesel hydro-mechanical) have 2 engines per unit – in this case the driver can shut down one of the engines during idling or light load, reducing fuel consumption and emissions.

ČD also has two locomotives (Type 751) fitted with auxiliary engines (Type Zetor Z 1001, 66 kW) with electric generator to drive compressor, battery supply, preheating of cooling system and drivers cabin is and for moving the vehicle alone. These were formerly tractor engines and are much larger in size and therefore more difficult to retrofit compared to the oil burners (or electric pre-heaters). An auxiliary asynchronous generator can supply power for one electric traction engine for shunting. The common cooling system can also be pre-heated from the auxiliary engine. Its utilization depends on the engine

driver. In summer, this is 1% of the total time, but in winter, about 4000 litres of fuel is saved every month[34].
Advantages include power for air compressors for the main brakes (particularly for freight locomotives), enabling switching off the main engine sooner, reducing emissions, fuel consumption and hours/maintenance for the main engine.
Disadvantages include cost (relative to the oil burner = 6-8 times the cost to purchase and fit), plus significant space requirements and additional complexity. This concept was not extended further due to necessary investment costs to old locomotives.

ČD also operates 60 Class 714 multi-engine diesel-electric locomotives (in addition to 2 locomotives operating with auxiliary engines already discussed). These were converted from single engined vehicles (original engine from 70's and designed in 60's) because of the low availability and high cost of the original engines (S.E.M.T. Pielstick 12PA4-185). The vehicles now use 2 x 300kW engines plus alternators (same as Class 843 railcar), and one of the engines may be switched off when idling or under light load. The compressor (for brakes) can only be driven from one of the engines. Fuel consumption when idling is now 10 times less than for the previous engine. The cost to re-engine/rebuild the vehicles was around €400,000 per vehicle, however the original engine would have been maybe 10 x this price to replace.

ČD is not applying this multi-engine concept to other locomotives (new or current) for a variety of reasons:
1. Significant additional space requirements and complexity;
2. Price – new engines are similar in price for 2 x small or 1 large;
3. New engine idling consumption is much better than previously.

Box 7: ÖBB experience with auxiliary engines

Background

ÖBB operates approx. 420 diesel locomotives. Of these locomotives (Series 2043/2143 constructed 1965 - 1977), 85 are equipped with an auxiliary diesel engine to produce compressed air and charge the battery. In 1997/1998 the question of auxiliary diesel engines in diesel locomotives was investigated when the basis for new acquisitions was being established. The study covered main-line diesel locomotives and shunting locos, with the results of the evaluation provided in the following table.

Shunting locos		**Main-line locos**	
Benefit	*Disadvantage*	*Benefit*	*Disadvantage*
Not dependent on outside energy supply (shunting locomotives also have to be shut down in stations).	Added maintenance		Added maintenance
Air-conditioning of driver's cab possible when the diesel traction motor is not running	Added investments		Added investments
Idling of diesel traction motor reduced	No product demonstrated suitable for railway use available on the market		No product demonstrated suitable for railway use available on the market.
Battery charging possible without diesel traction motor		Battery charging possible without diesel traction motor	

[34] ERRI B 208 P/RP 5, Appendix 26 "Experience of ČD, ŽSR and ÖBB with the use of a second engine for auxiliary systems".

Fuel savings			

Summary:

Because shunting locomotives idle more than main-line locomotives (approx. 85% against 55% respectively) and need to be self-contained, auxiliary diesel engines for shunting locomotives were prescribed and installed at ÖBB when new stock was being acquired. They were to pre-heat the cooling water, charge the battery and supply the power for the air conditioning system in the driver's cab. Main-line locomotives did not receive auxiliary diesel engines.

Box 8: Swedish biogas powered railcar

Background

Swedish companies Euromaint and Svensk Biogas have developed a prototype train that runs exclusively on biogas. They converted a Fiat Y1 diesel engine coach to run on two Volvo bus biogas engines. The train is equipped with eleven canisters that give it a range of 600 kilometres (375 miles) and a maximum speed of 130 kilometres (80 miles) per hour. The single carriage prototype cost €1.08 million to develop and can carry a maximum of 54 passengers.

Biogas is a mixture of methane and carbon dioxide so the CO2, NOx and PM emissions performance of the prototype is likely to be significantly better than diesel powered traction. However, as yet no emissions testing has been untaken. Biogas is generated when bacteria degrade biological material in the absence of oxygen, in a process known as anaerobic digestion. Almost any organic material can be used to produce biogas since the process occurs naturally in digestive systems, marshes, rubbish dumps and septic tanks.

Initially the biogas prototype will be operated by SJ on Sweden's 80km east coast line between Linkoeping and Vaestervik. However, Euromaint and Svensk Biogas hope to roll out the concept across the Swedish network and have already begun preliminary discussions to export the technology to countries as far a field as India.

A key driver for the project was European Commission's Biofuels Directive that sets indicative targets for the biofuel share of all transport fuels at 2% by 2005 and 5.75% by 2010. Sweden's ambitious target to replace 3.0 percent by the end of 2005 is the highest among European Union member states, most of which have set a target of 2.0 percent. However, in Sweden's favour is their history of embracing biogas as an alternative to petrol or diesel. According to the Swedish Environment Ministry there are currently has 779 biogas buses in Sweden and more than 4,500 bi-fuel cars that are able to run on petrol and either biogas or natural gas.

Box 9: Evaluation of alternative fuels for rail by SNCF

SNCF has carried out tests on biodiesel (10-20% mixed with regular diesel), water diesel emulsion (WDE) and diesel additives (see Figures below). The mean time for a run test was about 1 week, with a cost around 10 k€. Tests showed no significant emission benefits, and in some cases even reductions in performance. For WDE corrosion of the injection elements was noted; the result was not positive for an application.

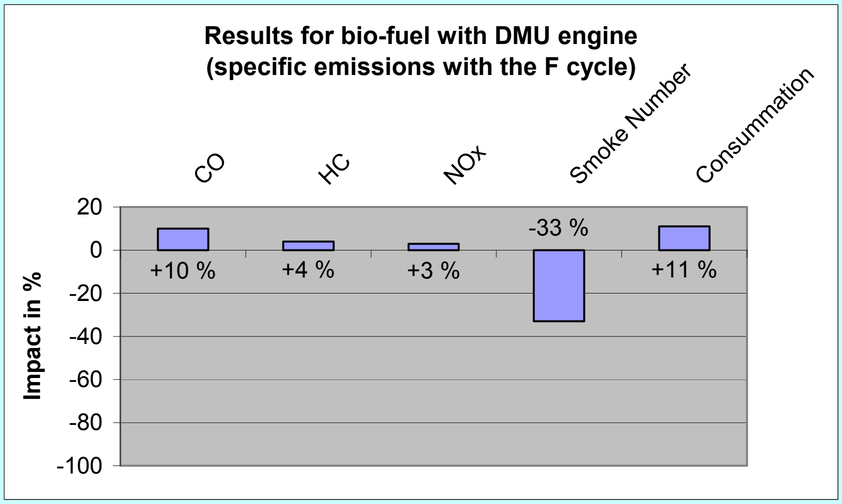


Figure 1: Bio-fuel (80 % of diesel and 20 % of bio-fuel), DMU engine

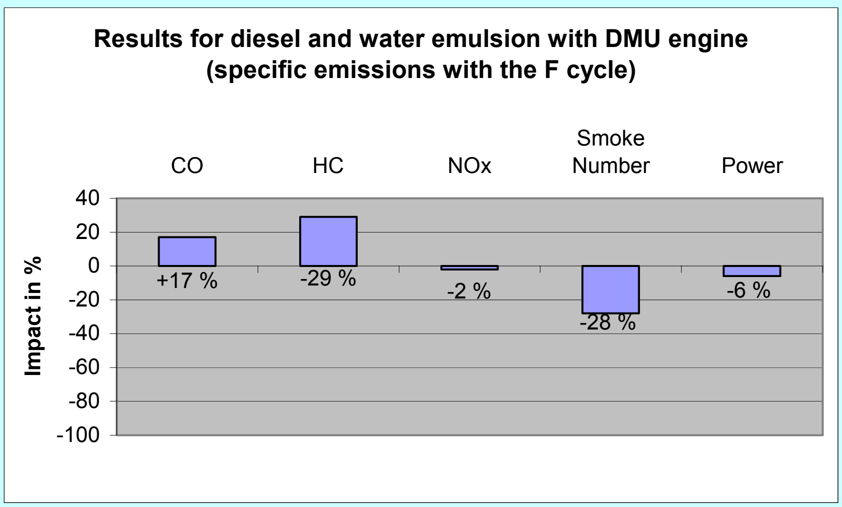


Figure 2: Diesel and water emulsion (between 10 and 20 % of water), DMU engine (440 kW)

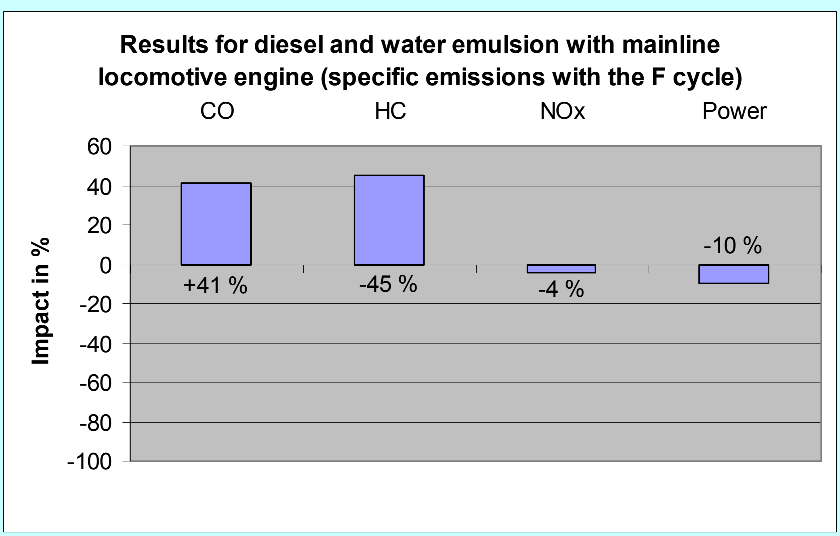


Figure 3: Diesel and water emulsion (between 10 and 20 % of water), Mainline locomotive engine (600 kW)

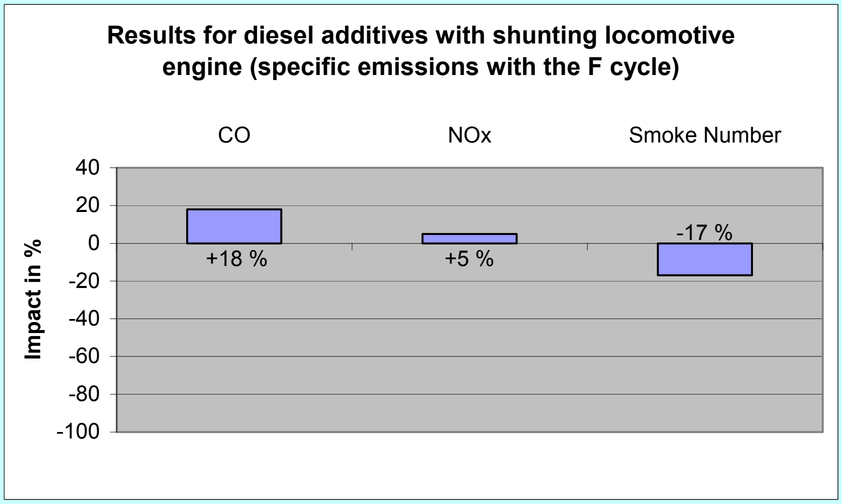


Figure 4: Diesel additives, shunting locomotive engine

Box 10: DSB Experience with modern mechanical transmissions in DMUs

DSB (Danish State Railways) is a train operator based in Denmark. The Minister of transport is the shareholder, but DSB is controlled by its own board. 10 years ago, DSB included rail infrastructure, cargo trains, buses and ferries, but now the main product is passenger trains. In 2002 DSB produced 57.4 millions train-km and 5490 millions passenger km. DSB trains are in regular service to Hamburg and southern parts of Sweden, but the majority of the traffic is in Denmark.

Traditionally DSB has owned its rolling stock. This still applies to the majority of the trains, but due to the market situation, recently some train sets and cars have been leased. Generally – DSB takes care of maintenance. The Danish rail infrastructure does not belong to DSB. The infrastructure is now owned and operated by the Danish state (Bane Danmark – formerly Banestyrelsen). The primary network is partly electrified, meaning that intercity traffic runs on electrified as well as not electrified lines.

The Major part of the **Intercity traffic** runs from Copenhagen to the bigger towns of Zealand, Funen and Jut land. The main route goes to Aarhus in Jutland, but in order to offer regular service in most parts of Jutland the traffic (and trains) takes several directions in Jutland. The numbers of passengers differs radically along the main line. The intercity infrastructure has a top speed of up to 180 km/h. But the intercity network stretches out to the “thinner” lines with reduced speed limits. Good energy efficiency over a broad speed range is thus important.

The average distance between stations in the intercity traffic is approx. 30 km. In addition to these stops, the allowed top speed varies along the main lines, calling for frequent accelerations/braking. These conditions mean that a fast acceleration is more important than high top speed, in order to obtain a high average velocity (low travelling time).

In the mid-eighties DSB had a need for new intercity rolling stock. Electrified lines were expected for the future. In order to reduce travelling time and win more passengers, DSB chose to offer modern DMUs as an intermediate solution.

Demands/wishes for a new IC train concept included: Easy and fast up- and downsizing of train (partly due to ferry transport between Zealand and Funen). DMUs seemed to be the obvious answer to this demand. The conditions listed above, favoured a lightweight high-power unit. High energy efficiency and low emissions had a high priority as well. Different engine/transmission concepts/configurations were investigated. The combination of truck-size diesel engines with individual automatic mechanical transmissions (known from city buses), seemed to be an obvious choice, based on weight, efficiency, emissions etc., but train experience with these transmissions was limited.

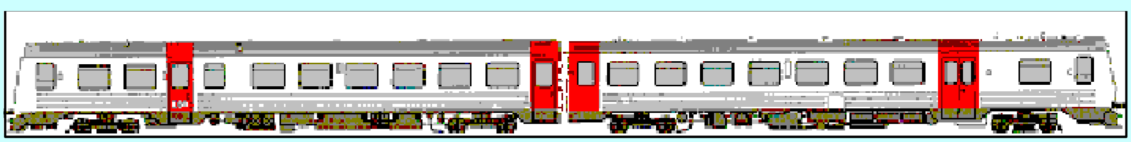
DSB's evaluation/comparison of the different transmission types is listed in Figure 1. The well-known hydrodynamic transmission is used as a baseline.

Transmission type	**Hydrodynamic**	**Electric**	**Mechanical (incl. Rev. Axle drive)**
Transmission efficiency	**basis**	**0**	**+**
Engine efficiency (operating conditions)	**basis**	**+**	**+**
Weight	**basis**	**-**	**+**
Price	**basis**	**-**	**+**
Maintenance frequency	**basis**	**-**	**-**
Maintenance LCC	**basis**	**0**	**0**
Overall LCC (fuel included)	**basis**	**0**	**+**

The hydrodynamic transmission is used as a baseline. **+** indicates better performance compared to the hydrodynamic transmission, **-** indicates that the hydrodynamic (basis) performance is better than the alternative, **0** indicates no significant difference.

Figure 1: Different types of transmissions, compared according to DSB experience

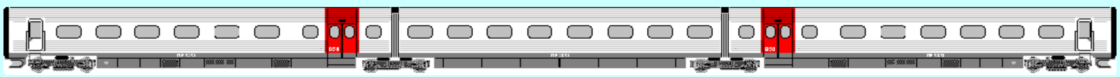
As part of the feasibility study, an existing DMU (Figure 2) was converted from diesel-hydraulic to diesel-mechanic traction. ZF Ecomat transmissions and new diesel engines were tested. Except for running-in/prototype-problems, the concept proved to work well, and the converted DMU was operated in normal service - alone, or coupled to the hydrodynamic sisters from the fleet.



	Standard	**Converted**
Engine	2 x Deutz BF12 L 413	2 x MAN2865LUE / Deutz BF8 L 513
Engine rated power	2 x 240 KW	2 x 265 KW
Transmission	2 x Voith T320r	2 x ZF ecomat 5HP600
Delivered	1978 - 1985	
Max. speed.	130 km/h	
Lenght	44,68 m	
Structure	Steel	
Weight	74,6 t	
Nr. of passengers	131	

Figure 2: DSB train, DMU type MR, used for the test

Based on the comparisons, test results, LCC calculations etc., it was decided that the new intercity DMUs (called **"IC3")** should feature mechanical transmissions. The IC3 was developed by DSB and Scandia (now Bombardier Transportation DK) as a lightweight concept (Figure 3). Each train unit features 4 engines and transmissions. Up to 5 DMUs can be coupled together, meaning that 20 power-packs are controlled by the driver.



Engine	4 x Deutz BF 8 L 513 CP
Engine rated power	4 x 293 KW
Transmission	4 x ZF ecomat 5HP600
Delivered	1989 - 1998
Max. speed.	180 km/h
Lenght	58,8 m
Structure	Alu
Weight	97,0 t
Nr. of passengers	144

Figure 3: IC3 DMU Specification

The choice of mechanical transmission required special components and developments for the IC3. A reversing axle drive was needed (since the Ecomat-transmission features 5 forward steps, but only 1 reverse). Controlling algorithms for wheel-slip-control, ABS, creeping (washing and coupling), etc. had to be developed/optimised. The "old" driving strategy (full power acceleration /coasting to next station) was not applicable to this concept, and the initial test drives showed that a "cruise control" was needed for this power/weight ratio.

January 1990, the first IC3 units went into regular intercity service. At the moment the IC3-fleet runs the majority of the intercity traffic, but they are also used as commuter trains in the peak traffic. And since 1992 IC3s travel the Copenhagen – Hamburg connection several times a day, crossing the Baltic on a ferry.

In **the Intercity service**, the Great Belt ferry connection (which the units were initially specially tailored for) has been replaced by a bridge and a tunnel. But the trains' ability to upsize/downsize is still used extensively. Train sets are coupled or divided in service 140 times a day. This way, train capacity is adjusted according to different needs along the track, ensuring high overall efficiency of the system (few empty seats). And the possibility to divide the trains, and make the separated parts go in different connections, increases the number of destinations with frequent direct connections

The electrifying of the infrastructure has now been stopped by the Danish government. As mentioned above, this means that some parts of the network are electrified. In order to get the most usage out of the rolling stock, DMUs are often coupled together with EMUs on this part of the intercity network. The control systems of the related train sets have been upgraded for this purpose, and this possibility is widely used. Except for differences in wheel diameters, or switched off traction units, the load is shared equally between coupled train sets.

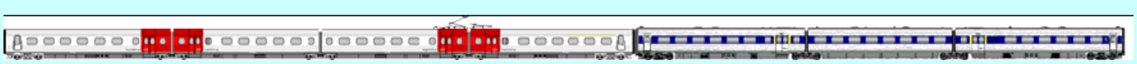


Figure 4: EMU (IR4) and DMU IC3 are coupled and running together (IC3now in new DSB colours).

The IC3 fleet has grown bigger several times, and 96 units are now in service at DSB. Together they have produced 350 million km., meaning that DSB now has approx. 1.4 billion kilometres (4 transmissions/DMU) of experience with these mechanical transmissions. The transmissions have clearly complied with the expectation. There have been no major surprises compared to the initial LCC calculations. Unplanned repairs are very infrequent and during the period until now, transmission cases has only been replaced on 2 (of 400) transmissions.

The Ecomat mechanical transmissions are overhauled every 600,000 km (initially 500,000 were expected). DSB's workshop is able to do the overhaul, but until now it has been done by workshops outside DSB. Other types of transmissions could run longer distances between overhauls, but as mentioned, the LCC-expectations are still met.

Each of the DMUs consumes 1.0 litres/km (1990 - 2002 average consumption), based on driven kilometres and fuel supplied to the trains. This means that everything is included (idling, "shunting", and even the oil used by the fuel burner, to heat the trains when parked). It is not possible to measure the fuel savings related to the mechanical transmission, but based on the efficiency curves etc., we believe that the consumption would be at least 10% higher for the same DMU with a more traditional transmission.

Most of the IC3s are now well past the 3 million kilometres. They are "still going strong", but new traction units/power packs are considered in order to optimise maintenance and reduce exhaust emissions. A prototype featuring EURO 3 engines and a new mechanical transmission is under evaluation in regular service. The new transmission is necessary to utilize the torque potential of the new diesel engine. The 12-speed transmission is controlled and optimised together with the engine. This way the entire traction system is even more capable of working in the "best points". The new transmission (truck-based) has longer overhaul intervals and an even better LCC.

Based on more than 12 years experience DSB has chosen mechanical transmissions for new DMUs. DSB has ordered 83 IC4-DMUs from ANSALDOBREDA. The first units are under test in Denmark. A smaller IC2 will follow. Both will feature EURO 3 engines, and 16-speed transmissions similar to the 12-speed version in the IC3 prototype.

But the Ecomat mechanical transmission is still used in new train sets. DSB has leased 12 new Siemens DESIRO trains, similar to the 150 VT642, which are in service at DB and other operators, all using this mechanical transmission. The Talent from Bombardier and the Lint from Alstom are other examples of train sets offering this transmission.

Figure 5: IC4

More information on mechanical transmission used in IC3 & IC4

The torque converter decouples after the train is stationary for 10 seconds. It was originally disengaged after 3 minutes, but it was changed to 10 seconds when it was apparent that this was workable. The load on each engine is reduced to about 20 kW with the de-coupling. There is an approximate reduction in NOx by a factor of 3. The short decoupling time has not resulted in changes to maintenance schedules.

The new IC4 does not have a torque converter at all but a dry clutch linked to a 16-speed gearbox. It is not easy to state the exact weight saving by using mechanical transmission instead of hydraulic as hydraulic also required additional cooling – entailing additional mass not counted as part of the gearbox. The test-bed train used by DSB for mechanical transmission does also not give a comparison – it was converted from hydraulic transmission but this had to be retained to allow reversing.

IC3 train has been exported from Denmark to Sweden and Israel. Sweden has some IC3 with Cummins engines and CRT®.

Box 11: ZSSK experience with locomotive modernisation and battery-electric operation

Locomotive modernisation

Modernisation costs include the following items:
Anti-skid and anti-slide protection for bogies
New Caterpillar engine + new generator + new rectifier
Brake resistor for electrodynamic brakes
New compressor, ventilator, and transmission
New cab and new bonnet
New brake system

Class 736 modernisation: 48 million Koruny (€1.24 million)
Class 773 modernisation: 45 million Koruny (€1.16 million)

At a depot based in south central Slovakia, 99% of operations are diesel, and they also operate both old and new engines, and old, new, and modernised vehicles. Representative examples of old locomotives include the Class 751 and Class 752. Representative examples of modernised locomotives include the Class 773 and Class 736. For all of these vehicles, the log depot carried out a survey of fuel consumption in May 2005.

Class 751: Average fuel consumption ranges from 5.1 to 5.5 litres per 1000 gross tonne km (or 2.75 litres per km)
Class 736: Average fuel consumption ranges from 4.5 to 4.8 litres per 1000 gross tonne km (or 2.0 litres per km)
Class 773 (shunting version): Average fuel consumption of 13 litres per 1000 gross tonne km
Class 773 (mainline locomotive): Average fuel consumption ranges from 5.0 to 5.5 litres per 1000 tonne km

It should be noted that the Class 773 operates on much steeper gradients than the other locomotives, hence fuel consumption is higher. For new locomotives, there is approximately a 10% improvement in fuel efficiency compared to older designs. With regard to NO_x and PM emissions reductions, ZSSK have not carried out any tests themselves, but they do have emission factor data from engine manufacturers demonstrating improvements.

Battery electric operation

80% of ZSSK diesel electric locomotives are equipped with starter batteries that can be used to provide traction power for moving short distances at low speed. Originally, this equipment was used only for moving in and out of maintenance workshops – in practice, battery electric operation is now used for moving locomotives for distances of up to 1 km. The batteries (which are nickel cadmium) have a voltage specification of 110 Volts with a current specification of 175 Ah. For Class 773 locomotives, the batteries are 24 Volts and 360 Ah. To allow battery electric operation requires only a very simple modification to the control system – a new controller, including one switch and several metres of cabling is required. This was carried out by the locomotive manufacturer with modification costs €1000 per locomotive.

Annex 6: Technical Measures – Detailed Analysis for Current Fleet

9.7 Selection of representative traction units for the detailed analysis

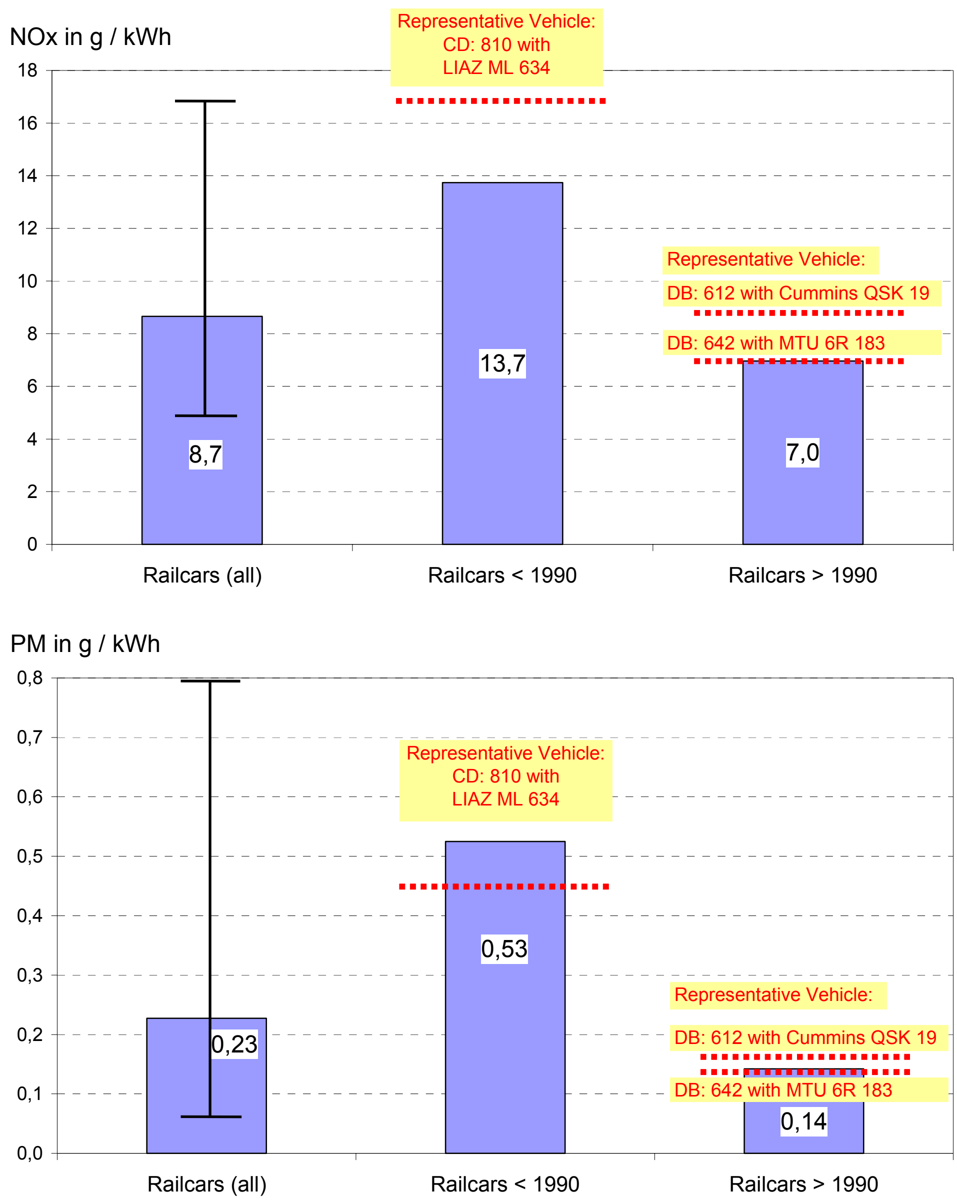


Figure 9.7: Average and range of NO_x and PM emission factors (in g/kWh) for representative railcar engines (Source: questionnaire survey); red dotted lines show the values for the chosen vehicles

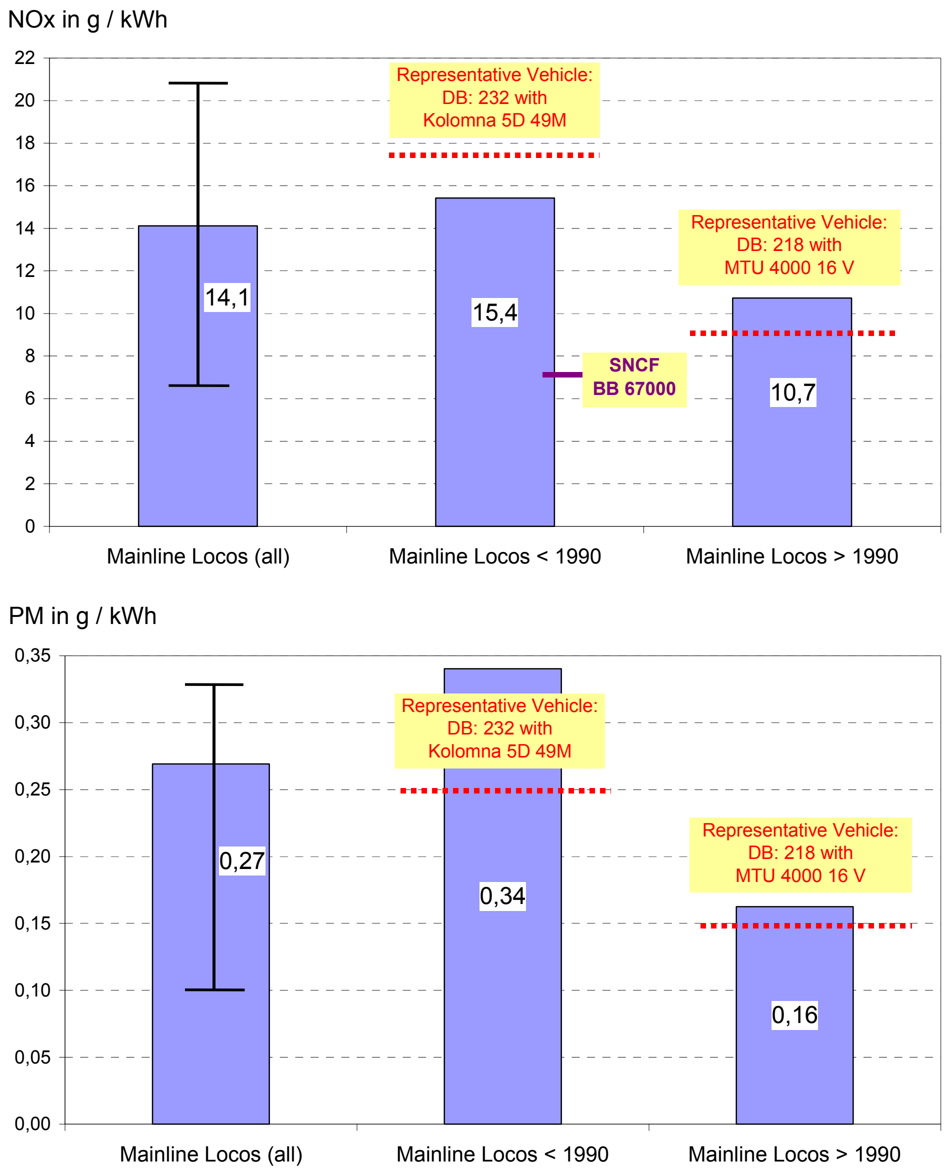


Figure 9.8: Average and range of NO_x and PM emission factors (in g/kWh) for representative mainline locomotive engines (Source: questionnaire survey); red dotted lines show the values for the chosen vehicles

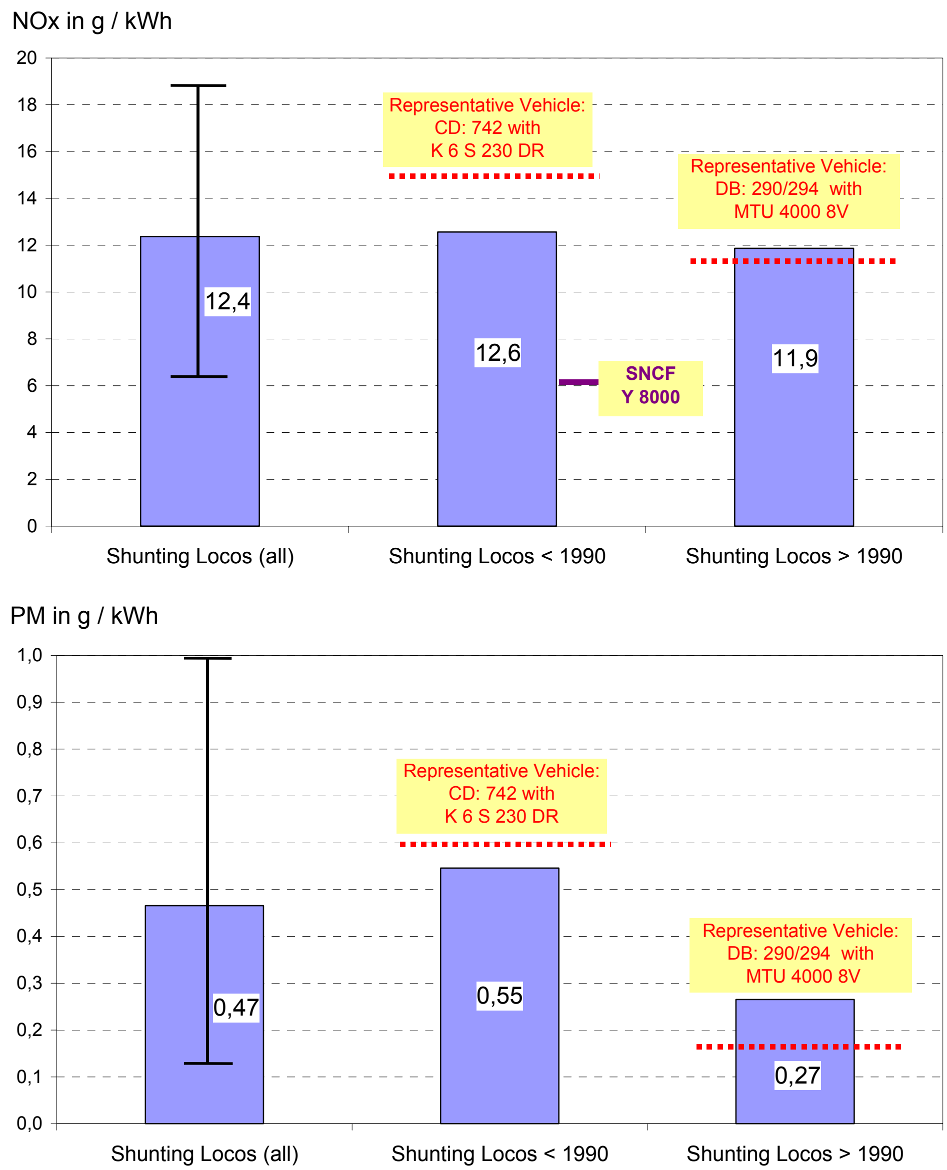


Figure 9.9: Average and range of NO_x and PM emission factors (in g/kWh) for representative shunting locomotive engines (Source: questionnaire survey); red dotted lines show the values for the chosen vehicles

The investigations are based on the following base technical data for the different vehicles:

Table 9.2: Technical data and parameters for representative vehicles

	Railcars			Mainline locomotive		Shunting locomotive	
	< 1990	>= 1990 ~300 kW	>= 1990 ~600 kW	< 1990	>= 1990	< 1990	>= 1990
Company	ČD	DB AG	DB AG	DB AG	DB AG	ČD	DB AG
Type of vehicle	810	642	612	232	218	742	290 / 294.5-294.9
Average diesel consumption [g/kWh]	235.9	220	212	230	214	228	219
CO emissions factor [g/kWh]	2.5	0.50	1.07	5.30	0.59	2.82	0.8
HC emissions factor [g/kWh]	1.25	0.34	0.61	1.20	0.43	0.79	0.6
NO_x emissions factor [g/kWh]	17.29	7.0	8.74	17.6	9.10	15.1	11.6
PM emissions factor [g/kWh]	0.45	0.14	0.16	0.25	0.152	0.6	0.160
Test cycle	ISO-C1	ISO-F	ISO-F	ISO-F	ISO-F	ISO-F	ISO-F
Engine power [kW]	155	275	557	2226	2100	883	1000
Exhaust temperature (°C)	640	450		420	478	650	480
Flow of exhaust (kg/h)	930	1535		14725	11732	Input 7250	5585
Flow of exhaust (cu.m/h)		3170		31860	24527		11680
Weight of silencer (kg)	100	150		600	500	219	250
Dimensions of silencer (length x width x height)	1250 x 520 x 420	D=350, l=1000		1800 x 1200 x 850	1800 x 1200 x 500	1400 x 600 x 600	D=700, l=1000
Clearance for aftertreatment (length x width x height)	1250 x 520 x 420	D=300, l=1000		1800 x 1200 x 850	2200 x 1200 x 650	1600 x 700 x 700	1100 x 1000 x 700
Length between end of turbo-charger and silencer (mm)	3000	2000		500	600	300	1300
Termination diameter for aftertreatment (mm)	150	180		450	2 x 280	300	300

9.8 A6.1 Railcar (DMU) < 1990: Class 810

Figure 9.10: Photo of the Class 810

Figure 9.11 shows the layout of the engine and exhaust-gas unit components on the VT 810.

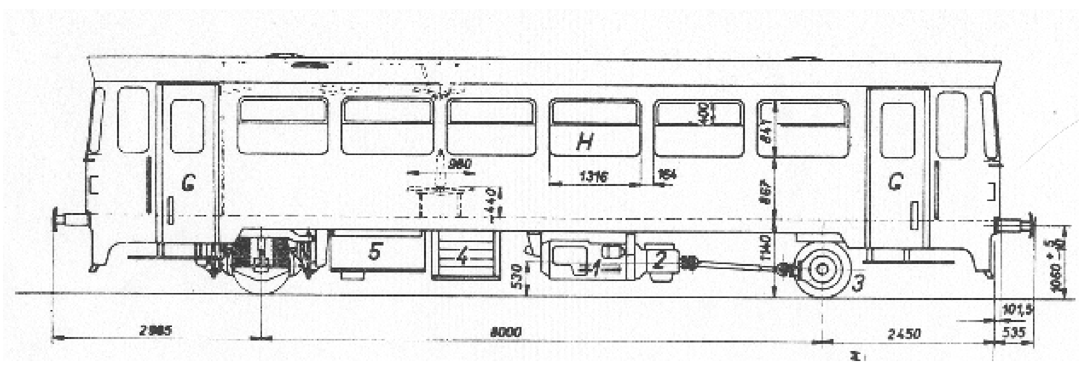


Figure 9.11: Schematic of the Class 810 railcar

The layout is typical of older internal combustion engine railcars (DMUs) where the engine is mounted on the main body of the railcar using a separate frame. Transmissions, cooling plant and exhaust-gas unit are individually mounted to the underside of the railcar. This mode of design allows individual components to be replaced and flexibly adapted to the fitting conditions but also results in a large gap between the engines exhaust gas outlet and the silencer. This causes the exhaust gas to cool down to a greater or lesser degree depending on the point of operation of the engine, which impacts adversely on the efficiency of catalysts or the regeneration of DPFs. The parameters cited yield the following options for the various exhaust gas after treatment technologies:

A6.1.1 Feasibility and Performance of the Technologies When Considering the Available Space (Variant A).

The performance of the systems/technologies has been assessed whilst taking account of the installation space available.

Diesel DPF

- Only conversion rates up to 40% achievable in space available
- Insufficient space to fit burner for active regeneration purposes

Only an open-channel system can be fitted in the space available on the internal combustion engined railcar with a view to reducing diesel particulates. This is a technology that does not require active regeneration and has conversion rates of 30-40%, which is similar to from the performance achieved in automotive applications. Emissions of carbon monoxide and hydrocarbons are reduced by approximately 80% beyond an exhaust-gas temperature of 200 and 300°C respectively. Emissions of nitrogen oxides are not affected.

With this system it is possible to achieve a PM value of around 0.3 g/kWh for the VT 810, given existing emissions of 0.45g/kWh, as long as particle size distribution is comparable to that for modern automotive diesel engines – something it is not currently possible to gauge**.** This value lies within the limit prescribed for stage IIIA, which modern diesel engines adhere to with ease. The particulate limit value prescribed for stage IIIB is exceeded with this system by a factor of 12.

Filter systems with closed channels require either an exhaust-gas temperature in the filter higher than 250°C for 50 % of the operating period or else some form of active regeneration (electric heating or burner). The constraints on the exhaust-gas temperature profile are not acceptable for rail vehicles. Lengthy idling and partial-load phases are typical of railway operations and cannot be universally ruled out. Thus, some form of active regeneration is essential. Adherence to the permissible exhaust-gas backpressure necessitates the filter elements being correspondingly dimensioned. For these reasons it is not possible to fit a closed DPF system in the space available on the VT 810. The costs of fitting and operating an open DPF system on the VT 810 are as follows:

Table 9.3: Life Cycle Costs of operating an open DPF system on the VT 810 railcar

Constraints	***Amount***	***Unit of measure***
Anticipated average life	**8**	years
Annual average performance vehicle	**68,000**	km
Diesel consumption	**35**	l/100 km
Cost of diesel	**0.75**	€/l
System data		
Purchase of system	**7,000**	€
Development of system (per track vehicle)	**2,000**	€
Integration of system in track vehicle	**500**	€
Installation of system	**1,500**	€
Change in diesel consumption	**1**	l/100 km
Change in diesel costs	**510**	€/year
Consumption of additional operating supplies	**0**	l/100 km

Constraints	Amount	Unit of measure
Cost of additional operating supplies	**0.00**	€/l
Cost of additional operating supplies	**0**	€/year
Change in costs for maintenance	**750**	€/year
Total fixed costs	**11,000**	**€**
Total variable costs	**1,260**	**€/year**
Expenses per track vehicle and year	**3,320**	**€/year**

Extra outlay totalling €3,320 per year or 4.8 eurocents per kilometre is to be anticipated.

Selective Catalytic Reduction

- It is not possible to integrate reducing agent tank, injector, compressed air supply, control gear and catalyst into space available on vehicle.

The constituents of the SCR system are set out in Subsection 4.1 above. Besides the actual catalyst a large number of other components are required to successfully implement selective catalytic reduction. A supply of compressed air is required vehicle-side to ensure injection of the reducing agent. Control of reducing agent dosage requires load and speed information from the vehicle and engine control gear. In the case of older traction stock without any electronic regulation this data is generally not available in the required form. Furthermore, in order to achieve an acceptable vehicle range it is necessary to fit a sufficiently large reducing agent tank. These measures cannot be carried out in the space available on the VT 810.

SCRT

- As for SCR + DPF

The points made above regarding the two systems hold true for a combination of SCR and DPF. Hence, an SCRT system cannot be integrated.

Combined Particulate Oxidation Catalyst (POC)

- As for DPF

The points made above regarding the DPF also hold true for a combination of oxidation catalyst and DPF. The problems of integration are exacerbated in that the system's two components require even more space than a DPF and the backpressure through the oxidation catalyst increases still further.

Exhaust Gas Recirculation

- Feasibility of retrofitting a LIAZ engine with EGR very questionable
- Larger cooling system necessary
- Integration of a larger cooling system is not possible

Integrating an exhaust gas recirculation system represents an input-intensive means of cutting NO_x emissions from existing engines. Whereas this is a technology that finds successful application in the development of new engines, retrofitting it is technically very difficult if not impossible. Firstly, the engine control system requires a variety of data so it can regulate the exhaust gas recirculation rate and, secondly, it is necessary to integrate a larger cooling system. Neither is possible on the VT 810 in the space available.

Re-engining

- Compatible engine is not available?

A6.1.2 Feasibility and performance of technologies when conformity with stage IIIB of directive 97/68/EC is considered (Variant B).

The technologies described in Section 1 were tested on the VT 810 to determine whether they permit conformity with stage IIIB of Directive 97/68/EC. The available space was no longer considered a constraint and vehicle refit measures were deemed acceptable:

Oxidation Catalyst

- Emissions of CO and HC reduced.
- NOx limit value (2.0 g/kWh) and particulate limit value (0.025 g/kWh) not adhered to.

Diesel DPF

- Particulate emissions reduced.
- NOx limit value (2.0 g/kWh) not adhered to.

Selective Catalytic Reduction

- Emissions of HC, CO, NOx and particulates reduced
- particulate limit value (0.025 g/kWh) not adhered to

SCR + DPF

- Currently the only technology facilitating adherence to the limit values prescribed for stage IIIB where existing traction stock is concerned.

A combination of SCR technology and a DPF is necessary in order to meet the strict limit values for NO_x and particulates prescribed for stage IIIB. Only if both technologies are integrated can high conversion rates be achieved for all noxious constituents subject to limit values. In the case of the VT 810, however, the conversion rates are not sufficiently high. The initial value for NO_x emissions is 17 g/kWh with a limit value of 2.0 g/kWh. That necessitates a rate of reduction in the C1 cycle of greater than 88 %. This value is only achieved with SCR technology over a small characteristic range. The rate of reduction is lower in the C1 cycle. The initial value for particulates is 0.45 g/kWh given a limit of 0.025 g/kWh, which equates to a conversion rate of greater than 94%. That necessitates a large filter system with a corresponding rise in exhaust-gas backpressure, which then exceeds the permissible limit value for the engine.

Combined Particulate Oxidation Catalyst (POC)

- Emissions of HC, CO and particulates reduced.

- NOx limit value (2.0 g/kWh) not met.

Exhaust Gas Recirculation

- Stage IIIB not complied with.

Re-engining

- Stage IIIB not complied with.

It becomes evident that, based on the emission values for the engine on the VT810, there is currently no technology available to meet the limit values prescribed for stage IIIB. Combining SCR with a DPF allows noxious constituents subject to limit values to be reduced to a high degree. Providing a conversion rate of approximately 70-80% for CO, HC, NO_x and PM and assuming that exhaust-gas backpressure remains at a reasonable level, the cost of procuring such a system would be of the order of the price for a new diesel engine with the same rating. However, it is also necessary to use a reducing agent, which would further increase the level of fuel consumption that is already too high by today’s standards, thus negatively impacting on running costs.

Summary of the feasibility of technical measures for the VT 810

The points made in this section clearly indicate the limited feasibility of adding exhaust gas after treatment units to existing internal combustion engine railcars as well as the limited conversion rates that are achievable for noxious constituents. The exhaust gas values for older internal combustion engine railcars are far higher than those for modern diesel engines. It is impossible, even with $comple_x$ and expensive exhaust gas after treatment technology, to adhere to the limit values prescribed for stage IIIB.

Moreover, it is also frequently the case that the after treatment regulating variables (required by the vehicle and engine control systems) are not available, thus rendering integration an arduous if not impossible undertaking. The permissible exhaust-gas backpressure for rail diesel engines is generally far lower than the values for motor cars or commercial vehicles. In many cases the engine cannot cope with the increase in backpressure induced by positioning a catalyst or filter downstream.

Therefore, where older internal combustion engine railcars (built before 1990) are concerned, re-engining constitutes the most sensible way of lastingly improving exhaust-gas emissions. However, the availability of compatible engines has a large bearing on the feasibility of this course of action and is not something that can always be guaranteed.

9.9 A6.2 Railcar (DMU) >1990: Class 612

Figure 9.12: The VT 612 railcar

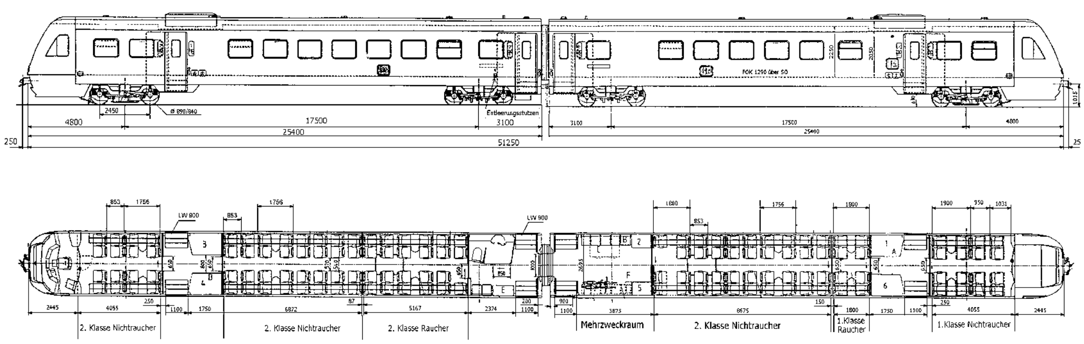


Figure 9.13: Schematic of the VT 612 railcar

Figure 9.14 illustrates the layout of the engine and exhaust-gas unit components on the VT 612.

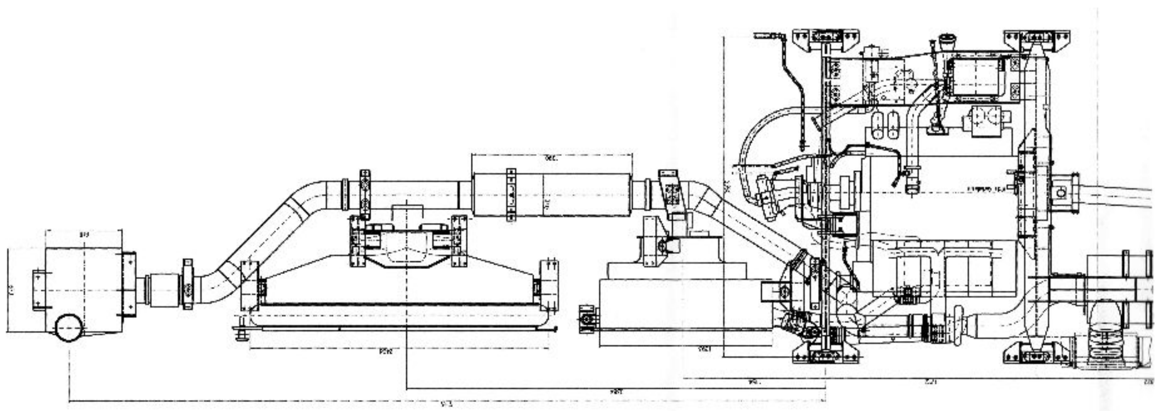


Figure 9.14: Layout of the engine and exhaust-gas unit components on the VT 612

The layout is typical of internal combustion engine railcars with higher-output diesel engines (>500kW) and no low-floor sections. The drive components (engine, transmission/generator, cooling system, exhaust gas unit) are individually mounted on the body and are relatively easy to access. On the latest designs of internal combustion engine railcars these components are grouped together in what are known as power packs with differing degrees of integration depending on their output category (cf. VT 642, VT 644).

The exhaust gas unit comprises a front and rear silencer plus piping. There is comparatively little space in the immediate proximity of the exhaust gas unit in which to integrate any additional components (please see Figure 9.15 and Figure 9.16)

Figure 9.15: Area around front silencer

Figure 9.16: Area around rear silencer

It is not possible to integrate exhaust gas after treatment components in the area around the front silencer. The only additional fitting space available is in the area of the rear silencer (approximately 140 litres). Where the rear silencer is replaced by a catalyst or filter, the thermal insulation requirements need to be considered. The parameters cited for the VT 612 yield the following options for the various exhaust-gas after treatment technologies:

A6.2.1: Feasibility and Performance of the Technologies When Considering the Available Space (Variant A).

The performance of the systems/technologies has been assessed whilst taking account of the installation space available.

Diesel DPF

- It is feasible to integrate a DPF with active regeneration.

A closed filter system for reducing diesel particulates can be integrated into the space available on the internal combustion engine railcar. This technology requires a form of active regeneration in rail applications to prevent the filter clogging up and backpressure becoming too high as a consequence. The conversion rate is generally greater than 90% and is dependant on the filter's size and configuration (cellular density, carrier material etc.) as well as on the test cycle. Using this system on the VT 612 allows a particulate value of < 0.02g/kWh to be achieved in place of the initial value of 0.16g/kWh, thus adhering to the limit value prescribed for stage IIIB. However, due to the increase in weight it is necessary to modify the means of mounting for the exhaust gas unit.

Furthermore, checks need to be made to determine whether the railcar body's current design will withstand the additional, whether a counterweight may be required between the two sides of the vehicle (due to uneven loading), and whether the vehicle's licence is still valid given the additional loading on the axles. The latter can be negated by reducing the maximum number of passengers. Should the additional weight not constitute an insurmountable problem, the following costs are incurred when integrating and using a closed DPF system on the VT 612:

Table 9.4: Life Cycle Costs of operating an open DPF system on the VT 612 railcar

Constraints	***Amount***	***Unit of measure***
Anticipated average life	**8**	Years
Annual average performance vehicle	**200,000**	Km
Diesel consumption	**81**	l/100 km
Cost of diesel	**0.75**	€/l
System data		
Purchase of system (per track vehicle)	**56,000**	€
Development of system (per track vehicle)	**2,500**	€
Integration of system in track vehicle	**1,000**	€
Installation of system	**2,500**	€
Change in diesel consumption	**2.5**	l/100 km
Change in diesel costs	**3,750**	€/year
Consumption of additional operating supplies	**0**	l/100 km
Cost of additional operating supplies	**0.00**	€/l
Cost of additional operating supplies	**0**	€/year
Change in costs for maintenance	**3,000**	€/year
Total fixed costs	**62,000**	**€**
Total variable costs	**6,750**	**€/year**
Expenses per track vehicle and year	**18,370**	**€/year**

The VT 612 is a multiple unit incorporating 2 internal combustion engines. Thus, each train set requires 2 after treatment systems costing €28,000 each. Extra outlay totalling €18,370 per year or 9.2 eurocents per kilometre should be expected.

Selective Catalytic Reduction

- It is feasible to integrate an SCR system if the vehicle is modified.

The VT 612 is fitted with a Cummins QSK 19 diesel engine incorporating electronic regulation, so transfer of the regulating variables for the SCR system is possible. The reducing agent tank can be integrated into the passenger accommodation area (e.g. under a double seat). The catalyst replaces the rear silencer and is fastened to the body so as to be vibration-proof. The dosing gear for the reducing agent could be fitted next to the front silencer. With the SCR system NO_x and HC conversion rates of approximately 80% are possible and a NO_x value of < 2.0 g/kWh is achieved. Particulate emissions are likewise positively affected (conversion rate approximately 20 %) with an improvement to approximately 0.13g/kWh. The modest 10% rise in CO emissions, which is typical of SCR, can in principle be prevented by integrating an oxidation catalyst downstream. However, it is not possible with the VT 612 since the catalyst already takes up the available fitting space for the rear silencer. As with the DPF, attention needs to be paid to the problem of extra weight.

The following costs are incurred with the SCR system:

Table 9.5: Life Cycle Costs of operating an SCR system on the VT 612 railcar

Constraints	***Amount***	***Unit of measure***
Anticipated average life	**8**	Years
Annual average performance vehicle	**200,000**	Km
Diesel consumption	**81**	l/100 km
Cost of diesel	**0.75**	€/l
System data		
Purchase of system (per track vehicle)	**50,000**	€
Development of system (per track vehicle)	**2,500**	€
Integration of system in track vehicle	**2,000**	€
Installation of system	**4,000**	€
Change in diesel consumption	**0**	l/100 km
Change in diesel costs	**0**	€/year
Consumption of additional operating supplies	**4**	l/100 km
Cost of additional operating supplies	**0.40**	€/l
Cost of additional operating supplies	**3.200**	€/year
Change in costs for maintenance	**2,500**	€/year
Total fixed costs	**58,500**	**€**
Total variable costs	**5,700**	**€/year**
Expenses per track vehicle and year	**16,670**	**€/year**

Extra outlay totalling €16,670 per year or 8.3 eurocents per kilometre is to be expected.

SCRT

- It is not possible to integrate SCR and DPF into the space available.

Combined Particulate Oxidation Catalyst (POC)

- As for DPF.

The points made above regarding the DPF also hold true for a combination of oxidation catalyst and DPF. In fact, the integration problems are exacerbated since the two components that make up the system require even more space than a DPF and the addition of the oxidation catalyst increases the backpressure still further.

Exhaust Gas Recirculation

- Feasibility of retrofitting the Cummins engine with EGR questionable
- Larger cooling system necessary
- Not possible to integrate larger cooling system

The comments made for the VT 810 hold true here too.

Re-engining

- No compatible engine currently available.

A6.2.2 Feasibility and performance of technologies when conformity with stage IIIB of directive 97/68/EC is considered (Variant B).

The technologies described in Section 1 were tested on the VT 612 to determine whether they permit conformity with stage IIIB of Directive 97/68/EC. The available space was no longer considered a constraint and vehicle refit measures were deemed acceptable:

Oxidation Catalyst

- Emissions of CO and HC reduced.
- NO_x limit value (2.0 g/kWh) and particulate limit value (0.025 g/kWh) not adhered to.

Diesel DPF

- Particulate emissions reduced.
- NO_x limit value (2.0 g/kWh) not adhered to.

Selective Catalytic Reduction

- Emissions of HC, CO, NO_x and particulates reduced.
- Particulate limit value (0.025 g/kWh) not adhered to.

SCR + DPF

- Apart from SCRT, SCR + DPF is the only technology for existing traction stock that adheres to the limit values prescribed for stage IIIB.

A fully integrated combination of SCR technology with a particulate filter is necessary in order to meet the strict limit values for NO_x and particulates prescribed for Stage IIIB.

The initial value for NO_x emissions from the VT 612 is 8.74 g/kWh compared to a limit value of 2.0 g/kWh. This necessitates a rate of reduction in the C1 cycle of >77 %. This value can be achieved with SCR technology given the appropriate system size and layout. The initial value for particulates is 0.16 g/kWh, the limit for stage IIIB being 0.025 g/kWh. The requisite conversion rate is thus >84 %. This value is achievable with closed DPF systems given the appropriate design dimensions.

The fitting space already available or additionally achievable on the VT 612 is not, however, sufficient to integrate both components in the size required to meet the limit values prescribed for stage IIIB. One potential solution is a dual system in which a DPF is combined with an SCR system and maximum use is made of the potential fitting space.

The conversion rates for NO_x are somewhat lower than in the complex SCRT system (approximately 60%). This would allow a NO_x value of 3.5g/kWh to be produced. Particulate emissions are reduced by more than 85 %. As with the separate DPF and the SCR systems, attention needs to be paid to the problem of extra weight. The following outlay is incurred:

Table 9.6: Life Cycle Costs of operating an SCR + DPF system on the VT 612 railcar

Constraints	***Amount***	***Unit of measure***
Anticipated average life	**8**	years
Annual average performance vehicle	**200,000**	km
Diesel consumption	**81**	l/100 km
Cost of diesel	**0.75**	€/l
System data		
Purchase of system (per track vehicle)	**85,000**	€
Development of system (per track vehicle)	**3,000**	€
Integration of system in track vehicle	**3,000**	€
Installation of system	**5,000**	€
Change in diesel consumption	**2.5**	l/100 km
Change in diesel costs	**3,750**	€/year
Consumption of additional operating supplies	**4**	l/100 km
Cost of additional operating supplies	**0.40**	€/l
Cost of additional operating supplies	**3,200**	€/year
Change in costs for maintenance	**4,000**	€/year
Total fixed costs	**96,000**	**€**
Total variable costs	**10,950**	**€/year**
Expenses per track vehicle and year	**28,950**	**€/year**

Extra outlay totalling €28,950 per year or 14.5 eurocents per kilometre is to be anticipated.

SCRT

Costs are comparable to SCR + DPF, but additional space could be needed for integration.

Combined Particulate Oxidation Catalyst (POC)

- Emissions of HC, CO and particulates reduced.

- NO_x limit value (2.0 g/kWh) not adhered to.

Exhaust Gas Recirculation

- Stage IIIB not complied with.

Re-engining

- Stage IIIB not complied with.

Summary of the feasibility of technical measures for the VT 612

As detailed above, exhaust gas after treatment systems can be added to internal combustion engine railcars of comparable design to the VT 612. Using this approach it is possible to effectively reduce noxious constituents in exhaust gases. These improvements have a significant impact on the operating costs for the rolling stock. Table 9.6 underlines just how high the requisite outlay is. The increase in cost per kilometre is 14.5 eurocents. Furthermore, it becomes evident that given the emission values for the engine on the VT612, there is no technology available at present permitting adherence to the limit values prescribed for stage IIIB. Nevertheless, combining SCR with a DPF allows noxious constituents subject to limit values to be considerably reduced.

9.10 A6.3 Railcar (DMU) >1990: Class 642

Figure 9.17: The VT 642 railcar

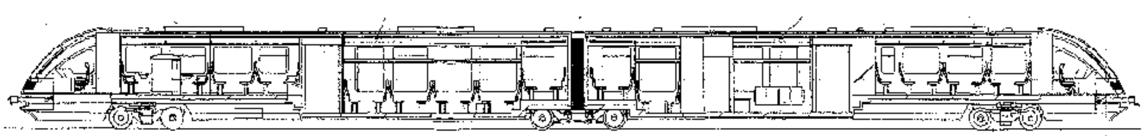


Figure 9.18: Sectional drawing of the VT 642

The VT 642 is a typical modern internal combustion engine railcar (DMU) on which the on-board components are laid out beneath the floor, allowing the available space to be used in such a way that there is as much room as possible for passengers and low boarding heights can be guaranteed. Going hand in hand with this is a high level of integration of the drive system in what are known as power packs.

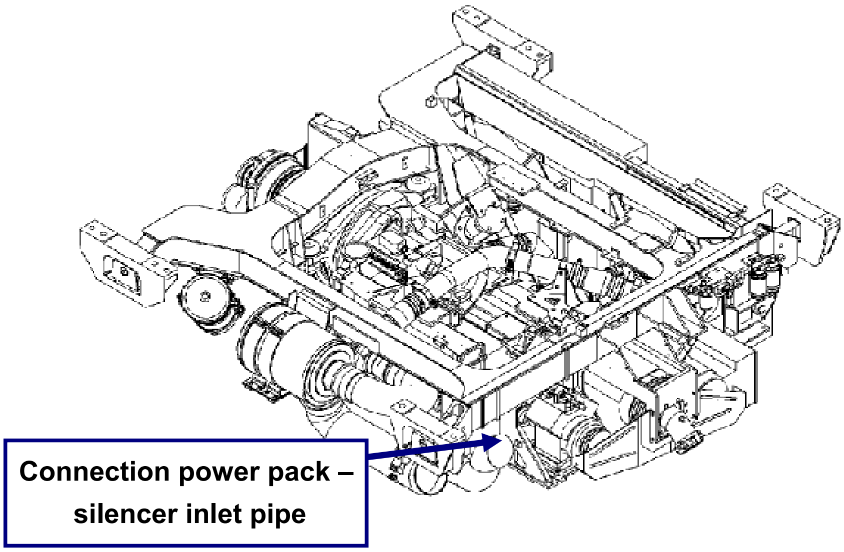


Figure 9.19: Power pack on the VT 642

Space is very cramped in the vehicle's under floor area:

Figure 9.20: Under-floor area on the VT 642

Figure 9.21: MTU 6R 183 TD 13 diesel engine with exhaust pipe on the VT 642

The exhaust piping on the VT 642 runs from the diesel engine through the vehicle body and passenger accommodation area to the vehicle's roof.

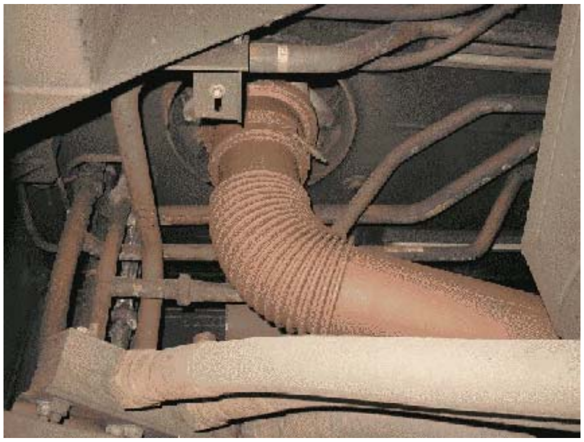


Figure 9.22: Exhaust pipe on the VT 642

The silencer is located in a control cabinet in the passenger accommodation area.

Figure 9.23: Control cabinet with exhaust silencer in the VT 642 passenger accommodation area

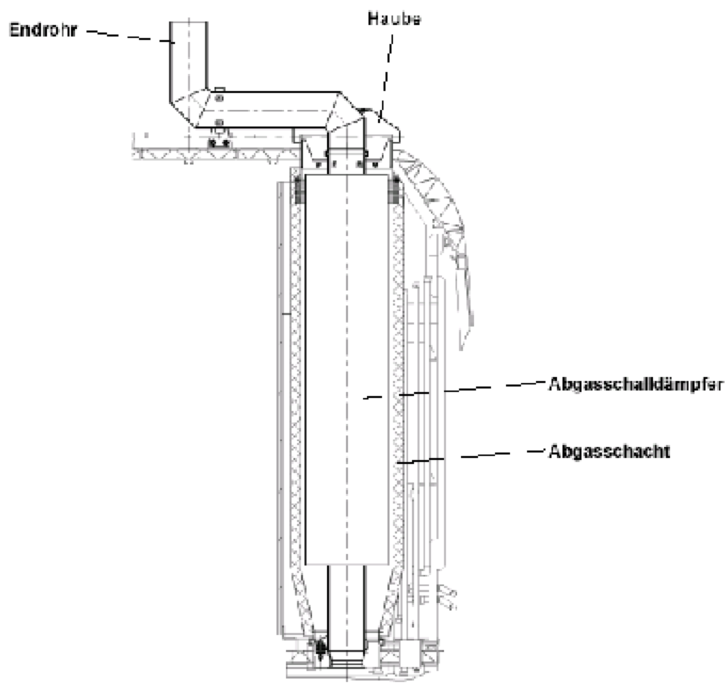


Figure 9.24: Schematic of exhaust silencer in the VT 642 passenger accommodation area

The parameters cited for the VT 642 yield the following options for the various exhaust-gas after treatment technologies:

A6.3.1 Feasibility and Performance of the Technologies When Considering the Available Space (Variant A).

The performance of the systems/technologies has been assessed whilst taking account of the installation space available.

Diesel DPF

- Only conversion rates up to 40 % achievable in space available
- Insufficient space to fit burner for active regeneration purposes

There is only sufficient fitting space on the internal combustion engine railcar to integrate an open-channel system for reducing diesel particulates (as with the VT810). To adhere to the permissible level of exhaust-gas backpressure, a closed-channel system requires an inflow surface that cannot be integrated into the space available on the VT 642. Moreover, the regeneration of such systems causes the filter temperature to rise steeply. The requisite thermal insulation cannot be integrated in the version required.

Particulate precipitation with open channels causes the particulate value for the VT 642 to fall from initially 0.14g/kWh to around 0.085 g/kWh assuming particulate size distribution is comparable to that for modern automotive diesel engines - something that cannot currently be gauged, since the relevant measurements have yet to be made. The particulate value of

0.085 g/kWh is achieved with new diesel engines currently being developed for multiple units without any after treatment equipment. It is necessary to modify the means of attachment for the exhaust gas unit owing to the increase in weight. In addition, checks need to be made to determine whether the body will withstand the additional loading in its current design, whether a counterweight may be required between the two sides of the vehicle (due to uneven loading), and whether the vehicle's licence is still valid given the additional loading on the axles. Reducing the maximum number of passengers could negate the latter issue. Should the additional weight not constitute an insurmountable problem, the following costs are incurred for integrating and using an open DPF system on the VT 642:

Table 9.7: Life Cycle Costs of operating an open DPF system on the VT 642 railcar

Constraints	***Amount***	***Unit of measure***
Anticipated average life	**8**	years
Annual average performance vehicle	**120,000**	km
Diesel consumption	**87**	l/100 km
Cost of diesel	**0.75**	€/l
System data		
Purchase of system (per track vehicle)	**20,500**	€
Development of system (per track vehicle)	**1,000**	€
Integration of system in track vehicle	**1,500**	€
Installation of system	**1,000**	€
Change in diesel consumption	**2**	l/100 km
Change in diesel costs	**1,800**	€/year
Consumption of additional operating supplies	**0**	l/100 km
Cost of additional operating supplies	**0.00**	€/l
Cost of additional operating supplies	**0**	€/year
Change in costs for maintenance	**1,000**	€/year
Total fixed costs	**24,000**	**€**
Total variable costs	**2,800**	**€/year**
Expenses per track vehicle and year	**7,300**	**€/year**

The VT 642 is a multiple unit incorporating 2 internal combustion engines. Thus, each trainset requires 2 after treatment systems costing €10,250 each. Extra outlay totalling €7,300 per year or 6.1 eurocents per kilometre is to be anticipated.

Selective Catalytic Reduction

- Not possible to integrate reducing agent tank, injector, compressed air supply, control gear and catalyst into space available on vehicle.

The inflow surface required for adherence to the permissible level of exhaust-gas backpressure cannot be integrated into the space available on the VT 642. Neither will the necessary thermal insulation gear fit into the control cabinet. Extensive vehicle modifications would be needed (cf. B Variants). Control of reducing agent dosage requires information from the vehicle and engine control gear concerning load and speed. These interfaces would need to be integrated subsequently.

SCRT

- As for SCR + DPF.

The points made above regarding the two systems hold true for a combination of SCR and DPF. Hence, an SCRT system cannot be integrated.

Combined Particulate Oxidation Catalyst (POC)

- As for DPF

The points made above regarding DPF also hold true for a combination of oxidation catalyst and DPF. The problems of integration are exacerbated in that the system’s two components require even more space than a DPF and backpressure through the oxidation catalyst increases still further.

Exhaust Gas Recirculation

- Feasibility of retrofitting the MTU engine with EGR is questionable.
- Larger cooling system necessary.
- Not possible to integrate larger cooling system.

Integrating exhaust gas recirculation gear into existing engines as a means of lowering NO_x emissions is an input-intensive measure. Whereas this is a technology that finds successful application in the development of new engines, retrofitting it is technically very difficult if not impossible. It is not possible to include a cooling system of the requisite size on the VT 642.

Figure 9.25: Space available for a cooling system on the VT 642

Re-engining

- No compatible engine available.

There is no compatible engine available for the purpose of re-engining the VT 642. MTU have ceased building the 183 series. Fitting the successor MTU 6H 1800 engine involves replacing the entire power pack, making this a costly option.

A6.3.2 Feasibility and performance of technologies when conformity with stage IIIB of directive 97/68/EC is considered (Variant B).

The technologies described in Section 1 were tested on the VT 642 to determine whether they permit conformity with stage IIIB of Directive 97/68/EC. The available space was no longer considered a constraint and vehicle refit measures were deemed acceptable:

Oxidation Catalyst

- Emissions of CO and HC reduced.
- NO_x limit value (2.0 g/kWh) and particulate limit value (0.025 g/kWh) not adhered to.

Diesel DPF

- Particulate emissions reduced.
- NO_x limit value (2.0 g/kWh) not adhered to.

Selective Catalytic Reduction

- Emissions of HC, CO, NO_x and particulates reduced
- Particulate limit value (0.025 g/kWh) not adhered to

SCR + DPF

- Currently the only technology facilitating adherence to the limit values prescribed for stage IIIB where existing traction stock is concerned

A fully integrated combination of SCR technology and a diesel particulate filter is necessary in order to meet the strict limit values for NO_x and particulates prescribed for stage IIIB.

The initial value for NO_x emissions from the VT 642 is 7.0 g/kWh given a limit value of 2.0 g/kWh. That necessitates a rate of reduction in the C1 cycle of >71 %. This value can be achieved with SCR technology given the appropriate system size and layout. The initial value for particulates is 0.14 g/kWh, the limit for stage IIIB being 0.025 g/kWh. The requisite conversion rate is thus >82 %, which can only be achieved with closed DPF systems of the appropriate design dimensions. Integrating such a system involves modifying the vehicle configuration. It is necessary to remove two seats and integrate a “regeneration container”. Special attention needs to be paid to thermal and acoustic insulation. Regeneration of the DPF releases approximately 30kW of thermal energy, of which as low an amount as possible must be allowed to penetrate into the passenger accommodation area. Likewise, burner noise has to be attenuated.

Figure 9.26: Space for the "regeneration container" on the VT 642

These measures increase the weight of the system to greater than 450kg. That necessitates comprehensive adjustments to the means of mounting the system and possibly the vehicle body. The additional uneven loading of approximately 300 kg needs to be counterbalanced, thus leading to a further increase in weight. Checks must also be made to determine whether the vehicle licence is still valid given the additional load on the axles or whether a fresh homologation process is required including redesign (and possibly replacement) of the axles. The latter can only be avoided by drastically lowering the maximum number of passengers (by approximately 8). Should the additional weight not constitute an insurmountable problem, the following approximate costs are incurred when integrating and using an SCRT system on the VT 642:

Table 9.8: Life Cycle Costs of operating an SCR + DPF system on the VT 642 railcar

Constraints	***Amount***	***Unit of measure***
Anticipated average life	**8**	years
Annual average performance vehicle	**120,000**	km
Diesel consumption	**87**	l/100 km
Cost of diesel	**0.75**	€/l
System data		
Purchase of system (per track vehicle)	**45,000**	€
Development of system (per track vehicle)	**2,500**	€
Integration of system in track vehicle	**2,500***	€
Installation of system	**6,000***	€

Constraints	Amount	Unit of measure
Change in diesel consumption	**3**	l/100 km
Change in diesel costs	**2,700**	€/year
Consumption of additional operating supplies	**2,2**	l/100 km
Cost of additional operating supplies	**0.40**	€/l
Cost of additional operating supplies	**1,056**	€/year
Change in costs for maintenance	**3,000**	€/year
Total fixed costs	**56,000**	**€**
Total variable costs	**6,756**	**€/year**
Expenses per track vehicle and year	**17,256**	**€/year**

*estimated values

Extra outlay totalling €17,256 per year or 14.4 eurocents per kilometre is to be anticipated.

SCRT
Costs are comparable to SCR + DPF, but additional space could be needed for integration.

Combined Particulate Oxidation Catalyst (POC)

- Emissions of HC, CO and particulates reduced.
- NO_x limit value (2.0 g/kWh) not adhered to.

Exhaust Gas Recirculation

- Stage IIIB not complied with.

Re-engining

- Stage IIIB not complied with.

Summary of the feasibility of technical measures for the VT 642

The VT 642 is configured in a manner typical of modern internal combustion engine railcars. Its low-floor design greatly limits the options for integrating additional items into the existing layout. Extensive conversion measures are required to create sufficient space for exhaust gas after treatment systems. The additional weight is likely to lead to a restriction on the number of passengers permissible. Improvements in exhaust-gas emissions have a significant impact on the cost of operating the stock. The increase in cost per kilometre is 14.4 eurocents.

9.11 A6.4 Mainline locomotive < 1990: Class 232

Figure 9.27: Class 232 mainline locomotive

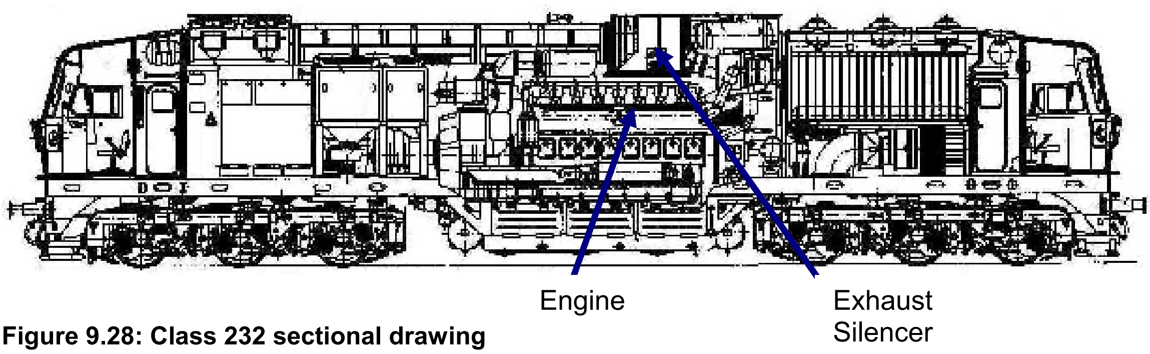


Figure 9.28: Class 232 sectional drawing

Figure 9.28 illustrates the locomotive’s architecture and how its components are laid out. The principal subassembly consists of the diesel engine and exhaust silencer. The exhaust silencer is flexibly connected to the engine and fastened to the locomotive roof. Figure 9.29 gives an impression of the fitting space:

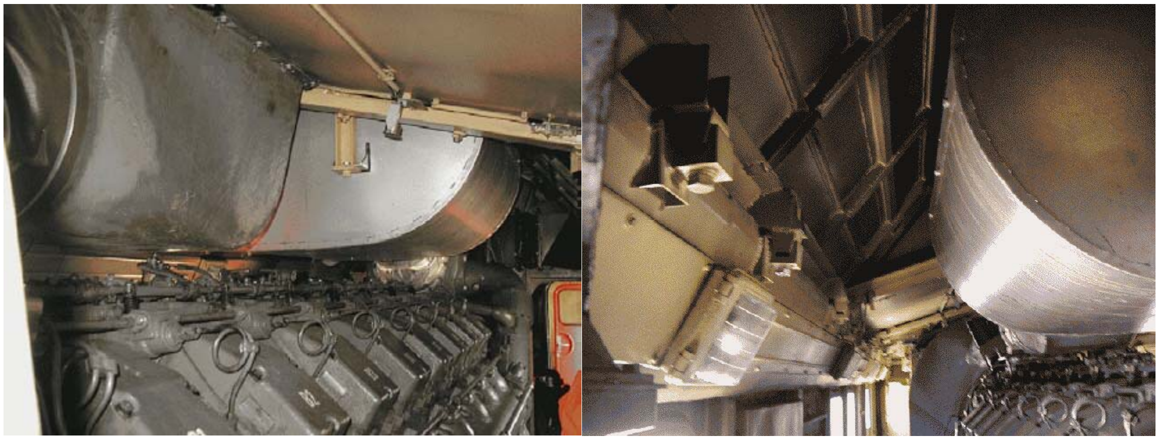


Figure 9.29: Installation set-up for the exhaust silencer

The photos underline just how little space is available on the locomotive. Nothing else can be fitted around the exhaust silencer. The area to the side has to be kept clear to allow operating staff to pass.

A6.4.1 Feasibility and Performance of the Technologies When Considering the Available Space (Variant A).

The performance of the systems/technologies has been assessed whilst taking account of the installation space available.

Diesel DPF (Filter)

- Only conversion rates up to 40% are achievable in space available.
- Not possible to fit a burner for active regeneration or a closed-channel system.

Only an open system for reducing diesel particulates can be incorporated into the existing installation space on the locomotive. This technology does not require any active regeneration and its conversion rates (30-40%) are similar to those produced by retrofit kits employed in the automotive sector. It has no effect upon NO_x emissions. If the exhaust temperature is above 300°C, hydrocarbons and carbon monoxide are reduced by 80%. As illustrated in Table 9.9 retrofitting the locomotive with a DPF with open channels causes its operating costs to rise, so in this instance it makes better sense to fit a successor engine (see below).

Table 9.9: Life Cycle Costs of operating an open DPF system on the Class 232 Locomotive

Constraints	***Amount***	***Unit of measure***
Anticipated average life	**8**	years
Annual average performance vehicle	**47,500**	km
Diesel consumption	**350**	l/100 km
Cost of diesel	**0.75**	€/l
System data		
Purchase of system (per track vehicle)	**80,000**	€
Development of system (per track vehicle)	**5,000**	€
Integration of system in track vehicle	**5,000**	€
Installation of system	**7,500**	€
Change in diesel consumption	**7**	l/100 km
Change in diesel costs	**2,494**	€/year
Consumption of additional operating supplies	**0**	l/100 km
Cost of additional operating supplies	**0.00**	€/l
Cost of additional operating supplies	**0**	€/year

Constraints	***Amount***	***Unit of measure***
Change in costs for maintenance	**5,000**	€/year
Total fixed costs	**97,500**	**€**
Total variable costs	**7,494**	**€/year**
Expenses per track vehicle and year	**25,774**	**€/year**

Extra outlay totalling €25,774 per year or 54.2 eurocents per kilometre is to be anticipated.

Selective Catalytic Reduction

- Not possible to fit reducing agent tank, injector, compressed air supply and control within existing installation space

SCRT

- As for SCR + DPF.

Combined Particulate Oxidation Catalyst (POC)

- As for DPF.

Exhaust Gas Recirculation

- Larger cooling system necessary (increase in size about 30%).
- Not possible to fit larger cooling system.

Re-engining

- Compatible engine available.
- 64 locomotives have been re-engined with Kolomna 12D 49
- (reduction in PM = 50 %, NO_x = 40 %)

Sixty-four DB AG locomotives have been fitted with the more modern Kolomna 12D 49M engine, which yields the following improvements:: NOx: 40 %, PM: 50 %, HC: 25 %, CO: 40 %. Re-engining leads to all pollutant constituents being reduced as well as improving fuel consumption and, by association, the locomotive’s CO2 record and operating costs.

A6.4.2 Feasibility and performance of technologies when conformity with stage IIIB of directive 97/68/EC is considered (Variant B)..

The technologies described in Section 1 were tested on the Class 232 to determine whether they permit conformity with stage IIIB of Directive 97/68/EC. The available space was no longer considered a constraint and vehicle refit measures were deemed acceptable:

Oxidation Catalyst

- Reduction of CO and HC emissions.

- NO_x limit value (4.0 g/kWh) and particulate limit value (0.025 g/kWh)
- are not complied with.

Diesel DPF

- Reduction of particulate emissions.
- NO_x limit value (4.0 g/kWh) is not complied with.

Selective Catalytic Reduction

- Reduction of HC, CO, NO_x and particulate emissions.
- Particulate limit value (0.025 g/kWh) is not complied with.

SCRT

- Currently the only technology delivering compliance with the stage IIIB limit values for heritage stock.

Given the emission values for the engines on Class 232 stock, it is necessary to use the complex technology in the SCRT system to comply with the limit values for stage IIIB. The parameters for a system of this sort would include the following:

- *Dimensions:* 2770x1580x950 (length/width/height) + reducing agent tank (approximately 300l)
- *Pressure loss:* < 100 mbar at full load.
- *Weight:* approximately 2,200 kg + reducing agent (approximately 500 kg)
- *Guide price for the system:* approximately €180,000.

(These data were obtained from the HUG Engineering company, makers of the exhaust gas cleaning system for the G2000 diesel locomotive, a mainline locomotive fitted with exhaust gas cleaning equipment as new)

It is not possible to incorporate the system components in the required configuration as set out above into the existing locomotive layout. A number of the locomotive’s parameters can be cited to explain why this is:

- *Installation space:* The system is approximately 3 times as big as the exhaust silencer. It would be impossible to create the space required even if the locomotive were to be extensively remodelled. The limit for the top of the exhaust silencer is the locomotive roof. It cannot be extended, as the clearance between the top of the silencer and the loading gauge is already no more than about 30 mm. The bottom of the silencer is located directly above the engine. It is likewise impossible to lower the latter since minimum track clearance must be maintained. Located to the sides of the silencer are the exhaust-gas turbocharger for the diesel engine, the traction generator blower and the engine room passageways. No extension is conceivable here either.

- *Weight:* The system is 4 times as heavy as the exhaust silencer. With the system weighing 2,200 kg and reinforcement measures required at the sides and on the roof of the locomotive, axle loads will rise to such an extent that the Class 232 will no longer enjoy Route Availability CE (Class 232 axle load to 21.3t). From an operational point of view this would be a killer blow.

- *Backpressure:* The engine's maximum permissible exhaust gas backpressure is 35 mbar. Backpressure from the aforementioned exhaust gas after treatment system amounts to 100 mbar at full load. The permissible value is significantly exceeded. It is generally possible to exceed this limit value but this gives rise to reduced boost pressure, hotter exhaust gases, higher levels of smoke and higher fuel consumption. Given the level of exhaust-gas backpressure demanded, checks need to be made to determine whether the increase in backpressure can be coped with by adopting relief measures elsewhere (such as limiting height working, reducing the maximum permissible ambient temperature, lowering output, etc) or whether hardware modifications to the supercharging, exhaust piping etc. are required. The input this entails is considerable.

It is impossible to accommodate a system of this size (approximately 4.2 cubic metres) even if the laborious step of increasing the installation space were to be undertaken, since there is insufficient clearance between the locomotive roof and the loading gauge. Neither is it possible to reposition the engine, since the limit values for maximum permissible axle loads are only just complied with under the present load distribution regime.

The system's weight of 2.2 t and the need to secure it to the locomotive's superstructure represent further insurmountable obstacles. Firstly, the maximum permissible axle loads would be exceeded and, secondly, extensive reinforcement of the sidewalls and locomotive roof would be required so as to anchor the system securely and that would further add to the overall weight. The following photos give a good idea of the superstructure on a mainline locomotive - here ÖBB's Class 2016. The fixing points for the exhaust gas unit are visible in Figure 9.31:

Figure 9.30: Locomotive superstructure

Figure 9.31: An illustration of how the exhaust gas system is accommodated

Basic tests accurately replicating the dimensional conditions involved have been carried out at DB AG to establish the correlation between the size of a SCR system and rates of conversion. Using the system, it was possible to reduce emissions of nitrogen oxides by 80 % in the ISO F cycle. No reduction stage for particulates was included.

Figure 9.32: Basic tests on a Class 233 locomotive fitted with the SCR system to reduce nitrogen oxides

It was necessary to set up all the system's components (catalyst unit, reducing agent tank, dosing equipment for the reducing agent, compressed-air and system control) on a road lorry, as it was not possible to install it on the locomotive or establish suitable testing conditions there.

Combined Particulate Oxidation Catalyst (POC)

- Reduction of HC, CO and particulate emissions.
- NO_x limit value (4.0 g/kWh) is not complied with.

Exhaust Gas Recirculation

- Stage IIIB is not complied with.

Re-engining

- Stage IIIB is not complied with.

Summary of the feasibility of technical measures for the Class 232

The explanations in this section clearly highlight the limits to the feasibility of fitting exhaust gas after treatment units on older designs of mainline locomotives. Large, heavy engines with a high throughput of air require corresponding cross sections and system dimensions. It is only possible to fit Class 232 stock with a system for reducing particulates having a conversion rate of between 30 and 40%. Complex systems such as SCR or combinations of SCR and DPFs cannot be entertained because they take up too much space and are too heavy. In this instance it makes far more sense to fit a new engine that reduces all pollutant constituents that are subject to legislation whilst simultaneously cutting CO_2 emissions.

The following Table 3.5 gives an overview of the axle loads of the Class 232 locomotive comparable with Class 233/234, in comparison to maximum allowable axle load for track class CE.

Table 9.10: Summary of axle limits for the Class 232 and similar locomotives

Axle Number	1	2	3	4	5	6
Axle load – track class CE	21.3t	21.3t	21.3t	21.3t	21.3t	21.3t
Weighted Axle load - Class 232 154	20.85	20.8	20.7	20.7	**21.3**	20.5
Weighted Axle load - Class 233 547	20.55	20.7	**21.0**	20.35	20.7	20.35
Weighted Axle load - Class 241	20.5	21.05	**21.25**	**21.3**	**21.3**	**21.3**

9.12 A6.5 Mainline locomotive >1990: Class 218

Figure 9.33: Class 218 mainline locomotive

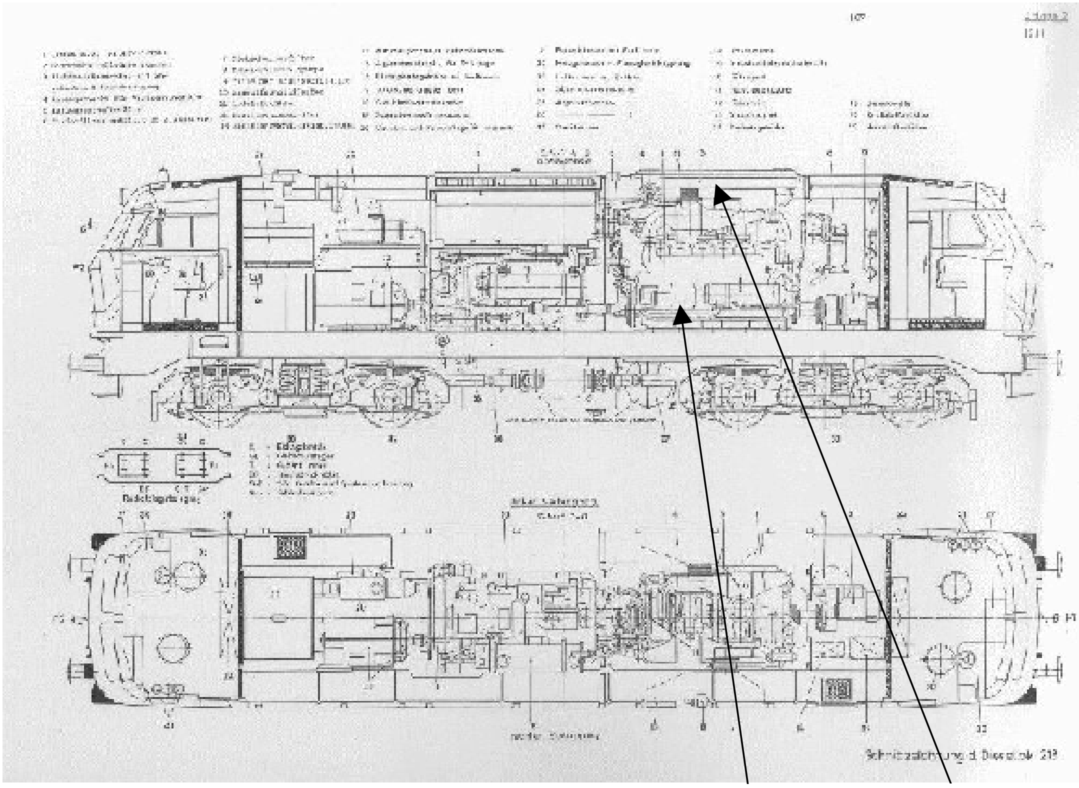


Figure 9.34: Sectional drawing of the 218 engine

Figure 9.34 provides a schematic account of the locomotive's configuration and component layout. The silencer is flexibly connected to the engine and fastened to the locomotive roof. The following pictures convey an impression of the fitting space available:

Figure 9.35: Installation set-up for the exhaust silencer

Figure 9.36: Space to the sides of the exhaust silencer

Figure 9.36 illustrates the spatial conditions on the locomotive. The only additional fitting space available around the exhaust silencer is to the side and beneath it (between engine and exhaust silencer). This would, however, require making modifications to the engine/exhaust gas unit interface and the means of attachment. Modifications would also need to be made to the locomotive roof and side walls in order to accommodate the surplus weight.

A6.5.1 Feasibility and Performance of the Technologies When Considering the Available Space (Variant A).

The performance of the systems/technologies has been assessed whilst taking account of the installation space available.

Diesel DPF

- Integrating a DPF with active regeneration is feasible.

A closed-channel filter system for reducing diesel particulates can be integrated into the space available on the Class 218 locomotive. This technology requires a form of active regeneration in rail applications to prevent the filter clogging up and backpressure becoming unacceptably high as a consequence.

The system inclusive of burner weighs approximately 1,600 kg and thus approximately 1,100 kg more than a serial exhaust silencer. It is therefore necessary to take extensive action to reinforce the means of attachment, the locomotive roof and its side walls. It may be necessary to design and integrate an auxiliary frame supported on the locomotive base frame and accepting the exhaust gas cleaning system.

If Class 218 stock is to continue to enjoy C2 Route Availability, during any retrofit programme thought must be given the locomotive’s permissible axle tonnage ratings since axle loads must not exceed 20t. Exceedance of these values cannot be tolerated.

The conversion rate depends on the filter’s size and configuration (cellular density, carrier material etc.) as well as on the test cycle and is generally greater than 90%. Using this system on Class 218 stock allows the particulate value to be improved from initially 0.152g/kWh to < 0.025g/kWh and thus meet the limit value prescribed for stage IIB. Should the additional weight not constitute an insurmountable problem, the following costs are incurred when integrating and using a closed DPF system on Class 218 stock:

Table 9.11: Life Cycle Costs of operating a closed DPF system on the Class 218 Locomotive

Constraints	***Amount***	***Unit of measure***
Anticipated average life	**8**	years
Annual average performance vehicle	**125,000**	km
Diesel consumption	**250**	l/100 km
Cost of diesel	**0.75**	€/l
System data		
Purchase of system (per track vehicle)	**110,000**	€
Development of system (per track vehicle)	**3,500**	€
Integration of system in track vehicle	**5,000**	€
Installation of system	**10,000**	€
Change in diesel consumption	**10**	l/100 km
Change in diesel costs	**9,375**	€/year
Consumption of additional operating supplies	**0**	l/100 km
Cost of additional operating supplies	**0.00**	€/l
Cost of additional operating supplies	**0**	€/year
Change in costs for maintenance	**5,000**	€/year
Total fixed costs	**128,500**	**€**
Total variable costs	**14,375**	**€/year**
Expenses per track vehicle and year	**38,475**	**€/year**

Extra outlay totalling €38,475 per year or 30.8 eurocents per kilometre is to be anticipated.

Selective Catalytic Reduction

- While it is possible to integrate the reducing agent tank, injector, compressed air supply and control gear into the space available, the blending section for reducing agent + exhaust gas is too short.

A series of additional components need to be integrated along with the catalyst for the SCR system. In the case of Class 218 stock, this could conceivably be in the transmission room.

Figure 9.37: Class 218 transmission room

Successfully reducing NO_x is dependent on there being a section of sufficient length for blending the reducing agent with the exhaust gas prior to their entering the catalyst. Given the volume flows produced by the MTU 4000 engine, a minimum length of approximately 2 m is necessary (cf. basic tests on Class 232, Figure 9.32). This is not achieved in the case of the Class 218 locomotive where the distance between turbocharger outlet and exhaust silencer inlet is approximately 0.5 m (please see Figure 9.37) and is thus far too short to achieve adequate homogenisation. SCR technology cannot, therefore, be successfully utilised on Class 218 stock.

SCRT

- As with SCR + DPF

Combined Particulate Oxidation Catalyst (POC)

- Due to space and weight constraints it is not possible to integrate an oxidation catalyst as well a DPF.

Dividing the space available up between DPF and oxidation catalyst to suit the desired ratio of conversion rates for particulates and, respectively, HC and CO would be feasible. Given that particulates are the more critical component in terms of future limit values, POC technology does not serve the desired purpose especially well. Nevertheless, should its use on Class 218 stock be considered, the costs are comparable with those for the DPF.

Exhaust Gas Recirculation

- Possibly feasible to retrofit the MTU engine with EGR.
- Larger cooling system necessary.
- Not possible to integrate larger cooling system.

Integrating an exhaust gas recirculation system represents an input-intensive means of cutting NO_x emissions from existing engines. Firstly, the engine control system requires a variety of data so it can regulate the exhaust gas recirculation rate and, secondly, it is necessary to integrate a larger cooling system. The latter is not possible in the case of the Class 218 mainline locomotive.

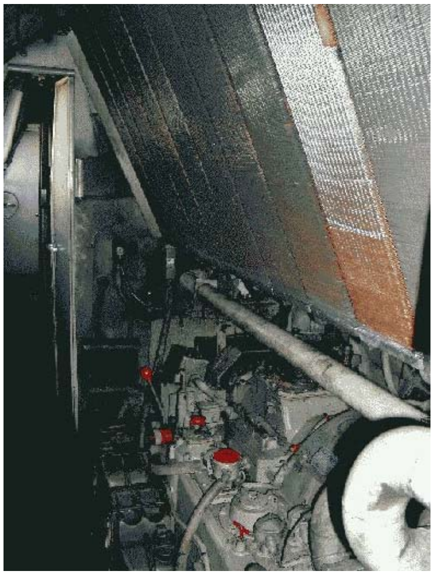


Figure 9.38: Class 218 cooling system

Re-engining

- No compatible engine currently available.

A6.4.2 Feasibility and performance of technologies when conformity with stage IIIB of Directive 97/68/EC is considered (Variant B).

The technologies described in Section 1 were tested on the Class 232 to determine whether they permit conformity with stage IIIB of Directive 97/68/EC. The available space was no longer considered a constraint and vehicle refit measures were deemed acceptable:

Oxidation Catalyst

- Emissions of CO and HC reduced.
- NO_x limit value (4.0 g/kWh) and particulate limit value (0.025 g/kWh) not adhered to.

Diesel DPF

- Particulate emissions reduced.
- NO_x limit value (4.0 g/kWh) not adhered to.

Selective Catalytic Reduction

- Emissions of HC, CO, NO_x and particulates reduced.
- Particulate limit value (0.025 g/kWh) not adhered to.

SCR + DPF

- Apart from SCRT, SCR + DPF is the only technology for existing traction stock that adheres to the limit values prescribed for stage IIIB.

A fully integrated combination of SCR technology with a particulate filter is necessary in order to meet the strict limit values for NO_x and particulates prescribed for Stage IIIB.

Such a system would include the following parameters:
- Dimensions: 2770 x 1580 x 950 (length x width x height) + reducing agent tank (approximately 200 litres)
- Pressure loss < 100 mbar at full load.
- Weight approximately 2,200 kg + reducing agent (approximately 300kg)
- Guide price for the system approximately €180,000

(Details from HUG Engineering, makers of the exhaust gas cleaning system on the G2000, a new mainline diesel locomotive being fitted out with exhaust gas cleaning gear).

Integrating the system constituents in the requisite configuration as set out above is not possible even if the appropriate modifications are carried out. The reasons are as for the Class 232 mainline locomotive: requisite fitting space, additional weight and permissible exhaust-gas backpressure.

A combination of smaller versions of SCR and DPF involving lower weights and sizes and reduced conversion rates would be feasible. The problem of the necessary homogenisation length (or time) can be overcome by fitting the DPF upstream of the SCR catalyst. Adherence to the limit values prescribed for stage IIIB would not be delivered, but improvements in NO_x and particulates in the range of 50 to 70 % would be achievable.

This is, however, conditional upon the weight problem being resolved (cf. pronouncements concerning the DPF). Dealing with such a problem would give rise to the following additional LCC costs:

Table 9.12: Life Cycle Costs of operating an SCR + DPF system on the Class 218 Locomotive

Constraints	***Amount***	***Unit of measure***
Anticipated average life	**8**	years
Annual average performance vehicle	**125,000**	km
Diesel consumption	**250**	l/100 km
Cost of diesel	**0.75**	€/l
System data		
Purchase of system (per track vehicle)	**150,000**	€
Development of system (per track vehicle)	**5,000**	€
Integration of system in track vehicle	**5,000**	€
Installation of system	**15,000**	€

Constraints	***Amount***	***Unit of measure***
Change in diesel consumption	**7.5**	l/100 km
Change in diesel costs	**7,031**	€/year
Consumption of additional operating supplies	**10**	l/100 km
Cost of additional operating supplies	**0.40**	€/l
Cost of additional operating supplies	**5,000**	€/year
Change in costs for maintenance	**7,500**	€/year
Total fixed costs	**175,000**	**€**
Total variable costs	**19,531**	**€/year**
Expenses per track vehicle and year	**52,331**	**€/year**

Extra outlay totalling €52,331 per year or 41.9 eurocents per kilometre is to be anticipated.

Combined Particulate Oxidation Catalyst (POC)

- Emissions of HC, CO and particulates reduced.
- NO_x limit value (4.0 g/kWh) not adhered to.

Exhaust Gas Recirculation

- Stage IIIB not complied with.

Re-engining

- Stage IIIB not complied with.

Summary of the feasibility of technical measures for the Class 218

The points made in this section clearly reveal the limits to the feasibility of adding exhaust gas after treatment units to newer mainline locomotive designs. No thought was given to fitting exhaust gas after treatment systems when the locomotive layout was conceived and configured. Factors limiting the system's feasibility are the fitting space required, high additional loadings and increased exhaust-gas backpressure. Modification measures would create sufficient space to integrate a DPF system inclusive of regeneration facility or else a combination of SCR system and DPF on Class 218 stock. This is, however, conditional upon the weight problem being resolved. (cf. Subsection DPF). It remains to be seen whether the successor to the MTU 4000 16V R40 engine can deliver significant improvements regarding emissions of NO_x and particulates without any form of exhaust gas after treatment. The rise in LCC costs would be less drastic in that case.

The following Table 9.13 shows the allowable axle load of the track class C2, for the BR 218 locomotive and the locomotive with MTU 4000 16V engine.

Table 9.13: Summary of allowable axle loads of track class C2 in relation to the BR 218 locomotive

Axle Number	1	2	3	4
Axle load – track class C2	20 t	20 t	20 t	20 t
Maximum axle load for locomotive	20.4 t	20.4 t	20.4 t	20.4 t
Weight of locomotive with engine MTU 4000 16V	78 t			

9.13 A6.6 Shunting locomotive < 1990: Class 742

Figure 9.39: Class 742 shunting locomotive

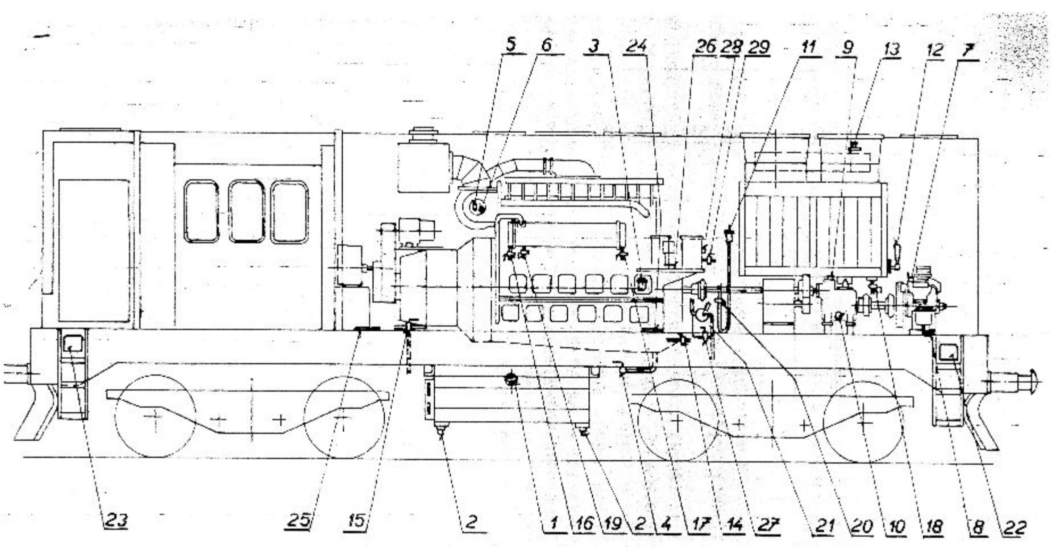


Figure 9.40: Sectional drawing of Class 742 engine and exhaust silencer

Figure 9.41: Locomotive configuration with engine and exhaust gas unit

Figure 9.40 and Figure 9.41 illustrate the configuration of the locomotive and the layout of components. The exhaust silencer is located to the rear of the engine and could be enlarged.

A6.6.1 Feasibility and Performance of the Technologies When Considering the Available Space (Variant A).

The performance of the systems/technologies has been assessed whilst taking account of the installation space available.

Diesel DPF

- Possible to integrate a DPF with active regeneration.

A closed-channel filter system for reducing diesel particulates can be integrated into the fitting space available on the Class 742 locomotive. Including the burner the system weighs approximately 500 kg and it is therefore necessary to reinforce the means of attachment. It may be necessary to design and integrate an auxiliary frame that accepts the exhaust gas cleaning system and is supported on the locomotive base frame. Another factor that warrants serious consideration is the locomotive’s axle tonnage ratings.

The conversion rate depends on the filter’s size and configuration (cellular density, carrier material etc.) as well as on the test cycle and is generally greater than 90%. Using this system on Class 742 stock allows the particulate value to be improved from 0.6g/kWh initially to less than 0.06g/kWh and thus meet the limit value prescribed for stage IIIA. Should the additional weight not constitute an insurmountable problem, the following costs are incurred when integrating and using a closed DPF system on Class 742 stock:

Table 9.14: Life Cycle Costs of operating a closed DPF system on the Class 742 Locomotive

Constraints	***Amount***	***Unit of measure***
Anticipated average life	**8**	years
Annual average performance vehicle	**2,500**	h
Diesel consumption	**35**	L/h
Cost of diesel	**0.75**	€/l
System data		
Purchase of system	**45,000**	€
Development of system (per track vehicle)	**3,000**	€
Integration of system in track vehicle	**3,000**	€
Installation of system	**2,500**	€
Change in diesel consumption	**1.5**	L/h
Change in diesel costs	**2,813**	€/year
Consumption of additional operating supplies	**0**	l/100 km
Cost of additional operating supplies	**0.00**	€/l
Cost of additional operating supplies	**0**	€/year
Change in costs for maintenance	**3,000**	€/year
Total fixed costs	**53,500**	**€**
Total variable costs	**5,813**	**€/year**
Expenses per track vehicle and year	**15,843**	**€/year**

Extra outlay totalling €15,843 per year or 6.33 eurocents per kilometre is to be anticipated.

Selective Catalytic Reduction

- Whilst it is possible to integrate the reducing agent tank, injector, compressed air supply and control gear into the space available, the blending section for reducing agent + exhaust gas is too short.

A series of additional components need to be integrated along with the catalyst for the SCR system. In addition, successfully reducing NO_x is dependent on there being a section of sufficient length for blending the reducing agent with the exhaust gas prior to them entering the catalyst.

Given the volume flows produced by the engine on Class 742 stock, a minimum length of approximately 1.5 m is necessary (cf. basic tests on Class 232 see earlier section). In a similar manner to the Class 218 stock, this is not achievable on the Class 742 locomotive. The distance between turbocharger outlet and exhaust silencer inlet is approximately 0.4 m (cf. Figure 9.41) and is thus far too short to achieve adequate homogenisation. SCR technology cannot, therefore, be utilised successfully on Class 742 stock.

SCRT

- As for SCR + DPF.

Combined Particulate Oxidation Catalyst (POC)

- Due to space and weight constraints, it is not possible to integrate an oxidation catalyst along with the DPF.

Dividing the space available up between DPF and oxidation catalyst to suit the desired ratio of conversion rates for particulates and, respectively, HC and CO would be possible. Given that particulates are the more critical component in terms of future limit values, this technology does not serve the desired purpose especially well. Nevertheless, should its use on Class 742 stock be considered, the costs are comparable with those for the DPF.

Exhaust Gas Recirculation

- Feasibility of retrofitting engine with EGR very improbable
- Larger cooling system necessary.
- Not possible to integrate larger cooling system.

Integrating an exhaust gas recirculation system represents an input-intensive means of cutting NO_x emissions from existing engines. Firstly, the engine control system requires a variety of data so it can regulate the exhaust gas recirculation rate and, secondly, it is necessary to integrate a larger cooling system. The former is not possible in the case of the Class 742 shunting locomotive.

Re-engining

- No compatible engine currently available

A6.6.2 Feasibility and performance of technologies when conformity with stage IIIB of Directive 97/68/EC is considered (Variant B).

The technologies described in Section 1 were tested on the Class 742 to determine whether they permit conformity with stage IIIB of Directive 97/68/EC. The available space was no longer considered a constraint and vehicle refit measures were deemed acceptable:

Oxidation Catalyst

- Emissions of CO and HC reduced.
- NO_x limit value (4.0 g/kWh) and particulate limit value (0.025 g/kWh) not adhered to.

Diesel DPF

- Particulate emissions reduced.
- NO_x limit value (4.0 g/kWh) not adhered to.

Selective Catalytic Reduction

- Emissions of HC, CO, NO_x and particulates reduced
- Particulate limit value (0.025 g/kWh) not adhered to

SCR + DPF

- Apart from SCRT, SCR + DPF is the only technology for existing traction stock that adheres to the limit values prescribed for stage IIIB.

Given the present emission values for Class 742 stock, it would be necessary to reduce NO_x by more than 77 % in the ISO-F cycle to meet the limit values prescribed for stage IIIB. Particulate emissions would have to be cut by more than 96 % in the test cycle. An SCR + DPF system of this sort would have the following dimensions: 1,500 x 1,200 x 1,000 (mm) and would weigh approximately 850 kg. A system of that scale cannot be accommodated on Class 742 stock. The maximum fitting space available is roughly 1,500 x 1,000 x 700 (mm).

A combination of smaller versions of SCR and DPF involving lower weights and sizes and reduced conversion rates would be feasible. The problem associated with the requisite homogenisation length (or time) can be overcome by fitting the DPF upstream of the SCR catalyst. Adherence to the limit values prescribed for stage IIIB would not be delivered, but improvements in NO_x and particulates in the range of 50 to 70% would be achievable. This is, however, conditional upon the weight problem being resolved (cf. pronouncements concerning the DPF). Assuming that is possible, a system achieving 50-70% abatement would give rise to the following additional LCC costs:

Table 9.15: Life Cycle Costs of operating an SCR + DPF system on the Class 742 Locomotive

Constraints	***Amount***	***Unit of measure***
Anticipated average life	**8**	years
Annual average performance vehicle	**2,500**	H
Diesel consumption	**35**	l/h
Cost of diesel	**0.75**	€/l
System data		
Purchase of system	**70,000**	€
Development of system (per track vehicle)	**4,000**	€
Integration of system in track vehicle	**4,000**	€
Installation of system	**6,000**	€
Change in diesel consumption	**1.5**	l/h
Change in diesel costs	**2,813**	€/year
Consumption of additional operating supplies	**1**	l/h
Cost of additional operating supplies	**0.40**	€/l
Cost of additional operating supplies	**1,000**	€/year
Change in costs for maintenance	**3,000**	€/year
Total fixed costs	**84,000**	**€**
Total variable costs	**6,813**	**€/year**
Expenses per track vehicle and year	**22,563**	**€/year**

Extra outlay totalling €22,563 per year or 9.03 eurocents per kilometre is to be anticipated.

Combined Particulate Oxidation Catalyst (POC)

- Emissions of HC, CO and particulates reduced.
- NO_x limit value (4.0 g/kWh) not adhered to.

Exhaust Gas Recirculation

- Stage IIIB not complied with.

Re-engining

- Stage IIIB not complied with.

Summary of the feasibility of technical measures for the Class 742

The points made in this section clearly reveal the limited feasibility of adding exhaust gas after treatment units to older designs of shunting locomotive as well as the limited results that can be achieved even if feasibility wasn't an issue. Modification measures would create sufficient space to integrate a DPF system inclusive of regeneration facility or else a combination of SCR system and DPF on Class 742 stock. This is, however, conditional upon the weight problem being resolved. (cf. Subsection DPF). As with the representative of older 'heritage' mainline locomotives (Class 232), fitting a modern diesel engine appears to be the most effective means of reducing emissions. This depends on a suitable model being available, which cannot always be guaranteed. This option would also make it possible to reduce CO_2 levels and operating costs.

9.14 A6.7 Shunting locomotive >1990: Class 290

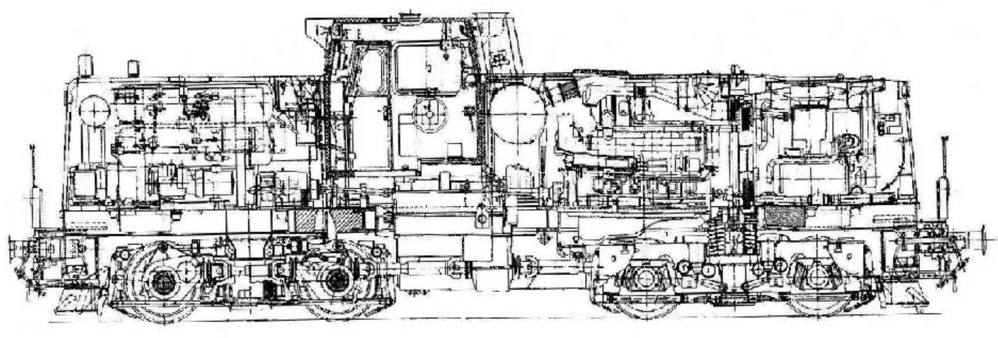


Figure 9.42: Sectional drawing of Class 290 shunting locomotive

Figure 9.43: Engine compartment of Class 290 vehicle

Figure 9.42 to Figure 9.45 illustrate the configuration of the locomotive and the layout of components. The exhaust silencer is located to the rear of the engine and could be enlarged. There is also utilisable space above the engine.

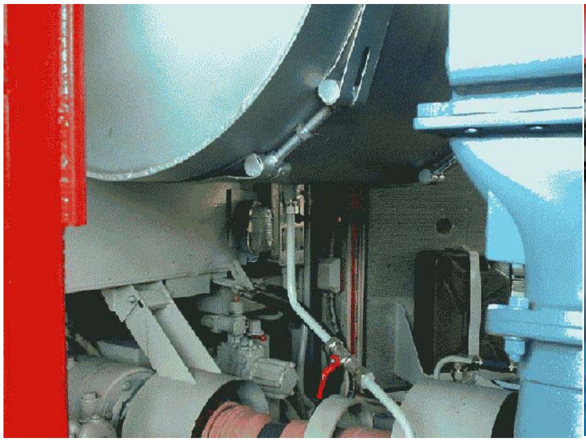


Figure 9.44: Class 290 exhaust silencer

Figure 9.45: Engine-silencer connection on the Class 290 vehicle

A6.7.1 Feasibility and Performance of the Technologies When Considering the Available Space (Variant A).

The performance of the systems/technologies has been assessed whilst taking account of the installation space available.

Diesel DPF

- It is possible to integrate a DPF with active regeneration.

A closed-channel filter system for reducing diesel particulates can be integrated into the fitting space available on the Class 294 locomotive. Including the burner the system weighs approximately 600 kg and it is therefore necessary to reinforce the means of attachment. It may be necessary to design and integrate an auxiliary frame that accepts the exhaust gas cleaning system and is supported on the locomotive base frame. Another factor that warrants serious attention is the locomotive's axle tonnage ratings.

The conversion rate depends on the filter's size and configuration (cellular density, carrier material, etc.) as well as on the test cycle and is generally greater than 90%. Using this system on Class 290 stock allows the particulate value to be improved from 0.16g/kWh initially to less than 0.025g/kWh, thus meet the limit value prescribed for stage IIIB. Should the additional weight not constitute an insurmountable problem, the following costs are incurred when integrating and using a closed DPF system on Class 294 stock:

Table 9.16: Life Cycle Costs of operating a closed DPF system on the Class 290 Locomotive

Constraints	Amount	Unit of measure
Anticipated average life	**8**	Years
Annual average performance vehicle	**3,500**	H
Diesel consumption	**42**	l/h
Cost of diesel	**0.75**	€/l
System data		
Purchase of system	**55,000**	€
Development of system (per track vehicle)	**3,000**	€
Integration of system in track vehicle	**3,000**	€
Installation of system	**3,000**	€
Change in diesel consumption	**2**	l/h
Change in diesel costs	**5,250**	€/year
Consumption of additional operating supplies	**0**	l/100 km
Cost of additional operating supplies	**0.00**	€/l
Cost of additional operating supplies	**0**	€/year
Change in costs for maintenance	**3,000**	€/year
Total fixed costs	**64,000**	**€**
Total variable costs	**8,250**	**€/year**
Expenses per track vehicle and year	**20,250**	**€/year**

Extra outlay totalling €20,250 per year or 5.78 eurocents per kilometre is to be anticipated.

Selective Catalytic Reduction (SCR)

- Possible to integrate the reducing agent tank, injector, compressed air supply and control gear into the space available with some adjustments.

A series of additional components need to be integrated along with the catalyst for the SCR system. The largest of these is the reducing agent tank, which needs to be housed on the locomotive so as to be readily accessible. In the case of the Class 294 vehicle, the auxiliaries' room is a potential solution.

Figure 9.46: Auxiliaries room on the Class 294 vehicle

Taking on reducing agent during refuelling would necessitate a volume of approximately 60 litres. Furthermore, successfully reducing NO_x is dependent on there being a section of sufficient length for blending the reducing agent with the exhaust gas prior to their entering the catalyst. This is not the case with Class 290 stock. The distance between turbocharger outlet and exhaust silence inlet is only about 1.40 m (cf. Figure 9.44 and Figure 9.45). 80% conversion rates are possible in respect of NO_x and HC emissions. Particulates are cut by about 20%. This allows a NO_x value of 2.3g/kWh and a PM value of 0.13g/kWh to be achieved for Class 290 stock. The following outlay is to be anticipated:

Table 9.17: Life Cycle Costs of operating an SCR system on the Class 290 Locomotive

Constraints	***Amount***	***Unit of measure***
Anticipated average life	**8**	years
Annual average performance vehicle	**3,500**	h
Diesel consumption	**45**	l/h
Cost of diesel	**0.75**	€/l
System data		
Purchase of system	**50,000**	€
Development of system (per track vehicle)	**3,000**	€
Integration of system in track vehicle	**3,000**	€
Installation of system	**3,500**	€
Change in diesel consumption	**0**	l/h
Change in diesel costs	**0**	€/year
Consumption of additional operating supplies	**1.5**	l/h
Cost of additional operating supplies	**0.40**	€/l

Constraints	Amount	Unit of measure
Cost of additional operating supplies	**2,100**	€/year
Change in costs for maintenance	**3,000**	€/year
Total fixed costs	**59,500**	**€**
Total variable costs	**5,100**	**€/year**
Expenses per track vehicle and year	**16,260**	**€/year**

Extra outlay totalling €16,260 per year or 4.65 eurocents per kilometre is to be anticipated.

SCR + DPF

- Integrating an SCR + DPF system is only possible to a limited extent (cf. B Variants – SCR + DPF)

Combined Particulate Oxidation Catalyst (POC)

- Due to space and weight constraints, it is not possible to integrate an oxidation catalyst along with the DPF.
- Dividing the space available up between DPF and oxidation catalyst to suit the desired ratio of conversion rates for particulates and, respectively, HC and CO would be conceivable. Given that particulates are the more critical component in terms of future limit values, this technology does not serve the desired purpose especially well. Nevertheless, should its use on Class 290 stock be considered, the costs are comparable with those for the DPF.

Exhaust Gas Recirculation

- Feasibility of retrofitting engine with EGR questionable.
- Larger cooling system may be required.

Integrating an exhaust gas recirculation system represents an input-intensive means of cutting NO_x emissions from existing engines. The desired purpose is better served if EGR is factored into actual development of the engine. MTU has been trialling this technology together with DB since May 2005 on a Class 290 technology carrier. The diesel engine on this locomotive was not retrofitted with EGR, however; instead, the complete engine was replaced.

Re-engining

- No compatible engine currently available.

A6.7.2 Feasibility and performance of technologies when conformity with stage IIIB of directive 97/68/EC is considered (Variant B).

The technologies described in Section 1 were tested on the Class 290 to determine whether they permit conformity with stage IIIB of Directive 97/68/EC. The available space was no longer considered a constraint and vehicle refit measures were deemed acceptable:

Oxidation Catalyst

- Emissions of CO and HC reduced.
- NO_x limit value (4.0 g/kWh) and particulate limit value (0.025 g/kWh) not adhered to.

Diesel DPF

- Particulate emissions reduced.
- NO_x limit value (4.0 g/kWh) not adhered to.

Selective Catalytic Reduction

- Emissions of HC, CO, NO_x and particulates reduced.
- Particulate limit value (0.025 g/kWh) not adhered to.

SCR + DPF

- Apart from SCRT, SCR + DPF is the only technology for existing traction stock that adheres to the limit values prescribed for stage IIIB.

A fully integrated combination of SCR technology with a particulate filter is necessary in order to meet the strict limit values for NO_x and particulates prescribed for Stage IIIB.

Given the present emission values for Class 290 stock, it would be necessary to reduce NO_x by more than 70% in the ISO-F cycle to meet the limit values prescribed for stage IIIB. Particulate emissions would have to be cut by more than 85% in the test cycle. A system of this sort would have the following dimensions: 1,600 x 1,250 x 1,000 (mm) and would weigh approximately 900 kg. This is a scale that cannot be accommodated on Class 290 stock. The maximum fitting space available is roughly 1,200 x 1,000 x 700 (mm). A combination of smaller versions of SCR and DPF involving lower weights and sizes and reduced conversion rates would be feasible as with Class 742 stock. Adherence to the limit values prescribed for stage IIIB would not be delivered, but improvements in NO_x and particulates in the range of 50 to 70% would be achieved. This is, however, conditional upon the weight problem being resolved (cf. pronouncements concerning the DPF). Assuming those issues were dealt with, the following additional LCC costs would be incurred:

Table 9.18: Life Cycle Costs of operating an SCR + DPF system on the Class 290 Locomotive

Constraints	***Amount***	***Unit of measure***
Anticipated average life	**8**	years
Annual average performance vehicle	**3,500**	h
Diesel consumption	**45**	l/h
Cost of diesel	**0.75**	€/l
System data		
Purchase of system	**85,000**	€
Development of system (per track vehicle)	**5,000**	€

Constraints	Amount	Unit of measure
Integration of system in track vehicle	**5,000**	€
Installation of system	**7,000**	€
Change in diesel consumption	**2**	L/h
Change in diesel costs	**5.250**	€/year
Consumption of additional operating supplies	**1.5**	L/h
Cost of additional operating supplies	**0.40**	€/l
Cost of additional operating supplies	**2,100**	€/year
Change in costs for maintenance	**3,000**	€/year
Total fixed costs	**102,000**	**€**
Total variable costs	**10,350**	**€/year**
Expenses per track vehicle and year	**29,470**	**€/year**

Extra outlay totalling €29,470 per year or 8.42 eurocents per kilometre is to be anticipated.

Combined Particulate Oxidation Catalyst (POC)

- Emissions of HC, CO and particulates reduced.
- NO_x limit value (4.0 g/kWh) not adhered to.

Exhaust Gas Recirculation

- Stage IIIB not complied with.

Re-engining

- Stage IIIB not complied with.

Summary of the feasibility of technical measures for the Class 290

The points made in this section clearly reveal the limited feasibility of adding exhaust gas after treatment units to older designs of shunting locomotive as well as the limited results that can be achieved even if feasibility wasn't an issue. Modification measures would create sufficient space to integrate a DPF system inclusive of regeneration facility or else a combination of SCR system and DPF. This is, however, conditional upon the weight problem being resolved. (cf. Subsection DPF). It remains to be seen whether the successor to the MTU 4000 8V engine can deliver significant improvements in NO_x and particulate emissions without any form of exhaust gas after treatment. Under those circumstances the rise in LCC costs would be less drastic.

The following Table 9.19 shows the allowable axle load of the track class C2, for the Class 294 locomotive and the locomotive with MTU 4000 8V engine.

Table 9.19: Summary of allowable axle loads of track class C2 in relation to the Class 294 locomotive

Axle Number	1	2	3	4
Axle load – track class C2	20 t	20 t	20 t	20 t
Maximum axle load for locomotive	20.5 t	20.5 t	20.5 t	20.5 t
Weight of locomotive with engine MTU 4000 8V	78.7 t			

9.15 A6.8 Applicability for SNCF vehicles

For each type of representative vehicle, the potential to integrate a post-treatment system has been examined. The conclusions in the tables are from a basic feasibility study and so when it is indicated a technical solution might be possible, it will be necessary:

- To ask the manufacturers to undertake complete feasibility and integration study.
- To undertake some tests in order to determine the efficiency of the system.

The costs are based on road technology.

Table 9.20: Technical data of representative vehicles

	Railcars	Mainline locomotives	Shunting locomotives
Type of vehicle	X 73500	BB 67000	Y 8000
Type and name of engine	MAN D 2866 LUH 21	PIELSTICK 16 PA4 185	RVI MIDR 06 20 45
Engine power [kW]	2 x 257	1765	220
Type of power transmission	Diesel hydraulic	Diesel electric	Diesel hydraulic
Diesel consumption [g/kWh]	2 x 240	270	230
CO emissions factor [g/kWh]	2 x 0,67	2,25	0,66
HC emissions factor [g/kWh]	2 x 0,41	0,23	0,40
NOx emissions factor [g/kWh]	2 x 7,69	6,66	6,20
PM emissions factor [g/kWh]	2 x 0,16	0,22	0,12
Test cycle	ISO 8178 F	ISO 8178 F	ISO 8178 F

Type of vehicle	X 73500	BB 67000	Y 8000
Idle point			
Engine power [kW]	3	5	1
Exhaust gas temperature [°C]	148	105	105
Exhaust gas flow [kg/h]	334	1971	178
Intermediate point			
Engine power [kW]	110	500	72
Exhaust gas temperature [°C]	340	345	375
Exhaust gas flow [kg/h]	873	4493	548
Full power point			
Engine power [kW]	259	1764	218
Exhaust gas temperature [°C]	428	479	465
Exhaust gas flow [kg/h]	1962	13221	1462

A6.8.1 X 73500 Railcar

Figure 9.47: Class X 73500 railcar

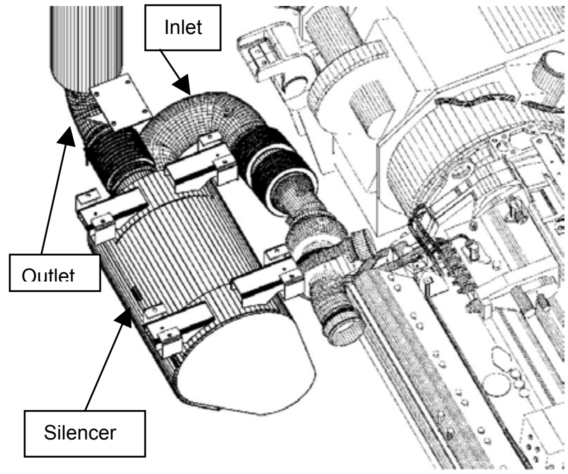


Figure 9.48: Class X 73500 railcar schematic of silencer area

Table 9.21: Technical solutions for X 73500 railcar

Technical solutions	Application on X 73500
Diesel particles trap	No clearance
Catalytic oxidation	Possible
Selective Catalytic Reduction (SCR)	Possible
Continuous Regenerating Trap (CRT)	No clearance
SCRT (SCR + CRT)	No clearance
Exhaust Gas Recirculation (EGR)	Possible with modifications of the cooling system
Re-engining	Possible with important modifications
Compressed Natural Gas	Possible with important modifications
Liquefied Natural Gas	Not possible
Bio-fuels	Not positive results
Fuel and water emulsions	Not positive results
Fuel additives	Not positive results

It's not possible to integrate a DPF even if the silencer was replaced. The reasons are as follows:

- The exhaust gas inlet and outlet are in the same face on the silencer.
- Volume of the silencer and existing space.

For catalytic oxidation (reduction of CO and HC emissions), the system be incorporated in area occupied by the silencer. The mean constraint is the value of the gas pressure at the turbocharger's outlet. The maximum allowable pressure is 100 mbar at full load. The estimated cost for a prototype is around €13,000.

The SCR technology for the reduction of NO_x emissions is applicable although it would be necessary to integrate a urea tank. The minimum capacity in order to be compatible with the fuel consumption is 35 l for one refuelling. The estimated cost for a prototype is around €33,000.

Technologies such CRT®, SCRT® are not feasible due to the lack of available space. In order to apply compressed natural gas, a complete redesign is required. It is the same situation for re-engining and EGR (integration of the engine, dimensions of the cooling system, etc).

Table 9.22: Possible technical solutions for stage IIIB for the X 73500 railcar

Technical solutions	Application on X 73500
Diesel particles trap	No clearance
Catalytic oxidation	Possible
Selective Catalytic Reduction (SCR)	Possible
Continuous Regenerating Trap (CRT)	No clearance
SCRT (SCR + CRT)	No clearance
Exhaust Gas Recirculation (EGR)	Possible with modifications of the cooling system
Re-engining	Possible with important modifications

Table 9.22 shows the technical solutions for the respect of the stage IIIB limit values. It's necessary to use several systems:

- *Particles limit value:* particle trap;
- *CO and HC limit values:* catalytic oxidation;
- *NO_x limit value:* SCR technology.

It will be only possible to try to respect limit values for CO, HC and NO_x. Tests will confirm the real efficiency of each system.

A6.8.2 BB 67000 Mainline Locomotive

Figure 9.49: BB 67000 Mainline Locomotive

Table 9.23: Technical solutions for the BB 6700 mainline locomotive

Technical solutions	Application on BB 67000
Diesel particles trap	Possible
Catalytic oxidation	Possible
Selective Catalytic Reduction (SCR)	Possible with reduction of the fuel tank capacity
Continuous Regenerating Trap (CRT)	Possible
SCRT (SCR + CRT)	No clearance
Exhaust Gas Recirculation (EGR)	Possible with modifications of the cooling system
Re-engining	Possible with important modifications
Compressed Natural Gas	Possible with important modifications and a decrease of the autonomy
Liquefied Natural Gas	Possible with important modifications and a decrease of the autonomy
Bio-fuels	Not positive results
Fuel and water emulsions	Not positive results
Fuel additives	Not positive results

A DPF can be fitted to the locomotive. The system would replace the two silencers. The characteristics would be:

- Volume: 2 m^3.
- Weight: 1,700 kg.
- Maximum backpressure: 60 mbar at full load.
- Regeneration with a fuel burner.
- Cost for a prototype: €39,000.

For catalytic oxidation (reduction of CO and HC emissions), the system can be incorporated in space for the silencer, as with the DPF:

- Volume: 2,5 m^3;
- Weight: 2,300 kg;
- Maximum backpressure: 60 mbar at full load;
- Regeneration with a fuel burner;
- Cost for a prototype: €72,000.

The main difficulty associated with installing a DPF or a dual system with catalytic oxidation and a DPF above the engine is the additional weight. Some modifications to the locomotive’s structure would be necessary.

The SCR technology for the reduction of NO_x emissions is applicable. It would be necessary to integrate a urea tank and decrease the size of the fuel tank. The minimum capacity of the urea tank in order to be compatible with the fuel consumption is 140 litre for one refuelling. The estimated cost for a prototype is around €110,000.

SCRT is not feasible because of the limited available space. In order to apply compressed natural gas or liquefied natural gas engines and storage, a complete re-design of the vehicle is required. It is the same situation for re-engining and EGR (integration of the engine, dimensions of the cooling system, …).

Table 9.24: Possible technical solutions for stage IIIB for the BB 6700 mainline locomotive

Technical solutions	Application on BB 67000
Diesel particles trap	Possible
Catalytic oxidation	Possible
Selective Catalytic Reduction (SCR)	Possible with reduction of the fuel tank capacity
Continuous Regenerating Trap (CRT)	Possible
SCRT (SCR + CRT)	No clearance
Exhaust Gas Recirculation (EGR)	Possible with modifications of the cooling system
Re-engining	Possible with important modifications

Table 9.24 shows the technical solutions for the respect of the stage IIIB limit values. It's necessary to use several systems:

- *Particles limit value*: particle trap;
- *CO and HC limit values*: catalytic oxidation;
- *NO_x limit value*: SCR technology.

In conclusion:

- It is possible to achieve the stage IIIB particulate limit value.
- It is possible to achieve the stage IIIB HC and CO limit values.
- It is possible to achieve the stage IIIB NO_x limit value if the fuel tank capacity is reduced.

A6.8.3 Y 8000 Shunting Locomotive

Figure 9.50: Y 8000 Shunting Locomotive

Figure 9.51: Y 8000 Shunting Locomotive area around silencer

Table 9.25: Technical solutions for the Y 8000 shunting locomotive

Technical solutions	Application on Y 8000
Diesel particles trap	Possible
Catalytic oxidation	Possible
Selective Catalytic Reduction (SCR)	Possible with reduction of the fuel tank capacity
Continuous Regenerating Trap (CRT)	Possible
SCRT (SCR + CRT)	Possible
Exhaust Gas Recirculation (EGR)	Possible with modifications of the cooling system
Re-engining	Possible with important modifications
Compressed Natural Gas	Not possible
Liquefied Natural Gas	Not possible
Bio-fuels	Not positive results
Fuel and water emulsions	Not positive results
Fuel additives	Not positive results

A DPF can be fitted to the Y8000 locomotive. The system will replace the silencers. The characteristics will be:

- Volume: 0,4 m^3.
- Weight: 300 kg.
- Maximum backpressure: 100 mbar at full load.
- Regeneration with a fuel burner.
- Cost for a prototype: €5,500.

For catalytic oxidation (reduction of CO and HC emissions), the system can fit in the space for the silencer with the diesel particles trap:

- Volume: 0,5 m^3.
- Weight: 400 kg.
- Maximum backpressure: 100 mbar at full load.
- Regeneration with a fuel burner.
- Cost for a prototype: €11,000.

In a similar manner to the BB 67000, the main difficulty associated with installing a DPF or a dual system with catalytic oxidation and a DPF would be the weight. Some modifications to the locomotive’s structure would be necessary.

The SCRT technology for the reduction of CO, HC, NO_x and particulate emissions is feasible. However, it would be necessary to integrate a urea tank and decrease the size of the fuel tank. The minimum capacity in order to be compatible with the fuel consumption is 15 litres for one refuelling. The estimated cost for a prototype is around €25,500.

Neither compressed natural gas nor liquefied natural gas are feasible due to the lack of available space.

A significant redesign is required for re-engining and EGR (integration of the engine, dimensions of the cooling system, …).

Table 9.26: Possible technical solutions for stage IIIB for the Y 8000 shunting locomotive

Technical solutions	Application on Y 8000
Diesel particles trap	Possible
Catalytic oxidation	Possible
Selective Catalytic Reduction (SCR)	Possible with reduction of the fuel tank capacity
Continuous Regenerating Trap (CRT)	Possible
SCRT (SCR + CRT)	Possible
Exhaust Gas Recirculation (EGR)	Possible with modifications of the cooling system
Re-engining	Possible with important modifications

Table 9.26 summarises the feasibility of the technical solutions that could be utilised to meet stage IIIB limit values.

Y 8000 locomotives have been re-engined recently (between 1998 and 2004). The best solution is SCRT.

In conclusion:

- It is possible to achieve the stage IIIB particulate limit value.
- It is possible to achieve the stage IIIB HC and CO limit values.
- It is possible to achieve the stage IIIB NO_x limit value if the fuel tank capacity is reduced.