



HEAVY-DUTY VEHICLES: SAFETY, ENVIRONMENTAL IMPACTS AND NEW TECHNOLOGY “RASTU”.

Annual report 2006

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Abstract <p>In the years 2003 – 2005 VTT conducted a comprehensive project on energy savings for heavy-duty vehicles (“HDEnergy”). Several ways to save fuel were identified and quantified, and in addition, new transport business related information technology systems were ideated.</p> <p>The research work now continues within the new “RASTU” research integrate for 2006 - 2008. Naturally, the work for reduced fuel consumption continues. Emission focused activities for buses and trucks, previously carried out as separate tasks, have been merged into the new research integrate. In addition, the new integrate also covers safety issues, e.g. the development of ITS applications for improved safety.</p> <p>In 2006, six new buses and six new trucks with Euro 4/5 emission certification were tested for fuel economy and exhaust emissions. The general observation is that going from Euro 3 to Euro 4/5 technology does not increase fuel consumption. The results for exhaust emissions are mixed. Of six urban buses tested, only one corresponded to its certification class in real city driving. The picture for heavy-duty trucks (42 and 60 ton) running on high load is brighter, as most vehicles provide significant emission reductions compared with the Euro 3 class.</p> <p>Tests with Swedish MK1 diesel fuel and the new renewable NExBTL diesel fuel demonstrate that clear fuel effects on emissions can also be seen for Euro 4 certified vehicles.</p>	
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PREFACE

For 2006 – 2008 VTT initiated a new research integrate on heavy-duty vehicle exhaust emissions and energy savings. The new integrate is a continuation of the work focusing on energy savings carried out in 2003 – 2005. The scope of work has been broadened, and now more elements related to exhaust emissions and ITS systems have been added.

The French Energy Agency ADEME and the Swedish Road Administration are contributing to the funding of the project. For the benefit of these agencies, an English report with the main findings regarding the performance of new Euro 4 and Euro 5 vehicles has been compiled. The report at hand, the shorter English version of the annual report for 2006, also touches upon issues like fuel and lubricants, eco-labelling of heavy-duty vehicles and special emission analysis.

Full reporting of the year 2006 activities will be in Finnish.

In the case of new Euro 4 and Euro 5 vehicles it should be noted that so far only one vehicle individual of each vehicle model has been measured.

Espoo 25.5.2007

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1 BACKGROUND AND PREVIOUS RESEARCH PHASE

The environmental impacts of heavy-duty vehicles are considerable, both regarding emissions of carbon dioxide and harmful exhaust compounds. Especially in urban conditions heavy-duty vehicles contribute to air quality problems. Biofuels for transport are being vividly discussed at the moment. The best biofuel options can reduce both carbon dioxide emissions and toxic emissions.

As for engine technology, we are at a turning point. The Euro 4/5 emission regulations are forcing the engine manufacturers to use internal measures (such as EGR) or/and exhaust gas after-treatment to fulfil the new emission regulations. The number of technology options is increasing, and therefore it will become increasingly difficult for the transport companies to make decisions when procuring new vehicles. Most probably, the variation in both fuel economy and true exhaust emissions from vehicle to vehicle will increase. The Euro 4 requirements entered into force in 2005 and 2006. The next set of requirements, Euro 5, will enter into force October 1st 2008 (new engine types) and October 1st 2009 (all engines sold as new).

A number of questions arise from new engine and vehicle technology:

- which are the optimal solutions for lowest possible energy consumption and best overall economy?
- what will be the exhaust emissions in true operating conditions?
- will it be possible to find a correlation between implementation of new vehicle technology and improved urban air quality?
- how will new types of engines respond to various types of biocomponents in the fuel?
- what about requirements on lubricants and maintenance?
- how will new engines perform in wintertime conditions?

In the beginning of 2002, VTT commissioned a new emission laboratory for heavy-duty vehicles. The laboratory possesses a heavy-duty transient-type chassis dynamometer which makes it possible to test heavy-duty vehicles according to varying speed and load patterns. The equipment is well suited for measurements simulating fuel consumption and exhaust emissions in real world driving conditions. So far VTT has tested more than 150 heavy-duty vehicles on the chassis dynamometer, both buses and trucks, building up a comprehensive data base on the performance of various heavy-duty vehicles.

In the years 2003 – 2005 VTT conducted a comprehensive project on energy savings for heavy-duty vehicles. The aggregate included 13 subprojects. The annual budget was approximately 600.000 €/a, meaning that the total budget was some 1.800.000 €. Six research institutes took part in the work. For the project, a web site (in Finnish with some details in English) can be found in conjunction of the web site of Motiva Oy

(Motiva produces, refines and disseminates information, develops methods and boosts the introduction of advanced technology) at: www.rastu.fi. On the web site, a summary report in English can be found (HDEnergy Summary Report 2006).

For the project, a target of permanent fuel savings of 5 – 10 % was set. The main achievements of the project were:

- Cooperation amongst sponsors, researchers and transport companies
 - synergy benefits
 - a continuous process to improve fuel economy
 - a critical mass enabling efficient communication of the results
 - a strong linkage to the national energy savings program for the trucking sector
- Methodology
 - chassis dynamometer measurement methods for various types of buses and trucks (representative load patterns, including simulation of road gradient)
 - on-road measurements (recording information from the CAN data bus, coast-down measurements, measurements on trailers)
 - identification of the most important parameters affecting fuel consumption (vehicle weight, aerodynamic drag, engine and transmission line, lubricants, tyres etc.)
 - sufficient measurement accuracy to enable vehicle-to-vehicle comparisons for fuel efficiency
- Identification of fuel saving potentials
 - reduced vehicle weight and improved aerodynamics up to 30 %
 - guiding the driver using technical devices 20 %
 - variations from one vehicle brand to another 5 – 15 %
 - tyres 5 %
 - type of trailer 3 % (fuel consumption of the vehicle combination)
 - lubricants 1 – 2 %
- Innovation platform
 - hybrid technology
 - driver's assistance systems
 - automatic detection of load
 - automatic detection of slippery road surfaces

Within the project, a comprehensive evaluation of Euro 3 class vehicles was carried out. Most vehicle manufacturers launched their Euro 4 vehicles in 2006. Thus the availability of Euro 4 certified vehicles was limited, and in 2005, only two Euro 4 trucks were available for measurements.

2 NEW RESEARCH INTEGRATE FOR 2006 – 2008

2.1 GENERAL

The research work now continues within the new “RASTU” research integrate. RASTU is a Finnish acronym derived from the words “raskaan kaluston tutkimus”, i.e., research on heavy-duty vehicles.

Naturally, the work for reduced fuel consumption continues. Emission focused activities for buses and trucks, previously carried out as separate tasks, have been merged into the new research integrate. In addition, the new integrate also covers safety issues, e.g. the development of ITS applications for improved safety.

The objectives of the new project can be summarised as follows:

- To ascertain the true performance of new types of vehicles (Euro 4/5 certified vehicles, fuel efficiency and real-life exhaust emissions)
- Development of ITS technology to reduce energy consumption and improve safety and service levels for heavy-duty vehicles
- Improvements in vehicle technology for reduced fuel consumption
- Verification of measures to reduce fuel consumption and information transfer to transport companies, development of various monitoring system, support to national energy saving programs in the transport sector
- Interconnectedness between urban air quality (NO₂/PM) and new vehicle technology

The following research institutes/partners contribute to the work:

- VTT
- Technical University of Technology, Automotive Laboratory
- Tampere Technical University, Institute of Transportation Engineering
- University of Oulu, Department of Electrical and Information Engineering
- TEC TransEnergy Consulting Ltd, coordination

VTT acts as the responsibility centre for the integrate. Coordination is handled by TEC TransEnergy Consulting Ltd, and communication by Motiva Oy. In 2006, the research integrate included altogether 9 technical sub-projects. Most of the technical reports will be in the public domain (available on the web site www.rastu.fi), and part of the reporting will be done in English.

The annual budget is approximately 800,000 €. The main sponsor is Tekes- The Finnish Funding Agency for Technology and Innovation. Other sponsors are the Finnish Vehicle Administration, the Ministry of Transport and Communications and in addition,

public authorities responsible for the procurement of transport services, transport companies and other related companies. Two foreign sponsors contribute to the project, the French Energy Agency ADEME and the Swedish Road Administration.

The aggregate is comprised of 10 subprojects:

1. True performance (fuel consumption, exhaust emissions) of new Euro 4/5 vehicles
2. Fuels and lubricants for Euro 4/5 vehicles
3. Development of vehicle technology
4. Development of ITS technology for heavy-duty vehicles
5. Optimisation of bus operations
6. Monitoring and bonus systems for truck operations
7. Evaluation of measures for reduced energy consumption
8. Development of measurement methods, including development of eco-labelling for heavy-duty vehicle
9. Research into exhaust emissions (interconnectedness between new vehicle technology and NO₂ and PM concentrations in urban air)
10. Coordination and communication

The project will be reported in Finnish. The project will produce annual reports as well as a summary report. In due time, a summary report in English will also be prepared. For ADEME and the Swedish Road Administration, VTT will, on an annual basis, provide reporting of selected subprojects (1, 2, 8 and 9) in English.

In the previous research phases, VTT has not announced vehicle makes or models, instead a coding system has been used for the vehicles. In this new research phase, vehicle models are disclosed, and the local representatives of the vehicle manufacturers have been notified about this.

2.2 ACTIVITIES IN 2006

In 2006, the project proceeded as planned. Compared with 2005, the supply of Euro 4 and Euro 5 certified vehicles was plentiful. A good number of vehicles were measured. For buses, a separate study was carried out on assignment from the Finnish Public Transport Association (PLL). An agreement of piggybacking was reached with PLL. Thus the vehicles measured for the PLL project could also be measured for the RASTU project.

The Finnish oil company Neste Oil will start full-scale production of hydrotreated renewable diesel “NExBTL” in June 2007. The raw material for this fuel is vegetable oils and animal fats. In 2006, the availability of this highly interesting fuel was very limited, as production has taken place only in pilot scale. However, there was enough fuel available to carry out emission measurements on two Euro 4 certified buses.

Measurements of fuel consumption show that with Euro 4 and Euro 5 technology, vehicle-to-vehicle variations have rather diminished than increased, which was a surprise. However, for emissions, the situation is the opposite. The general impression

is that neither SCR nor EGR technology performs in an optimum way in the case of city buses with the current level of sophistication. On the other hand, for heavy-duty trucks operating under high load both technologies seem to work rather well for emissions. The greatest variations in emissions were seen for the ratio between NO and NO₂.

The general methodology for measurements on heavy-duty vehicles is described in the summary report of the previous research phase (HDEnergy Summary Report 2006).

In this report, the order for presentation of results follows the list of subprojects presented in 2.1, focusing on task 1, 2, 8 and 9.

3 MEASUREMENTS ON BUSES

3.1 GENERAL

In 2006, six new Euro 4/5 buses were measured. Four of these were in fact the same individuals that were measured for the project by the Finnish Public Transport Association (PLL). In PLL's measurements, roughly quarter load was used, i.e., 1,500 kg for two-axle buses and 2,000 kg for three-axle buses. In previous measurements VTT has used half load (some 3,000 kg for two-axle buses). Thus all vehicles were also tested with half load for the RASTU -project.

In PLL's project three different duty cycles were used (Braunschweig, Helsinki 2 and Helsinki 3), whereas only the Braunschweig cycle was used for the RASTU project. VTT's data base on bus emissions is based on results from the Braunschweig cycle. VTT has found the Braunschweig cycle representative for urban bus services, and in fact it gives more or less equivalent results as the Helsinki 2 cycle developed by VTT. The Helsinki 3 -cycle, also developed by VTT, includes elements describing suburban driving.

In addition to the new Euro 4/5 vehicles, the test matrix for 2006 also comprised some vehicles subjected to continuous follow-up and vehicles equipped with retrofit exhaust after-treatment. The retrofit systems evaluated were a flow-through type particle catalyst (P-DPF) installed on the MY 2000 follow-up Volvo and a combined SCR/DPF -system. The latter system was installed on a Swedish Volvo bus which was shipped over to VTT for measurements (Retrofit 2006).

Table 3.1. The 2006 vehicle matrix.

Code	Engine disp. (l)	Emission class	Model year	Mileage (km)	Exhaust after-treatment	Classification
A= Volvo	10	Euro 2	1999	630 429	Oxicat	dev. of methodology
A= Volvo ¹⁾	10	Euro 2	2000	433 631	Oxicat	follow-up
A= Volvo ¹⁾	10	Euro 2	2000	433 675	P-DPF	retrofit, new
A= Volvo ¹⁾	10	Euro 2	2000	461 000	P-DPF	retrofit, conditioned
C= Scania	9	Euro 3	2002	560 256	Oxicat	follow-up
A= Volvo ²⁾	7	Euro 4	2006	13 525	SCR	new vehicle
B= M-B ²⁾	12	Euro 4	2006	10 896	SCR	new vehicle
C= Scania	9	Euro 4	2006	101 888	EGR	new vehicle
G= Kabus ³⁾	4.5	Euro 4	2006	993	SCR	new vehicle
A= Volvo ²⁾	12	Euro 5	2006	1 400	SCR	new vehicle, boggie
C= Scania ²⁾	9	Euro 4	2006	28 204	EGR	new vehicle, boggie
A= Volvo	10	Euro 2	1997	554 220	SCR+DPF ⁴⁾	retrofit

¹⁾ same vehicle individual

²⁾ vehicles used for the PLL study

³⁾ Kabus lightweight full-aluminium bus with 4 -cylinder Cummins Euro 4 SCR -engine

⁴⁾ continuously regenerating trap= CRT

Earlier bus measurements have been reported in the 2002 – 2004 bus study summary report and in the 2005 annual report of bus measurements. (Bus 2002 – 2004 and Bus 2005)

3.2 RESULTS FOR VTT'S BUS EMISSION MONITORING

Figures 3.1 (CO), 3.2 (THC), 3.3 (NO_x) and 3.4 (PM) show emission results generated in 2006. The data is for the Braunschweig cycle and half load.

Typically CO- and THC –emissions from diesel buses are very low. In addition, oxidation catalysts effectively reduce these components. The most challenging components are NO_x and PM. Relative to Euro 3 limits values, Euro 4 calls for a 30% reduction in NO_x –emissions and an 80% reduction in PM –emissions.

The variation in CO –emissions is very high. The typical level for conventional diesel buses is in the order of 1 g/km. Two vehicles stand out for high CO, both of them Volvo SCR –buses. The CO –level is some 9-10 g/km. The two other new SCR –buses tested, Kabus (Cummins) and Mercedes-Benz, show moderate CO –emissions of some 1.5 g/km. In the case of the MY 2000 Volvo –bus, the effect of a fresh particle catalyst can clearly be seen, with CO –levels dropping down close to zero level. The 1997 Volvo bus with the retrofitted SCR/DPF –system also showed very low CO –emissions.

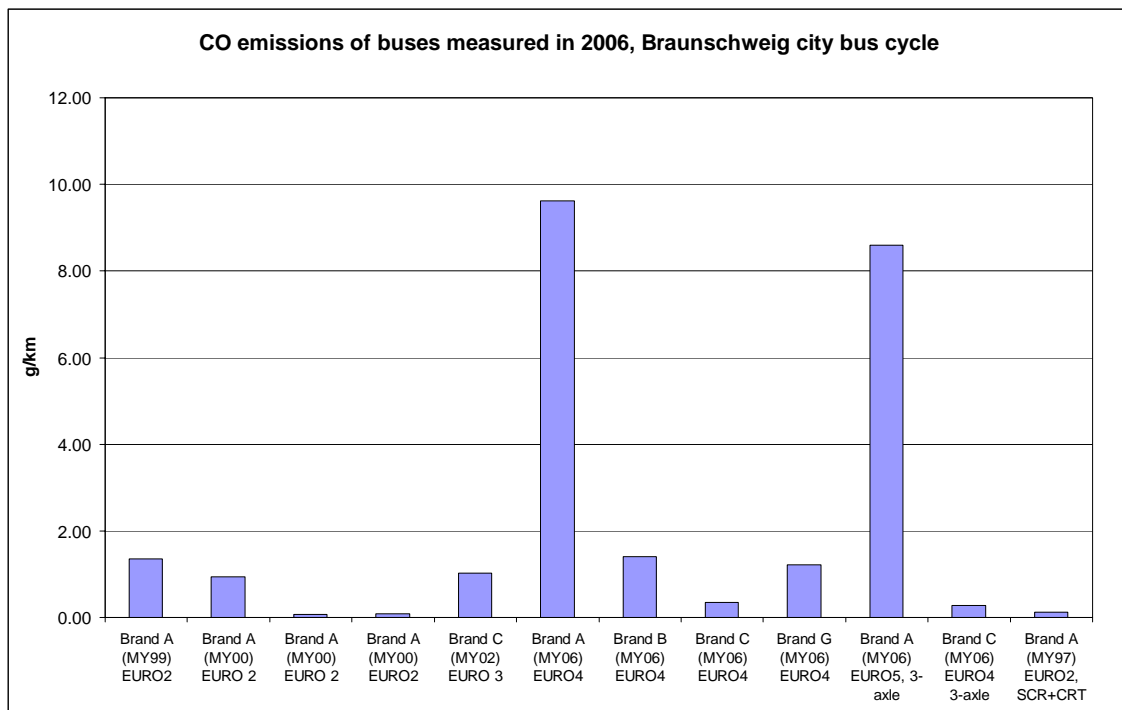


Figure 3.1. CO –emission results.

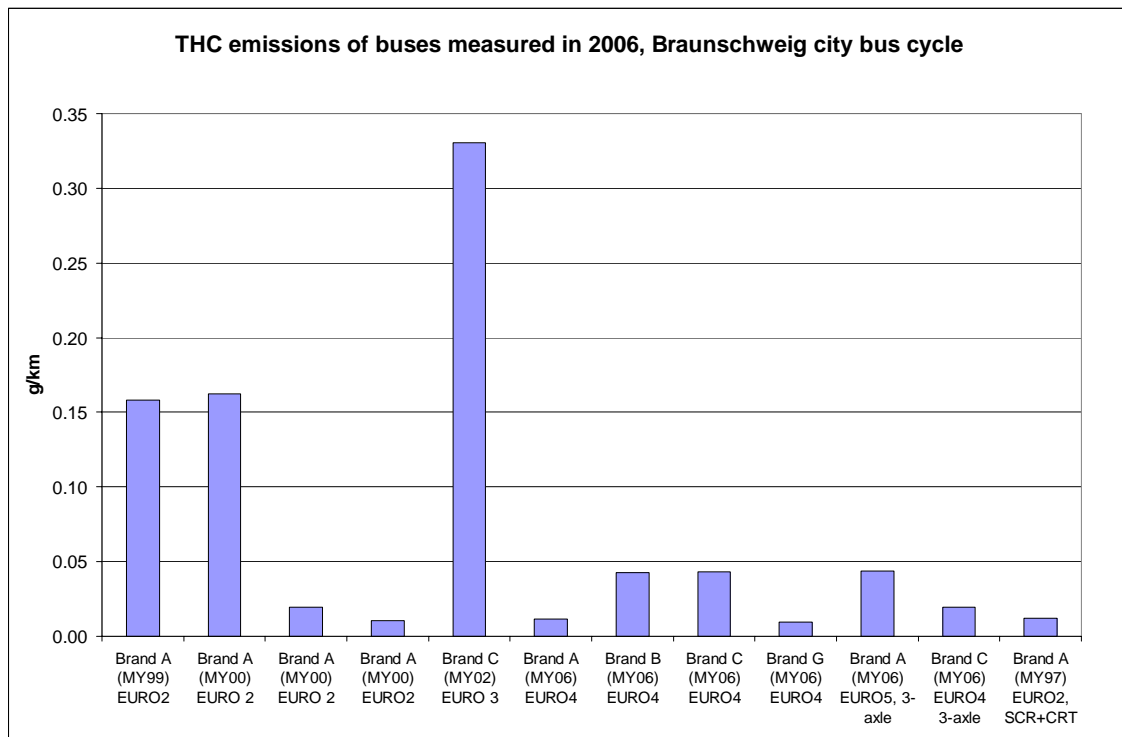


Figure 3.2. THC –emission results.

The highest THC –value, some 0.35 g/km, was recorded for the MY 2002 Scania Euro 3 bus subjected to continuous follow-up. When the vehicle was new in 2002, it was measured both without and with oxidation catalyst. The value without catalyst was 0.35 g/km and with fresh catalyst some 0.05 g/km. This means that the catalyst has lost its effectiveness completely. The same applies for the MY 2000 Volvo follow-up vehicle. With an old oxidation catalyst the THC –emission was some 0.15 g/km, a value dropping to some 0.02 g/km with a fresh particle catalyst. Also the SCR/DPF –retrofitted vehicle produced low THC emissions. For all new Euro 4 and Euro 5 vehicles THC –emissions were below 0.05 g/km.

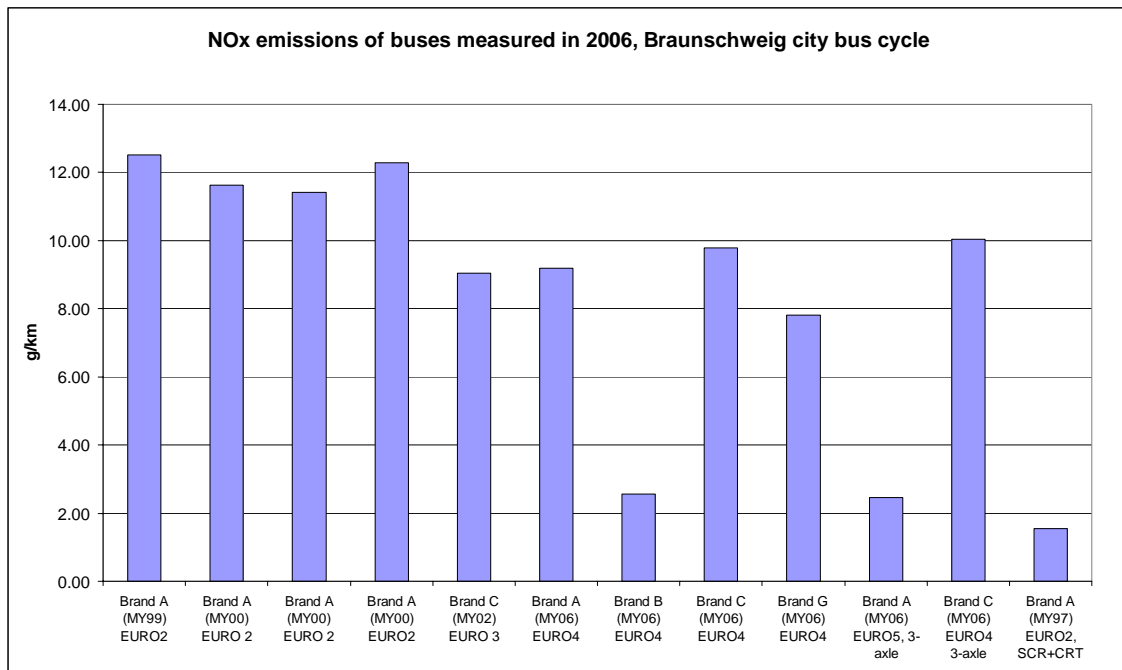


Figure 3.3. NO_x–emission results.

In the case of the older Euro 2 and Euro 3 vehicles, the results for NO_x did not provide any surprises. The results obtained for these emission classes were very close to the average values in VTT's data base of 13.6 g/km for Euro 2 vehicles and 8.8 g/km for Euro 3 vehicles. The results for the new Euro 4 and Euro 5 vehicles, however, were surprising. Three of six vehicles had NO_x emissions of Euro 3 level or even higher, one vehicle had a NO_x –level slightly lower than Euro 3 average, and only two vehicles had NO_x –levels which were significantly below Euro 3 level.

Volvo's 7 –litre Euro 4 SCR –vehicle and Scania's two Euro 4 EGR –vehicles (two-axle and boggie) are high NO_x emitters. The Cummins –engine equipped Kabus gives marginally lower NO_x –emissions than Euro 3 average, but taking into account the light-weight construction and the low fuel consumption of the Kabus, NO_x –emissions are actually of Euro 3 level.

Only the Mercedes-Benz Euro 4 SCR –vehicle and Volvo's Euro 5 SCR –vehicle produce NO_x -emissions genuinely matching their respective emission classes. Lowest NO_x –emission, 1.5 g/km, was, surprisingly enough, recorded for the SCR/DPF –retrofitted bus.

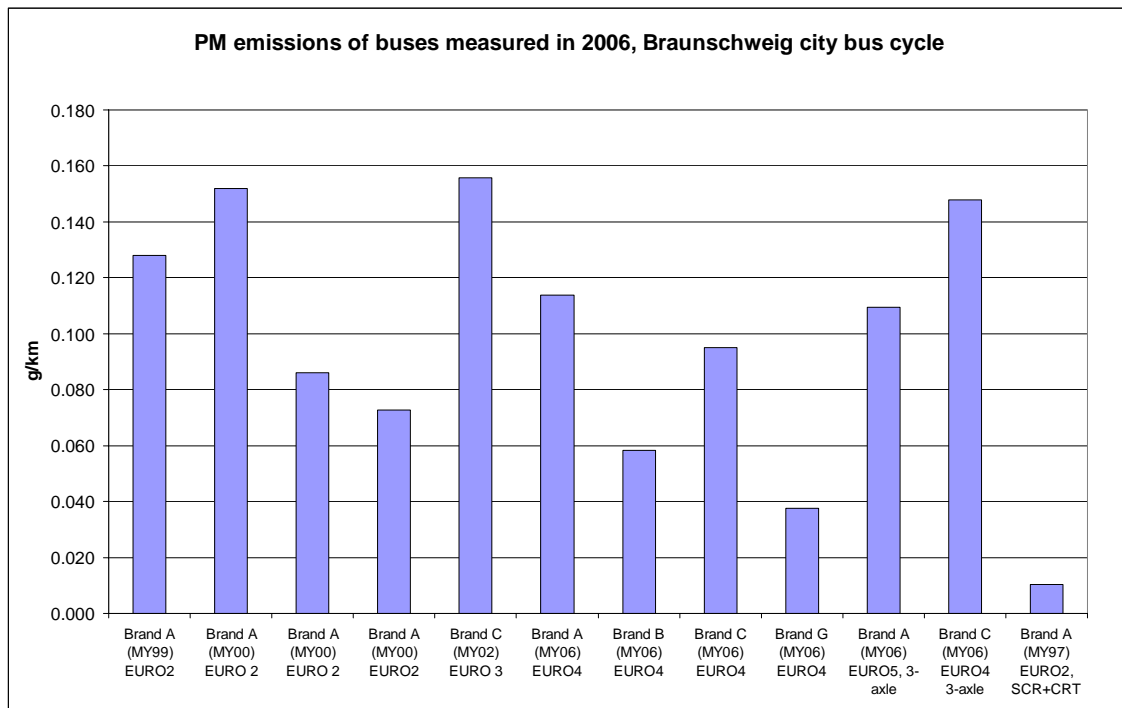


Figure 3.4. PM –emission results.

As in the case of NO_x , the results for particle emissions are mixed. Again, the Euro 2 and Euro 3 vehicles provided no surprises as the recorded values corresponded average values. However, with a PM limit value reduction of 80% from Euro 3 to Euro 4/5, the new Euro 4 and Euro 5 vehicles did not perform as well as expected. The PM emissions of Scania Euro 4 and Volvo Euro 4/5 buses were in the range of 0.1 – 0.15 g/km. The average PM emission for Euro 3 vehicles in VTT's measurements is 0.2 g/km, so only a moderate reduction can be seen for these brands. The Cummins –engine equipped Kabus and the Mercedes-Benz performed better, with PM values of 0.04 and 0.06 g/km, respectively. The PM –emission of the Kabus is in fact within a whisker of Euro 4/5 level, the PM –emission of the Mercedes-Benz only just above.

As in the case of NO_x , lowest PM emission was recorded for the SCR/DPF retrofitted bus. In fact, this bus provided EEV –performance. The low emissions, however, come at the cost of increased fuel consumption, as the fuel penalty was close to 10%. In addition, urea consumption is some 6 – 8 % of fuel consumption (Retrofit 2006).

The retrofitted P-DPF particle catalyst reduced particle emissions of the MY 2000 Volvo by some 45 - 50%. No noteworthy fuel penalty was recorded for the P-DPF –device. From now on the retrofitted P-DPF will be subjected to follow-up measurements.

Figure 3.5 shows how the emissions of the Scania Euro 3 follow-up bus have changed over time. As mentioned above, the oxidation catalyst has lost its effectiveness. This can be seen in CO-, THC- as well as PM -emission results, although the changes in PM –

emissions are not as linear as for CO and THC. NO_x –emissions vary slightly from test to test, but no clear trend is seen.

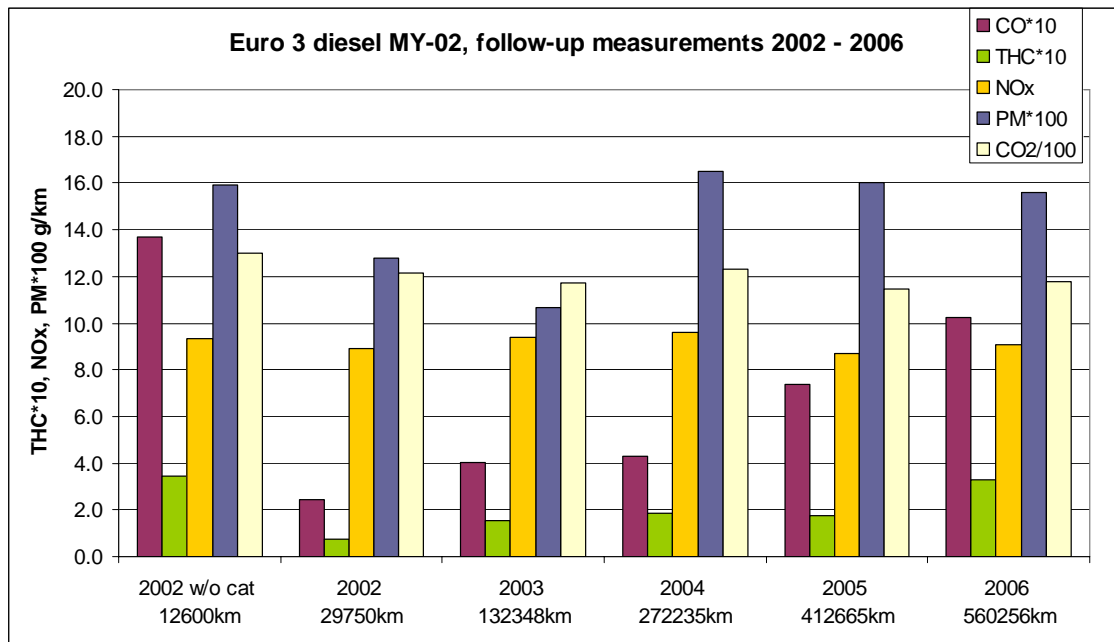


Figure 3.5. 2002 – 2006 follow-up measurements of the MY 2002 Scania Euro 3 bus.

3.3 VTT'S DATA BANK ON BUS EMISSIONS

Based on its bus measurements in 2002 – 2006, VTT has established a comprehensive data base for bus emissions. The data base is used, e.g., to evaluate how well various new vehicles perform in real-life service. VTT has deemed the Braunschweig bus cycle representative for normal downtown bus operations, and VTT's data base is built on Braunschweig results.

Nowadays all new engines have electronic engine control, and therefore also a so called CAN –bus for data transfer. It is possible to read, for instance, the engine's instantaneous power from the CAN –bus. This way the work produced by the engine in a certain test cycle can be calculated by integrating the power data over the cycle. Emissions can therefore, with a moderate accuracy, be proportioned to the work performed at the crankshaft as in engine test stand measurements.

A bus engine performs the following work load per kilometre in the Braunschweig – cycle (approximate values):

- two-axle vehicle, quarter load (1.500 kg): 1.7 kWh/km
- two-axle vehicle, half load (3.000 kg): 1.8 kWh/km
- three-axle vehicle, quarter load (2.000 kg): 2.0 kWh/km

This makes it possible to roughly compare work specific engine dynamometer emission limits in g/kWh with distance specific emission values in g/km generated on the chassis dynamometer.

Figures 3.6 (NO_x) and 3.7 (PM) show emission trends for the vehicles measured so far. Triangles represent results for diesel vehicles, circles results for natural gas vehicles, and squares results for DPF (CRT) equipped vehicles.

The blue bars in the Figures represent converted limit values for the respective Euro classes. An example clarifies the comparison. The NO_x limit value for Euro 3 is 5 g/kWh on the engine crankshaft. Using the scaling factor of 1.8, this translates into a distance based reference value of 9 g/km. These “converted limit values” should be considered indicative only, as the load pattern of the engine when running the Braunschweig cycle does not match the one of the European Transient Cycle (ETC) used for emission homologation. Engine manufacturers are required to meet the given emission limit values only with stand-alone engines in specific test cycles used for certification. VTT’s approach, however, gives a good indication real-life emission performance.

Going from Euro 1 to Euro 3 regulations have reduced real-life NO_x –emissions in proportion to the limit values, i.e. the trend is clearly downwards. As discussed above, there is a scatter in results from Euro 4 and Euro 5 diesel vehicles. Some vehicles are in reality Euro 3 level, some vehicles are genuinely matching their respective emission classes. The best natural gas vehicles provide true Euro 5/EEV performance for NO_x –emissions.

The scatter for PM –emissions is ever greater than for NO_x. Independent of age, natural gas vehicles in practise provide zero particle emissions. The results for DPF –equipped vehicles vary significantly, as the filters on two out of five vehicles measured were out of order.

Of the new Euro 4/5 diesel vehicles only one fulfils the expectations for low particle emissions (Kabus/Cummins), and in addition, one vehicle comes close (Mercedes-Benz). The PM –emissions of the other vehicles were comparable with well performing Euro 3 vehicles.

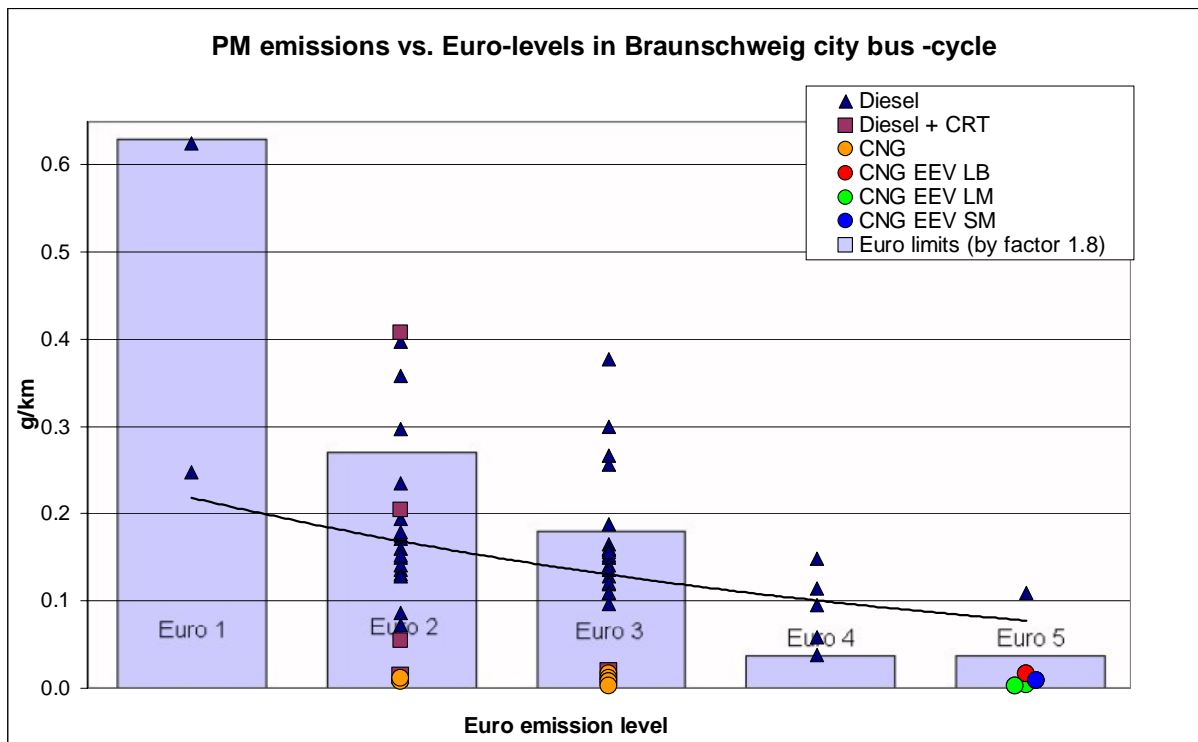


Figure 3.6. NO_x -emission trend.

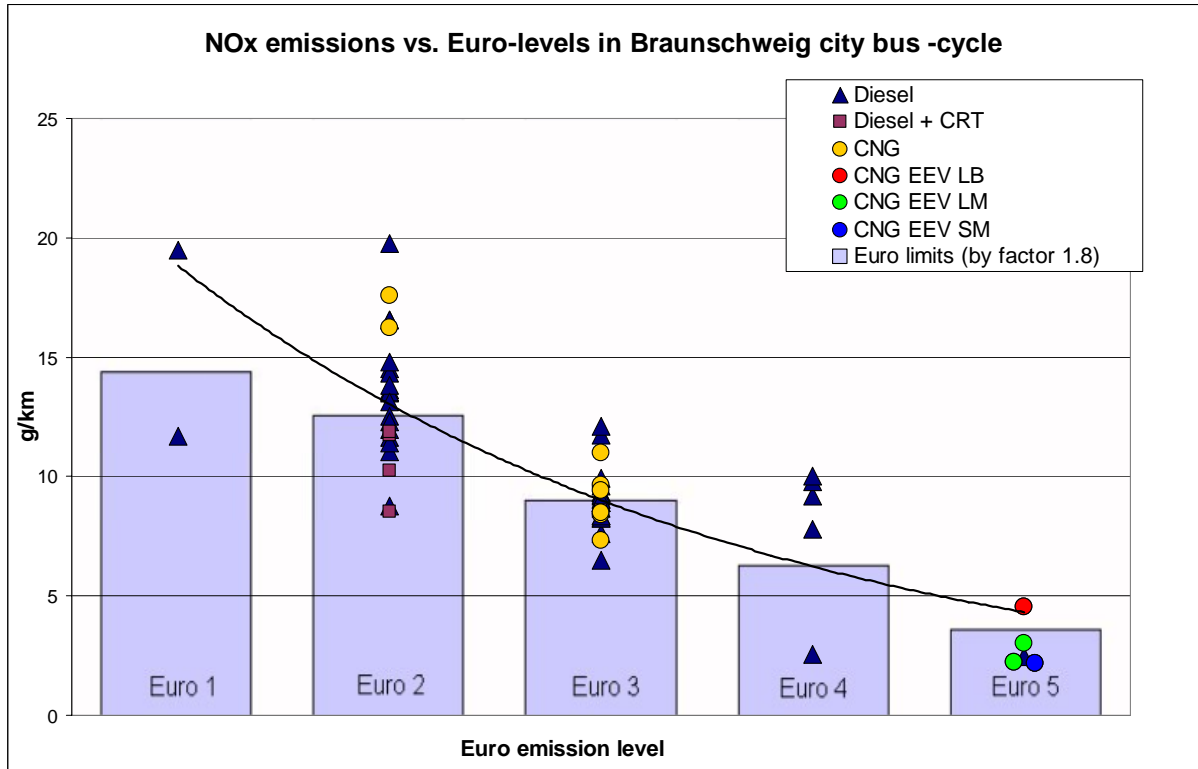


Figure 3.7. PM-emission trend.

Figure 3.8 shows the results in a NO_x/PM chart. This manner of presentation gives a better understanding of the performance of groups of vehicles and individual vehicles. The Figure shows a "calibration curve" for Euro 3 vehicles, showing the interdependence of NO_x and PM. Breaking this interdependence requires and moving towards origo requires major technical improvements, either internal measures in the engine or external measures in the form of exhaust after-treatment.

Table 3.2 present emission factors and fuel consumption figures for various vehicle and emission classes. For the time being, the values for Euro 4 and Euro 5 diesel vehicles must be considered indicative. With the exception of Euro 5 diesel vehicles, the data is based on actual measurements. In the case of Euro 5 diesel, only one vehicle has been measured so far. In Table 3.1, Euro 4 values are used for Euro 5 for all other components except NO_x . For Euro 5 NO_x , the Euro 4 average result scaled with the difference in limit values (2.0/3.5) has been used.

For natural gas buses, the division into total hydrocarbons and methane is only a rough estimation (THC is the measured value).

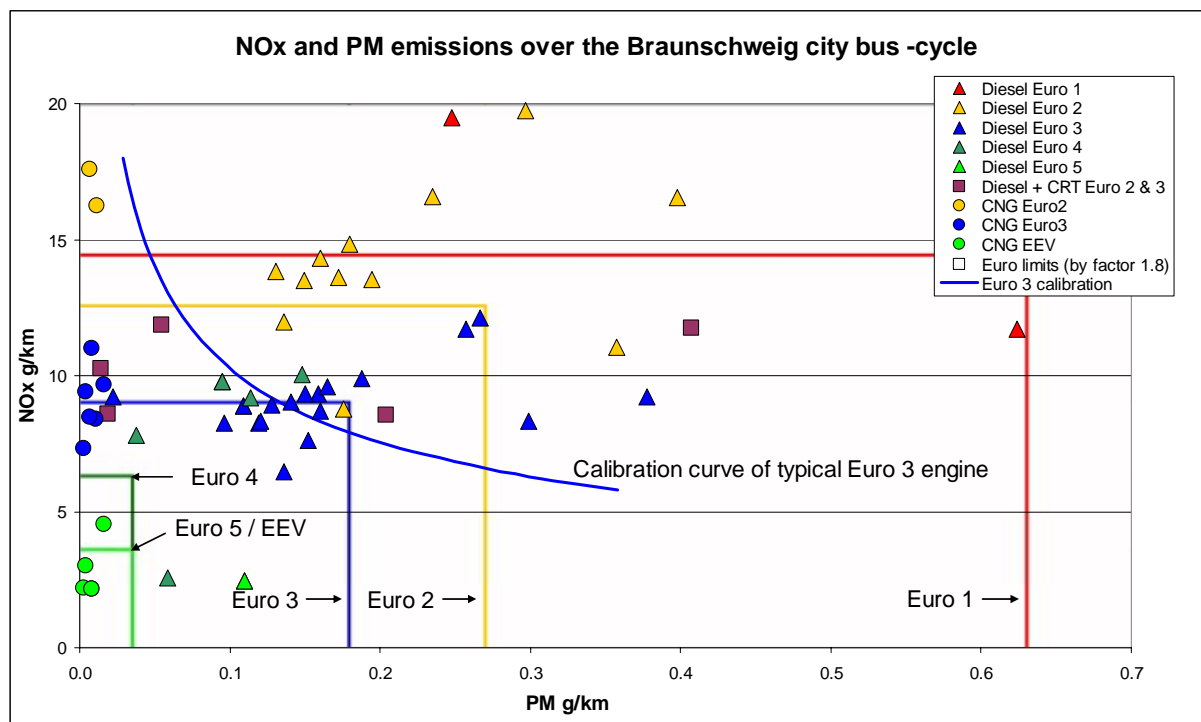


Figure 3.8. Emission results in a NO_x/PM chart.

Table 3.2. Emission factors for two-axle buses in city driving (Braunschweig cycle).

Braunschweig	CO g/km	HC g/km	CH ₄ * g/km	NO _x g/km	PM g/km	CO ₂ g/km	CO ₂ eqv** g/km	FC kg/100km	FC MJ/km
Diesel Euro 1	1.39	0.32	0.00	15.59	0.436	1219	1219	38.6	16.4
Diesel Euro 2	1.55	0.20	0.00	13.56	0.218	1281	1281	40.9	17.4
Diesel Euro 3	0.76	0.13	0.00	8.78	0.201	1196	1196	38.1	16.2
Diesel Euro 4	3.79	0.03	0.00	7.19	0.089	1123	1123	36.5	15.5
Diesel Euro 5***	3.79	0.03	0.00	4.11	0.089	1123	1123	36.5	15.5
CNG Euro 2	4.32	7.12	6.76	16.92	0.009	1128	1283	42.1	20.1
CNG Euro 3	0.18	1.33	1.26	10.02	0.009	1254	1284	45.8	21.9
CNG EEV	1.53	0.97	0.92	2.76	0.007	1230	1249	45.7	21.8

*For CNG vehicles CH₄ = THC * 0.95, for diesel CH₄ = 0
** CO₂ eqv = CO₂ + 23 * CH₄
*** Euro 5 emission factors are estimated by Euro 4 results

3.4 THE BUS STUDY FOR FINNISH PUBLIC TRANSPORT ASSOCIATION (PLL)

As described in 3.1 and 3.2.1, a study for the Finnish Public Transport Association (PLL) was carried out back to back with the bus measurements for the “RASTU” project integrate. In fact, four of the five new buses measured for the PLL study (Mercedes-Benz, one Scania, two Volvo) were the same vehicle individuals measured for the “RASTU” project integrate (the two-axle Scania Euro 4 bus was another individual). Two Euro 3 buses (Scania L94 UB4x2LB 230 and Volvo B7RLE/680) were measured for reference. The measurements for the PLL project were done using three duty cycles (Braunschweig, Helsinki 2 and Helsinki 3) and quarter load. Due to the smaller load (half load for the RASTU measurements), there are some differences in the emission results for the common Braunschweig cycle. Two reports, one in Finnish and one in English, are available for the PLL study (PLL).

In the PLL project, fuel consumption was also studied. Fuel consumption was measured gravimetrically, as the accuracy for CO₂ –emission measurements and the calculatory carbon balance method for fuel consumption is not good enough for vehicle-to-vehicle comparisons.

Fuel consumption proportioned to work on the driving wheels depicting driveline efficiency as well as fuel consumption proportioned to distance depicting the fuel consumption of the whole vehicle was evaluated.

Here only a brief summary of the results is presented. Figure 3.9 shows the vehicles’ fuel consumption in litres relative to travelled distance, taking into account the weight of the vehicle.

The average fuel consumption for two- and three-axle vehicles is in different cycles as follows:

- Braunschweig: 41 & 50 l/100 km

- Helsinki 2: 44 & 54 l/100 km
- Helsinki 3: 33 & 40 l/100 km

Differences in fuel consumption, measured in litres, are at their most 10 – 12% for two-axle vehicles, Volvo's Euro 3 –vehicle having the worst fuel economy. If the Volvo's Euro 3 –vehicle is not taken into account, differences are 3 – 11%. The difference is at its greatest in the Helsinki 3 –cycle. Volvo's Euro 4 –vehicle, on the other hand, consumes on average the least fuel.

Scania's Euro 4 –vehicle weighs some 650 kilograms more than its Euro 3 –version, which reflects on the fuel economy values proportioned to the travelled distance. A heavy vehicle invalidates the advantage gained from an efficient power train.

The fuel consumption of Scania's Euro 4 –vehicle is in different cycles on average at the same level as that of Mercedes-Benz. Scania's Euro 3 and Volvo's Euro 4 –vehicle consume the same amount of fuel in the Braunschweig –cycle, some 39 l/100 km. Mercedes-Benz' Euro 4 and Scania's Euro 4 –vehicle consume on average 40.5 l/100 km, which is about 3% more.

What comes to fuel consumption, the tree-axle vehicles naturally fall into their own group. The difference in fuel consumption is 3 – 5% to Scania's credit.

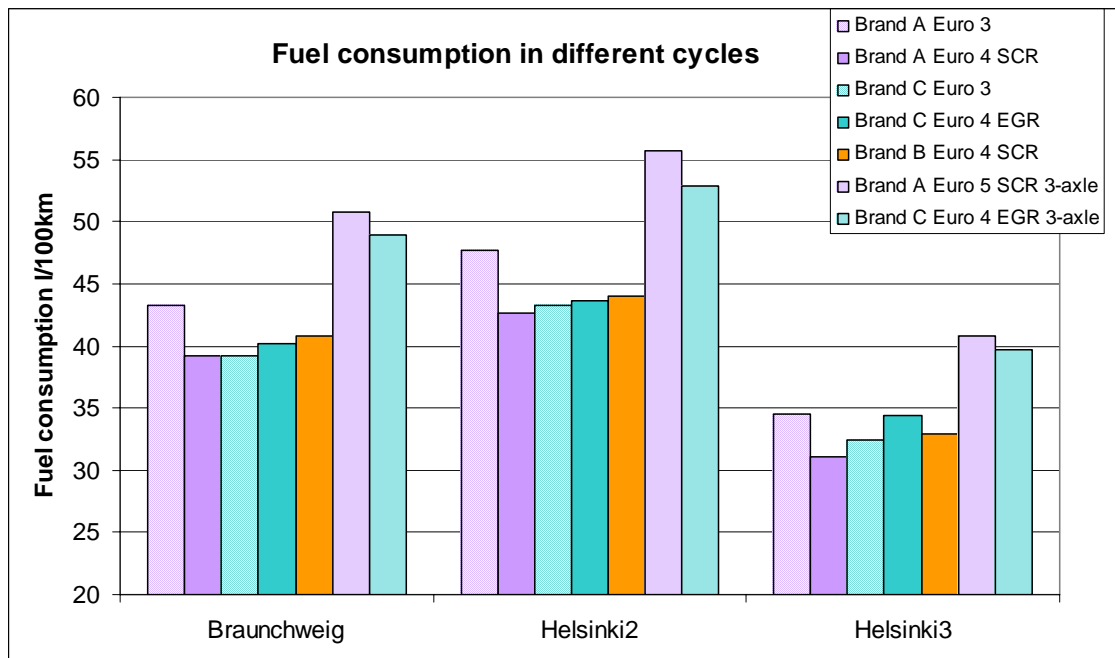


Figure 3.9. Fuel consumption in litres, observing vehicle weight, proportioned to travelled distance (l/100 km). Fuel consumption in litres describes the actual differences in fuel economy. (Brand A Euro 3= Volvo B7RLE/680, Brand C Euro 3= Scania L94 UB4x2LB 230). (PLL)

A solution of urea (AdBlue) needs to be used in SCR –vehicles in order for the catalyst to bring down nitrogen oxides. The amount of urea depends on, among others, the engine load and the temperature of the exhaust gas.

The temperature of the exhaust gas is in all driven cycles over 200 °C. Therefore urea can be injected, and the reduction reactions can take place. Figure 3.10 shows the consumption of urea, measured in litres, in different cycles.

Volvo’s Euro 4 –vehicle consumes about 1 litre of urea per 100 km. The consumption of urea is in other words only some 2 – 4% of the fuel consumption. Urea is in proportion most used in the Helsinki 3 –cycle. Mercedes-Benz’ Euro 4 -vehicle and Volvo’s Euro 5 –vehicle consume 2 – 2.5 litres of urea per 100 km. The proportional part is 5 – 6% for Mercedes-Benz, and 4 – 5% for Volvo’s three-axle Euro 5 –vehicle.

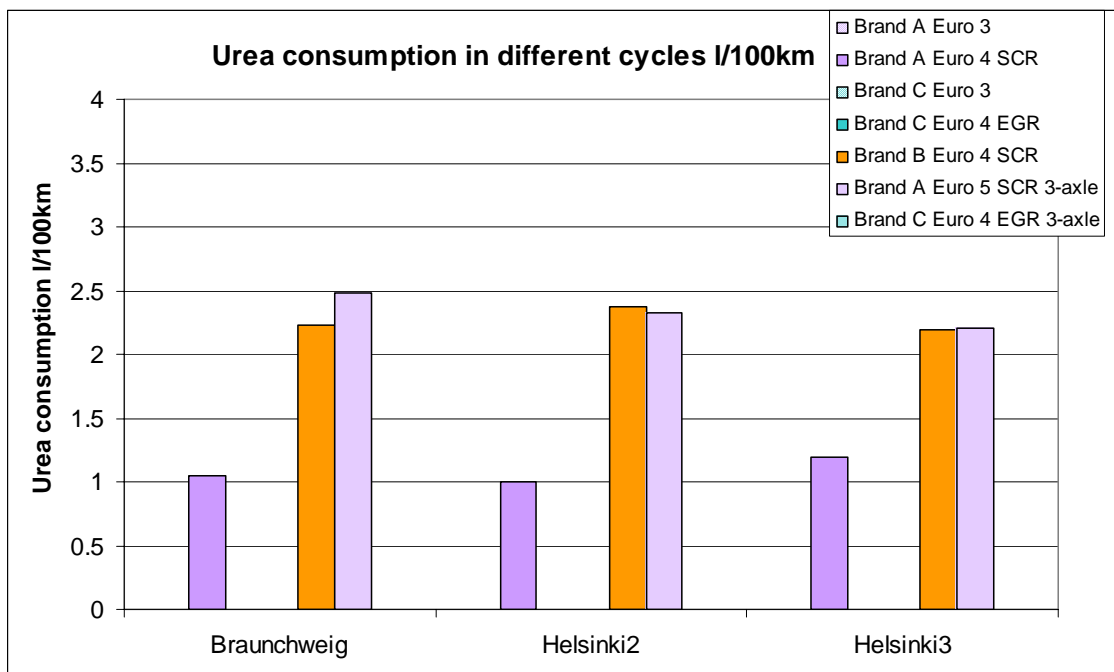


Figure 3.10. Consumption of urea, measured in litres per 100 km. (PLL)

Figure 3.11 illustrates the aggregate cost of fuel and urea, calculated per 100 km. The EGR –vehicles do not use urea. The calculations have been made using the following price estimates (prices without VAT, price levels are presumed to reflect those paid by large bus operators, situation in Finland at the end of 2006):

- diesel fuel 0,74 €/l (including VAT 0,90 €/l)
- urea 0,55 €/l (including VAT 0,67 €/l)

The aggregate cost of fuel and urea is 24 €/100 km at its lowest (Helsinki 3 –cycle, two-axle Scania Euro 3 and Volvo Euro 4) and 43 €/100 km at its highest (Helsinki 2 –cycle, three-axle Volvo Euro 5). The cost of urea is at its highest some 4% of the total costs.

Volvo's Euro 3 –vehicle has the highest costs among the two-axle vehicles. Volvo Euro 4, Scania Euro 3 and Scania Euro 4 give nearly the same costs in the Braunschweig- and Helsinki 2 –cycles. Mercedes-Benz' Euro 4 –vehicle gives 5 – 6% higher costs than the three above mentioned vehicles. The Mercedes-Benz Euro 4 –vehicle gives although at all times smaller costs than the Volvo's Euro 3 vehicle.

The study within brands shows, that in Scania's case a move to Euro 4 –technology does not alter fuel costs. Volvo's Euro 4 –vehicle gives a lower combined fuel and urea cost than its Euro 3 –vehicle (without urea).

In the class of three-axle vehicles, Volvo's Euro 5 –vehicle is 7 – 9% more expensive to operate than Scania's Euro 4 –vehicle.

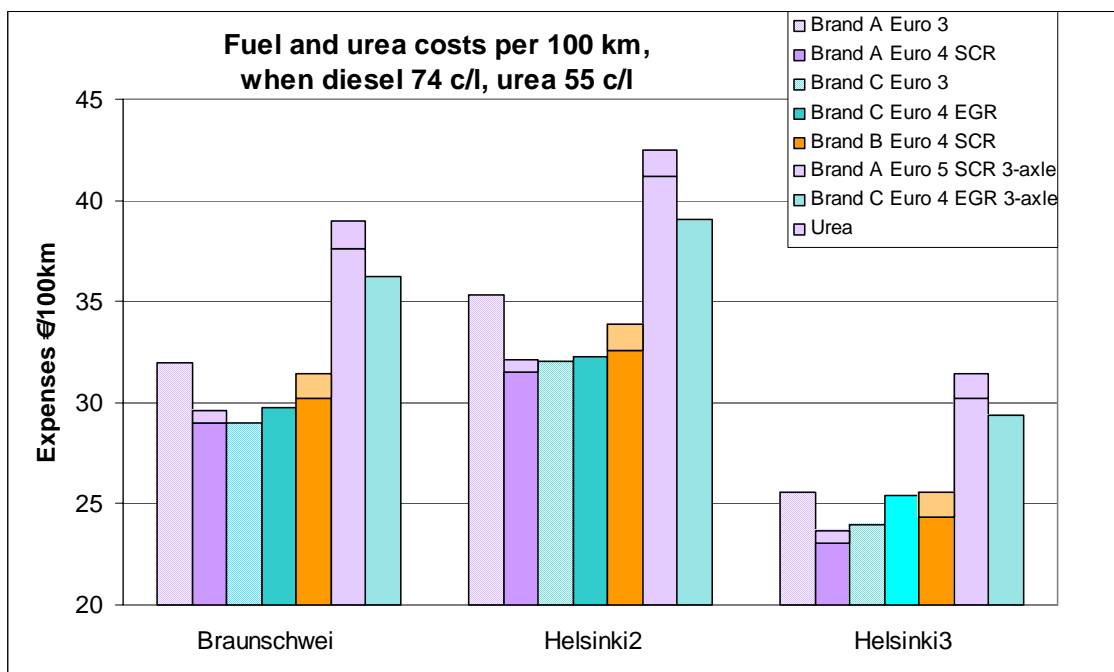


Figure 3.11. Aggregate cost of fuel and urea. (PLL)

In the PLL report, emissions were reported both proportioned to distance (g/km) and to work at the driving wheels (g/kWh). Analysis of emission compliance was based on the latter approach.

The integrated work read from the engine can also be proportioned to the work measured from the driving wheels. Exploring it this way makes the engine work 1.8 times more (approximate value) than the driving wheels, resulting from losses in auxiliary equipment, power train and tires.

As mentioned earlier, it must although be noticed that the engine load in a standard accordant ETC –transient test for stand-alone engines, differs remarkably from the load of chassis dynamometer cycles which represent real life driving conditions. The U.S.

exhaust gas legislation includes a so called not-to-exceed (NTE) –requirement. This requirement means that an engine’s emissions under no circumstances (different driving situations or different load) may exceed the emission limits by more than a factor of 1.25 (DieselNet).

The rationale for increasingly stringent emission regulations is to achieve lower emissions also under real life driving conditions. Therefore NTE –like requirements should be applied in Europe too.

The compliance analysis was limited to the most essential emissions, in other words nitrogen oxides and particulate matter.

Reference values were generated as follows:

- the limit values of the ETC accordant standard engine test are multiplied by a factor taking into account losses in the power train (1.8)
- the limiting value is furthermore multiplied by a factor of 1.25, according to NTE –reasoning
- the overall factor will this way be 2.25
- the limiting value multiplied by that factor is compared against the specific emissions determined from the driving wheels

Table 3.3 shows reference values for emissions which have been defined this way.

Table 3.3. Generating reference values for emissions.

Reference value ETC * 2,25	Euro 3 (g/kWh)	Euro 4 (g/kWh)	Euro 5 (g/kWh)
NO _x limit	5,0	3,5	2,0
observing losses	9,0	6,3	3,6
reference value	11,3	7,9	4,5
PM limit	0,16	0,03	0,03
observing losses	0,29	0,05	0,05
reference value	0,36	0,07	0,07

Figure 3.12 illustrates the vehicles’ emissions in proportion to the work of the driving wheels in the Braunschweig –cycle. The results are displayed in a NO_x/PM –coordinate system. Based on these values, it is possible to estimate how the vehicles’ emissions correspond with the limiting values of the Euro –classes. Reference values for different Euro emission classes (factor 2.25, including NTE –factor, see Table 3.3) are in the picture marked by coloured rectangles. The limit values for Euro –classes, multiplied by

only the dissipation coefficient of the power train (1.8), are in the picture marked by dashed lines.

The results are presented in table format in Table 3.4.

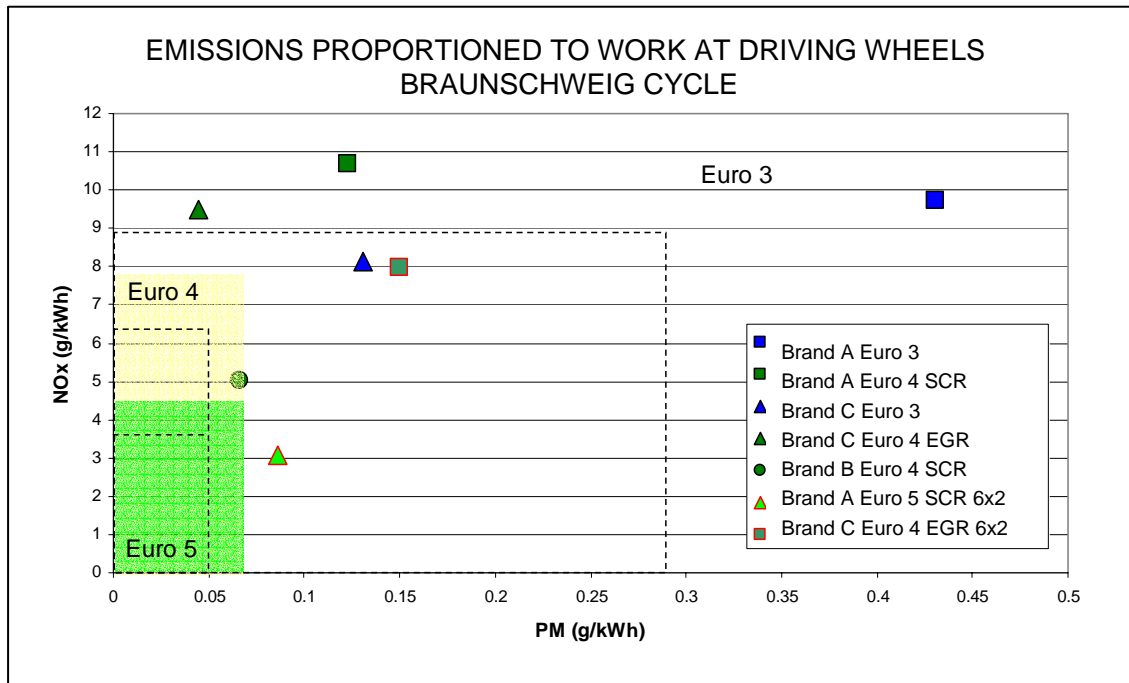


Figure 3.12. Emissions proportioned to the work of the driving wheels in the Braunschweig –cycle. Coloured rectangles represent Euro –limit values by a factor of 2.25 (including NTE –factor), the dashed rectangles represent Euro –limit values by a factor of 1.8 (power train dissipation). (PLL)

Only Scania's Euro 3- and Mercedes-Benz' Euro 4 –vehicle conform to the requirements of the NTE –accordant Euro –class. Scania's two-axle Euro 4 –vehicle is easily Euro 4/5 –class what comes to particulate emissions, but only Euro 3 –class considering NO_x –emissions. Scania's three-axle Euro 4 –vehicle is Euro 3 –class what comes to NO_x- and particulate emissions. The same goes for Volvo's Euro 4 –vehicle. Volvo's Euro 5 –vehicle meets Euro 5 NO_x –emission standards, but it emits slightly more particulates than what is allowed according to the shared Euro 4 and Euro 5 –particulate emission level.

If the NTE –factor is not taken into account (dashed rectangles) Volvo's Euro 3 and Euro 4 –vehicles and Scania's two-axle Euro 4 -vehicle do not even meet Euro 3 –limit values. The other vehicles meet in this case the Euro 3 –limit values.

Table 3.4. Emissions proportioned to the work at the driving wheel in the Braunschweig –cycle and an estimate of meeting emission limits.(PLL)

Model	NO _x (g/kWh)	PM (g/kWh)	NO _x –class (NTE –concept)	PM –class (NTE –concept)	Total result (NTE –concept)
2 –axle					
Volvo Euro 3	9.7	0.43	Euro 3	Euro 2	Euro 2
Volvo Euro 4	10.7	0.12	Euro 3	Euro 3	Euro 3
Scania Euro 3	8.1	0.13	Euro 3	Euro 3	Euro 3
Scania Euro 4	9.5	0.05	Euro 3	Euro 4/5	Euro 3
Mercedes-Benz Euro 4	5.0	0.07	Euro 4	Euro 4/5	Euro 4
3 –axle					
Volvo Euro 5	3.1	0.09	Euro 5	Euro 3	Euro 3
Scania Euro 4	8.0	0.15	Euro 3	Euro 3	Euro 3

4 MEASUREMENTS ON TRUCKS

4.1 GENERAL

The specific fuel consumption for no less than 16 new Euro 3-class trucks were measured on the chassis dynamometer during the years 2004 – 2005. The vehicles represented four different weight categories, 18 ton, 26 ton, 42 ton and 60 ton. Depending on the weight category, measurements were made for three or four load levels. In 2005, two Euro 4 certified 42 ton semi-trailer tractors could be tested. All these measurements are reported in the summary report of the previous (2003 – 2005) research phase.

In 2006, altogether six new Euro 4/5 certified trucks were tested, one semi-trailer tractor (42 ton) and five three-axle vehicles meant to pull full trailers (60 ton). The 60 ton vehicles were also measured “solo” in 26 ton configuration, corresponding to the tractor of the 60 ton combination without trailer. The vehicles were tested using the delivery cycle (26 ton only), the highway cycle and the freeway cycle developed in cooperation between VTT and the transport company Transpoint.

The tested vehicles are presented in Table 4.1. The Table and the subsequent Figures also include the two Euro 4 trucks measured in 2005.

Table 4.1. 2005 – 2006 Euro 4/5 truck matrix.

Brand	Model	Emission class	Emission control	Model year	Mileage (km)	Category	Measured in
MAN	TGA 18.433	Euro 4	EGR ¹⁾	2005	750	42 t	2005
Scania	R 420	Euro 4	EGR	2005	4 700	42 t	2005
Iveco	Stralis 500	Euro 5	SCR	2006	600	42 t	2006
Iveco	Stralis 420	Euro 4	SCR	2006	300	60 t	2006
MAN	TGA 26.430	Euro 4	EGR ¹⁾	2006	25 900	60 t	2006
MB	Actros 1844	Euro 4	SCR	2006	15 100	60 t	2006
Scania	R 470	Euro 4	EGR	2006	400	60 t	2006
Volvo	FH480	Euro 4	SCR	2006	54 400	60 t	2006

¹⁾ in addition, PM-KAT particle catalyst

The test vehicles were delivered to VTT by or with the help of the manufacturers' representatives in Finland. The actual choice of vehicles was determined by vehicle availability, and therefore a variation in, e.g., power ratings can be seen. Thus the Iveco Stralis semi-trailer tractor had a 500 hp engine, whereas the power rating of the three-axle truck for a 60 ton combination was only 420 hp.

4.2 FUEL CONSUMPTION

Figures 4.1 (42 t), 4.2 (60 t) and 4.3 (26 t) present volumetric fuel consumption for the three weight classes. As in the previous research phase, zero, half and full load was simulated. The Figures also include average values for Euro 3 vehicles. The development is interesting. On an average, the new Euro 4/5 vehicles consume less fuel than Euro 3 vehicles. Unlike the situation for buses, in the case of heavy-duty trucks the SCR vehicles clearly are more fuel efficient than the EGR vehicles. The EGR vehicles consume roughly the same amount of fuel as the average Euro 3 truck. The SCR – vehicles consume, on an average some 10% less fuel than the average Euro 3 truck in the highway and freeway cycles. In the delivery cycle (26 ton vehicles) the average difference in fuel consumption between EGR and SCR vehicles is more than 10% in favour of the SCR vehicles.

Figure 4.4 shows aggregate fuel and urea costs in the 60 ton class. The advantage of SCR vehicles over EGR vehicles remains even though the cost for urea is taken into consideration.

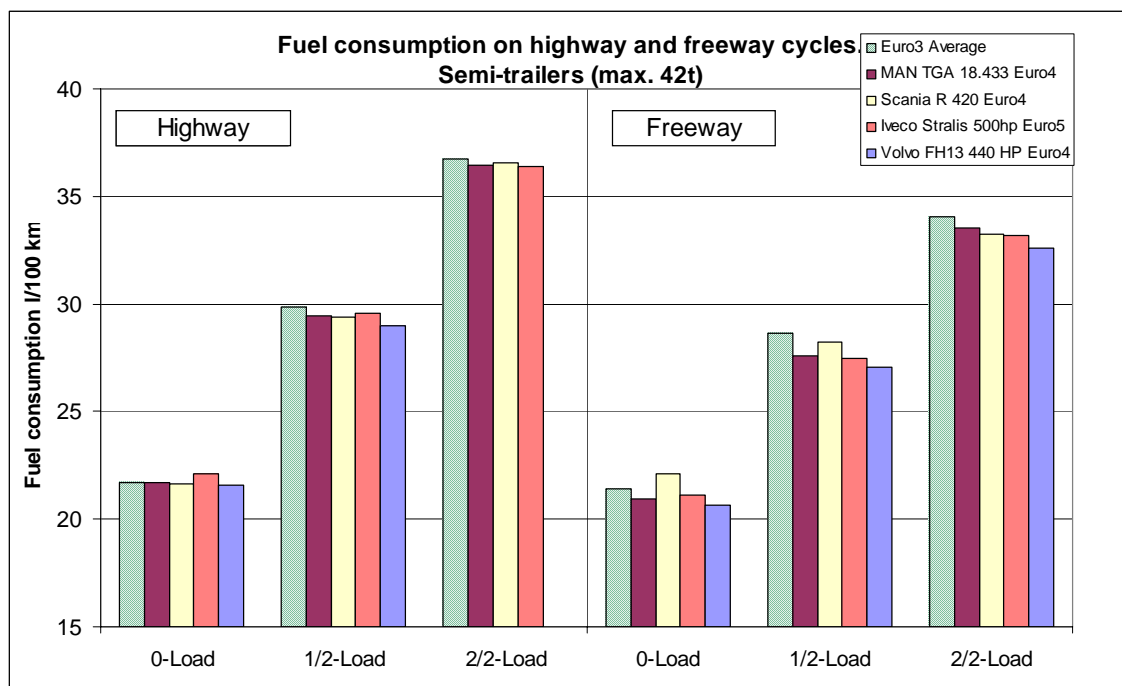


Figure 4.1. Fuel consumption of 42 ton combinations.

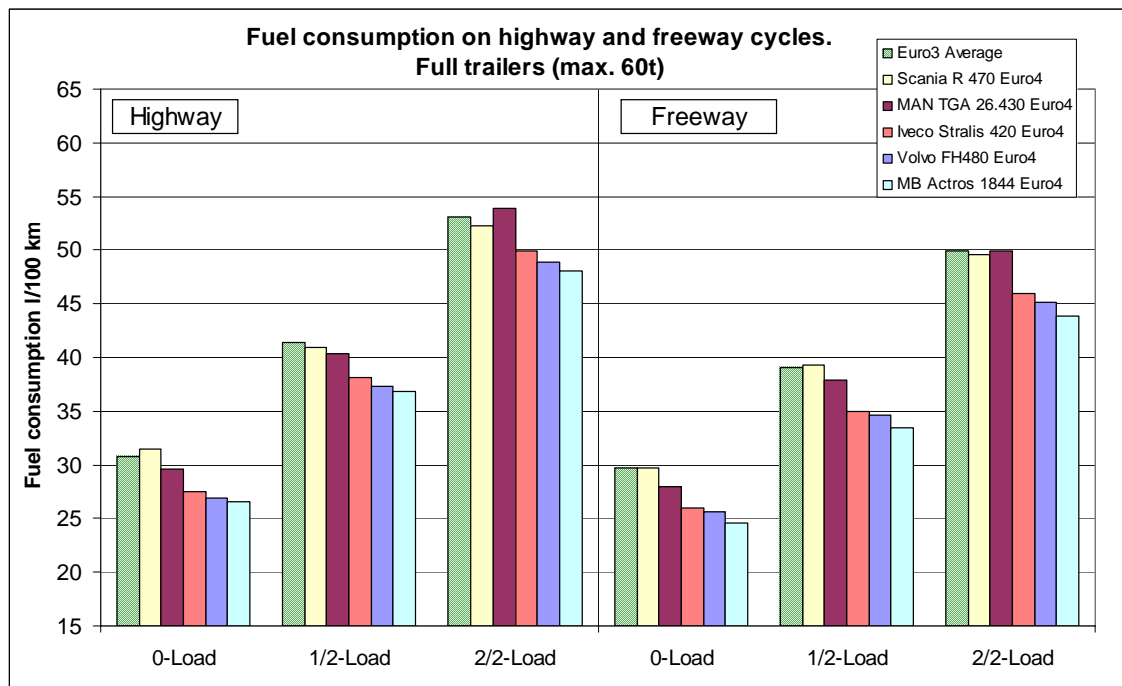


Figure 4.2. Fuel consumption of 60 ton combinations.

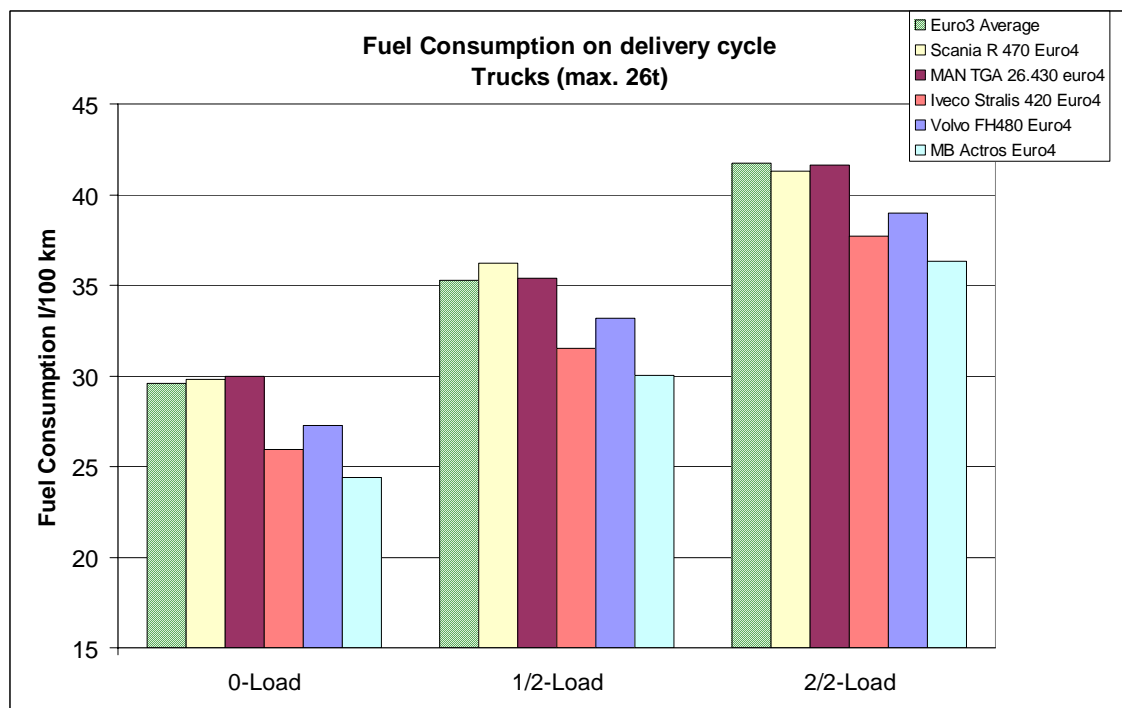


Figure 4.3. Fuel consumption of 26 ton vehicles (delivery cycle, tractors for 60 ton combinations).

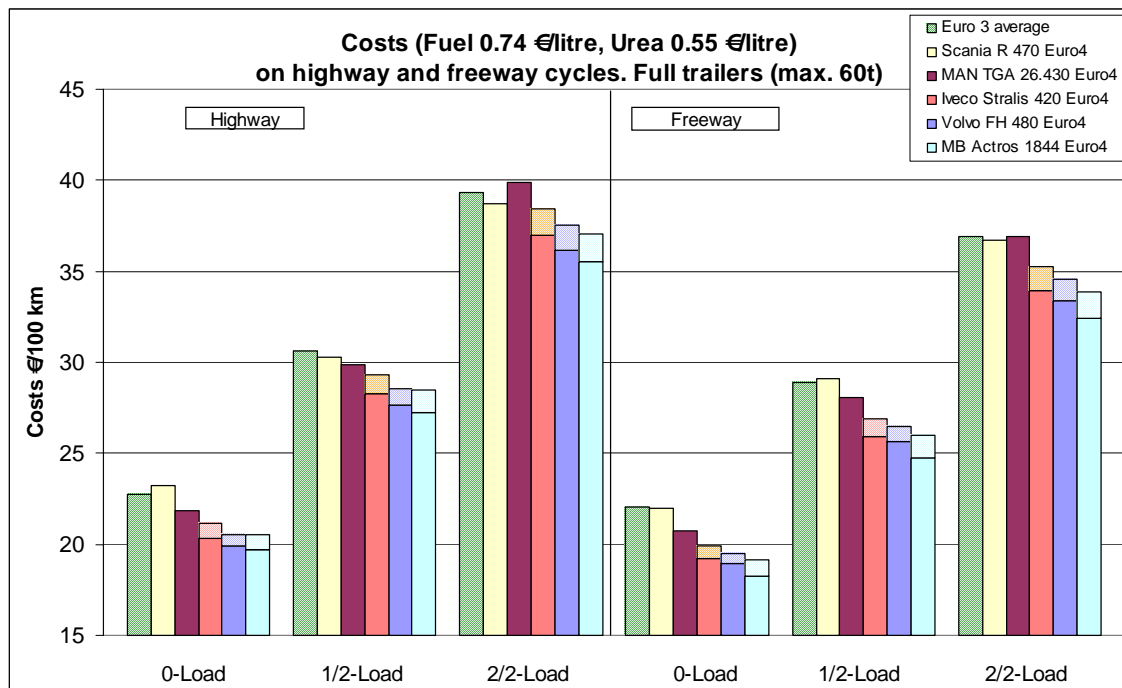


Figure 4.4. Aggregate cost of fuel and urea for 60 ton combinations.

4.3 EXHAUST EMISSIONS

Figures 4.5 (42 ton) and 4.6 (60 ton) show NO_x - and PM –emission proportioned to work at the driving wheels when running highway and freeway cycles. For each vehicle three different load levels are shown. Heavy-duty trucks running on high load seem to work better regarding emissions than urban buses in very transient conditions.

As in the case of buses, a scaling of values measured on the driving wheels and on the engine crankshaft can be made. In the previous research phase (2003 – 2005) a coefficient of 1.5 was used for taking into account losses caused by the power-train and auxiliary devices. The limit values for Euro 4 class engines in the ETC – engine test are 3.5 g NO_x and 0.03 g PM/kWh. If the coefficient 1.5 is used on these values (no NTE – coefficient), the reference values for the chassis dynamometer test-stand would be about 5 g NO_x and 0.05 g PM/kWh. This is only a rough estimate, as the coefficient in reality varies with load and driving cycle.

In the case of the 42 ton combinations, the Euro 4 vehicles are truly Euro 4 –level and the Euro 5 vehicle is truly Euro 5 –level for NO_x . For both the highway- and freeway cycles, the lowest level of load caused the highest emissions of NO_x . All vehicles are clearly better than Euro 3 average.

There are large variations in PM –emissions. The Scania Euro 4 vehicle is actually Euro 3 level for PM –emissions, whereas Iveco’s SCR –vehicle and the PM-KAT equipped MAN are truly Euro 4/5 –level.

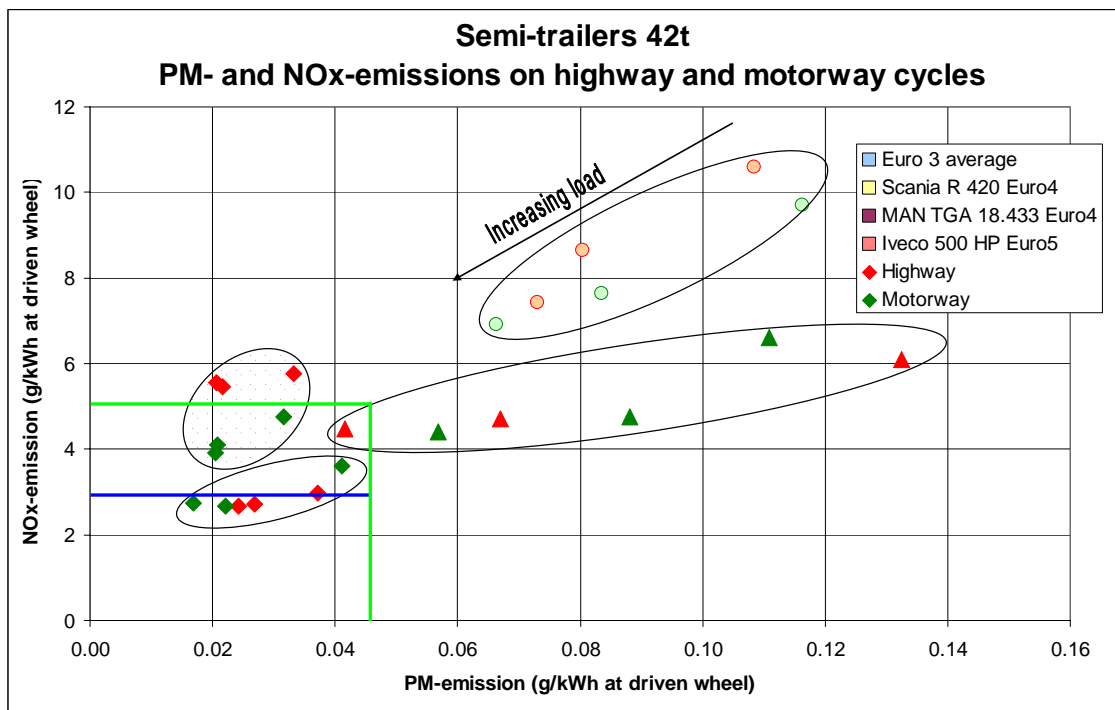


Figure 4.5. NO_x and particle emissions of 42 ton trucks for the highway and freeway cycle. Vehicles measured without load, half loaded and fully loaded.

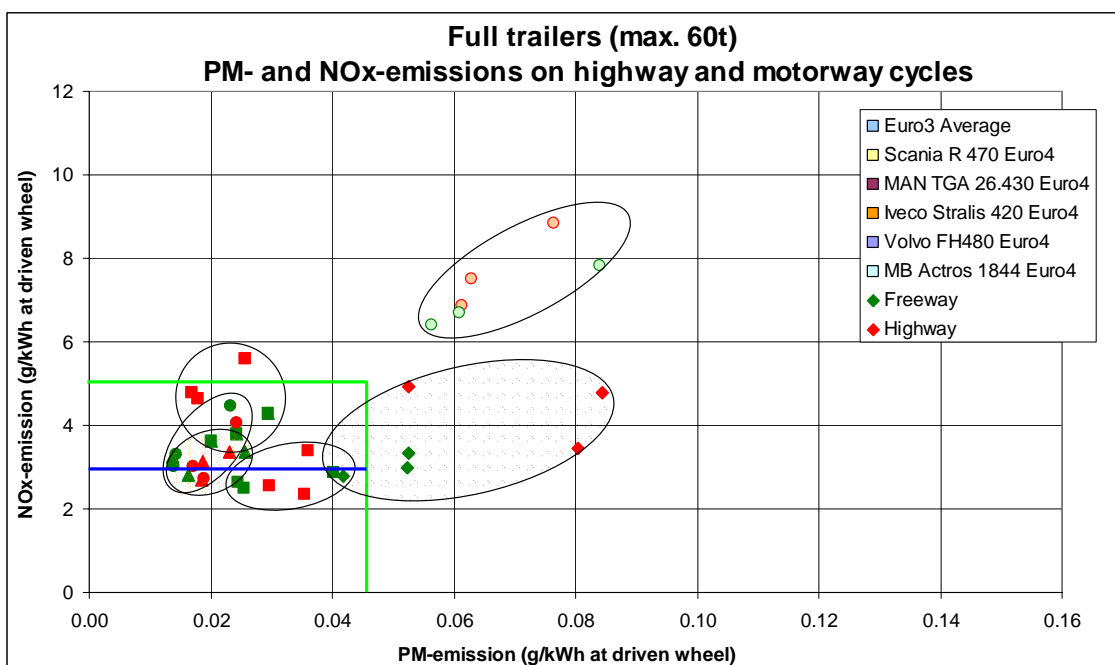


Figure 4.6. NO_x and particle emissions of 60 ton trucks for the highway and freeway cycle. Vehicles measured without load, half loaded and fully loaded.

For the 60 ton combinations, all vehicles were Euro 4 certified. Also in this case all vehicles meet the expectations for NO_x , and in fact, Iveco's and Volvo's SCR –vehicles are close to Euro 5. For particles, all vehicles except the MAN fulfil the combined Euro 4/5 requirement. The MAN, also in this case equipped with a PM-KAT, was deemed faulty based on the fact that the 42 ton vehicle with corresponding technology worked quite well. In 2007, another vehicle individual will be measured.

The PM emissions of the 470 hp Scania in the 60 ton class were Euro 4 level. This was a little bit surprising since the corresponding 420 hp engine in the 42 ton class had high PM emissions. One explanation could be that the 42 ton vehicle measured in 2005 was some kind of “pre-series” or “incentive” Euro 4 vehicle.

The 60 ton vehicles were also run without trailer, i.e. as 26 ton vehicles using the delivery cycle (Figure 4.7). The delivery cycle resembles suburban bus service, and therefore a comparison to buses is interesting.

On an average, NO_x –emissions are some 50% and PM –emissions some 100% higher than for highway and freeway driving. Variation of NO_x with load increases significantly. In the case of Iveco NO_x –emissions were roughly 3 g/kWh in the highway and freeway cycles, whereas for the delivery cycle values range from some 4 to 8 g/kWh.

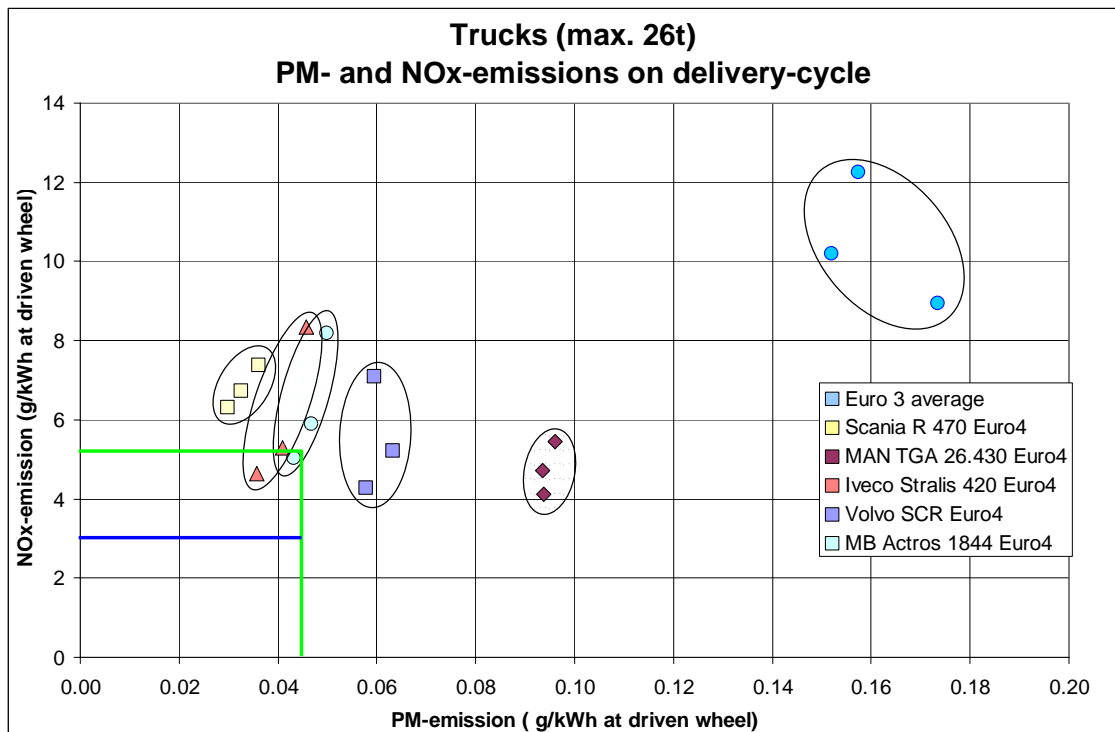


Figure 4.7. NO_x and particle emissions of 26 ton trucks for the delivery cycle. Vehicles measured without load, half loaded and fully loaded. (Note: different scale as in Figures 4.5 and 4.6).

In the delivery cycle only Iveco and Mercedes-Benz correspond to Euro 4, and this only on high load. Scania is slightly high for NO_x, Volvo for PM. MAN is out of range for PM but aright for NO_x (faulty vehicle).

In the case of buses and the Braunschweig cycle, the values for the Mercedes-Benz SCR –bus, which represented the best case, were 5 g NO_x/kWh and 0.07 g PM/kWh (Figure 3.12). This is an indication that the Braunschweig bus cycle is more severe than the delivery cycle. However, for the suburban Helsinki 3 bus cycle, the result for the Mercedes-Benz Euro 4 bus was as low as 0.7 g NO_x and 0.05 g PM/kWh.

5 FUELS AND LUBRICANTS

5.1 GENERAL

As mentioned in Chapter 2, the availability of the new NExBTL renewable diesel fuel was limited, and therefore only two buses could be measured using this fuel. In addition, on request from the Swedish Road Administration two trucks were tested on Swedish Miljöklass 1 (MK1, Environmental Class 1) diesel fuel.

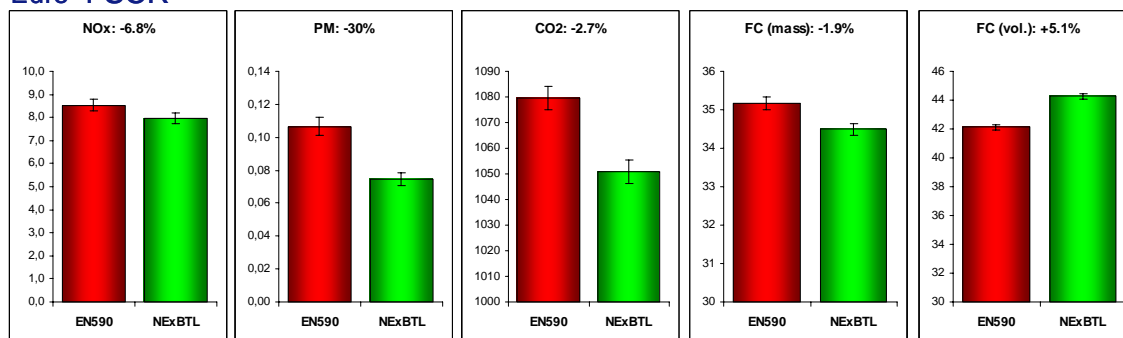
As for engine lubricants, a comprehensive test of crankcase oils meant for Euro 4 and Euro 5 certified engines was carried out.

5.2 FUEL TESTING

5.2.1 NExBTL

100% NExBTL was tested in two Euro 4 certified buses, the 9 –litre Scania with EGR and the 7 –litre Volvo with SCR. Figure 5.1 shows the results with 100% NExBTL for NO_x, PM and fuel consumption in comparison with high quality summer-grade European diesel fuel (Neste DIKC with less than 10 ppm S).

Euro 4 SCR



Euro 4 EGR

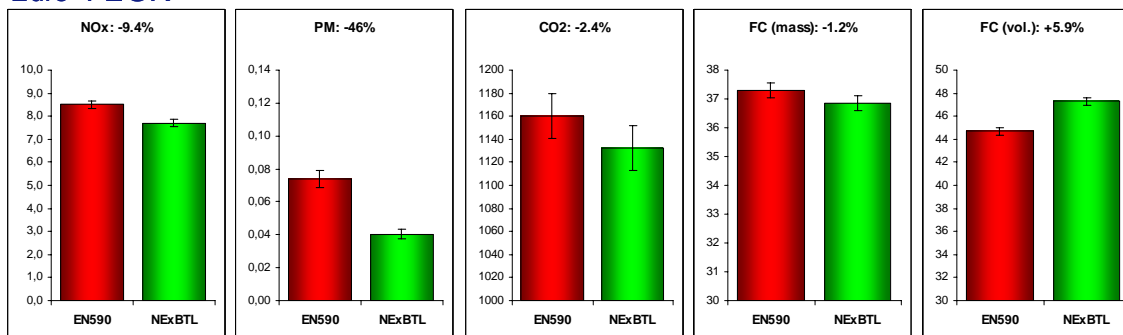


Figure 5.1. The effect of 100% NExBTL on emissions and fuel consumption. Emissions in g/km, fuel consumption in kg/100 km and l/100 km.

For both vehicles, a NO_x reduction of slightly less than 10% was found. The effect on particles, however, was substantial. In the case of the SCR –equipped Volvo PM –emissions were reduced by 30%, in the case of the EGR Scania as much as 46%. Tailpipe CO₂ –emissions were reduced some 2.5% due to the more favourable hydrogen/carbon –ratio of NExBTL compared with ordinary diesel fuel.

The gravimetric fuel consumption is slightly reduced, some 1.5%, with NExBTL, due to the higher heat value expressed as MJ/kg. The volumetric fuel consumption, on the other hand, increases some 5% due to the low density of NExBTL which gives lower heat value expressed as MJ/l. Energy consumption remains more or less unaffected.

This comparison was made to summer grade diesel fuel. The relative results for fuel consumption will vary slightly depending on the reference fuel.

5.2.2 Swedish Miljöklass 1 (MK1)

Two 60 ton trucks, MAN and Mercedes-Benz were tested using MK1 fuel. The MK1 quality corresponded to the pre-2006 formulation. The reference was sulphur-free (< 10 ppm S) summer-grade diesel fuel (DIKC).

The results are presented in Figures 5.2 (MAN NO_x- and PM –emissions), 5.3 (Mercedes-Benz NO_x- and PM –emissions) 5.4 (fuel consumption MAN) and 5.5 (fuel consumption Mercedes-Benz). Measurements were made simulating half load for a 60 ton vehicle. When evaluating the results, it should be noted that the MAN truck was not functioning properly.

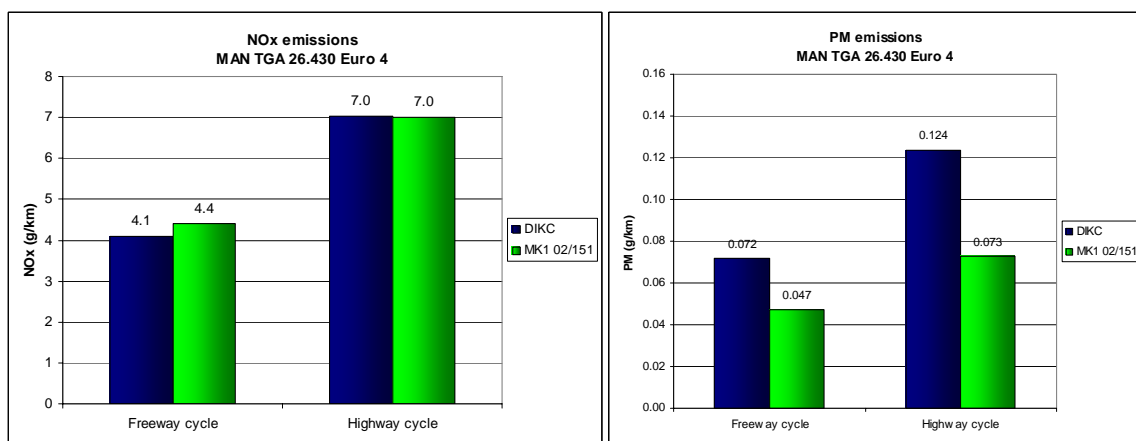


Figure 5.2. MK1 effects on NO_x- and PM –emissions (MAN).

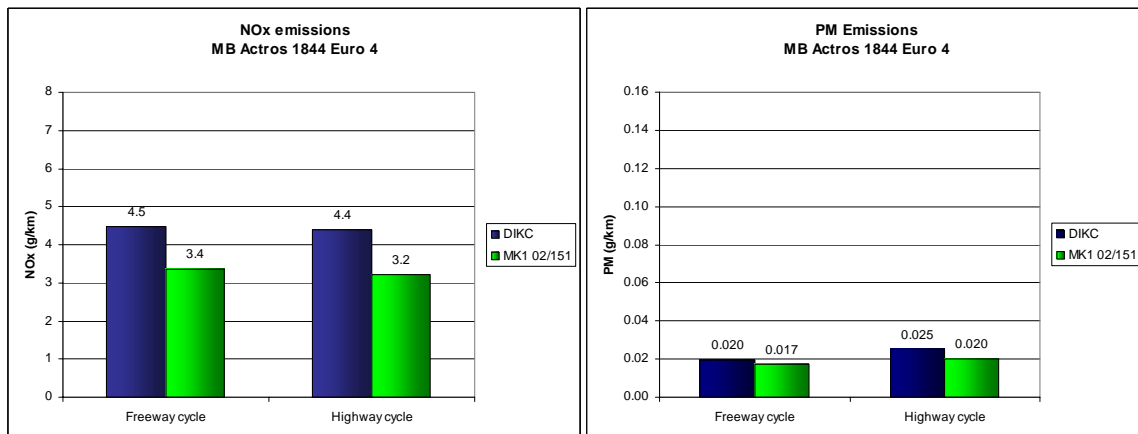


Figure 5.3. MK1 effects on NO_x- and PM –emissions (Mercedes-Benz).

For both vehicles the MK1 fuel reduced PM –emissions, some 15 – 20% for the Mercedes-Benz and much as 40% for the MAN. In the case of the EGR equipped MAN, MK1 even increased NO_x –emissions, whereas a quite substantial NO_x –reduction of some 25% was recorded for the SCR Mercedes-Benz.

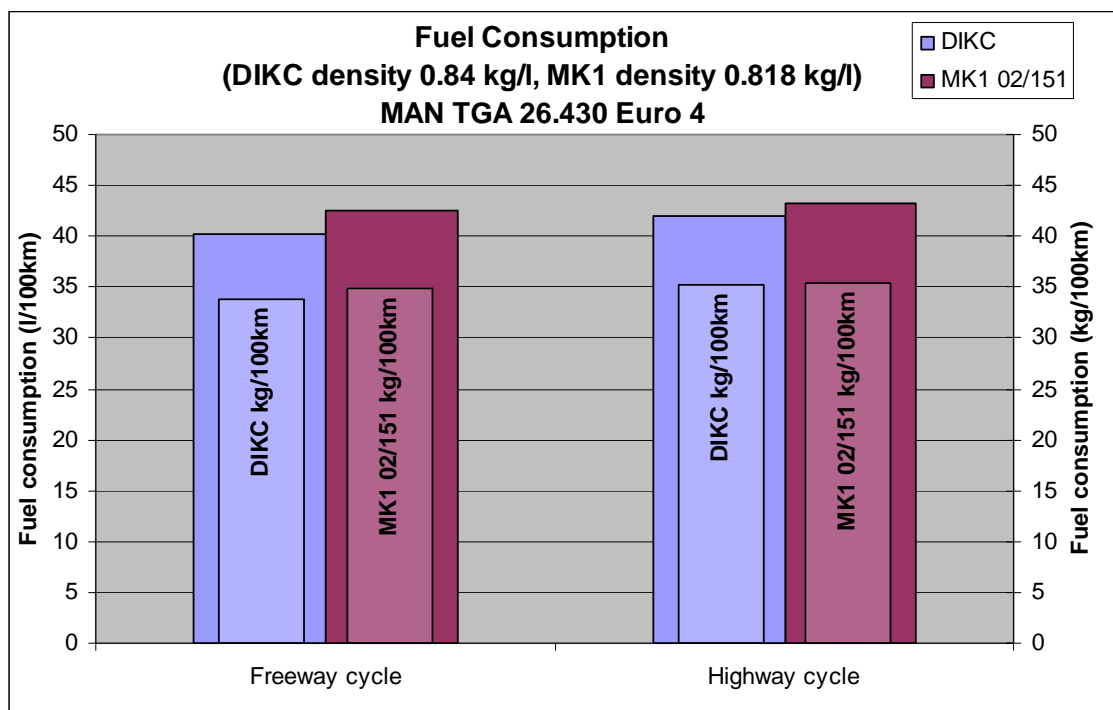


Figure 5.4. MK1 fuel consumption effects (MAN).

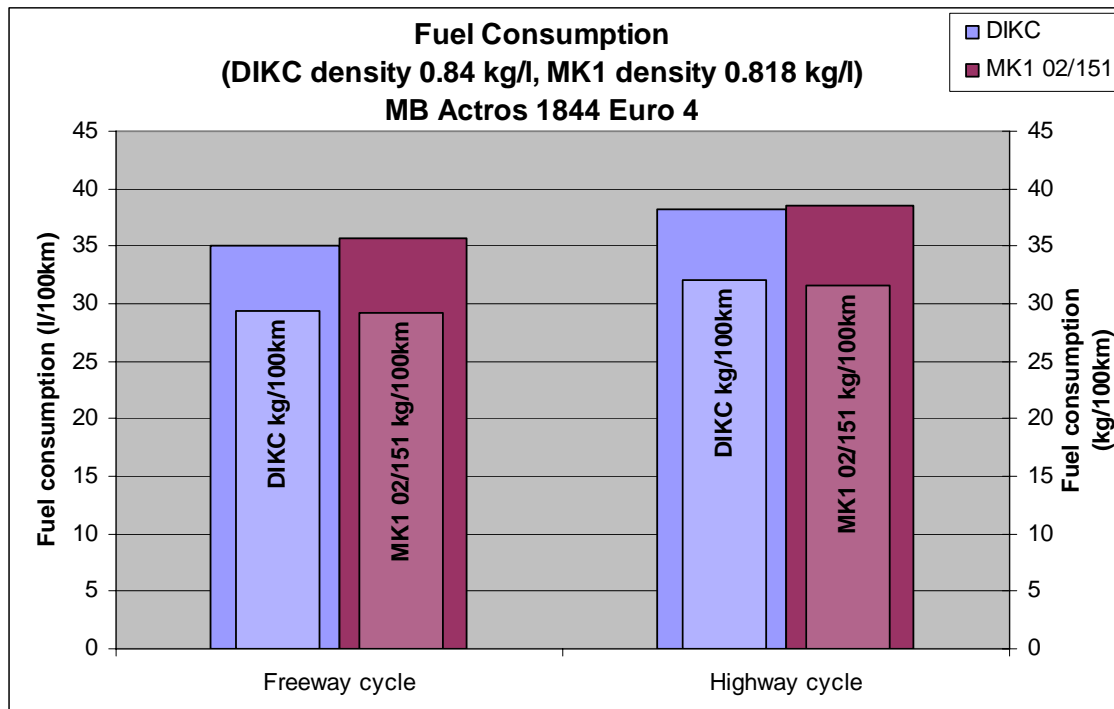


Figure 5.5. MK1 fuel consumption effects (Mercedes-Benz).

The effect of MK1 on fuel consumption was what could be expected, no changes in gravimetric fuel consumption and a small increase in volumetric fuel consumption. There was one exception, the freeway cycle with the MAN, which rendered higher fuel consumption (both gravimetric and volumetric) as well as higher NO_x with MK1. As mentioned before, the MAN was not functioning properly.

5.3 LUBRICANT TESTING

Testing of crankcase lubricants was carried out using a Cummins Euro 4 –certified engine installed in an engine test stand. Technical data for the SCR –equipped engine is given in Figure 5.6.

Altogether 14 different crankcase oils were tested (reference oil included, Table 5.1). The reference oil was a commercial oil of 15W-40 viscosity class.

The measurements were done with a fully warmed-up engine running six load points (modes) of the ESC duty cycle, with emphasis on partial load. Fuel consumption was measured gravimetrically, and the fuel consumption reference value for each oil quality was calculated as an average value of the specific fuel consumption in each load point.

Each load point was run for 38 minutes, and during this period 8 measurements with a duration of some 3 minutes were made. Each lubricant was broken in with 2.5 hours of running before the measurements.

Engine Model: ISBe4 160B		CPL: 8781
Advertised Power: 118kW @ 2500rpm		Peak Torque: 600Nm @ 1500rpm
158BHP @ 2500rpm		443lbft @ 1500rpm
Displacement: 4.5 Litre	Bore: **mm	Aspiration: Turbocharged & Aftercooled
Configuration: 4 cylinder in-line	Stroke: **mm	Fuel System: Bosch HPCR

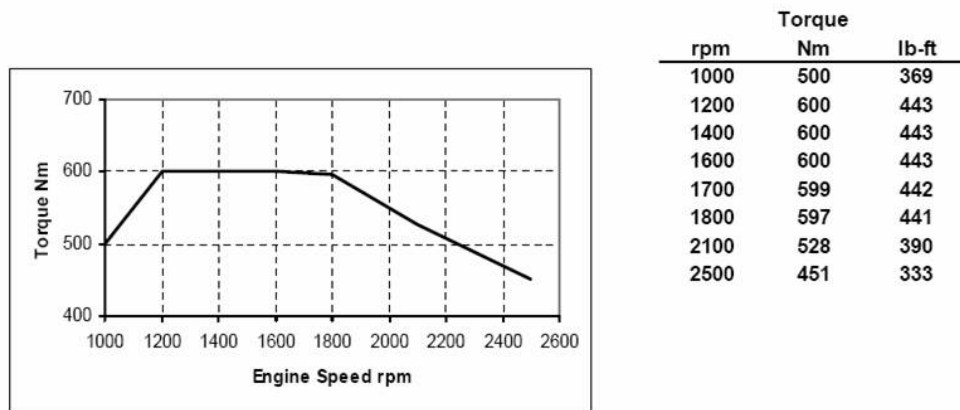


Figure 5.6. Technical data for the Cummins ISCe4 160B engine. (Cummins)

Table 5.1. Coding and basic data of the test lubricants.

Lubricant	SAE viscosity class	Kinematic viscosity at 100 °C (cSt)	HSHT - viscosity (cP)
Reference	15W-40	13.54	3.95
111	10W-30	11.7	3.54
222	0W-30	11.63	3.36
333	10W-40	14.18	3.95
444	5W-40	15.05	4.12
555	15W-30	11.75	3.66
666	10W40	13.67	3.9
777	5W-30	11.3	3.47
888	10W-40	13.78	3.96
999	10W-40	13.17	3.9
1001	10W-30	10.89	3.34
2002	5W-40	14.47	3.67
3003	10W-40	14.26	4.21
4004	15W-30	12.14	3.58

Figure 5.7 presents average results for the six load points. In the case of the Cummins engine it is possible to save around 1% of fuel choosing the engine lubricant correctly.

The differences between the lubricants increase when load is reduced. Figure 5.8 shows results for one of the individual load points, in this case mode 11 of the ESC test cycle (25% torque at 2212 rpm). In this case the maximum potential for fuel savings is some 1.5%.

Figure 5.9 shows X-30 and X-40 lubricants coded in different colours and sorted by W - viscosity class (low temperature viscosity). Lubricants with 30 -classification provide, on an average, slightly lower fuel consumption than 40 -classified oils. Some 40 -classified oils, however, provide fuel economy equivalent to 30 -classified oils. Oils with 10W-40 -classification, on the other hand, with one exception only, are worse for fuel economy than the other oils.

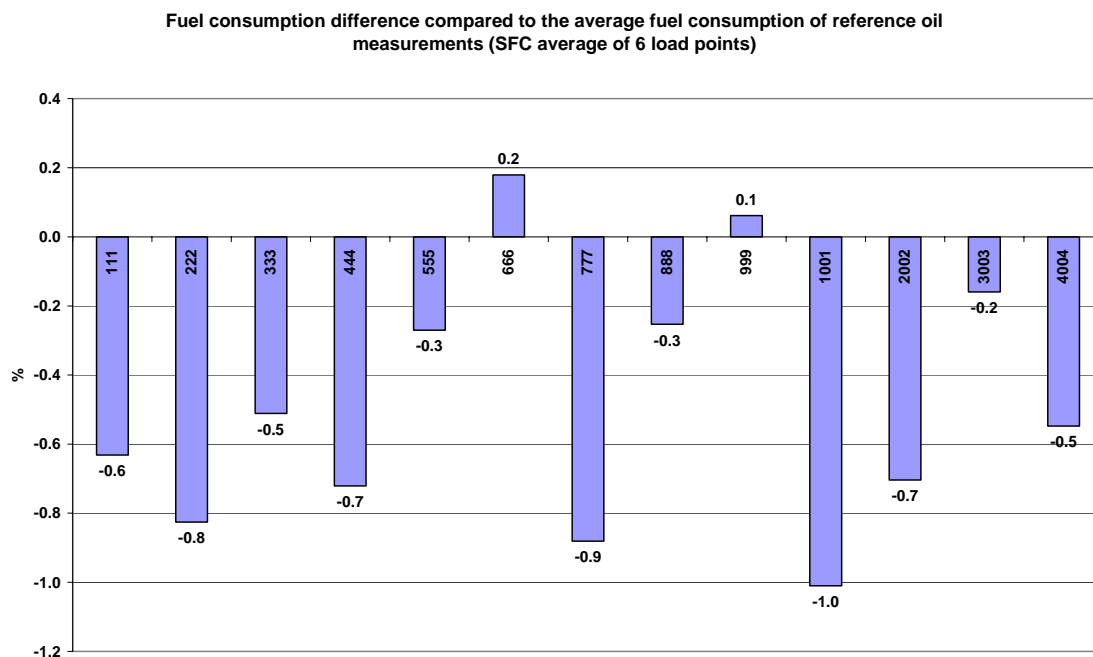


Figure 5.7. The effect of crankcase lubricant of fuel economy. Average results for six modes of the ESC test cycle (Cummins ISBe4 160B).

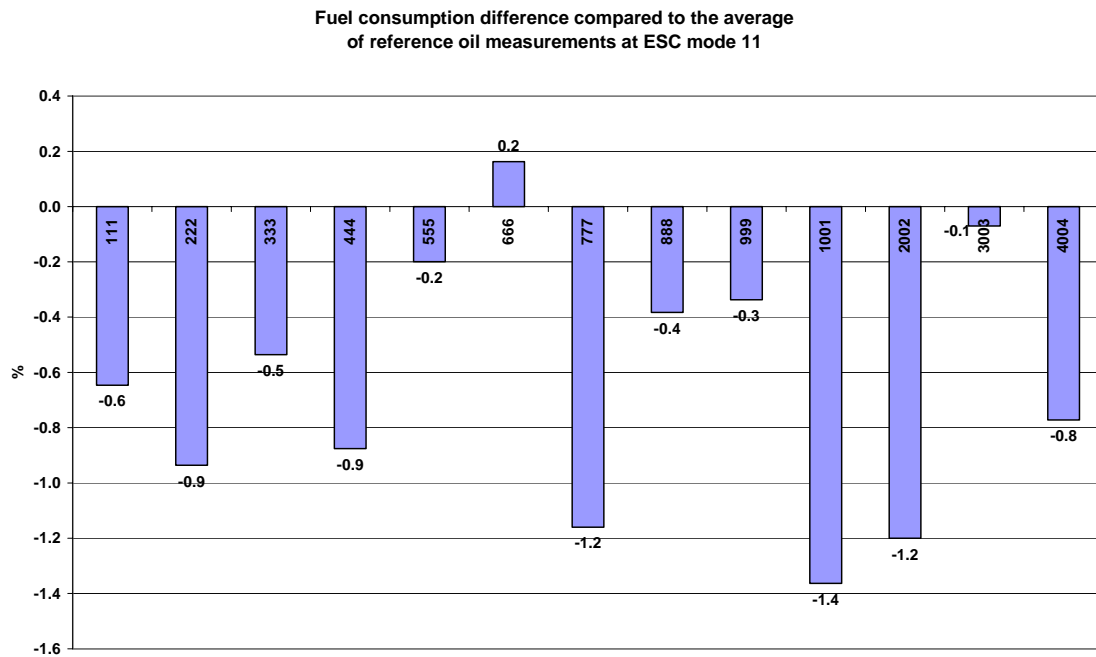


Figure 5.8. The effect of crankcase lubricant of fuel economy. Results for mode 11 of the ESC test cycle (Cummins ISBe4 160B).

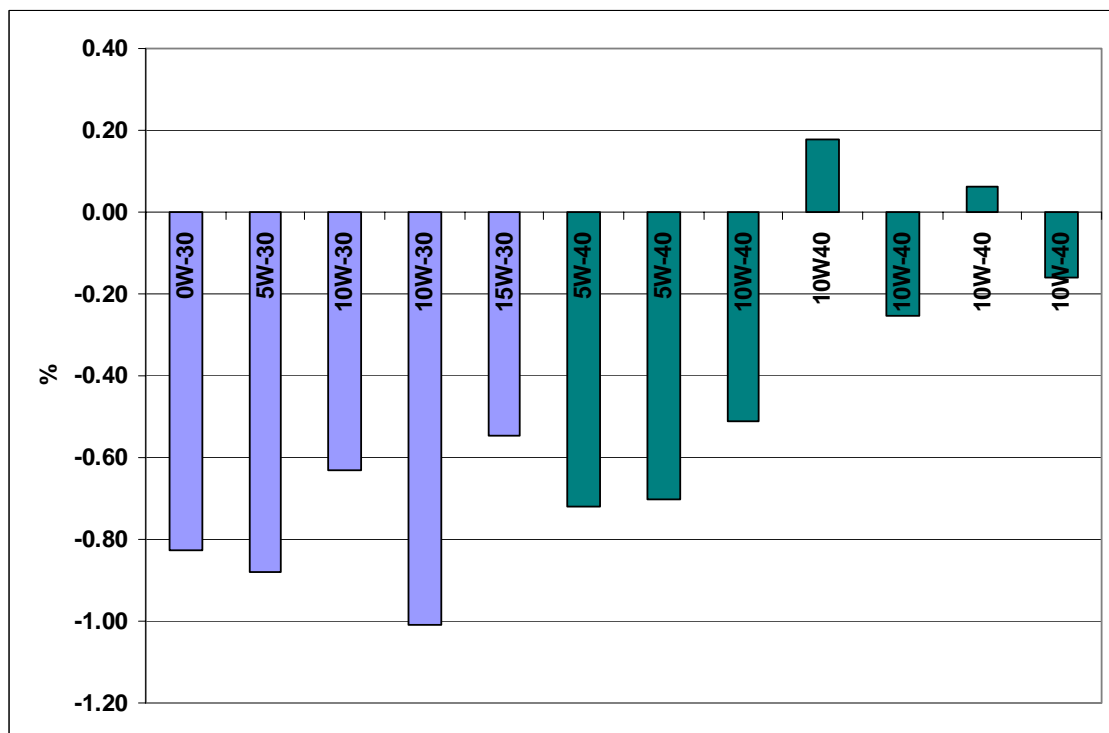


Figure 5.9. Test results sorted by viscosity class of the lubricants tested. Viscosity class of the reference oil 15W-40.

6 ECO-LABELLING OF HEAVY-DUTY VEHICLES

6.1 TRANSPORT ERA-NET

Since 2004 a comprehensive and powerful network of national ministries and supporting organisations in the field of transport research has been building up ERA-NET TRANSPORT (ENT). The ERA-NET TRANSPORT pre-dominantly serves to the owners and managers of transport research programmes. By facilitating cooperation among publicly financed transport research programmes it is ENT's goal to improve the outcome and quality of transport research in Europe. The main mechanism is seen in the structuring of the European Research Area (ERA) for Transport.

Action Groups (AG) are groups of national programme managers intending to set up and prepare joint activities within the selected topic. An Action Group is set up on a specific research topic that has been endorsed by three or more ERA-NET TRANSPORT partner countries. This can be done either by the outcome of the consultation following a targeted workshop (pro-active approach), or by demand of one or more members of the ERA-NET TRANSPORT (responsive approach). Every country has the freedom to choose whether it wants to participate at the related Action Group following national priorities. New participants have the possibility to join an Action Group later on.

The drafting of the following AG was initiated at the second Thematic Workshop held in Paris in June 2005, when representatives of member states participating in ERA-NET transport met to discuss of possible actions based on vehicle technology.

6.2 ERA-NET AG ENT9 - "ENVIRONMENTAL PERFORMANCE INDICATORS FOR HEAVY DUTY VEHICLES"

6.2.1 Background

There is a growing urgency amongst the Member States for lowering air emissions and energy use of road transport. Applying BAT technology in all new vehicle procurement occasions should positively affect vehicle fleet characteristics. Furthermore, for the benefit of ensuring the success of best-performing vehicles on the market, the public sector wishes to provide dissemination of relevant and unbiased information on environmental performance and energy use of motor vehicles. Also the public sector seek to entertain economical guidance (tax differentiation, subsidies etc.), based on the same criteria. This entails primarily the passenger car fleets, but it is increasingly important to implement this approach also to the heavy vehicle sector, as their share of the total emissions and energy use is usually about the same as that of the passenger vehicles. Furthermore, assessing the performance of retrofitted emission control systems that are commonly subject to investment subsidies needs proper procedures.

6.2.2 Status Quo and the Needs

To be successful, new heavy vehicle procurement and selection of ‘the-most-suitable-candidate’ for a given application (with reference to duty-cycle and performance requirements) needs support from data on real-life vehicle performance, preferably a harmonised rating system. However, there are today no rating systems developed for HDV’s, not even a uniform system for measuring and expressing the fuel consumption does exist. The only common data available are the values of regulated exhaust emissions (CO, HC, NO_x, PM_{mass}), measured according to the type approval standards, and expressed as specific emissions in (g/kWh). Therefore, there is an urgent need to increase the availability of real-world data in this area (related to output, i.e. vehicle-km or tonne-km), to disseminate this information and to develop similar rating scheme and guidelines as already exist for passenger cars.

A fundamental prerequisite regarding any policy that is set to guide vehicle choice, whether it is done just by dissemination of information or also by applying some economical instruments, is that we must be able to characterise and differentiate products. This characterisation and rating (expressed as “A is better than B” or “C holds a ★★ rating”) must be based on valid and relevant information that reflects the performance of the given product or technology in real-world duty and operating conditions. Therefore, any data that is used for the purpose of characterising the performance (regarding energy use and emissions, other environmental parameters) must be based on test procedures that can be traced and linked to the actual in-use duty-cycles and other conditions (loading, ambient temperature, fuels etc.). Those need to be duly reflected in the performance of the vehicle or technology that is to be assessed. To adequately fulfil these “musts”, the Action Group has deduced that a chassis dynamometer procedure must be used for this kind of assessments.

6.2.3 Objectives

Furthermore, to fulfil the Needs described, the objectives of this AG are:

- List and assess the characteristics of existing HD vehicle test facilities and collect data of the real-world duty-cycles used for assessment of vehicle performance (energy & emissions)
- Collect, evaluate and assess information available of energy consumption & environmental performance of heavy-duty vehicles (related to real-world duty-cycles) in order to develop a database and basis for a rating methodology
- Analyse the (critical) connections between the duty-cycle and vehicle environmental performance & energy use in order to come up with a draft proposal of a harmonised system for measuring and expressing the fuel consumption in this category (incl. set of duty-cycles and test protocol).

- Develop a draft for a rating system for heavy-duty vehicles, resulting in a proposal for EcoLabel scheme for heavy-duty vehicles

6.2.4 Contents of the work

Provisionally, the contents of the work envisaged consists of the following tasks:

- **Task 1: Testing**
 - **Task 1.0: Hardware & Facilities**
 - Identify existing test facilities and assess their characteristics
 - **Task 1.1: Test Procedure & Protocol**
 - Collect data on procedures & protocol used by partners (and other relevant parties)
 - **Task 1.2: Duty cycles**
 - Collect data on duty-cycles used by partners (and other relevant parties)
 - **Task 1.3: Correlations**
 - Collect data on correlation Chassis dyno vs. Engine dyno & Chassis dyno vs. On-road/On-board (PEMS)
- **Task 2: Models**
 - Help to provide sensible information besides actual testing
- **Task 3: Data & Databases**
 - Identify other parallel activities (for sourcing data & comparisons)
 - Collect relevant test data from partners (and other relevant parties)
- **Task 4: Rating Schemes**
 - Status quo & state-of-the art of existing ratings for heavy vehicles
 - User "guidelines" for the database in terms of rating
- **Task 5: Assessment Framework**
 - "Selling" the framework idea & application

6.2.5 Consortium and work progress

At present the following organizations participate in the joint effort to develop a harmonised assessment framework described above:

- VTT Technical Research Centre, Finland
- AVL MTC, Sweden
- Millbrook Laboratories, UK
- Technical University of Graz, Austria

The group has held two preparatory meetings during 2006 (on May 4 in Sweden, and on September 26 to 27 in Finland) to discuss the objectives and draft the work programme. It is intended to engage national funding from those four member states listed above to start a 24 month collaborative task-sharing project on the second half of this year.

ERA-NET is not providing funding for the actual research work, but rather for coordination. In the case of Finland, the activities within the RASTU –integrate form the platform to feed information into the ERA-NET eco-labelling work.

Information on ERA-NET Transport can be found at:

<http://www.transport-era.net/>

<http://www.transport-era.net/action-groups/ent9-environ-performance-indicators-heavy-duty-veh.html>

7 SPECIAL EMISSION MEASUREMENTS

7.1 GENERAL

In 2004, VTT published a study called “Transient Bus Emission Study: Comparison of Emissions from Diesel and Natural Gas Buses”. For that study, VTT carried out a comprehensive set of special emission measurements. (Transient Bus Emission Study 2004)

The increased use of exhaust after-treatment devices and new fuels motivates a closer study of exhaust gas composition. According to roadside air quality tracking, street- and roadside NO_x concentrations have statistically significantly decreased within the last few years, but NO_2 concentrations have not. Absolute NO_2 concentrations and the NO_2/NO_x proportion have been rising since 2001 - 2002. NO_2 effects can be found in the vicinity of the emission source.

There is inconsistency between environmental (air quality) measurements and vehicle emission measurements. The basis for air quality measurements and limit values is NO_2 concentration (health effects), whereas only total NO_x emissions (climate and regional effects) are considered in vehicle measurements. It has been discovered that oxidising after-treatment solutions of new diesel vehicles increase NO to NO_2 conversion. Oxidation catalysts and catalysed filters are becoming more common now when Euro 4 and Euro 5 emission regulations take effect. In addition, the decreasing fuel sulphur level and declining PM emissions increase the relative share of NO_2 in exhaust.

The principal objective is to experimentally prove features in the exhaust after-treatment systems of new vehicles and new (diesel) fuels that affect the air quality in an unrated and unfavourable way. Background information will be produced on how new vehicle technologies will influence the NO_2/PM concentrations in urban areas.

Currently only PM mass is regulated. There is some work done to also include particle numbers in emission certification in the future. In Switzerland the VERT verification system for diesel particulate filters requires a 95% particle number reduction in all particle size classes from 20 to 300 nm. (VERT 2005)

7.2 SPECIAL EMISSION MEASUREMENTS ON A SCR VEHICLE

In 2006, VTT carried out special emission measurements on Volvo’s Euro 5 –certified 12 –litre SCR vehicle. The methodology was the same as for VTT’s Transient Bus Study in 2004, with the exception that in 2006 no Ames tests were carried out. In 2006, the Braunschweig bus cycle was used in all measurements.

All in all, SCR technology did not provide any negative surprises regarding unregulated components. NO₂- and priority-PAH –emissions were very low, and practically no ammonia slip was detected. Particle numbers were equivalent to conventional diesel, as total particle mass was relatively high.

7.2.1 Oxides of nitrogen

Exhaust gas after-treatment alters the ratio of NO₂ to NO in the exhaust. The relative share of NO₂ grows with increased oxidation capability. For conventional diesel engines without exhaust after-treatment the share of NO₂ is typically some 5% of total NO_x.

The SCR system of the Volvo worked quite effectively, resulting in low total NO_x, but also in close to zero NO₂ –emissions. Figure 7.1 shows NO and NO₂ –emissions of the SCR bus in comparison with emissions from baseline diesel vehicles (Scania Euro 3 without and with oxidation catalyst).

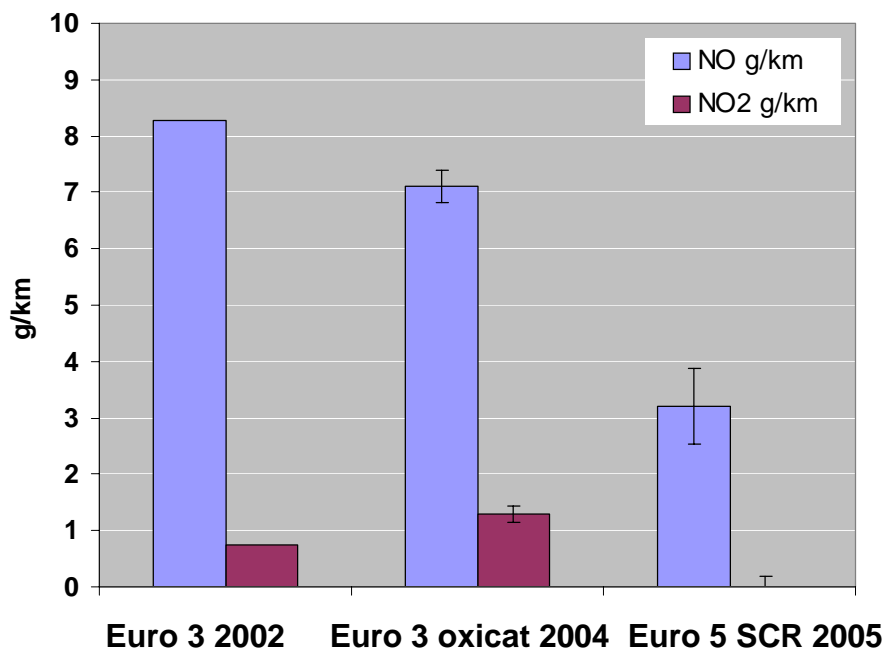


Figure 7.1. NO and NO₂ –emissions for various technologies.

Directive 2006/51/EC limits post-catalyst average ammonia concentration in undiluted exhaust to 25 ppm. In this case ammonia was measured using a FTIR –instrument (Gaset). Figure 7.2 shows ammonia concentration over the Braunschweig cycle. Ammonia slip was in general low with a maximum momentary value of 4 ppm, and average value as low as some 1.5 ppm.

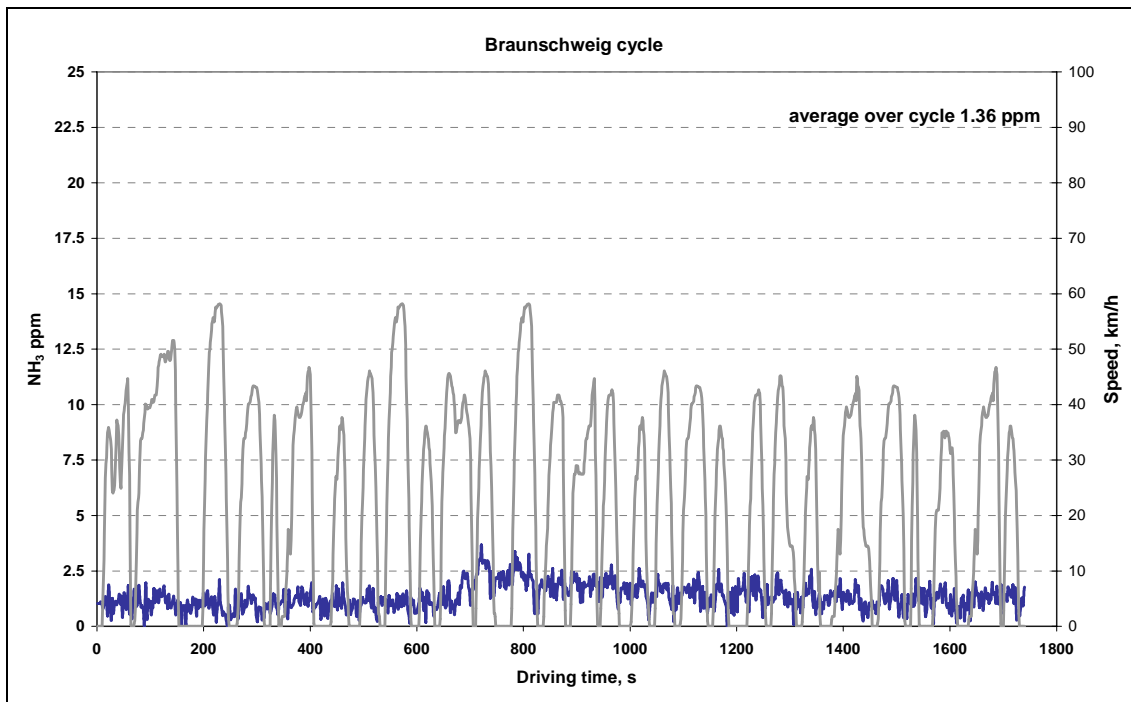


Figure 7.2. Concentration of ammonia in undiluted exhaust.

7.2.2 Aldehydes

Figure 7.3 shows a comparison of aldehyde emissions. The vehicles included are the SCR vehicle, two Euro 3 diesel vehicles (as in Figure 7.1) and a stoichiometric natural gas bus. In general, a catalyst with oxidation capabilities effectively reduces formaldehyde and acetaldehyde emissions. An oxidation catalyst on the Euro 3 diesel vehicle cuts formaldehyde emissions by 50%. In comparison with the diesel with oxidation catalyst, formaldehyde emissions are still much lower with SCR, at 1/3 level. The aldehyde levels of the three-way catalyst equipped natural gas vehicle were below detection limit.

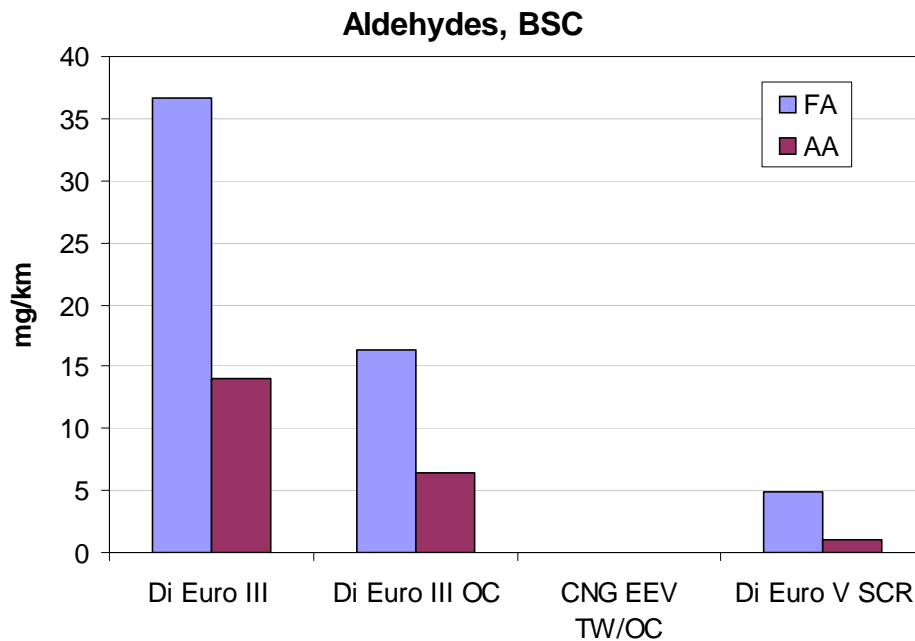


Figure 7.3. Form (FA)- and acetaldehyde -emissions (AA).

7.2.3 Particle size and numbers

An ELPI –instrument by Dekati Ltd was used for particle number measurements. Results are shown in Figure 7.4 (with logarithmic axis). Volvo’s SCR vehicle had quite high PM mass emissions, and this can also be seen in particle number measurements. For particle numbers, Volvo’s Euro 5 SCR vehicle does not differ significantly from Scania’s baseline Euro 3 vehicles. Only natural gas ND diesel with CRT particulate filter (in this case Scania Euro 3 with CRT) give significantly reduced particle numbers (approximately two orders of magnitude).

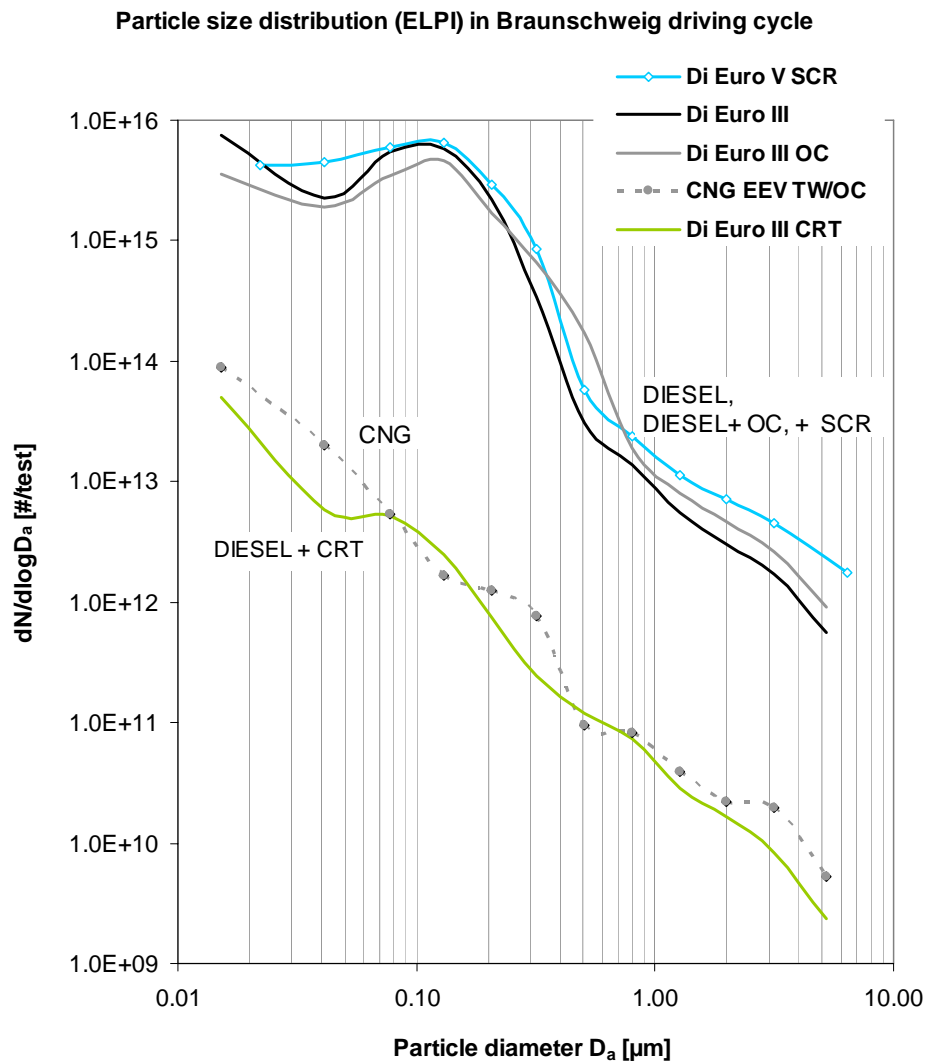


Figure 7.4. Particle number size distribution.

7.2.4 Hydrocarbon and PAH –emissions

The concentration of all NMHC components was below detection limit for the SCR vehicle. Methane was the only C_1 to C_8 component that could be detected.

Regarding PAH –emissions, the vehicles can be grouped into three categories:

- high for base line diesel and diesel with oxidation catalyst
- intermediate for SCR and CRT diesel and lean-burn natural gas
- low for stoichiometric natural gas (full-time stoichiometric)

Figure 7.4 shows emissions of different PAH compounds:

- 2 – 3 ringed PAH compounds (least harmful)
- compounds with 4 and more rings
- priority (toxic) PAHs as defined by IARC (International Agency for Research on Cancer) and US EPA

The list of priority PAHs includes the following compounds:

- benzo(a)anthracene
- benzo(b)fluoranthene
- benzo(k)fluoranthene
- benzo(a)pyrene
- dibenzo(a,h)anthracene
- indeno(1,2,3-cd)pyrene
- krysene
- 7,12 -dimethylbenzo(a)anthracene (added by EPA in 2006)

Diesel with CRT or with SCR as well as stoichiometric natural gas produce very low priority-PAH –emissions.

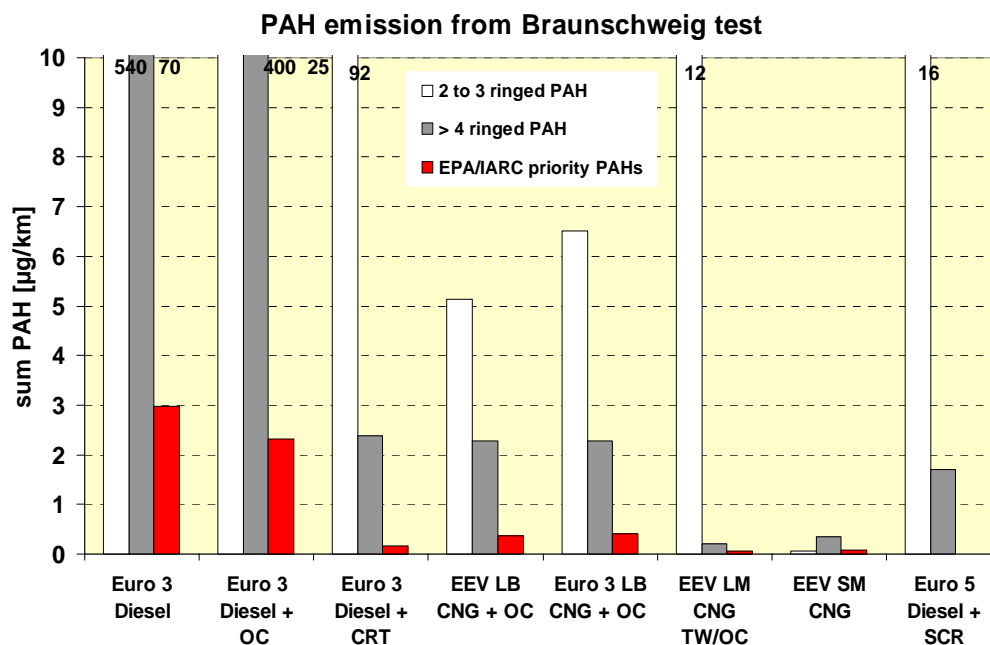


Figure 7.5. Sum of various PAH compound groups.

7.3 SUMMARY OF NO₂ MEASUREMENTS

Figure 7.6 shows a summary of NO₂ to NO measurements for diesel buses so far. The NO₂ to NO ratio varies significantly. NO₂ –emission close to zero is obtained for stoichiometric natural gas and certain SCR vehicles. For conventional diesel engines without exhaust after-treatment the share of NO₂ is typically some 5% of total NO_x.

With most oxidations catalysts the NO₂ portion of NO_x is some 10 – 20%, for the particle oxidation catalysts slightly higher. For two EGR vehicles with oxidation catalysts NO₂ to NO is roughly 1:1.

VTT is in a process of renewing its instrumentation for NO and NO₂ measurements, and an improved system will be in use during spring 2007. The results in Figure 7.6 should be considered indicative. However, it is evident that there are great variations among the technologies. Thinking about urban air quality, direct NO₂ –emissions should be controlled.

In 2007 Californian Air Resources Board CARB introduced a regulation for retrofit diesel exhaust after-treatment devices regarding NO₂ –emissions. The new limit is defined as a maximum incremental increase of 20% over the baseline NO₂ emission level. For instance, for an engine with a baseline NO₂ fraction of 10%, this corresponds to total NO₂ emissions of 30% of the NO_x. (DieselNet)

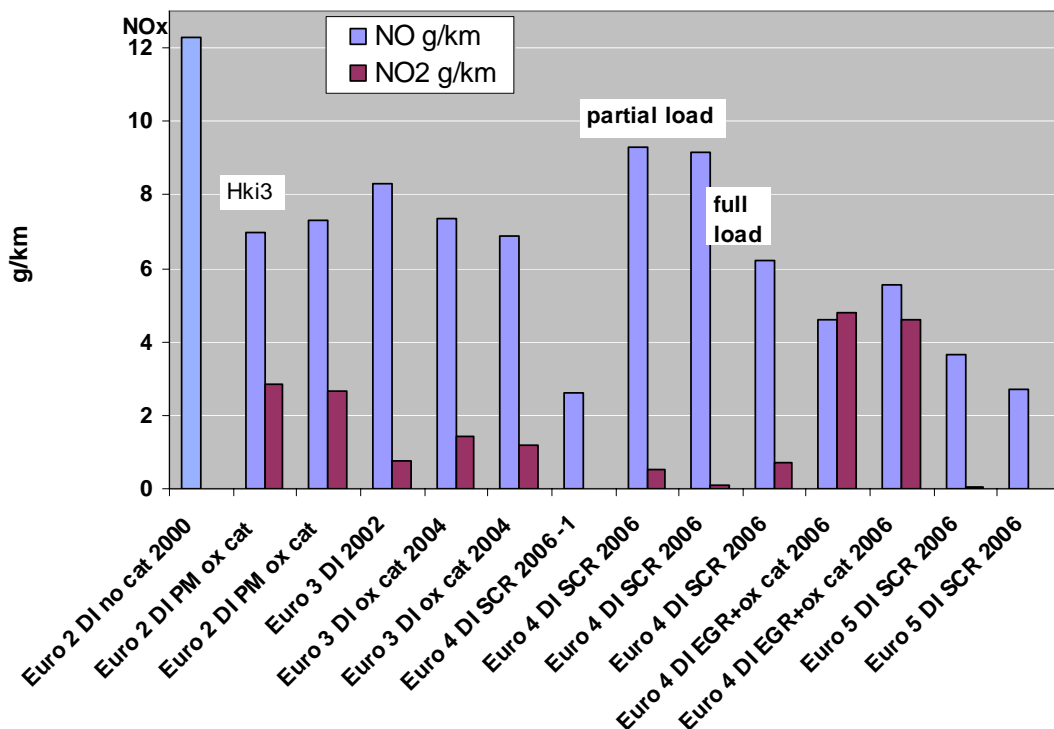


Figure 7.6. NO₂- and NO –emissions for diesel vehicles (indicative).

8 SUMMARY

In 2006, the “RASTU” research integrate proceeded as planned. Compared with the situation in 2005, the supply of Euro 4 and Euro 5 certified vehicles was plentiful. In 2006, a good number of new Euro 4 and Euro 5 certified vehicles were measured (six buses and six heavy-duty trucks).

The general observation is that going from Euro 3 to Euro 4/5 technology does not increase fuel consumption. Measurements of fuel consumption show that with Euro 4 and Euro 5 technology, vehicle-to-vehicle variations have rather diminished than increased. This is contrary to the expectations.

The results for exhaust emissions are mixed. The general impression is that neither SCR nor EGR technology performs in an optimum way in the case of city buses with the current level of technology sophistication. Of six urban buses tested, only one corresponded to its certification class in real city driving. The picture for heavy-duty trucks (42 and 60 ton) running on high load is brighter, as most vehicles provide significant emission reductions compared with the Euro 3 class.

Tests with Swedish MK1 diesel fuel and the new renewable NExBTL diesel fuel demonstrate that clear fuel effects on emissions can also be seen for Euro 4 certified vehicles.

Altogether 13 different crankcase lubricants were evaluated for fuel efficiency using an Euro 4 certified SCR engine. By choosing the lubricant correctly, fuel savings on some 1 – 1.5% can be achieved.

Within ERA-NET Transport work has commenced to evaluate the possibilities to develop an eco-labelling system for heavy-duty vehicles. Organisations from Austria, Finland, UK and Sweden are participating in this work.

Special emission measurements are included in the RASTU integrate. A comprehensive test matrix was carried out for one SCR bus, revealing no surprises regarding unregulated emissions. The emission of highly toxic priority-PAHs was extremely low.

Euro 4 and Euro 5 vehicles show rather large variations in regulated emissions. However, regarding emissions, the greatest variations can be found for NO₂ to NO – ratio, as the share of NO₂ of NO_x varies from around zero to 50%.

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