HEAVY-DUTY VEHICLES: SAFETY, ENVIRONMENTAL IMPACTS AND NEW TECHNOLOGY "RASTU"

Annual report 2007

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Heavy-duty vehicles: Safety, environmental impacts and new technology "RASTU". Annual report 2007.

Edited by Nils-Olof Nylund

Abstract

Research on fuel savings for heavy-duty vehicles continues in the 2006 – 2008 "RASTU" research integrate. The scope has been broadened so that now more tasks related to emissions, IT technology and safety are included. Five research units participate in the work, and the research integrate has some 20 sponsors. The number of subprojects is 9.

The research continued largely as planned in 2007. More than 20 buses were tested. Among the tested vehicles were three EEV -level diesels, which all turned out to be fairly clean-running. Additional measurements were made on 60 ton goods vehicles. Measurements of 18 ton goods vehicles were also introduced. Biofuels were studied using a van and a medium sized truck. Research on lubricants was now carried out in a chassis dynamometer test stand. These tests demonstrated that choosing the optimal transmission oil can improve the fuel economy of an automatic transmission equipped truck by some 3 %.

Lightweight engineering of trailers, the stability of full trailer trucks and the impact of tires on fuel economy was studied in the field of vehicle engineering. The result of the stability research was a recommendation for optimal tires for a full trailer. Bus- and truck tires, as well as trailer tires, were compared for fuel efficiency. Equipment problems, however, hindered the research on vehicle IT -applications. The algorithm for skid detection was proven workable, although verification was held up by the inoperability of vehicle devices. Because of this, the data had to a great extent be processed manually. Driver aid systems were installed in 15 busses, but active driving assistance was not engaged in 2007 yet.

Three Master Thesis came out of the project during 2007, two of them relating to vehicle engineering and one covering follow-up and incentive systems.

Circulation	**Publicity**
ADEME, Swedish Road Administration, RASTU Executive Committee	Public
Revisions	**Date**

PREFACE

In 2006 – 2008 VTT Technical Research Centre of Finland, in cooperation with other research institutes, carries out a research integrate on heavy-duty vehicle exhaust emissions and energy savings. This 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, ITS -systems and safety have been added.

Five research institutes and some 20 different sponsors are taking part in the project. The French Energy Agency ADEME and the Swedish Road Administration are also contributing to the funding of the project. In courtesy to them, two separate reports have been produced for 2007, the one at hand, a shorter English version of the annual report for 2007, and a more extensive report in Finnish.

The research progressed as planned in 2007. New even better running diesel vehicles were tested. Encouragingly, both regulated emissions and fuel consumption seem to be decreasing. This holds particularly for the largest heavy-duty vehicles.

Measurements performed by VTT on heavy-duty vehicles have gained international attention. The results have been presented in seminars held by both the U.S. Department of Energy and the International Energy Agency.

Lightweight engineering of trailers and the impact of tires on fuel economy, to mention a few, was studied in the field of vehicle engineering. A praiseworthily made thesis, in which the impact of tire selection on trailer stability was studied, came out of the project as well. Vehicle IT -applications were enhanced too.

Espoo 15.5.2008

Nils-Olof Nylund
Co-ordinator of the project

1 RESEARCH INTEGRATE FOR 2006 – 2008 "RASTU"

The research integrate for 2003 – 2005 was heavily emphasized on fuel savings for heavy-duty vehicles. Fuel economy is fairly central in the RASTU –integrate too, but emissions are now accentuated. Emission focused activities for buses and trucks, previously carried out as separate tasks, have been merged into the new research integrate. The new integrate also covers safety issues, e.g. the development of ITS -applications for improved safety.

The objectives of the new research integrate can be summarised as follows:

- To ascertain the true performance of new vehicle types (Euro 4/5/EEV certified vehicles)
  - fuel efficiency and exhaust emissions under real-life driving conditions
  - development work aiming at ecolabelling heavy-duty vehicles
  - adapting new vehicle technology as efficiently as possible under Finnish conditions
  - optimizing the performance of fuels lubricants for new vehicles

- Development of ITS -technology to reduce energy consumption and improve safety and service levels of 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 (NO_2/PM) and new vehicle technology

The following research institutes/partners contribute to the work:

- VTT Technical Research Centre of Finland
- Helsinki University of Technology, Automotive Laboratory (HUT)
- Tampere University of Technology, Institute of Transportation Engineering (TUT)
- University of Oulu, Department of Electrical and Information Engineering (UO)
- Turku University of Applied Sciences
- 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 Ltd.

In the years 2006 – 2007 the aggregate comprised of 10 subprojects (9 subprojects with technical content, responsible parties put in brackets):

1. Performance (fuel consumption, exhaust emissions) of new Euro 4/5/EEV vehicles (VTT)
2. Fuels and lubricants for Euro 4/5/EEV vehicles (VTT)
3. Development of vehicle technology (HUT, VTT)
4. Development of ITS -technology for heavy-duty vehicles (VTT, UO)
5. Optimisation of bus operations (VTT)
6. Monitoring and bonus systems for truck operations (TUT)
7. Evaluation of measures for reduced energy consumption (VTT, TUT)
8. Development of measurement methods, including development of eco-labelling for heavy-duty vehicles (VTT)
9. Research into exhaust emissions (VTT)
10. Coordination and communication (TEC TransEnergy Consulting Ltd, VTT PRO, Motiva)

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.

In the English version of the 2007 Annual Report, subprojects 1, 2, 3 (partly), 8 and 9 are dealt with.

The City of Helsinki, Helsinki City Transport, Helsinki Metropolitan Area Council (YTV) and RASTU organised a seminar "Transport related environmental challenges – Climate and air quality" in Helsinki December 12, 2007. The seminar had more than 100 participants. Measures taken by the City of Helsinki and YTV for reducing emissions were discussed before noon. The RASTU –subject matter and technical measures for reducing emissions were discussed in the afternoon.

The annual budget of the project is approximately 800,000 €. The main sponsor is Tekes- the Finnish Funding Agency for Technology and Innovation and their ClimBus-technology program. 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 research integrate mainly progressed as planned, although some minor delays also occurred. The time-scale of subproject 4 (Development of ITS -technology for heavy-duty vehicles) has been drawn out due to device failures.

Chapter 2 consists of a short summary on the activity of the project in 2006. The progress of the project in 2007 is described in detail from chapter 3 onwards. The number of each chapter contains the subproject (SP) number. Vehicle models are disclosed, accordingly to the year 2006 report.

2 ACTIVITIES IN 2006

Activities in year 2006 were reported in the annual report dated May 25, 2007. The following was stated in the summary:

"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.

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.

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."

3 PERFORMANCE OF EURO 4/5/EEV –VEHICLES (SP 1)

Responsible party: VTT

Writing: Kimmo Erkkilä, Petri Laine & Nils-Olof Nylund

A separate report on measurements conducted in 2007 has not been prepared. Several independent reports have been prepared in previous years (RAKEBUS). Measurement results have although been published in some international and domestic seminars. To mention a few:

- International Conference on Transport and Environment: A global challenge. Technological and Policy Solutions. Milan, Italy, 19-21 March, 2007.
- 57th UITP World Congress. Helsinki, 20–24 May, 2007.
- Efficiency Policies for Heavy-duty Vehicles. International Energy Agency. Paris, 21-22 June, 2007.
- 13th Diesel Engine Emission Reduction Conference. Detroit, Michigan, Aug 13 – 16, 2007.
- Paikallisliikennepäivät (Seminar of the Finnish Public Transport Association). Pori, 20-21.9.2007.
- EU Interaction –seminars, 14.6 and 14.9.2007 in Helsinki

3.1 MEASUREMENTS OF CITY BUSES

3.1.1 General

Emphasis was in 2007 set on the newest Euro 4/5/EEV –emission level diesel vehicles, and the newest EEV –emission level natural gas vehicles. Natural gas buses are of special interest for Helsinki City Transport. Older Euro 2 and Euro 3 class vehicles were also measured in connection to follow-up measurements on the aging of the vehicles. In addition, measurements on particulate catalysts (pDPFs) were carried out.

Taking into account measurement results from 2007, VTT's emission database for city buses now contains measurement data for altogether 71 diesel powered and 21 natural gas powered buses. Altogether, the measured buses now mount to a total of 92 samples, including the follow-up measurements. Table 3.1 shows the measured vehicles' emission categories. Diesel and natural gas diesel powered vehicles are presented separately.

Table 3.2 presents the individual vehicles that were added to the database in 2007. These vehicles were measured in the RASTU –project and in other parallel projects in 2007. The vehicles marked by red are light-weight vehicles and those marked by green retrofitted pDPF –vehicles. Two of the vehicles (Volvo Euro 2 and Scania Euro 3) are equipped with pDPF –particulate catalysts supplied by Proventia (former Finnkatalyt) in order to monitor the functionality of the catalysts in long-duration tests.

Table 3.1. Vehicles found in the emission database, categorized by fuel and emission levels.

Diesel		**NGV**	
Euro 1	2	Euro 2	2
Euro 2	26	Euro 3	7
Euro 3	28	EEV	12
Euro 4	10	**Total**	**21**
Euro 5	2		
EEV	3		
Total	**71**		

Table 3.2. City buses measured in 2007

2007	**Recognition code**	**lic.no.**
Volvo	Brand A (MY99) Euro 2	AIZ-927
Volvo	Brand A (MY04) Euro 3	VSG-460
Volvo	Brand A (MY05) Euro 3	CYJ-154
Scania	Brand C (MY02) Euro 3	ZOF-209
Scania	Brand C (MY05) Euro 3	GFK-597
Scania	Brand C (MY05) Euro 3	CYK-132
Volvo	Brand A (MY06) Euro 4	
Volvo	Brand A (MY07) Euro 4	VPY-601
Scania	Brand C (MY06) Euro 4	FHG-230
Scania	Brand C (MY06) Euro 4	MRG-632
Kabus	Brand G (MY07) Euro 4	
Volvo	Brand A (MY06) Euro 5, 3-axle	OXI-692
Iveco	Brand E (MY07) EEV	BBY-981
Volvo	Brand A (MY07) EEV	
VDL	Brand H (MY07) EEV	BS-BF-23
Volvo	Brand A (MY00) Euro 2	ZIX-131
Scania	Brand C (MY05) Euro 3	GFK-597
Scania	Brand C (MY05) Euro 3	GFK-597
MB	Brand B (MY06) EEV,CNG	JGV-918
MAN	Brand D (MY05) EEV,CNG	CYU-745
MAN	Brand D (MY07) EEV,CNG	JGZ-922
MAN	Brand D (MY06) Euro 5,CNG	CYU-808
MAN	Brand D (MY07) EEV,CNG	GHI-763

The first new EEV –certified diesel vehicles (Iveco Irisbus, Volvo and Dutch VDL) were obtained for measurement in 2007. All above mentioned vehicles use SCR –technology. The Iveco and VDL have an additional effective particulate filer. The light-weight VDL was measured at VTT in a bilateral commission. The client gave permission to publish the results in the RASTU –project. The VDL –bus has a Cummins engine, with an engine control system that has been optimised by VDL themselves.

Table 3.3 presents new updated emission factors for urban- (Braunschewig) and suburban driving (Helsinki 3). The factors have been obtained from the measurements.

The special vehicles marked by red and green in table 3.2 have not been included into the averages of table 3.3.

Table 3.3. Updated emission factors for city buses.

Emission chart, updated 08.11.2007

Braunschweig	CO g/km	HC g/km	CH4* g/km	NOx g/km	PM g/km	CO2 g/km	CO2 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	1.59	0.20	0.00	13.48	0.217	1277	1277	40.9	17.4
Diesel Euro 3	0.83	0.14	0.00	8.65	0.188	1191	1191	38.1	16.2
Diesel Euro 4	3.22	0.05	0.00	6.36	0.096	1171	1171	37.9	16.1
*Diesel Euro 5****	*3.22*	*0.05*	*0.00*	*3.63*	*0.096*	*1171*	*1171*	*37.9*	*16.1*
Diesel EEV	2.63	0.01	0.00	4.75	0.023	1098	1098	35.3	15.0
CNG Euro 2	4.32	7.12	6.29	16.92	0.009	1128	1283	42.1	20.1
CNG Euro 3	0.18	1.33	0.90	10.02	0.009	1254	1284	45.8	21.9
CNG EEV	1.32	1.06	0.85	2.81	0.008	1282	1307	47.2	22.5

*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

Emission chart, updated 08.11.2007

Helsinki3	CO g/km	HC g/km	CH4* g/km	NOx g/km	PM g/km	CO2 g/km	CO2 ekv** g/km	Kulutus kg/100km	Kulutus MJ/km
Diesel Euro 1	1.12	0.26	0.00	12.63	0.353	988	988	31.1	13.2
Diesel Euro 2	1.29	0.16	-0.01	10.92	0.175	1034	1034	32.9	14.0
Diesel Euro 3	0.67	0.12	-0.01	7.01	0.152	965	965	30.7	13.0
Diesel Euro 4	2.61	0.04	0.00	5.15	0.078	949	949	30.6	13.0
*Diesel Euro 5****	*2.61*	*0.04*	*0.00*	*2.94*	*0.078*	*949*	*949*	*30.6*	*13.0*
Diesel EEV	2.13	0.01	0.00	3.85	0.019	890	890	28.5	12.1
CNG Euro 2	3.50	5.76	5.09	13.70	0.007	914	1039	33.9	16.2
CNG Euro 3	0.15	1.08	0.73	8.12	0.008	1016	1040	36.9	17.6
CNG EEV	1.07	0.86	0.69	2.28	0.006	1039	1058	38.0	18.1

*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

3.1.2 Nitrogen oxides and particulates

Figure 3.1 shows vehicle specific nitrogen oxide- (NO_x) and particulate- (PM) results for the newest vehicle types. Older Euro 2 and Euro 3 level vehicles are used as references. Their results are presented as averages (large triangles and circle). In contrast to pictures presented earlier by VTT, the scale has been adjusted in this new manner of representation. Euro 3 level particulate limit values for both ESC- (European Steady Cycle) and ETC- (European Transient Cycle) engine tests have been added too. Limits for pre- Euro 3 level vehicles are based on ESC –tests and its predecessor, the R49 –test, which is a static test. Limiting values for the newest vehicles are based on the ETC –cycle. A coefficient of 1,8 is used in both cases for proportioning the results to those of the Braunschweig cycle. The coefficient is obtained by dividing energy usage with the travelled distance (kWh/km).

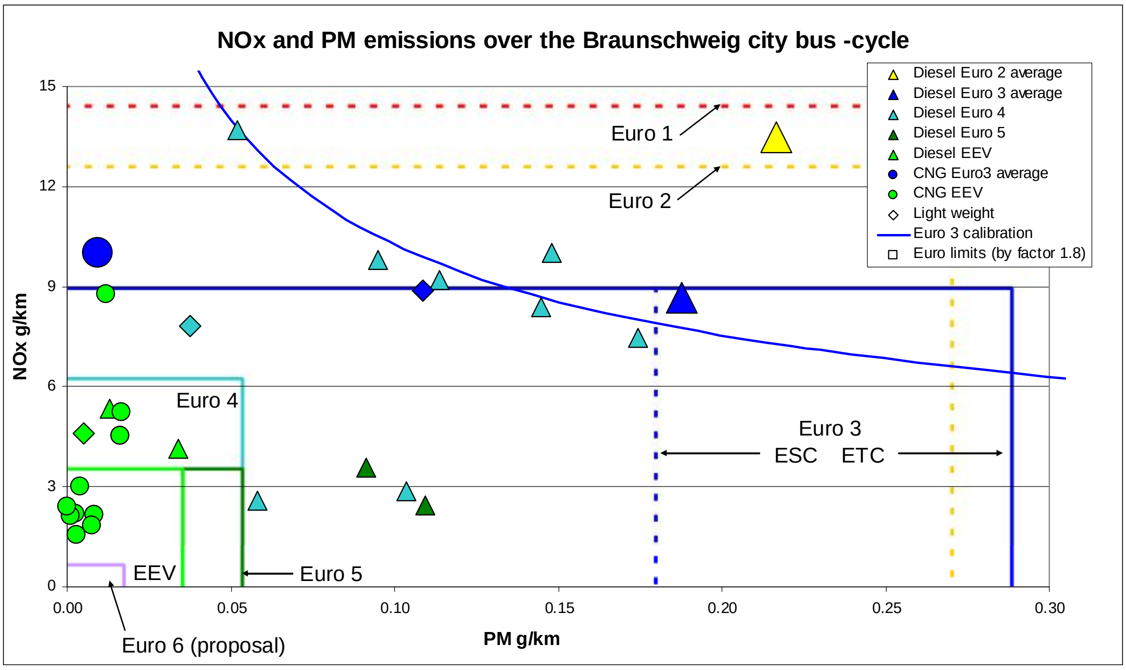

Figure 3.1. NO_x and PM –emissions of the newest city buses in relation to traveled distance.

As Figure 3.1 shows, the great bulk (6/8) of the Euro 4 –level vehicles measured in 2006 – 2007 (turquoise) give in practice only results equal to average Euro 3 –level vehicles. The results of these vehicles (Volvos and Scanias) landed on the calibration line drawn for Euro 3- level engines, which depicts the NO_x-PM dependency when altering engine adjustments. All points that land on the curve can therefore be considered technically equally demanding from the engine point of view.

Two Euro 4 –level vehicles gave, on the other hand, NO_x –emissions clearly below the limiting-values (MB and 9 -litre Volvo). The MB was also close to the limit value for particulate emissions. The particulate emissions for the Volvo were, on the other hand, rather high. The particulate emissions of the 9 -litre Volvo are in fact quite similar to those of Volvo's bogie –type Euro 5 –vehicles (vehicles used on the circular Joker bus line, dark green triangles), and in fact they do belong to the same engine family.

The two conventional (not light-weight) diesel powered EEV- (Enhanced Environmentally friendly Vehicle) vehicles were also under real-life driving circumstances notably cleaner-running that the other diesel powered vehicles (bright green triangles). One of the vehicles, the CRT –particulate filter equipped Iveco, gave extremely low particulate emissions, but its NO_x –emissions were closer to Euro 4 –level. Volvo does not use any particular after-treatment technology to lower particulate emissions. Despite this, using only SCR technology its NO_x- and PM- emissions still do settle close to the EEV- limit values (corner point of the EEV –area). The vehicle does in other words comply with EEV- emission levels under real-life driving circumstances too.

Figure 3.1 also shows results for light-weight Euro 3 (Kabus), Euro 4 (Kabus) and EEV (VDL) vehicles. The light-weight buses are coded with rhombus-like markings with colouring based on their respective emission certification class. Both light-weight manufacturers use SCR –technology based Cummins engines, but VDL has optimized the engine control system themselves. The VDL EEV –vehicle has further got a CRT –particulate filter. The particulate emissions of the VDL are equal to those of the cleanest-running natural gas vehicles. Its NO_x –emissions fall in between those of the Iveco and EEV Volvo. The light-weight Kabus easily fulfills Euro 4 –level particulate emission requirements. Its NO_x -emissions are something between Euro 3- and Euro 4 –level.

Natural gas powered EEV vehicles (bright green circles) mainly confirmed previous findings; they were in most cases found inside the "EEV –box" on the NO_x-PM –map. Particulate emissions were low in all occurrences, but some differences in NO_x-emissions were observed between the different technologies. All but one of the MAN vehicles, which all operate on a stoichiometric blend, produced low NO_x –emissions. The conflicting vehicle gave high NO_x –emissions (around 9 g/km), which most likely explains itself by some sort of an engine failure. The lean mixture MB vehicles once again produced Euro 4 level NO_x –emissions, but their PM –emissions were easily EEV level.

3.1.3 Carbon dioxide emissions and fuel efficiency

Figure 3.2 presents carbon dioxide- (CO_2) and nitrogen oxide- (NO_x) emissions of city buses. The Figure shows the margin of error for the CO_2-results of one natural gas- and one diesel vehicle. The CO_2-results of the diesel powered vehicles were significantly more accurate, because they are based on weighed fuel consumption and calculation of carbon balance. The results of the natural gas vehicles are, on the other hand, analysis results of exhaust gases.

Figure 3.2 shows how the new two-axle EEV-diesel vehicles produced relatively low CO_2 -emissions. The emissions settled in the range of 1100 g/km, which can be considered a good result. The limit of 1100 g/km can be used as a benchmark for normal two-axle city buses in the Braunschweig cycle. The typical weight of these vehicles when half loaded is about 15 000 kg. The more energy efficient Euro 4 SCR –vehicles reached similar CO_2 -levels as well, but naturally their NO_x-emissions were higher. The most efficient natural gas vehicles also got close to the 1100 g/km target, but due to measurement inaccuracy it is not possible to put the diesel and natural gas vehicles in a very accurate order of superiority based on these results. The magnitude of CO_2 –emissions of these two technologies is the same.

Figure 3.2 also shows the heavier three-axle bogie-type vehicles, which have a greater carrying capacity than the two-axle vehicles. The typical weight of these vehicles when half loaded is around 19 000 kg, which proportioned to two-axle vehicles would give a target result of 1300 g CO_2/km. The best results did although not reach levels below 1400 g/km, which means that these measured vehicles cannot be considered outstandingly energy efficient. The model range of the three-axle vehicles measured in the tests is limited. It might well be that there are alternatives on the market which are nearly 10 % more energy efficient than the tested vehicles.

The carrying capacity of the light-weight buses was not significantly lower compared to conventional two-axle city buses; hence the advantage of light-weight technology on CO_2-emissions and fuel consumption is undisputable. Using light-weight vehicles, which weigh half loaded circa 11 500 kg, it is possible to achieve CO_2 -emissions of slightly over 900 g/km. The difference is roughly 20 % compared to conventional vehicles.

The bench mark result for NO_x -emissions is 3 g/km, in other words less than 2 g/kWh on the engine's crankshaft. This level is reached using stoichiometric natural gas vehicles and the most clean-running SCR-diesel vehicles.

Figure 3.3 shows carbon dioxide emissions in proportion to particulate emissions. The Figure shows how natural gas vehicles (regardless of age), and vehicles equipped with particulate filters produce very low particulate emissions.

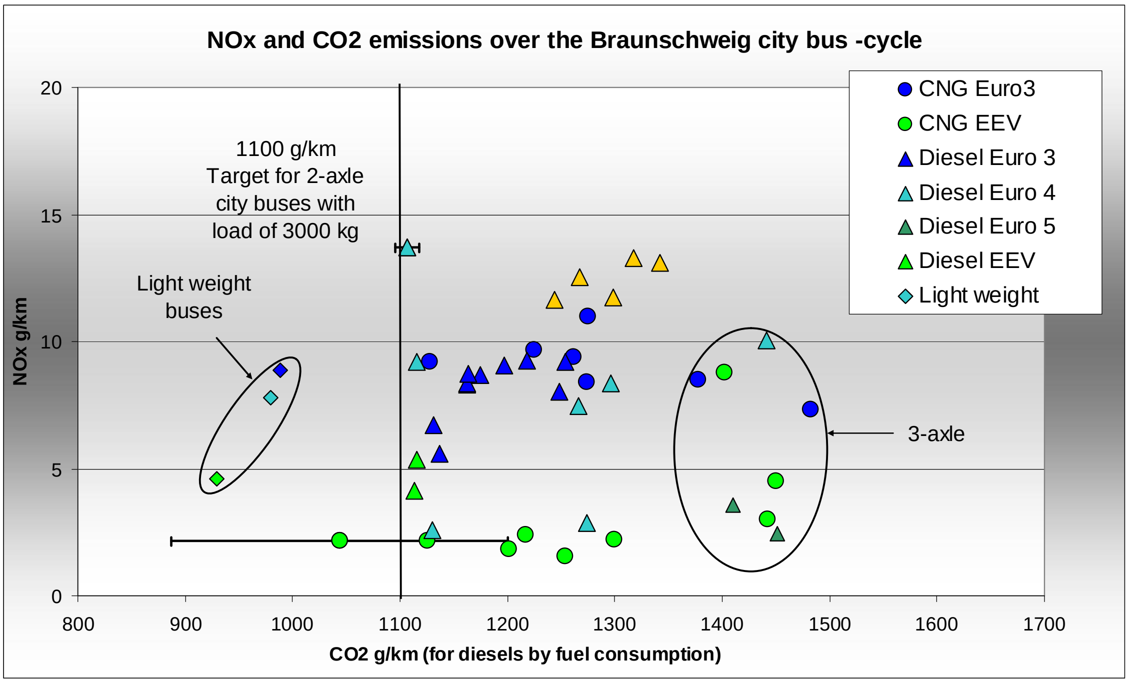

Figure 3.2. Carbon dioxide- (CO_2) and nitrogen oxide- (NO_x) emissions of city buses.

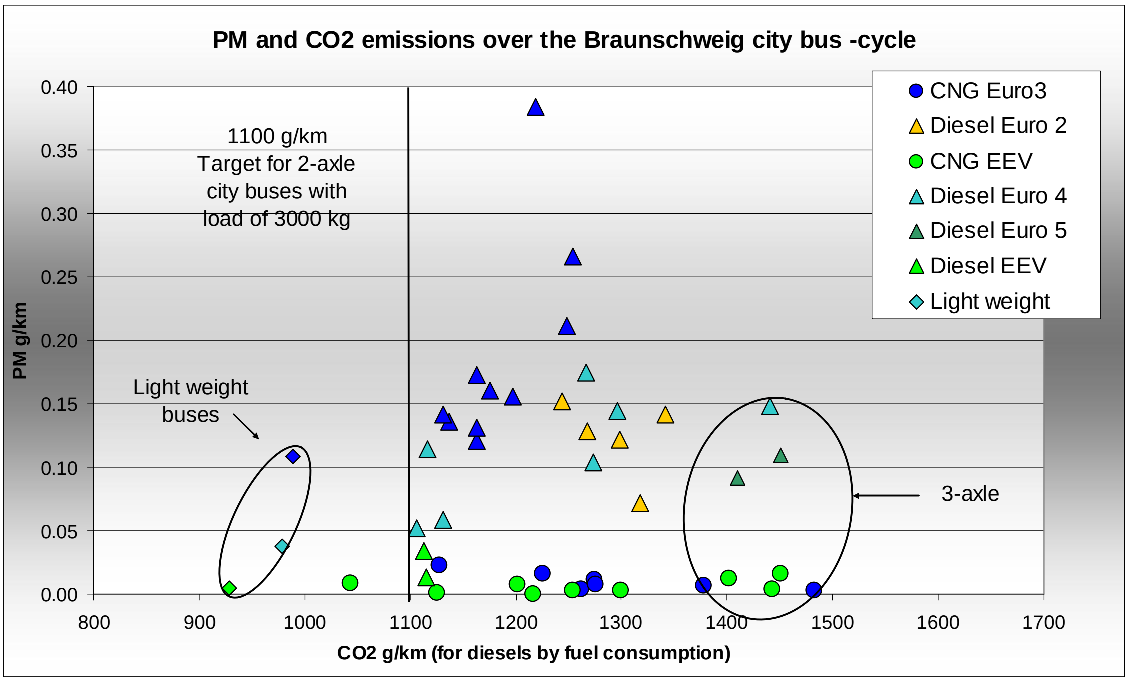

Figure 3.3. Carbon dioxide- (CO_2) and particulate matter- (PM) emissions of city buses.

3.1.4 Follow-up vehicles

Figure 3.4 shows emission results for a MY 2000 Volvo Euro 2 city bus (ZIX-131) which has participated in a long-term follow-up during the years. In 2006 an oxidizing particulate catalyst (pDPF) was installed in the vehicle. No significant changes were found in the newest tests from 2007 compared to those performed in 2006. At this point the vehicle had been driven 70 000 km equipped with the pDPF -cleaner.

The newest results for the 2002 model year Euro 3 Scania follow-up vehicle (ZOF-209) showed that the vehicle's emissions were at the same level as in 2002 when the first measurements were made, before the catalyst was installed. Figure 3.5 clearly shows the fading of its oxidizing catalyst in 2002 – 2005. In the measurements from 2006, emissions were roughly at the same level as in the initial measurements without a catalyst. The measurement in 2007 gave slightly lower emission levels than that in 2006.

Neither the Euro 2 nor the Euro 3 vehicle type showed any clear sign of engine wear to be causing the change in emission levels. The change is most probably due to aging of the after-treatment devices, in other words the aging of the catalyst. At this point the Euro 2 vehicle has a mileage of some 500 000 kilometres and the Euro 3 vehicle a mileage of roughly 700 000 kilometres.

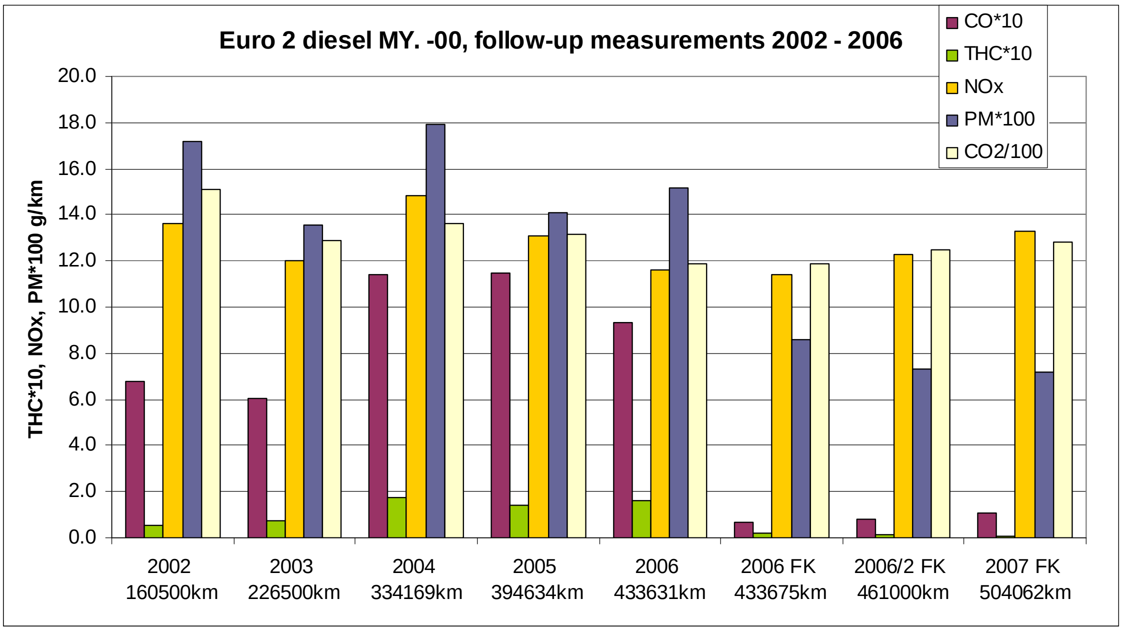

Figure 3.4. Emission results from 2002 – 2007 for the Euro 2 follow-up vehicle (ZIX-131, Volvo model year 2000). A pDPF -cleaner was installed in 2006 (FK= Finnkatalyt pDPF).

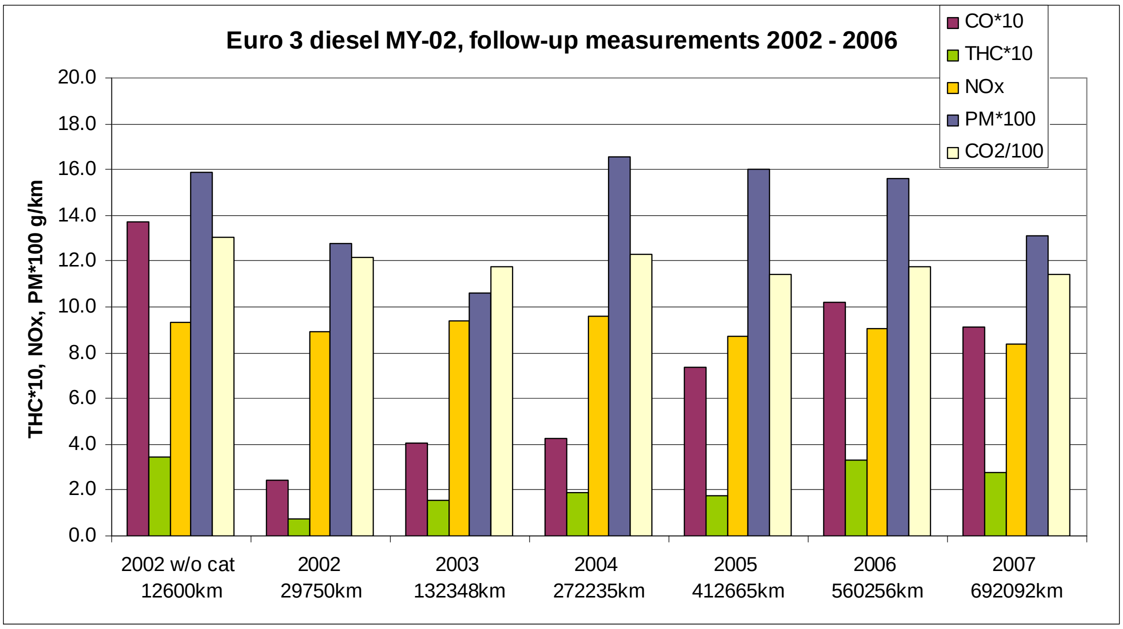

Figure 3.5. Emission results of the Euro 3 follow-up vehicle (ZOF-209, Scania model year 2002) during 2002 – 2007.

In 2007 the pDPF -cleaner follow-up matrix was supplemented by a model year 2005 Euro 3 Scania city bus (GFK-597). Figure 3.6 shows the cleaner's effect on NO_x– and PM –emissions, and the results compared to other vehicle models. The dark blue triangles represent the Euro 3 Scania, which is now equipped with a pDPF. The yellow triangles correspondingly represent the results of the Euro 2 Volvo, also equipped with a pDPF. When it comes to emissions, both vehicles are among the cleanest of their vehicle types. As a point of comparison, the Euro 2 vehicle had an original worn-out catalyst, whereas the Euro 3 Scania was compared with an original muffler without catalyst. In both vehicles the particulates decreased by some 45 %. It should be noted that, different from this point of comparison, most Euro 3 Scanias imported to Finland have typically been equipped with oxidizing catalysts.

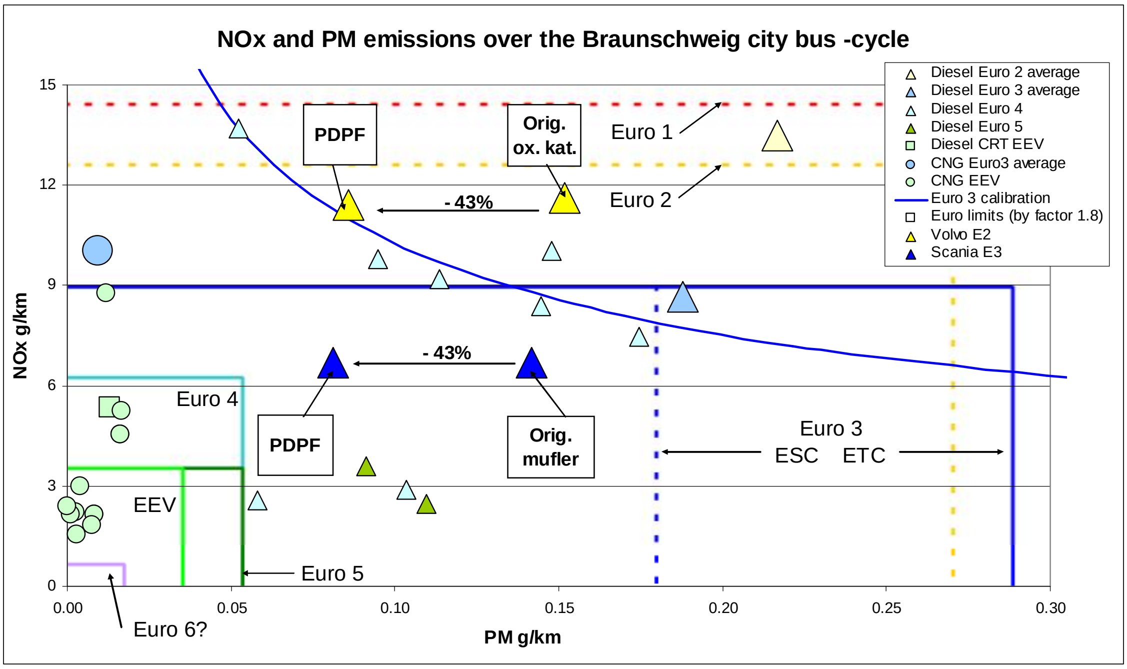

Figure 3.6. The effect of the pDPF-cleaner on NO_x- and PM-emissions in the follow-up vehicles.

A follow-up on a Euro 4 diesel vehicle equipped with exhaust gas recirculation (EGR) (MRG-632) and a natural gas (CNG) operated EEV -vehicle running on a stoichiometric mixture (CYU-745) was also initiated in 2007. Both vehicles had been tested prevoiusly, the EGR – vehicle in 2006 and the EEV CNG –vehicle in 2005.

During the year, surprising changes occurred in the emission levels of the EGR -vehicle. In the newest measurements CO– and HC -emissions rose about four-fold, from 0.4 g/km to 1.8 g/km (CO) and 0.04 g/km to 0.17 g/km (HC). PM –emissions rose from 0.1 g/km to 0.15 g/km, an increase of some 50 %. NO_x-emissions on the other hand decreased by roughly 15 % (Figure 3.7).

Even though the relative change in CO and HC was notable, the absolute change in these emissions still remained minute. The increase in particulate emissions by 50 % can, on the other hand, translates into a significant change on the environmental impact. The change in CO and HC (THC) emissions do although confirm that changes have occurred in the vehicle's emission performance. The reduction of NO_x -emissions by 15 % can on the other hand be seen as a major positive change. In mileage, a one year follow-up interval meant in this case roughly 140 000 km. One possible cause of the variation could e.g. be a clogged air filter.

No remarkable changes were seen in the emissions of the natural gas vehicles running on a stoichiometric mixture (Figure 3.8). Total hydrocarbon emissions increased by some 25 %. The great extent of hydrocarbon emissions from a natural gas vehicle (typically over 95 %) is however methane, which is not classified harmful to health. The impact of methane is instead perceived as a greenhouse gas. At these hydrocarbon emission levels, the CO_2 -equivalent effect is about 1 %.

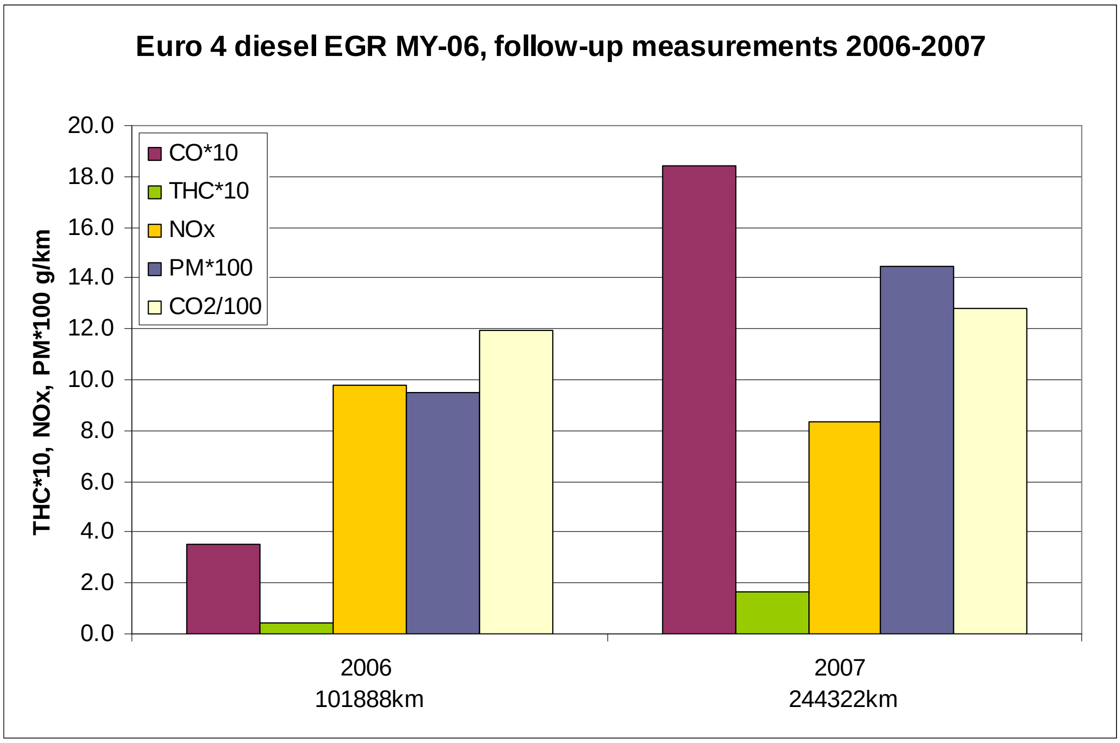

Figure 3.7. Emission results from 2006 and 2007 for the Euro 4 EGR follow-up vehicle (MRG-632, Scania model year 2002).

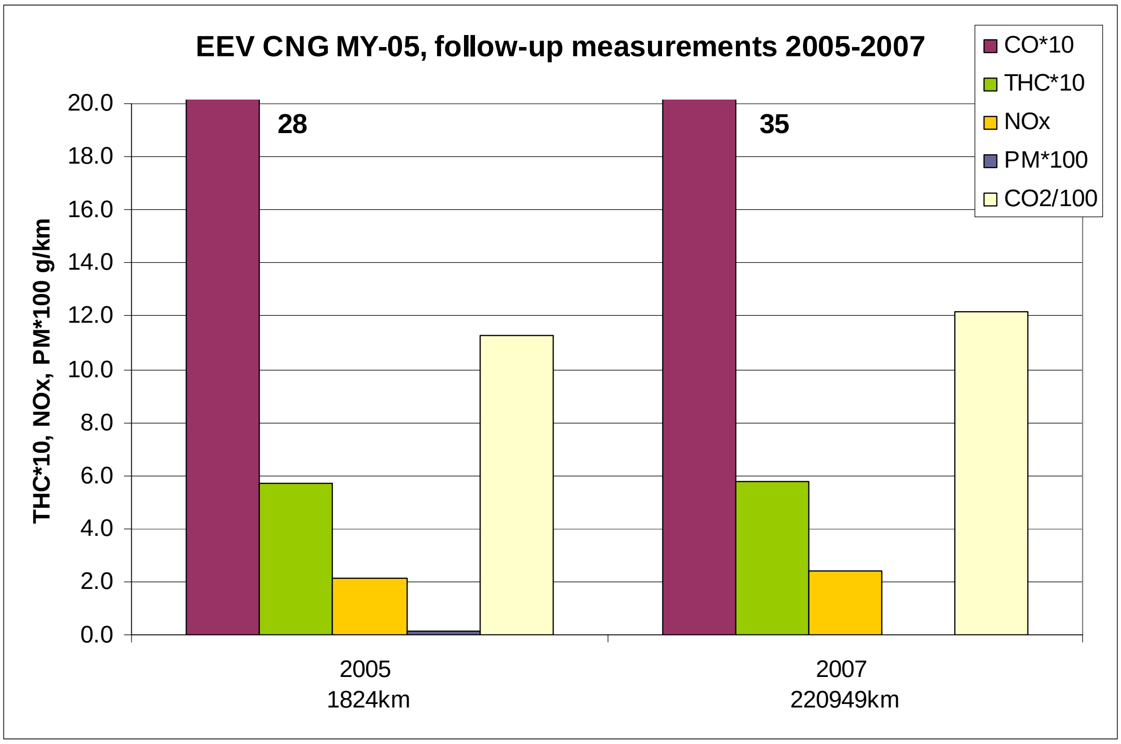

Figure 3.8 .Emission results from 2005 and 2007 for the EEV natural gas (CNG) follow-up vehicle (CYU-745, MAN model year 2005).

3.2 MEASUREMENTS OF TRUCKS

3.2.1 General

Measurements were in 2007 performed on 18, 42 and 60 ton trucks. The tests covered measurements of new vehicle types, complementing old series of measurements as well as running follow-up tests on one vehicle. The first Euro 4 -level 42 ton trucks were measured in 2005. These first Euro 4 –vehicles were pre-series versions which had been produced before the current emission regulations came into force, and they differ from currently produced vehicles. VTT's measurement methods have also continuously been improved, among others by introducing special standardised measurement tires and by defining the compensation of tire losses more precisely. Due to the above mentioned reasons, measurements of 42 ton Euro 4 -trucks performed in 2005 have been excluded from the summary pictures.

3.2.2 Follow-up measurements

The subject of the follow-up measurements is a 60 ton Iveco Stralis 420 SCR full trailer combination truck. The vehicle was first measured in 2006 with a mileage of 2000 km. The next measurements were performed after roughly 20 000 and 50 000 km. Figures 3.9 – 3.12 show results on fuel economy, urea consumption and emissions.

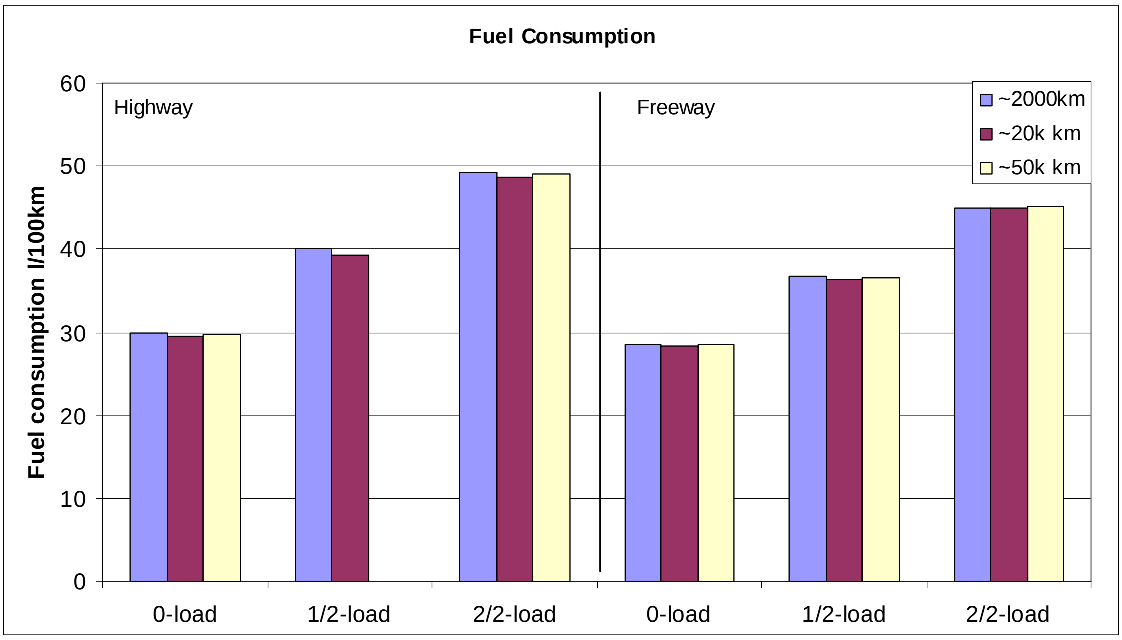

Figure 3.9. Fuel consumption (Iveco Stralis follow-up).

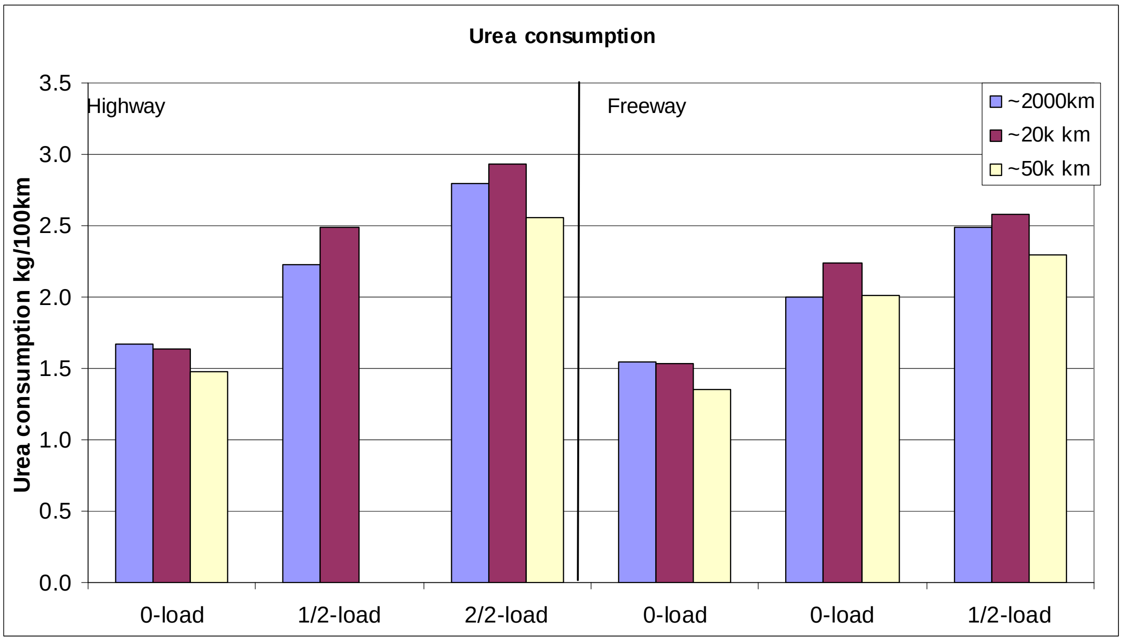

Figure 3.10. Urea consumption (Iveco Stralis follow-up).

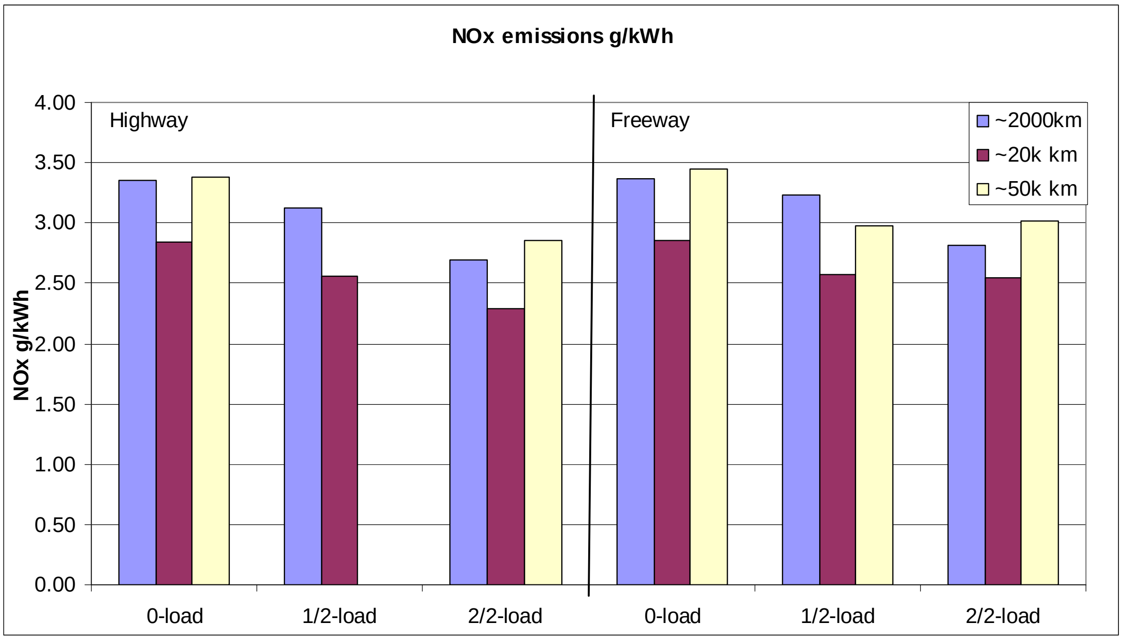

Figure 3.11. NO_x-emissions (Iveco Stralis follow-up).

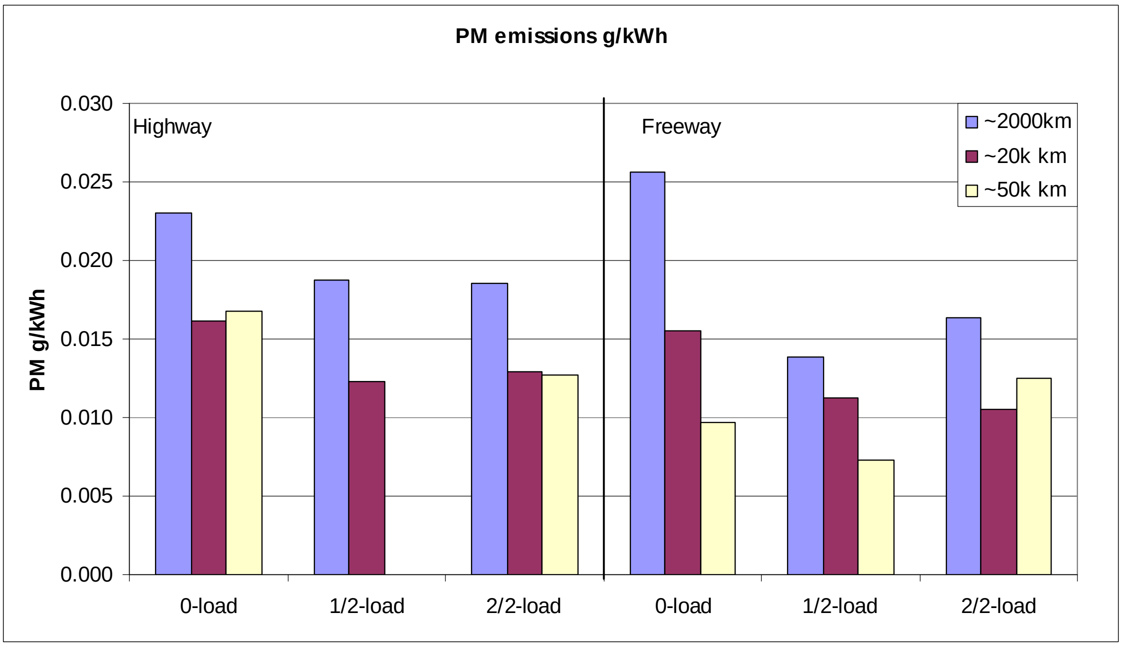

Figure 3.12. Particulate emissions (Iveco Stralis follow-up).

The follow-up reveals that fuel consumption has remained highly constant as the mileage has increased. The consumption of urea was at its highest at 20 000 km, which can be seen as reduced NO_x -emissions. The difference between the largest and smallest NO_x -value is on average roughly 20 %.

Particulate emissions had fallen by some 30 % after 20 000 km, and were after 50 000 km nearly 50 % lower than at outset. The reduction in particulate emissions might be due to the running-in of the engine, which, among other things, brings down the consumption of engine oil.

3.2.3 Comparison measurements of 60 ton trucks

Five new 60 ton Euro 4 –certified full trailer combination trucks were measured in 2006. The 60 ton trucks were also measured as such without trailers (3 -axle 26 ton truck). Three driving cycles developed in co-operation with Transpoint Ltd were measured; one that simulates delivery driving, one simulating highway driving and one simulating freeway driving. The delivery driving cycle is run without a trailer, whereas the two latter are run with trailers.

In 2006 it was discovered that the PM-KAT particulate catalyst equipped MAN did not run properly. The problem was expressly thought to be caused by a faulty particulate catalyst. As a result this vehicle type was re-measured in 2007. A MAN TGA 26.430 was measured in 2006 and in 2007 a MAN TGA 26.440 which had replaced the former. Measurements were also completed for Scanias. The previously measured Scania R470 was replaced by a Scania R420, which is better suited for the measurement series as for its maximum power output.

In the following is presented results of the re-measured vehicles, as well as the whole measurement series all together (without the MAN TGA 26.430 and Scania R470).

Figure 3.13 shows that the compensatory models give better fuel economy than the previous models. The difference is at most some 4 %. Figure 3.14 shows how particulate emissions of the MAN truck are notably lower than in the previous measurements. Now the emissions of the MAN truck are truly Euro 4 –level.

Figure 3.15 shows a roundup of the fuel economy for 60 ton trucks. SCR –vehicles still consume less fuel than EGR –vehicles, but the difference has slightly decreased. Figure 3.16 shows the comparable measurement series converted to running costs based on fuel and urea. The cost of fuel is assumed to be 1.00 €/l (VAT 0 %) and the cost of urea 0,50 €/l (VAT 0 %) according to prices in Finland at the beginning of 2008. Fuel was assumed to cost 0.74 €/l in the annual report of 2006. The MAN and Scania trucks, which use EGR –technology, battle almost evenly against the SCR -Iveco when it comes to running costs. The Mercedes-Benz and Volvo still give the lowest running costs.

Figure 3.17 shows a comparison between the running costs (fuel + urea) of Euro 3 and Euro 4 –trucks. At full load, the cost associated with Euro 4 EGR –vehicles is on average 4 % lower and for Euro 4 SCR –vehicles typically 9 % lower than the average cost for Euro 3 –vehicles. The comparison is although slightly distorted because the average output of Euro 3 –vehicles was slightly higher than that of the other vehicle types.

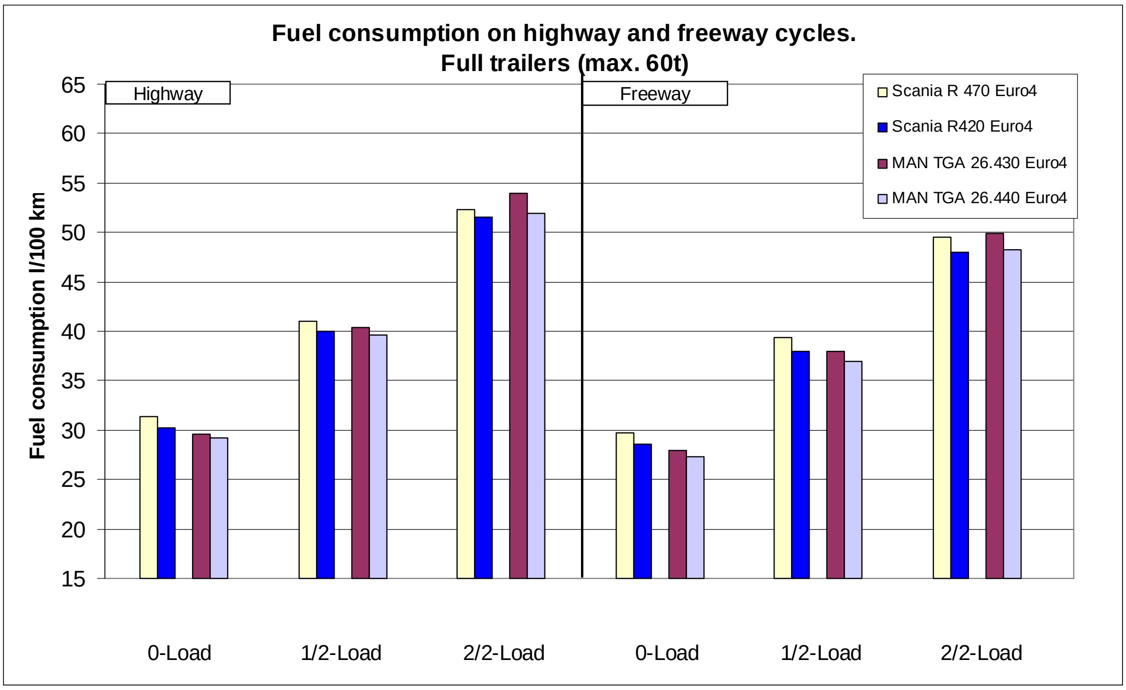

Figure 3.13. Differences in fuel consumption between substitutive and substituted vehicles (60 ton vehicles).

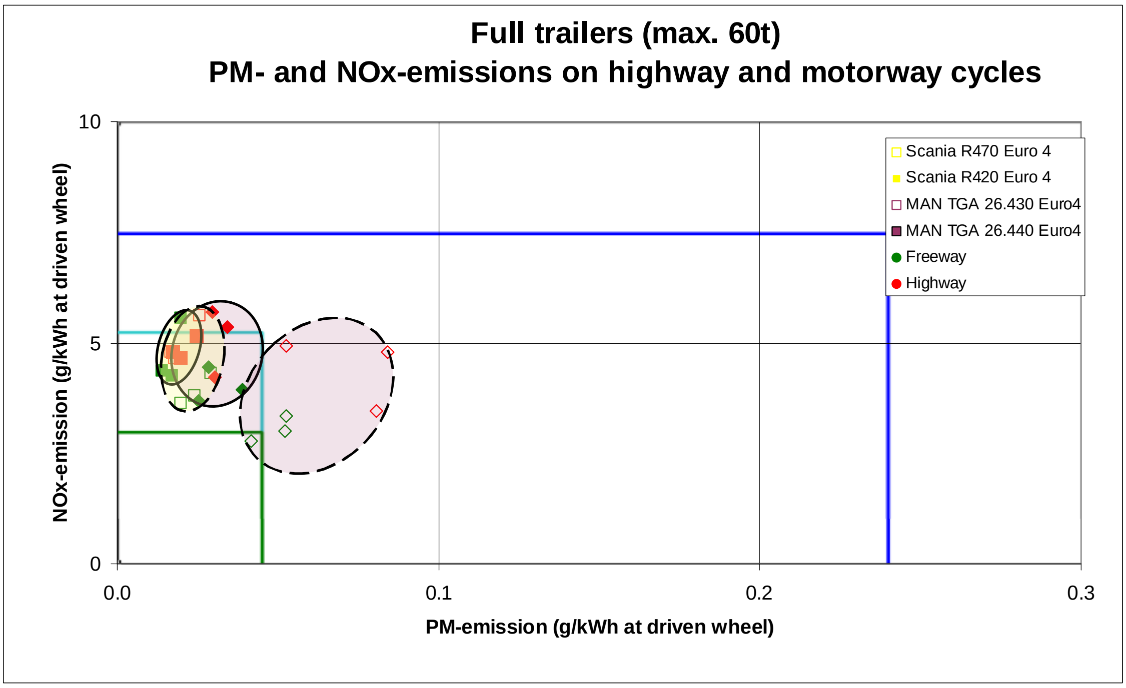

Figure 3.14. Differences in emissions (NO_x, PM) between substitutive and substituted vehicles (60 ton vehicles).

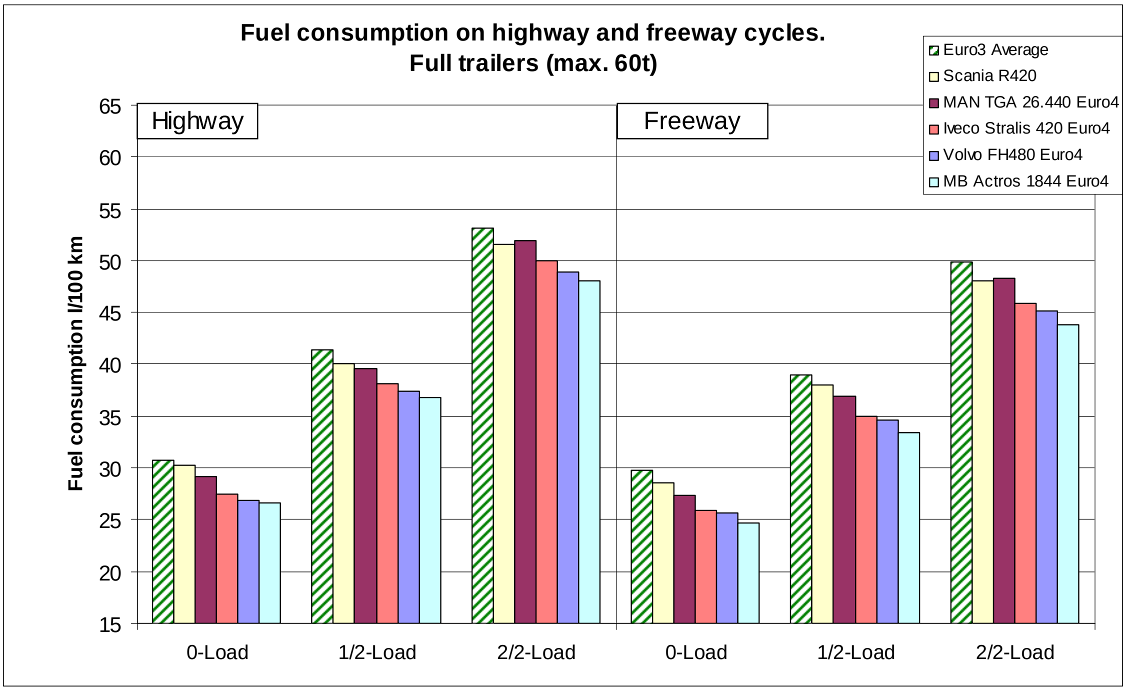

Figure 3.15. Measurement series with substitutive results (fuel consumption, 60 ton vehicles).

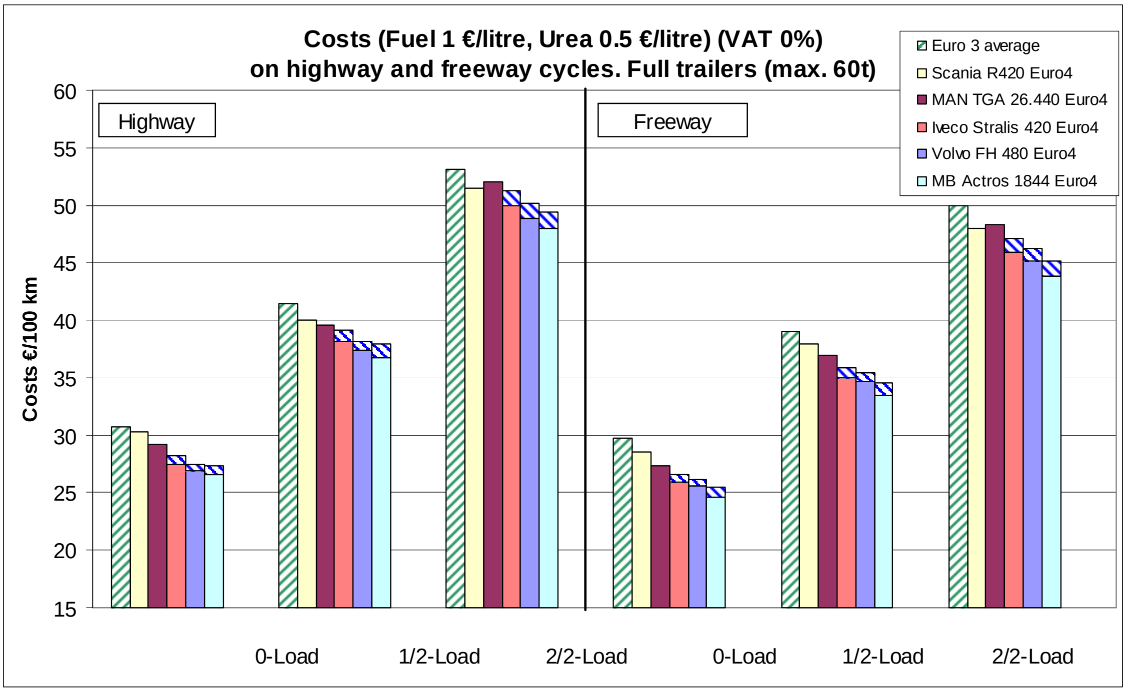

Figure 3.16. Measurement series converted to running costs (fuel + urea, 60 ton vehicles).

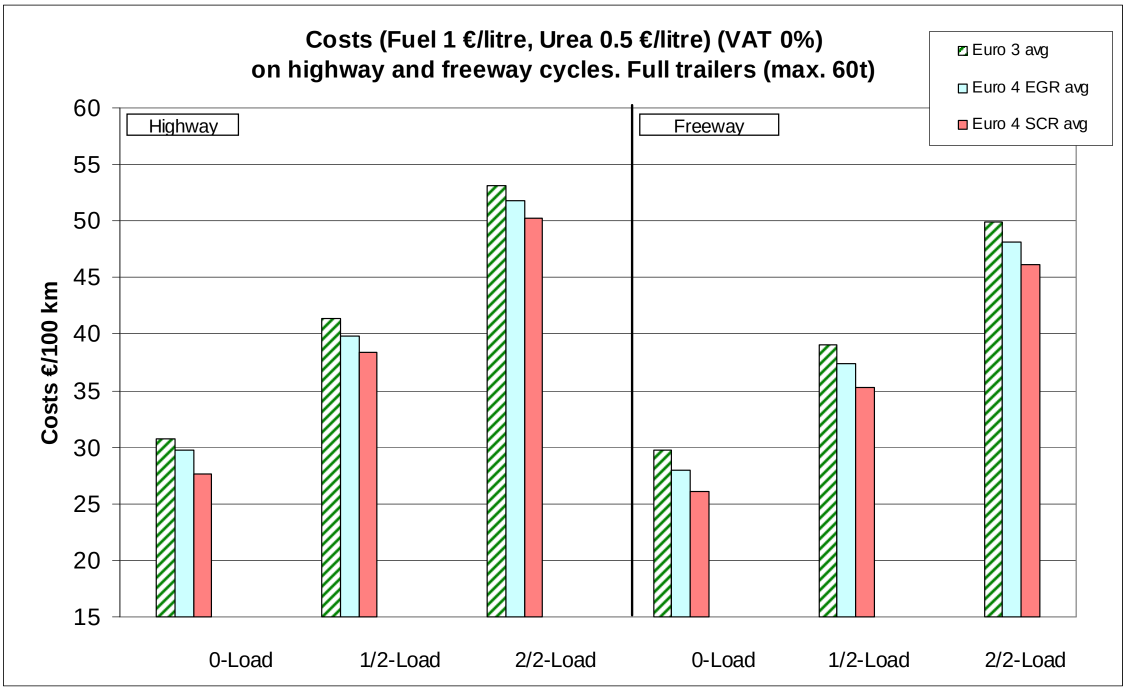

Figure 3.17. Comparison of fuel- and urea costs for Euro 3- and Euro 4 –vehicles (60 ton vehicles).

3.2.4 Comparison measurements of 42 ton trucks

As was mentioned in section 3.2.1, two of the vehicles measured in 2005, the EGR - MAN and -Scania, have been excluded from the roundup pictures. The results of the 42 ton Iveco Stralis from 2006 can still be considered relevant. The vehicle in question was however rather powerful with its 500 hp. A less powerful version might have given better fuel economy. One new vehicle type was measured in 2007, a 440 hp Euro 4 –certified Volvo FH13 SCR.

Fuel consumption is presented in Figure 18. Both the Iveco and the Volvo consume less fuel than Euro 3 –vehicles on average. The Volvo consumes slightly less fuel than the Iveco, possibly due to the difference in maximum power output.

Emissions are presented in Figure 3.19. Both vehicles easily comply with Euro 4 –emission requirements. The Iveco gives lower NO_x -emissions than the Volvo and almost conform to Euro 5 –standards.

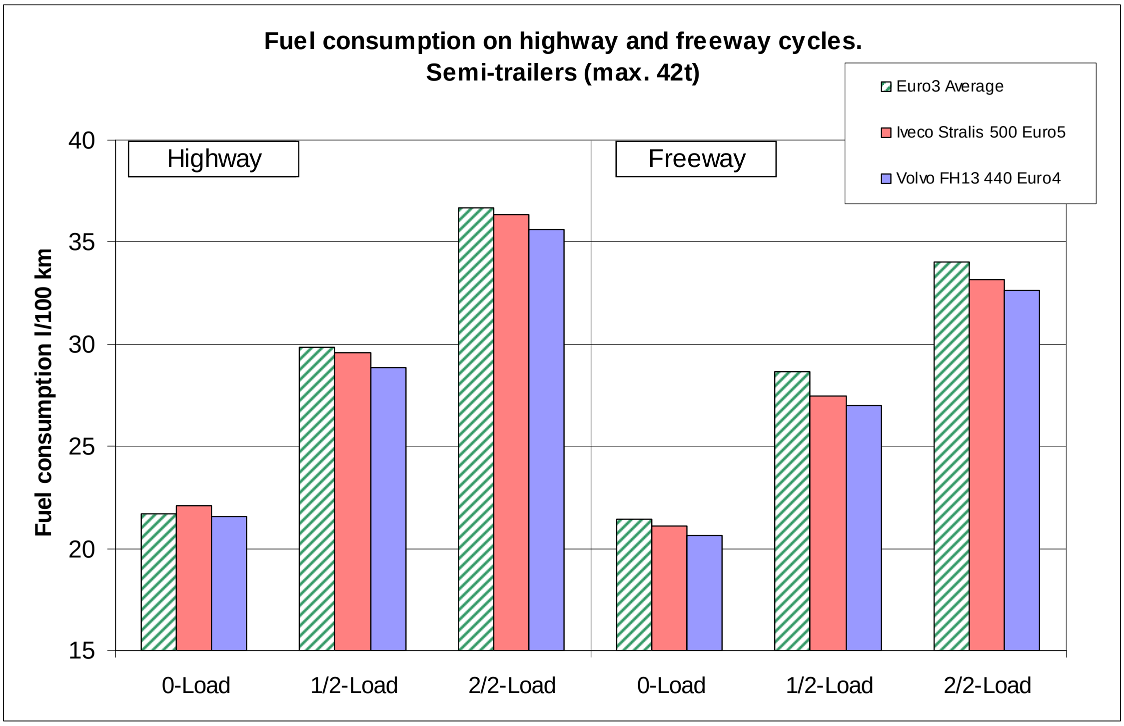

Figure 3.18. Fuel consumption (42 ton vehicles).

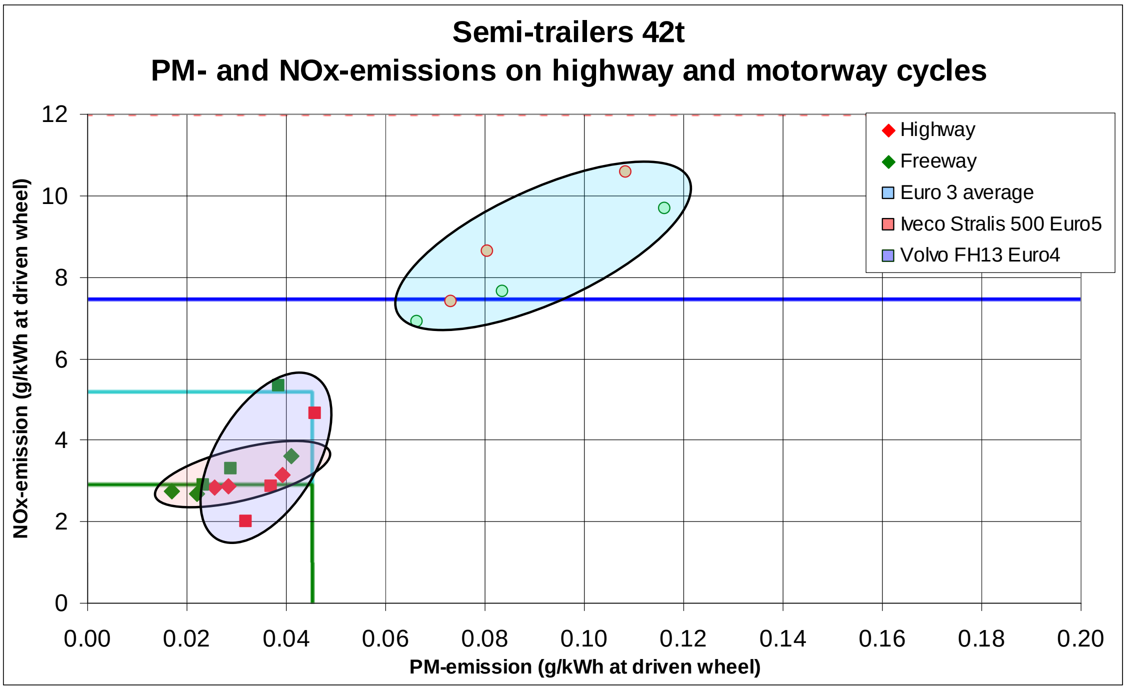

Figure 3.19. NO_x- and PM –emissions (42 ton vehicles).

3.2.5 Comparison measurements of 18 ton delivery trucks

Measurements of 18 ton delivery vehicles were launched in 2007. This report presents the results for two Euro 4 –level vehicles (Renault Premium 280 DXI and Volvo FE320). The measurements are to be continued in 2008 when the series of measurements will be expanded by several vehicles. Both the highway- and delivery cycle will be used. Figure 3.20 presents the fuel consumption in the delivery cycle, and Figure 3.21 the fuel consumption in the highway cycle.

A remarkable difference in fuel economy was observed, which is unexpected when both vehicles represent the same technology (SCR). The Volvo did on average consume less fuel; 4 % in the delivery cycle and 6 % in the highway cycle. The accuracy of fuel consumption measurements is $\pm$ 1 %.

Figure 3.22 shows the emission results of the measurement series. The Volvo consumes less fuel, but produces on average more emissions than the Renault. The Renault had NO_x -emissions equal to the Volvo under all load levels in the delivery cycle, but its PM-emissions were generally about 30 % lower.

In the highway cycle, the Renault produced on average 40 % lower NO_x -emissions, and some 15 % lower particulate emissions than the Volvo. In highway driving the Volvo meets Euro 4 –standards, whilst the Renault almost complies with Euro 5 –standards. Figure 3.22 shows once again how delivery driving increases emissions compared to highway driving.

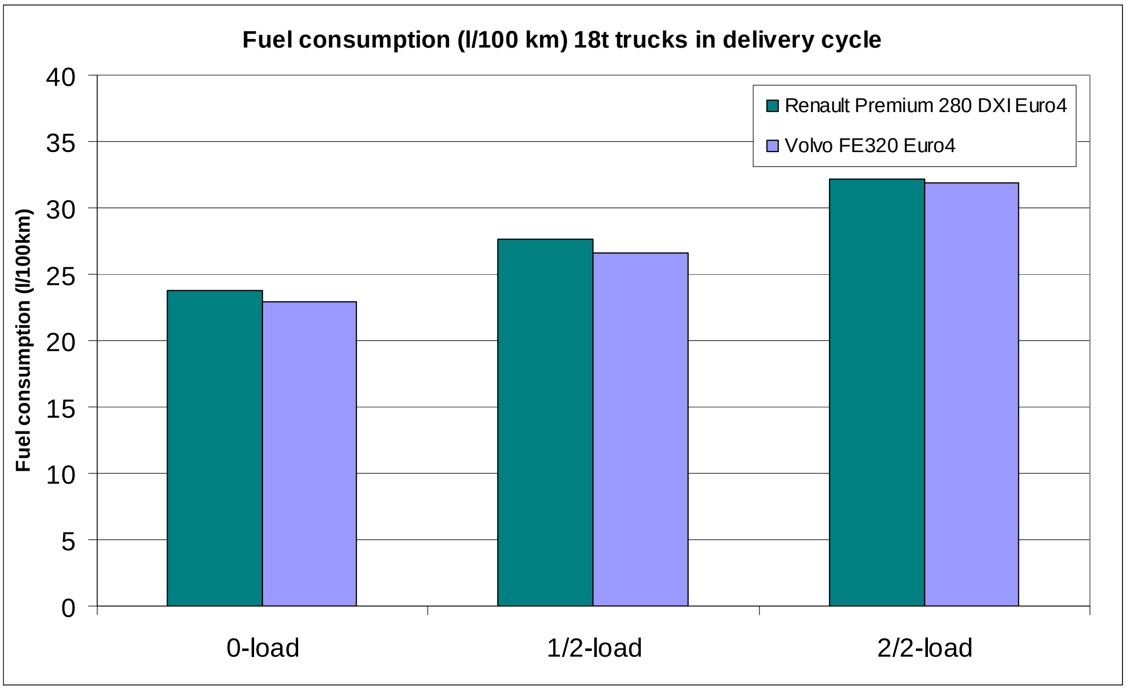

Figure 3.20. Fuel consumption results for delivery trucks in the delivery cycle (18 ton vehicles).

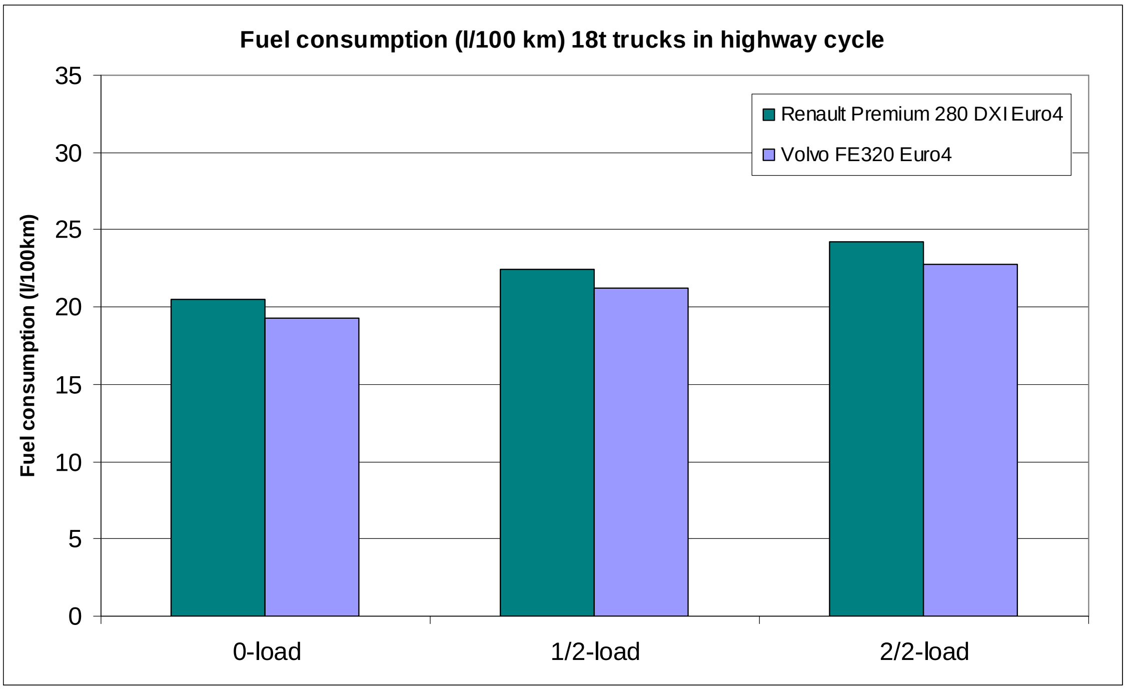

Figure 3.21. Fuel consumption results for delivery trucks in the highway cycle (18 ton vehicles).

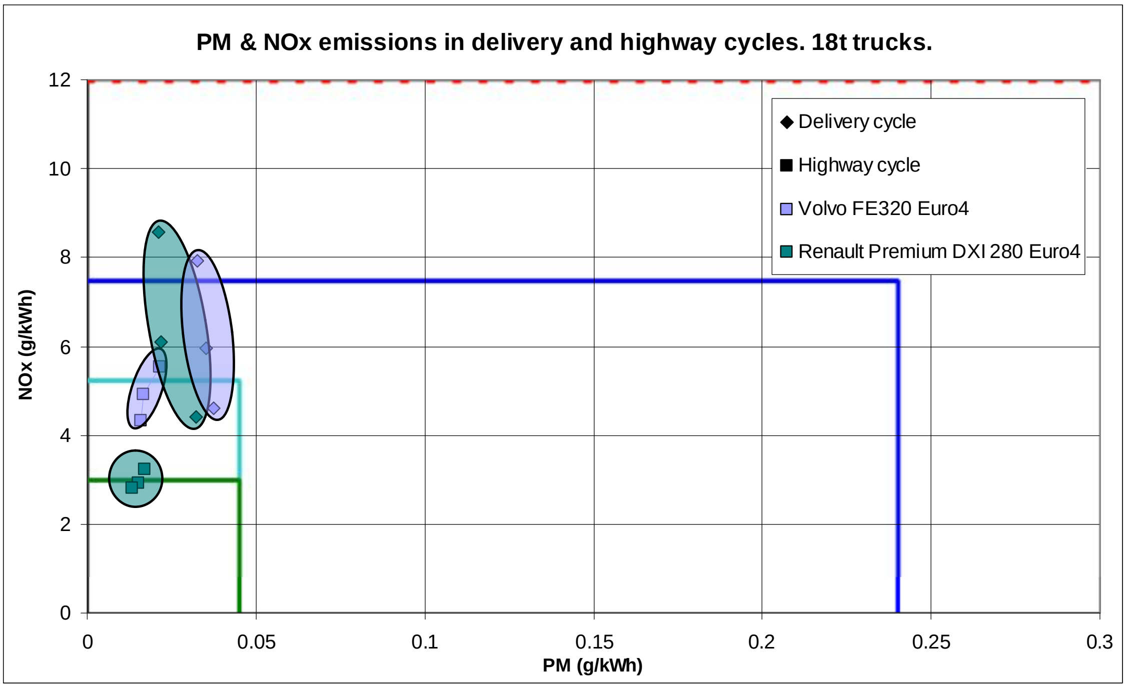

Figure 3.22. NO_x- and PM –emissions (18 ton delivery trucks).

4 FUELS AND LUBRICANTS FOR EURO 4/5/EEV – VEHICLES (SP 2)

Responsible party: VTT

Authors: Matti Kytö & Nils-Olof Nylund

A separate report on the experimental part of this subtask has not been produced. An independent report on fuel alternatives, "Liikenteen polttoainevaihtoehdot - Kehitystilanneraportti" (Fuel alternatives in transport – Status report) was prepared on request of the Ministry of Transport and Communications in Finland. The Ministry granted additional funding for the making of the report.

4.1 GENERAL

Postal delivery vehicles were used for fuel testing in 2007. The vehicles were mainly tested using delivery cycles. Tests were run using commercial grade diesel fuel, rapeseed oil methyl ester (conventional biodiesel RME) and hydrotreated second generation NExBTL biodiesel produced by Neste Oil Ltd. The RME –tests were part of Itella Ltd's (daughter of the Finnish General Post Office) field tests on RME –fuel.

Lubricant tests were performed using a complete vehicle. Extensive test series had been run on the same engine type in an engine test bench. A bus was used for studying how the engine- and transmission oil (automatic transmission) affects the fuel economy of a complete vehicle.

4.2 FUEL TESTING

4.2.1 Tests on light-duty vehicles

Laboratory tests were carried out using a 2004 model year Volkswagen Transporter 1.9 TDI-7HK-Kasten van. Mere diesel fuel tests were performed using an analogous vehicle. Follow-up measurements will in the future be made on both vehicles. The fuel tests were run using a cycle simulating postal delivery driving. Conventional diesel fuel, pure RME and mixtures of these two with a 5, 10, 30 and 50 % RME –content were used. In addition, the MVEG type approval cycle was run on diesel and pure RME. The tests were performed on VTT's light-duty vehicle roller-type test stand. Two tests were run for each fuel. The RME –fuel used in the tests was supplied by Itella Ltd, the summer quality diesel fuel was acquired by VTT.

Regulated exhaust emissions (carbon monoxide, overall hydrocarbons, nitrogen oxides, particulate matter and carbon dioxide) as well as fuel consumption was measured in the tests. Fuel consumption was measured on a balance by recording the mass during the test. This data was calculatorily translated into a figure of l/100 km.

The following tabular values were used as settings for the dynamometer:

- Inertia 1810 kg, F0= 8, F1= 0, F2= 0.0557,

where F0 is the resisting force independent of speed, F1 the force factor proportionate to speed and F2 the force factor proportionate to the square of speed.

Average results for the delivery cycle are presented in table 4.1. The results from the type approval cycle for pure diesel- and RME fuel is presented in table 4.2. NO_x- and particulate results for different RME –blends in the delivery cycle are shown in Figure 4.1.

Table 4.1. Average emissions and fuel consumption for different fuel blends in the cycle simulating delivery driving.

Postal delivery cycle						
Fuel	CO (g/km)	HC (g/km)	NO_x (g/km)	CO_2 (g/km)	PM (g/km)	Fuel consumption (l/100km)
Diesel 100%	0.05	0.02	0.54	206.7	0.079	7.9
RME 5%	0.04	0.02	0.55	207.2	0.058	7.8
RME 10%	0.02	0.02	0.54	204.9	0.065	7.8
RME 30%	0.05	0.02	0.55	206.7	0.048	8.0
RME 50%	0.05	0.02	0.62	209.4	0.037	8.2
RME 100%	0.09	0.01	0.65	209.1	0.028	8.5

Table 4.2. Average emissions and fuel consumption using pure fuels in the type approval cycle.

MVEG-B-cycle (vehicle type approval cycle)						
Fuel	CO (g/km)	HC (g/km)	NO_x (g/km)	CO_2 (g/km)	PM (g/km)	Fuel consumption (l/100km)
Diesel 100%	0.09	0.02	0.41	193.1	0.107	7.0
RME 100%	0.11	0.03	0.46	197.5	0.026	7.8

Compared to diesel fuel, running on RME significantly lowered particulate emissions and increased nitrogen oxide emissions. The result is very typical. This has also been noticed in other tests with similar fuels; NO_x -emissions increase slightly and particulate emissions decrease substantially. The percentual change fluctuates a little in different engines. Particulate emissions decreased by some 65 – 75 % using pure RME, NO_x– emissions correspondingly increased by 12 – 20 %. The change in nitrogen oxides and particulate emissions were fairly linear, even though the change seems to become slower when moving to 100 % RME –fuel.

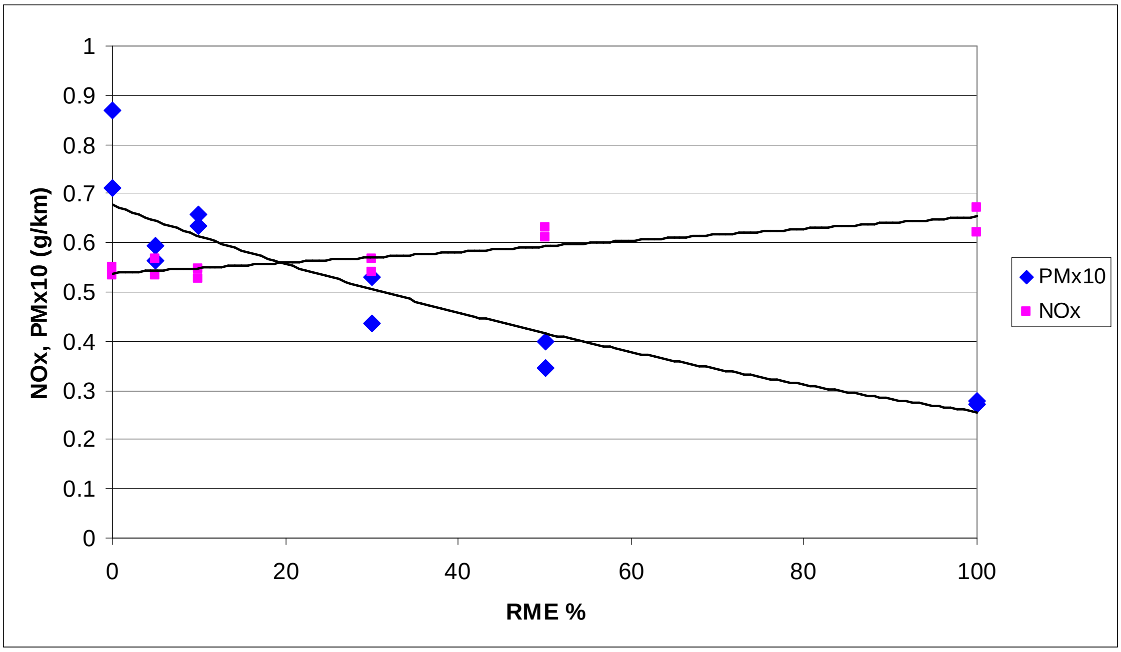

*Figure 4.1. NO_x- and particulate emissions (particulate emissions * 10) using different blends of fuel in the cycle describing postal delivery driving.*

Compared to equivalent values recorded for diesel fuel, the volumetric fuel consumption increased by 8 – 11 % when running on pure RME. The increase is greater than what would be expected based on the difference in heat value (diesel fuel typically contains 36 MJ/l, whereas RME 34 MJ/l – the difference is in other words 6 %). CO_2 –emissions measured from the tailpipe were 1 – 2 % higher for RME than for diesel fuel. Theoretically one kilogram of RME generates some 10 % less carbon dioxide than one kilogram of diesel fuel, but actually carbon dioxide emissions increase slightly because the fuel consumption increases clearly.

Neither carbon monoxide nor hydrocarbon emissions changed significantly. The scatter of carbon monoxide emissions in different measurements was greater than the scatter of any other emission component, but the absolute emissions were still low. Therefore too much attention should not be paid on e.g. the great relative change in average results when switching from diesel fuel to RME in the delivery cycle.

4.2.2 Tests on heavy-duty vehicles

Heavy-duty vehicle tests were performed using a medium-duty model year 2004 MAN Euro 3 –truck (Figure 4.2). This vehicle represents the type of truck used by the Finnish postal service in short distance delivery. Even this MAN vehicle is equipped with EGR –technology for reducing NO_x –emissions. The Transpoint delivery cycle developed by VTT was used as test cycle. The cycle is based on a recording from the CAN –bus of an actual drive, and the cycle simulates typical suburban delivery driving.

Summer quality diesel fuel, NExBTL renewable diesel, pure RME and mixtures of RME and diesel fuel with a 5, 30 and 50 % RME –content were used as test fuels. The tests were run on the heavy-duty chassis dynamometer test stand at VTT. Two tests were performed on each fuel, except for the diesel fuel which was tested twice in the beginning of the tests and twice at the end. The following settings simulating half load were used on the dynamometer:

- Inertia 9000 kg, F0= 173, F1= 5.977, F2= 0.1951

Regulated exhaust emissions (carbon monoxide, overall hydrocarbons, nitrogen oxides, particulate matter and carbon dioxide) and fuel consumption were also measured for the medium-duty truck. Fuel consumption was measured on a balance by recording the mass during the test. This data was calculatorily translated into a figure of l/100 km.

Figure 4.2. A truck at the test site.

Table 4.3 presents the average results of the measurements. Nitrogen oxides and particulate emissions are also presented in Figures 4.3 and 4.4.

Table 4.3. Average emissions for the MAN –truck using different fuels.

Fuel	CO (g/km)	HC (g/km)	NOx (g/km)	PM (g/km)	CO_2 (g/km)	Fuel consumption (l/100km)
Diesel	2.5	0.1	5.6	0.18	558	20.7
NExBTL	1.7	0.1	5.1	0.12	521	21.5
5% RME	2.2	0.1	5.8	0.16	549	20.8
30% RME	2.2	0.1	6.0	0.13	552	21.1
50% RME	2.0	0.1	6.3	0.12	548	21.6
100% RME	1.4	0.1	6.8	0.08	562	22.5

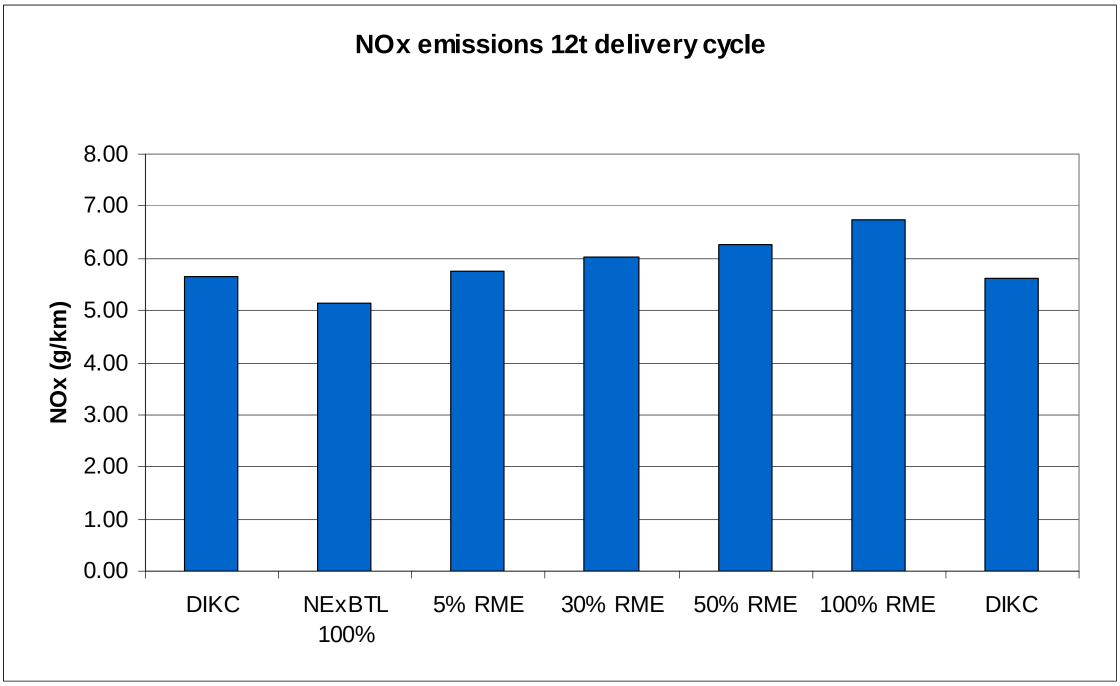

Figure 4.3. Nitrogen oxide emissions from different fuels in tests run with the MAN –truck.

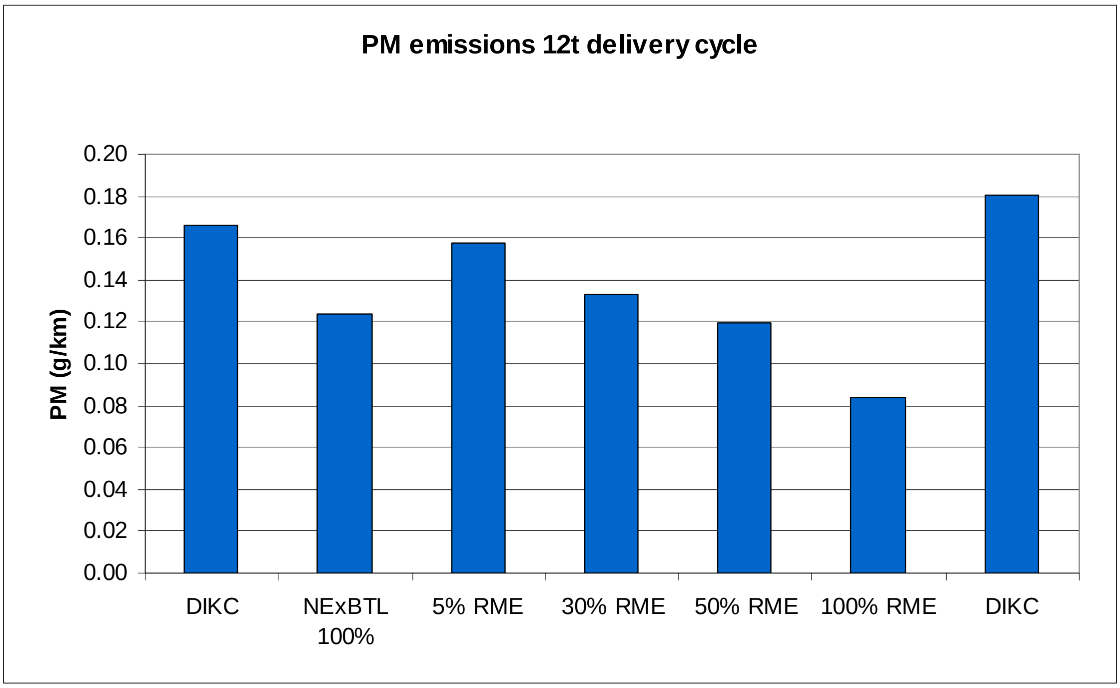

Figure 4.4. Particulate emissions from different fuels in tests run with the MAN –truck.

Results from the RME and diesel fuel tests for the truck were much like those of the van. Compared to diesel fuel, running on RME significantly lowered particulate emissions and increased nitrogen oxide emissions. When running on pure RME, particulate emissions decreased by 65 % compared to diesel fuel, NO_x–emissions on the other hand increased by 21 %. Increasing the amount of RME resulted in a quite linear change for the truck too. The scatter of the results was very small.

What comes to particulate emissions, NExBTL generated emissions comparable to that of a diesel fuel and RME 50/50 blend (-30 %). Its NO_x –emissions were however nearly 10 % lower compared to conventional diesel fuel and some 25 % lower compared to pure RME.

Compared to conventional diesel fuel, using pure RME increased the volumetric fuel consumption by some 9 %, whereas the corresponding increase for NExBTL was roughly 4 %, which actually means slightly reduced (1 – 2 %) energy consumption. The density of NExBTL is lower than that of conventional diesel fuel, which leads to a higher volumetric fuel consumption. CO_2 –emissions for RME were about 1 % higher than for diesel fuel, which within the accuracy of measurement is the same. CO_2 –emissions for NExBTL were 7 % lower, due to its different hydrogen/carbon ratio (paraffin fuel) and slightly reduced energy consumption.

Hydrocarbon emissions were also in this case very low and stable regardless of the fuel. RME and NExBTL generated lower CO –emissions than the other fuels, but as with the van, the CO –emissions of the truck fluctuated more than the other emissions. The CO –level of this truck was comparable to the average level of Euro 3 –trucks (HDEnergy Annual Report 2004, www.rastu.fi).

4.3 LUBRICANT TESTING

Lubricant tests that very initially planned to be performed in an engine test stand in 2007 were advanced and therefore completed already in January 2007. The tests were also reported in the previous annual report. The tests were performed using a Cummins ISBe4 160B (Euro 4) –engine. A small-scale test series with a complete vehicle (Kabus ML low-floor city bus) was run on the chassis dynamometer test stand in 2007. This vehicle had a 4.5 litre Cummins engine, identical to that used in the engine tests. As for the engine oil, the difference between the oils remained small in, whereas major divergence was seen in previous tests with two other engines (Volvo DH10A 285, Euro 2 and Scania DC11 03 340, Euro 3).

Vehicle tests were made using three different engine oils: a 10W40 –class prototype oil (code 333) and commercial 10W40 and 15W40 –class oils. The tests were carried out using the Braunschweig cycle, which simulates urban driving. Two tests were performed on each lubricant.

In the engine test stand, the lowest fuel consumption was obtained using the 10W40 –class prototype oil. The difference compared to the 15W40 –class reference oil was in engine tests only some 0.5 %. The 15W40 –class reference oil used in the bus tests was different from that used in the engine tests, but the results were parallel, even though the difference in consumption was roughly twice as big, 1,1 % to be precise (Figure 4.5). The margin of error is bigger in vehicle tests than in engine tests, due to a greater number of factors affecting the result, of which the two most important are the driver and the tires. All bus tests were driven by the same driver. As such, a slightly higher difference compared with testing in an engine test stand would be logical, because the load rate of the engine is on average low in urban bus cycles, which means that the relative importance of friction losses increases. The difference between the two 10W40 –class oils was 1.8 %, which is a great deal. The oil that produced the high result was not used in the engine test because of availability problems.

A similar engine has previously been used for studying how different transmissions (mechanical transmission/automatic transmission) affect fuel consumption. Friction losses of the automatic transmission were rather high. Due to high friction losses it is, at least in theory, possible to significantly affect the losses by choosing the right oil. On the chassis dynamometer, tests were run using the same bus and same experimental arrangements as in the engine oil tests. Two oils were tested, the vehicle's original automatic transmission oil and Neste ATF-X oil. Based on the average of two tests, fuel consumption decreased by 2.9 % when using Neste's ATF-X oil. The scatter of the results for the original transmission oil is regrettably substantial, but the difference between the oils is still clear and also proves that it is possible to lower the fuel consumption by choosing the right transmission oil for vehicles equipped with automatic transmissions (Figure 4.6). When it comes to automatic transmission oils, as well as for other oils, it is important to notice limitations on use of oil set by the vehicle manufacturer.

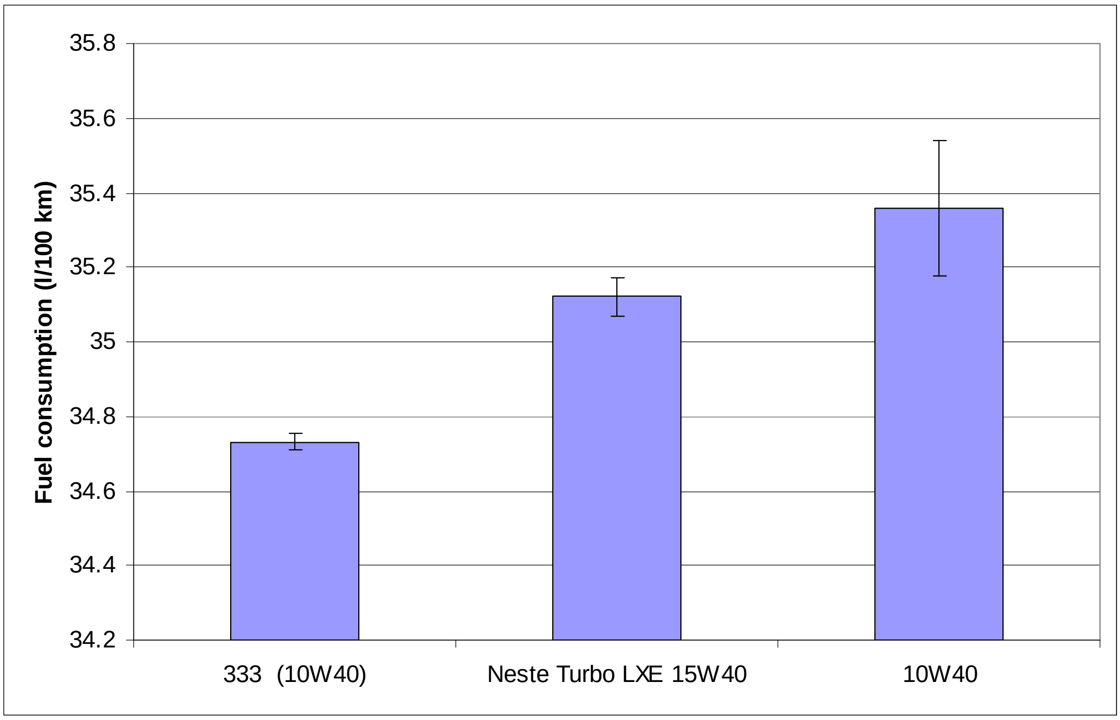

Figure 4.5. Effect of engine oil quality on the fuel consumption of a bus. Tested using the Braunschweig bus cycle.

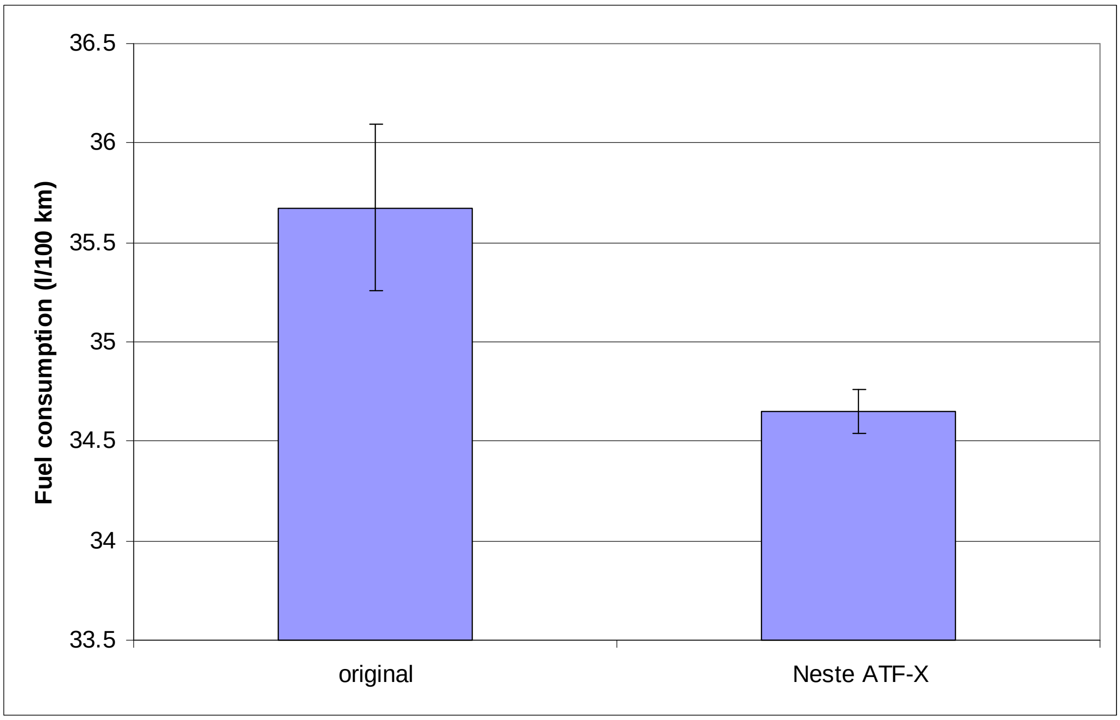

Figure 4.6. Effects of automatic transmission oil quality on the fuel consumption of a bus. Tested using the Braunschweig bus cycle.

4.4 FUEL ALTERNATIVES IN TRANSPORT – PROGRESS REPORT

In 2002, VTT carried out a literature study within the MOBILE[2] –research integrate on emission- and end-use features of fuel alternatives. This report was mainly presented in table format. In 2007 the Ministry of Transport and Communications ordered an update on the matter. The report is now presented as a normal progress report. An updated table format summary is enclosed too. The report and its summary can be downloaded from the RASTU webpage at:

http://www.motiva.fi/fi/raskaskalusto/rastu/rasturaportit/polttojavoiteluaineet/.

The development of biofuels has advanced rapidly since 2002. A directive on the promotion of the use of biofuels in EU was given in 2003. The directive calls for a target of 2 % biofuels in 2005 and 5,75 % in 2010, measured in energy content. Consequently the production of biofuels in Europe increased five fold between 2002 and 2006. An obligation enters into force in Finland too in 2008. It has now however become clear that so called first generation biofuels raise environmental concern. Synthetic, so called second generation biofuels have become the main target of interest.

Emission- and end-use features were dealt with as in the previous report, but environmental challenges in general, the global production and usage of traffic fuels and the promotion of alternative fuels were now approached too. Nowadays alternative fuels make up for some 3.5 % of the global fuel usage, the share of biofuels is roughly 1.5 %. The most important alternative fuels are in order of magnitude; ethanol, liquefied petroleum gas and natural gas.

A life-cycle inventory on greenhouse gas emissions of different fuel alternatives was studied at the request of the Ministry of Transport and Communications. The latest research results have been used when measuring the performance and evaluating emission impacts of different fuel alternatives.

5 *VEHICLE TECHNICAL DEVELOPMENT WORK (SP3)*

Responsible parties: HUT and VTT

Authors: Henri Ritola, Mikko Lehessaari & Osku Kaijalainen (HUT), Tommi Hangasmaa & Petri Laine (VTT)

The following independent reports referring to this sub task have been produced:

- Ritola, Henri: Light-weight technology for heavy-duty trailers. HUT, Master Thesis. (In Finnish)
- Lehessaari, Mikko: The stability of heavy-duty full trailer combination and the effect of tires. HUT, Master Thesis. (In Finnish)

5.1 GENERAL

According to the deal with ADEME and the Swedish Road Administration, only parts of the work related to vehicle technology is reported in English. The subjects that are covered in this report are the effects of tires on the stability of a full trailer vehicle combination, energy efficiency of heavy-duty vehicle combinations and the effects of tires on fuel economy.

5.2 THE STABILITY OF FULL TRAILER COMBINATIONS AND THE EFFECT OF TIRES (HUT)

5.2.1 Goal

Some fatal truck accidents have raised questions regarding the safety of heavy-duty truck combinations and forced the authorities to seek for new measures for improved road safety. Safety can be enhanced in many ways. Improving vehicle stability is one way to increase vehicle control and to prevent serious accidents.

The stability of vehicle combinations has been subject to rather extensive research. Studies relevant for Finland have been carried out first and foremost by VTT Technical Research Centre of Finland and VTI, the Swedish National Road and Transport Research Institute. It has been demonstrated that full trailer combinations are significantly less stable than, e.g, semi-trailer combinations. Not much attention has been given to tires in this context.

A study on the stability of a full trailer combination and especially the effects of the tires on stability was conducted at Helsinki University of Technology. Tires were varied with respect to degree of wear and placing on the different axles of the trailer. In short, the objective was to define how to achieve maximum stability with minimum investment just by choosing the tires in a smart way.

5.2.2 Stability

Today, almost all vehicles are designed for a certain degree of understeering. Trucks in general and particularly vehicles with a bogie, are heavily understeering. The lateral force induced by a bogie is significantly higher than that of a single axle.

The behaviour of a trailer often differs from the truck itself, due to amplification of movements and accelerations. Increased lateral acceleration often promotes lateral swing of the trailer even though the pulling truck travels stably or is inherently understeering. The problem of trailers is the loss of lateral traction on slippery roads, alternatively tipping over in high friction conditions.

In slippery conditions full trailer combinations can often be seen swaying. This is often referred to as “snaking”. Several factors can lead to snaking, but the foremost reason is tender swaying of the truck amplified by the trailer itself.

If the forward bogie of a full trailer looses traction, the result can be kneeling of the trailer. In the case of a full trailer the amplification of the movements and accelerations take place in two stages. First the movement of the truck is transferred to the forward bogie of the trailer, and from there to the rest of the trailer. Thus the behaviour of the forward bogie has a significant effect on the total trailer.

5.2.3 Previous studies and simulations

In Finland, VTT, Oulu University and Helsinki University of Technology have all conducted studies on the stability of vehicle combinations. In Sweden, VTI has carried out public research on the subject. Studies carried out in the U.S., Australia and some European countries are not considered that relevant for Nordic conditions.

VTI has carried out several studies related to heavy-duty vehicles, and VTI has also studied the effects of winter tires on vehicle dynamics. VTI has also issued recommendations for the design of trucks and trailers. In a study called “Tunga fordons däckanvändning: Effekter vid is/snöväglag” VTI studied the effects of studded tires as well as new and worn tires without studs on the stability of vehicle combinations.

Volvo has studied the effects of steering axles (active and passive) on dynamic stability. Dynamic stability means that the vehicle stays in balance during a manoeuvrering test. Stability was measured based on vertical rotation and lateral acceleration.

VTT has carried out several simulations on the stability of heavy-duty vehicles. The effects of, e.g., vehicle speed and loading have been evaluated. In a study called “Täysperävaunullisten kuorma-autojen talviajan nopeusrajoitusten alentamisen vaikutukset” (The effects of reducing winter-time speed limits for full trailer combinations) VTT studied the stability of various vehicle combinations and the effects of speed. The RA –value of lateral acceleration was used as criterion for stability. In addition, some studies on the stability of tank trucks and vehicle transporter trucks have been carried out. In most cases the simulation software has been MSC.ADAMS.

Even though the RA –acceleration values reported by VTT on one hand and VTI on the other hand diverge somewhat, a general conclusion is that stability decreases with the number of joints in the vehicle combination. In addition to the number of joints, the length of the vehicle, the number of wheels, the weight as well as the speed all affect stability and the RA –acceleration value.

5.2.4 Layout of a modular combination and tires

A modular combination is a vehicle combination with a length of more than 22 metres and a total weight of 60 tons. Maximum length is 25.25 metres. A modular combination can be assembled in four different ways; truck plus full trailer, truck plus “towdolly” plus semi-trailer, truck plus semi-trailer plus single-axle trailer or truck plus semi-trailer plus a second semi-trailer, the latter often called a “b- train”. Regarding stability, modular combinations and especially full trailers, alternatively towdolly plus semi-trailer, are troublesome.

Truck tires differ from passenger car tires in the sense that driving wheels are often equipped with different tires than freely rotating wheels, e.g., the front axle or the axles of a trailer. Low rolling resistance and low wear rate are considered important features for truck tires. Tires for driving axles are often claimed to give good traction. Re-treaded tires are commonly used on trucks. As in the case of new tires, different kinds of treads are offered for driving and freely rotating wheels.

In Finland and Sweden it is common practise to use winter tires on the driving wheels and M+S –marked all-season tires on the front axle even in summertime. Trucks normally get new tires in the autumn to maximise traction. However, little attention is paid to trailer tires, which normally are switched when completely worn out or damaged. As a consequence, different types of tires can be found on trailers even on the same axle.

5.2.5 Simulation of a full trailer combination

The simulation was carried out using the ADAMS/car simulation tool from MSC Software. This tool is designed for the automotive industry. The automotive laboratory at HUT has earlier carried out simulations using a semi-trailer vehicle model. This model was now transformed into a model depicting a full trailer combination by adding a towdolly module to the model (Figure 5.1). The truck module is developed from Volvo’s semi-trailer tractor module by extending the frame, removing the turning table and by adding a third axle and load. The basis for the towdolly is a unit manufactured by Närko Ltd. No modifications were made to the semi-trailer module, originally designed by Volvo and verified by actual vehicle tests.

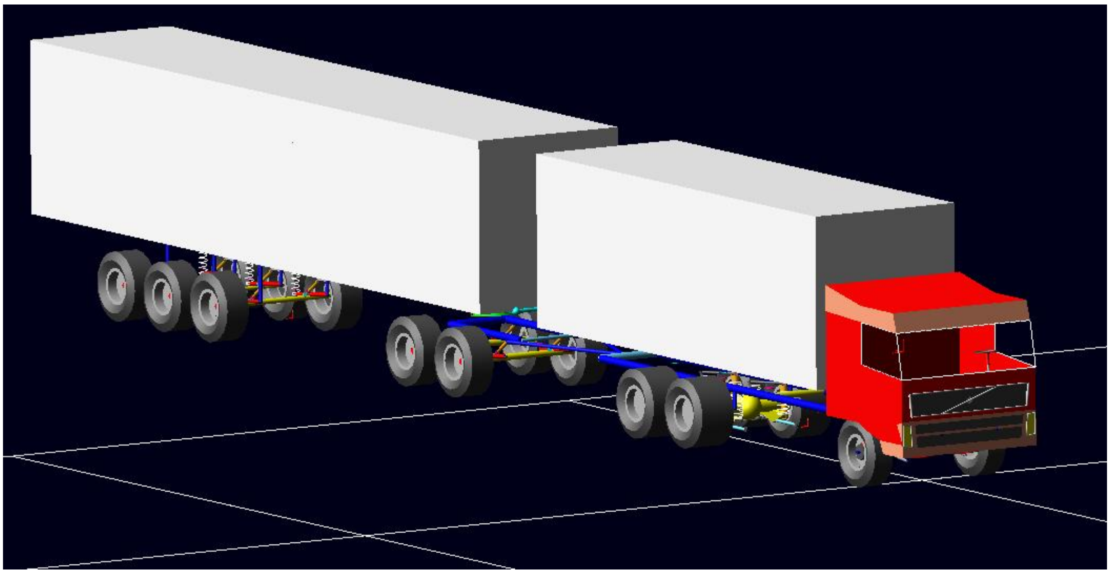

Figure 5.1. The simulation model for a full trailer combination.

The dimensions of the vehicle combination are based on data from vehicle and trailer manufacturers. Component weights are partly based on manufacturers' data. However, when creating the model a number of assumptions had to be made for individual components. As the tool was designed primarily for the evaluation and ranking of tires, it was deemed that the accuracy of the tool was good enough.

A tire forms a spot-like contact with the road surface. The force acting in this contact is calculated using the Magic Formula schemata. The parameters required by the schemata have been adjusted manually to match calculated friction with the actual friction curve. All the tire simulations in the model are based on actual measured performance of M+S –labelled winter or all-season tires. However, the tire models are composites of different measurements, so the models do not depict the performance of a specific tire, rather the models describes the influence of good or bad tires or worn tires on the stability of the vehicle combination. The objective was to create truthful tire modules. Especially the difference in behaviour between a worn tire and a good tire is accurate, and corresponds to actual measurements. Maximum traction and the lateral slip for maximum traction are based on actual measurements.

Simulations were carried out for slippery conditions, and maximum friction was 0.22 0.25 depending on the tire. The simulated manoeuvres were lane change and continuous sine-wave test. The single lane change test was chosen because it is relatively easy to implement using the ADAMS tool, it is easy to perceive and it is more readily evaluated than a twin lane change, although the twin lane change would be more realistic. For all lane change exercises lateral movement was 3.5 metres, or the width of a regular highway lane.

The objective of the simulation was to establish a scheme for mounting tires on the trailer for maximum stability with minimum effort and costs. The different tire options were evaluated based on the slip angle of the towdolly and the trailer itself.

Both the lane change test and the sine-wave test demonstrated that rearmost axle of the towdolly and the rearmost axle of the trailer itself are decisive for stability of the trailer. New tires with good grip on these two axles increase the stability of the trailer significantly.

Which one of these axles is more critical for stability, depends on the speed. In rapid manoeuvres the rearmost axle of the towdolly has a stronger impact on slip angles. In gentle manoeuvres the rearmost axle of the trailer itself has a stronger impact on swaying. The same kind of result was obtained from the sine-wave test. Installing tires with good grip on both these axles maximizes the damping effects.

5.2.6 Summary and recommendations

Tires have significant impacts on the behaviour of vehicles and vehicle combinations. The recommendation for passenger cars is that the better set of tires should be mounted on the rear axle. The recommendation also seems to be valid for heavy-duty vehicle combinations; the rearmost axle of each and every unit should have the best tires.

As tires are quite expensive and as a vehicle combination can have more than 20 tires, renewal of tires is a costly affair. However, periodical renewal of tires is a must. When installing new tires, and if all tires are not renewed, the placement of the new tires should the thought of. Optimum order is shown in Figure 5.2.

In the case of a five-axle full trailer, axles number 2 and 5 should have the best tires. A general rule is that tires should be renewed when tread depth is 3 mm. For safety, recommended tread depth in wintertime is 5 mm, and axles 2 and 5 should have even better tires.

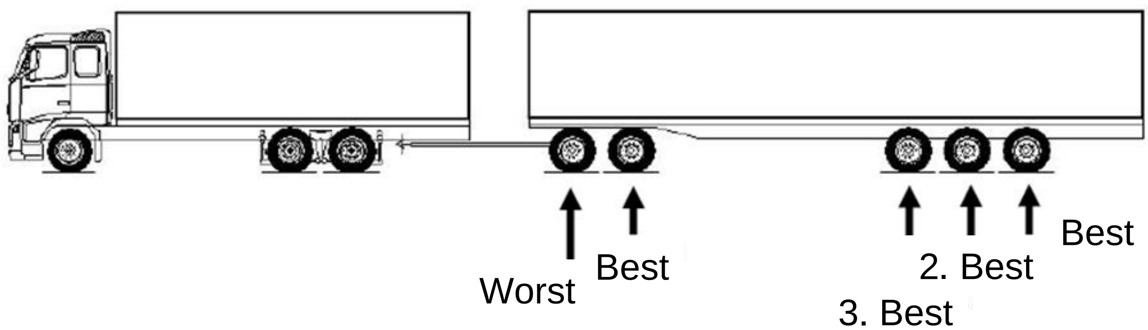

Figure 5.2. Tire recommendation for a full trailer.

5.3 ENERGY EFFICIENCY COMPARISON OF 42/60 –TON VEHICLE COMBINATIONS

5.3.1 Goal

The goal of the comparison was to determine the relative energy efficiency of a 42 ton semi-trailer and a 60 ton full trailer combination truck. 60 ton combinations are in use Finland and Sweden, and are under consideration for other European countries.

The comparison is made by first selecting two highly conventional trailer trucks which can be considered equivalent to each other. The trailer trucks are then rolled out (coast-down) on the highway in order to determine their true tractive resistances. Tractive resistance values are then calculated for both vehicles. The vehicles are then tested on the heavy-duty chassis dynamometer test stand at VTT in highway- and freeway –cycles using these values. Based on the obtained test results it is possible to determine which combination truck carries its load more efficiently.

5.3.2 Highway testing

This sub task was started during spring 2007 with preliminary studies, and by inquiring about the possibility to borrow vehicles from Volvo and a trailer from Närko for the measurements. The vehicles had to have comparable cabins and power lines. The same trailer was used for both vehicles. Certain compromises had to be made concerning the vehicles, but they were comparable enough what comes to the crucial factors. The cargo needed for the measurements, in this case concrete weights, were borrowed from Volvo and Rajamäen Työtehoseura, an institute training drivers. The vehicles used in the tests are shown in Figure 5.3.

The initial intention was to complete the coast-down measurements during summer and then test the vehicles in the chassis dynamometer during fall. Obtaining suitable vehicles for the comparison turned out to be harder than imagined; therefore the highway rolling tests could not be completed until October 2007 during week 41 and 42. The weather was luckily favourable, and both vehicles could be rolled both empty and fully loaded. The weather needs to be windless and the road surface dry during the rolling tests. A wet road surface increases the roll resistance and wind strongly affects the rolling distance either by reducing or increasing the distance depending on the direction of the wind. The highway rolling tests were carried out on arterial highway 3 on the so called Nurmijärvi straight some 50 kilometres north of Helsinki.

The tractive resistances for the 42 ton trailer truck has now been calculated, the results for the 60 ton truck are still being calculated. The goal is to acquire suitable vehicles for the roller-type test stand measurements in the near future, and thus get the final results. The largest and weather-dependent job has however already been completed, so even though there is still work to be done, no big obstacles should be in the way anymore.

Figure 5.3. Vehicles used in the coast-down tests.

5.4 TIRE TESTS

5.4.1 General

The research on tires continued during 2007.

The measurement method created for VTT's chassis dynamometer allows for measuring the effect and losses of freely rolling- and traction wheels, as well as the effect of the transmission. The method makes it possible to study factors affecting the complete vehicle's resistance in detail. The accuracy of the method has been evaluated by comparing it to the official roll resistance method and to results obtained from highway measurements.

Comparisons on tires for driving wheels for buses and trucks were carried out on the chassis dynamometer in 2007. The impact of trailer tires on the rolling resistance was measured on the highway. The rolling resistance for all tires measured in 2007 was determined using a towdolly trolley. Comparative fuel consumption measurements were carried out running a complete vehicle on the chassis dynamometer. Both fuel consumption figures and roll resistances are compared in the results. The results indicate that mere roll resistance values are not enough to describe the energy efficiency of tire transferring power.

VTT has begun using standardised test tires on the driving axle in bus- and truck measurements. These longitudinally grooved Michelin XZA 2 tires are in the tables denoted by "ref".

5.4.2 Tested vehicles

An Iveco Crossway Euro 4 long distance bus and a Volvo B7RLE Euro 3 city bus were used in the fuel consumption tests (Figure 5.4). A simulated load of 15 ton was used in the measurements. The Braunschweig –cycle was used for testing the city bus. The highway cycle for busses was used for testing the long distance bus.

Figure. 5.4. Buses used in the tire testing. Vehicles from Koiviston Auto –yhtymä and Pohjolan Liikenne.

The Scania 124G Euro 3 –truck used in the tire measurements was borrowed from Transpoint Ltd (see the cover of the report). The Scania was tested using the highway cycle (see 3.2). The highway measurements were also performed using this truck.

5.4.3 Measured tires

Bus driving wheel tires

Eight tires were chosen for the series of measurement. The dimension of the tires was the same 295/80 R22.5 for all bus tires. The tires differed in their purpose of use and season suitability. Some of the tires were tires suited for the driving wheels and some tires can be used on all wheels. Some of the tires were re-treade. Details on the tires are shown in Figure 5.5 and Table 5.5.

Table 5.5. Driving wheel tires for buses. The first four tires are true driving wheel tires. The others are primarily front wheel tires, but they can with some restriction be used on the driving wheels under good weather conditions.

Brand	Model	Dimension	Body	Groove depth	Grooving	Axle
Bandag	BDA 4	295/80	Michelin XZE 2+	17 mm	Crosswise	Driving
Nokian	D141 Noktop 41	295/80	Michelin XZE 2+	20 mm	Crosswise	Driving
Michelin	X Coach	295/80	Michelin X Coach	19.5 mm	Crosswise	Driving
Nokian	D140 Noktop 40	295/80	Michelin XZE 2+	17 mm	Crosswise	Driving
Michelin	XJW 4+	295/80	Michelin XJW 4+	16 mm	Crosswise	Front/all
Michelin	XZE 2+	295/80	Michelin XZE 2+	16 mm	Longwise	Front/all
Bridgestone	M788	295/80	Bridgestone M788	16 mm	Longwise	Front/all
Michelin	XZA 2 (ref)	295/80	Michelin XZA 2	13 mm	Longwise	Front/all

Figure 5.5. Driving wheel tires for buses.

<u>Truck tires</u>

The series of measurements consisted of four tire models. Details on the tires are shown in Table 5.6 and Figure 5.6.

Table 5.6. Driving wheel tires for trucks. The first three tires are true driving wheel tires, the fourth is primarily a front wheel tire.

Brand	Model	Dimension	Body	Groove depth	Grooving	Axle
Bandag	BDR-W	315/80	Michelin X	21 mm	Crosswise	Driving
Nokian	D140 Noktop 40	315/80	Goodyear Marathon	17 mm	Crosswise	Driving
Nokian	D143 Noktop 45	315/80	Goodyear Regional	20 mm	Crosswise	Driving
Michelin	XZA 2 (ref)	315/80	Michelin XZA 2	13 mm	Longwise	Front/all

Figure 5.6. Driving wheel tires for trucks.

Trailer tires

Two different trailer tires were tested, longitudinally grooved Noktop 72 tires with a Nokian body and new Nokian NTR-844 tires (Figure 5.7). The trailer tires were also tested in highway rolling tests, in addition to dynamometer measurements.

Figure 5.7. Trailer tires.

5.4.4 The impact of driving wheel tires on fuel consumption

Bus driving wheel tires

Figure 5.8 shows how tires affect the fuel consumption of long distance buses. The difference in fuel consumption between transversely grooved tires is at its greatest 3.3 %. The difference in roll resistance is correspondingly some 25 %. The difference in fuel consumption for the longitudinally grooved tires was 1.8 %. The Michelin XZA2 Energy tire is VTT's own measurement tire.

An interesting result was noticed for the Michelin XZE2+ tire, which fuel consumption result behaves strangely in relation to its roll resistance. The roll resistance of the tire is relatively high, but this did not affect the fuel consumption. The phenomenon might arise from e.g. the tire type's small slip when transferring power. The result could also be explained by different characteristics between longitudinal- and transverse grooving. The groove depth does not seem to affect this phenomenon.

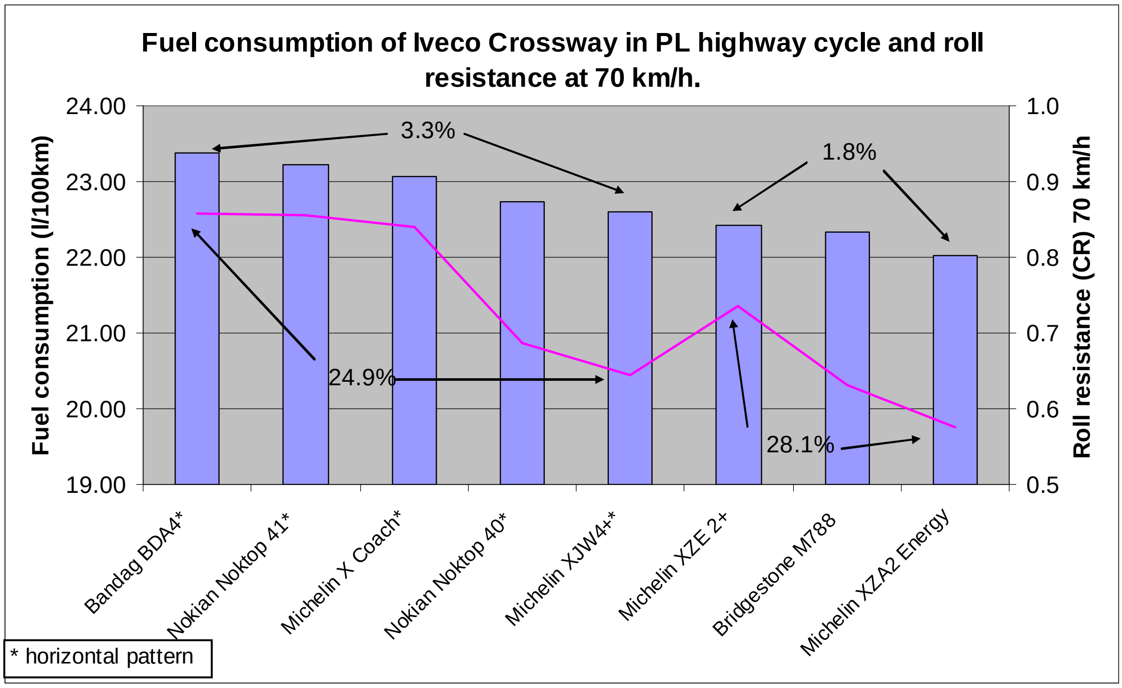

Figure 5.8. Difference in fuel consumption and roll resistance for different tires, long distance bus.

The fuel consumption figures for city buses in the Braunschweig –cycle are very much alike those of the highway –cycle. The tires' effect on fuel consumption is unexpectedly of almost the same magnitude in urban driving as in highway driving (when studying the extremes). The measured difference in fuel consumption for transversally grooved tires is at its greatest 2.5 % in the urban cycle. The difference was 2.6 % for longitudinally grooved tires. Fuel consumption in urban driving was in all cases roughly the double compared to the above-mentioned highway results. The results are presented in Figure 5.9.

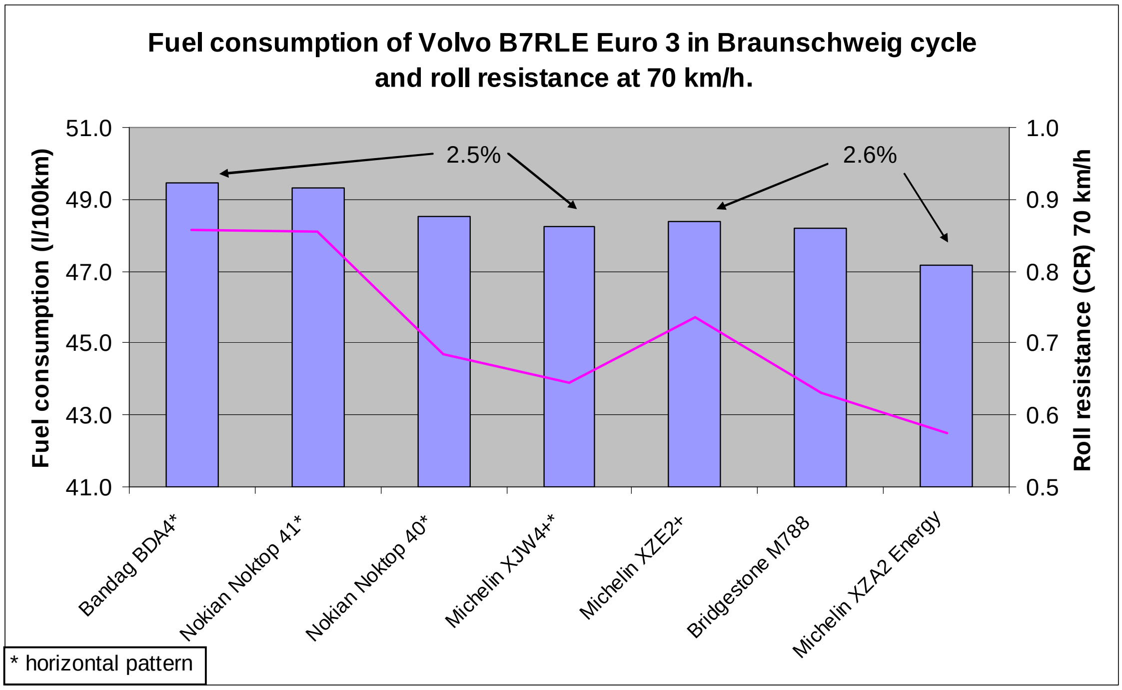

Figure 5.9. Differences in fuel consumption and roll resistance between the tires, city bus.

<u>Truck tires</u>

The difference in fuel consumption between the tires was at its greatest 3.7 % in tests performed with the truck (Figure 5.10). It was also noticed that the re-treaded Noktop tires gave almost the same fuel economy, even though there was a clear difference in roll resistance. The difference between the re-treaded tires is their body on which the tread is laid. There was a 3 mm difference in the groove depth of the Noktop tires.

5.4.5 Defining the roll resistance

A correlation between the tire measurement methods was determined by comparing results of the highway measurements to the test stand results of trailer tires. By catering to the calculatorily estimated air resistance, it is possible to confirm that the test stand tests coincide well with the highway measurements over the whole speed range (Figure 5.11).

A difference in roll resistance of some 20 N/ axle between the tires was measured on the test stand. It was, however, not possible to define a difference this small in the highway measurements, hence both tires (Noktop 72 with Nokian body and Nokian NTR-844) gave almost the same result.

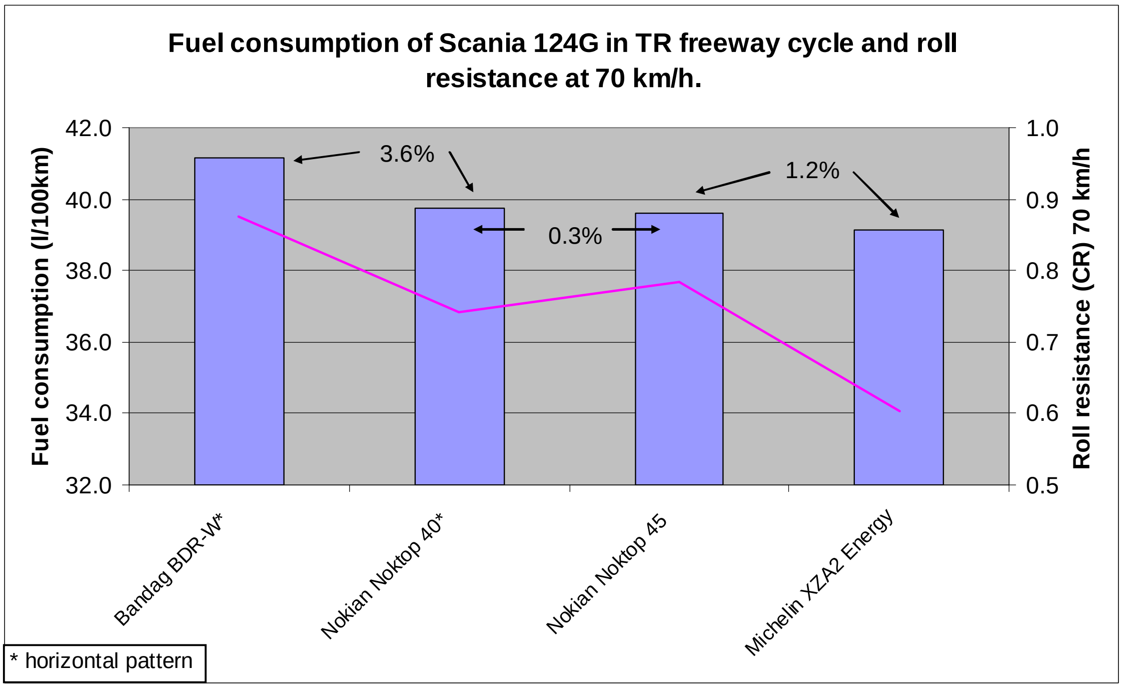

Figure 5.10. Differences in fuel consumption and roll resistance between the tires, truck.

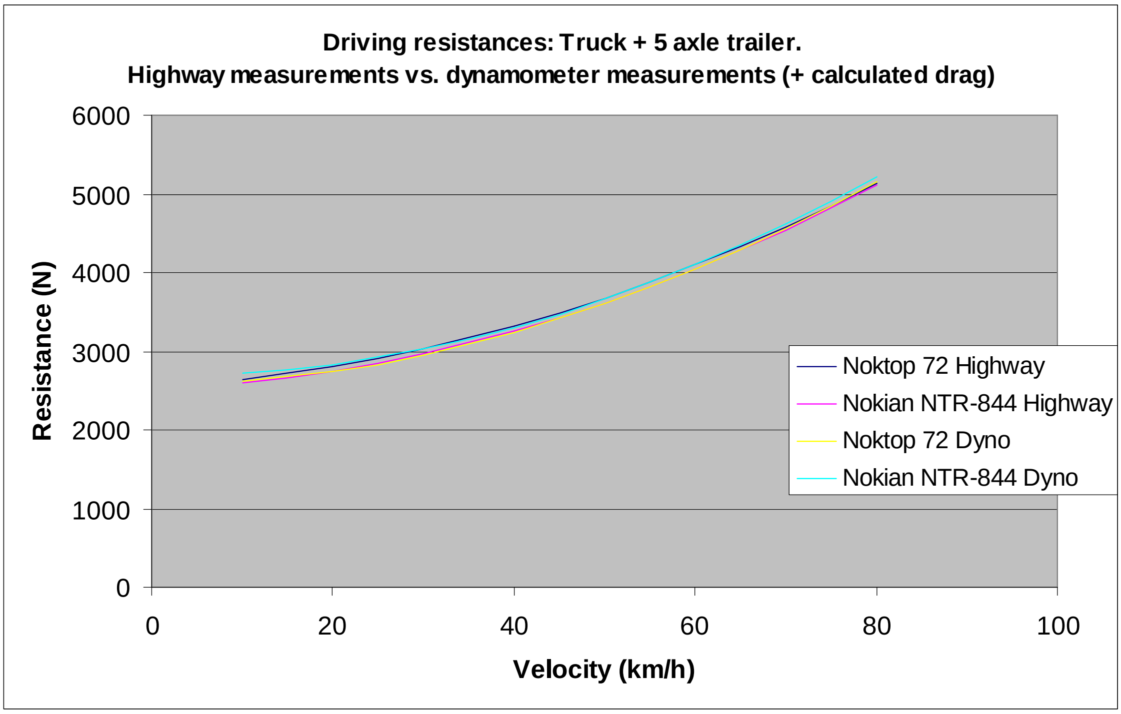

Figure 5.11. Highway measurement results compared to roll resistances defined on the test stand.

When comparing VTT's method for defining roll resistances to the official method (ISO 9948), one discovers that the results are a bit different. VTT's method gives a higher CR value for the roll resistance under all circumstances. The tires are measured on a twin wheel axle in the VTT method. Its resistances increase the total resistance, which partly explains the difference between the models. The total resistance might also be affected by the alignment of the tires on the axle. The official model still measures a single freely rolling tire.

The axle load was 4 980 kg in VTT's measurements. Tire loads of 3 130 kg on the driving wheels and 3 540 kg on the trailer wheels are used in the official method.

Figure 5.12 shows the difference in results between VTT's method and the official method. At 70 km/h the difference in the CR –value is roughly 0.1 percentage units. The results between the measurement methods can at this speed be compared coarsely.

Differences in roll resistance of the measured tires remain steady over the whole speed range when measured using VTT's method. As a result it can be used for reliably studying differences between the tires.

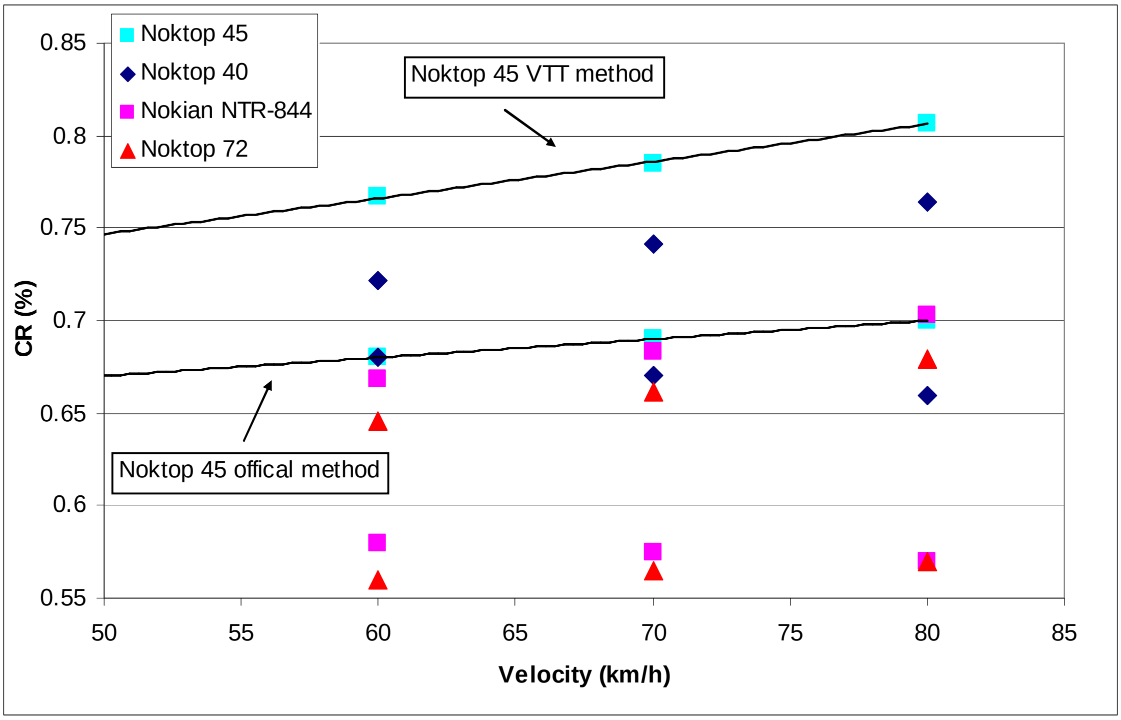

Figure 5.12. Roll resistance CR –values for different measurement methods. VTT's method gives a higher roll resistance value without exception.

6 DEVELOPMENT OF METHODOLOGY (SP 8)

Responsible party: VTT

Authors: Kimmo Erkkilä, Juhani Laurikko & Nils-Olof Nylund

An independent report has not been produced for this subtask.

6.1 GENERAL

The annual report of 2006 covered topics such as introducing measurement tires, producing comparable test results, highway bus testing and the ERA-NET Transport – cooperation.

Less effort was spent on developing measurement methods in 2007. What comes to tire testing, it was confirmed that the highway- and chassis dynamometer measurements give congruent roll resistance results (part 5.5.5, Figure 5.11).

Exhaust emission measurements were carried out under cold weather conditions in early 2008 at Rissala airport close to the city of Kuopio. Portable PEMS –exhaust measuring instruments (Portable Emissions Measurement System) that had been borrowed from Volvo in Sweden (Volvo Buses) were used in the tests. The results will be reported in the annual report of 2008. Preparation work for this series of measurements was part of the project in 2007.

6.2 ERA-NET TRANSPORT

The Transport ERA-NET Action Group ENT9, under the headline "Environmental performance indicators for heavy-duty vehicles", is an operation aimed at spawning international co-operation on actual fuel consumption and environmental emissions of heavy-duty vehicles. What this primarily means is standardising chassis dynamometer testing, which at least in the first stage would be done by harmonising the praxis of the major research laboratories. It would, if possible, of course also be desirable to include chassis dynamometer measurements in the actual norms, or even in the type approval regulations.

Finland (VTT), Sweden (AVLMTC and the Swedish Road Administration) and Great Britain (Millbrook Laboratories) have actively been involved in planning the activities of the ENT9 –group. In addition, contacts with TU Graz in Austria have been made. A research plan was prepared for this consortium in late 2006. The different parties got their own parts of the task. The parties were hoped to come up with suitable national funding for their own work, meaning that the project would go ahead on a "cost-sharing by task-sharing" –principle.

Sweden and Finland (the RASTU –entity in Finland) had their own background funding taken care of, but both Millbrook and TU Graz were devoid of funding. ERA-NET activities do although require each Action Group to have at least three participating member countries, whereupon the project could not be formally launched. Work was done on the “missing-link” during 2006 in order to find suitable financiers for both the British and Austrian parts of the task. Promising expansions were found for prospective parties interested in the subject, but none of them could come up with financing from their budgets for 2007, since their allocation schemes had already been planned fairly far.

Even though the Action Group was not officially launched in 2007, the internal communication inside the network worked. The work plan was to some extent carried on in both Finland and Sweden, in the hope of having a third party in 2008 when the financing would be decided, usually at the turn of the year in which case the activities could commence at greater volume. Allusive signals could be heard from Austria in late 2007, Great Britain did although not appear all too promising.

Since administering the ERA-NET –forum began to appear demanding, other international actors and operational environments, which might offer an alternative or a parallel forum for interaction, were surveyed. E.g. IEA’s interest for the project sprung to life, and they gave reference to participating in it. Nils-Olof Nylund reported on work carried out in Finland on fuel consumption of heavy-duty vehicles in an IEA workshop held in Paris in June 2007.

6.3 PROPOSAL FOR A DIRECTIVE ON THE PROMOTION OF CLEAN AND ENERGY EFFICIENT ROAD TRANSPORT VEHICLES

The European Commission gave a proposal for a directive on the promotion of clean and energy efficient road transport vehicles (COM (2007) 817) on December 12 2007.

The aim of the directive is to include an obligatory comparison ground in which a vehicle’s operational lifetime costs of energy consumption, CO_2 emissions, and pollutant emissions shall be included as award criteria for all procurement of road transport vehicles by public authorities and by operators providing services under a contract with a public authority and also for all procurement of road transport vehicles for the provision of public passenger transport services under licence, permit or authorisation by public authorities.

The directive defines how costs are to be assessed. The comparison should be based on distance based fuel consumption-, CO_2- and emission values (COM(2007) 817):

“Fuel consumption, CO_2 emissions, and pollutant emissions per kilometre for vehicle operation shall be based on standardised EU test procedures for the vehicles for which such test procedures are defined in EU type approval legislation. For vehicles not covered by standardised EU test procedures, comparability between different offers

shall be ensured by using widely recognised test procedures, or the results of tests for the authority, or in the absence of these, information supplied by the manufacturer."
The proposed directive is in fact a "requisition" for heavy-duty vehicle testing like performed within the RASTU –project. If the principle of comparing vehicles based on distance based fuel consumption and emission values would be adopted definitely for all vehicle classes, it would result in a substantial increase in testing and a need for harmonising testing practices, e.g. through ERA-NET –cooperation. The Finnish public sector would, as a result of the RASTU –project, have good potential to adapt to the requirements of the directive.

The directive proposal is however insufficient in several ways. "Widely recognized test procedures" is not defined in any way. The cost of energy is calculated using a fixed price for energy, which is the tax-exempt price of gasoline or diesel. Such an evaluation method would favour liquid fuels, but would impede the use of natural- and biogas in heavy-duty vehicles, since the energy consumption of a gas engine is higher than that of an equivalent diesel engine. The directive proposal does neither unequivocally define how CO_2 –emissions of biofuels are calculated. The directive proposal will presumably not be passed as such. The directive proposal is however a strong proof of the great demand for distance based fuel consumption and emission data for heavy-duty vehicles.

7 SPECIAL EMISSION MEASUREMENTS (SP 9)

Responsible party: VTT

Authors: Maija Lappi, Kimmo Erkkilä & Nils-Olof Nylund

This subproject is part of the project “Connection between new vehicles and NO_x -compounds and the particulate content in urban air (Uusipäästö)”. The following independent reports have been produced for the Uusipäästö-project.

- Lappi, Maija: Connection between new vehicles and NO_x -compounds and the particulate content in urban air. Status report 2007. VTT-R-11133-07. (In Finnish)
- Kauhaniemi, Mari: Uusipäästö – Results of the dispersion calculations. Finnish Meteorological Institute. 17.1.2008. (In Finnish)

7.1 GENERAL

The special emission measurements are part of the “Connection between new vehicles and NO_x -compounds and the particulate content in urban air (Uusipäästö)” -study. This project is financed by VTT, the Ministry of the Environment, the Helsinki Metropolitan Area Council, the Vehicle Importers’ Association, Gasmet Technologies Ltd, Helsinki City Environmental Centre and the Finnish Metrological Institute. The project is connected to the RASTU –project by having its heavy-duty vehicles tested as part of the RASTU –measurements. The special emission project reports its findings to the RASTU –entity as well.

The Uusipäästö –project studies how the emission legislation affects the vehicle pool, and how this for one affects NO_x -compounds and secondarily primary particulate levels of high density routes. As a result, e.g. real urban driving NO- and NO_2 –emission factors for light duty (LD) and heavy-duty (HD) vehicles are being produced. Urban air quality and pollutant dispersion in street canyons will also be modelled. The research began in September 2006 and will last until the end of 2008. The main part of the experimental work was done in 2007. It consisted of road- and chassis dynamometer measurement series for passenger cars, outdoor -FTIR measuring instrument development and the bulk of the heavy-duty vehicle chassis dynamometer measurements. Results are now available on some twenty urban buses with emission certification ranging from Euro 2 to EEV, eight Euro 4 –emission level trucks and ten light-duty vehicles representing gasoline- and diesel car pools.

Heavy-duty NO/NO_2 –testing was revised in April 2007 when a second NO_x -analyzer was commissioned. Testing is now performed so that one analyser continuously measures NO and the other NO_x (NO_2= NO_x - NO). Continuous NO- and NO_x –contents were in previous tests measured in successive trials, because there was only one nitrogen oxide –analyser at disposal. It is known that nitrogen oxides cannot be analysed using CVS –bag sampling due to their rapid transformation. It was noted at VTT that even NO_x measured from a gas bag accordingly to the standard is not permanent due to its susceptibility to light. NO_x –samples were discovered to decrease rapidly in the bag when placed in a well-lit place (when oxidising into NO_3-ions).

7.2 CHASSIS DYNAMOMETER MEASUREMENTS OF HEAVY-DUTY VEHICLES IN 2007

7.2.1 Buses

Nitrogen compounds of five new Euro 4/5 –level buses were presented in the annual report of 2006. These buses representing new technology were compared against catalyst-free Euro 2- and Euro 3 –emission level buses, a newish oxidation catalyst equipped Euro 3 –emission level bus and a particulate catalyst (pDPF) retrofitted Euro 2 –emission level bus.

The bus measurements were complemented in 2007 by tests on new SCR-diesel- and natural gas buses. Some of the SCR –vehicles were equipped with just SCR –catalysts, while some were equipped with SCR- and particulate catalyst combinations (SCRT).

Figure 11.1 presents examples on NO/NO_2 –emissions of different types of city buses. The results in the Figure are for the Braunschweig –bus cycle on half load (the basic case for VTT’s bus measurements), and they are based on vehicles measured in 2007. The Figure also shows the results for two Euro 3 –level and two Euro 4 –level Scanias.

A basic diesel without exhaust gas after-treatment gives a low NO_2 -share. The NO_2 -share increases when using oxidizing exhaust gas after-treatment (oxidising catalyst, particulate catalyst and CRT –type particulate filter). The oxidation catalysts of the now measured vehicles were not “aggressive”, and their impact on the NO_2 -share was therefore not significant. Aging also reduces the efficiency of the catalysts, which is why the oxidising of nitrogen monoxide into nitrogen dioxide is reduced. The NO_2 -share in oxidation catalyst equipped vehicles was now at most under 10 %.

The NO_2 -share of the total NO_x –emissions was at most some 60 % for CRT –vehicles, which for EEV –level vehicles translates into an absolute level of 3 g/km (4 tests, 2 vehicles). The NO_2 -share of a particulate catalyst equipped vehicle is roughly 25 – 40 %. The absolute NO_2 -share of a Euro 2 –level vehicle is also some 3 g/km, resulting from the vehicle’s rather high NO_x -emissions.

NO_2-emissions of vehicles equipped with only SCR –catalysts are low. NO_2 -emissions of natural gas buses are very low. This goes particularly for stoichiometric vehicles.

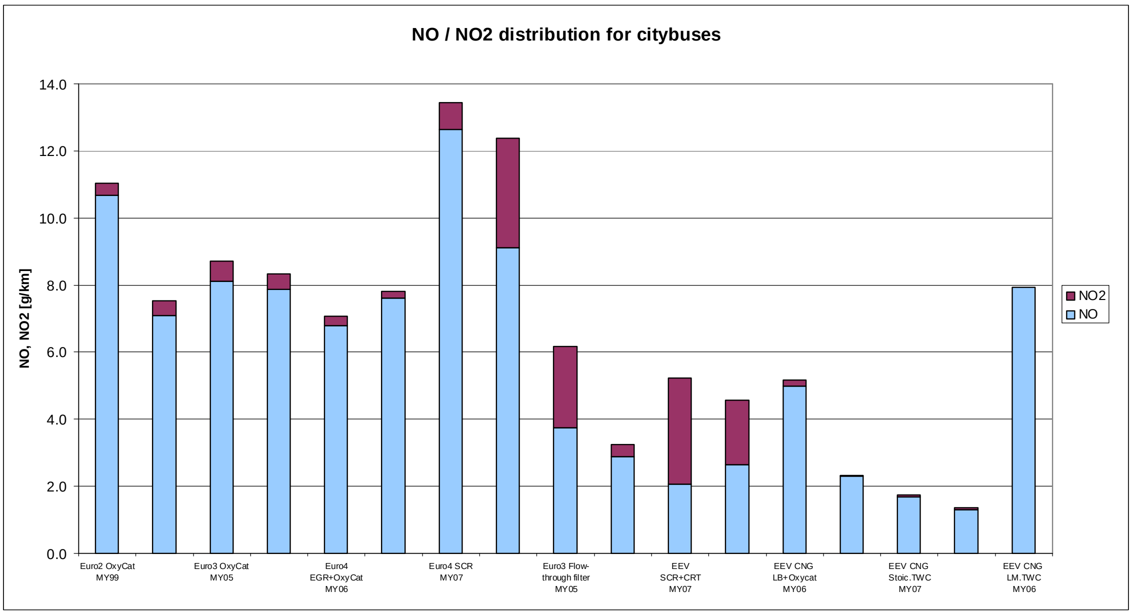

Figure 11.1. NO/NO_2 distributions of buses measured in 2007.

Tests on EGR –vehicles (Scania) showed that the NO/NO_2 –ratio is not constant (Figure 11.2). The NO/NO_2 –ratio of a fairly new vehicle was nearly 50:50 (see annual report of 2006), whereas the NO_2 –share of the follow-up vehicle (mileage 240 000 km) was only under 5 % of the total NO_x –emissions. The cause seems to be the wear of the oxidation catalyst, which in the follow-up vehicle also resulted in increased CO –emissions (compare 3.1.4, follow-up vehicle). The vehicles might also have malfunctioned due to some other reason.

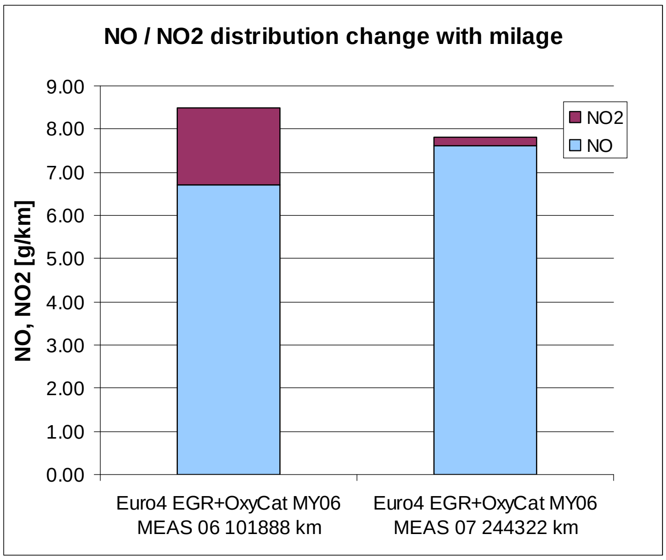

Figure 11.2. Change in NO_2-emissions of the Euro 4 EGR –Scania.

7.2.2 Trucks

Figure 11.3 shows NO/NO_2 –emission ratings for Euro 4 –level trucks. Both SCR –vehicles as well as particulate- and oxidation catalyst equipped EGR –vehicles are shown (the 60 ton EGR –vehicles are from the 2006 measurement series). The results are similar to those obtained in the bus tests; oxidising exhaust gas after-treatment increases the NO_2 -share. The MAN is equipped with a PM-KAT –particulate catalyst, the Scania (EGR –vehicles in the Figure) with an oxidation catalyst.

The NO_2 -share of the PM-KAT equipped MAN is at its most some 40 %. Most SCR –vehicles produce rather low NO_2 –emissions, some of the vehicles do although emit more NO_2. The NO_2 -share is at its most roughly 15 % for SCR –vehicles. The average NO_2 -share of trucks is slightly lower than that of buses. The difference might be explained by a higher load, which results in higher temperature exhaust gas. Exhaust gas purification works altogether better in heavily loaded trucks than in buses.

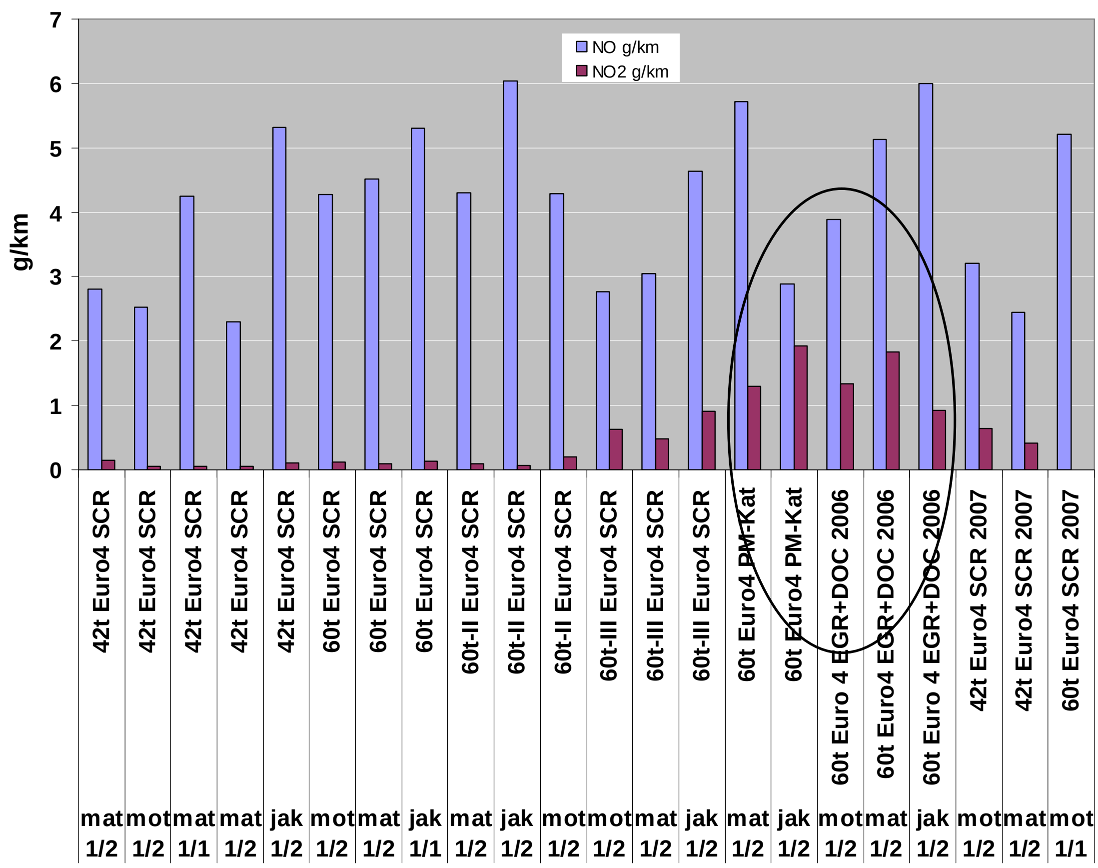

Figure 11.3. Examples of the NO/NO_2 –distribution of Euro 4 –level trucks. Del, hwy and fwy refer to the test cycles (delivery, highway and freeway).

Particulate size distributions of trucks were measured in 2007 using ELPI –equipment. The results are still being processed.

8 SUMMARY

The research continued largely as planned in 2007. The time schedule for subtask 4 (vehicle IT –applications) was further delayed due to device failures.

More than 20 buses were measured. Among the tested vehicles were three EEV -level diesels, which all turned out to be fairly clean-running. There is still a difference in emissions between the cleanest running diesel buses and stoichiometric natural gas buses, in favour of the latter. The most efficient standard design (not light-weight) buses produce 1100 grams CO_2 per kilometre in the Braunschweig –cycle. This holds true for both diesel- and natural gas buses.

Follow-up measurements were performed on five vehicles. Two vehicles (Volvo Euro 2 and Scania Euro 3) were equipped with retrofitted pDPF particulate catalysts. When installed, the particulate catalysts lowered both vehicle types' emissions by some 45 %. Two new vehicle types were included in the follow-up measurements; one Euro 4 –level Scania EGR -diesel and one natural gas powered stoichiometric MAN.

Additional measurements were made on 60 ton vehicles. Measurements of 18 ton vehicles were also introduced. One 60 ton Iveco SCR –vehicle is part of the follow-up measurements. The only significant change in the vehicle's performance during its first 50 000 kilometres was the decrease in its particulate emissions.

Tests on 60 ton MAN and Scania trucks were repeated. Both vehicles showed slightly improved fuel consumption figures. In addition, particulate emissions of the MAN now settled on the expected level (the previously tested vehicle was probably faulty). One new 42 ton vehicle type was measured. Testing of 18 ton vehicles was launched using two vehicles. The testing will continue during 2008.

Different blends of diesel fuel and conventional biodiesel (RME) were studied using a van (Volkswagen) and a medium sized truck (Euro 3 MAN). Tests were also run using 100 % RME. The truck was on top of that tested running on 100 % NExBTL renewable diesel.

The results came up to expectations. RME efficiently reduces particulate emissions, but increases NO_x –emissions. The van's particulate emissions decreased by 65 – 75 % while its NO_x –emissions increased by 12 – 20 % when running on 100 % RME. Running the truck on 100 % NExBTL had the same reductive effect on particulate matter as running it on a 50 % RME –blend. NExBTL did although not increase its NO_x –emissions, quite the contrary it produced some 10 % less NO_x compared to conventional diesel fuel. An independent status report on alternative fuels was prepared with funding provided by the Ministry of Transport and Communications.

Research on lubricants was now carried out on a chassis dynamometer. The difference in fuel consumption between two 10W40 –class motor oils was at its most 1.8 %.

Choosing the optimal transmission oil for a bus equipped with an automatic transmission can lower its fuel consumption by some 3 %.

Two thesis works on vehicle engineering, one on light-weight trailer engineering and one on the stability of full trailer combination trucks, were written at HUT. Full trailers are in fact a Nordic phenomenon; they are hardly used anywhere else in the world. Full trailers have not developed correspondingly to semi-trailers what comes to light-weight design, mostly due to the small manufacturing volume. This gives great potential for designing even lighter full trailers.

Tires play an important part on how vehicles and vehicle combinations perform. Tires with more tread are always recommended to be mounted on the rear wheels of cars. The same seems to go for heavy-duty vehicles; good tires should be mounted on all rear axles. This holds true for the front bogies of full trailer combination trucks too, tires with more tread should be mounted on the rearmost axle in order to prevent oversteering and instability.

VTT defined rolling resistances for semi-trailer- and full trailer combinations trucks in highway tests. Testing continues on the chassis dynamometer. The goal is to determine the energy efficiency of different vehicle combinations. VTT also performed an extensive series of measurements on bus-, truck- and trailer tires. The difference between different driving wheel tires was at most 5 – 6 %. These measurements showed that energy efficiency of driving wheel tires cannot be described using only their rolling resistances, since tires act differently under traction.

Device failures hindered to some extent the research on vehicle IT –applications. Particularly the research on automated skid recognition suffered. Driver’s aid systems were installed in 15 buses in Jyväskylä and the Helsinki Metropolitan Area during 2007. The circular “Joker” regional line and Helsinki internal bus line 58 have produced good measurement data on the traffic in the Helsinki Metropolitan Area since summer 2007. The driver assistance algorithm was implemented in the onboard computers late 2007. The device could although not be activated in 2007 yet, e.g. identification of bus stops has proven challenging. The automated driving style evaluation system also has to be in operation before the driver assistance device can be activated.

Device failures still troubled the research on automated skid recognition in early 2007. Only six vehicles out of ten have provided useful data. In May 2007 VTT made an official complaint to the hardware supplier, TechnoSmart Ltd., for not delivering the devices as promised. Because the project was already halfway through, it was not considered reasonable to replace the supplier.

The algorithm for automated skid recognition was proven workable, although verification was held up by the inoperability of vehicle devices. Because of this, the data had to be processed manually to a great extent. The University of Oulu has developed software for skid detection. This software works, at least in theory, in vehicles’ onboard devices. The algorithm for skid recognition seems, based on preliminary analysis, to work well.

Data acquisition devices, in fact devices which are going to be used as driver's aids, have been mounted in buses in order to collect data for optimizing operations. Since there is plenty of data (35 million lines), customised tools have to be used in order to analyse it. Tools have been further developed based on accumulated experience. The developed tools have, among others, been used for optimising green light traffic signal timing. The driver's aid could adjust the driving speed so that unnecessary accelerations and starts could be avoided, which would make it easier to make use of green waves.

An incentive system has been developed for bus drivers at Tampere City Transport. This system rewards drivers who drive fuel efficiently by returning a share of the cost savings to the driver as an incentive bonus. This increasingly motivates the drivers to an economical way of driving. The decision to extensively implement this system at Tampere City Transport has not been made yet. It is on one hand difficult to obtain driver specific data on the driving style, on the other hand it is hard to compare different drivers due to the great impact of different driving conditions. These factors combined have generally been an obstacle for implementing these systems. The project has although shown that technology makes it possible to fairly compare different drivers and that way develop an incentive system. One Master Thesis for Tampere University of Technology (TUT) was completed from this sub task.

An Excel calculation model has been developed for the energy conservation measures sub task. Vehicle numbers and vehicle attributes can be entered into this model. How changes in the vehicles affect fuel consumption can be calculated using factors which describe the respective differences in fuel consumption of these measures. The general effect of the changes during the period under review is obtained after all measures have been entered into the model. The model will in its final format include both a calculation on the impact of the realised measures and a tool for evaluating future changes. Preliminary calculations have been made based on vehicle data from Helsinki City Transport's bus operators.

Less effort was spent on developing measurement methods in 2007. What comes to tire testing, it was confirmed that the highway- and roller-type test stand measurements give congruent roll resistance results. Testing which is to be done using portable PEMS – exhaust measuring instruments was prepared too. The Transport ERA-NET aims at spawning international co-operation on actual fuel consumption and environmental emissions of heavy duty vehicles. Even though this Action Group was not officially launched in 2007, the internal communication inside the network worked. The work plan was to some extent carried on in both Finland and Sweden, hoping the actual work would commence in 2008.

The European Commission also demands for distance based fuel consumption and emissions values in its directive proposal on the promotion of clean and energy efficient road transport vehicles (COM (2007) 817) given on December 12, 2007. The aim of the directive is to include an obligatory comparison ground for public procurement, in which a vehicle's life span energy use, carbon dioxide emissions and pollutant emission costs would be considered. The directive is in fact a "requisition" for heavy-duty vehicle testing performed within the RASTU –project.

The exhaust gas measurements were complemented by NO/NO_2 –measurements on new vehicle types. The testing equipment was supplemented in spring 2007, so that nitrogen oxides can now be continuously analysed. The highest NO_2 -share (60 %) that has so far been measured was for an EEV –level SCR –catalyst and CRT –particulate filter equipped bus. Direct NO_2 -emissions of simple SCR –catalysts are low. These same holds for natural gas vehicles as well.

Particulate size distributions of trucks were measured in 2007. The results could however not be processed during 2007.

APPENDIX 1.

FINANCING PARTIES OF THE RASTU PROJECT

Tekes - the Finnish Funding Agency for Technology and Innovation

Ministry of Transport and Communications

Ministry of the Environment (2006)

Vehicle Administration (AKE)

Finnish Road Administration

Helsinki City Transport Planning unit (HKL)

Helsinki Metropolitan Area Council (YTV)

ADEME, France

Swedish Road Administration

Concordia Bus Finland Ltd. (2006)

Kabus Ltd.

Volvo Bus Foundation Finland

Neste Oil Plc.

Nokian Tyres Plc.

Oy Närko Ab

Oy Pohjolan Henkilöliikenne Ab

Proventia Emission Control Ltd.

Itella Plc.

Tampere City Transport

Transpoint Oy Ab

VTT Technical Research Centre of Finland