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In-use compliance programme

Overview of Automotive LPG vehicles 1999 - 2003

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1 Introduction

This report presents a general overview of the results of automotive LPG vehicles that have been tested within the framework of the Dutch In-Use Compliance programme for passenger cars over the years 1999 to 2003. The work in these years was executed under a contract with the Dutch Ministry of Housing, Spatial Planning and the Environment. The report on this subject has been written on special request of the Ministry.

The passenger car in-use compliance programme basically assesses car emission performance in use, against the corresponding emissions legislation. In addition relevant data for emission modelling purposes are gathered. The results presented in this report are anonymised, since it is not the purpose of this report to point out typical manufacturer related issues, but to give an overview of the vehicle emission situation.

The passenger car in-use compliance programme was started in 1986 in order to obtain objective relevant data on the environmental performance of the then sold first generation of “clean” vehicles. These vehicles received a tax incentive based on the expected environmental benefits, but these benefits still had to be proven in real-world use. This basic concept of vehicles proving their actual environmental performance in real-world use is still utilised in the ongoing programme, but with evolving vehicle technology and legislation over the years, the set-up of the in-use compliance programme has changed also. A major point that has gained importance over the years is real-world driving conditions during testing. In this respect the European Type Approval Procedure proves to be little representative for real-world driving. Therefore next to testing vehicles on the type approval procedure, additional tests are conducted nowadays to gain insight into the real-world emission behaviour of passenger cars. The data gained from testing have proved to be very useful for emission modelling purposes. Therefore gathering information on the real world emission behaviour of passenger cars has become one of the basic targets of the Dutch in-use compliance programme.

The basic programme consists of testing about 50 different types of vehicles per year (tested basically in threefold per type). The selection of vehicle types that will be tested is based on the actual sales of certain vehicle types. Generally relatively young cars are tested (usually below 35,000 kilometres in the so-called initial test) in order to check whether the cars that have actually been sold during the last years meet their emission limits “in use” also. Executing the in-use compliance programme in this set-up for many consecutive years now supplies a valuable database on the emission performance of the Dutch passenger car fleet. In addition to the “initial vehicles”, vehicles with a higher age and mileage are tested to check whether the durability of exhaust aftertreatment systems meet the durability requirements.

In the Netherlands, the third ‘mainstream’ fuel for passenger cars, next to petrol and diesel, is Liquefied Petroleum Gas (LPG). Although the automotive LPG market share has decreased during the last decade, vehicles equipped with a LPG system (mostly retrofitted) form a considerable portion of the Dutch vehicle fleet. Therefore LPG vehicles are also included in the In-Use compliance programme.
In order to be granted with the incentives from the Dutch government in the form of road tax reduction, LPG vehicles have to meet the so-called G3 specifications. In

relation to the limits this means that the emissions should be below 70% of the Euro 2 petrol vehicle limits of 1997. This implicates that the LPG vehicles have to be tested on the ‘old’ Eurotest including 40 seconds idling before the measurements start. In the current Euro 3 procedure the measurements start directly after the engine is started. Therefore the LPG G3 emission values can’t be compared directly with the Euro 3 emission values of petrol cars.

Table 1 The G3 emission specifications for the LPG vehicles tested are:

Emission component	G3 specification (= 70% of Euro 2) (g/km)	Euro 2 limit (g/km)	Euro 3 limit (g/km)
CO	1,54	2,2	2,3
$HC+NO_x$	0,35	0,5	-
HC	-	-	0,20
NO_x	-	-	0,15

The reasons for writing a separate report on vehicles running on automotive LPG are the following:

It has been a while since a general overview has been made of the current state of performance of automotive LPG vehicles on the Dutch roads. In the annual report 2002 [2] the first results of the most recent results were already published, but as indicated in that report, the testwork had to be completed in 2003 in order to be able to draw conclusions. These tests were completed in the first half of 2003.

Based on results in the past the Dutch Ministry of the Environment has some concerns about the in-use performance of automotive LPG vehicles. In the discussions that followed, the LPG equipment manufacturers promised to improve on this. Therefore this report also has the objective to assess whether these improvements can be found in the results. For this reason the results of the LPG vehicles are presented in this report in two parts, 1) the 1999-2001 vehicle selection and 2) the 2002-2003 vehicle selection. These results consist of the emission results on the Eurotest.

Real world emissions of passenger cars are becoming increasingly more important for emission modelling purposes. In this respect a knowledge gap exists for automotive LPG. Therefore the LPG vehicles of the 2002 and 2003 vehicle selection have additionally been tested on real world testcycles. In a separate chapter these results on real world driving cycles will be presented.

Because the cold start emissions become an increasingly more important source of emissions, the results of the measurements on the cold start effect are also described in a separate chapter.

2 The 1999 – 2001 vehicle selection

As explained in the introduction, the vehicles tested consist of two groups. This chapter describes the results of the 1999-2001 vehicle selection, which consists of only Euro 2 vehicles.

The LPG-vehicle selection of the years 1999 to 2001 was based on the best selling vehicles (combination of vehicle make, type and LPG equipment manufacturer) in these years. In the table below the vehicle selection is listed.

Table 2 LPG vehicles tested in 1999 to 2001

Vehicle make	**Vehicle type**	**LPG equipment manufacturer**	**legislation category of reference petrol vehicle**	
			Euro 2	**Euro 3**
Alfa Romeo	156 1.6 T.S.	Vialle	x	
BMW	316I	Vialle	x	
Chrysler	Voyager 2.4I	Koltec/Necam	x	
Citroen	Xsara 1.4I	AG Autogas	x	
Daewoo	Leganza 2.0	Koltec	x	
Ford	Mondeo 1.8I	Eurogas	x	
Honda	Accord 1.8I	AG Autogas	x	
Hyundai	Lantra 1.6	Prins	x	
Mazda	Premacy 1.8	Koltec	x	
Mitsubishi	Carisma 1.6	Vialle	x	
Opel	Astra 1.6	Koltec	x	
Peugeot	306 1.6	Vialle	x	
Peugeot	406 1.8 16v	AG Autogas	x	
Renault	Megane 1.6e	Eurogas	x	
Renault	Megane 1.6e	Vialle	x	
Renault	Megane Scenic 1.6 16v	Eurogas	x	
Renault	Megane Scenic 1.6 16v	Vialle	x	
Toyota	Picnic 2.0I	AG Autogas	x	
Volkswagen	Golf 1.6 74 kW	Koltec/Necam	x	
Volvo	S40 1.8i 16v	Vialle	x	
Volvo	S70 2.4i Bi-Fuel	OEM	x	

The procedure is as follows: for each vehicle type, 3 vehicles (the initial selection) are tested on the Eurotest. If one or more of these vehicles appear to exceed the limit values, it is decided whether a correction can be made to that vehicle or that more (usually two) vehicles of that type need to be tested. In cases when a certain vehicle type is very difficult to obtain, despite sufficient sales figures, it is possible that a lower number of vehicles is tested.

In the next figure, the average results on the Eurotest (for 3 or more vehicles tested per vehicle type) of each vehicle type are plotted in comparison with the G3 and Euro 2 limits, where applicable.

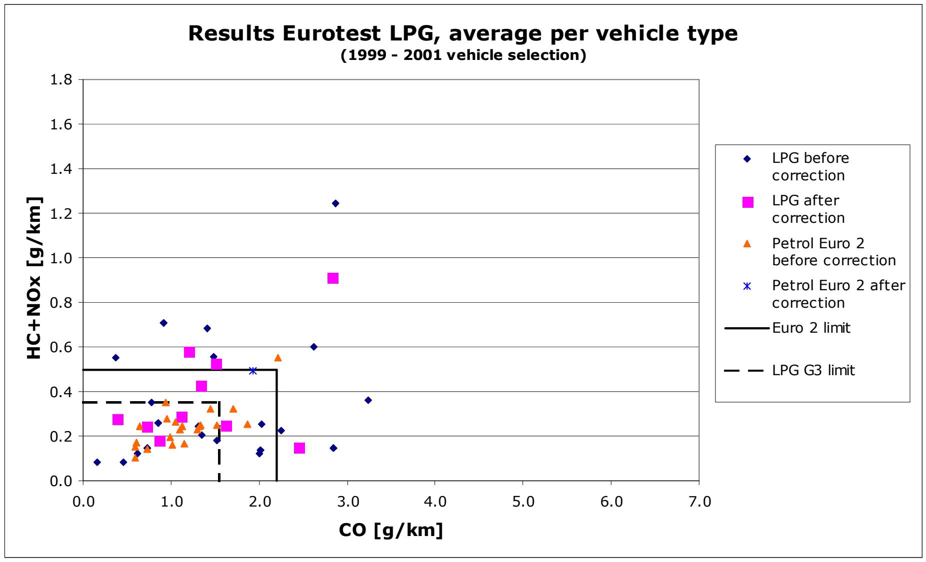

Figure 1 Results of in-use LPG passenger car types (1999-2001) during the standard type approval test procedure (average result per vehicle type)

The average results per vehicle type, as displayed in figure 1, show a large spread, especially when the vehicle types tested were run on LPG. Regarding the initial test on LPG, before correction, 8 vehicle types didn't comply with the Euro 2 values and the G3 values, and additional 3 vehicle types didn't comply with the G3 values. After correction of the vehicles that exceeded the limits, if possible, the test results improved but then still 4 vehicle types didn't comply with the Euro 2 values and the G3 values, and one vehicle type didn't comply with the G3 values.
When these vehicle types were tested running on petrol, all but one vehicle type performed well within the Euro 2 values. After correction, the vehicle type that didn't meet the limit on the initial test, fell within the Euro 2 limits but only with a tight margin.

The overall picture shows that the LPG test results have the largest spread, varying from better than the petrol results too much worse than the petrol results.

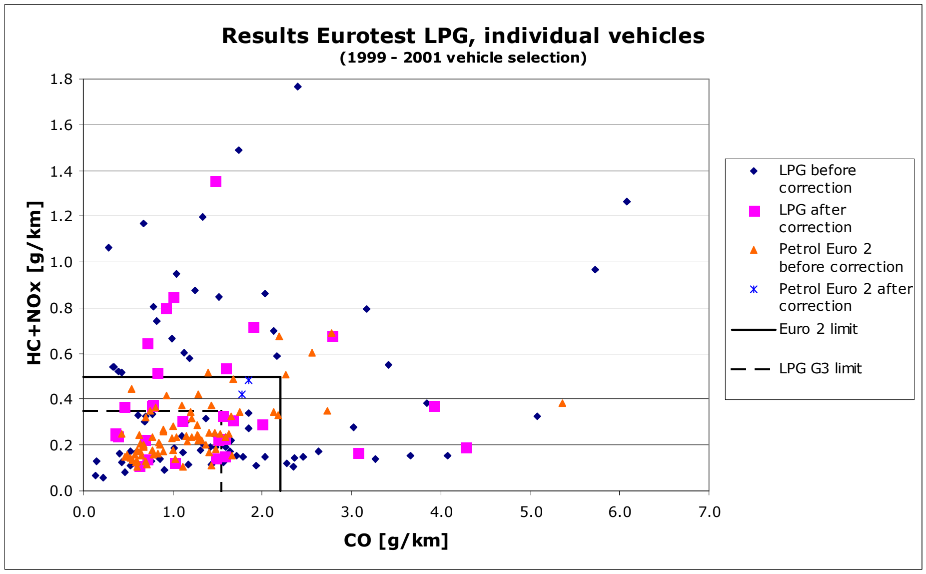

Figure 2 Results of in-use LPG passenger cars during the standard type approval test procedure (individual results)

When the results of the individual vehicles are assessed, it can be clearly seen that the spread in the results becomes larger, especially in the case of the LPG test results. One vehicle type though showed a large variation on petrol as well.

For further clarification, figures 3 and figure 4 (see page 9 and 10) have been included to indicate the results per vehicle type. Note that the designation of the vehicle types in these figures does not correspond with table 2. The overall picture that can be made up based on these figures is that they confirm the conclusions that were drawn from figures 1 and 2, i.e. that the emission results on the Eurotest can be very good, but there is a large variation of the LPG results even leading to exceedances of the limit values.

In the standard procedure of the in-use compliance programme, three initial vehicles are tested per vehicles type. As explained, if any exceedances of the limit values occur on these three vehicles, two or more vehicles are tested additionally. When the test results are analysed from the point of view of exceedances of limit values for the three initial vehicles, the following tables can be made. These tables must be regarded as complementary to figures 3 and 4.

Table 3 % of initial vehicles tested on LPG that passed or exceeded the G3, respectively Euro 2 values, before and after correction, 1999 to 2001 vehicle selection

LPG	% of vehicle types that passed on G3:	% of vehicle types that exceeded G3 values on:				% of vehicle types that exceeded Euro 2 values on:		
		CO	HC+NOx	CO & HC+ NOx		CO	HC+NOx	CO & HC+ NOx
Before correction	47%	24%	19%	10%	=100%	15%	22%	5%
After correction	59%	24%	14%	3%	=100%	12%	10%	0%

For automotive LPG vehicles it can be concluded that in the event of exceedances this concerns in many cases the Euro 2 limit values. Results in between the G3 and the Euro 2 limit values occur with a lower frequency. The results “after correction” improve the scores in the table above, but even then only 59% of the initial vehicles score below the applicable limit values (G3).

Table 4 % of initial vehicles tested on petrol that passed or exceeded the Euro 2 values, before and after correction, 1999 to 2001 vehicle selection

Petrol	% of vehicle types that passed:	% of vehicle types that exceeded Euro 2 values on:			
		CO	HC+NOx	CO & HC+ NOx	
Before correction	93%	3%	2%	2%	=100%
After correction	95%	3%	2%	0%	=100%

When tested on petrol, these initial vehicles resulted in only three exceedances of the Euro 2 limit values. One of these vehicles improved to values below the limits after correction.

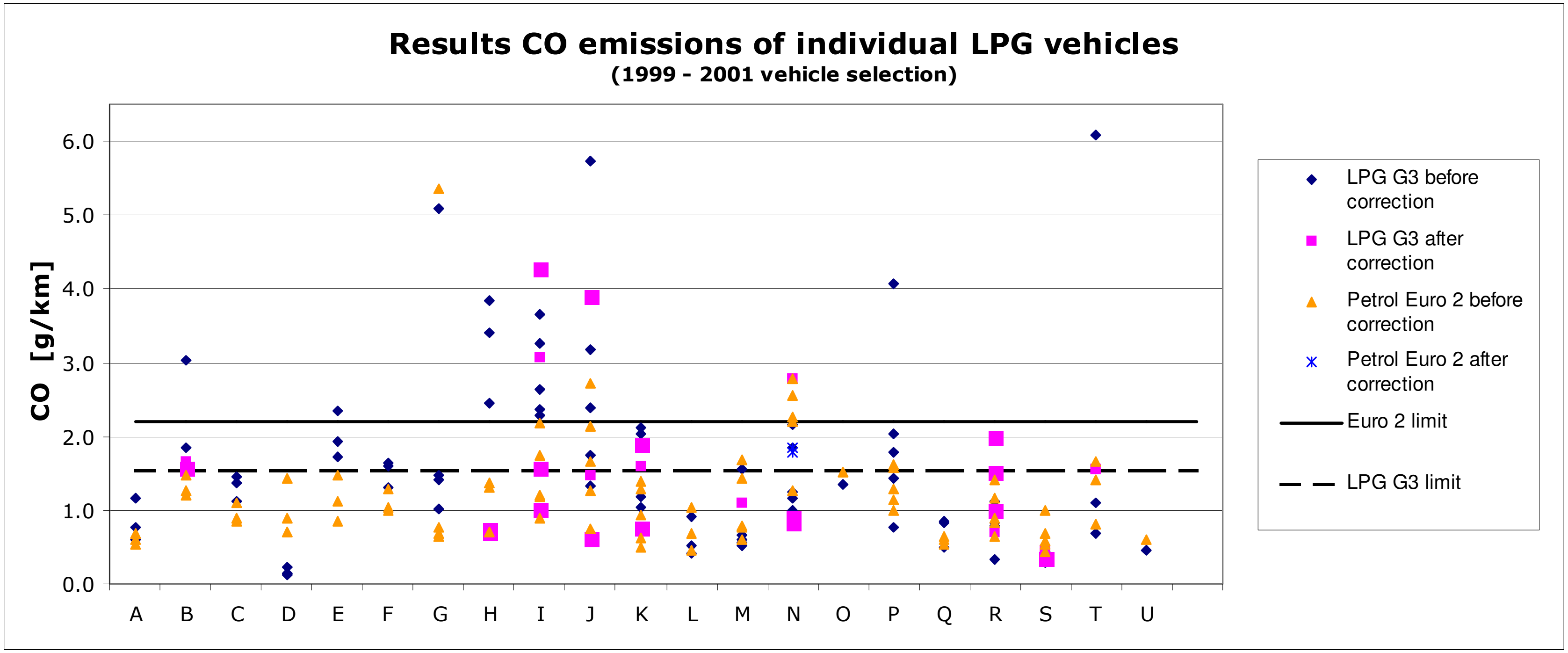

Figure 3 CO-emission results of individual vehicles

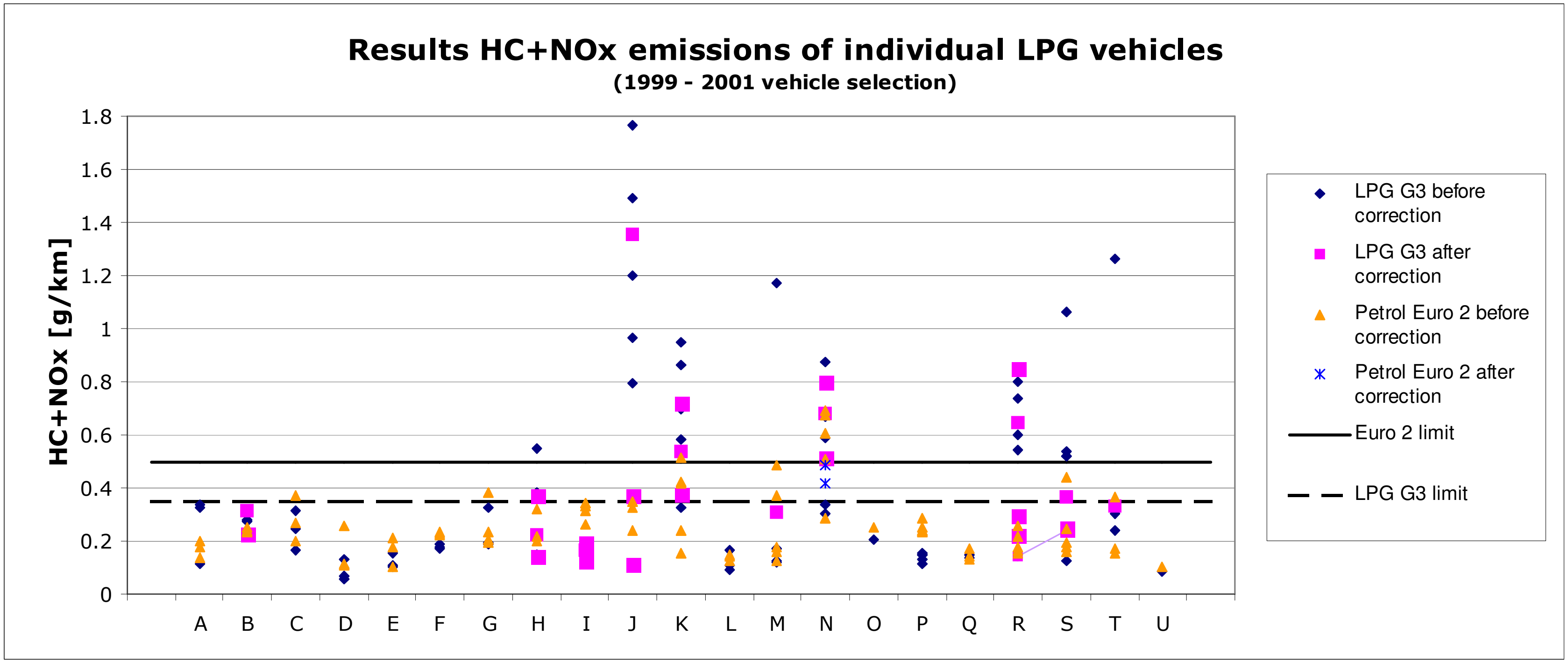

Figure 4 : HC+NOx emission results of individual vehicles

3 The 2002 – 2003 vehicle selection

As explained in the introduction, the vehicles tested have been divided into two groups. This chapter describes the results of the 2002-2003 vehicle selection, which consists of mainly Euro 3 vehicles.

The LPG-vehicle selection of the years 2002 and 2003 was based on the best selling vehicles (combination of vehicle make, type and LPG equipment manufacturer) in these years. In the table below the vehicle selection is listed.

Table 5 LPG vehicles tested in 2002 and 2003

Vehicle make	**Vehicle type**	**LPG equipment manufacturer**	**legislation category of reference petrol vehicle**	
			Euro 2	**Euro 3**
Alfa Romeo	147 1.6 77 kW	Vialle		x
Chrysler	Neon 2.0i 16v	Koltec		x
Chrysler	PT Cruiser 2.0i 16v	Prins		x
Citroen	Xsara Picasso 1.8i 16v	Autogas Holland		x
Daewoo	Tacuma 1.8	Koltec		x
Mitsubishi	Carisma 1.6	Vialle	x	(x)
Renault	Megane Scenic 1.6 16v	Eurogas		x
Skoda	Octavia 75 kW	Autogas Holland		x
Volvo	S60 2.4 140pk	Vialle		x

As explained in the introduction the LPG vehicles have to be tested on the ‘old’ Eurotest including 40 seconds idling before the measurements start. In the current Euro 3 procedure the measurements start directly after the engine is started. Therefore the LPG G3 emission values can’t be compared directly with the Euro 3 emission values of petrol cars.

In the next figure, the average results (for 3 or more vehicles tested per vehicle type) of each vehicle type are plotted in comparison with the G3, Euro 2 and Euro 3 limits, where applicable.

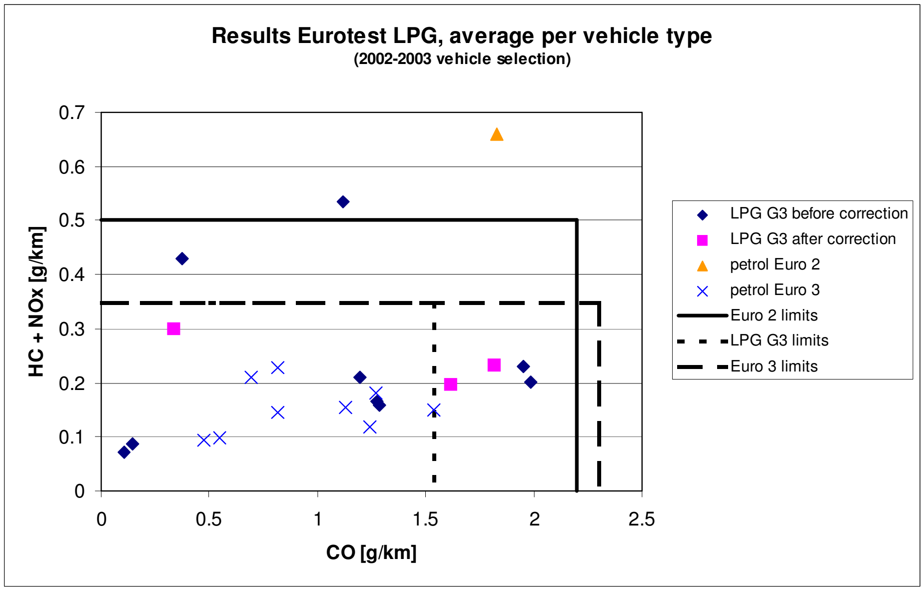

Figure 5 Results of in-use LPG passenger car types (2002-2003) during the standard type approval test procedure (average result per vehicle type)

The figure above shows a large variation of the results. The Euro 3 vehicles tested on petrol showed that these vehicles met the corresponding limits with a large margin. The Euro 2 vehicle however exceeded the $HC+NO_x$ limit quite excessively. When this vehicle was tested on LPG it failed also. Furthermore it is not clear how this Euro 2 vehicle could have been sold in 2001 when the Euro 3 legislation was already in force. After these initial tests it was decided to test two more vehicles of this type, but of a later date. These vehicles appeared to be of the Euro 3 legislative category, and met these limits by a large margin when run on petrol. When tested on LPG, one vehicle met the G3 limit values, and the other vehicle exceeded the G3 limit for $HC+NO_x$.
Four out of the other eight LPG vehicles performed very well on average. The other LPG vehicle types exceeded on average the G3 limit values on the initial test, of which one passed the test after correction.

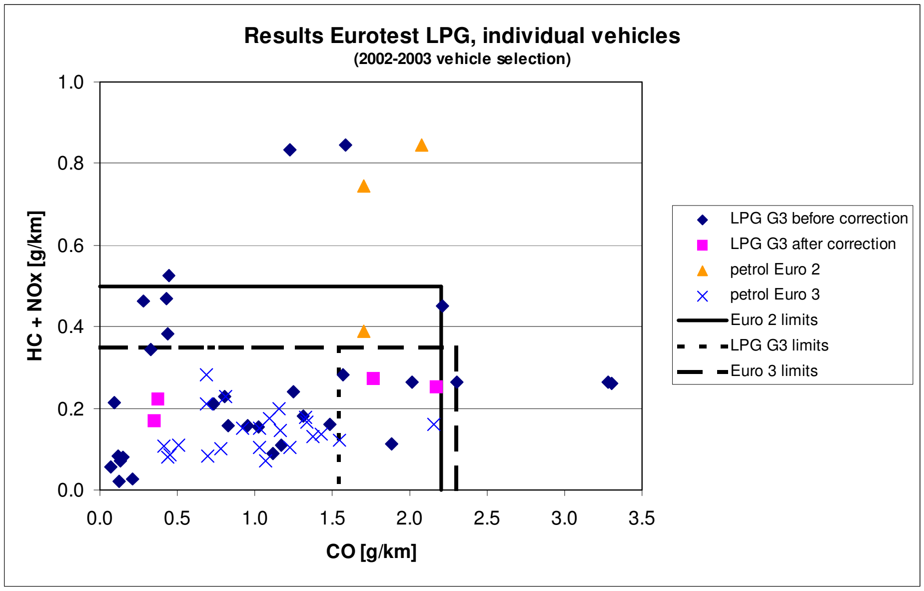

Figure 6 Results of in-use LPG passenger cars (2002-2003) during the standard type approval test procedure (individual results)

The emission results of the individual vehicles show about the same picture as the average results per vehicle type. Only the spread of the results is larger.

For further clarification of the results figure 7 and figure 8 have been included to indicate the results per vehicle type. Note that the designation of the vehicles types in these figures does not correspond with table 5. The overall conclusion that can be drawn from these figures is that they confirm the conclusions that were drawn based on figures 5 and 6, i.e. that the results can be very good, but that there is a rather large variation of results even leading to exceedances of the limit values. This variation is less than the variation of the exceedances observed in the 1999-2001 vehicle selection.

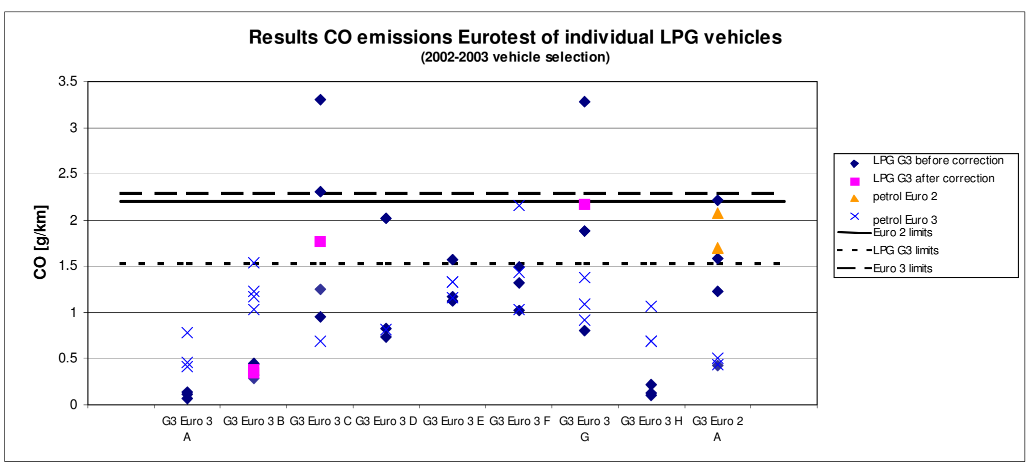

Figure 7 CO-emission of individual LPG vehicles

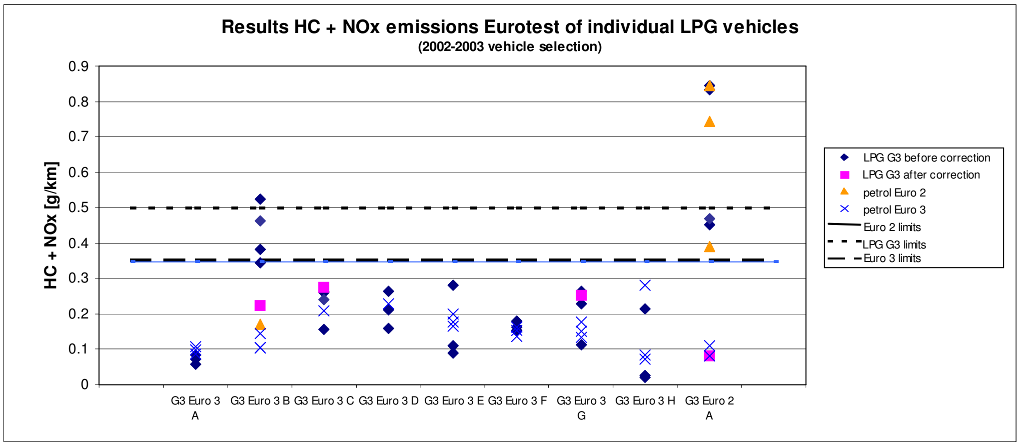

Figure 8 HC+NO$_x$-emission of individual LPG vehicles

As explained earlier, in the standard procedure of the in-use compliance programme, three initial vehicles are tested per vehicles type. If any exceedances of the limit values occur, it is decided to test two or more vehicles additionally. When the test results are analysed from the point of view of exceedances of limit values for the three initial vehicles, the following tables can be made. These tables must be regarded as complementary to figures 7 and 8.

Table 6 % of initial vehicles tested on LPG that passed or exceeded the G3, respectively Euro 2 values, before and after correction, 2002-2003 vehicle selection

LPG	% of vehicle types that passed on G3:	% of vehicle types that exceeded G3 values on:				% of vehicle types that exceeded Euro 2 values on:		
		CO	HC+NOx	CO & HC+ NOx		CO	HC+NOx	CO & HC+ NOx
Before correction	63%	19%	11%	7%	=100%	11%	11%	0%
After correction	67%	19%	7%	7%	=100%	4%	7%	0%

When the results as displayed in figures 9 to 12 and table 6 are regarded, a large improvement over the 1999-2001 results can be observed. Table 6 shows that 63% of the vehicles passed on the initial test, but this percentage is higher than the percentage of vehicles that passed in the 1999-2001 vehicle selection.

Table 7 % of initial vehicles tested on petrol that passed or exceeded the Euro 2 or Euro 3values, before and after correction, 2002-2003 vehicle selection

Petrol	% of vehicle types that passed:	% of vehicle types that exceeded Euro 2 or Euro 3 values on:			
		CO	HC+NOx	CO & HC+ NOx	
Before correction	91%	0%	9%	0%	=100%
After correction	91%	0%	9%	0%	=100%

In the table above is reflected that the Euro 2 vehicle type showed very bad results when tested on petrol. Just as its results on LPG, this case must be regarded as an exception when considered that 29 Euro 3 and Euro 4 vehicles have been tested in recent years without any problem at all [1, 2]. In this perspective all Euro 3 vehicle types performed faultlessly, as was to be expected from these past results.

4 Real world emissions

Another, and increasingly important, objective of the Dutch in-use compliance programme is the gathering of information on the real-world emission behaviour of vehicles on the road. With changing situations on the roads, and vehicle technology being able to adapt to these changed situations, the data gathered using the European type approval procedure, is more and more losing its value as representative emission data. These data were not really meant to be used for this purpose, but have been used as (a basis for) emission factors for a long time, since little else was available and originally they could be used for this purpose without much error.

For the purpose of deriving real-world emission factors for the Dutch national situation, in fact two things are needed: 1) Dutch real world compressed trips, and 2) data on a representative Dutch vehicle test fleet. The second issue is easy to solve within the Dutch in-use compliance programme, since one of the main ideas behind the programme is exactly to test a sample that is representative for the Dutch fleet. The first issue is more difficult to address, since there is no national average set of real-world driving patterns. The only option at this moment close to a national set, is a set of 11 different driving patterns that have been recorded on Dutch motorways in 1999 (Emissions and congestion project). These cycles have been added to the testprogramme in 2001. For the urban and rural part of real-world driving the Common Artemis Driving Cycles (CADC) were added to the testprogramme from 2002 onwards. The CADC cycles have recently been developed in the European 5th Framework project Artemis in which all prominent European institutes participated. As a result, these cycles can be regarded as representative for the average European real world driving.

In summary, it was decided to use:
1. The ‘Emissions and congestion’ test cycles
2. The Common Artemis Driving Cycles (CADC)
for determining the real-world emissions of the Dutch car fleet. In practice this meant that from every vehicle type selected one vehicle was additionally tested on test 1 and test 2. This selective (but cost efficient) way of testing is also the cause of the fact that there are no petrol and LPG results available for exactly the same vehicle type. Therefore comparisons of the LPG and petrol results on real-world cycles can only be done based on averages per fuel type.

Because the results presented in this report comprise the years 1999 to 2003, not every LPG vehicle has been tested on these real world cycles, as indicated in the table below.

Table 8 LPG vehicles tested on real world cycles

	Vehicle make	Vehicle type	LPG equipment manufacturer	testcycle	
				'Emissions and congestion'	CADC
1999-2001 vehicle selection	Alfa Romeo	156 1.6 T.S.	Vialle		
	BMW	316i	Vialle		
	Chrysler	Voyager 2.4i	Koltec/Necam		
	Citroen	Xsara 1.4i	AG Autogas		
	Daewoo	Leganza 2.0	Koltec		
	Ford	Mondeo 1.8i	Eurogas		
	Honda	Accord 1.8i	AG Autogas	x	
	Hyundai	Lantra 1.6	Prins		
	Mazda	Premacy 1.8	Koltec	x	
	Mitsubishi	Carisma 1.6	Vialle		
	Opel	Astra 1.6	Koltec		
	Peugeot	306 1.6	Vialle		
	Peugeot	406 1.8 16v	AG Autogas		
	Renault	Megane 1.6e	Eurogas		
	Renault	Megane 1.6e	Vialle		
	Renault	Megane Scenic	Eurogas		
	Renault	Megane Scenic 1.6 16v	Vialle	x	
	Toyota	Picnic 2.0i	AG Autogas		
	Volkswagen	Golf 1.6 74 kW	Koltec/Necam		
	Volvo	S40 1.8i 16v	Vialle		
	Volvo	S70 2.4I Bi-Fuel	OEM	x	
2002-2003 vehicle selection	Alfa Romeo	147 1.6 77 kW	Vialle	x	x
	Chrysler	Neon 2.0i 16v	Koltec	x	x
	Chrysler	PT Cruiser 2.0i 16v	Prins	x	x
	Citroen	Xsara Picasso 1.8i 16v	Autogas Holland	x	x
	Daewoo	Tacuma 1.8	Koltec	x	x
	Mitsubishi	Carisma 1.6	Vialle		
	Renault	Megane Scenic 1.6 16v	Eurogas	x	x
	Skoda	Octavia 75 kW	Autogas Holland	x	x
	Volvo	S60 2.4 140pk	Vialle	x	x

It must be noted that a vehicle is only tested on the real-world cycles after it was correct on the initial Eurotest. Therefore all results presented in this chapter are based on correct vehicles that have met the limit values.

The results from using both test cycles will be further discussed in the following sections.

4.1 Emissions and congestion

On behalf of the Transport Research Centre of the Dutch Ministry of Transport and the Dutch Ministry of Housing, Spatial planning and the Environment, TNO executed a research programme in order to determine the effects of road traffic congestion on exhaust gas emissions and fuel consumption of road vehicles on motorways. The need for information on this topic occurred when policy makers wanted to know what the benefits for emissions could be of decreasing traffic congestion by using traffic management measures. As a result an extensive research programme was executed in 1999 and 2000 [3]. Important milestones in this project were the development of test cycles that represent Dutch motorway traffic and an extensive measurement campaign in which 19 vehicles were tested in the TNO laboratory on these test cycles. Table 9 shows the congestion categorisation used in the project.

Table 9 Congestion categorisation as used in the study

Congestion category	*Definition*
1aa	Speed <10 km/h; 'stop and go'
1ab	Speed between 10 and 25 km/h
1a	1aa and 1ab combined, speed between 0 en 25 km/h
1b	Speed between 25 and 40 km/h
1c	Speed between 40 and 75 km/h
2a	Speed 75-120 km/h, traffic volume over 1000 vehicles per lane per hour, speed limit = 100 km/h
2b	Speed 75-120 km/h, traffic volume over 1000 vehicles per lane per hour, speed limit = 120 km/h
2c	Speed 75-120 km/h, traffic volume below 1000 vehicles per lane per hour, speed limit = 100 km/h
2d	Speed 75-120 km/h, traffic volume below 1000 vehicles per lane per hour, speed limit = 120 km/h
2e	Speed over 120 km/h, independent of traffic volume
3	Traffic jam 'avoidance' route

When the emission results were weighted for their share in the Dutch vehicle fleet of 1998, the following relatively weighted 'bathtub-shaped' emission correction curves were constructed for the national Dutch vehicle fleet. Driving pattern 2C is put at 100%.

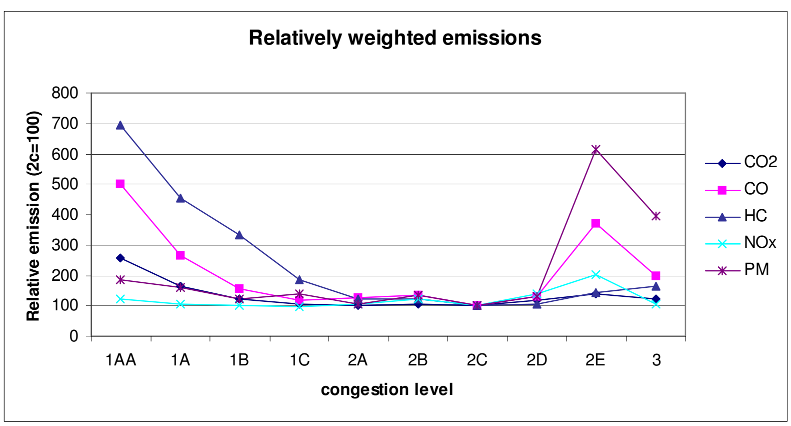

Figure 9 Relative emission profile total Dutch fleet in 2000 (2C=100)

The emission results of the vehicles indicated in table 8 are displayed in the figures below. The height of the bars in the figures indicates the standard deviation of the measured results around the mean values.

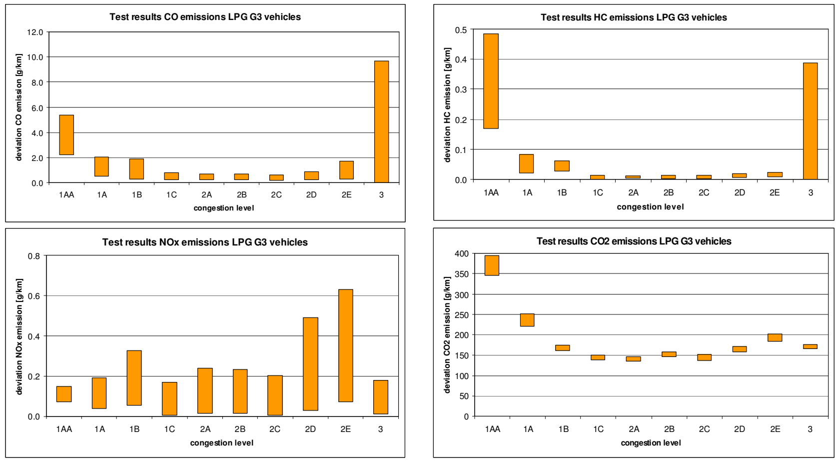

Figure 10 Emission results on the 'Emissions and Congestion' cycles for LPG vehicles

For the emission components CO, HC and CO_2 the bathtub shaped curve of figure 9 is clearly visible in the results presented in the figure above. On cycle 1aa and cycle 3 the CO and HC emissions show a very large variation of the results. This is mainly caused by a number of high-emitters. For the bathtub shape NO_x this is less clearly visible.

When the relative weighted emissions are calculated as displayed in figure 11, the following figure appears. For reasons of comparison, the pre-G3 results (3 vehicles tested from before 1996) are also given [3].

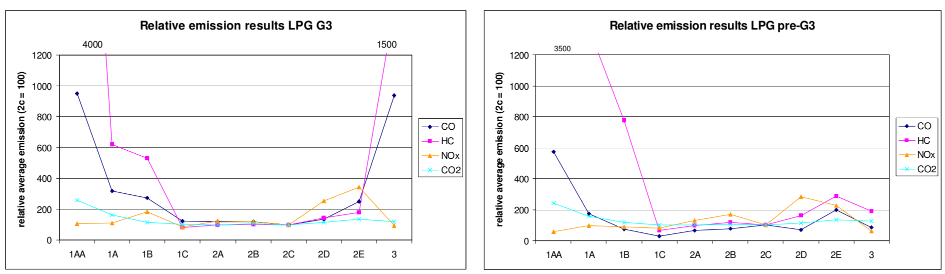

Figure 11 Relative average emission profiles for the 'Emissions and congestion' cycles for LPG G3 and pre-G3 vehicles

When both figures are compared it can be noticed that the shape of the curves per emission component have not changed a lot. For CO and HC cycle 3 shows a very sharp increase for G3, that wasn't present in the pre-G3 case.

During 2001 and 2002 many petrol fuelled vehicles have been tested on the 'Congestion and emissions' cycles also [1, 2]. A comparison of the average emission results is given in the following table.

Table 10 Differences of emission results for automotive LPG vehicles (G3, 2001 to 2003) compared to petrol vehicles (Euro 3) [%]

Congestion category	**CO [%]**	**HC [%]**	**NOx [%]**	**Average speed [km/h]**	**Driving dynamics [RPA]**
1aa	+423	+659	+87	7.0	0.10
1a	+219	+498	+342	15.5	0.18
1b	+413	+184	+97	35.9	0.18
1c	+95	-11	+186	57.4	0.16
2a	-5	-36	+271	91.2	0.09
2b	-7	-36	+459	96.9	0.10
2c	+64	-21	+582	98.1	0.06
2d	-7	-30	+652	112.3	0.07
2e	-82	-79	+550	125.7	0.04
3	+647	+1384	+208	36.3	0.18

This comparison between LPG G3 and Euro 3 petrol emissions can be done because all vehicles tested were available on the Dutch market in the period of 2000 to 2002. Although the average size and weight of the vehicles selection tested (based on sales figures) is lower for petrol compared to LPG vehicles, it has been proven that there is no significant correlation between emissions and vehicle weight and size, as there was is the past before Euro 2.

Some remarkable conclusions can be drawn from this table. In the case of high driving dynamics (cycle 1aa, 1a, 1b, 1c and 3) the LPG emissions are much higher than the petrol emissions for the components CO and HC. On the other hand, when the driving dynamics are relatively low and the speed is more constant (cycle 2a, 2b, 2c, 2d and 2e) the LPG emissions are equal to or even considerably lower than the petrol emissions, especially for HC. Closer analysis of the data revealed a high emitter for CO and HC on testcycle 3. When this vehicle was excluded, the differences with petrol vehicles became of a much lower magnitude.

For NO_x a trend can be observed of an increasing difference between petrol and LPG emissions with increasing speed. It appeared though that three high emitting vehicles mainly caused these differences. Apparently these vehicles were calibrated towards a 'lean' setting, a phenomenon that can sometimes also be observed among petrol vehicles, but not as 'strong' though as is the case here. Whether or not this can be regarded as structural, without these vehicles the average NO_x values would have about the same levels as the petrol values.

4.2 Common Artemis driving Cycles

As explained earlier, the Common Artemis Driving Cycles (CADC) have been added to the testprogramme for producing information on the real-world emission behaviour of cars in comparison to the Type Approval testing. The CADC consists of an urban part, an extra-urban part and a highway part.

Comparing the data from the CADC-cycles with the EU test data gives relevant information on the transient behaviour of vehicle emissions outside the EU test window.

This information is essential for emission modelling purposes. The following figure shows the test results of the LPG G3 vehicles tested on the CADC cycles. For reasons of comparison the results on the urban (hot) part and extra-urban part of the standard EU testcycle are also displayed. The height of the bars in the figures indicates the standard deviation of the measured results around the mean values.

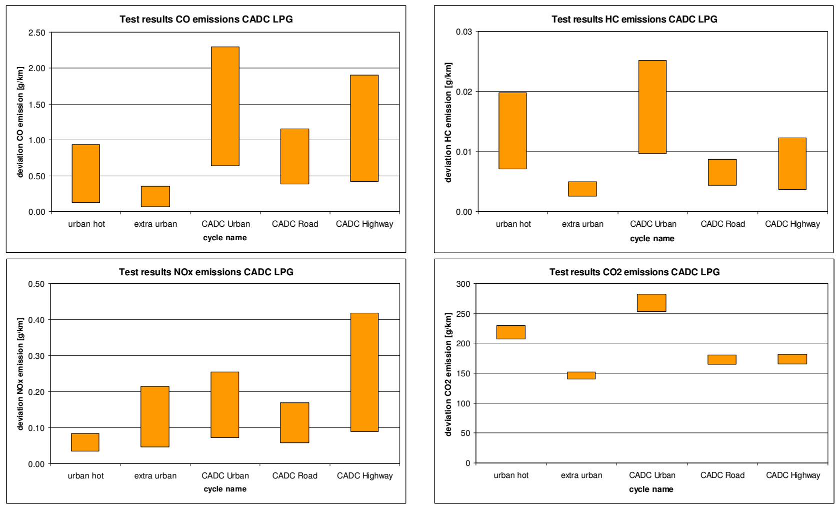

Figure 12 Emission results from the CADC cycles compared to the 'urban hot' and 'extra urban' ECE cycles for LPG vehicles

When the urban hot cycle is compared with the CADC urban cycle, and the extra urban cycle is compared with both the CADC extra urban and the CADC highway cycles it can be concluded that for the emission component CO, the CADC emission are considerably higher, showing a large variation too. The results for HC and NO_x show comparable results regarding average values and variation of the results, though the CADC results are slightly higher.

During 2002 several petrol vehicles have been tested on the CADC cycles as well [2]. A comparison of the average emission results gives the following table.

Table 11 Differences of emission results on the CADC, urban (UDC) and extra urban (EUDC) cycles for automotive LPG vehicles (G3, 2001 to 2003) compared to petrol vehicles (Euro 3) [%]

cycle name	**CO [%]**	**HC [%]**	**NOx [%]**	**Average speed [km/h]**	**Driving dynamics [RPA]**
urban hot (UDC)	+857	+588	+82	18.7	0.14
extra urban (EUDC)	+183	-44	+408	62.6	0.09
CADC Urban	+754	+87	+113	17.5	0.30
CADC Road	+61	-23	+69	60.3	0.16
CADC Highway	-2	-63	+438	116.4	0.10

When the differences in emissions on the UDC and EUDC cycles are observed, it can be seen that all LPG results except for HC extra urban are considerably higher than the petrol results. When the CADC cycles are observed, the same picture as for the

'Congestion and emissions' cycles can be seen. In the case of high driving dynamics (cycle CADC Urban) the LPG emissions are significantly higher than the petrol emissions for the components CO and HC. On the other hand, when the driving dynamics are relatively low and thus speed is more constant (cycle CADC Road and Highway) the LPG emissions are equal to or even considerably lower than the petrol emissions, especially for HC.

For NO_x a trend can be observed towards an increasing difference with the petrol emission with increasing speed, but again some high emitting vehicles were observed. Without these vehicles the average NO_x values would have about the same levels as the petrol values.

5 Cold start emissions

Apart from executing the standard Euro 2 testcycle from cold start, one vehicle per vehicle type underwent an additional test to collect data on the effects on emissions of a cold start. For this purpose, the urban part of the Eurotest was driven twice: (1) with a cold start from 20°C and (2) with a hot start (conditioned on a full UDC + EUDC). The difference between the results on the ‘cold’ and ‘hot’ test gives the additional emission during a cold start. This value is important for emission modelling purposes.

It must be noted that in the Euro 2 test procedure that is followed the measurements start after 40 seconds of engine idling, which is different from the Euro 3 procedure where measurements begin directly after engine start. The differences in emissions from both procedures are mainly caused by the time it takes to reach catalyst light-off temperature from cold start.

5.1 Cold start emissions of the 1999 – 2001 vehicle selection

In the next figures, the results for LPG vehicles of the 1999 – 2001 vehicle selection are plotted per emission component.

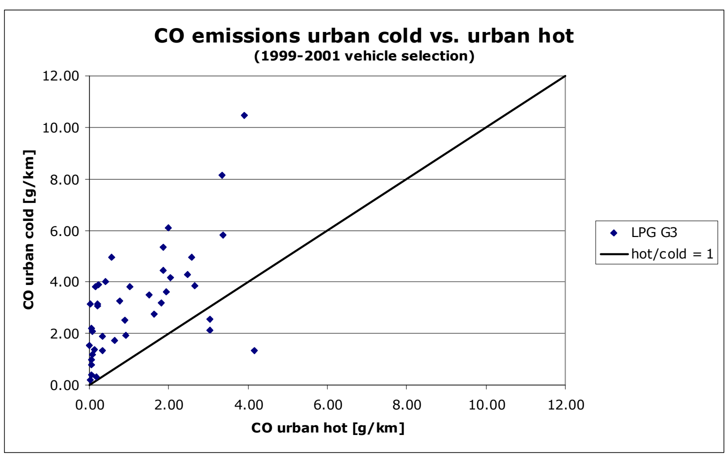

Figure 13 LPG 1999-2001 vehicle selection UDC cold start emissions versus UDC hot start emissions: CO

The cold start effect for CO shows a large variation. It is remarkable to see that there is a group of vehicles that has close to zero ‘hot’ emissions’ and ‘cold’ emission of up to 4 g/km, a very common behaviour also for modern petrol vehicles. On the other hand there is a group of vehicles for which the hot and cold emissions are rather similar, with ‘warm’ values of up to 4 g/km and ‘cold’ values of up to over 10 g/km. Finally it is remarkable that even vehicles exist that have lower ‘cold’ emissions than ‘hot’ emissions.

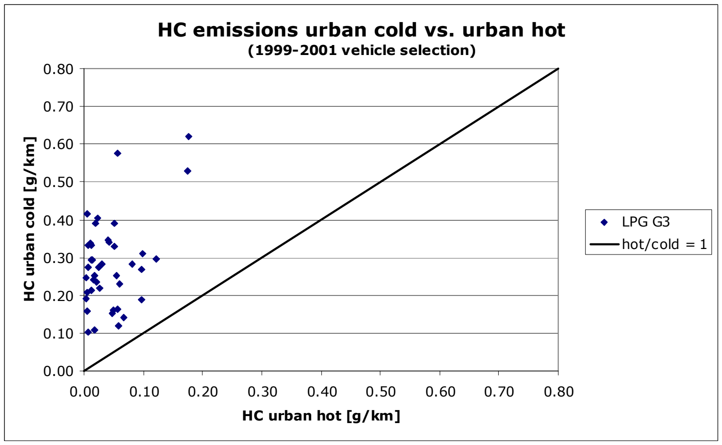

Figure 14 LPG 1999-2001 vehicle selection UDC cold start emissions versus UDC hot start emissions: HC

For the cold start effect of HC, about the same picture as for CO cold start emissions appears. There clearly is a group of vehicles with close to zero 'hot' emissions and 'cold' emissions of up to 0,4 g/km, and on the other hand a small group of vehicles from which both the 'cold' and 'hot' emissions are not close to zero.

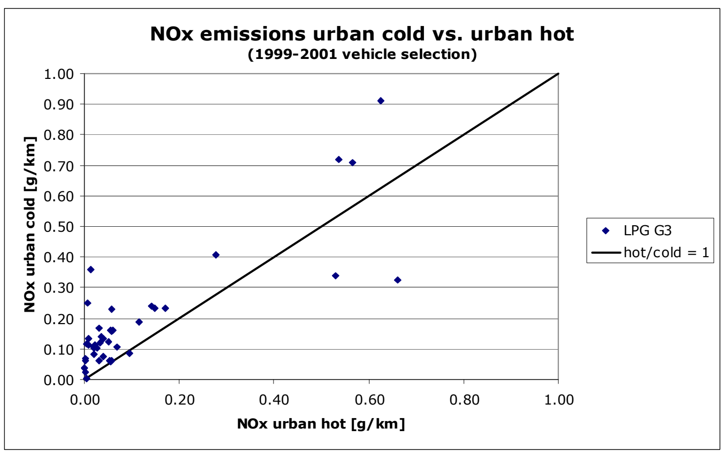

Figure 15 LPG 1999-2001 vehicle selection UDC cold start emissions versus UDC hot start emissions: NO_x

For NO_x, the relative effect of the cold start can be regarded as more or less constant, since the measured values have about the same distance to the hot/cold=1 line. The absolute values show a large variation though, and two groups can be distinguished. There is a rather large group of vehicles with a 'hot' start close to zero (< 0,1 g/km) and with a 'cold' start of up to 0,25 g/km. A small group of vehicles shows almost no additional cold start effect, in combination with rather high emission levels (both during cold and hot start).

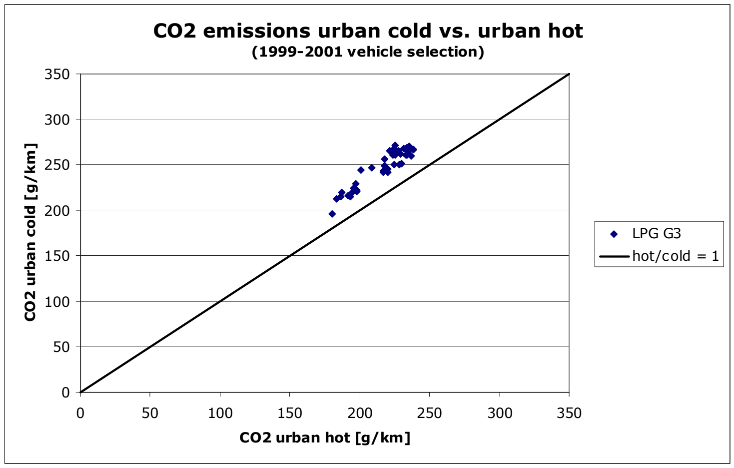

Figure 16LPG 1999-2001 vehicle selection UDC cold start emissions versus UDC hot start emissions: CO_2

CO_2 emission increase at cold start shows a stable picture, averaging at an increase of 14 % during cold start. This effect points at an increased friction at a 20-°C start and probably some minor cold start enrichment effects

5.2 Cold start emissions of the 2002 – 2003 vehicle selecion

In the next figures, the results for LPG vehicles of the 1999 – 2001 vehicle selection are plotted per emission component.

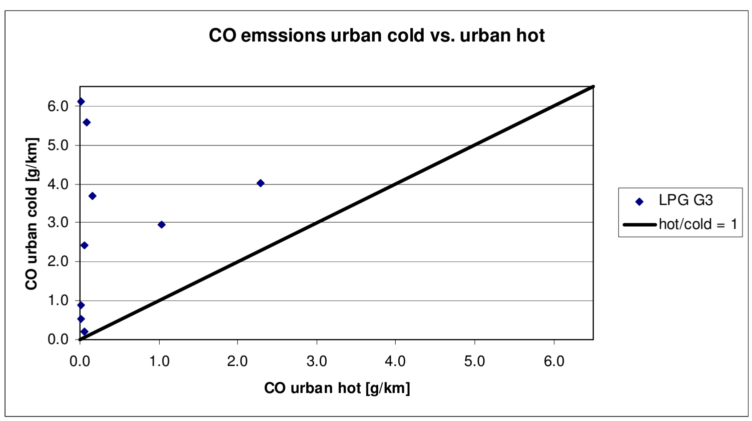

Figure 17 LPG 2002-2003 vehicle selection UDC cold start emissions versus UDC hot start emissions: CO

As can be concluded from this figure, the CO emissions after a hot start are close to zero, whereas the cold start emissions are higher and vary considerably, just like the effects observed for petrol vehicles of the same emission technology class. The absolute emissions are rather different from petrol Euro 3 vehicles though, ranging to a maximum of 2,5 g/km on the urban cold cycle, bearing in mind that these measurements were started directly after engine start [1, 2].

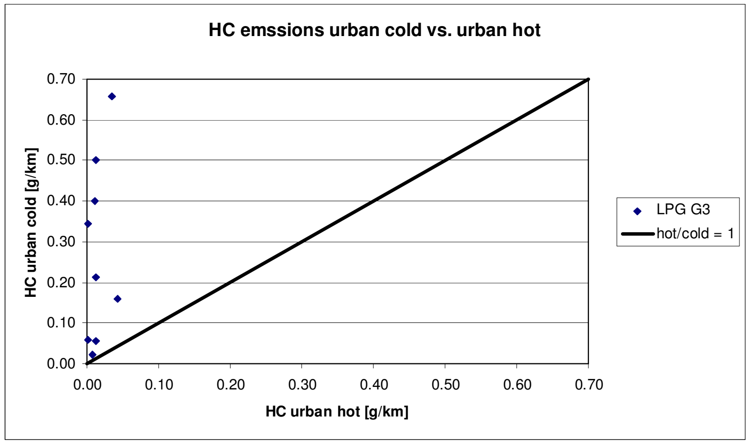

Figure 18 LPG 2002-2003 vehicle selection UDC cold start emissions versus UDC hot start emissions: HC

Just as for CO emissions, the HC emissions under hot conditions are at a very low level, whereas the cold emissions are considerably higher and vary considerably. The absolute emissions are rather different from the petrol cold start emissions, ranging for petrol to a maximum of 0,25 g/km on the urban cold cycle [1, 2]

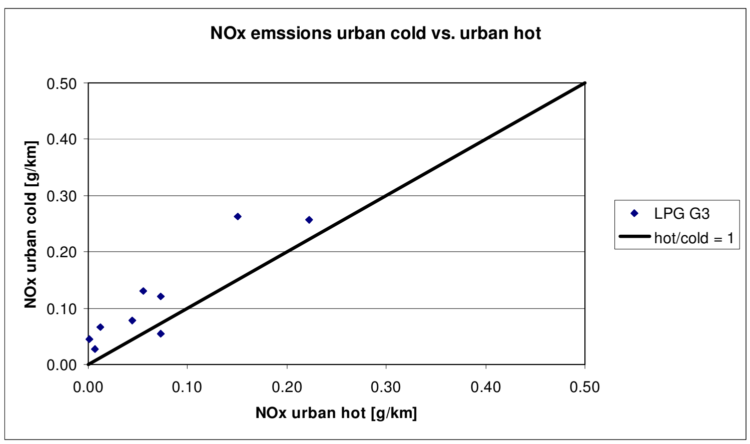

Figure 19 LPG 2002-2003 vehicle selection UDC cold start emissions versus UDC hot start emissions: NO_x

The differences between cold start and hot start NO_x emissions are smaller when compared to the CO and HC emissions. The absolute cold start emissions are in the same order of magnitude as for petrol.

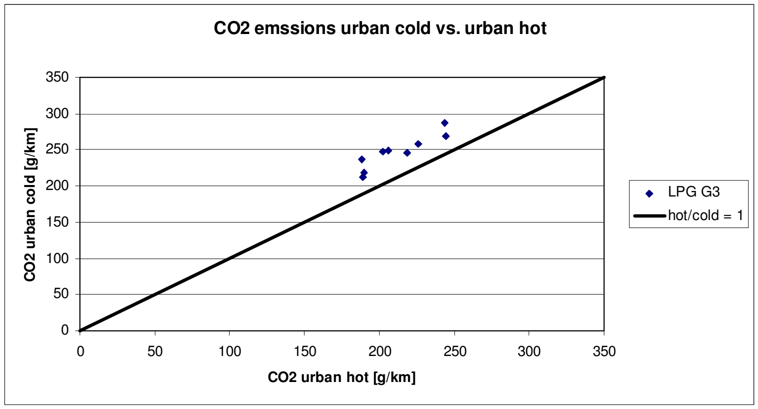

Figure 20 LPG 2002-2003 vehicle selection UDC cold start emissions versus UDC hot start emissions: CO_2

CO_2 emission increase at cold start shows a stable picture, averaging at an increase of 18 %. This effect points at increased friction at a 20-°C start and probably some minor cold start enrichment effects.

6 Discussion of the results

This report has been written for the purpose of creating an overview of the emission performance in-use of automotive LPG retrofitted vehicles on the Dutch roads with respect to legislation at Type Approval, real world behaviour and cold start behaviour. For this purpose two research periods of testing automotive LPG retrofitted vehicles during the course of the Dutch In Use Compliance programme were observed separately; 1) the 1999 to 2001 vehicle selection and 2) the 2002 and 2003 vehicle selection.

When the emission performance of the LPG vehicles tested in the period 1999 to 2001 is assessed, it can be observed that the test results vary considerably. These variations reaching from a number of very well performing vehicles, to many cases of vehicles tested exceeding not only the G3 limit values, which they are approved for, but even the less stringent Euro 2 limits (for both CO and $HC+NO_x$). A correction applied by either TNO or the LPG-equipment manufacturer to the vehicles exceeding the limits resulted in only a small number of cases in actual improvements.

The vehicles tested in the 2002 and 2003 programme revealed a somewhat different picture. Not only the number of exceedings of the applicable emissions limits was lower as in the earlier period, but also the amounts by which the limits were exceeded were smaller. Therefore in general it can be stated that the conformity of production of automotive LPG has improved in recent years. In this context one must be aware however that the last series of 29 petrol Euro 3 vehicles tested in the in-use compliance programme showed no problem at all. Therefore it is clear that regarding conformity of production and meeting the (G3) limits, retrofit automotive LPG vehicles as available on the Dutch market still have to improve further in order to catch up with petrol vehicles.

When the real-world emissions of automotive LPG are assessed (2002-2003 selection), it can be concluded that the CO and HC emissions under constant load (or speed) are comparable, or even below the level of petrol vehicles. Under such circumstances the vehicle is operating at lambda = 1 conditions at which the catalyst efficiency is highest. When driving under dynamic conditions, the CO and HC emissions are significantly higher for LPG, compared to petrol. This indicates that the lambda control of LPG vehicles probably cannot match the high-speed lambda control of modern petrol vehicles in combination with an electronically operated throttle valve.
The measured overall real-world NO_x emissions of automotive LPG vehicles were negatively influenced by some high emitting vehicles. As a result the average real world NO_x emissions of LPG vehicles are much higher than the for petrol vehicles. When these high emitters were excluded from the sample, the NO_x emissions were comparable to those of petrol cars.

Another area for possible improvement for automotive LPG vehicles is the additional emission during cold start (for the components CO and HC). When the cold start emissions of Euro 3 petrol vehicles is compared with the cold start emissions of LPG G3 vehicles, a significantly higher value for LPG vehicles is observed. This difference is remarkable because LPG vehicles cold start on petrol fuel also. This again indicates towards current LPG engine management/cold start strategies not being as sophisticated as those of modern (and especially the -7° C type approved) Euro 3 vehicles. In addition it must be taken into account that the Euro 3 vehicles are type approved on the Euro 3 procedure in which the measurements begin directly after engine start. In the Euro 2 procedure, which is used for type approving LPG G3 vehicles, the measurements begin after the engine has idled for 40 seconds (giving the catalyst some time to heat up before the measurement start). It can therefore be assumed that in practice the difference between petrol cold start and LPG cold start on CO and HC emissions will be even bigger.

7 References

[1] Burgwal, H.C. van de, Gense, N.L.J., Rijkeboer, R.C. and Binkhorst, R.P.; *"In-use compliance programme passenger cars - Annual report 2001"*, TNO-Automotive, Delft, October 2002
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[2] Burgwal, H.C. van de, Gense, N.L.J., Rijkeboer, R.C. and Binkhorst, R.P.; *"In-use compliance programme passenger cars - Annual report 2002"*, TNO-Automotive, Delft, July 2003
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[3] Gense, N.L.J., Wilmink, I.R. en van de Burgwal, H.C.: "*Emissions and congestion – Estimation of emissions on road sections and the Dutch motorway network - Executive summary*".
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