4 MEASUREMENT OF EXHAUST EMISSIONS AND EMISSION REGULATIONS

4.1 General

The first exhaust emission regulations emerged in the 1960s in California and some other areas with a severe pollution problem. National exhaust emission limits for the US were first set in 1968. For Europe, emission regulations were introduced in 1970. Today, most countries have emission legislation in place /87/.

Basically the emissions from motor vehicles are regulated in two ways. Firstly, limit values are set on gaseous pollutants and particulates/smoke, and also on evaporative hydrocarbon emissions. Secondly, some fuel parameters, which are clearly related to exhaust emissions, exhaust toxicity or the performance of exhaust gas aftertreatment devices, are regulated. Such parameters include /14/:

- benzene
- total aromatics
- polyaromatics
- olefins
- lead
- sulphur

The tailpipe components, which normally are regulated, are:

- carbon monoxide (CO)
- total hydrocarbons or non-methane hydrocarbons (THC or NMHC)
- nitrogen oxides (sum of nitrogen oxide and dioxide, NO_x)
- particulates (PM)

In the US, the legislation differentiates between methane and non-methane hydrocarbons in the exhaust. Methane has low photochemical reactivity and low toxicity, and is therefore not regulated.

In Europe, new light-duty vehicle emission regulations for 2000 and 2005 were adopted in 1998 /5/. The new Directive for light-duty vehicles regulates total hydrocarbons, which is a disadvantage for natural gas engines, especially lean-burn engines. The European Natural Gas Vehicle Association (ENGVA) has worked hard to change this situation /90/.

In late 1999, an agreement on future European heavy-duty emission regulations was reached /91/. The new regulations contain limit values for 2000, 2005 and 2008. Gas engines are recognised as a separate category, and, contrary to the light-duty regulations, a split in total/non-methane hydrocarbons has been made /92/.

An emission test procedure consists of the following elements:

- requirements for the ambient conditions
- a defined speed/load pattern for the vehicle/engine
- reference fuel
- measuring apparatus
- gaseous component concentrations
- particulate mass emission or smoke density
- exhaust gas flow
- calibration gases
- calculation procedures

For each type of fuel, the appropriate reference fuel and also the correct calculation formulas have to be chosen.

For Europe, already in 1995 proposals to amend natural gas and LPG engines in the heavy-duty emission regulations were discussed /93,94/. These proposals contained modified formulas for calculating the emissions and also specifications for the reference fuels. In the case of natural gas it was proposed that the methane content of the reference fuel should be 97.5 – 99.9 mole-% /94/.

The new heavy-duty regulations now contain both calculation formulae and reference fuels for gas engines. Three natural gas qualities have been defined:

- G_{20}, high calorific gas (H-range) with a methane content of 99…100 %
- G_{25}, low calorific gas (L-range) with a methane content of 84…88 %
- G_{23}, intermediate gas (low H-range/high L-range) with a methane content of 91.5-93.5 %

Some debate is still going on regarding the natural gas reference fuel issue. ENGVA is developing a new position paper to allow greater flexibility in the certification fuels to also cover so-called outlying gases. Engines, which have a closed-loop fuel system automatically, at least to some extent, compensate for variations in fuel quality.

For LPG, two qualities have been defined:

- A with a propane content of 48…52 %
- B with a propane content of 83…87 %

4.2 Light-duty vehicles

4.2.1 Test methods

Emission testing of light-duty vehicles is carried out with a complete vehicle on a chassis dynamometer. Figure 4.1 shows a schematic representation of a measurement set-up for light-duty vehicles.

The same kind of measuring equipment can be used to measure emissions according to US, European and Japanese regulations. Exhaust dilution and exhaust volume flow determination is done with a CVS (Constant Volume Sampling) system.

There are, however, considerable differences in both driving cycles and emission limit values. Figure 4.2 shows the US EPA FTP75 driving cycle, a highly transient cycle. The FTP75 cycle still forms the basis for US emission testing. In addition, there are some Supplemental Federal Test Procedures (SFTP). The US06 cycle represents aggressive and microtransient driving, whereas the SC03 cycle simulates driving with air conditioning on in warm conditions. There is also a separate test to measure CO emissions in cold conditions (-7 ^{o}C), and a highway driving cycle to measure fuel consumption and NO_x emissions (HWFET) /86,87/.

The European driving cycle (Figure 4.3) is more of an artificial one, with one part simulating urban driving (maximum speed 50 km/h) and one part simulating extra urban driving (maximum speed 120 km/h).

Until now, the European test has included a 40 second idle period without exhaust sampling at the beginning of the test. From the year 2000 onwards, sampling will be started simultaneously as the engine. This means that the test will become more stringent.

Beginning 2002, a low temperature emission test will be introduced also for Europe. The test temperature will be the same as for the US (-7 ^{o}C), but for Europe limit values will be set on both CO and HC /5/.

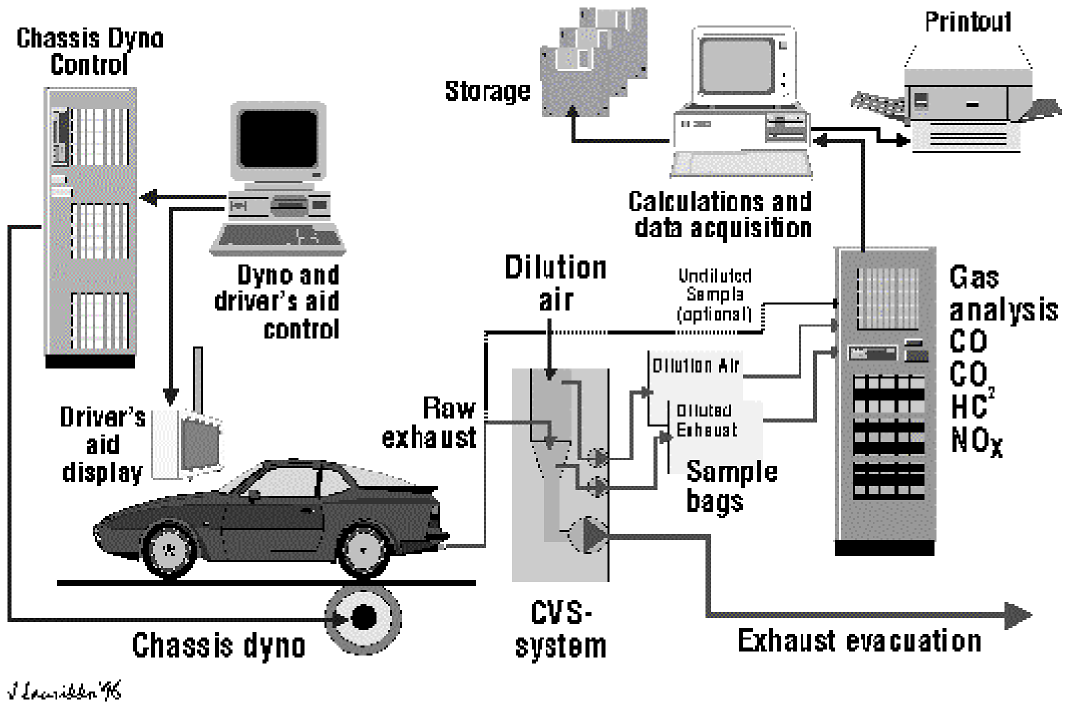

Figure 4.1. *Schematic representation of a measurement set-up for light-duty gasoline vehicles /4/.*

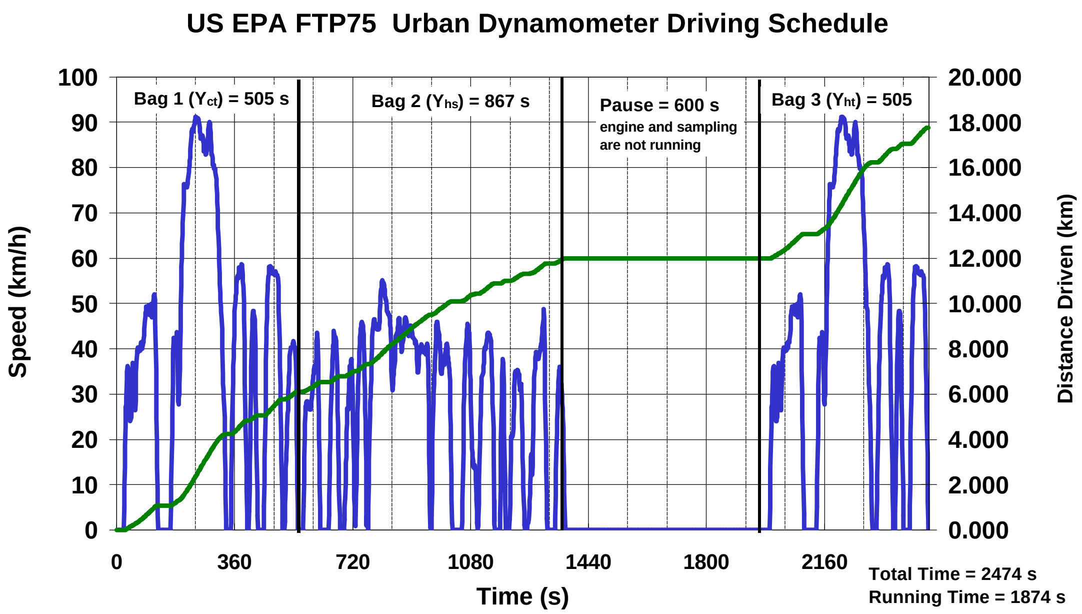

Figure 4.2. *The US EPA FTP75 test cycle for light-duty vehicles /86/.*

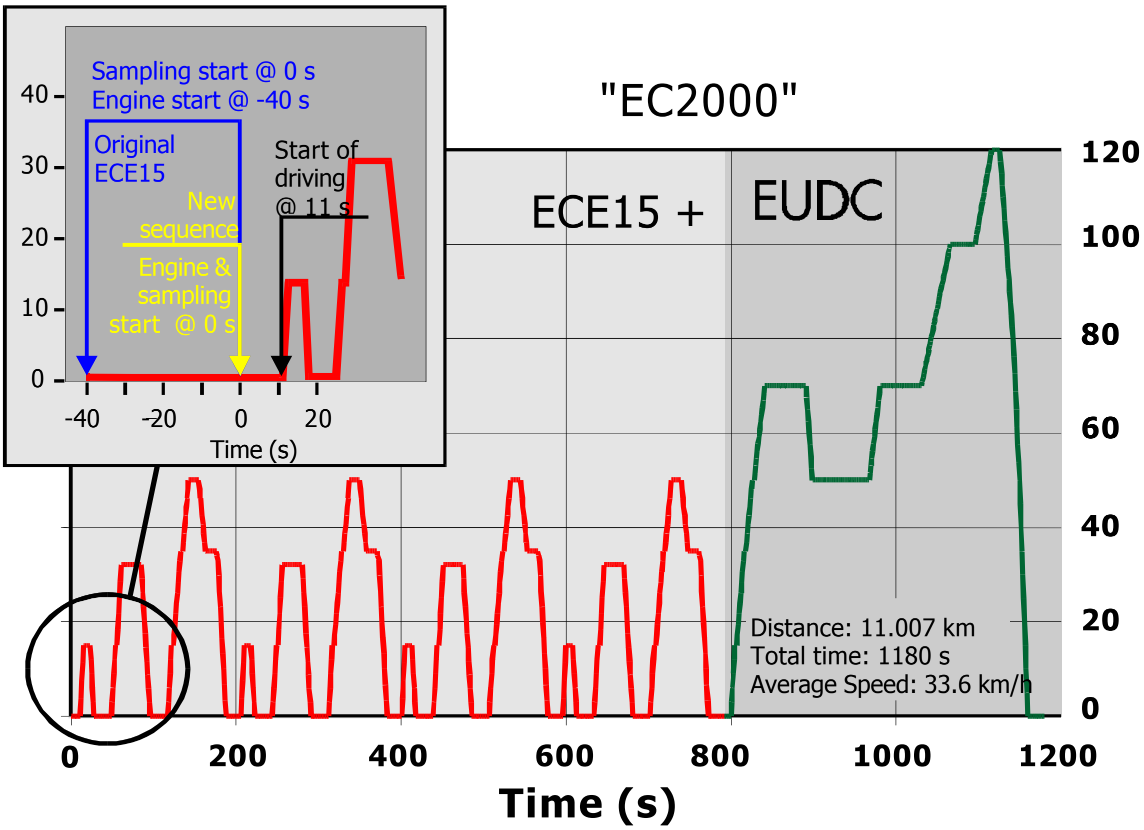

Figure 4.3. The European driving cycle for light-duty vehicles /5/.

4.2.2 US emission legislation

The emission legislation for US is rather complicated. There are Federal Regulations and State Regulations, and in addition different programs for low-emission vehicles and alternative fuels. New Federal Tier II emission regulations will phased in 2004-2009. Table 4.1 presents the current and future US Federal emissions regulations for light-duty vehicles and also the Californian standards for light-duty vehicles /87/. The regulations involve progressive introduction of different vehicle classes:

- TLEV= transitional low-emission vehicles
- LEV= low emission vehicles
- ULEV= ultra-low emission vehicles
- ZEV= zero emission vehicles

In addition, consideration is being given to creating two new classes. One is EZEV, which stands for equivalent zero emission vehicle. According to one proposal, it can mean a hybrid vehicle, which has emissions per unit energy equivalent to an electric generating plant.

The other, SULEV for super ultra-low emission vehicle is also currently under discussion as part of the Californian LEV II program. Some light-duty vehicles have already been certified for the SULEV category on a voluntary basis. /95/. Medium-duty vehicles in California can already be certified to a SULEV category.

Originally it was planned that the ZEV category share of new car sales in California should be 2 % in 1998, this figure progressively rising to 10 % in 2003. This requirement, however, has been relaxed, and the obligation to begin selling ZEVs has been moved to 2003 /87/.

Table 4.1. Current and future US Federal emissions regulations and Californian standards for light-duty vehicles /87,95/.

Category	CO (g/mile)	NMHC/NMOG [1)] (g/mile)	NO_x (g/mile)	Formaldehyde [2)] (g/mile)	Particulates [3)] (g/mile)
Tier I gasoline	3.4 (4.2) [4)]	0.25 (0.31)	0.4 (0.6)	--- (---)	--- (---)
Tier I diesel	---- (4.2)	--- (0.31)	--- (1.0)	--- (---)	--- (0.08)
TLEV	3.4 (4.2)	0.125 (0.156)	0.4 (0.6)	0.015 (0.018)	--- (0.08)
LEV	3.4 (4.2)	0.075 (0.090)	0.2 (0.3)	0.015 (0.018)	--- (0.08)
ULEV	1.7 (2.1)	0.04 (0.055)	0.2 (0.3)	0.008 (0.011)	--- (0.04)
ZEV	0.0	0.0	0.0	0.0	0.0
EZEV [5)]	0.17	0.004	0.02	----	0.004
SULEV [5)]	1.0	0.01	0.02	?	?

1) NMOG= reactivity corrected values for alternative fuelled vehicles
2) methanol and flexible-fuel vehicles only
3) diesels only
4) limits for 50.000 miles with 100.000 miles in parentheses
5) under discussion

The NLEV program

In 1996, 100% of all light and medium duty vehicles had to meet Tier 1 emission standards. In 1997, the Ozone Transport Assessment Group (OTAG) petitioned EPA to adopt the more stringent California LEV standards in the OTAG States known as the North East Trading Region (NTR), comprising 11 States. These States adopted the California LEV emissions control program under Section 177 of the Clean Air Act. This led EPA to introduce the optional National Low Emissions Vehicle program (NLEV), which is intended to harmonize EPA and California LEV standards.

23 automobile manufacturers opted into the voluntary NLEV program, and EPA declared the NLEV program to be in effect in March 1998. 45 States also opted in, forming what is known as the All States Trading Region (ASTR). New York, Massachusetts, Vermont and Maine did not opt into the NLEV program. New York and Massachusetts currently have Section 177 programs in place; Vermont will follow in 2000, and Maine in 2001.

In 1999 the Clean Fuel Fleet (CFF) program was initiated to reduce emissions in covered areas designated as being in non-attainment of either ambient ozone or CO standards.

Covered fleets of public or private fleets of more than 10 vehicles that are centrally fuelled 100% of the time and are operated in the covered areas, are required to purchase 30% of cars and light trucks in 1999 which are federally certified Clean Fuel Vehicles (CFVs) under the Clean Fuel Fleet standards. This increases to 50% in 2000 and 70% in 2001. 50% of heavy-duty trucks must also meet the CFF standards throughout this period. Clean fuels include alternative fuels, but also reformulated gasoline and California Phase II gasoline.

A number of metropolitan areas have adopted the Clean Fuel Fleet program, including Atlanta, Chicago, Denver, and Washington DC, for example. The NLEV program does not change anything in the Federal Clean Fuel Fleet regulations. In most cases, CFF vehicles will also meet NLEV requirements.

However, not all NLEV vehicles will meet CFF requirements. In 1999, therefore, alternative fuel companies certifying new vehicles could obtain the following types of emissions certificates from EPA:

- Federal (Tier 1)
- California only (Tier 1, TLEV, LEV, ULEV)
- NLEV Restricted Certificate, which allows sales in California, the NTR, and contiguous States, as defined in EPA's Cross Border Sales Policy (TLEV, LEV, ULEV)
- NLEV Unrestricted Certificate, which allows sales in the ASTR (TLEV, LEV, ULEV)
- NLEV and Clean Fuel Fleet Certificate which covers the full set of NLEV requirements and the CFF program requirements. (LEV, ULEV)

The NLEV program has a requirement for manufacturers to meet fleet average NMOG standards equivalent to LEV levels. California has a similar requirement to phase in progressively tighter fleet average NMOG standards which will bring into the market place increasing numbers of LEV and ULEV certified vehicles. As of 2000, small volume manufacturers must meet fleet average NMOG requirements equivalent to LEV standards. This covers all of the alternative fuel companies. The NLEV standards are really the precursor to the Tier II standards which will be phased in 2004, and apply nationally at the 100% level in 2009.

Emissions Durability Requirements

EPA assigns emissions standards on the basis of years or miles in service. These are known as intermediate and full useful life standards. The standards for full useful life are less stringent than those for intermediate useful life, in recognition of the emissions deterioration, which occurs in the emission control system with mileage accumulation. For example, the intermediate useful life standards are 50,000 miles for cars and light/medium duty trucks, and the full useful life standards are 100,000 miles for cars, and 120,000 miles for light/medium duty trucks.

Compliance with both intermediate and full useful life standards is determined by applying the appropriate emissions deterioration factor (DF) to the emissions test results, with the vehicle having sufficient mileage accumulated to stabilise the "green" catalyst's efficiency (usually 4000 miles or 125 hrs for an engine test). This results in projected useful life emissions, which must meet the standards. Vehicle to vehicle test variability must also be taken into account to determine the standard deviation in the test results.

The 4,000 miles emissions targets are therefore set to be two standard deviations below the maximum permissible target based on application of the DF. DFs therefore become critical to the determination of the final useful life emissions values, but determining actual DFs through vehicle durability testing can be very costly and time consuming.

In 1995, EPA published a list of assigned emissions DFs for gaseous fuelled vehicles and engines, which may be used by small volume manufacturers. However, the EPA assigned DFs are conservatively large, which, of course, results in a higher useful life emission value. The large OEMs establish their own DFs through vehicle durability testing, or use of bench aged catalysts, and usually have relatively small DFs compared to the EPA assigned DFs. The alternative fuel useful life emissions results are therefore disadvantaged in this respect, which can affect comparative emissions assessment between conventional and alternative fuels.

Bi-fuel vehicles which operate on gaseous fuels or gasoline, must be tested on both fuels to obtain emissions certificates. EPA assigned DFs are normally used for the gaseous fuel, but it is permitted to carry across the OEM gasoline DFs to calculate useful life gasoline emissions. Evaporative emissions must be tested with the vehicle operating on the gaseous fuel to demonstrate that the carbon canister is purged sufficiently to provide the head room necessary to pass the shed test for both 3 day and 2 day diurnal tests. It should be recognised that the purge strategy developed to operate the vehicle on the gaseous fuel results in gasoline vapour being combusted along with the gaseous fuel, which affects the emissions results. Vehicle calibration takes this into account, since the vehicle must pass an FTP test starting with a fully loaded canister, immediately before the vehicle is rolled into the shed.

Aftermarket conversions

After-market CNG and LPG conversions have traditionally been carried out under EPA Mobile Source Enforcement Memorandum 1A, issued in 1974. This provides guidance on how the Agency intends to enforce the "tampering" prohibition under Section 203 of the Clean Air Act, with respect to use of aftermarket parts. Memo 1A provides that alterations to the vehicle will not constitute tampering if the dealer has a "reasonable basis" to believe that such acts will not adversely affect emissions performance when operated on the fuel for which the vehicle was originally designed. It also provides options under which the converter would have "reasonable basis" to believe he is in compliance.

As of MY 2000, these options have been severely curtailed. Reasonable basis for certification of aftermarket conversions is now limited to obtaining a full EPA certificate, as described above, or certifying a 50 state engine family under California retrofit procedures for 1994 and subsequent model years. The disadvantage of the California aftermarket certification approach is that use of assigned DFs are not permitted. After an Executive Order has been issued, the manufacturer has two years to demonstrate durability of his system for the useful life of the vehicle.

The certification issues described above, together with the OBD II issues described in 3.6 have severely curtailed aftermarket alternative fuel conversions in North America.

4.2.3 European emission legislation

In the autumn of 1998, both fuel specifications and light-duty vehicle emission regulations for the European Community for the years 2000 and 2005 were set in the form of a new Directive (some fuel parameters for the year 2005 were left open) /5,14/. Table 4.2 gives the emission limit values for Europe.

Because of the big differences in the driving cycles, it is difficult to compare US and European limit values. The FTP tests lights off the catalyst more rapidly than the low-load European ECE15 cycle. Some comparisons though have been made. The Tier I limits correspond roughly to the Euro 2 limit values. The Californian LEV and ULEV regulations are clearly aimed at reducing hydrocarbon emissions. Thus the hydrocarbon limits are stricter than for the Euro 3 regulations, whereas the NO_x limits are at roughly the same level. The hydrocarbon limit of Euro 4 corresponds roughly to the hydrocarbon limit of LEV, but the NO_x limit is stricter for Euro 4 /5,87/.

Table 4.2. Current and future light-duty emission regulations for Europe /5,87/.

Pollutant	Limits (g/km) 1996 -> Euro 2 [1)]	Limits (g/km) 2000 -> Euro 3 [2)]	Limits (g/km) 2005 -> Euro 4 [2)]
Gasoline			
CO	2.2	2.3	1.0
THC	-	0.2	0.1
THC + NO_x	0.5	-	-
NO_x	-	0.15	0.08
Diesel			
CO	1.0	0.64	0.5
THC + NO_x	0.7/0.9 [3)]	0.56	0.3
NO_x	-	0.5	0.25
Particulates	0.08/0.10 [3)]	0.05	0.025

[1)] test starts with 40 second idling without exhaust sampling
[2)] engine and exhaust sampling started simultaneously
[3)] IDI/DI diesel

In the European regulations no provision is made for a THC/NMHC split, an issue that ENGVA is actively working on.

4.3 Heavy-duty vehicles/engines

4.3.1 Test methods

The emission certification for heavy-duty applications is done by running engines in engine dynamometers, not with complete vehicles. The rationale for this is that a certain engine can be used for a number of different vehicle applications. However, the interest to carry out dynamic emission testing with complete vehicles either on a chassis dynamometer or on the road is increasing.

Transient type testing of heavy-duty engines has been used in the US since 1985. Figure 4.4 shows the US HD Transient Cycle for heavy-duty engines. It features rapid load changes and also periods of motoring, i.e. simulated engine braking of the vehicle.

Transient engine testing requires expensive apparatus. The engine dynamometer has to have motoring capability and a very sophisticated control system to handle the rapid load changes. Dilution is used for exhaust sampling. The emission measurement system corresponds in principle with the CVS system shown in Figure 4.1 (two-stage dilution and particulate sampling added).

In Europe and Japan, steady-state type testing has been used for emission certification of heavy-duty engines. The situation for Europe will change, as transient testing will be introduced beginning with the new Euro 3 requirements.

4.3.2 US emission legislation

Table 4.3 lists current and future Federal regulations for heavy-duty engines. The 2004 values are still under discussion. The current Californian regulations are equivalent to the Federal regulations with the exception that California has separate THC and NMHC limits. California has also introduced LEV, ULEV and SULEV classes for medium-duty trucks. The SULEV category has been introduced at the request of the natural gas industry /87/.

Although the US HD Transient Cycle is rather complicated and covers numerous load points, it is possible using modern engine electronics to carry out cycle beating or cheating. This means, that the engine can detect an emission tests, and use a different control strategy in the test than on the road. On the road, a strategy optimising fuel economy is used. Several major diesel engine manufacturers were recently caught for this kind of cheating, and were obliged to pay huge fines.

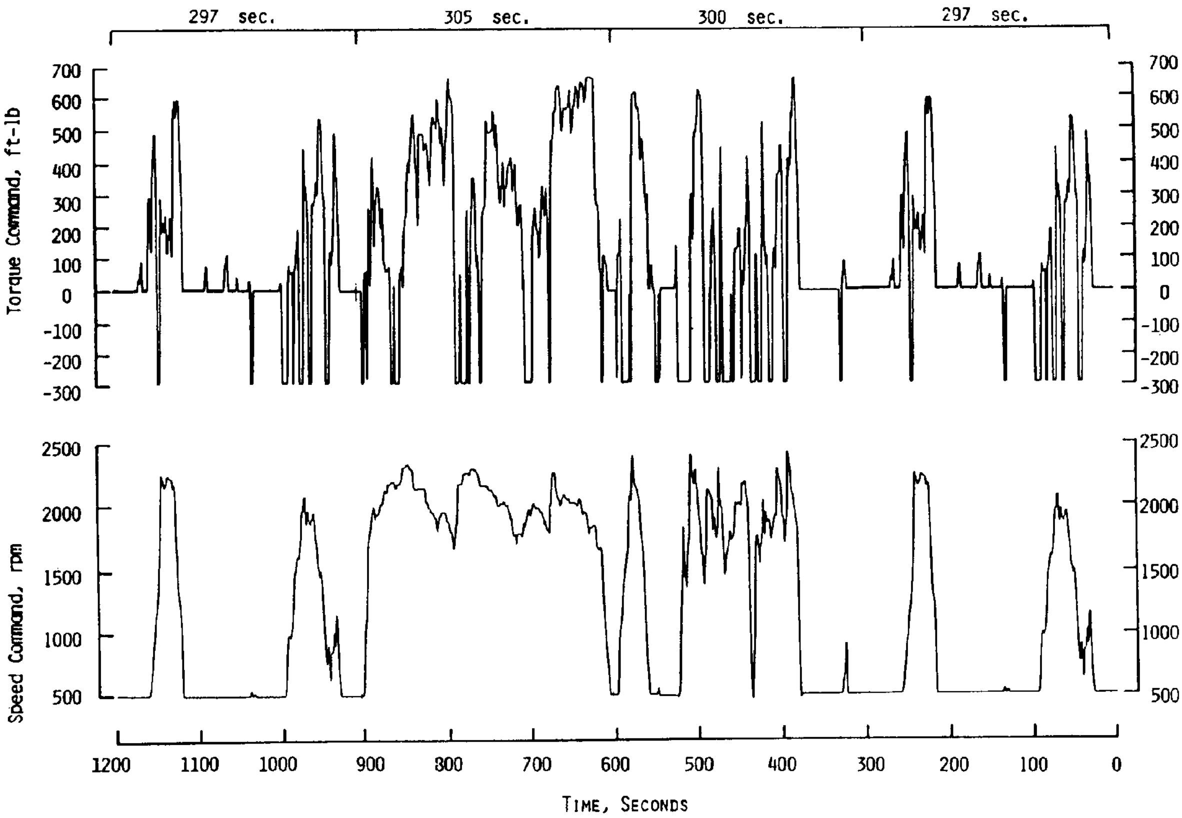

Figure 4.4. The US HD Transient Cycle for heavy-duty engines /96/.

Table 4.3. US Federal HD emission regulations /96,97/.

Effective date	Vehicle type	CO (g/hph)	HC (g/hph)	NMHC + NO_x (g/hph)	NO_x (g/hph)	Particulates (g/hph)
1998 ->	Diesel	15.5	1.3	-	4.0	0.1
	Urban bus	15.5	1.3	-	4.0	0.05
2004 -> (proposal)	Diesel	15.5	-	2.4 or 2.5	-	0.1
	Urban bus	15.5	-	2.4 or 2.5 $^{*)}$	-	0.05

$^{*)}$ NMHC limit 0.5 g/kWh

4.3.3 European emission legislation

Europe has been slow in introducing transient engine testing. The current European test for heavy-duty engines is a steady-state 13-mode test. Sampling of the gaseous components is made from undiluted exhaust, and partial sampling can be used for measuring particulates. Thus the apparatus is simpler than for transient testing.

Now new regulations for Europe have been agreed upon (see 4.1) /91,92/. Three new tests will be introduced for Europe:

- European Steady Cycle (ESC)
- European Load Response Test (ELR)
- European Transient Cycle (ETC)

The ESC test resembles the current 13-mode (ECE R49) test. For the ESC, however, the measurements are done at three engine speeds plus idle. The weighting factors are also different, and the certification staff may freely choose three additional load points to measure. These "free points" have to give "not to exceed" measurement results. Figure 4.5 shows the measuring points and the weighting factors of the ESC test /92/.

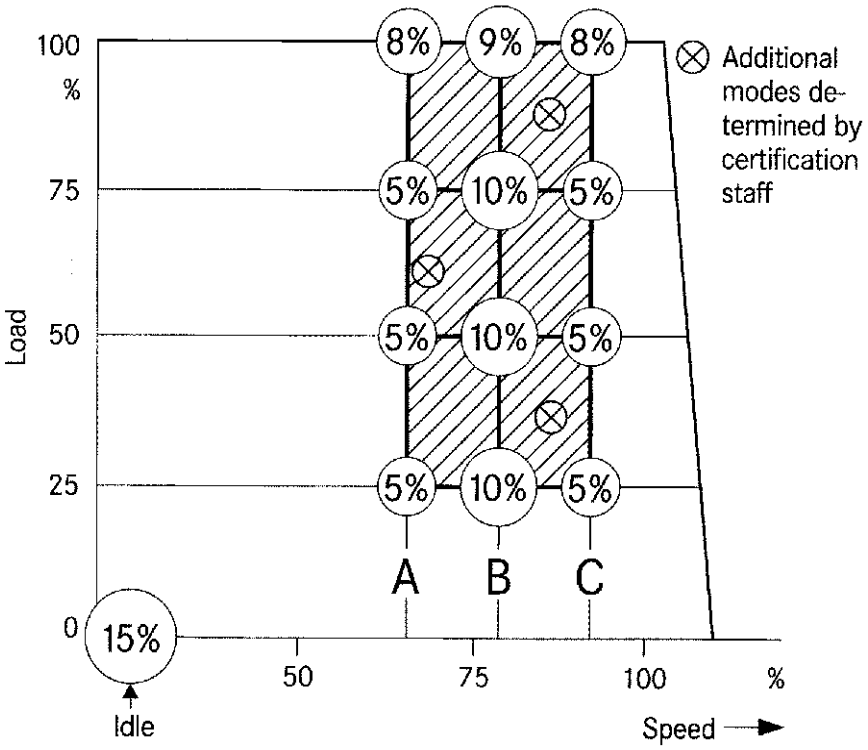

Figure 4.5. Measuring points and the weighting factors of the ESC test /92/.

The relation between ECE R49 and ESC test results for a conventional diesel engine is roughly as follows /98/:

CO: ESC result = 0.75 * ECE R49 result
HC: ESC result = 0.85 * ECE R49 result
NO_x: ESC result = 1.03 * ECE R49 result
Part.: ESC result = 0.90 * ECE R49 result

The ELR test is an acceleration smoke opacity test corresponding to the current ECE R24 test.

The ETC test is a transient test similar to the US HD Transient Test, although the cycle itself is different. Figure 4.6 shows the load pattern of the ETC test.

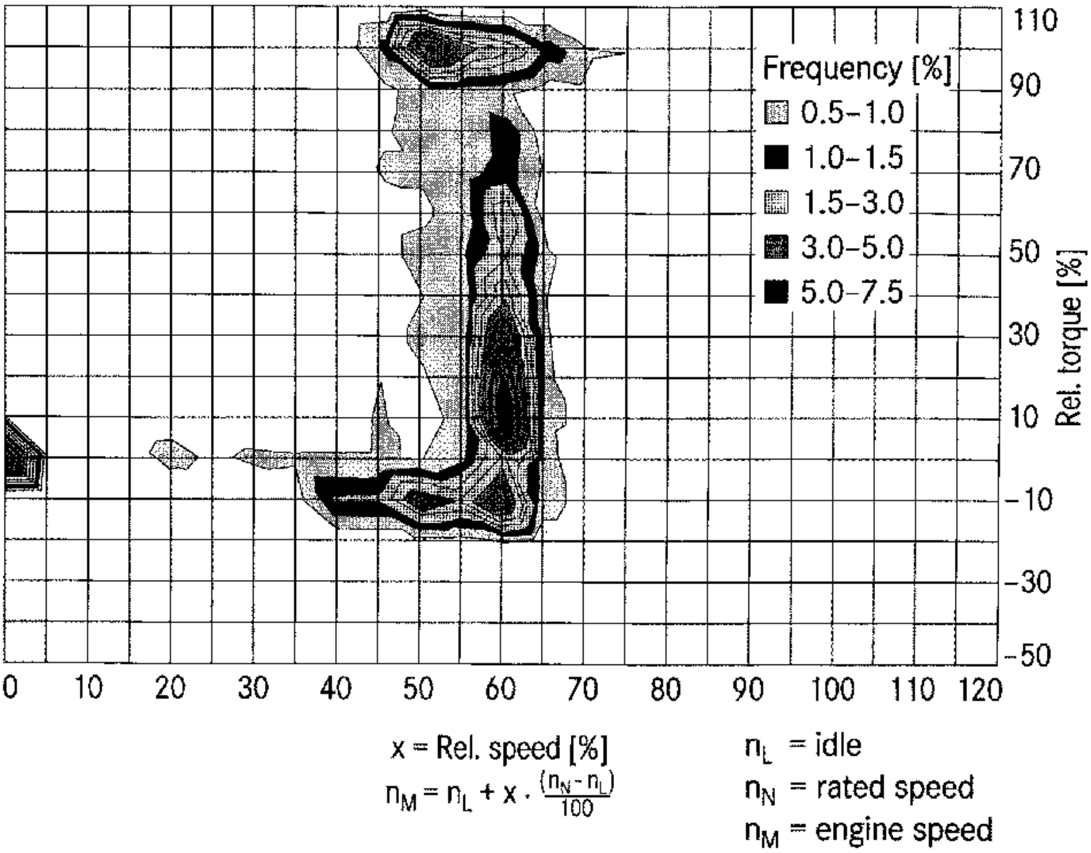

Figure 4.6. The load pattern of the ETC test /99/.

Correlation factors between the ETC and the ESC cycles have also been developed /99/:

CO: ETC result = 2.7 * ESC result
HC: ETC result = 1.3 * ESC result
NO_x: ETC result = 1.02 * ESC result
Part.: ETC result = 1.6 * ESC result

This means that for conventional diesel engines NO_x comparisons are easy to make independent of the cycle (ECE R49, ESC, ETC, see Table 4.4).

It should be noted that in the new European regulation applicable between 2000 and 2004, i.e. Euro 3, different engines will be tested using different procedures. Conventional diesel engines will be subjected to the ESC and ELR tests. Natural gas and LPG engines and also diesel engines with exhaust gas aftertreatment will be tested according to the ETC test. Starting with Euro 4 in 2005, all diesel engines will have to be tested on both the ESC/ELR and ETC cycles.

Table 4.4 lists the new European emission limit values /92/. A special low-emission vehicle class (Environmentally Enhanced Vehicle = EEV) is defined. The idea is that tax incentives can be granted for vehicles complying with these requirements

Table 4.4. Current and future European heavy-duty emission limit values /91,94/.

	CO (g/kWh)	THC (g/kWh)	NMHC (g/kWh)	NO_x (g/kWh)	Part. (g/kWh)	Smoke (m^{-1})
ECE R49/ Euro 2	4.0	1.1	-	7.0	0.15	-
ESC/ELR						
A (2000)	2.1	0.66	-	5.0	0.10	0.8
B1 (2005)	1.5	0.46	-	3.5	0.02	0.5
B2 (2008)	1.5	0.46	-	2.0	0.02	0.5
C (EEV)	1.5	0.25	-	2.0	0.02	0.15
ETC						
A (2000)	5.45	1.6 *)	0.78	5.0	0.16	-
B1 (2005)	4.0	1.1 *)	0.55	3.5	0.03	-
B2 (2008)	4.0	1.1 *)	0.55	2.0	0.03	-
C (EEV)	3.0	0.65 *)	0.40	2.0	0.02	-

*) CH_4 for natural gas engine only

The requirement of dynamic testing will have a major impact on European heavy-duty gas engine technology. The new regulation sets both THC and NMHC limits for natural gas engines.

Diesel engines without exhaust gas aftertreatment will be able to meet the A-level (Euro 3) requirements. The B1-level (Euro 4) would most probably require a particulate trap, and B2- (Euro 5) and EEV-levels also a De-NO_x system. Thus it looks like gas engines, which easily can comply with Euro 4/5 and EEV emission levels, will become more competitive over time compared to diesel engines, provided that the dynamics of the engine management system is sufficient.

4.4 Unregulated emissions

Exhaust gases from motor vehicles contain a high number of different chemical compounds. Only a part of these are accounted for when the emissions regulated by legislation are measured.

Normally the concentration of hydrocarbons is measured with a FID (flame ionisation detector) instrument, which gives the total mass of hydrocarbons. Included in the group of hydrocarbons are both less harmful compounds like methane, ethane and propane as well as very harmful components like benzene and polyaromatic hydrocarbons. Therefore, especially when evaluating health effects and reactivity of exhaust, speciation of the hydrocarbons is needed.

The CLD (chemiluminescent detector) instrument used for measuring nitrogen oxides measures only nitrogen oxide and –dioxide, and does not react to other nitrogen containing compounds like nitrous oxide (laughing gas) and ammonia.

The regulated measurement of total particulate mass does not give any information on chemical composition of the particulate matter nor particulate size distribution. The health effects of ultra-fine particulates have been much discussed lately. New instrumentation to measure on-line particulate size distribution has been developed.

The first “unregulated” exhaust compound to become regulated is formaldehyde from methanol fuelled vehicles according to the US regulations. Special instrumentation is also needed to separate total hydrocarbons and methane/non-methane hydrocarbons.

Many of the unregulated emission components are considered harmful to human health. The US Environmental Protection Agency EPA already long ago listed the most important air toxics /100/:

- benzene
- 1,3-butadiene
- formaldehyde
- acetaldehyde
- polycyclic organic matter associated with particulates

In order to do a full characterisation of the exhaust one has to check both the gaseous, semivolatile and particulate phase. Heavy polyaromatic hydrocarbons can be found in both the semivolatile and the particulate phase.

Table 4.5 lists some of the methods to characterise exhaust gases from vehicles. Figure 4.7 shows a high volume flow sampling device to collect particulate and semivolatile samples from gasoline vehicle exhaust /101/.

Table 4.5. Methods to characterise exhaust gases.

Component	Measurement technology
Light hydrocarbons (C_1-C_{12})	Speciation of hydrocarbons by gas chromatography (GC) from diluted exhaust gas.
Polyaromatic hydrocarbons	Collection of particulates on filter papers or semivolatile phase on adsorbent, analysis with gas chromatography coupled with mass spectrometry (GC/MS) or High Performance Liquid Chromatography (HPLC) after extraction and purification steps.
Aldehydes and ketones	Collection with di-nitrophenylhydrazine (DNPH) cartridges (or liquid), analysis with HPLC. Also possible to analyse from the exhaust gas with a Fourier Transformation Infra-Red Instrument (FTIR)
Methanol, ethanol	Collection by water absorption method, analysis with GC.
Nitrous oxide	Analysis by GC or FTIR from exhaust gas.
Ammonium	Collection by water absorption method, analysis with photometry. Also possible to analyse from exhaust gas by FTIR.
Sulphates and other anions of particulates	Analysis by ion chromatography or capillary electrophoresis after extraction step.
Mutagenicity of soluble organic fraction of particulates	Ames-test after extraction and purification steps.
Metals of particulates	Several technics available, e.g. Particle Induced X-ray Emission (PIXE)
Particle size distribution	Several technics available e.g. low pressure impactor, Scanning Mobility Particle Sizer (SMPS), Electrical Low Pressure Impactor (ELPI)

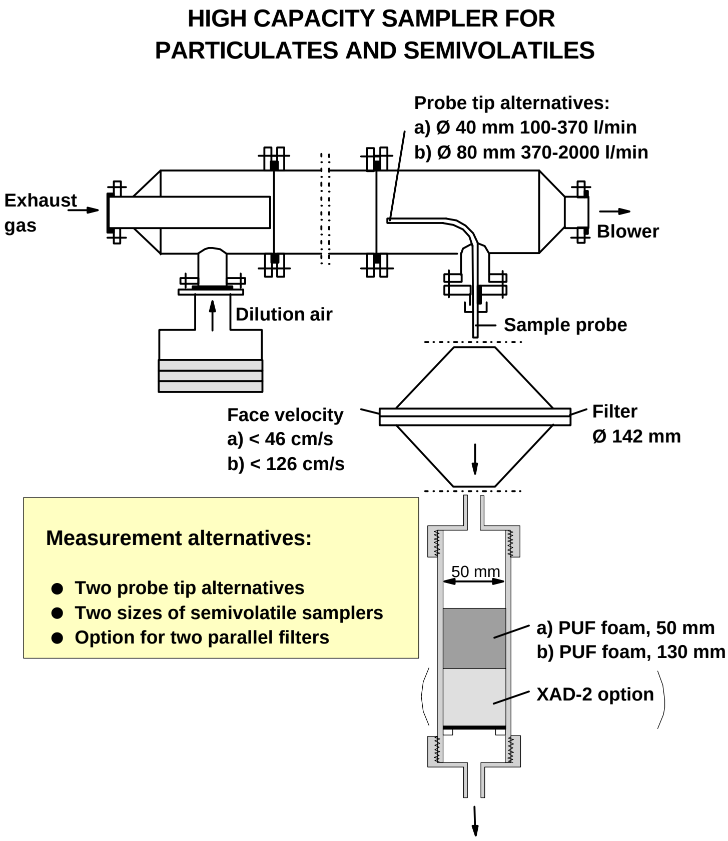

Figure 4.7. *A high volume flow sampling device to collect particulate and semivolatile samples /101/.*