Traffic, Transportation and Environment
Emission Legislation and Test System Requirements

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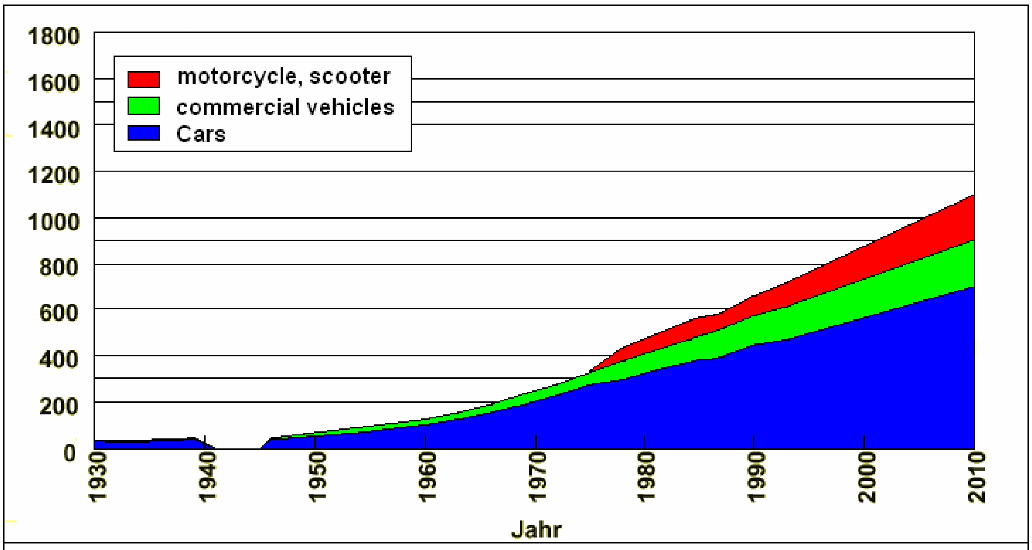
INTRODUCTION

In recent years, global pollution concerns have increased and the motor vehicle contribution has been found to be increasingly important. Around the world the focus is on problems such as toxic emissions, global warming and in use emissions performance. Over the course of the past five decades the vehicle population around the world has exploded as well as the local, regional and global environmental problems caused by it. In recent years, global pollution concerns have increased and the motor vehicle contribution has been found to be increasingly important. Around the world the focus is on problems such as toxic emissions, global warming and in use emissions performance.

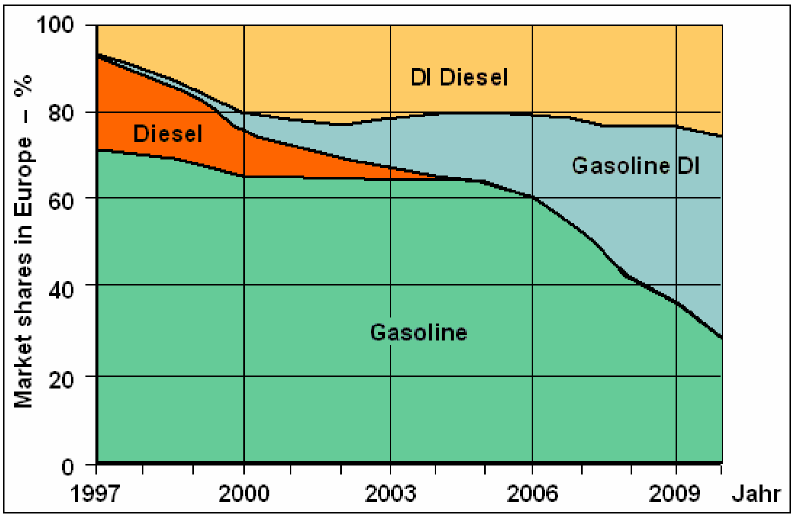
TRAFIC

About 800 million vehicles are currently on world's roads, almost 500 million of which are cars and the remainder commercial trucks and buses or motorcycles and scooters. Registrations are sharply upward. The United States, Japan, and Europe account for most of the ownership but the future growth is expected to be most rapid in Asia and Latin America where most of the world's 6 billion people already reside.



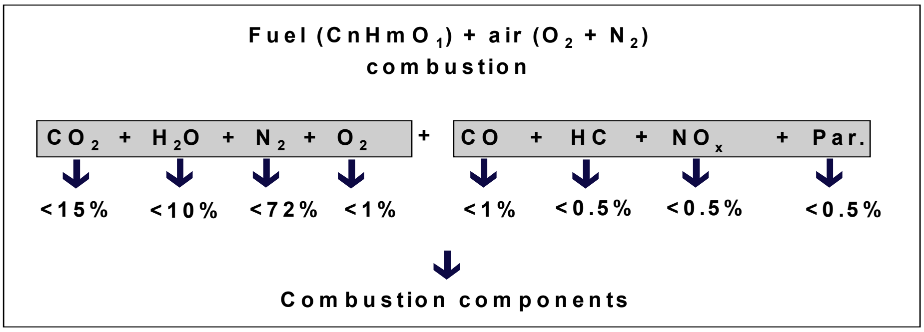
Number of Vehicles in Millions, world wide

Also engine technology and the distribution and market share of different engine types has and will change over the years. In the figure below the expected trend of the market share between diesel and gasoline engines and the type of injection systems is presented for the next decade in Europe. In the 90's the diesel engine has increased its market share because of the better fuel economy compared to the gasoline engine and the continuos improvement of its performance and driveability, especially of the direct injection (DI) engines. For the next years it is expected that also the direct injected gasoline engine will replace most of the conventional gasoline engines.



EMISSION

Exhaust makes up a part of any vehicle emissions. It is created when fuel and air are burned in the engine and is emitted during vehicle operation. Exhaust emissions are generally greater when the engine is started cold and are quickly reduced as the engine warms up. Which is especially true for all exhaust aftertreatment systems. The most closely regulated emissions are hydrocarbons (HC), carbon monoxide (CO), oxides of nitrogen (NOx), and particulate matter (PM).



Evaporates make up the other part of vehicle emissions. The evaporates are generally fuel vapours and are a function of temperature: the higher the temperature, the more emissions are produced. Evaporates emissions are produced when the vehicle is operating, parked, and during refuelling. Other emissions can be produced additionally from fluids, tyres, paint, plastic components and adhesives.

HISTORY of
POLLUTION, VEHICLE and REGULATORY DEVELOPMENT

Ancient time
It is an old problem. Already the ancient civilizations, like Babylonia, India, Greece and Rome, complained about pollution from dust, wood smoke and animal manure.

1306 Edward I. (England) forbids coal burning when English Parliament is in session

That was the first known emission legislation

1661 "Fumifugium" by John Evelyn first study of London's air pollution problem

1775 English scientist Percival Pott finds that coal is causing cancer among chimney sweeps.

1848 USA: Public Health Act is passed, smoke abatement becomes a political responsibility of the health department.

1850 – 1960 Killer smogs:

- 1873 London, England 1.150 people die caused by killer smogs
- 1909 Glasgow, Scotland winter inversion, over 1.000 people die. In a report about the incident, the term "smog" was coined as a contraction for Smoke and fog
- 1930 Meuse River Valley, Belgium, 3-day inversion, 63 people die, 6.000 ill
- 1939 St. Louis, USA "St. Louis smog episode"
- 1948 Donora, Pennsylvania, USA 20 dead, 600 hospitalized
- 1948 London, England 600 dead
- 1950 Poza Rica, Mexico 22 dead, hundreds hospitalized
- 1952 London, England 3.000 - 4.000 people die
- 1953 New York, USA, 170 - 260 people die in November
- 1954 Los Angeles, USA Industry and schools shut for most of October
- 1956 London, England, 1000 dead
- 1962 London, England, 750 people die
- 1965 New York City, USA, weather inversion, four day air pollution 80 people die

1960's

During the 1960's, important steps were taken to begin the reduction in automotive emissions. During this time, vehicle emissions were under minimal control. The main technology steps in vehicle developments have been

- Positive Crankcase Ventilation valve introduced
- Controlled combustion system introduced

In the US the air pollution in large cities, mainly in California, has triggered to increase the amount of research programs, to establish regulatory demands and government departments to regulate pollution’s from traffic.

- CARB (California Air Resources Board) created
- Clean Air Act introduced in U.S. and U.S. EPA (Environmental Protection Agency) established

1970's

Building on what began during the 60's, new technology and new fuels were the focus during the 70's. Air pollution from vehicles decreased.

Vehicle Developments

- Catalytic converter introduced nationwide in U.S.
- Open Loop Control systems introduced
- Electronic engine emissions controls introduced
- Evaporative emissions controls introduced
- Exhaust Gas Recirculation (EGR) introduced

Regulatory Developments

- Emissions control regulations introduced in Europe
- 10-mode test introduced in Japan

Fuel Developments

- Unleaded gasoline introduced

1980‘s

The 80's saw widespread acceptance of emissions technology and the implementation of initiatives begun during the 70's. Further developments in cleaner fuels and control systems continued to push total vehicle emissions down.

Vehicle Developments

- Three-Way Catalytic converters introduced
- Catalytic converter applications became standard equipment
- Closed loop emissions control systems introduced
- All-altitude emissions controls introduced
- Electronic engine emissions controls improved

Regulatory Developments

- 10/15-mode test introduced in Japan

Fuel Developments

- Low-sulfur diesel fuel introduced
- Fuel vapor recovery systems at pumps introduced

1990's

The 1990's has been the decade of emissions-reduction technology. With commercial acceptance of alternative fuels, the development of zero-emission vehicles and the realization of a systems approach to further reduce of all pollutants

Vehicle Developments

- Systems approach introduced for improving air quality
- Alternative fuel vehicles introduced into commerce
- Zero emissions (electric) vehicles introduced into commerce
- Fuel cell development increased
- Intelligent Transportation Systems (ITS) introduced
- Enhanced evaporative emissions control systems introduced
- On-board vapor recovery systems introduced
- CO_2 emissions limited voluntarily

Regulatory Developments

- Cold carbon monoxide (CO) test requirements introduced
- Kyoto Conference conducted. Kyoto Protocol adopted by US and 121 other nations (but not ratified by US and Japan). American industry predicts "disaster" if CO_2 reductions are enforced even while scientific evidence shows CO_2 buildup.
- Extra Urban Driving Cycle (EUDC) introduced in Europe
- Off-Road engine test requirements introduced

Fuel Developments

- Worldwide Fuel Charter developed

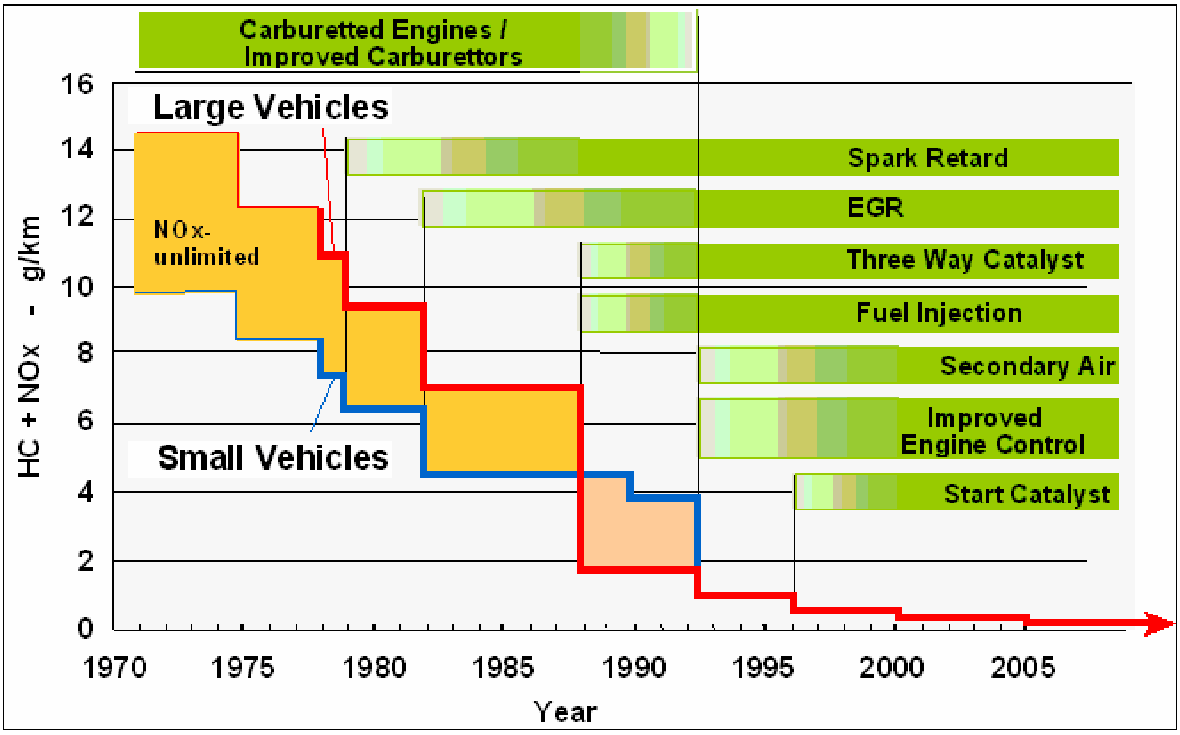
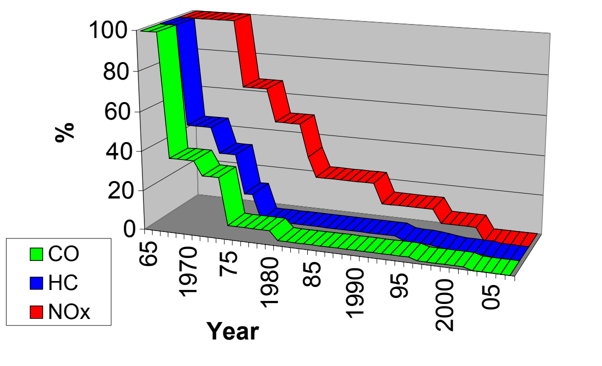


Figure of the link between engine development and emission regulations.

EMISSION REGULATIONS

Over the past thirty years, countries around the world have gradually imposed increasingly stringent emissions regulations. These emissions regulations on the motor vehicle industry has the result, that new cars today emit only a small fraction per mile driven of what they did when the process began.

US Emission Limits Light Duty Vehicles	European Emission Limits Light Duty Vehicles



Emission Limits for Gasoline Fueled Vehicles

	EU 2 (1996) [g/km]	EU 3 (2000) [g/km]	EU 4 (2005) [g/km]
CO	2,2	2,3	1,0
HC + NO_x	0,5	/	/
HC	/	0,2	0,1
NO_x	/	0,15	0,08

Emission Limits for Diesel Vehicles

CO	1,0	0,64	0,5
HC + NOx	0,7 / 0,9	0,56	0,3
NOx	/	0,50	0,25
PM	0,08 / 0,10	0,05	0,025

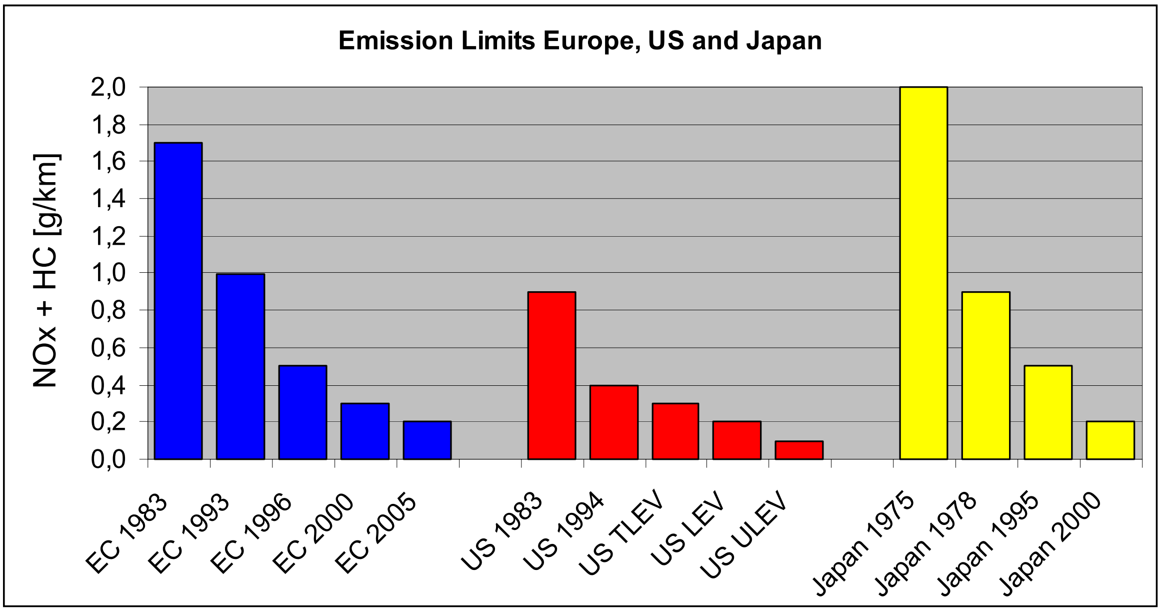
Development of light duty vehicle emission limits in the US and Europe

Stufe	Year	Particulate		NOx	HC		CO		Opacity
		g/kWh		g/kWh	g/kWh		g/kWh		m-1
		ESC	ETC		ESC	ETC	ESC	ETC	ELR
EURO 1		0,36		8,0	1,10		4,5		
EURO 2	1996	0,15		7,0	1,10		4,0		
EURO 3	2000	0,10	0,16	5,0	0,66	0,78	2,1	5,4	0,8
EURO 4	2005	0,02	0,03	3,5	0,46	0,55	1,5	4,0	0,5
EURO 5	2008	0,02	0,03	2,0	0,25		1,5		0,15

Development of heavy duty engine emission limits in Europe

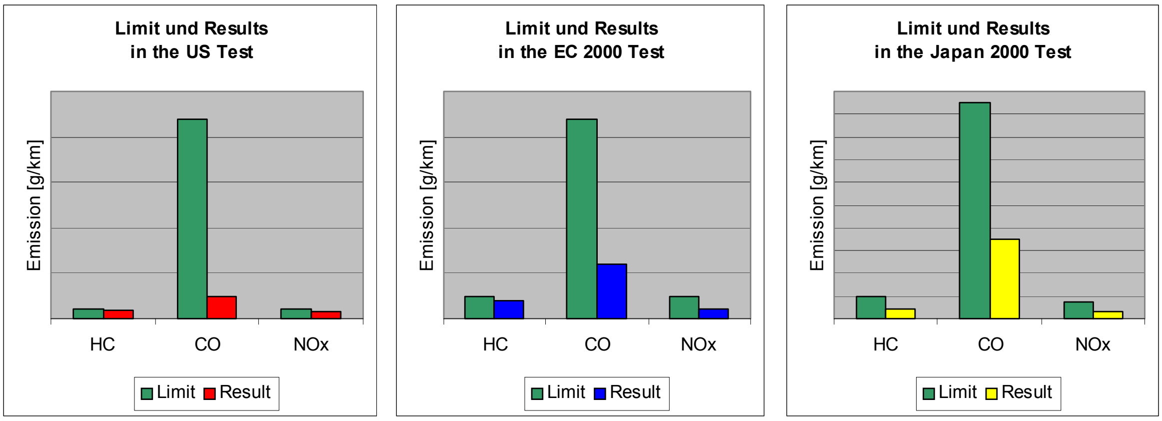
OUTLOOK for an WORLD HARMONIZED TEST CYCLE

World wide there are currently different emission test procedures and regulations in use for light duty vehicles, heavy duty and off road engines. The main regulations are originated from the three regions US, Europe and Japan. The figure below shows the reduction for HC and NOx emissions for light duty vehicles in these three regions. However it must be considered that each of the three regulations define also different driving cycles, which effect the test result. Each driving cycle is expected to simulate the actual driving behavior of the region.



Even though the amount of vehicle emissions has steadily declined, it might be possible that more could be done with common regulatory requirements. Common test procedures and diagnostic requirements could greatly reduce the development and certification test burden and provide greater product availability for all consumers, as all three regions would move to adopt lower emissions limits. First test indicate that a modern vehicle in the same set up can pass all three regulations. The graphs below show the regulatory limits of all the US, European and Japanese emission regulation and the result of the same low emission vehicle tested in all three procedures.

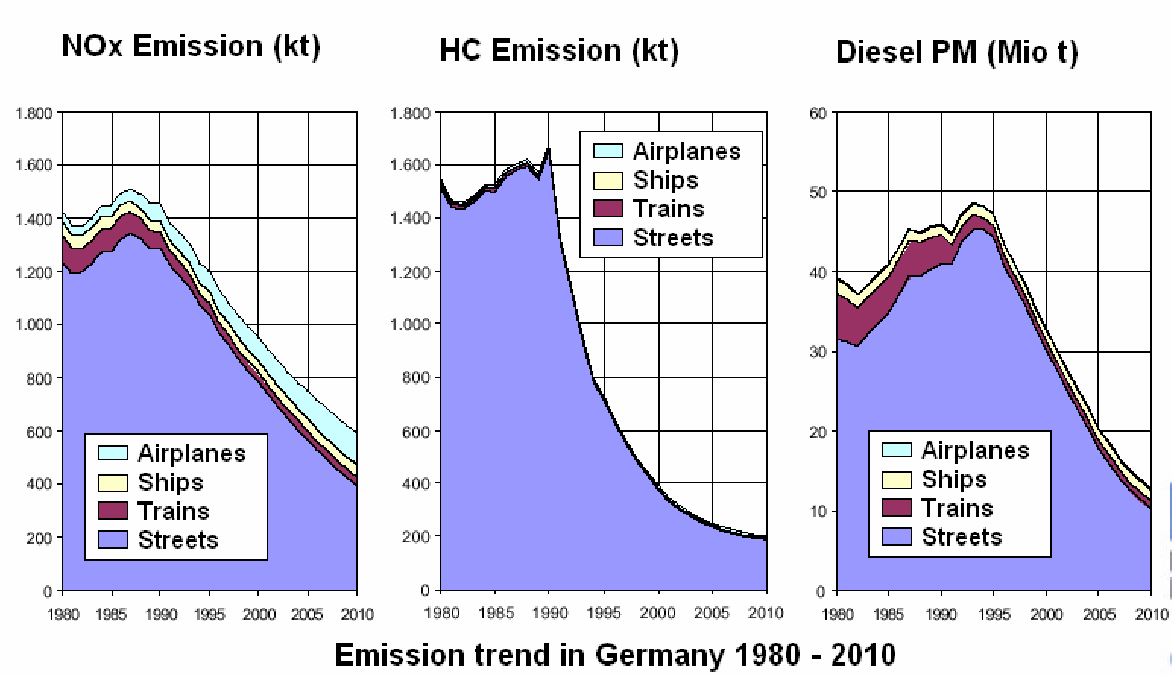
The vehicle was a 1998 model year vehicle with California LEV engine calibration, equipped with a 3.0 L displacement engine with automatic transmission, California Phase 2 Fuel, and 80.000 km aged catalyst.



The graphs show, that it is possible to compare the ratio of the actual result to the limit of the individual test of all three regulations. By that it seems realistic that a world harmonized test procedure could serve the needs of all individual countries. The limits itself and the time schedule to implement such limits could still be different for a single country or a region. There might be some disadvantages of such an approach, when compared to a local regulation. For example the driving cycle does not match exactly the local driving behavior. But that is already true within a region itself. The overall result and especially the global environment benefice should be greater for a world harmonized cycle.
The change for a realization is currently best for off road engines, based on the ISO 8178 test procedure . For heavy duty engine certifications some work is done to establish such an world harmonized test cycle (WHTC). At moment, the most optimistic date for the implementation could be 2008. Also it seems realistic that the US might implement the test cycle, but that the test procedure itself will be different. Also in a most optimistic view, I can currently not see a realization for light duty vehicles. However the main test laboratory layout and requirements for light duty vehicles are nearly the same for all regulations, while only the driving cycle itself and the calculations are different.

EMISSION REGULATIONS and AIR POLLUTION LEVELS

The main question for any limitation of air pollution is the following. Does it only lower the emitted emission of each single engine, or does it improve the total air quality - since in the same time, when the emission limits have been reduced, the number of vehicles has increased and also engines, manufactured accordingly to old limits, are still in use. However overall air pollution levels have improved strongly in most industrialized countries. The figures below show the effect of emission regulations in Europe on the example of the total emitted mass of NOx, HC and diesel particulates in Germany from 1980 up to now and give a trend for the next decade.



Further, the clean vehicle technologies and fuels originally developed for the US, Europe or Japan in response to their standards are increasingly finding there way onto the roads of all countries around the world, as well with the result that some air quality improvements also are occurring there. World wide about 80% of all gasoline to be sold this year will be unleaded and almost 90% of all newly produced cars will contain a catalytic converter.

EMISSION TEST SYSTEMS and PROCEDURES

Emission legislation is an important guideline in development of new engines as well as in development of measurement concepts for emission systems. Emission measurement systems needed for certification are described in detail in several regulations. The main system layout has been established in the early 70's. For example, the CVS (Constant Volume Sampler) systems have been used since 1972 without major changes in the specifications. The principles of measurement devices are still the same, although some improvements and many refinements have taken place. This means that the limits - and therefore the values which have to be measured - have changed dramatically, whereas the procedures and system layout for emission measurement are still the same. Also the test or driving cycles in all new regulations has or will be extended by additional test procedures, such as highway and aggressive driving and air conditioning effects as well as exhaust emissions after cold start at low temperatures.

System Layout and System Modularity

One important factor for a modern emission system is the modularity of the system layout. The large variety of engine applications and test procedures will quickly guide to the design of modules instead of whole systems. These modules can be combined to result in the proper system for a certain application or can serve several applications, with a minimum of additional options. However the key factor is, that a system build out of modules is not a collection of independent modules, but a holistic system which is based on well integrated sub modules. There are several user benefits of a system, which is based on such standard modules. A true modular system can only be realized, when the modularity is accomplished by the hardware as well as by a modular and open software concept.

Classification of Test Requirements

The selection of the system layout and the type of instrumentation depends on the type of engine, its application, the test procedure and the region of use. The requirements and specifications will be different, based of the kind of work done. A certification laboratory must fulfill all regulatory requirements in detail and might only produce a single final result, while for research and development much more data, like online mass emission calculations, will be requested.

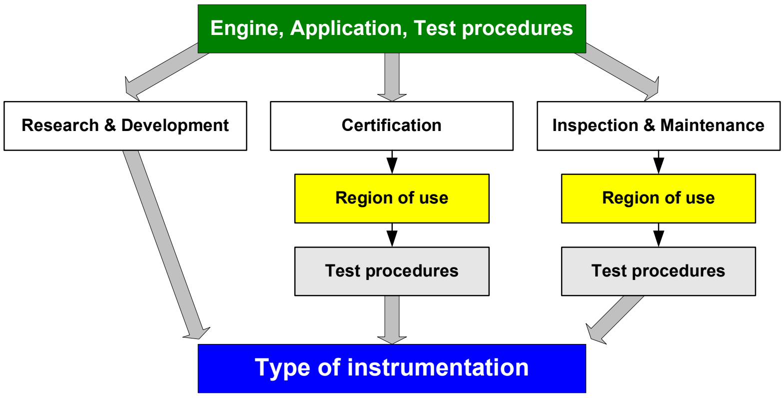


Figure: Chart for test work requirements

Classification of Test Procedures and Test Systems (for Certification)

The classification of an emission laboratory can be done in several ways.

1. The user requirement view will group it by the engine application (light duty, heavy duty or off road).
2. For the test bed layout it is more logical to group it by the object to be tested. An engine used in a light duty vehicle (motor cycle, 3 wheelers, passenger cars and light duty trucks) will be tested together with the vehicle. The same engine used in different vehicles will be tested in each of the vehicles separately. The test cycle is a driving pattern, which defines for each time during the test a velocity of the vehicle. In order to test a whole vehicle and to simulate its behavior on the street a chassis dynamometer is required. The final result is given in mass emitted per distance (g/km). For heavy duty and off road engines only the engine itself is tested, which requires an engine test bed. The final result is given as specific mass emitted per time (g/kWh). The engine is tested at certain engine speed and torque conditions. These setting might change frequently (each second) in a transient test or will be changed stepwise (each step will be kept for minutes) at a steady state test.
3. For the emission measurement system layout the main grouping can be done best by transient or steady state test requirements.

The figure below can serve as a flow chart for the selection of the correct test procedure and test equipment. It shows the requirements for light, medium and heavy duty engine application and the most common off road applications. It focuses on the core test requirements.

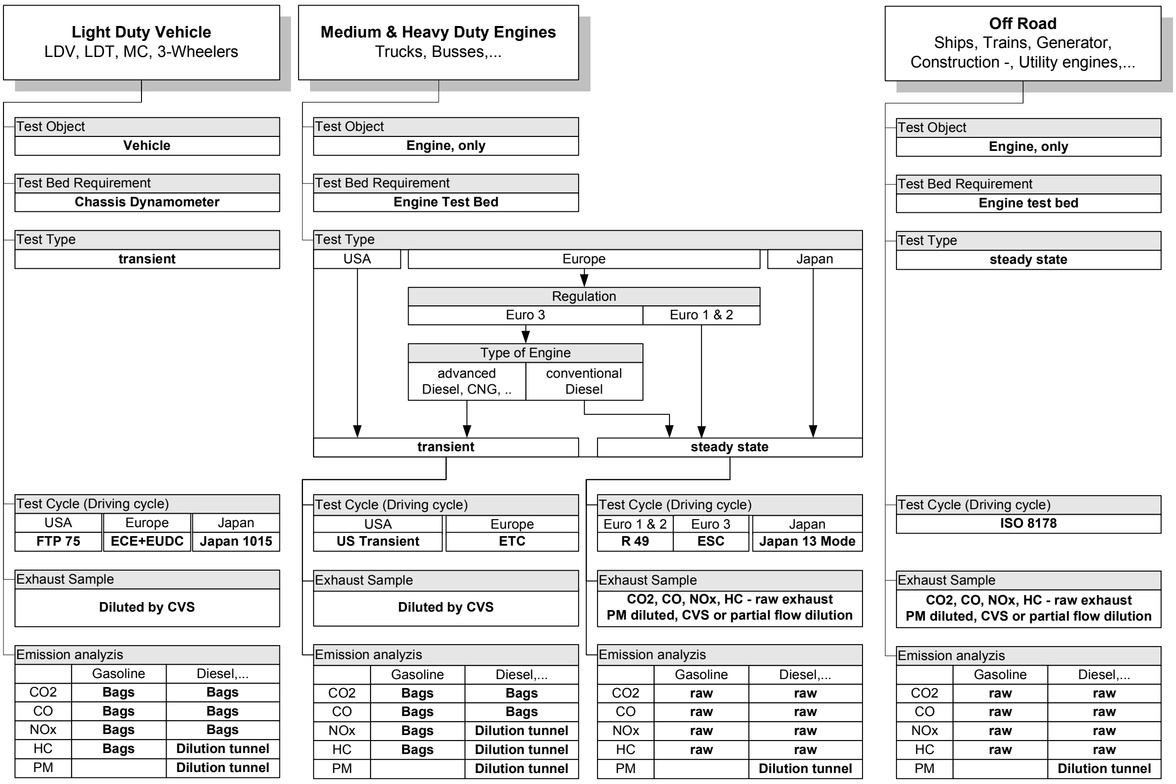


Figure: Selection chart for certification test applications

Emission Laboratory Layout for Light Duty Vehicles

The vehicle follows on a chassis dynamometer a driving cycle. The total exhaust emitted by the vehicle is diluted with clean ambient air by the CVS system (Constant Volume Sampler). A small fraction of the total CVS flow (dilution air and exhaust) is sampled into a Bag. At the same time the dilution air is sampled into a second Bag, in order to evaluate the background concentration, which is not caused by the vehicle itself. The Bags perform a mechanical average over the test. After the test the Bags are analyzed. An emission bench measures the concentrations of CO_2, CO, NO_x and HC in the Bags. For most tests the test itself is separated into different phases, for each phase a separate pair of Bags is filled and analyzed. For diesel engine vehicles the dilution of exhaust with air is done in a dilution tunnel. By that the diesel particulate formation shall be simulated in a more realistic way. From the dilution tunnel the particulates are collected on filters, and after the test the particulate mass can be evaluated. Also the HC measurement is done by a heated FID (Flame ionization detector) continuously from the dilution tunnel and not from the Bags.

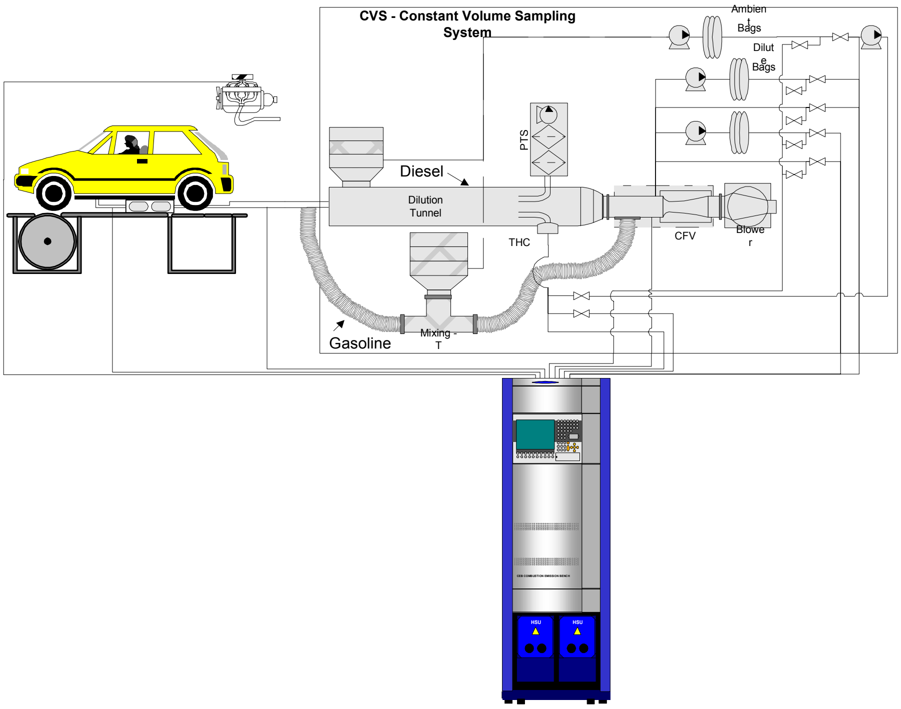


Figure: Emission Laboratory Layout for passenger cars

The laboratory layout for motor cycle testing is very similar compared to testing of passenger cars. 2 stroke engines with pre mixed fuel emit high concentrations of HC. Therefor a lube oil separator (cyclon separator) shall be used on the CVS as well as a separate set of sample bags. Also the CVS is not connected directly to the tail pipe, but a funnel will be used instead.

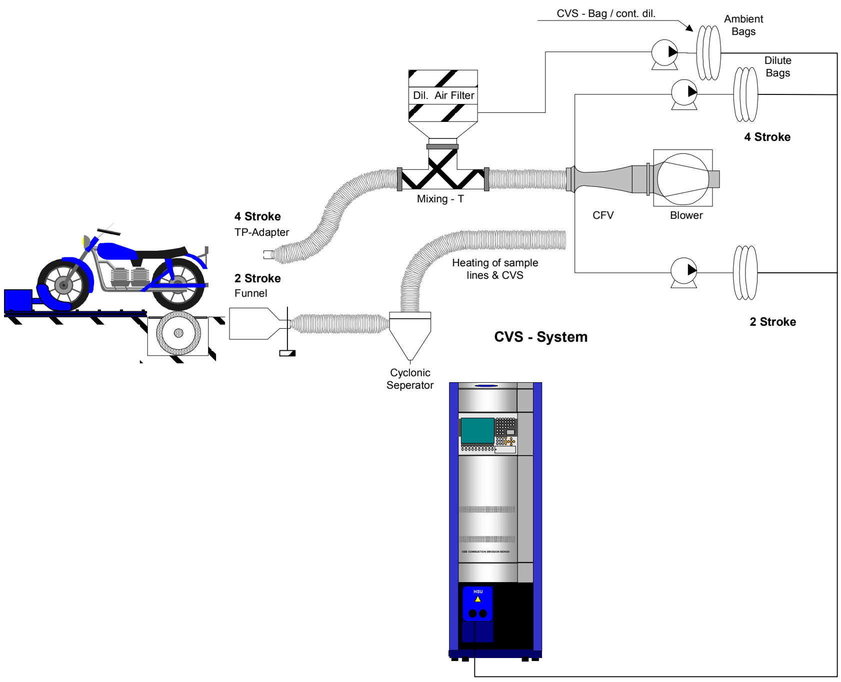


Figure: Emission Laboratory Layout for Motor Cycles (4 and 2 Stoke Engines)

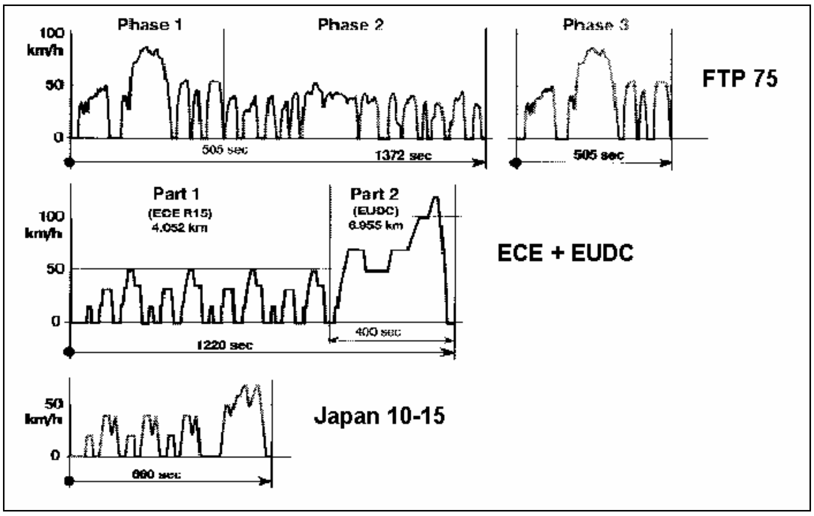


Figure: Driving Cycles for Light Duty Vehicles for USA, Europe and Japan

Emission Laboratory Layout for Heavy Duty and Off Road Engines

The engine is operated on an engine test bed. Certain speed and torque conditions operated.

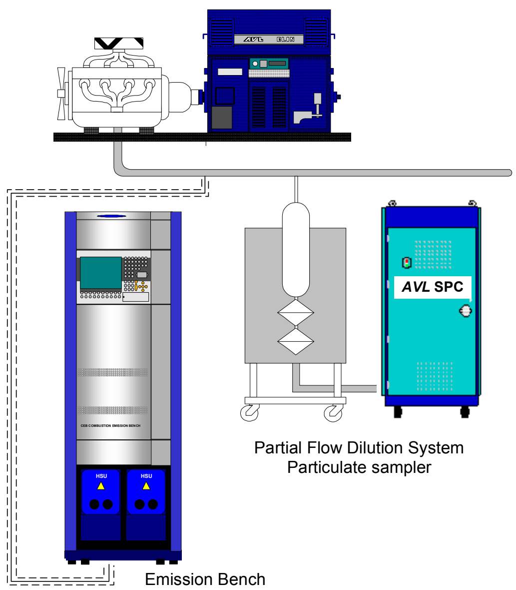
Steady State Tests

A fraction of the exhaust emitted by the vehicle is sampled by an emission bench. The bench will measure the concentrations of CO2, CO, NOx and HC of the raw exhaust. For diesel engines also a partial flow dilution tunnel will sample a small fraction of exhaust. This sample will be diluted with clean ambient air. The diluted exhaust will flow through particulate filters. In addition the intake air and fuel consumption of the engine is measured. With these data, the particulate mass collected on filters and the concentrations measured by the bench the final result can be calculated in mass per hour (g/h) and specific mass per hour (g/kW h).

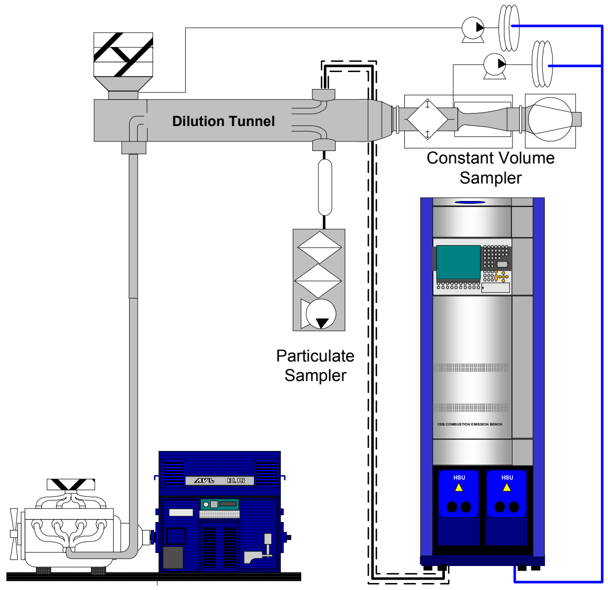
Transient Tests

The total exhaust emitted by the engine is diluted with clean ambient air by the CVS system (Constant Volume Sampler). A small fraction of the total CVS flow (dilution air and exhaust) is sampled into a Bag. At the same time the dilution air is sampled into a second Bag, in order to evaluate the background concentration, which is not caused by the engine itself. The Bags perform a mechanical average over the test. After the test the Bags are analyzed. An emission bench measures the concentrations of CO2, CO; NOx and HC in the Bags. For diesel engines the dilution of exhaust with air is done in a dilution tunnel. By that the diesel particulate formation shall be simulated in a more realistic way. From the dilution tunnel the particulates are collected on filters, and after the test the particulate mass can be evaluated. Also the HC and NOx measurement is done by a heated HC and NOx measurement continuously from the dilution tunnel and not from the Bags.

Heavy Duty Engine Emission System Layout



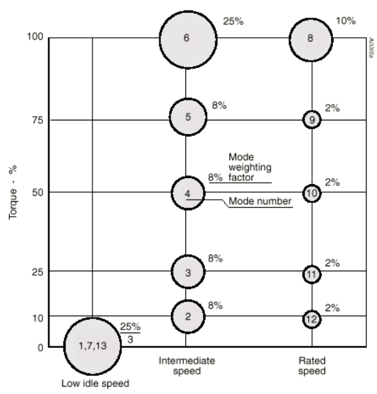
Steady State System Layout



Transient Test System Layout

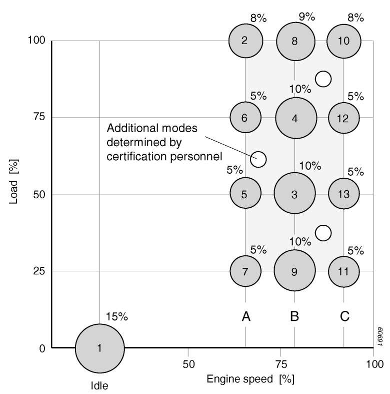
Steady State Engine Test Procedures

13 Mode Test (Euro 2)



Heavy Duty Euro 2

ESC (Euro 3)



Heavy Duty Euro 3

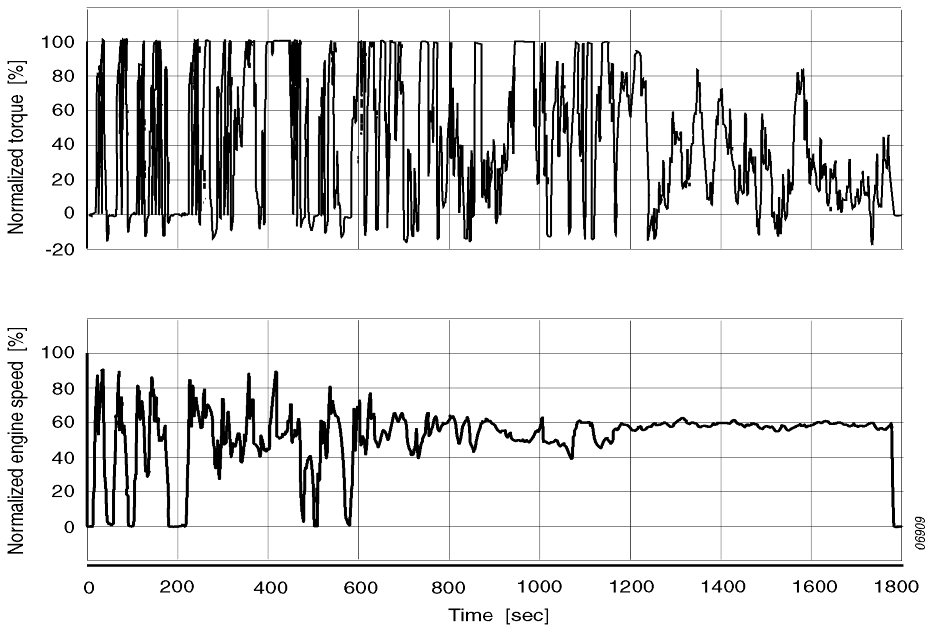
ISO 8178

The ISO 8178 standard has been designed for various non-road engine applications. It is actually a collection of many steady-state test cycles (type C1, C2, D1, etc.). Each of these cycles represents a sequence of several steady-state modes with different weighting factors. The particular engine modes and their weighting factors depend on the application.

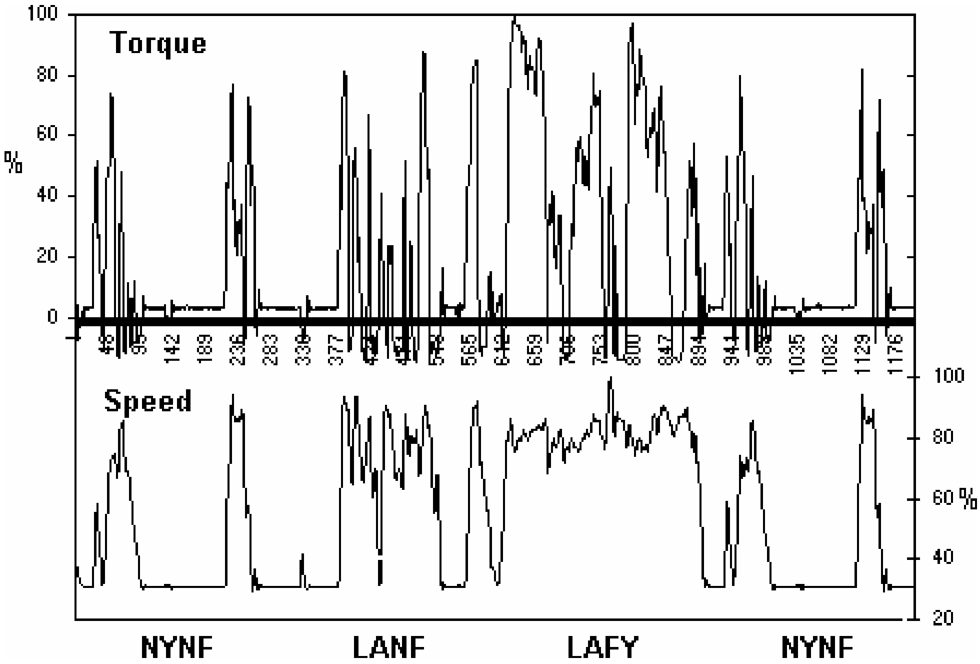
When an engine is tested once at all defined modes, which is a maximum of 11 modes, it is possible to calculate all results for the different applications by the single mode results of this test.

Off Road

Transient Heavy Duty Engine Test Procedures



European Transient Cycle (ETC)



USA Federal Test Procedure (FTP)

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