AVL EMISSION TESTING HANDBOOK – 2016

AVL Emission Test Systems

GLOSSARY

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PUBLICATION INFORMATION

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1. INTRODUCTION

AVL is pleased to offer you this Emission Testing Handbook and we hope you will find it helpful.

The purpose of this handbook is to give a first overview of different emission test and measurement methods that are commonly used in engine, powertrain and vehicle development. While for R&D work all technically possible methods can be used, only certain methods are accepted for engine or vehicle type approval tests.

Every emission legislation consists of two main parts. The first part deals with the maximum emission limits. Several sources are available to provide information on these limits, such as the online AVL Emission Report, or the "Worldwide Emission Standards Booklets" from Delphi. The second part explains how the engine or vehicle is tested and how emissions are measured. This AVL Emission Testing Handbook focuses on the second part of emission legislation, namely how emissions are tested and measured. Even though a handbook cannot entirely replace familiarization with legislation and regulations, we hope to provide a structured overview for a better understanding. We sometimes use general terms and explanations to give a better overview and to highlight differences within the regulations. Please note that sometimes general terms are used that are not related to specific emission legislation, where the same word may be used with a slightly different meaning.

Please feel free to use the information provided for presentations, documents, or testbed configurations. However, we kindly ask you to provide a reference to the "AVL Emission Testing Handbook" within it.

An electronic version of this booklet is available at: *www.avl.com/emission-testing-handbook*

For comments and notes please email to: *emission-testing-handbook@avl.com*

2. STANDARDS AND TECHNICAL REGULATIONS

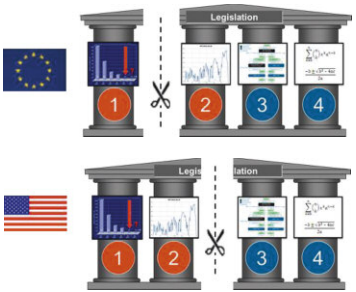
Emission standards are built on 4 main pillars:

1. Emission limits that define the maximum tailpipe emissions allowed.
2. Test cycle that defines how an engine or vehicle is operated for the emission test.
3. Test procedures that describe how to perform the tests and specifications for the test- and measurement systems
4. Equations describing how to calculate the final result.

1 and **2** are important for protection of the environment and the requirements for powertrain engineering.

3 and **4** define the requirements for planning and operating a testbed, which is also the focus of this handbook.

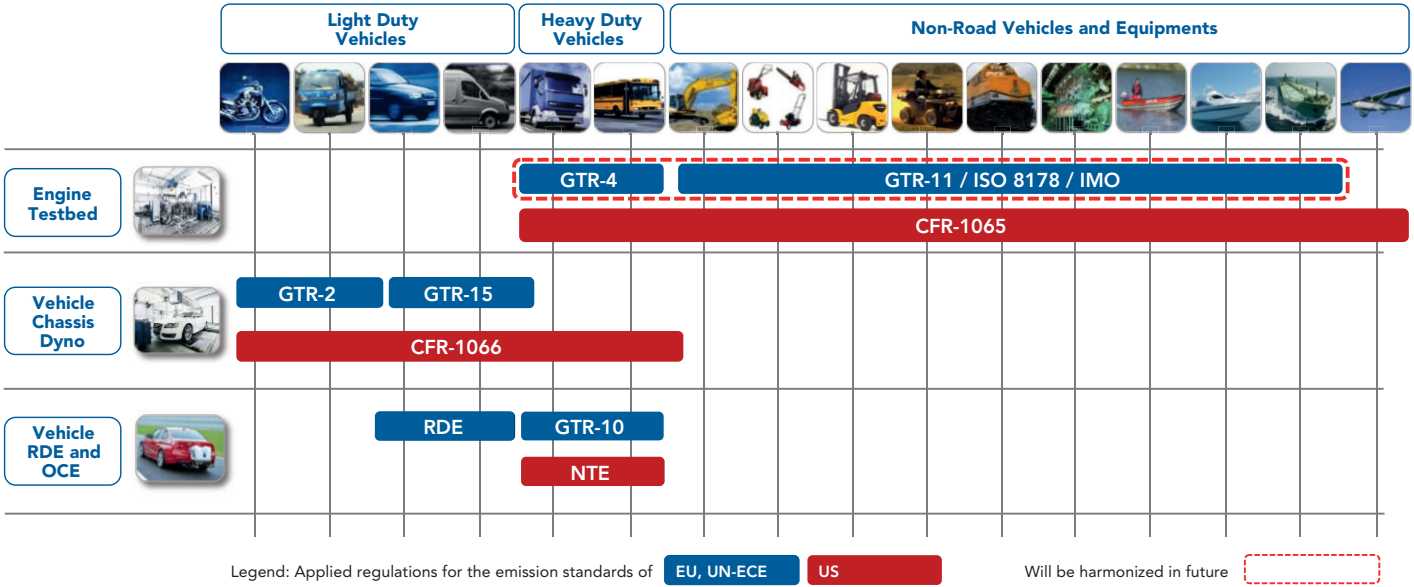
Split-level approach of modern emission standards:



While older emission legislation covered all 4 parts in one "book", the latest legislation split it up into two books. One book focuses on the environmental and engineering relevant requirements, whereas a second book defines the test procedures and its specifications. Furthermore, it explains which test and measurement systems shall be used and what requirements must be fulfilled.

- In Europe, this approach is called the "split-level approach". The limits (1) are specified while the technical specifications (2, 3, 4) are adopted from the UN-ECE Global Technical Regulations (GTR).
- In the US, different "standard setting parts" for different engine applications define the emission limits (1), the test cycles (2) and "technical regulations", in which the test and measurement procedures and specifications (3, 4) are explained.

TECHNICAL REGULATIONS



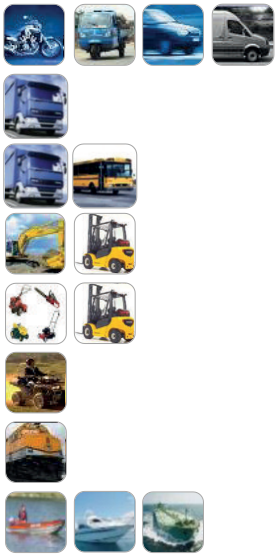
UN-ECE GLOBAL TECHNICAL REGULATIONS

GTR's: Global Technical regulations:

GTR-01: Door locks and door retention components
GTR-02: Measurement procedure for two-wheeled motorcycles with regard to the emission of gaseous pollutants, CO_2 emissions and fuel consumption
GTR-03: Motorcycle brake systems
GTR-04: Test procedure for compression-ignition (C.I.) engines and positive-ignition (P.I.) engines fuelled with natural gas (NG) or liquefied petroleum gas (LPG) with regard to the emission of pollutants
GTR-05: Technical requirements for on-board diagnostic systems (OBD) for road vehicles
GTR-06: Safety glazing materials for motor vehicles
GTR-07: Head restraints
GTR-08: Electronic stability control systems
GTR-09: Pedestrian safety
GTR-10: Off-cycle emissions (OCE)
GTR-11: Engine emissions from agricultural and forestry tractors and from non-road mobile machinery
GTR-15: Global technical regulation on Worldwide Harmonized Light vehicles Test Procedure.
This GTR is often called WLTP (World Light duty vehicle Test Procedures), since the project and the informal working group has this title. However, the final and official document is the GTR-15.

US STANDARDS AND TECHNICAL REGULATIONS

Applications:



Standard Setting Parts:

- (40 CFR 86 SubPt. B – Light-duty vehicles)
- 40 CFR 1037 – Heavy-duty motor vehicles
- 40 CFR 1036 – Heavy-duty highway engines
- 40 CFR 1039 – Nonroad CI engines
- 40 CFR 1048 – Large Non-Road SI engines (>19 kW)
  40 CFR 1054 – Small Non-Road SI engines (<19 kW)
- 40 CFR 1051 – Recreational engines and vehicles
- 40 CFR 1033 – Locomotives
- 40 CFR 1045 – Marine SI engines and vessels
  40 CFR 1042 – Marine CI engines and vessels
  40 CFR 1043 – Marine engines and vessels (Marpol)

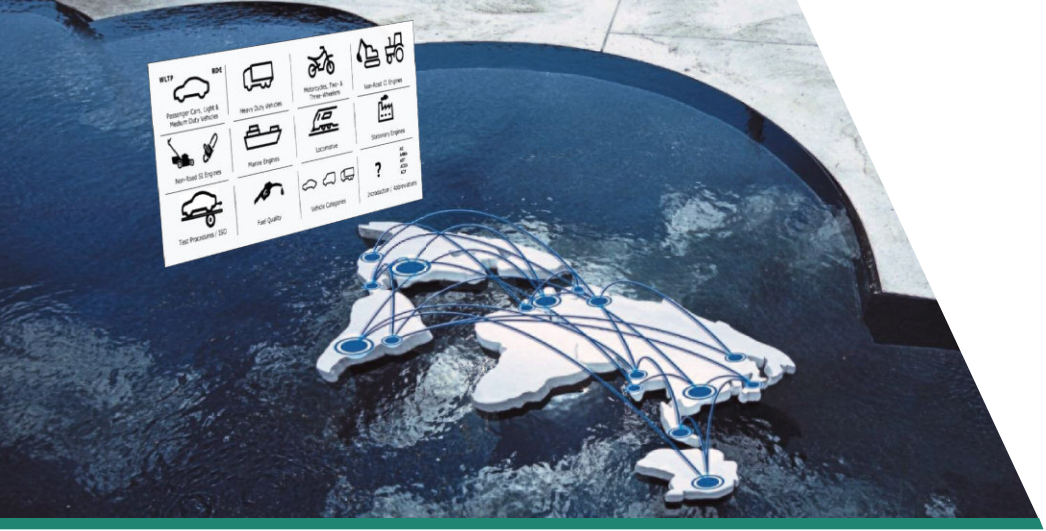
Technical Regulations:

CFR-1066
Vehicle testing on Chassis Dyno

CFR-1066 refers wherever possible to the CFR-1065 specifications.

CFR-1065
Engine testing on Engine Testbed

Large impact on measurement system specifications and differences in the validation and performance checks, when compared to the former CFR-86 specifications or compared to EU and UN-ECE specifications.



www.avl.com/emission-legislation-world/index.html

AVL EMISSION LEGISLATION WORLD

- AVL Emission Report
- AVL Emission Mobile
- Studies and forecasts
- Legislation consulting

3. VEHICLE/ENGINE CLASSIFICATION

Light Duty Vehicles




Mopeds, Motorcycles (MC), 2- and 3-Wheeler
Passenger Cars (PC)
Light Duty Commercial Vehicles (LCV)

Heavy Duty On-Road Vehicle Engines


Medium and Heavy Duty Commercial Vehicles, such as Trucks and Buses

Non-Road Engines

SI = Spark Ignition
CI = Compression Ignition


Nonroad CI


Nonroad SI < 19 kW


Nonroad SI > 19 kW


Recreational Vehicles


Locomotives


Marine Spark Ignition


Marine Compression Ignition


Marine Vessels


Aircraft Engines


Power Plants

4. ENGINE, FUEL AND PROPULSION SYSTEM

Emission regulations differentiate vehicles or engines according to several criteria. By these criteria the suitable type of emission test is selected. For example, SI or CI engines may have different limits, hybrids have different test procedures, bi-fuel vehicles require more tests and evaporative emission test are only done with gasoline fueled vehicles.

Type of Ignition:

- SI – Spark Ignition
- CI – Compression Ignition

SI is also often called PI (Positive Ignition).

Propulsion System:

- Conventional
- Hybrid - NOVC
- Hybrid - OVC
- E-Vehicles

NOVC Not Off Vehicle Charging
OVC Off Vehicle Charging (plug-in)

Fuel System:

- Mono-Fuel
- Bi-Fuel
- Dual-Fuel
- Flex-Fuel

Fuel Type:

Adequate fuel quality is a mandatory pre-requisite for any low emission standard.

Gasoline (E5)	Bio-Ethanol	E10 – E85
Diesel (B5)	Bio-Diesel	B10 – B??
NG	LPG	Hydrogen
PtG	PtL	others

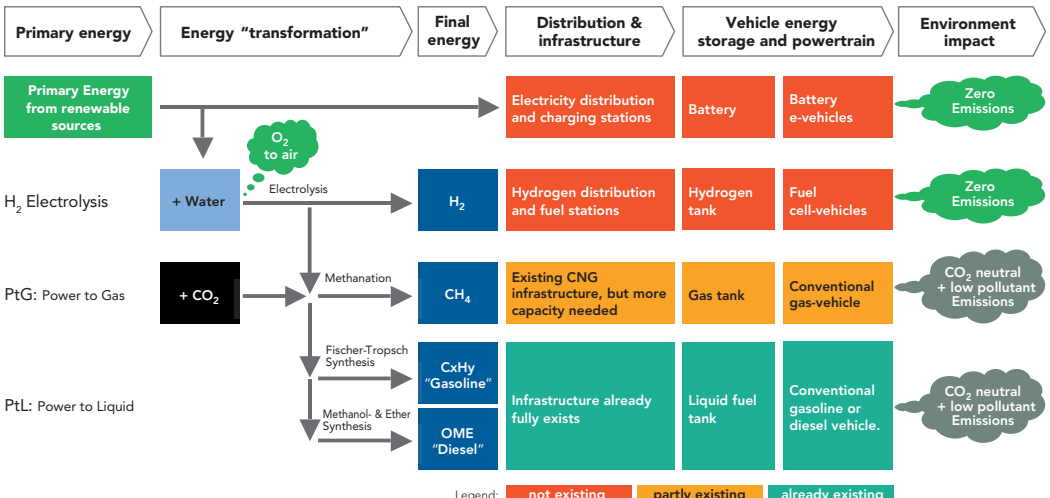
Fossil fuels: Fossil fuels are a limited resource. They are also needed for medicine, plastic, etc.

Bio-Fuels: Ethanol and bio-diesel are environmentally sustainable, if produced from bio mass (waste).

PtG, PtL: "Power to Gas" and "Power to Liquid" - alternative energy sources (solar, wind, ...) are used to produce fuels from water and CO_2 (from industrial processes). It is a form of "technical photo synthesis"

POWER TO GAS/LIQUID = CO_2 NEUTRAL FUEL

In order to achieve overall CO_2 reduction targets, a strong reduction is needed particularly for individual transportation. As a first step, all energy should be gained from renewable sources, such as water-, sun- and wind energy. The figure below demonstrates how this energy could be used. Furthermore, factors such as energy transportation, distribution and storage have to be considered as well as the already existing vehicle fleet.



Possibility 1:
Direct use of electricity or use of hydrogen generated from water and electricity. This requires the construction of a new infrastructure and new vehicles.

Possibility 2:
Combining hydrogen with CO_2 from industrial plants would result in gas (PtG) or liquid fuel (PtL). Gas vehicles and infrastructure already exist on a small scale.
PtL: The entire infrastructure exists. Furthermore, it may be used for already existing cars, airplanes or ships.

ENGINE, FUEL AND PROPULSION SYSTEM

The reduction of CO_2 (green house gas) requires an increase in the efficiency of the vehicle's powertrain. Hybrid vehicles combine the benefits of combustion engines with the benefits of electrical motors. Additionally, the type of fuel used plays a role in reducing CO_2 emissions (e.g. bio-fuels).
On the one hand, CO_2 emissions from bio-fuels are CO_2-neutral for the world and some countries could become independent of fuel imports. On the other hand, negative impacts on food supplies and prices may occur.

This will all lead to a large variety of propulsion systems and fuel options in a vehicle. Therefore, emission legislation and regulations divide vehicles into different fuel (energy) and propulsion system categories:

- Mono-fuel vehicles
- Bi-, flex- and dual-fuel vehicles
- Hybrid vehicles
- Electric vehicles

Fuel- and Propulsion-Systems: Mono-Fuel Vehicles

Vehicle	Engine	Energy Storage	Energy Supply	Energy Source	Notes
Mono-Fuel Vehicle	Combustion Engine	Liquid Fuel Tank	Fuel Station	Crude Oil	Vehicle designed to run on 1 type of liquid fuel
Mono-Fuel-Gas Vehicle	Combustion Engine	Gas Tank	Gas Station	Gas	Mono-fuel vehicles run primarily on LPG, NG, bio-methane or hydrogen. The vehicle may have a small petrol tank (<15 l) for emergency or starting purpose.
		Liquid Fuel Tank < 15 l	Fuel Station	Crude Oil	

ENGINE, FUEL AND PROPULSION SYSTEM

Fuel- and Propulsion-Systems: Bi-, Flex- and Dual-Fuel Vehicles

Vehicle	Engine	Energy Storage	Energy Supply	Energy Source	Notes
Bi-Fuel Vehicle	Combustion Engine	Liquid Fuel Tank	Fuel Station	Crude Oil	Vehicle with 2 different fuels in 2 separate tanks. It runs only on 1 fuel at a time.
		Liquid Fuel Tank	Fuel Station	Bio-Fuel	
Bi-Fuel-Gas Vehicle	Combustion Engine	Liquid Fuel Tank	Fuel Station	Crude Oil	Vehicle with 2 different fuels in 2 separate tanks. It can run on petrol (>15 l Tank) or on either LPG, NG, bio-methane or hydrogen.
		Gas Tank	Gas Station	Gas	
Flex-Fuel Vehicle	Combustion Engine	Liquid Fuel Tank	Fuel Station	Crude Oil	Vehicle with 1 tank that can run on different mixtures of 2 or more fuels, for example any mixture of gasoline and ethanol or diesel and bio-diesel.
			Fuel Station	Bio-Fuel	
Dual-Fuel-Gas Vehicle	Combustion Engine	Liquid Fuel Tank	Fuel Station	Crude Oil	Vehicle can burn gas and liquid fuels from separate tanks (mainly gas and diesel) at the same time.
		Gas Tank	Gas Station	Gas	
Dual-Fuel-Gas Vehicle	Combustion Engine	Liquid Fuel Tank	Fuel Station	Crude Oil	Vehicle can burn 2 different liquid fuels from separate tanks at the same time, RCCI (Reactivity Controlled Compression Ignition).
		Liquid Fuel Tank	Fuel Station	Crude Oil	

ENGINE, FUEL AND PROPULSION SYSTEM

Hybrid and Electric Vehicles

Vehicle	Engine	Energy Storage	Energy Supply	Energy Source	Notes
NOVC-Hybrid (Not Off-Vehicle Charging)	Combustion Engine Electric Motor	Liquid Fuel Tank Battery	Fuel Station	Crude Oil	Vehicle with 1 combustion engine, 1 or more electric motors and 2 energy storages. Battery cannot be charged externally.
OVC Hybrid (Off-Vehicle Charging)	Combustion Engine Electric Motor	Liquid Fuel Tank Battery	Fuel Station Power Grid	Crude Oil Power Station	Vehicle with 1 combustion engine, 1 or more electric motors and 2 energy storages. Battery can be charged externally (plug-in).
Electric Vehicle with Range Extender	Electric Motor	Battery Range Extender	Power Grid Fuel Station	Power Station Crude Oil	Vehicle with an electric motor and battery. Additionally there is a power generator with a combustion engine to extend the driving range.
Fuel Cell Vehicle	Electric Motor	Battery Fuel Cell	Power Grid H2 Station	Power Station Hydrogen	Vehicle with an electrical motor and fuel cell that converts hydrogen into electrical energy.
Pure Electric Vehicles	Electric Motor	Battery	Power Grid	Power Station	Vehicle with an electric motor and a battery. Also called Battery Electrical Vehicle (BEV)

HYBRID AND ELECTRIC VEHICLES

When talking about hybrid vehicles many different names are used. For instance, a plug-in hybrid is called an off-vehicle charging (OVC) hybrid in EU regulations, whereas it is referred to as grid connected electric vehicle in US regulations.

Hybrid and Electric Vehicle Definition – Functional Matrix

Hybrid Related Nomenclature			Electrification Functionality Matrix						
Technology Name	EU Related Emission Regulation Naming	US Related Emission Regulation Naming	Engine Start-Stop	E-Boost Systems	Regener-ative Braking	E-Motor moves vehicle	External Battery Charging	Pure Electric Driving	Electric Driving Only
Micro-Hybrid	These vehicles are not tested as hybrid vehicles for emission regulations. Testing is like any conventional vehicle with a combustion engine		✓	✓					
Mild-Hybrid			✓	✓	✓				
Full-Hybrid	NOVC Hybrid Not off vehicle charging	Hybrid electric vehicle	✓	✓	✓	✓			
Plug-In Hybrid	OVC Hybrid Off vehicle charging	Plug-In Hybrid, Grid connected electric vehicle	✓	✓	✓	✓	✓		
Range Extender			✓		✓	✓	✓	✓	
Pure Electric Vehicle	BEV Battery Electrical Vehicle	Grid connected electric vehicle			✓	✓	✓	✓	✓

AVL EVAPORATIVE EMISSION

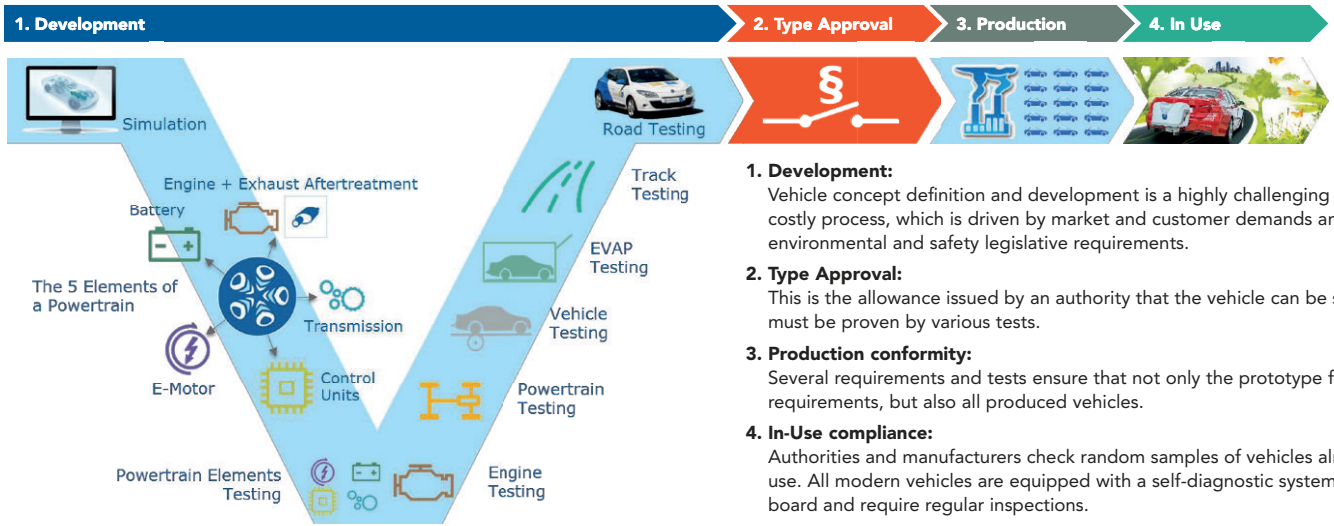
The most comprehensive AVL EVAPORATIVE emission testing product line supports the easy and reliable determination of hydrocarbon evaporation from fuel tanks of gasoline-driven vehicles.

5. DEVELOPMENT AND EMISSION TESTING LIFE CYCLE

Examples based on EU passenger car regulations

DEVELOPMENT AND EMISSION LIFE CYCLE

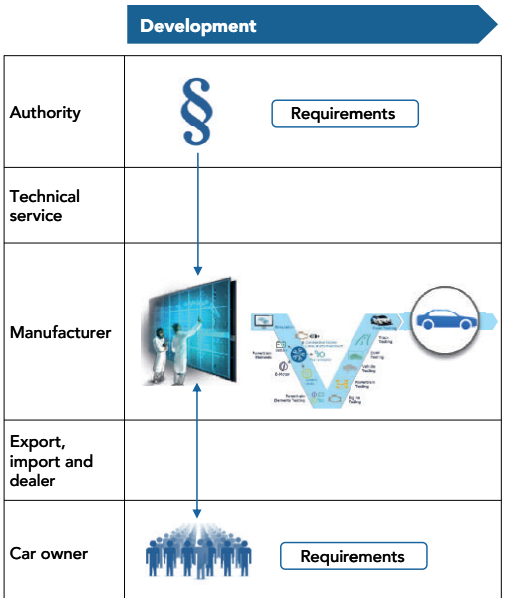
The "vehicle life cycle" starts with development and testing. After a type approval is issued, production begins.
Individual vehicles will be in use for several years. During this period emission control measures ensure a sustainable and environmentally friendly operation. The vehicle's recycling usually starts when put out of operation.



1. **Development:**
   Vehicle concept definition and development is a highly challenging and costly process, which is driven by market and customer demands and strict environmental and safety legislative requirements.
2. **Type Approval:**
   This is the allowance issued by an authority that the vehicle can be sold. This must be proven by various tests.
3. **Production conformity:**
   Several requirements and tests ensure that not only the prototype fulfills the requirements, but also all produced vehicles.
4. **In-Use compliance:**
   Authorities and manufacturers check random samples of vehicles already in use. All modern vehicles are equipped with a self-diagnostic system on board and require regular inspections.

Development and emission testing life cycle

DEVELOPMENT



Development and emission testing life cycle

Product development is mainly driven by

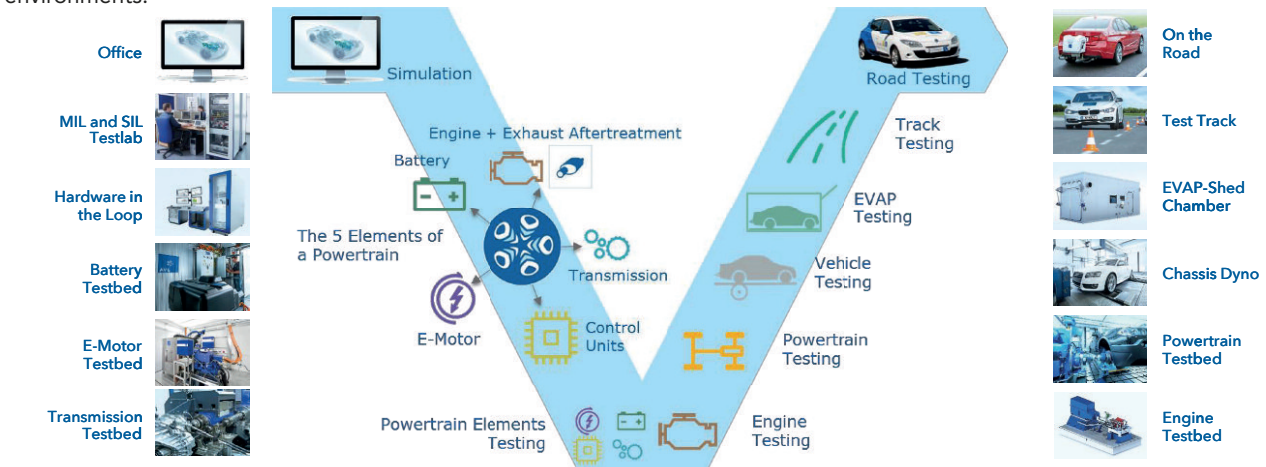
- Market and customer demands, such as price, drivability and driving pleasure, fuel consumption etc.
- Various legislation and regulations to ensure a safe and environmentally friendly operation.

Both the market and the legislative demands are becoming more challenging. While the market demands a wider variety of models, legislation is becoming stricter with respect to test performance, lower emission limits and expanding laboratory tests simulating real driving emissions.

These aspects will drive the powertrain development towards new development methodologies, tools and higher efficiency. The usage of advanced simulation and hardware-in-the-loop development will increase and more conventional tests both in laboratories and on the road will be done.

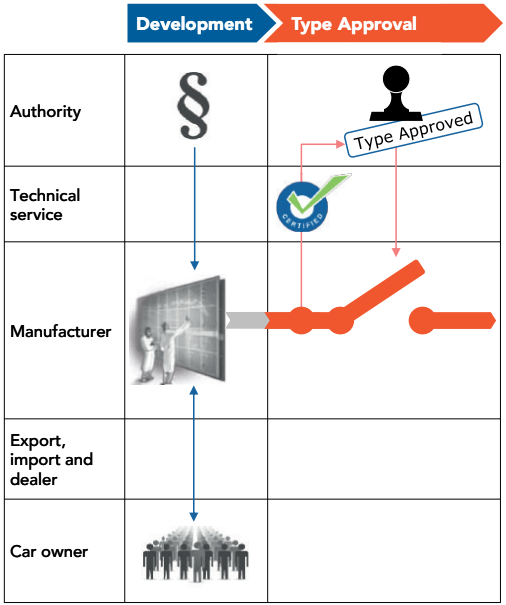
DEVELOPMENT PROCESS

A powertrain development process is like a "V" and starts on the left with high level concept studies and simulation. It continues with the selection of powertrain elements and is followed by design and testing. After the powertrain is assembled, it is integrated into a vehicle. The process ends on the right with a prototype. During the process several testing and optimization steps are carried out in various test environments.



Development and emission testing life cycle

TYPE APPROVAL



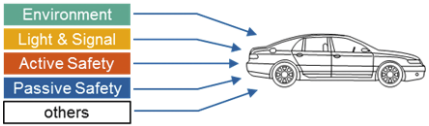
Development and emission testing life cycle

Type Approval:
A manufacturer must obtain type approval from a local vehicle authority, in order to be able to sell a vehicle.
It is issued all required documents and test reports have been reviewed.
It is done based on pre-production vehicles.

Europe and most countries that follow EU or UN-ECE regulations:
The type approval tests are performed or witnessed by a technical service. The technical service certifies the correctness of the executed tests and results by so called "certification tests". The technical service is selected and paid for by the manufacturer. Alternatively, a test laboratory may undergo an accreditation process to perform tests afterwards without a technical service organization (such as TÜV, DEKRA, ...).

USA type approval:
The USA does not use the concept of a "technical services organization". This is one reason why US regulations are written using more technical details than EU documents. The manufacturer performs a "self certification" and presents the data to EPA or CARB. EPA and CARB then issue a type approval for the period of one year, which must be extended every year. High civil penalties apply for vehicles that do not fulfill the legislation.

TYPE APPROVAL: EMISSION



Emission Type Approval Test Types	
Type - I	Average emission after a cold start
Type - Ia	Real Driving Emission (RDE)
Type - II	CO Idle test
Type - III	Crankcase emission
Type - IV	Evaporative emission
Type - V	Durability test
Type - VI	-7 °C low temperature emission test (like Type-I testing but at -7° C)
OBD	On Board Diagnostic
CO_2 + FC EC + E-Range	CO_2 + fuel consumption, energy consumption and electric range for E-vehicles
Reg - 24	Smoke opacity for compression ignition engines

Type Approval:
A vehicle has to fulfill a lot of legislation and regulations. These concern environment, lighting and signals, active-and passive safety: for instance, there are approx. 80 EU directives and 70 UN-ECE regulations in Europe.

Emission related type approval requirements:
There are several emission related test types for the EU type approval. The main differences to the US legislation are the different drive cycle (FTP-75 vs WLTC) and some additional drive cycles used to test aggressive driving and driving with air conditioning. Furthermore, the emission limits are totally different. The EU legislation focuses mainly on low NOx and PN emissions balanced with also low CO_2 emission. In the US standards the main focus is to bring smog-forming emissions (HC speciation and NOx) close to zero while CO_2 targets are still high compared to EU. Limits are based on limits for each vehicle and on fleet average emission limits, also allowing some higher emissions on a small number of vehicles as long the fleet average is fulfilled.

Real driving emission requirement:
A new approach includes the extension of laboratory tests to driving under conditions of normal use (measured on the road) as well as the definition emission limits. This approach was first applied to heavy-duty vehicles in the US, and later in the EU. For passenger cars it will start in the EU (planned 2017), followed most likely by South-Korea and China.

Test types selection:
The test types performed depend on the ignition type of the engine (CI, SI), the fuel system (mono, bi, or flex-fuel) and the fuel itself (gasoline, diesel, bio, …).

TYPE APPROVAL: TEST TYPES/FUELS

Emission Test Types		SI-Vehicle including Hybrids									CI-Vehicle including Hybrids		Pure Electric	H_2 Fuel cell
Fuel System =		Mono-Fuel				Bi-Fuel			Flex-Fuel		Mono-Fuel	Flex-Fuel		
Fuel Type =		Gasoline	LPG	NG	Hydrogen	Gasoline LPG	Gasoline NG	Gasoline Hydrogen	Gasoline Ethanol	NG H_2NG	Diesel	Diesel Bio-Diesel		
Type-I	Average emission	✓	✓	✓	✓	✓ both fuels	✓ both fuels	✓ both fuels	✓ both fuels	✓ both fuels	✓	✓ both fuels		
Type-Ia	Real Driving Emission	✓	✓	✓	✓	✓ both fuels	✓ both fuels	✓ both fuels	✓ both fuels	✓ both fuels	✓	✓ both fuels		
Type-II	CO idle test	✓	✓	✓		✓ both fuels	✓ both fuels	✓ Gasoline	✓ both fuels	✓ NG				
Type-III	Crankcase emission	✓	✓	✓		✓ Gasoline	✓ Gasoline	✓ Gasoline	✓ Gasoline	✓ NG				
Type-IV	Evaporative emission	✓				✓ Gasoline	✓ Gasoline	✓ Gasoline	✓ Gasoline					
Type-V	Durability test	✓	✓	✓	✓	✓ Gasoline	✓ Gasoline	✓ Gasoline	✓ Gasoline	✓ NG	✓	✓ both fuels		
Type-VI	-7°C low temperature	✓				✓ Gasoline	✓ Gasoline	✓ Gasoline	✓ both fuels					
OBD	On Board Diagnostic	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		
CO_2 + FC Energy + Range	CO_2 and FC E-energy cons. and electric range	✓	✓	✓	✓	✓ both fuels	✓ both fuels	✓ both fuels	✓ both fuels	✓ both fuels	✓	✓ both fuels	✓	✓
Reg-24	Smoke opacity										✓	✓		

Note: Gasoline includes E5/E10 and Diesel includes B5/B7 and NG includes Bio-methane

MEMBER OF AVL iGENERATION SII

AVL iGENERATION SERIES II –

THE SMARTER WAY OF EMISSION TESTING

The AVL iGENERATION Series II takes emission testing to the next level and sets new standards for intelligent and intuitive emission measurement systems.

TYPE APPROVAL: EMISSION TEST SYSTEMS

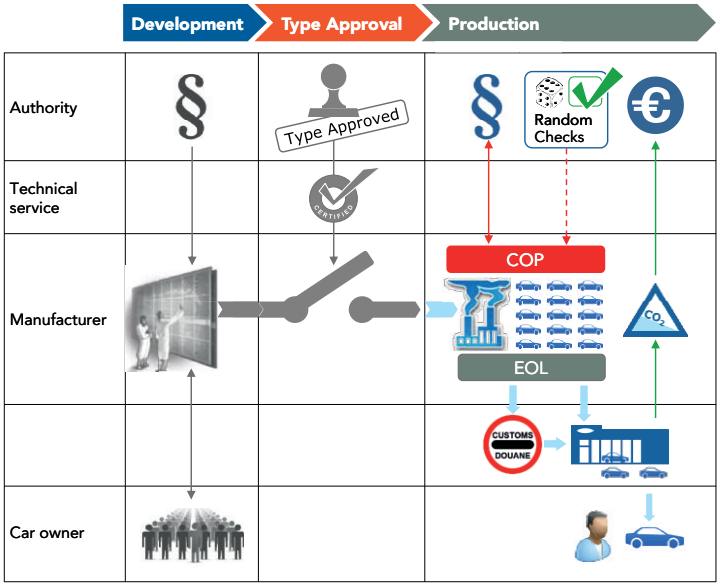
Emission Test Types		Laboratory test and measurement systems required									EVAP
		Load Unit	Climatic Chamber	Automation System	CVS	Emission Bench	Particulate Sampler	Particle Counter	PEMS	Other Instruments	SHED, etc
Type-I	Average emission	Chassis Dyno		✓	✓	✓	✓	✓			
Type-Ia	Real Driving Emission	Road		✓					✓		
Type-II	CO idle test									Workshop analyzer	
Type-III	Crankcase emission	Chassis Dyno								Pressure or bag	
Type-IV	Evaporative emission	Chassis Dyno		✓		✓					✓
Type-V	Durability test	Chassis Dyno		✓	✓	✓	✓	✓			
Type-VI	-7°C low temperature	Chassis Dyno	✓	✓	✓	✓					
OBD	On Board Diagnostic	Chassis Dyno		✓	✓	✓	✓	✓			
CO_2 + FC Energy + Range	CO_2 and FC E-energy cons. and electric range	Chassis Dyno		✓	✓	✓					
Reg-24	Smoke opacity	Engine dyno (Chassis Dyno)		✓						Opacimeter	

Note: More detailed information as well as emission regulation specific information on the required emission test system will be given in the next chapter of this handbook.

AVL M.O.V.E iS IN-VEHICLE TEST SYSTEM

The perfectly tailored and leading solution for EU6d Real Driving Emissions (RDE) testing.

PRODUCTION AND DISTRIBUTION



COP (Conformity of Production):
Type approval is required for pre-production vehicles, while COP ensures the emission compliance of the produced vehicles. The testing itself is similar to Type-I approval testing. Testing is done by the manufacturer, who has to report statistical results to the authority. The number of vehicles tested depends on agreements between manufacturer and authorities. Authorities may also perform random tests during the production process.

Fleet Average Values (like CO_2 in Europe):
Some limits account for a fleet average and not for single models, e.g. CO_2 in the EU or fuel economy in the USA. A fleet average depends on the individual models' values and the number of models sold per year. In the EU, a manufacturer pays an "excess premium fee" whenever the fleet average exceeds the permitted CO_2 targets.

EOL (End of Line):
Is a manufacturers internal quality test. It is not required or defined by legislation.

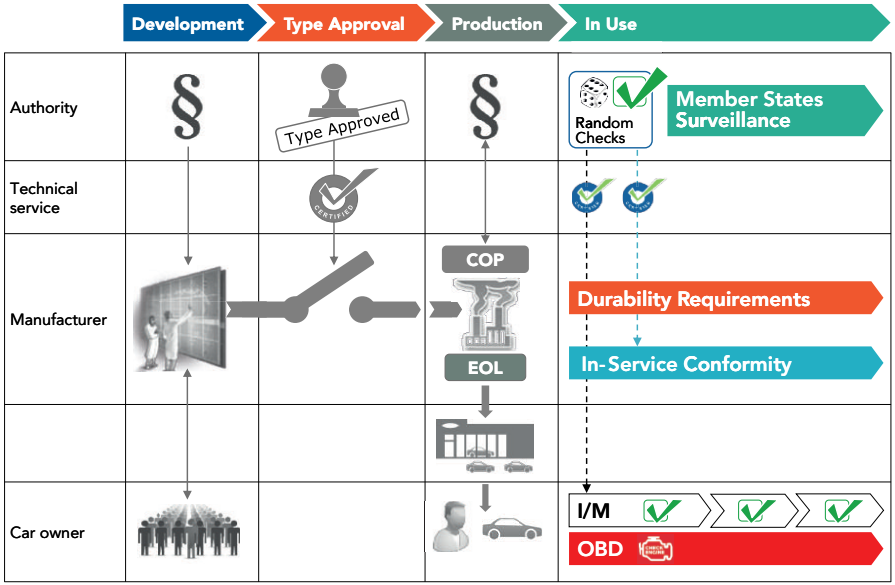
Exporting and Importing:
Typically, customs are responsible to ensure that imported engines and vehicles have a valid type approval. Each EU member state must accept a type approval issued by other EU Member states.

Development and emission testing life cycle

AVL M.O.V.E IN-VEHICLE TEST SYSTEM

The perfectly tailored and leading solution for EU In Service Conformity and US EPA Heavy Duty In-Use Testing.

IN USE



In-Use Emission Control:
Type approval and COP ensure that the vehicles are clean both during production and when leaving the factory. The third and last part of the emission life cycle is to ensure proper in-use emissions.

Member States Surveillance:
Currently in discussion for the EU, which requires all member states to perform in-use tests.

Durability:
Requirements define the lifetime in which emission limits have to be fulfilled (for example 100,000 km or 5 years in the EU). During type approval, this capability has to be demonstrated.

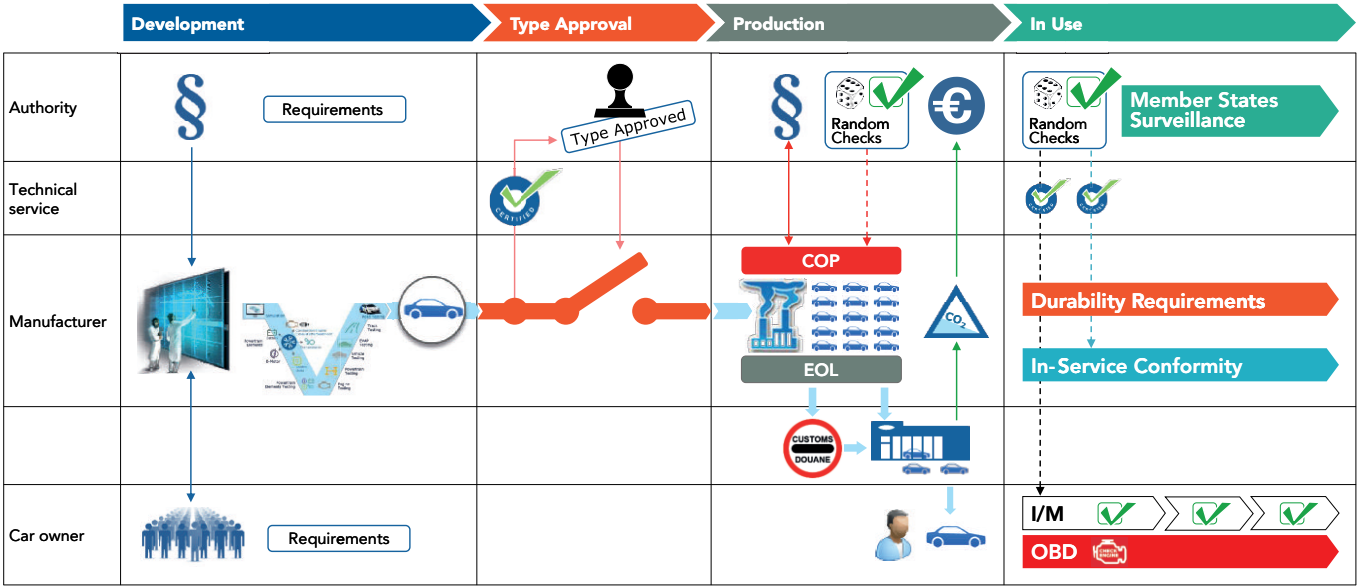
In-Service Conformity or Compliance:
These are random emission tests in real use, in both laboratory test as well as real driving conditions.

I/M (Inspection and Maintenance):
Quick and simple checks for all vehicles that have to be performed on a regular basis, e.g. annually.

OBD (On Board Diagnostic):
The engine control unit continuously monitors engine performance and indicates fault signals.

Development and emission testing life cycle

OVERVIEW



EOL = End of Line, COP = Conformity of Production, I/M = Inspection and Maintenance, OBD = On Board Diagnostic

TEST ENVIRONMENT

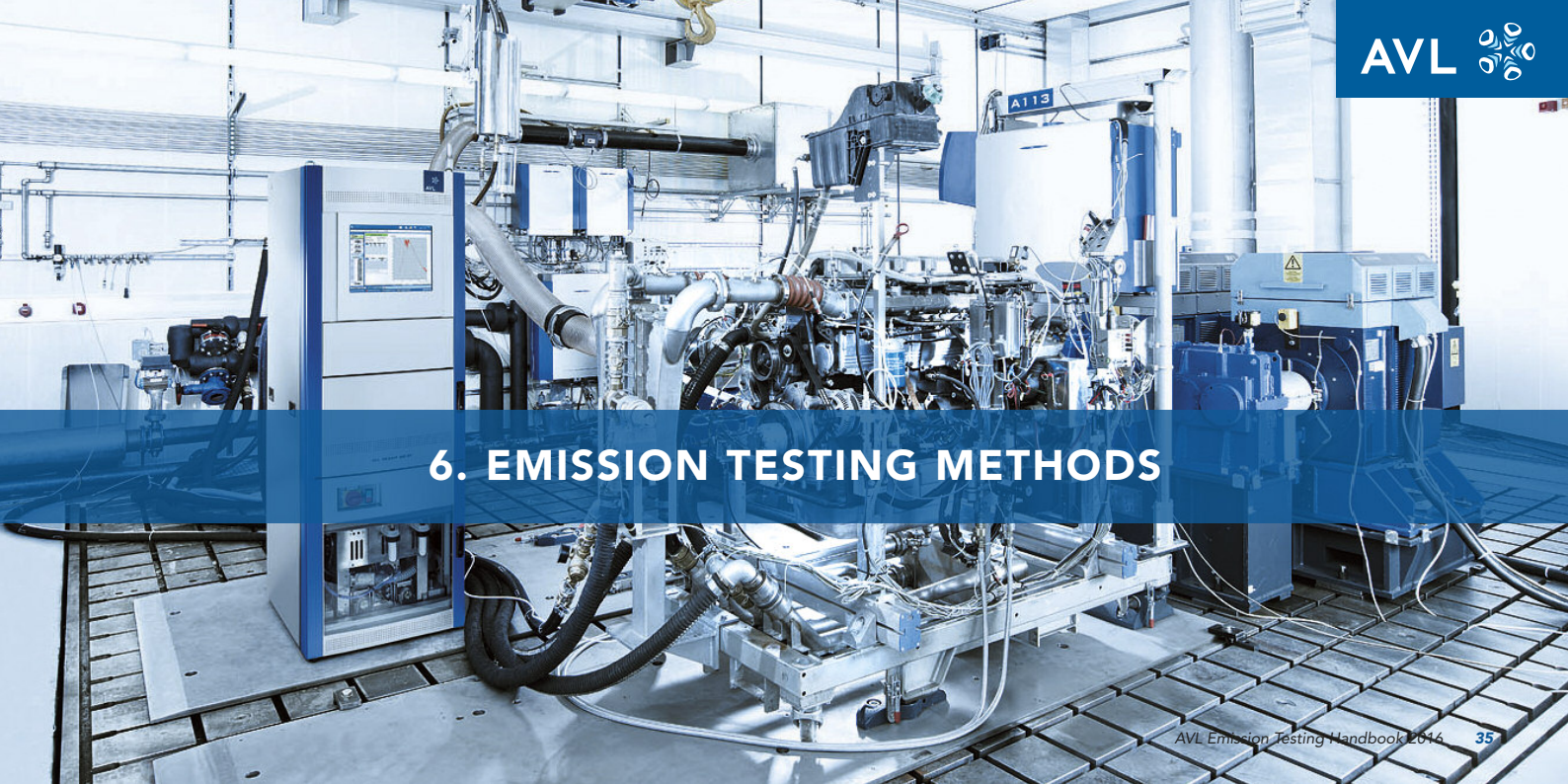
Test environment used during development, type approval, production and in-use testing

Test Environment	 Office Simulation	 MIL, SIL Testlab	 Hardware in the Loop	 Battery Testbed	 E-Motor Testbed	 Trans-mission Testbed	 Engine Testbed	 Powertrain Testbed	 EVAP-SHED Chamber	 Chassis Dyno	 Test Track	 On the Road	 I/M Tester
Light Duty Application													
Development	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	
Type Approval									✓	✓		✓	
Production							✓			✓			
In-Use										✓		✓	✓
Heavy Duty- and Non-Road Applications													
Development	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Type Approval							✓						
Production							✓						
In-Use							✓					✓	✓

Development and emission testing life cycle

AVL PARTICULATE FILTER WEIGHING MANAGEMENT

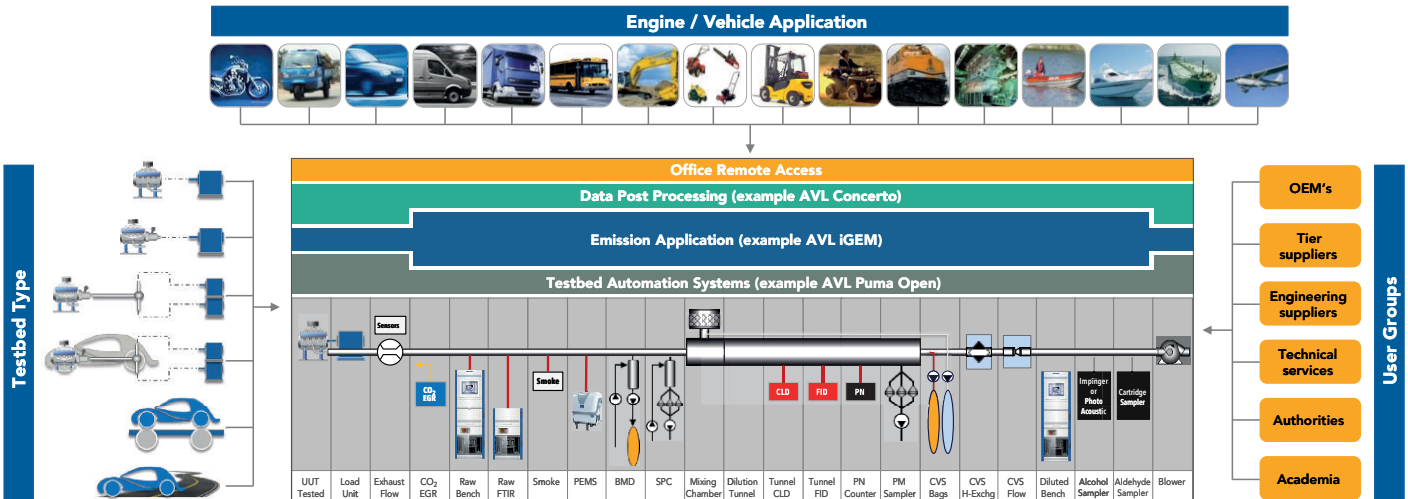
The AVL Filter Weighing Chamber combined with the AVL Filter Weighing Robot – both controlled by means of AVL ParticleScale – is the best and most efficient solution for automated PM weighing with highest accuracy (e.g. LEVIII/ TIER3).



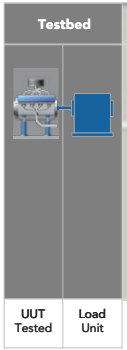
6. EMISSION TESTING METHODS

EMISSION TESTING METHODS

Testbed types and the emission test system configurations depend on the engine applications, local or global legislation requirements, and user groups and preferences. The schematic provides an overview of the different emission test systems and testbed configurations enabling different testbed types to be compared. It helps gain an understanding of the differences as well as what is the same.



TESTBED TYPES



Unit Under Test (UUT) and Load Unit

Engine only – Dyno

Engine plus transmission – Dyno

Engine plus powertrain – Wheel Dynos

Vehicle – Wheel Dynos

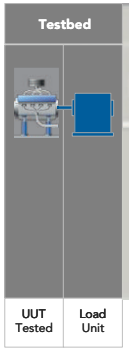
Vehicle – Chassis Dyno

Vehicle – Street

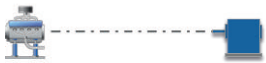
Unit Under Test:
On an engine testbed, the UUT is only the engine, whereas it is the entire vehicle on a chassis dyno. In real driving testing, the UUT is not only the vehicle due to other factors, such as the driver, traffic/weather conditions, etc.

Load Unit:
The load unit and its control systems simulate the same work load (speed, torque and dynamics) for the engine or vehicle as during "real-life" operations. This makes sure that the performance of the engine on a dynamic engine testbed is the same as it might be while driving on real roads.

TESTBED TYPES



Engine only – Dyno



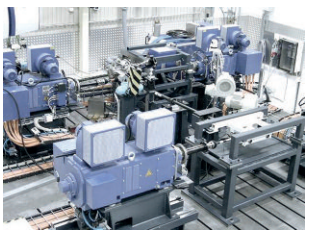
Only the engine is tested:
- Stationary version
- Transient version

Engine emission type approval tests are required for:
- On-road Heavy Duty vehicle engines
- Non-road engines

Powertrain (Driveline) – Dyno

Engine plus transmission

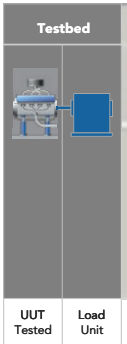
Engine plus powertrain



The engine and the transmission is tested, sometimes also the shafts, axles and differential are included.

These testbed types are not used for type approval testing.

TESTBED TYPES



Vehicle Wheel Dynos

Shaft Connection

Light Duty Passenger Car

Non-Road Vehicle

Heavy-Duty Vehicle

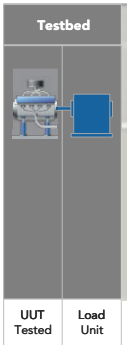
The whole vehicle is tested and dynos are connected instead of the wheels. This method makes it possible to simulate testing on a powertrain testbed or on a chassis dyno testbed.

Particularly useful for:

- Hybrid development
- Non-road vehicles allowing the application of high torque conditions found in real world operations, but can not be realized on a chassis dyno (i.e. a tractor in wet farmland). For tractors, a 5th dyno can be used to simulate load taken from the working drive shaft on the rear end of the tractor.

These testbed types are not used for type approvals.

TESTBED TYPES



Vehicle Chassis Dynos

Light Duty Passenger Car Chassis Dyno

Motorcycle and 3 - Wheeler

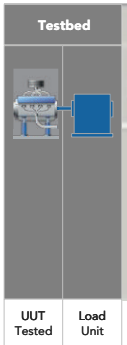
Truck and Bus

The entire vehicle stands on roller dynos.
- 2-WD versions
- 4-WD versions
- Motorcycle versions
- Bus and truck versions

The road load coefficients for the simulations are measured by a street coast down. It includes the load to accelerate / decelerate the vehicle mass, air resistance and roll resistance.

Chassis dyno is the mandatory test environment for all light-duty emission type approvals all around the world.
- 2-and 3 wheeler
- Passenger cars
- Light-duty commercial vehicles

TESTBED TYPES



Road testing (Real Driving Emission)

Light Duty – Passenger car

Heavy Duty Vehicle

Non-Road Vehicle

The vehicle is driven on a road.

A portable emission measurement system (PEMS) is installed and measures:

- Light duty: CO_2, CO, NOx, PN
- Heavy duty: CO_2, CO, NOx, THC, PM

while driving on the road.

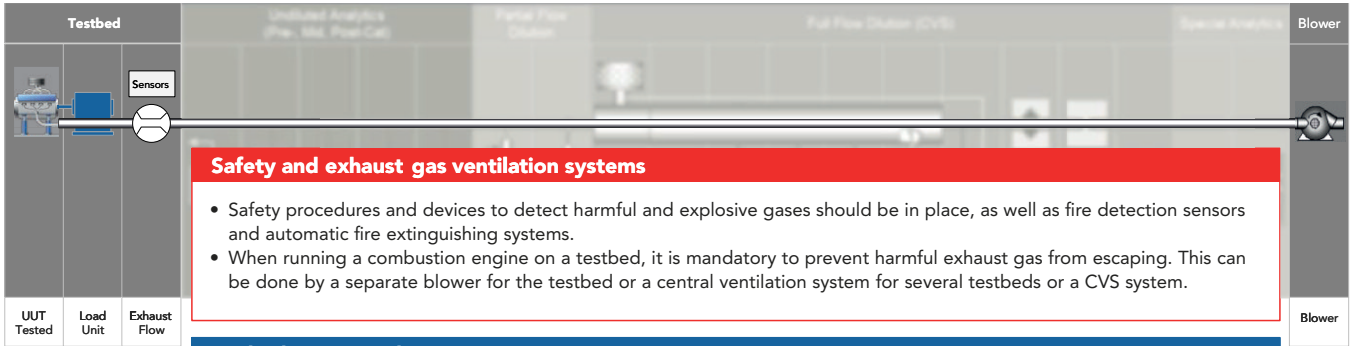
Emission measurement method used: undiluted raw modal.

It is mandatory for:

- Light-duty: EU
- Heavy-duty: EU, USA
- Non-road: in discussion

PEMS testing will be used by US environmental protection agencies for in-use scanning, in that case also CH_4 measurement will be beneficial. EU is discussing to change from PM to PN for Heavy Duty.

TESTBED SYSTEMS



Safety and exhaust gas ventilation systems

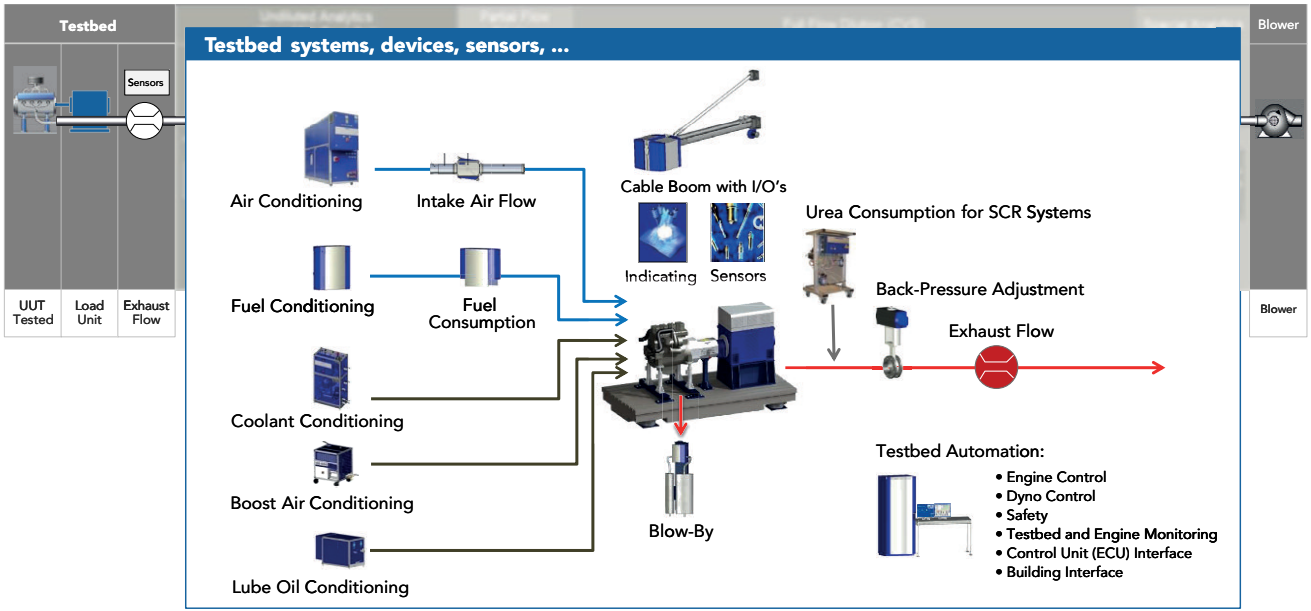
- Safety procedures and devices to detect harmful and explosive gases should be in place, as well as fire detection sensors and automatic fire extinguishing systems.
- When running a combustion engine on a testbed, it is mandatory to prevent harmful exhaust gas from escaping. This can be done by a separate blower for the testbed or a central ventilation system for several testbeds or a CVS system.

Testbed systems, devices, sensors, ...

There are numerous sensors and devices to monitor testbed and engine.

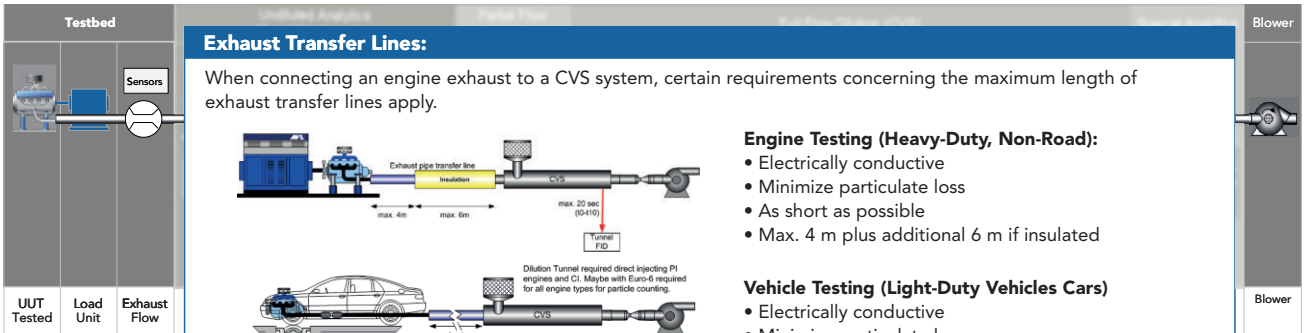
- Sensors for speed, torque, temperature, pressures and others
- Measurement of fuel consumption, intake air flow, oil consumption, Urea consumption, etc.
- Supplies of intake air, fuel, cooling water, compressed air, etc.
- Conditioning of intake air (temperature, humidity, pressure), boost air, fuel, lube oil and cooling water for the engine
- Ventilation and conditioning of the testbed. For instance, an engine running with 100 kW produces approx. 100 kW heat in the test cell.
- Calibration and operation gases for the emission analyzers.
- Safety devices for protection from harmful gas from the exhaust, fire protection, etc.

TESTBED SYSTEMS



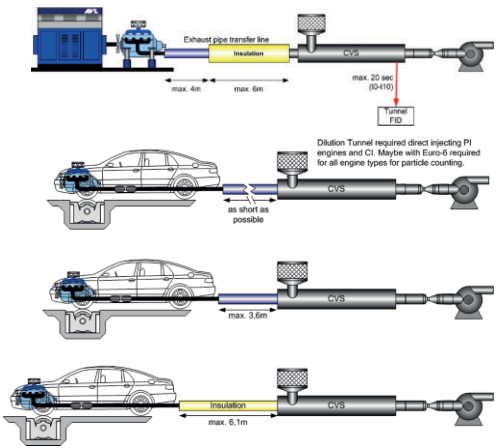
MSS^{PLUS} – AVL MICRO SOOT SENSOR

The new generation of the soot emission measurement standard has arrived.



Exhaust Transfer Lines:

When connecting an engine exhaust to a CVS system, certain requirements concerning the maximum length of exhaust transfer lines apply.



Engine Testing (Heavy-Duty, Non-Road):

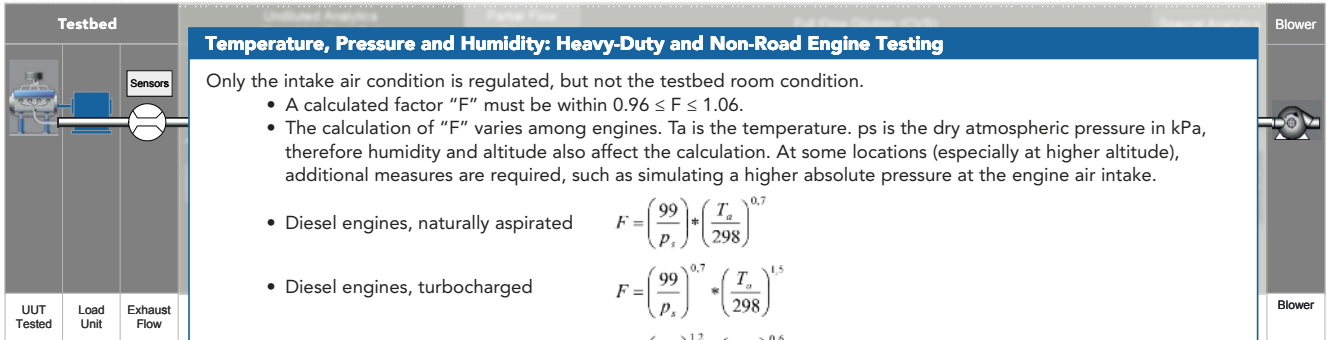
- Electrically conductive
- Minimize particulate loss
- As short as possible
- Max. 4 m plus additional 6 m if insulated

Vehicle Testing (Light-Duty Vehicles Cars)

- Electrically conductive
- Minimize particulate loss
- As short as possible
- Max. 3.6 m uninsulated
- Max. 6.1 m if insulated

Special provisions may exist in local emission regulations for alcohol fuelled vehicles.

It is recommended not to use elastomer connectors to bridge connections between the vehicle tailpipe and the transfer line, when performing particle number (PN) measurement.



Temperature, Pressure and Humidity: Heavy-Duty and Non-Road Engine Testing

Only the intake air condition is regulated, but not the testbed room condition.

- A calculated factor "F" must be within $0.96 \leq F \leq 1.06$.
- The calculation of "F" varies among engines. Ta is the temperature. ps is the dry atmospheric pressure in kPa, therefore humidity and altitude also affect the calculation. At some locations (especially at higher altitude), additional measures are required, such as simulating a higher absolute pressure at the engine air intake.

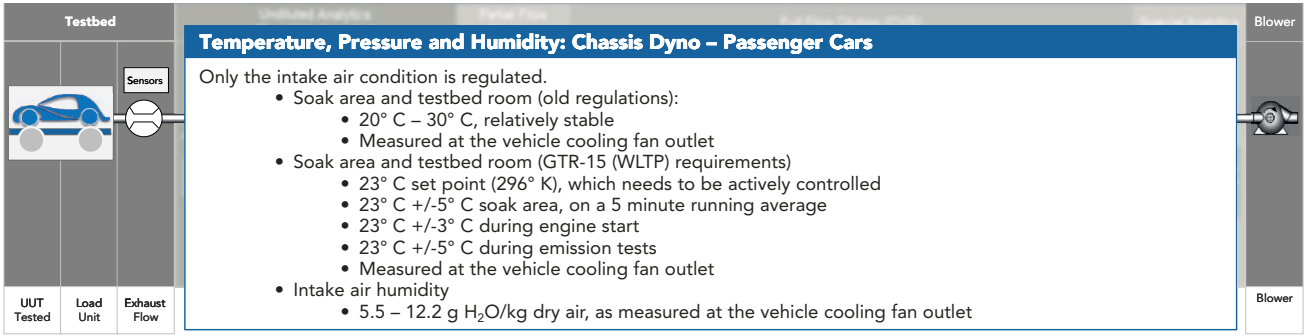
- Diesel engines, naturally aspirated $F = \left(\frac{99}{p_s}\right) * \left(\frac{T_a}{298}\right)^{0,7}$
- Diesel engines, turbocharged $F = \left(\frac{99}{p_s}\right)^{0,7} * \left(\frac{T_a}{298}\right)^{1,5}$
- Gas engines $F = \left(\frac{99}{p_s}\right)^{1,2} * \left(\frac{T_a}{298}\right)^{0,6}$

Temperature, Pressure and Humidity: Heavy-Duty and Non-Road Off-Cycle Emission

A manufacturer statement regarding off-cycle emission (OCE) compliance is mandatory. OCE covers a random stationary test cycle on the engine testbed and in-service road testing with portable emission measurement systems (PEMS).

- Absolute air pressure down to 82.5 kPa, that refers to approx. 1700 m above sea level
- All engine coolant temperatures within a range of 70° C to 100° C
- Ambient temperature less or equal to T = < – 0.4514 * (101.3 – pb) + 311
  with T = temperature in K, pb = dry absolute barometric pressure in kPa

TESTBED SYSTEMS



Temperature, Pressure and Humidity: Chassis Dyno – Passenger Cars

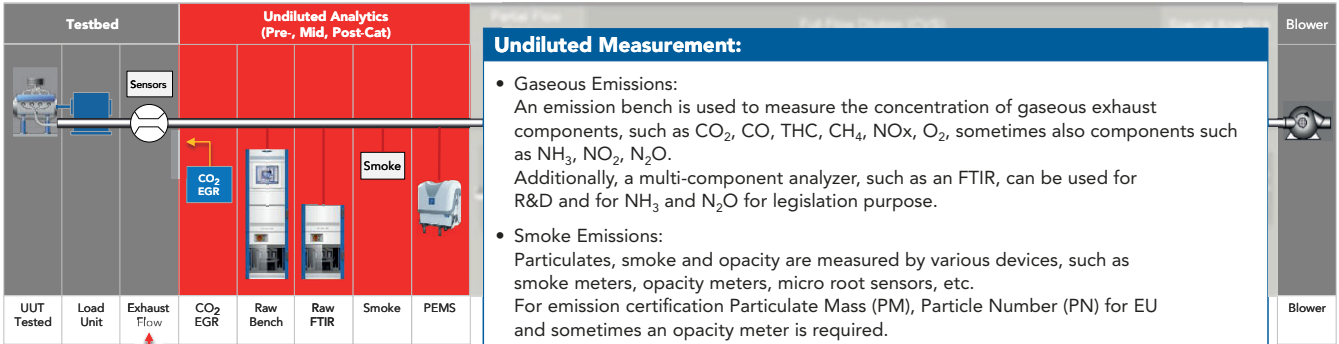
Only the intake air condition is regulated.

- Soak area and testbed room (old regulations):
  - 20° C – 30° C, relatively stable
  - Measured at the vehicle cooling fan outlet
- Soak area and testbed room (GTR-15 (WLTP) requirements)
  - 23° C set point (296° K), which needs to be actively controlled
  - 23° C +/-5° C soak area, on a 5 minute running average
  - 23° C +/-3° C during engine start
  - 23° C +/-5° C during emission tests
  - Measured at the vehicle cooling fan outlet
- Intake air humidity
  - 5.5 – 12.2 g H_2O/kg dry air, as measured at the vehicle cooling fan outlet

Temperature, Pressure and Humidity: Real Driving Emissions (Passenger Cars)

- Ambient temperatures
  - 0° C to 30° C moderate test conditions — -7° C to 35° C extended test conditions
- Maximum altitude
  - < 700 m moderate test conditions — < 1,350 m extended test conditions
- Humidity
  - Humidity is as it is.
  - No humidity correction factor is applied to the NOx result, as it is done on the chassis dyno.
- Cold start emissions is to be recorded, but are not included in the result calculation.
  - Until coolant temperature has reached 343°K (70° C) for the first time, or 5 minutes after the first engine start, which ever happens first.

EMISSION MEASUREMENT METHODS



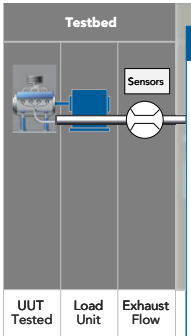
Undiluted Measurement:

- Gaseous Emissions:
  An emission bench is used to measure the concentration of gaseous exhaust components, such as CO_2, CO, THC, CH_4, NOx, O_2, sometimes also components such as NH_3, NO_2, N_2O.
  Additionally, a multi-component analyzer, such as an FTIR, can be used for R&D and for NH_3 and N_2O for legislation purpose.
- Smoke Emissions:
  Particulates, smoke and opacity are measured by various devices, such as smoke meters, opacity meters, micro root sensors, etc.
  For emission certification Particulate Mass (PM), Particle Number (PN) for EU and sometimes an opacity meter is required.
- RDE (Real Driving Emissions):
  The PEMS (Portable Emission Measurement Systems) also apply raw emission measurement. Small mobile partial flow dilution systems are integrated for the PM/PN measurement.

Exhaust flow determination is mandatory for undiluted measurement:

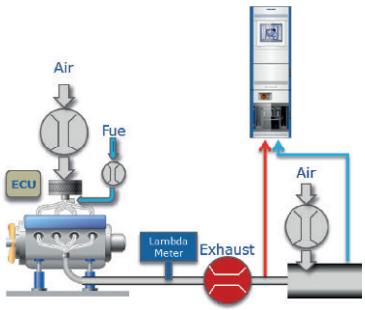
- It is mandatory to measure or determine the total exhaust flow rate of the engine in order to calculate the total mass emissions of an engine by undiluted measurement.
- Before calculating results all signals must be time aligned to compensate for different response times of the signals.

EMISSION MEASUREMENT METHODS



Exhaust Flow Rate Determination:

For emission testing, it is mandatory to measure the total flow rate (in mass or volume) of the engine exhaust. The only exception is when using a CVS system. For undiluted or partial flow diluted measurement, the exhaust flow rate determination is mandatory.



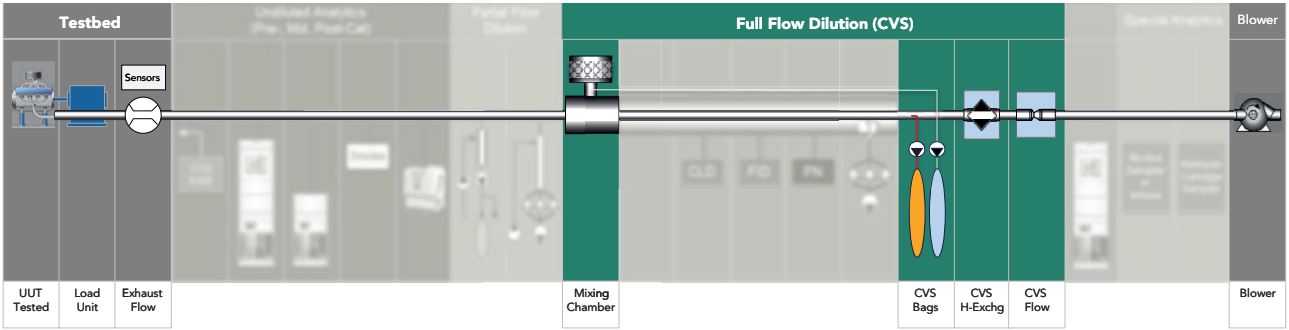
Exhaust Flow determination method	Note
Direct exhaust flow meter	Would be best. However, currently there are testbed devices available within specific technical limits. Used for RDE testing.
Intake air + fuel consumption	Standard method on engine testbeds.
Lambda + fuel consumption or Lambda + intake air	Only used if intake air or fuel is not measured.
ECU data from OBD - II or CAN - Bus	Used for in-service RDE testing. Requires verification/calibration before the operation.
CVS flow and dilution air flow rate	Mainly on chassis dyno testbeds. Recommended for all engines with start/stop and for hybrid vehicles.
CO_2 tracer method with CVS flow rate and dilution ratio calculated by undiluted and diluted CO_2 concentration	Standard method on CVS chassis testbeds. Not recommended for engines with start/stop and hybrid vehicles.

AVL CVS i60 SII & AVL PSS i60 SII –

MOST COMPACT FULL-FLOW DILUTION WITH INNOVATIVE PARTICULATE SAMPLING SYSTEM

Optimized for ultra-low emission testing of all modern engine technologies like HEV/PHEV, gas and alternative fuels - fully compliant to e.g. EPA 40 CFR 1065/1066 and GTR-15.

EMISSION MEASUREMENT METHODS



Full Flow Dilution System – CVS (Constant Volume Sampler):

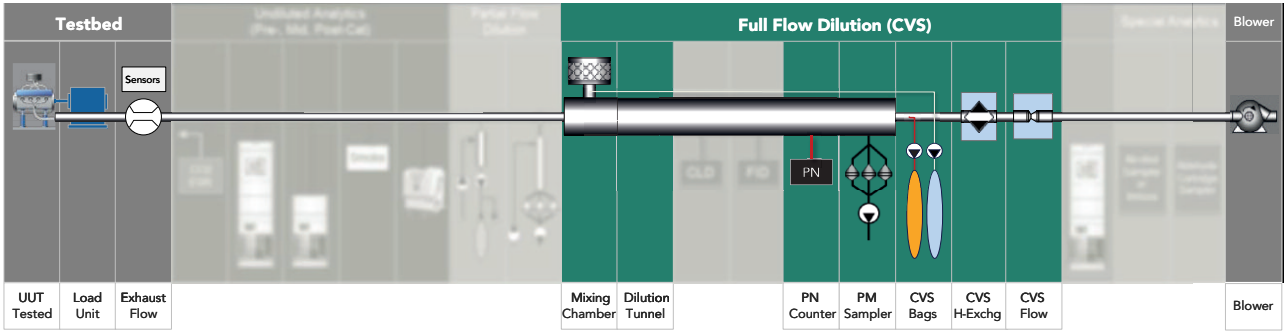
A CVS simplifies mass emission measurement, since there is no need to measure the exhaust flow. It avoids condensation of water from the exhaust and simulates the effects taking place in the ambient environment.
It consists of:

- Blower plus flow measurement and control device, which is typically a critical flow venturi (CFV)
- Mixing chamber and dilution air filter
- Bag sampler to collect samples of diluted exhaust and dilution air
- An optional heat exchanger (heat exchangers were mandatory in the past. Today it is only mandatory for the Japanese light-duty vehicle emission legislation, which will change as soon as Japan adopts the GTR-15 regulation.)

APC^{PLUS} – AVL PARTICLE COUNTER

The next generation of AVL particle number instrumentation for automotive research, development and certification.

EMISSION MEASUREMENT METHODS



Particulate Mass (PM) and Particle Number (PN) measurement:

Particulate formation is neither finished inside the engine nor inside the vehicle exhaust system and continues when the exhaust is diluted in ambient air. Therefore, the CVS is equipped with a "dilution tunnel" to ensure a proper particulate formation before it is measured.

- A particulate sampler (PTS) is used to collect the particulate mass (PM) from the diluted exhaust.
- A particle counter is used to measure the number of particles (PN) in the diluted exhaust.
- In the past, PM and/or PN measurement was only used for compression ignition (diesel) engines. Today, most light duty vehicle legislations require the measurement also for spark ignition engines (e.g. gasoline). Especially direct injection gasoline engines (GDI) can have high emissions of particle numbers.

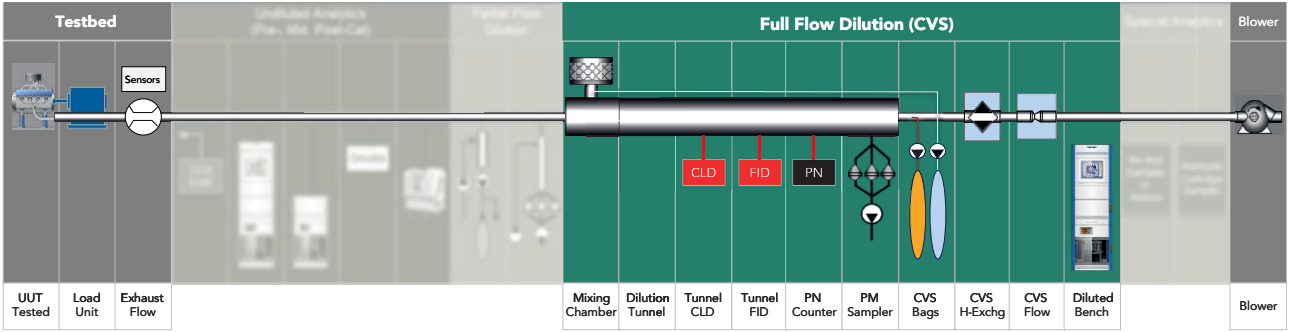
MEMBER OF AVL iGENERATION SII

AVL AMA i60 SII –

HIGH-END EXHAUST MEASUREMENT SYSTEM

Sophisticated, high-end exhaust measurement system focusing on emission testing for certification, R&D purposes and end-of-line testing covering all combustion engines and fuel types.

EMISSION MEASUREMENT METHODS



Gaseous Emission Measurement

- An emission bench for diluted concentrations analyzes the samples of diluted exhaust and dilution air in the CVS bags. Optionally, the diluted exhaust can be analyzed continuously direct from the CVS (modal diluted).

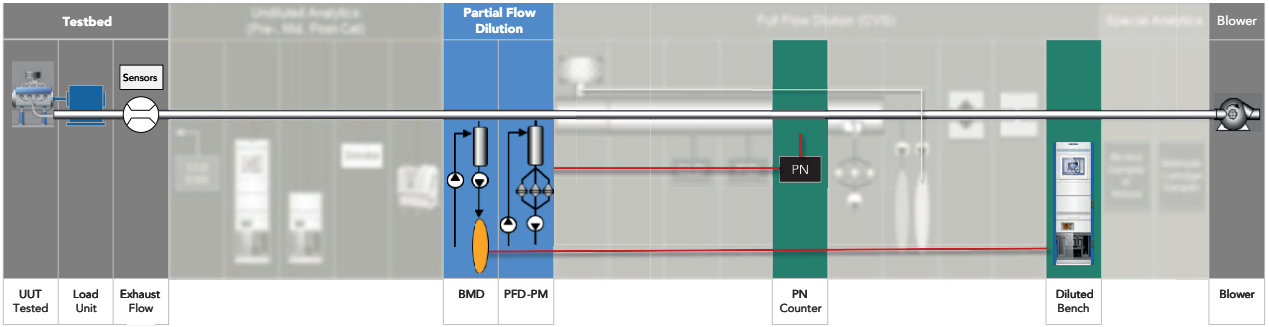
THC, NOx and NO_2 (NO):

- For compression ignition engines (such as diesel), a heated FID is used to measure the hydrocarbons directly and continuously from the dilution tunnel. For heavy-duty engines, a heated CLD is also used to measure the NOx directly and continuously from the dilution tunnel.
- If NO_2 is measured, it has to be measured directly from the diluted exhaust, or, if it is determined by NOx minus NO, the NO has to be measured directly and continuously from diluted exhaust while the NOx can be measured from the CVS bags.

AVL SMART SAMPLER

The next generation of gravimetric particulate matter measurement with partial flow dilution.

EMISSION MEASUREMENT METHODS



Partial Flow Dilution Systems (PFD):

Partial flow dilution systems sample only a small part of the total exhaust. This small sample is then diluted with air.
There are two partial flow dilution systems:

- Partial flow dilution and particulate sample systems for particulate measurement, such as the AVL smart sampler
- Bag mini diluter (BMD) systems for gaseous emissions

Exhaust flow determination is mandatory for partial flow diluted measurement (same as for undiluted measurement):

Exhaust flow rate determination is mandatory, since PFD systems need the exhaust flow rate for controlling its flows and also for result calculation. Therefore it must be:

- fast and
- online

AVL

RDE READY

AVL iGEM VEHICLE EMISSION AUTOMATION

The most advanced automation system for emissions test automation on chassis dynamometers.
Now featuring application solutions for RDE testing, global hybrid testing regulations as well as compliance to EPA 1066 and GTR-15.

EMISSION MEASUREMENT METHODS

Additional Pollutant Analytics: NH_3, Alcohol, Aldehydes

In some applications and regional emission standards, additional emission components must also be measured:

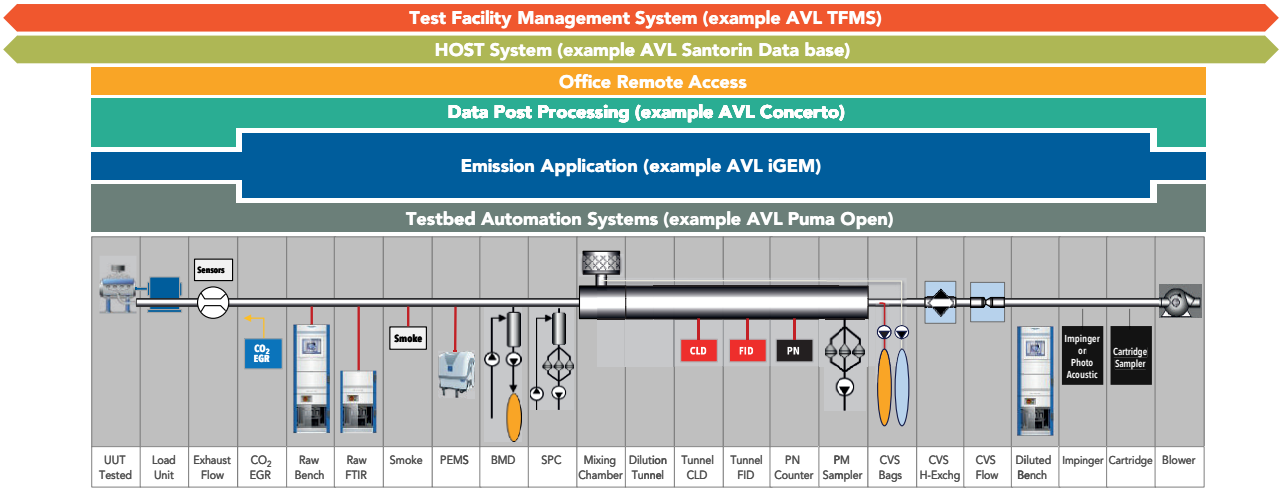
- An impinger sampler for alcohol analysis is required according to US emission regulations. Alternatively, a photo-acoustic analyzer may be used.
- A cartridge sampler for aldehyde analysis is required according to US emission regulations.

However, these measurements are often done manually by chemistry laboratory personnel.

Also, the test may be replaced by applying specific calculation factors on HC results.

- FTIR (multi gas analyzer system) can be used for the NH_3 slip certification on SCR exhaust aftertreatment systems and N_2O for US Green House Gas regulation. The new GTR-15 standard allows FTIR as an alternative measurement procedure for alcohol and aldehydes.

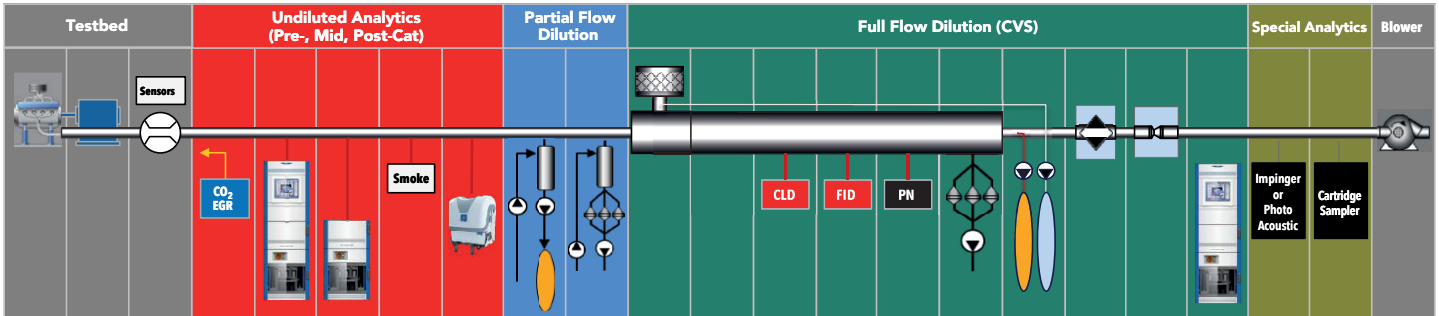
EMISSION MEASUREMENT AUTOMATION

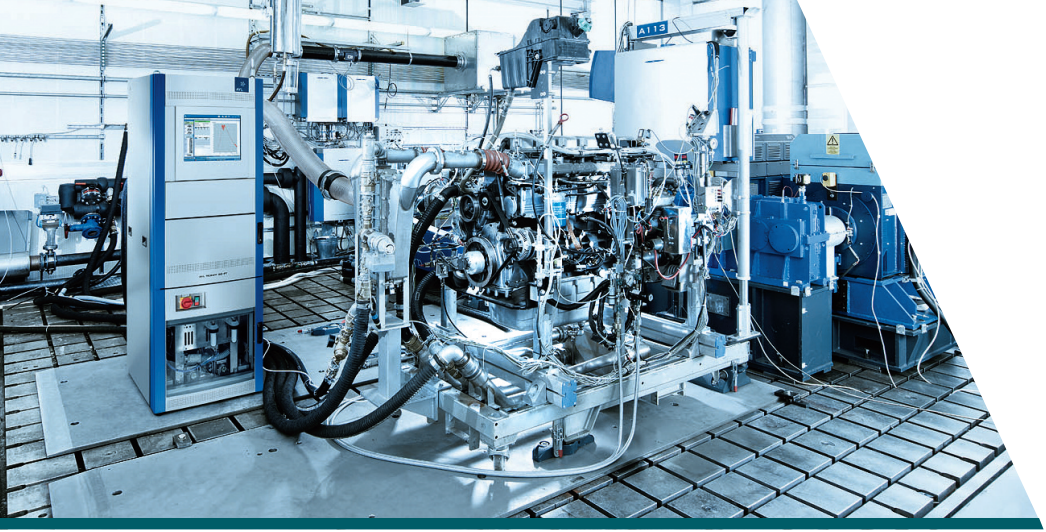


Emission Measurement Automation

An automation system controls the entire workflow of the test, coordinates and controls various devices in the testbed, and records all data. After the test, the data is processed and final results are calculated. In particular, the calculation has to be done in accordance with emissions legislations.

YOUR CONFIGURATION





MEMBER OF AVL iGENERATION SII

AVL SESAM i60 FT SII –

MULTI COMPONENT EXHAUST MEASUREMENT SYSTEM

The FTIR system for synchronous emission measurement of all important exhaust gas components within one system, including NH_3 for Euro VI and N_2O for EPA 40 CFR part 1065.

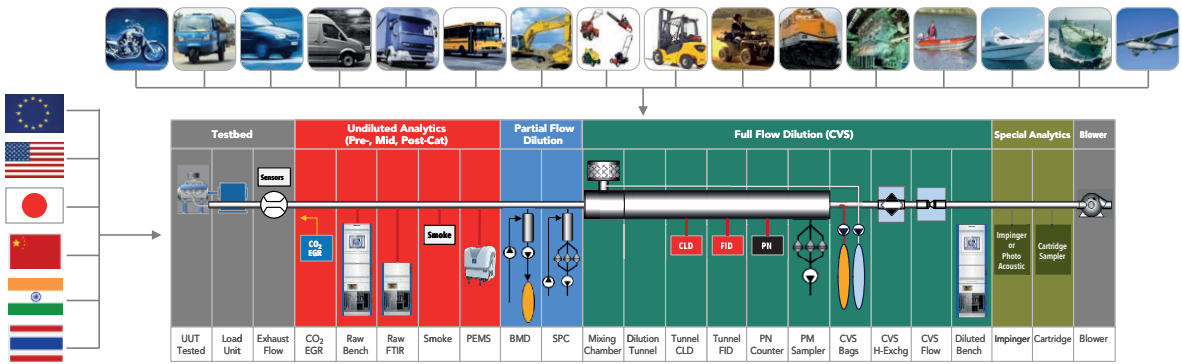
7. EMISSION CERTIFICATION METHODS

EMISSION CERTIFICATION METHODS

Type Approval:
A manufacturer needs to obtain a type approval issued by the local authority in order to sell an engine or vehicle. There are several legislations/regulations, which must be fulfilled. These regulations define the test's process as well as the appropriate measurement and test methods.

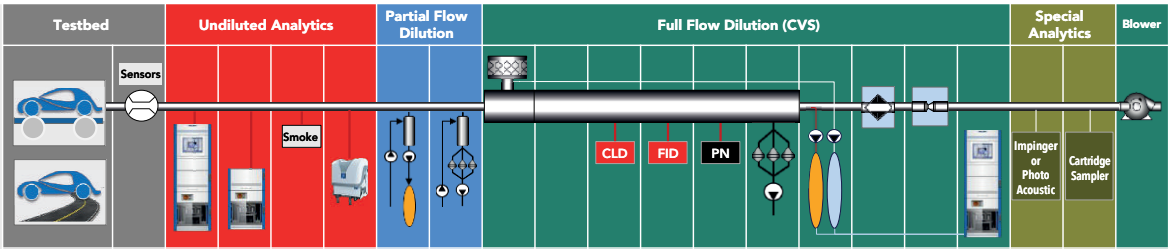
Certification:
Typically, the tests to demonstrate the compliance with these regulations are called "certification tests". In accordance with EU regulations, a technical service (such as TÜV) supervises the test execution and "certifies" the correctness of the test and results.

Testbed configuration for Certification Tests:
Each regulation defines requirements, technical specifications and the accepted measurement methods. The requirements are based on the engine applications and the local legislations.



LIGHT DUTY VEHICLES – CERTIFICATION

Light Duty Vehicles – Emission Certification



		Load Unit	Exh. Flow	Raw Bench	Raw FTIR	Smoke	PEMS	BMD	PFD PM	Mixing device	Dil. Tunnel	Tunnel CLD	Tunnel H-FID	PN	PM	Bags	Heat Exch.	Venturi	Diluted Bench	Alcohol Sampler	Aldehyde Sampler	Blower
EU	EU	Vehicle Chassis Dyno				✓				✓	✓		✓	✓	✓	✓		✓	✓			✓
	EU – RDE	Vehicle on Road	✓				✓															
US	US	Vehicle Chassis Dyno								✓	✓		✓		✓	✓		✓	✓	✓	✓	✓
	Alternative		✓					✓	✓										✓	✓	✓	✓
	Alternative		✓	✓					✓											✓	✓	✓
Japan	Japan	Vehicle Chassis Dyno								✓	✓		✓		✓	✓	✓	✓	✓			✓

Note: The alternatives for the US Standards relate to CFR-1066 and CFR-1065. Smoke measurement accordingly to UN-ECE R-24 on engine test bed or chassis dyno.

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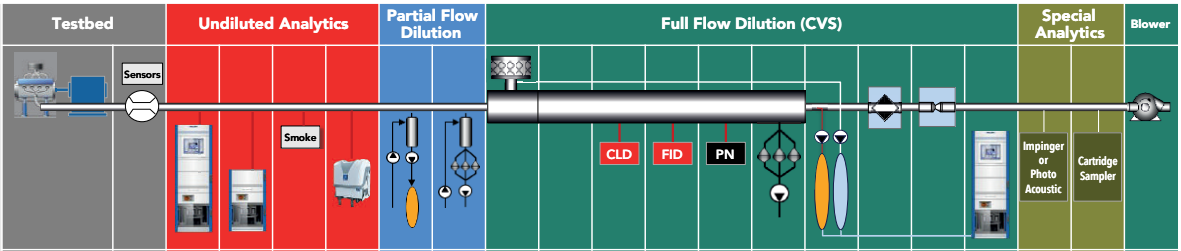
Our comprehensive service portfolio supports you to maintain and even increase the value of your test equipment while keeping the total costs of ownership down to a minimum.

UP-GRADING TESTBEDS FOR EU TESTING

Up-Grade Steps	Topic	Technical requirements added to test and measurement systems
EU-1 to EU-2		
EU-2 to EU-3	Fuel consumption measurement	Euro-1 and 2 fuel consumption was measured by a fuel flow meter. Starting with EU-3, the engine start is part of the test. Therefore, the fuel consumption has to be determined by the C-balance calculations from the emission mass measured during the test.
EU-3 to EU-4		
EU-4 to EU-5a	Methane (CH4) measurement	A NMHC limit was introduced. A CH_4 analyzer is added to measure methane from the bags.
EU-5a to EU-5b	Particle number (PN)	Diesel Particle number (PN) has to be measured for compression ignition engines.
	Particulate mass (PM)	Gasoline Particulate mass (PM) has to be measured for positive ignition engines (GDI).
EU-5b to EU-6b	Particle number (PN)	Gasoline Particle number (PN) has to be measured for positive ignition engines.
EU-6b to EU-6d	GTR-15 Worldwide Light Duty Vehicle Test Procedure (WLTP)	New test cycle WLTC, which is different for the C1, C2, C3a and C3b vehicle classes, depending on the vehicle mass to engine power ratio, and the maximum velocity.
		4 test phases require a CVS bag matrix for 4 phases (PM requires only 2 filters). Some countries may exclude the 4th extra high velocity phase.
		SOC measurement of the on-board battery (12 V). An electrical power analyzer is needed to measure the electrical energy flow into and out of the on-board battery to correct CO_2 and fuel consumption results.
		Test cell and soak area temperature requirements have changed from a temperature range (20° C to 30° C) to a set temperature of 23° C with a tolerance of +/-5° C and +/-3° C at engine starts.
		Major changes in road load determination, vehicle mass as well as testing a low and high CO_2 emitting vehicle must be tested for a vehicle family.
		Various changes in the procedures and vehicle conditioning.
	RDE Real Driving Emissions	In addition to the laboratory tests, a vehicle must be also tested for emissions on the road (CO_2, CO, NOx, PN). Limits will apply for NOx and PN. Already earlier (2016 in EU) a monitoring and reporting phase starts without limits.

HEAVY DUTY VEHICLES – CERTIFICATION

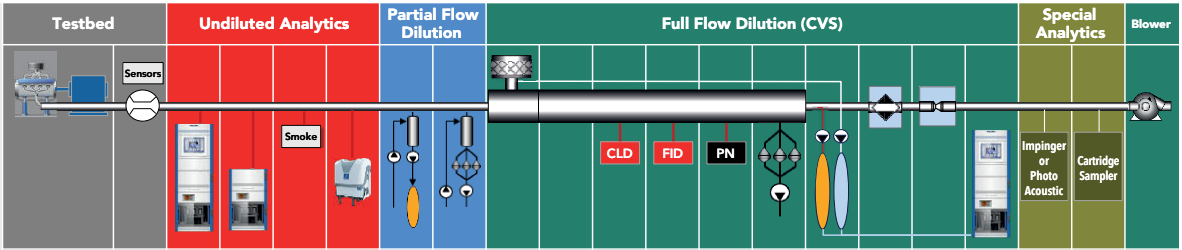
Heavy Duty Vehicle Engine – Emission Certification



		Load Unit	Exh. Flow	Raw Bench	Raw FTIR	Smoke	PEMS	BMD	PFD PM	Mixing device	Dil. Tunnel	Tunnel CLD	Tunnel H-FID	PN	PM	Bags	Heat Exch.	Venturi	Diluted Bench	Alcohol Sampler	Aldehyde Sampler	Blower
EU	EU	Engine Engine Dyno	✓	✓	✓	✓	In-service		✓					✓								✓
	Alternative				✓		In-service			✓	✓	✓	✓	✓	✓	✓		✓	✓			✓
US	US	Engine Engine Dyno	✓	✓			In-service		✓											✓	✓	✓
	Alternative						In-service			✓	✓	✓	✓		✓	✓		✓	✓	✓	✓	✓
Japan	Japan	Engine Engine Dyno	✓	✓		✓			✓													✓
	Alternative									✓	✓	✓	✓		✓	✓		✓	✓			✓

NON-ROAD ENGINES – CERTIFICATION

Non-road Engines – Emission Certification



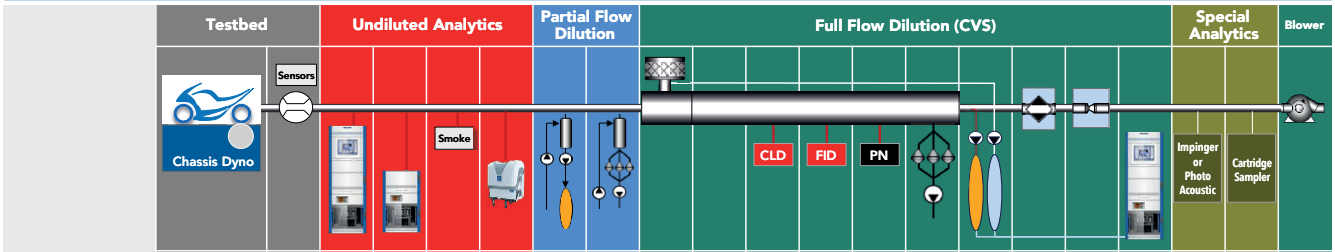
		Load Unit	Exh. Flow	Raw Bench	Raw FTIR	Smoke	PEMS	BMD	PFD PM	Mixing device	Dil. Tunnel	Tunnel CLD	Tunnel H-FID	PN	PM	Bags	Heat Exch.	Venturi	Diluted Bench	Alcohol Sampler	Aldehyde Sampler	Blower
	EU	Engine Engine Dyno	✓	✓		✓			✓													✓
	US	Engine Engine Dyno	✓	✓					✓													✓
	Japan	Engine Engine Dyno	✓	✓		✓			✓													✓

Note: Due to the wide range of engine sizes, usually no CVS system is used.
For small off-road engines (SORE), e.g. hand-held engines in garden equipment, a full flow dilution can be very useful for the following reasons:

- It is difficult to install a raw exhaust sample probe in the exhaust system of such small engines.
- These engines are usually 2-stroke engines. On such engines it is better to use an exhaust funnel covering most of the equipment, instead of attaching an exhaust transfer line, which might affect the engine performance.

2- AND 3-WHEELERS – CERTIFICATION

2- and 3-Wheelers – Emission Certification



		Load Unit	Exh. Flow	Raw Bench	Raw FTIR	Smoke	PEMS	BMD	PFD PM	Mixing device	Dil. Tunnel	Tunnel CLD	Tunnel H-FID	PN	PM	Bags	Heat Exch.	Venturi	Diluted Bench	Impinger	Cartridge	Blower
	EU	Vehicle Chassis Dyno								✓						✓		✓	✓			✓
	US	Vehicle Chassis Dyno								✓						✓		✓	✓	✓	✓	✓
	Alternative		✓					✓											✓	✓	✓	✓
	Alternative		✓	✓																✓	✓	✓
	Japan	Vehicle Chassis Dyno								✓						✓		✓	✓			✓

Note: The alternatives for the US Standards relate to CFR-1066 and CFR-1065

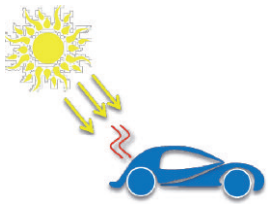
8. EVAPORATIVE EMISSIONS (EVAP)

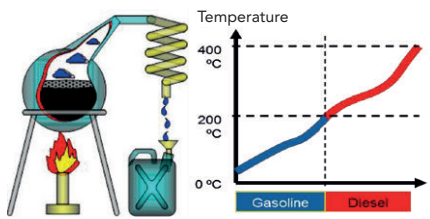
AVL PARTICLE MEASUREMENT

- Complete solutions made even better
- Compact, intelligent, maintenance-friendly

EVAPORATIVE EMISSIONS

While tailpipe emissions are only emitted when the engine is running, evaporative emissions are emitted also when the engine is off. Gasoline vapors are volatile hydrocarbons (VOC volatile organic compounds), which would be a significant contribution to hydrocarbon emissions and the formation of ground-level ozone and secondary organic aerosols, if not reduced. Without counter measures, evaporated hydrocarbons would be emitted into the environment from the vehicle fuel system, whenever the fuel temperature in the fuel tank increases and the fuelvapor would be emitted through the tank ventilation, as permeation losses or over system leaks. Also, when a vehicle is refueled at a gas station, the new fuel pushes out the air containing fuel vapor from the tank.





Evaporative emissions

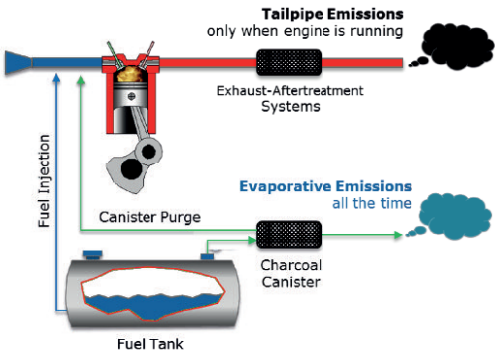
The fuel in the tank warms up and generates hydrocarbon vapor even when the vehicle is not running, e.g. when parking in the sun, or by hot return fuel coming from the fuel injection system. Evaporated fuel, in an entirely closed fuel system, would increase the pressure inside the system. This would be an issue in terms of safety and refueling. Therefore, tank systems are open to release air. Without counter measures the fuel vapor would be released and pollute the environment.

It is a gasoline only issue

- Only gasoline fuel has the potential to evaporate at ambient temperatures, therefore only gasoline fuelled vehicles undergo an evaporative emission test.
- The reason that gasoline evaporates at ambient temperatures results from how it is produced. Crude oil is heated up and the hydrocarbons evaporate, after cooling down the hydrocarbons condense to liquid fuel. Gasoline consists of hydrocarbons that evaporate between ambient temperature and 200° C. For example, diesel consists of hydrocarbons that evaporate between 200 and 400° C.

PREVENTING EVAPORATIVE EMISSIONS

Evaporated hydrocarbons (VOC volatile organic compounds) pollute the environment. They are restricted in most modern emission standards worldwide. In addition to the environmental impact, it would also be a waste of fuel and money since a certain amount of purchased fuel is not used to power the vehicle. Without counter measures it is estimated that there would be 1 million tons of evaporative hydrocarbon emissions emitted in the US, and fuel worth 1 billion US dollar would be lost per year.



Tailpipe Emission Control:

Tailpipe emissions only occur when the engine is running. In order to reduce tailpipe emissions, all modern engines are equipped with exhaust after-treatment systems, like catalytic converters, LNT, SCR, DPF, GPF …

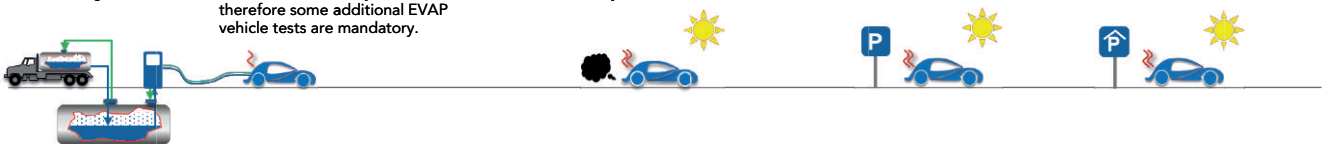
Evaporative Emission Control:

Evaporative emissions occur when the vehicle is running as well as when the vehicle is not operated.

- In order to reduce evaporative emissions, a charcoal filter (canister) is placed in the tank ventilation line. The charcoal filter temporarily stores the evaporated hydrocarbons.
- Since the storage capacity of the canister is limited, it has to be regenerated from time to time by purging the canister with ambient air. The purge air flow through the canister is generated by the vacuum of the engine intake air system (down stream of the throttle). By that
- the canister is regenerated,
- the evaporated hydrocarbons are burned instead of emitted to the environment and
- the fuel vapor is also not wasted, but drives the car. A canister might capture approx. 300 g of fuel vapor, where an engine may run in idle up to 30 minutes.

EVAPORATIVE EMISSIONS

Fuel supply chain	Vehicle refueling	Driving	Parking after driving	Long term parking
Balancing fuel and air between supply truck and gas station tank This is not part of emission regulations.	In some regions, like the EU, it is mandatory to balance the fuel and air between the gas station tank and the tank of the vehicle. This is not mandatory in the US, therefore some additional EVAP vehicle tests are mandatory.	While driving, the fuel temperature increases due to ambient temperature, heat of the exhaust system and hot fuel returning from the fuel injection.	Fuel evaporation during parking and cools down shortly after the vehicle was driven.	Fuel evaporation during long-term parking. The canister is continuously loaded but cannot be regenerated since the engine is not running.



Test Requirements	ORVR Test	Fuel Spit-Back	Point Source	Running-Loss	Hot Soak	Diurnal	Bleed Emission
	Onboard refueling vapor recovery (ORVR) test determines the fuel vapor coming out of the tank when a car is refueled.	Measures the liquid fuel spit-back from the fuel nozzle during refueling the car.	Measures fuel vapor at potential vapor emitting points during driving on a chassis dyno in a climatic chamber.	Measures fuel vapor during driving a car on a chassis dyno, which is built into a SHED chamber.	Measures fuel vapor emissions in a SHED after a car was driven on a chassis dyno.	Measures fuel vapor emissions in a SHED during parking for 24 h, 48 h or 72 h.	Like the diurnal test, but the bleed emissions are sampled by separate small SHED boxes.
							
Legislation in place							

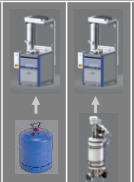
PASSENGER CAR – EVAP CERTIFICATION

EVAP Certification Requirements

		Conditioning								SHED Chambers				Sampling Systems			Analytics		others
																			
		Chassis Dyno	Canister Condition-ing with gas	Canister durability with Fuel	Purge air Condition-ing	Fuel station	Fuel Condition-ing	Heating Pads	Hot street surface simulation	SHED Chamber	Variable Vol./Temp Chamber	Running Loss Chamber	Bleed chamber	ORVR test Devices	Spit-Back test devices	Point source systems	H-FID Analysis	Ethanol	Perme-ability test
	EU	✓	✓	✓	✓	✓		✓			✓						✓		
	USA	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	
	Japan	✓	✓	✓	✓	✓		✓			✓						✓		
	China	✓	✓	✓	✓	✓	✓	✓	✓		✓			✓			✓		
	Brazil	✓	✓	✓	✓	✓	✓	✓		✓							✓	✓	
	Korea	✓	✓	✓	✓	✓		✓			✓						✓		

MOTORCYCLES – EVAP CERTIFICATION

EVAP Certification Requirements

		Conditioning								SHED Chambers				Sampling Systems			Analytics		others
																			
		Chassis Dyno	Canister Condition-ing with gas	Canister durability with Fuel	Purge air Condition-ing	Fuel station	Fuel Condition-ing	Heating Pads	Hot street surface simulation	SHED Chamber	Variable Vol./Temp Chamber	Running Loss Chamber	Bleed chamber	ORVR test Devices	Spit-Back test devices	Point source systems	H-FID Analysis	Ethanol	Perme-ability test
	EU	✓	✓			✓	✓	✓		✓							✓		✓ (2020)
	USA	✓	✓			✓	✓	✓		✓							✓		
	Japan	✓	✓			✓	✓	✓		✓							✓		
	China	✓	✓			✓	✓	✓		✓							✓		
	India	✓	✓			✓	✓	✓			✓						✓		
	Thailand	✓	✓			✓	✓	✓		✓							✓		✓

GLOSSARY

AVL	Anstalt für Verbrennungskraftmaschinen List
B5, B10	Diesel with 5, 10% Bio-Diesel content
BEV	Battery Electric Vehicle
CARB	California Air Resource Board
CFR	Code of Federal Regulations
CFV	Critical Flow Venturi
CH4	Methane
CI	Compression Ignition
CO	Carbon Monoxide
CO2	Carbon Dioxide
COP	Conformity Of Production
CVS	Constant Volume Sampler
CxHy	Carbon Hydrogen
DPF	Diesel Particulate Filter
E10, E85	Gasoline with 10, 85% Ethanol content
EC	Energy Consumption
ECU	Engine Control Unit
EOL	End Of Line (Testing)
EPA	Environmental Protection Agency
ETS	Emission Testing Systems (AVL company)
EU	European Union
EVAP	EVAPorative emission
E-Vehicle	Electric Vehicle
FC	Fuel Consumption
FID	Flame Ionization Detector (Analyzer)
FTIR	Fourier Transform InfraRed (Analyzer)
FTP-75	Federal Test Procedure 75 (Drive Cycle)
GPF	Gasoline Particulate Filter
GTR	Global Technical Regulation
H2	Hydrogen
HC	HydroCarbon
HEV	Hybrid Electric Vehicle
H-FID	Heated Flame Ionization Detector
I/M	Inspections and Maintenance
I/O	Input / Output
IMO	International Maritime Organization
ISO	International Standardization Organization
LCV	Light Commercial Vehicle
LEV	Low Emission Vehicle
LNT	Lean NOx Trap
LPG	Liquid Petrol Gas
MC	Motor Cycle
MIL	Module In the Loop
N2O	Dinitrogen Oxide
NG	Natural Gas
NH3	Ammonia
NO2	Nitrogen Dioxide
NOVC	Not Of Vehicle Charging
NOx	Nitrogen Oxides
O2	Oxygen
OBD	On Board Diagnosis
OCE	Off Cycle Emission
OEM	Original Equipment Manufacturer
OME	OxyMethylene Ether (Fuel)
ORVR	Onboard Refueling Vapor Recovery
OVC	Off Vehicle Charging
PC	Passenger Car
PEMS	Portable Emission Measurement System
PFD	Partial Flow Dilution
PHEV	Plug-in electric Hybrid Vehicle
PI	Positive Ignition (like SI)
PM	Particulate Mass
PN	Particle Number
PtG	Power to Gas (fuel)
PtL	Power to Liquid (fuel)
PTS	ParticulaTe Sampler
R&D	Research and Development
RCCI	Reactivity Controlled Compression Ignition engine burning two fuels
RDE	Real Driving Emissions
SCR	Selective Catalytic Reaction
SHED	Sealed Housing for Evaporative emission Determination
SI	Spark Ignition (like PI)
SIL	Software In the Loop
SORE	Small Off-Road Engine
TA	Type Approval
Tier	Step (used in legislation)
UN-ECE	United Nation - Economic Commission for Europe
US	United State (of America)
UUT	Unit Under Test
WLTC	Worldwide harmonized Light-duty vehicles Test Cycle
WLTP	Worldwide harmonized Light-duty vehicles Test Procedure

GLOSSARY

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