Appendix A: Glossary of terms

ASM	Acceleration simulation mode
BAR	Oregon Bureau of Automotive Repair
BIVV/IBSR	Belgisch Instituut voor Verkeesveiligheid/Institut Belge de la Sécurité Routière
C3I	Computer-controlled coil ignition
CARB	California Air Resources Board
CH_4	Methane
CI	Compression ignition
CKP	Crankshaft position sensor
CLD	Chemiluminescence detector
CLRTAP	Convention on Lang-range Transboundary Air Pollution
CO	Carbon monoxide
CO_2	Carbon dioxide
CRT	Continuously regenerating trap
CUEDC	Composite Urban Emissions Drive Cycle
CVS	Constant volume sampling (system)
DOC	Diesel oxidation catalyst
DPF	Diesel particulate filter
DTC	Diagnostic trouble code
EC	European Commission
ECU	Engine control unit
EEPS	Engine exhaust particle sizer
EGR	Exhaust gas recirculation
ELPI	Electrical Low-Pressure Impactor
EOBD	European on-board diagnostics
EU	European Union
EUDC	Extra-Urban Driving Cycle
FAS	Free acceleration smoke (test)
FID	Flame ionisation detector
FSN	Filter Smoke Number
FTP	(US) Federal Test Procedure
HC	Hydrocarbons
I/M	Inspection and maintenance
ISO	International Organization for Standardization
MAF	Mass air flow (sensor)
MIL	Malfunction indicator lamp
NDIR	Non-dispersive infrared absorption spectroscopy
NDUV	Non-dispersive ultraviolet absorption spectroscopy
NEDC	New European Drive Cycle
NH_3	Ammonia
NO	Nitric oxide
NO_2	Nitrogen dioxide
NO_x	Nitrogen oxides (NO + NO_2)
O_2	Oxygen

O_3	Ozone
OBD	On-board diagnostics
OBM	On-board measurement
PEMS	Portable Emission measurement system
PM	Particulate matter
PM_{10}	Particulate matter with an equivalent aerodynamic diameter of 10 µm or less
$PM_{2.5}$	Particulate matter with an equivalent aerodynamic diameter of 2.5 µm or less
PMP	Particle Measurement Programme
Ppb	Parts per billion
PTB	Physicalisch Teschnische Bundesanstalt Braunschweig
PTI	Periodic technical inspection
QCM	Quartz crystal microbalance
RC	Readiness code
rpm	Revolutions per minute
SCR	Selective catalytic reduction
SI	Spark ignition
SMPS	Scanning Mobility Particle Sizer
TEOM	Tapered Element Oscillating Microbalance
UDC	Urban Driving Cycle
UNECE	United Nations Economic Commission for Europe
VOCs	Volatile organic compounds

Appendix B: Reasons for emission test failures and methods of simulating faults

B1 Faulty EGR valve

B1.1 Description of fault

Where there is an EGR-related fault, pollutant levels in the exhaust will depend upon the position of the EGR valve, *i.e.*:

- Valve open: increased PM emissions.
- Valve closed: increased NO_x emissions.

A permanently open EGR valve can result in the engine being difficult to start, poor and irregular engine idle, white smoke in the exhaust, engine cut-off during driving, lack of power, and various EOBD fault codes.

The EGR-valve function is subject to closed-loop control by the mass air flow (MAF) sensor or by the position sensor on the EGR valve (if mounted). Faulty EGR valves can cause OBD diagnostic DTCs from the EGR valve or the MAF sensor. An additional EGR valve function check is provided by the wideband oxygen sensor.

B1.2 Simulation of fault

Excessive and insufficient EGR flow can be simulated (depending on the type of engine) using the methods described below.

1. *Excessive EGR flow:* This can be simulated by installing a calibrated pass-through (washer) in the MAF sensor of vehicles which use the sensor for EGR control (*e.g*. Mercedes-Benz CDI OM642). All the air drawn into the engine is forced through the washer and also through the MAF sensor. This will result in an excessive air measurement by the ECU. The ECU will conclude that the EGR valve is not working properly (not opening), and the engine controller will try to compensate for this by increasing the EGR valve duty cycle.
2. *Excessive EGR flow:* Excessive EGR flow can also be simulated by removing the EGR valve or modifying the valve position so that it is completely open. Another approach is to dismantle the EGR valve and remove the valve stem. The valve is then mechanically modified but remains electrically operational.
3. *Insufficient EGR flow:* For vehicles using the MAF for EGR control this fault can be simulated by blocking the calibrated opening in the MAF sensor with, for example, tape or silicone sealant. As a result of this action, none of the air drawn into the engine passes through the MAF sensor element, and there is an insufficient air measurement by the ECU. The ECU will conclude that the EGR valve is not working properly (completely open) and the engine controller will try to compensate this by lowering the EGR valve duty-cycle. In some cases, metal plates are mounted in the EGR lines to manually disturb/block the EGR functioning. In other cases, vacuum hoses, which are necessary to actuate the EGR valve properly, are removed, disassembled or blocked

When simulating excessive EGR flow care is required as it is possible that the (cold) engine will stall. Several DTCs relating to MAF and/or EGR valve operation may also result when simulating excessive or insufficient EGR flow.

B2 Dirty air filter

B2.1 Description of fault

Excessive black smoke can be produced during acceleration due to a dirty air filter element. Modern cars with state-of-the-art diesel engines have a pressure sensor mounted in the suction line between the turbocharger and the air filter. This sensor is continuously used to monitor the pressure drop (at all engine speeds and loads). When a low pressure is measured the engine controller reacts immediately by lowering the turbocharger pressure set point and fuel injection quantity (fail safe mode, power drop). A dirty air filter can lead to a vacuum in the suction line and a turbocharger over-speed condition (known as the 'vacuum cleaner' effect).

B2.2 Simulation of fault

This problem can usually be simulated by simply mounting a dirty air filter.

B3 Faulty injectors

B3.1 Description of fault

A faulty, dirty or worn diesel fuel injector can lead to poor atomization and a lean or rich air/fuel mixture which, in turn, will lead to poor combustion and increased pollutant emissions.

In older diesel engines the fuel quantity from the injectors is not controlled or adapted by the ECU. Worn springs in fuel injectors will lead to a rich air/fuel mixture and, usually black smoke from the exhaust. Dirty injector nozzles can cause irregular idle and poor engine performance.

Modern diesel engines with electronic high-pressure injection systems (e.g. common rail, unit injectors) have a 'smooth running adaptation/correction' from idle up to 2800 rpm which monitors the engine torque produced per cylinder.

B3.2 Simulation of fault

This fault can be simulated by installing worn or faulty injectors, although these may be difficult to obtain.

B4 Incorrect ECU codes

B4.1 Description of fault

Incorrect programming of the IMA/ISA/C2I/C3I codes in the ECU after replacing injectors can disturb the smooth running adaptation/correction and the measurements from the wideband oxygen sensor. This will result in:

- Increased PM emissions.
- Increased CO_2 and CO emissions.
- Increased NO_x emissions.
- Engine vibration, engine misfire.
- Poor engine performance, including engine cut-off during acceleration.
- EOBD DTCs.

The injector operation is closed-loop monitored by the CKP (crankshaft position sensor) and the wideband oxygen sensor. Faulty injector programming can cause DTCs. Each injector is classified by the manufacturer after having been tested on an engine test bed. The injector receives a special unique alphanumeric code. This code is programmed into the ECU and used as bias. After a specified distance travelled by the vehicle, the code will cease to be valid due to injector wear and soiling. In this case the offset is learned and the bias is adjusted. This value can be used for diagnostic purposes.

B4.2 Simulation of fault

This problem can easily be simulated by using an appropriate scan tool to modify/swap the coding/classification between 1, 2 or more injectors (for example injectors 2 and 3 are swapped). Another possibility is to program the ECU with codes for injectors which are currently in stock in the warehouse. However, these actions may result in the appearance of several DTCs relating to injector coding and emissions.

B5 Faulty or dirty wideband oxygen sensor (Euro 4 onwards)

B5.1 Description of fault

The wideband oxygen sensor measures the oxygen concentration in the exhaust. The ECU can easily determine the average amount of fuel injected at all engine speeds and the EGR operation with this information. The wideband oxygen sensor works in close collaboration with the MAF sensor.

A faulty wideband oxygen sensor can result in:

- Increased PM emissions.
- Increased CO_2 and CO emissions.
- Increased NO_x emissions.
- Poor engine performance.
- EOBD DTCs (such as oxygen sensor or MAF offset drift).

B5.2 Simulation of fault

This fault can be simulated by replacing a functioning oxygen sensor with a faulty or dirty one. Again, it is possible that several DTCs relating to MAF sensor and/or oxygen sensor operation will appear.

B6 Catalytic converter faults

B6.1 Description of fault

In diesel vehicles an (oxidising) catalytic converter is used to convert CO and HC to water and CO_2. NO is also converted to NO_2. The catalytic converter is made of a ceramic or metal monolith (support) which is axially perforated with cubic holes of 1 mm. The walls are coated with a wash of platinum and rhodium catalysts. Diesel vehicles equipped with particulate filter have the catalytic converter mounted in front of the filter. NO_2 produced in the catalytic converter oxidises the soot the DPF.

In some cases the catalytic converter can be removed to improve top-end performance and torque, as converters and filters create back pressure, especially at high engine speeds. This can result in the following:

- Increased emissions of PM, HC and CO.
- Noise from the exhaust.

In other cases the monolith is damaged or worn due to either mechanical shock or prolonged use. The monolith can be reduced in size so much that it can obstruct the exhaust line. This prevents the release of exhaust gases, and the back pressure in the engine results in extreme smoke. Sometimes the engine stalls and will no longer start. Aggressive acceleration or braking can influence the position of the obstruction. Excessive back-pressure can lead to the following problems:

- Increased emissions of PM, HC and CO.
- EOBD DTCs.
- Engine cut-off, lack of power, or poor performance.
- Smoke.
- Engine vibration and misfire.

B6.2 Simulation of fault

This fault can be simulated by:

- Removal of the catalytic converter.
- A damaged catalyst can be simulated by mounting an obstruction either in the exhaust or in the catalytic converter itself.

B7 Faulty DPF

B7.1 Description of fault

'Full-flow' DPFs have a very high efficiency under favourable conditions. Evidence of this can be found by examination of the inside of the exhaust pipe, which can be clean even after many kilometres of operation. Up to 95-98% of all particles produced by a diesel engine are removed by the DPF, and subsequently burned to ash, CO and CO_2 inside the filter. A certain amount of ash stays inside during the lifetime of the filter life.

During a free acceleration test on a diesel vehicle equipped with a DPF there will tend to be hardly any increase in the k value (opacity) over the background. If the k value does increase during the test - as would be the case for a vehicle without a DPF – it is likely that the DPF is faulty (monolith broken or removed). The inside of the exhaust pipe is also likely to be completely black.

A faulty DPF can result in the following problems:

- An increase in PM emissions.
- DTCs (e.g. excessive backpressure, mass airflow sensor offset).

It should be noted, however, that some 'partial-flow' DPFs have a lower particle removal efficiency (up to 40-50%) than full-flow DPFs, even if they are in good condition. It is therefore important to know what type of DPF is fitted to the vehicle before doing the test, as with a partial-flow filter particles will still be present in the exhaust gas.

B7.2 Simulation of fault

This fault can be simulated by installing a defective DPF, or by removing the DPF.

B8 Insufficient urea additive for SCR

B8.1 Description of fault

The current technology of choice for reducing emissions of NO_x is selective catalytic reduction (SCR). In an SCR system the exhaust gas is mixed with a reagent (usually ammonia) and passed over a catalyst. SCR systems have been available on a large scale since the introduction of Euro IV and Euro V road vehicles. For road vehicles the use of ammonia itself has been practically ruled out due to safety concerns, and urea solution ($CO(NH_2)_2$ in water) has been selected by a number of manufacturers as the additive of choice for meeting the Euro V (2008) limit (2 g/kWh) for heavy-duty engines.

The urea additive is stored in a separate tank near the diesel tank. It is important to ensure that there is always an adequate supply of urea solution in the tank. If a truck, bus or car with an SCR system is operated without the additive, then there is risk that the SCR system will be damaged and emissions will increase. The driver would also experience a loss of engine power until the additive is replenished. The quality of the urea is also important, and this is controlled by the DIN V 70070 standard.

B8.2 Simulation of fault

The problems associated by an insufficient supply of urea to the SCR system can be simulated by simply emptying the urea tank, although in some cases the vehicle may no longer start.

B9 Faulty turbocharger

B9.1 Description of fault

A turbocharger improves an engine's efficiency forcing a greater mass of air into the cylinders on each intake stroke. It consists of a small centrifugal pump driven by the energy of the exhaust gases. Turbochargers have decreased in size over the years, for quick spool-up during different engine loads and speeds. The bearing shaft can reach 200,000-240,000 rpm. The tips of the compressor and turbine wheel will reach the speed of sound during full acceleration.

The lifetime of a turbocharger is normally equal to that of the engine, but after around 250,000 km there is risk of reduced efficiency. The most common problems with turbochargers are:

- Dirt on the turbine and compressor wheel.
- Imbalance and excessive noise.
- Faulty variable turbine geometry (stuck, dirty).
- Oil leakage due to excessive crankcase pressure (blow-by gasses).
- Main bearing shaft and thrust collar wear due to oil impurities, lack of lubrication, too long service intervals or diesel fuel in the oil.
- Over speed, excessive temperature, worn out compressor wheel, turbine and compressor wheel touching the housing.

A slow turbocharger spool-up can increase PM emissions and black smoke during accelerations. A dirty, malfunctioning variable turbine geometry can provoke:

- DTCs for boost pressure, lack of power (poor engine performance), engine protection mode (electronic limitation).
- Turbocharger noise (galloping).

B9.2 Simulation of fault

Turbocharger faults can be simulated as follows:

- Intercooler hose partially removed: By creating an air leakage, one can simulate a faulty turbo charger.
- Mounting a dirty air filter, although care needs to be taken to avoid over-revving the engine.
- Removal of the turbo vacuum hose, or disconnection of the variable turbine geometry actuator.

B10 Faulty intercooler

B10.1 Description of fault

An intercooler is used to improve engine efficiency by increasing the density of the intake air through cooling. A common fault is a crack in the intercooler. The zone around the crack is normally wet, dirty and greasy as a result of oil from the crankcase ventilation system. Some of the pressure generated by the turbocharger can be vented to the atmosphere through the crack, resulting in a lower boost pressure in the inlet manifold. If the crack is small the turbocharger can compensate for the reduction in pressure by rotating more quickly. If the crack is large, the manifold pressure will be much lower than the set point and the engine performance will drop dramatically. The boost pressure is measured by the boost pressure sensor, and it is possible that the fuel injection quantity will be reduced by the ECU.

A cracked intercooler, hose or intake manifold can result in:

- DTCs for boost pressure, lack of power (poor engine performance), engine protection mode (electronic limited).
- Increased PM emissions, and black smoke when accelerating.
- Noise: a turbo whistle for a small crack, and dull, nasal engine manifold sound for a large crack.

B10.2 Simulation of fault

This problem can be simulated as follows:

- Intercooler hose partially removed: By creating an air leakage, one can simulate a faulty turbocharger.
- Mounting a dirty air-filter.
- Remove the turbo vacuum hose/disconnect the VTG (variable turbine geometry) actuator

B11 Damaged piston bowl

B11.1 Description of fault

A damaged piston bowl is often the result of thermal stress (*e.g.* through chip tuning) or a faulty injector. The piston will no longer have the properties of a brand new piston (regarding squish and swirl). Depending on the degree of deformation/damage to the piston, it is possible that the piston failure can only be noticed when the engine is cold (irregular idle, bad starting, engine noise) and no longer when the engine has warmed up. There could be hole and a small crack in the piston parallel to the piston/connecting rod pen. The next step is that the piston will crack completely.

A faulty piston bowl can result in:

- Increased HC and PM emissions.
- Lack of power.
- Excessive noise and engine damage (worn, grooved cylinder).
- Higher carter pressure (due to blow-by gasses).
- Irregular idle, engine vibrations, shudder.

B11.1 Simulation of fault

This fault is difficult to simulate. Usually an older vehicle with this existing fault must be used.

B12 Low compression

B12.1 Description of fault

A number of faults can result in reduced compression inside the engine, including worn piston rings, faulty valves, faulty valve guides, paved valve seals, wrong valve clearance and cracked pistons. This loss of compression can dramatically influence the combustion process and the formation of exhaust pollutants. Compression loss can result in:

- Increased PM emissions.
- Increased HC, CO, CO_2 and NO_x emissions.
- Engine vibration/shudder.

B12.2 Simulation of fault

This fault mode is difficult to simulate: an obstruction must be introduced into the intake system.

B13 Worn piston rings

B13.1 Description of fault

Worn piston rings lead to increased consumption of engine lubricating oil. This, in turn, leads to black and blue smoke in the exhaust during normal engine operation. This will not visible on a vehicle with a DPF, although the DPF will become saturated extremely quickly. The DPF will therefore require frequent regeneration (*e.g*. every 80 km instead of every 800-1,000 km). These forced regenerations are accompanied by abundant post injections which are used to burn particles into ash inside the filter. Excess fuel in the cylinders can also leak into the oil sump through the piston rings, and severe engine damage may result.

Excessive oil consumption can result in:

- Increased PM emissions and smoke in the exhaust.
- Increased HC, CO, CO_2 and NO_x emissions.
- Damage to the engine, turbocharger, bearings and timing chain.
- Engine over speed due to too much diesel fuel in the lubricating oil.

B13.2 Simulation of fault

This fault is difficult to simulate. Usually an older vehicle with this existing fault must be used.

B14 Incorrect camshaft timing

B14.1 Description of fault

Four-cylinder in-line engines are very sensitive to incorrect inlet and exhaust camshaft timing. If the timing of one or both camshafts is too advanced or retarded, engine vibrations/oscillations can be the result, especially at idle speed. Also, exhaust emissions will be higher than if the engine is properly timed due to bad filling and lower overall compression.

Faulty camshaft timing can result in:

- Increased PM emissions.
- Increased HC, CO, CO_2 and NO_x emissions.
- Engine vibration/shudder.

B14.2 Simulation of fault

This fault can be simulated in collaboration with vehicle manufacturer, although there is a risk of damage to the engine.

B15 Incorrect injection timing

B15.1 Description of fault

For older diesel vehicles injecting the fuel too early results in increased NO_x emissions and a harsh noise (diesel knock), whereas injecting the fuel too late results in increased HC and PM emissions. This is not a problem associated with modern systems such as unit injectors and common rail.

B15.2 Simulation of fault

The injection timing can be advanced or retarded.

B16 Faulty glow plugs

B16.1 Description of fault

The diesel glow plug heats up the combustion chamber so the diesel fuel can easily and spontaneously combust. The glow plug is also used for post-glowing. This means that if the engine is turning after a cold start, the glow plugs are still operational for several seconds/minutes to reduce pollutant emissions and white smoke (unburned HC and soot particles). Vehicles equipped with DPFs also use the glow plugs during filter regeneration 'DPF glowing'). Faulty glow plugs can be detected when the glow plug indicator light is always on or remains on during post-glow. Older direct-injection diesel vehicles can be started without glow plugs.

Faulty glow plugs can result in:

- Increased HC and PM emissions.
- Increased CO and CO_2 emissions.
- Irregular engine idle after start up (multiple misfire).
- Long cranking time.
- Poor DPF regeneration and excessive filter soiling.
- Engine soiling (due to impurities).

B16.2 Simulation of fault

Faulty glow plugs can be simulated by disconnecting the pre-glow module or one or more glow plugs, starting the engine from cold (coolant temperature below 40°C) and measuring emissions at idle. It should be noted that low-compression diesel engines will be hard to start (long cranking time) and will run very irregularly. Once the engine has warmed up the test must be stopped because the engine will start and run without any problems. Multiple cylinder fault codes on glow plugs can appear during pre and post-glow.

B17 Internal engine soiling

B17.1 Description of fault

Modern diesel engines use a high percentage of EGR during certain conditions: up to 40-50% for the low engine loads and speeds which are mostly used by drivers. The return of exhaust gases is always combined with internal engine soiling (soot particles), especially when the engine speed is low (low airflow speed). This is partially avoided by the EGR throttle valve. During low engine speeds and loads, the throttle valve is partially closed to enhance the air flow speed.

Soot particles can be transformed into 'carbides' during high temperatures and pressure phases. Carbides are known as been very abrasive. The engine will also draw in oil vapours from the carter ventilation system. The amount of oil returned into the intake system and turbocharger depends on oil quality, engine temperature, engine condition (blow-by gasses), *etc*.

The soot particles and oil deposits will be mixed in the intake manifold. This will create a thick tough coating inside the hoses and manifolds. The engine operation can be jeopardised by this restriction, affecting combustion

Internal engine soiling can result in:

- Increased PM emissions and fuel consumption.
- Increased CO, CO_2, HC and NO_x emissions
- Engine damage (sticking valves) and lack of power.
- Irregular idle, engine misfire, vibrations, shudder.
- Poor DPF regeneration and excessive filter soiling.
- DTCs for poor engine performance, engine protection mode (electronic limitation).

B17.2 Simulation of fault

This fault can easily be simulated as follows:

- Intercooler hose partially removed: by creating an air leakage one can simulate a soiled intake system.
- Mounting a dirty air-filter: attention. Again, care needs to be taken to avoid over-revving the engine.

B18 Incorrect pressure in carter ventilation system

B18.1 Description of fault

Carter ventilation is the collection of all blow-by gases mixed with the oil vapour. These blow-by gases and oil vapours are always present, but can increase under the following circumstances:

- Worn piston rings/cylinders.
- Cold engine/cold pistons.
- Extremely hot engine, causing engine oil to evaporate (low quality oil).
- Faulty valve seals or worn out valve guides.
- Dirty air filter.
- Faulty turbocharger (worn rings).
- Clogged carter ventilation filter.

B18.2 Simulation of fault

This fault can be simulated by installing a clogged air filter.

B19 Chip tuning

B19.1 Description of fault

'Chip tuning' is frequently used to increase engine power and torque. It is nothing more than increasing the maximum injection quantity and/or maximum injection time and maximum boost pressure in the ECU. The average increase in the injection quantity is 20-25%. This results in an average of 15-20% more power and torque.

This can be done through the OBD connector, or by removing the processor (the processor is programmed while removed from the ECU). In most cases the EGR system and the swirl valves are also deactivated. A modified ECU will often result in higher exhaust emissions and an increase in black smoke during acceleration. In some cases the engine will run worse after chip tuning than before. Some chip tuners also adapt the maximum engine speed limit in the ECU to obtain a higher top speed.

Badly tuned diesel engines can result in:

- Increased PM emissions.
- Increased HC, CO, CO_2 and NO_x emissions.
- Increased risk of engine damage due to thermal stress.
- Increased risk of damage to transmission, brakes systems, *etc.*
- Poor drivability, misfire, vibrations and shudder during misfire.

B19.2 Simulation of fault

This fault can be simulated as follows:

- Mounting a tuning box on the common rail pressure sensor.
- Mounting a tuning box on the common rail injectors.
- Mounting a tuning box on the fuel temperature sensor in the fuel return line from the unit injectors.
- Programming the ECU processor through OBD: to be done by a professional who can easily change the settings (EGR on/off, swirl valves on/off, *etc.*).

Appendix C: International standards for emission measurement equipment

The range of application of ISO standards is very wide. The standards which are directly linked to the measurement of emissions from M1 and N1 vehicles are described below.

ISO 11614:1999 *Reciprocating internal combustion compression-ignition engines -- Apparatus for measurement of the opacity and for determination of the light absorption coefficient of exhaust gas*

This standard describes the technical and metrological features applied to the production, the use, the maintenance and the verification of opacity meters using the light absorption coefficient to measure opacity. This type of device is compatible with the free acceleration test (72/306/EC) and the ELR test (88/77/EC). This type of device can be used for transient tests, both loaded (cf. chassis or engine dynamometer) and unloaded (cf. free acceleration).

ISO 10054:1998 *Internal combustion compression-ignition engines -- Measurement apparatus for smoke from engines operating under steady-state conditions -- Filter-type smoke meter*

This standard applies to stationary cycles used for the control of the exhaust of diesel engines.

ISO/TR 9310:1987 *Road vehicles -- Smoke measurement of compression-ignition (diesel) engines -- Survey of short in-service tests*

This ISO procedure describes and compares six short tests for measuring diesel smoke. The methods incorporate both unloaded and loaded test cycles, and can be carried out in PTI or on the road.

Appendix D: Instruments for measuring emissions during PTI

The photographs of emission-measurement devices in the report have been reproduced by kind permission of the manufacturers.

D1 Instruments for NO/NO_2 measurement

D1.1 Non-dispersive ultraviolet absorption spectroscopy (NDUV)

An example of an instrument which uses the NDUV principle to measure NO and NO_2 is the SEMTECH-DS system manufactured by Sensors Inc (Figure D1). The system is normally used in laboratory, such as for engine development. The SEMTECH-DS can be used to measure CO, CO_2, O_2, NO, NO_2 and THC in the raw exhaust from both spark ignition and compression ignition engines, and is compliant with the USEPA's CFR 1065 standard. There is an optional heated FID sampling probe which maintains the exhaust temperature at 191°C. Bespoke software is provided for controlling the SEMTECH-DS and calculating emissions. A wireless Ethernet connection can be used for communication between a computer and the instrument.

Sensors Inc. has also developed a NO/NO_2 analyser (SEMTECH-NO_x) which is specifically designed to measure NO and NO_2 on-board vehicles, in the laboratory, and during PTI. The analyser, shown in Figure D2, is based on the SEMTEC-DS, incorporating the same NDUV system, with the benefits of this measurement method (eliminates cross-sensitivity with water vapour, fast response time, good correlation with chemiluminescence analysers).

Figure D1: Sensors Inc. SEMTECH-DS.

Figure D2: Sensors Inc. SEMTECH-NO_x.

D1.2 Electrochemical cell instruments

Some examples of electrochemical cell instruments are described below.

MAHA MET series

The MET series is designed for the measurement of petrol and diesel vehicle exhaust during PTI. The MET 6.1 version is shown in Figure D3. Depending on the configuration, it can be used to measure the concentration of CO, CO_2, HC, O_2, NO_x, and particulate mass as well as opacity.

The device is available in a version with a simple display (LCD), showing values and configurations, or with a graphical display and menu-driven operation. Communication to a PC system is via wireless (WLAN) or LAN. MAHA note that the instrument is easy to maintain, with filters being accessed through covers on the side of the body. The analyser is approved to the requirements of OIML Class 1.

Figure D3: MAHA MET 6.1.

SAXON-Junkalor - Infralyt ELD

The Infralyt ELD instrument produced by SAXON-Junkalor GmbH is designed for the measurement of pollutant concentrations in diesel exhaust. It employs an infrared optical bench to measure CO, CO_2 and HC, and electrochemical cells to measure O_2, NO and NO_2. The Infralyt ELD is small, compact and easy to handle (Figure D4). The wide ranges available for measurement allow a diagnosis of modern diesel vehicles with DPFs. The instrument can be used with a small hand-held logging unit (with internal line printer) or with a PC/Notebook.

Figure D4: SAXON-Junkalor Infralyt ELD.

Autocal P550

The Autocal P550 is a small, light (5kg) instrument for analysing emissions (Figure D5) which is specifically designed for PTI emission checks on petrol and diesel vehicles. It employs NDIR to measure CO, CO_2, and HC, and electrochemical cells to measure O_2 and NO. The P550 also measures oil temperature, and displays engine speed and (calculated) lambda. The instrument works independently (*i.e.* it does not require an external computer), and has its own LCD screen. The analyser is approved to the requirements of OIML Class 1.

Figure D5: Autocal P550.

D1.3 Other methods

Ultraviolet resonance absorption analysers can also be used for type approval according to UNECE Regulation 83. However, there do not appear to be any instruments operating on this principle which are suitable for use in PTI emission tests.

One new instrument manufactured by Capelec (the CAP3800 model, as shown in Figure D6) is designed for PTI emission tests, but it is still at the prototype stage and therefore no information on the operational principle was available from the manufacturer. The instrument seems to have no active pump for exhaust gas; exhaust gas pressure is used to draw a representative gas sample into the analysis chamber. The construction suggests that it works like an opacimeter, combining opacimetry with the measurement of NO_x (which Capelec term 'OpaciNO$_x$').

Figure D6: Capelec CAP 3800.

D2 Instruments for opacity/PM measurement

D2.1 'Standard' opacimeters

Norris (2005) noted that the Bosch RT430 was the reference instrument in the UK, and as such it gave the 'accepted' absolute smoke values from free acceleration tests. The unit measures the percentage reduction in intensity of a green LED source by exhaust smoke along a 430 mm tube. Features include clean air purges for the windows through which the light is admitted and leaves the measurement tube, thermostatic control to reduce condensation, pressure regulation, and light intensity control to compensate for window fouling. Other models in widespread use include those produced by Capelec, Crypton/Dieseltune, MAHA, MEXA, Sensors Inc., TEN, and another of manufacturers.

D2.2 Advanced opacimeters

The AVL 439 opacimeter (Figure D7) is a dynamic partial-flow measuring instrument for the continuous measurement of exhaust gas opacity. It is more accurate and stable than standard opacimeters as a result of the inclusion of, for example, a diaphragm sampling pump for constant filling of the measuring chamber, sample re-circulation, a constant flow rate even at varying exhaust pressure, heated windows to protect the optical components, sample and conditioning. The measurement principle is shown in Figure D8.


Figure D7: AVL 439 opacimeter.

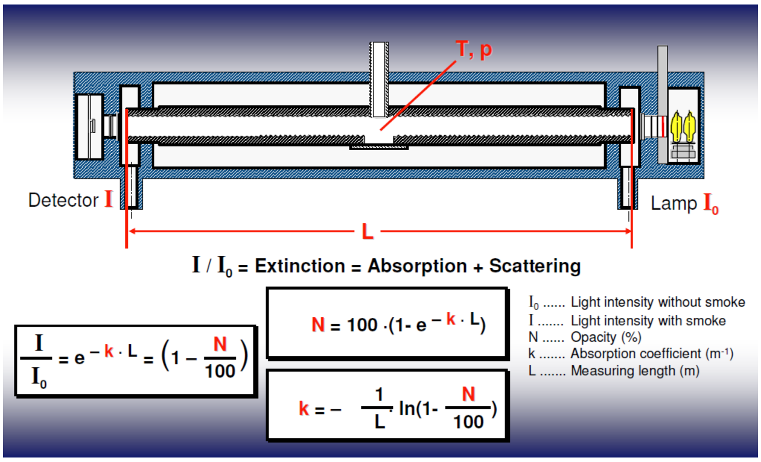

Figure D8: AVL 439 measurement principle (source: AVL).

D2.3 Light-scattering meters

Some specific instrument models are summarised below.

MAHA MPM-4 (now known as MET 6.2)

The MAHA MPM-4[1] is a laser light-scattering PM analyser which is specifically intended for measuring exhaust particle mass concentrations in a non-laboratory environment such as a test centre. According to the manufacturers the instrument can verify if a DPF is functioning within its claimed effectiveness. MAHA also notes that this type of measurement system is already being used by the Australian authorities.

The analyser measures the PM concentration (in mg/m^3) continuously, and logs the results at a frequency of up to 10 times per second. It can therefore track the effects of transient vehicle operation. The MPM-4 can identify particles which range in size from less than 100 nm up to 10 µm, and can also measure opacity (0.001 to 3 m^{-1}). Analyses presented by MAHA suggest that there is a good correlation between the opacity and particle mass concentration readings of the MPM-4 (MET 6.2) instrument, and with the mass concentration from an AVL 'micro soot' analyser. Stewart (2010) noted that the good correlation extended to high values.

BOSCH BEA 080

The BEA 080 – shown in Figure D9 - is designed to measure PM emissions from modern diesel vehicles during PTI, based on the scattered light principle. It can measure exhaust opacity down to 0.1 m^{-1}, and with a resolution of 0.001 m^{-1}. Following certification by the PTB (Physicalisch Teschnische Bundesanstalt Braunschweig) the BEA 080 will be available for use by inspection authorities in Germany. The device has no display of its own, and must be controlled using a PC.

Figure D9: BOSCH BEA 080.

[1] http://www.maha.co.uk/cps/rde/xchg/maha_internet_uk/hs.xsl/default.htm

AVL DiTEST Smoke 2000

AVL describes its Smoke 2000 model as a 'second generation opacimeter' which works according to the scattered light method. The system is driven by a pump with a typical exhaust flow of two litres per minute. With its fast response time and time resolution of 100 Hz the device is suitable for on-line transient measurements. Its robustness, portability and short start-up time also mean that it is suitable for use in the garage environment.

The manufacturer claims that the model is much more sensitive than the devices currently being used in the field, with a resolution of 0.001 m^{-1} (0.1 mg/m^3), a lower detection limit of 0.010 m^{-1} (1 mg/m^3) and an upper limit of 3.0 m^{-1}. It is claimed to be suitable for reliable measurements on current and future low-emission diesel engines and for the detection of defective DPFs.

Figure D10: AVL DiTEST Smoke 2000.

SICK FW100 series

The SICK FW100 series of dust monitors is designed for the continuous measurement of dust concentrations between 0.1 mg/m^3 and 200 mg/m^3. A laser diode directs a beam of modulated light (wavelength 650 nm) through the sample, and the light scattered by particles is recorded by a detector (Figure D11). The point of intersection between the transmitted beam and the receiver aperture defines the measuring volume in the gas duct. The scattered light intensity is proportional to the dust concentration. The FW100 series instruments must be calibrated with a gravimetric method (SICK MAIHAK, 2004).

Norris (2005) assessed a SICK FW102 model, and reported that the instrument's range was for particles larger than 500 nm; it had a low sensitivity for particles smaller than 200 nm.

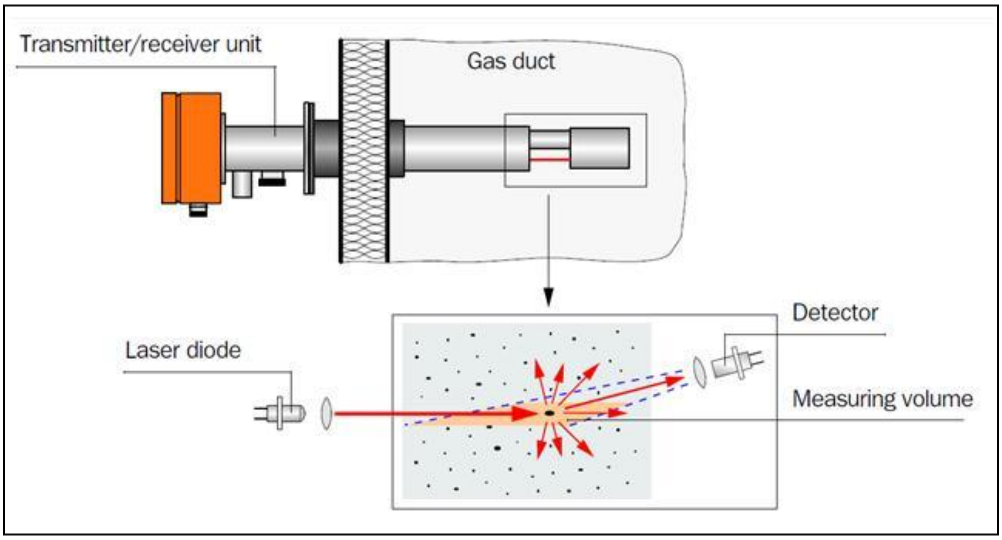

Figure D11: SICK FW100 series method of operation (SICK MAIHAK, 2004).

TSI DustTrak

The DustTrak is a relatively inexpensive general-purpose instrument. The manufacturer's calibration is based on particles of a mass and size range referred to as 'Arizona Dust'. Once calibrated it does not require further adjustment, close monitoring or even regular servicing. The DustTrak has a dynamic range of 0.1 μm to 10 μm.

In terms of operational practicality, Anyon *et al.* (2000) noted that the DustTrak was a robust, compact and a simple instrument to operate, and one that was suitable for widespread use as a means of measuring PM in vehicle I/M programmes.

D2.4 'Escaping current' sensors

Two examples of these devices are described below.

Pegasor PPS-M

Pegasor Ltd. has developed a compact, real-time PM sensor (the PPS-M) which can be installed at the point of measurement in engine exhaust without the need for a complex dilution system (Figure D12). The sensor can be calibrated for both particle mass and particle number concentrations.

The sensor operates by electrostatically charging particles using a corona discharge, with the concentration being determined as described above (Ntziachristos *et al.*, 2011). The operational principle is illustrated in Figure D13.

Figure D12: Pegasor PPS-M sensor.

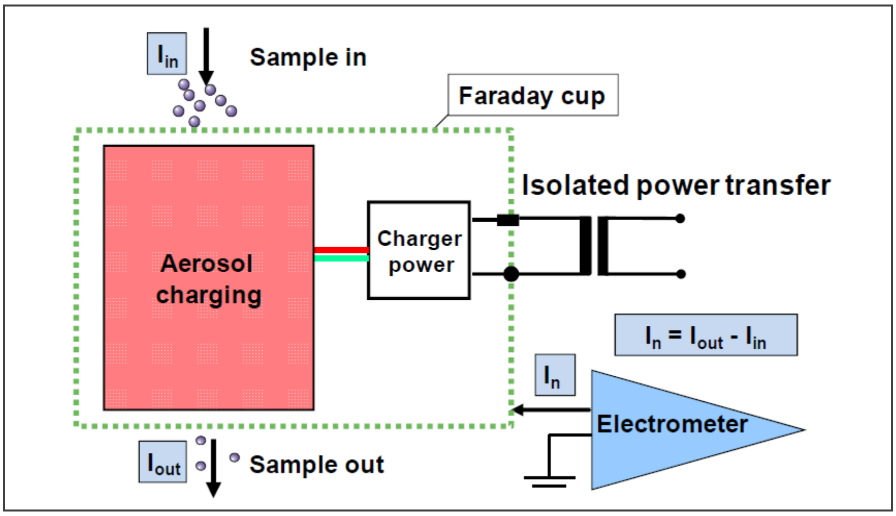

Figure D13: The basic principle of the electrical aerosol sensor based on the measurement of the escaping current (Ntziachristos *et al.*, 2011).

Even minimal soot deposition on critical surfaces may cause current leakage, thus affecting the measurements. Furthermore, the contamination of high-voltage insulators reduces the discharge voltage, preventing ion production. In order to address these issues all sensitive surfaces are protected from soot deposition. Figure D14 shows how this is achieved; clean filtered air is fed through an air nozzle where the corona tip is located (Ntziachristos *et al*., 2011).

The sensor provides high resolution (1 Hz), a fast response (0.3 seconds T_{90}) and high sensitivity. It has been found to be sensitive enough to clearly detect a defective particle filter, even at PM emission levels as low as 6 mg km^{-1} (Ntziachristos *et al*., 2011).

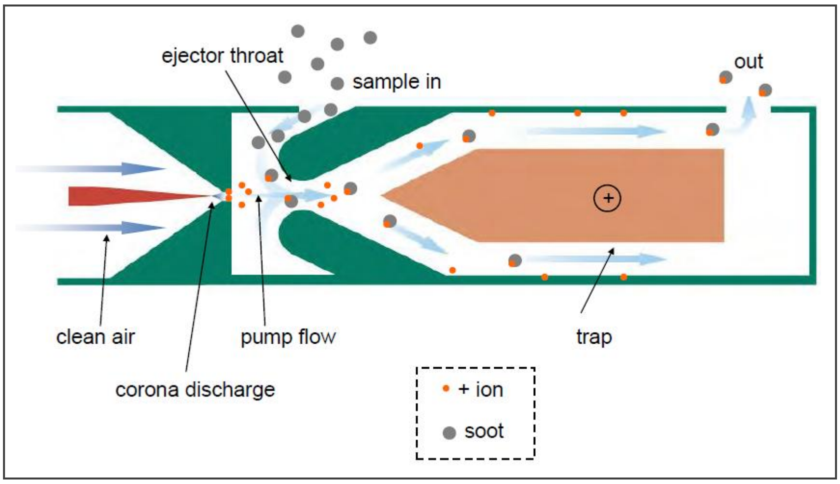

Figure D14: PPS-M sensor schematic.

Dekati ETaPS

Dekati's Electrical Tailpipe PM Sensor (ETaPS) is a flow-through device which can be used to measure particles in petrol and diesel exhaust under steady-state and transient conditions. The instrument has a fast response time (<0.5 seconds) and a wide dynamic range (0.01-100 mg/m^3), covering particle emission levels from DPF-equipped vehicles up to old heavy-duty diesel engines. It can operate up to a maximum temperature of 500°C, and can handle exhaust flow rates of between 3 and 60 m/s (Dekati, 2008).

The operational principle of the ETaPS sensor is illustrated in Figure D15, and is similar to that described above for the Pegasor PPS-M. However, there are several differences between ETaPS and PPS-M. The latter is much more protective of its electronics. Instead of exposing the corona to the exhaust flow (as ETaPS does), the PPS protects its corona in a sheath flow and exhaust particles are only charged by turbulent mixing with ions in a corona discharge region. This protects the corona, as it is never exposed to the exhaust stream. Moreover, the PPS contains a tiny ejector dilutor that sucks in the sample. This can reduce the sensor dimensions relative to EtaPS, and reduces particle losses (Ntziachristos, 2011).

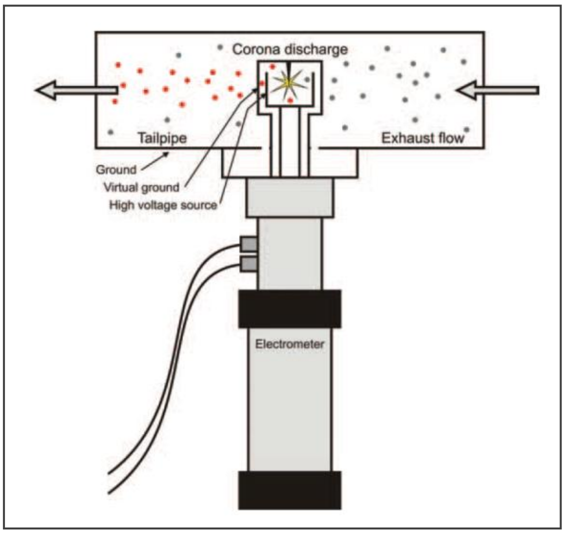

Figure D15: Schematic of ETaPS sensor (Dekati, 2008).

Appendix E: PTI test procedures

E1 Unloaded tests

E1.1 Idle tests

Idle tests are commonly used for petrol vehicles in I/M programmes. One-stage tests with the engine at natural idle are the most common, but there are some examples of two-stage tests in which emissions are measured at both low and high engine speed. The inclusion of a lambda test at high idle can help to reveal whether the catalytic converter is functioning, the exhaust pipe is leaking, and the testing has been carried out properly (USAID, 2004).

The test can last from less than one minute in the case of a one-stage test without pre-conditioning to about 10 minutes in the case of a two-stage test with pre-conditioning.

Idle tests are not considered to be appropriate for modern diesel vehicles, as NO_x and PM emissions under no-load conditions are low.

E1.2 Free acceleration smoke (FAS) test

In many countries the PTI emission test for all types of diesel vehicle involves the measurement of exhaust smoke opacity. Because smoke levels at engine idling speed (or under low load) are nearly always low regardless of the condition of the vehicle, free acceleration tests are often used (Faiz *et al.*, 1996). For example:

- In Europe, Directive 72/306/EEC describes the FAS test which is performed as part of the type approval procedure. This procedure is also used for PTI testing, as specified in Directives 2009/40/EC and 2010/48/EC.
- In the United States the EPA recommends (but does not mandate) the use of the free acceleration test described in SAE J1667 as the basis for diesel vehicle inspection. SAE refers to the test as a 'snap-acceleration procedure', but it is also commonly called the 'snap-idle test', the 'J1667 test' and the 'free-acceleration test'. Several jurisdictions have either implemented such tests or have pilot programmes under way.

The particular test procedures used are in all cases similar, though not identical.

E1.3 INCOLL/AUTONAT

These two tests were designed for use with petrol cars. The INCOLL test was devised by the University of Technology of Gothenburg. A similar test called AUTONAT has also been proposed by the Centre de Recherche en Machine Thérmiques in France. The tests were described by Samaras and Zachariadis (1995).

Neither the INCOLL nor the AUTONAT tests require the use of a chassis dynamometer. Instead, the vehicle's engine is accelerated and decelerated rapidly so that the load the engine has to overcome in order to accelerate its rotating and reciprocating parts (including flywheel and gearbox) approximates to the load during a normal driving cycle.

The INCOLL test involves increasing the engine speed from low idle to 4,500 rpm in less than 100 ms. In the AUTONAT test the accelerator pedal is actuated according to a driving schedule through an electronically controlled mechanism, while either the raw exhaust concentrations are continuously measured or diluted exhaust is collected and analysed after the end of the test.

Both the INCOLL and AUTONAT tests have demonstrated reasonably good correlation with emissions over type approval cycles. Whilst the conduct of the actual test cycle requires between only two and five minutes, it takes some time (around 30 minutes in the case of AUTONAT) to obtain the relationship between accelerator pedal position and engine speed and load for each car type. This approach is therefore considerably more complicated than applying a standard test to all vehicle types.

E1.4 Procedures described by Norris (2005)

In the UK Low-Emission Diesel Research project a gentle acceleration was used (Norris, 2005). The study showed that during gentle accelerations EGR systems operate in different ways. To ensure that the test included a working region of the EGR the engine speed was slowly increased from idle to a suitable upper limit (4,000 rpm), with the vehicle unloaded (*i.e.* neutral gear selected). The rate of increase in the engine speed was not described, but a slope of 50 rpm per second would appear to be reasonable. We refer to this test hereafter as 'Norris-A'. Since the EGR unit is an important emission-reduction system for NO_x emissions, this could be an important test. In the study itself the working of the EGR was determined using concentrations of CO_2 and O_2.

In the same study another test cycle was used in order to turn on the EGR. For some of the vehicles tested merely gently touching the accelerator pedal at idle (up to 900-1000 rpm) caused the EGR unit to turn on, and then after a certain time (2 minutes) to turn off again. We refer to this test hereafter as 'Norris-B'. This procedure was not applicable to all vehicles.

E2 Loaded steady-state tests

These are the simplest loaded tests, in which the engine is held at a specified speed (or a series of sequential speeds) for a desired amount of time by the variable brake loading provided by a power-absorbing dynamometer. In the steady state no inertia simulation is necessary: the load on the engine stays the same. The application of load permits the measurement of NO_x.

E2.1 US Federal 3-Mode

The Federal 3-Mode test was developed in the United States in the 1970s as a possible short procedure for evaluating emissions from petrol cars in I/M programmes. The vehicle is placed on a dynamometer without a flywheel. The test involves two different vehicle speed/load points (Table E1) and a low idle (unloaded) point. The load varies according to the vehicle's inertia weight. The whole test takes around 10 minutes to complete (including preparation, testing and documentation). The engine needs to be preconditioned for 10-15 seconds at 2,500 rpm. Each test phase can then take no longer than two minutes.

Table E1: US Federal 3-Mode test – loaded points.

Inertia [kg]	High speed		Low speed	
	Speed [km/h]	Load [kW]	Speed [km/h]	Load [kW]
≤ 1134	80.00	15.75	50.00	6.75
1135 - 1586	80.00	19.50	50.00	9.00
1589 - 2041	80.00	23.25	50.00	11.25
≥ 2041	80.00	27.00	50.00	13.50

Pollutant concentrations (CO, HC and NO_x) are measured in the raw exhaust. NDIR analysers are used for CO and HC, and a chemiluminescence analyser for NO_x. Whilst the results from the test correlated reasonably well with those from the Federal Test Procedure (FTP) used for type approval in the US, it was never implemented due to the high capital costs associated with the dynamometer and NO_x analyser (Norris, 2002).

E2.2 Clayton Key Mode

Like the Federal 3-Mode test, the Clayton Key Mode test was developed in the United States in the 1970s for the testing of petrol cars. The test itself is also very similar to the 3-Mode test, the main differences being the actual vehicle weight band and the speed/load points used (Table E2). Correlations with FTP test results were good, but again the test was not implemented because of high capital costs. Poor repeatability of the test was also a factor.

Table E2: Clayton Key Mode test.

Inertia [kg]	High speed		Low speed	
	Speed [km/h]	Load [kW]	Speed [km/h]	Load [kW]
≤ 1270	60.00	10.50	47.00	3.75
1271 - 1724	72.00	16.88	50.00	6.75
≥ 1725	80.00	21.38	53.00	8.25

E2.3 CalVIP

The CalVIP test was developed by the California Air Resources Board (CARB) and was used in the centralised I/M programmes that ran in Los Angeles from 1979 to 1984. Few details of the test appear to be available. It is again very similar to the US Federal 3-Mode test, but with different speed and load points (Table E3). Samaras and Zachariadis (1995) stated that it would be reasonable to assume that either a brief operation at 2,500 rpm (as in the Federal 3-Mode and Clayton Key Mode tests) or a 3-minute steady-state loaded operation on a dynamometer (as in transient loaded tests) would be used for preconditioning purposes.

Table E3: CalVIP test.

Number of cylinders	Speed [km/h]	Load [kW]
≤ 4	65.00	7.500
5 up to 6	65.00	11.250
≥ 7 and m ≤ 1477 kg	65.00	13.125
≥ 7 and m > 1477 kg	65.00	15.375

E2.4 D550

The D550 short steady-state test is described by Anyon (1995). It is conducted using a constant dynamometer load equivalent to a fully laden vehicle driving up a 5% gradient at 50 km/h. This represents a near full-load condition for most vehicles. As it is a constant load, constant-speed test, it requires only a simple dynamometer. The test is designed so that there is no need to establish maximum power or torque outputs.

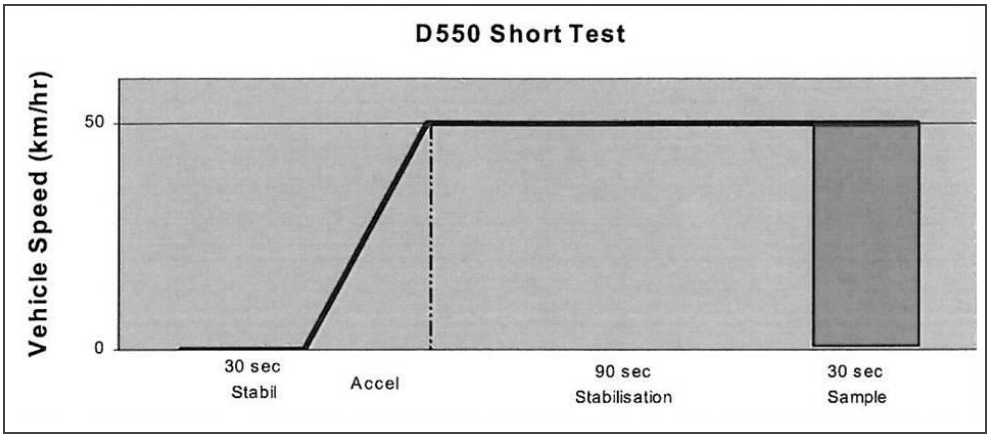

Figure E1: D550 test (Kolominskas *et al.*, 2005).

E2.5 Acceleration Simulation Mode (ASM) tests

In the ASM test for petrol cars the vehicle is driven on a basic chassis dynamometer without the use of inertial flywheels. The inertial load normally encountered during accelerations is simulated by applying additional load. The vehicle is driven on the dynamometer at a constant speed, with a steady-state power absorption that is equal to the actual road load of the car (except the rolling resistance) during acceleration. This circumvents the need for flywheels. However, at high speed / high acceleration combinations the required power absorption is too great to be achieved without the engine overheating. This restricts the useable speed/power range.

The US state of Texas has introduced the ASM test for I/M. Detailed procedures are available from the Texas Department of Public Safety (De la Torre Klausmeier Consulting Inc., 2002). In the Texas ASM test HC, CO and NO_x are measured during two modes: a high load / low speed condition (the 5015 test) and a moderate speed / moderate load condition (the 25/25 test):

- The ASM 5015 tests a vehicle at a load simulating 50% of the maximum acceleration rate on the FTP (50% of 3.3 mph s^{-1}) and 15 mph.
- The ASM 2525 tests a vehicle at a load simulating 25% of the maximum acceleration rate on the FTP (25% of 3.3 mph s^{-1}) and 25 mph.

The ASM test is more effective at identifying emission-related problems than the two-speed idle test which was previously used in Texas, and it is much more difficult to get a vehicle to pass it without performing necessary repairs. An evaluation study of ASM tests concluded that they can identify more than 80% of excess HC and CO emitters, with few errors of commission (Austin and Heirigs, 1995).

In the late 1980s TÜV also investigated the ASM principle for both diesel and petrol cars. In this variant the car was driven at a nominal speed and full load, and then at 45% of the nominal speed and full load. Two smoke measurements were taken at each condition. The study concluded that the test was more appropriate than a no-load test for characterising the emission behaviour of diesel cars. However, it was not legally enforced in Germany because the EC-wide free acceleration test was considered at the time to be satisfactory (Norris, 2002).

E2.6 'Lug-down' test

The lug-down test is a basic loaded test which has been used in some countries, including the United States and Hong Kong. The vehicle is operated on a chassis dynamometer at a fixed speed while the dynamometer load is increased to the point where the vehicle is running at full throttle. The dynamometer load is then gradually increased to reduce the engine speed until the engine is labouring or 'lugging'.

The International Standards Organisation specifies a test method (ISO 7644) for measuring opacity using a dynamometer-based lug-down test.

Colorado has introduced dynamometer lug down tests which, for heavy-duty diesel vehicles, are contained in Regulation 12, Part A.IV.C.4 and Part B.III.C.4.b (Colorado Department of Public Health and Environment, 2006). In this test, the vehicle is run on the dynamometer at wide-open throttle during the following sequence:

(1) The vehicle is run at no load and at maximum engine speed in a gear that produces a road speed between 60 and 70 mph (or the maximum that can be obtained).

(2) Load is applied to bring the engine to its rated speed and held for 10 seconds while opacity is measured.

(3) Load is applied to lug the engine to 90%, 80% and then 70% of rated speed, pausing at each speed for 10 seconds while opacity is measured.

The maximum smoke opacity is then compared with the standard. NO_x measurements could also be taken during the test.

The above procedure is not to be confused with the one of the same name which has previously investigated in the UK. In this case the vehicle is placed on inexpensive unloaded free rollers, and full throttle is applied to drive the road wheels to a reasonable operating speed in gear, with the vehicle's brakes being used to apply load to the engine. However, the use of the vehicle brakes to apply load whilst the vehicle is driven on free rollers may be considered to have safety implications and also has a tendency to cause tyre damage. Moreover, the test provides no information on engine load, although this could be inferred from OBD (McCrae *et al.*, 2005; Latham, 2007).

E2.7 Pennsylvania § 169.5 smoke test cycle

A smoke emissions test is specified in the provisions of The Pennsylvania Code[2]. The test is conducted according to the following sequence (Pennsylvania Code, 1977):

(1) *Idle mode.* The engine is kept at idle for 1.5 to 2 minutes at the recommended low idle speed of the manufacturer. The dynamometer controls are set to provide minimum load by turning the load switch to the 'off' position or by adjusting the controls to the minimum load position.

(2) *Acceleration mode.* This proceeds as follows:

- The engine is accelerated at full throttle against inertia, or alternatively against a pre-programmed dynamometer load, such that the engine speed increases to 85-90% of rated speed in 3.5 to 5.5 seconds. For maximum repeatability on turbocharged engines with more than 1.5 pressure ratio, this should be held to closer limits. The acceleration should be kept linear within plus or minus 100 rpm.
- When the engine reaches 85-90% of the rated speed the throttle is closed rapidly and any dynamometer load is removed.

[2] Title 67 Transportation, § 169 Diesel smoke measurement procedure.

- Based on a pre-set load, the engine speed is allowed to drop to the intermediate speed within plus or minus 100 rpm.
- Full throttle is then applied and the engine speed is increased against a dynamometer load schedule such that the engine speed reaches 95-100% of the rated speed in 10±2 seconds.

(3) *Rated speed mode.* This involves the following steps:

- Proceeding from the acceleration mode, the dynamometer controls are adjusted to permit the engine to develop full-load power at the rated speed.
- The engine is allowed to operate for one minute after the load and speed have stabilised at full-load power at rated speed.

(4) *Lugging mode.* Here, the dynamometer controls are adjusted without changing the throttle position to slow the engine gradually to the intermediate speed. This engine lugging operation is performed smoothly over a period of 35±5, seconds. The slowing rate of the engine is kept linear within plus or minus 100 rpm.

(5) *Intermediate speed mode.* The engine is allowed to operate at full power at the intermediate speed for one minute after the load and speed have stabilised.

(6) *Engine unloading.* After completion of the lugging and intermediate speed modes the dynamometer and engine are returned to the idle condition. The zero and span of the smoke opacimeter may be checked and reset if necessary. If either zero or span drift is in excess of 2% the test results are considered to be invalid.

E3 Loaded transient tests

In loaded transient tests the engine power and speed are varied throughout the test cycle. Different test cycles are used in different jurisdictions, and some of them are used in I/M programmes.

E3.1 HOT EUDC test

The HOT EUDC test was used during the Second CITA Programme on Emission Testing at Periodic and Other Inspections (CITA, 2002). The test is derived from the New European Drive Cycle (NEDC), or 'Type I' test, which is used for the type approval on new car and light-duty vehicle models in the EU, as outlined in Annex III of Directive 70/220/EEC.

The NEDC test consists of two phases: an Urban Driving Cycle (UDC) consisting of a series of accelerations, steady speeds, decelerations and idling, and an Extra-Urban Driving Cycle (EUDC) which is run immediately after the UDC. The latter consists of roughly half steady-speed driving (at 75-120 km/h) and half accelerations/decelerations and a little idling. The test is undertaken on a vehicle which has been left to soak at between 20°C and 30°C for at least 6 hours, and until the engine oil and coolant temperatures are within ± 2°C of the ambient temperature.

The duration of the NEDC is 1,180 seconds for Euro III vehicles and later, with the UDC and EUDC phases being 780 seconds and 400 seconds long respectively. The Euro III test differs from the Euro II and earlier certification procedure (specified in directive 98/69/EC), in that the earlier test included a 40-second idling period that preceded the start of emissions sampling.

However, key aspects of this cycle which make it unattractive for I/M testing are:

- It is a cold-start test, requiring at least a 6 hour pre-run soak.
- Its long duration.

- The requirement for a dynamometer with full inertia simulation.
- The specification of a full-flow dilution tunnel and emission-measurement system.
- The high specification of the analysers.

Even if raw exhaust measurements were made, the first three of these aspects render this test impractical for I/M programmes.

In the CITA Hot EUDC test the operating cycle consists of the EUDC only. The dynamometer inertia is set at the manufacturer's value or according to the Directive, and following sequence is applied:

(1) *First Type I test.* The exhaust gases are measured during the complete cycle and during the second part. A four-gas test and an EOBD test are also carried out.

(2) *HOT EUDC cycles.* One or more faults are introduced. During the driving cycle the fault should be detected by the EOBD system. After the driving cycle (a HOT EUDC test) the four-gas test and an EOBD test are conducted. The HOT EUDC cycles are started with the engine running at the same speed and the engine oil at the temperature reached during the Type I test. The HOT EUDC tests are repeated after each failure in a series of one or more failures. When the whole failure series for the vehicle has been completed, the emissions during the HOT EUDC test are compared with the results from the measurements of the vehicle with faults to decide which fault setting will be measured during a second complete Type I test.

(3) *Second Type I test.* After the series of HOT EUDC cycles, a supplementary Type I test is conducted. During this phase the four-gas test and an EOBD test are also carried out. There will therefore be at least two Type I results for each series of HOT EUDC tests.

E3.2 DT80 and DT60 tests

The DT80 procedure, which is applicable to diesel vehicles in Australia, is an aggressive, mixed-mode test with three full-load accelerations to 80 km/h, followed by a steady-state 80 km/h cruise (Brown *et al*., 1999). This test has been designed to evaluate vehicle emissions during typical 'real-world' operating modes and conditions, and requires the use of a dynamometer with inertia simulation.

The Australian National Transport Commission described the DT80 procedure for testing of diesel exhaust emissions as follows (National Transport Commission, 2006):

(1) Idle for 60 seconds.
(2) Accelerate rapidly to 80 km/h under simulated inertia.
(3) Decelerate and gently applying brakes to bring the vehicle to a standstill.
(4) Idle for 10 seconds.
(5) Accelerate rapidly to 80 km/h under simulated inertia.
(6) Decelerate and gently applying brakes to bring the vehicle to a standstill.
(7) Idle for 10 seconds.
(8) Accelerate rapidly to 80 km/h under simulated inertia.
(9) Maintain speed at 80 km/h for 60 seconds.

Figure E2 shows the modes of operation. The actual test will result in a graph that has more variation than the indicative graph, because of the need to change gears when accelerating. The driver selects the most appropriate gear-change points for the vehicle being tested to achieve the correct speed.

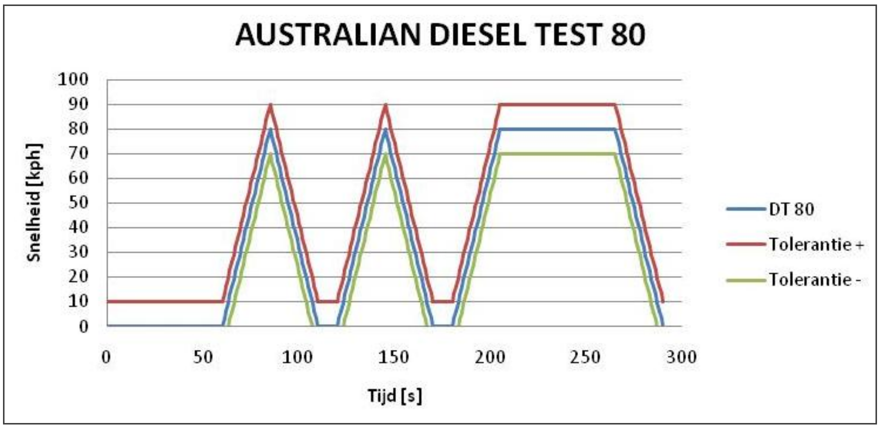

Figure E2: DT80 (indicative graph): Speed [km/h] as a function of time [s] (Vyt, 2008).

The DT60 is a shorter, aggressive, mixed-mode test which is very similar to the DT80. It has two full-load accelerations to 60 km/h, followed by a steady-state 60 km/h cruise (Figure E3). This test again requires the use of a dynamometer with inertia simulation.

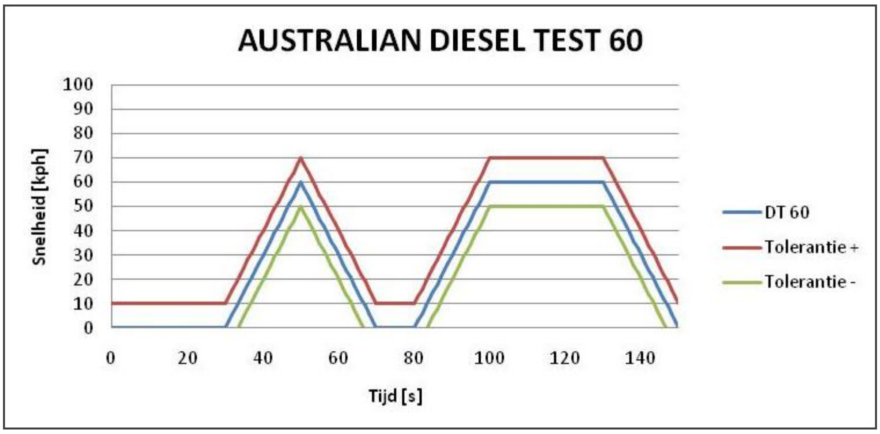

Figure E3: DT60 (indicative graph): Speed [km/h] as a function of time [s] (Vyt, 2008).

E3.3 AC5080

The AC5080 is a short I/M test proposed by Parsons Australia Pty Ltd for CARB (Figure E4). It is a mixed-mode test which begins with an 10-second idle followed by a wide-open throttle acceleration to 50 km/h, a steady-state cruise at 50 km/for 60 seconds, a wide-open throttle acceleration to 80 km/h, and finally a steady-state cruise at 80 km/h for 60 seconds.

It is less aggressive than the DT80, but according to Parsons it may be more representative of on-road driving. As with the DT80 and DT60 it requires the use of an inertia simulating dynamometer. Since the time taken to reach 50km/h and 80km/h is vehicle- and load-dependent, the speed-time profile varies.

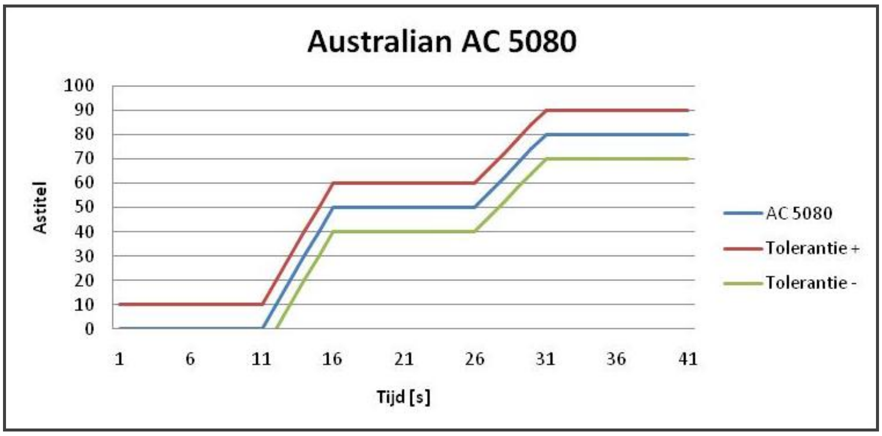

Figure E4: AC5080 simplified indicative graph: Speed [km/h] as a function of time [s] (Vyt, 2008).

E3.4 IM 240

The IM240 test was developed by the USEPA as an enhanced in-service emission test for light-duty vehicles, and is used in I/M programmes in a number of states. Under this procedure a vehicle is mounted on a dynamometer with associated flywheels - thus allowing the simulation of the vehicle inertia - and is driven over a transient cycle. The name of the test relates to its duration (240 seconds). It is a condensed version of the FTP-75 test; the first 240 seconds of the FTP are taken as the basis for the IM240.

The test cycle is shown in figure D5. The test cycle represents a 1.96 mile (3.1 km) trip with an average speed of 29.4 mph (47.3 km/h) and a maximum speed of 56.7 mph (91.2 km/h).

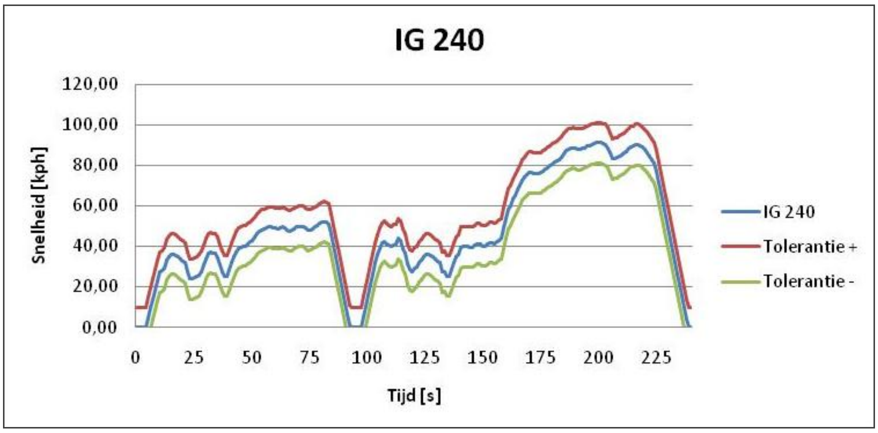

Figure E5: IM240 simplified indicative graph: Speed [km/h] as a function of time [s] (Vyt, 2008).

The IM240 procedure also incorporates a CVS and gas analysers, as used in the full FTP-75 (Pidgeon and Dobie, 1991; EPA, 2000). There is an alternative version of the IM240 test - known as IG240 - which utilises less expensive inspection-grade equipment. Like the IM240, it is a transient test but is designed primarily for use in a decentralised programme.

The advantage of this method is that it allows a more realistic simulation of real-world driving conditions, but the testing time and capital costs are far greater than for simple idle tests. The in-service IM240 has been found to show good correlation with the FTP-75 for CO_2 and NO_x but poor correlation with CO and HC (McCrae e*t. al.,* 2005).

E3.5 Oregon Bureau of Automotive Repair test (BAR31)

The BAR31 is a short, loaded dynamometer test used in some US states, primarily for measuring diesel opacity, but gaseous pollutants are also measured in some cases. The test uses similar equipment to the IM240, although the driving cycle has been truncated to 31 seconds, with the vehicle sharply accelerating and decelerating through the test. A vehicle is allowed three chances to pass the test before a failure is registered (McCrae e*t. al.,* 2005).

E3.6 CDH-226

One of the earliest short tests was the CDH-226 driving schedule, developed by the Colorado Department of Health. The driving cycle lasts for 226 seconds, and the total test duration is about 10 minutes. This short cycle was developed specifically for vehicles equipped with a three-way catalyst, and is aimed at achieving high correlation with the FTP.

The CDH-226 is a ‘smooth’ cycle which requires relatively little throttle action. Throttle action is an important variable affecting vehicle emissions, and could be important in identifying malfunctioning vehicles. For these reasons, EPA decided to develop a more transient alternative to the CDH-226, and the result was the IM240 (Pidgeon and Dobie, 1991).

Appendix F: Questionnaire to authorities responsible for PTI testing

The questionnaire form which was sent to the testing authorities is shown in Table F1. The numbers of responses per EU Member State are given in Table F2. The numbers of responses received from non-EU countries are summarised in Table F3.

Table F1: Questionnaire form sent to testing authorities.

General	
1.	Name:
2.	email address:
3.	Organisation:
4.	Description and status of organisation (*e.g.* Ministry, supervising authority, testing body, *etc.*):
5.	Geographical area where procedure is used (*e.g.* country, state, *etc.*):
Test procedures for diesel vehicles	
6.	Do you have a mandatory PTI emission test for diesel vehicles?
7.	What test procedure do you use (*e.g.* 2009/40/EC)? Please provide details.
8.	Does you PTI emission testing schemes differ from 2009/40/EC?
9.	Do you check other exhaust components? If yes, please specify.
10.	Do you have a fully documented emission test procedure? If yes, please attach a copy.
11.	What limit values and failure criteria do you apply to the PTI emission test?
12.	Do you have specifications for the emission test instruments? If yes, please provide a description.
13.	Do you use OBD for PTI emission testing?
14.	If the answer to question 13 is yes, then please specify the failure criteria.
15.	Do you have interesting papers or studies that are worth investigating during this project? Please specify or attach a copy.

Table F2: Numbers of responses by EU Member State.

Country	Responses	Country	Responses
Austria	1	Latvia	1
Belgium	1	*Lithuania*	*0*
Bulgaria	*0*	Luxembourg	1
Cyprus	*0*	Malta	1
Czech Republic	1	Netherlands	1
Denmark	1	*Poland*	*0*
Estonia	1	Portugal	1
Finland	1	Romania	1
France	3	Slovakia	2
Germany	2	Slovenia	2
Greece	*0*	Spain	3
Hungary	1	Sweden	1
Ireland	1	United Kingdom	1
Italy	3		

Table F3: Numbers of responses from countries outside the EU.

Participating country	Responses	Participating country	Responses
Brazil, Parana State	1	Paraguay	1
Colombia	1	Republic of Croatia	1
Japan	1	Singapore	1
New Zealand	2	Switzerland	1
Panama	1	Turkey	1

Appendix G: Results of NO_x instrument investigations

G1 Stability

The results of the stability tests are shown in Figures G1 to G9. The following approach has been used:

- Blue data series refer to the measured NO values.
- Red data series refer to the measured NO_2 values.
- Light green data series refer to the nominal concentration of calibration/span gas (middle line) and certificated inaccuracy (±*x*%).
- Green lines refer to the ±5% limit according OIML R99-1 (ISO 3930).

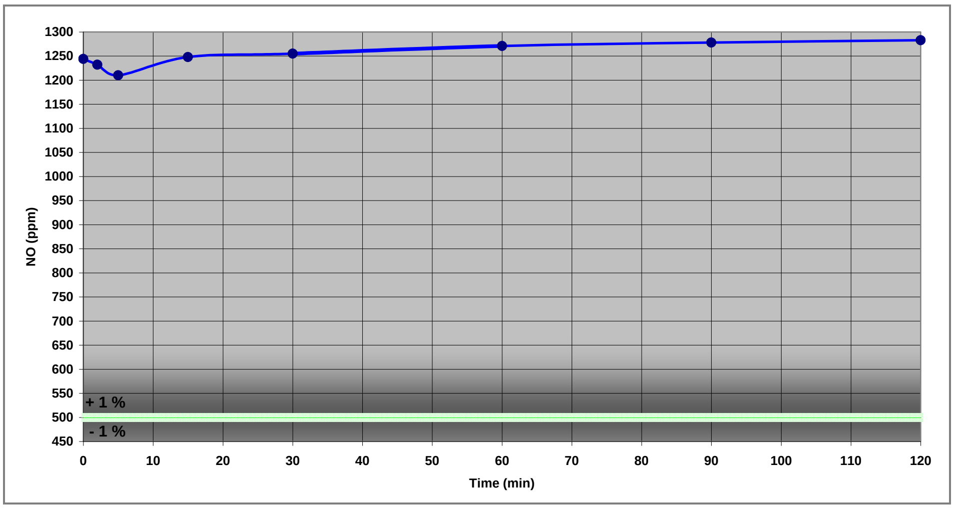

Figure G1: Stability –Autocal P550 (NO). Span gas = 499.3 ppm

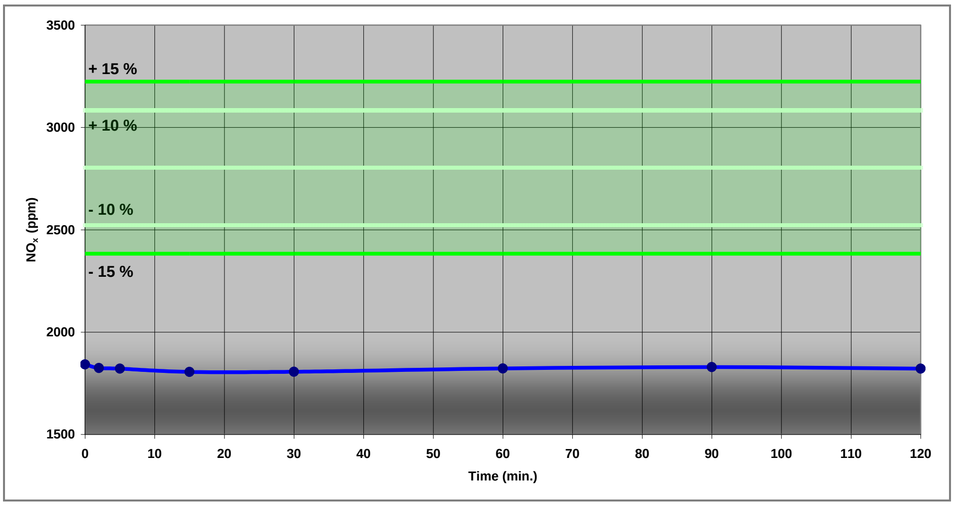

Figure G2: Stability – Capelec CAP3800 (NO). Span gas = 2803 ppm.

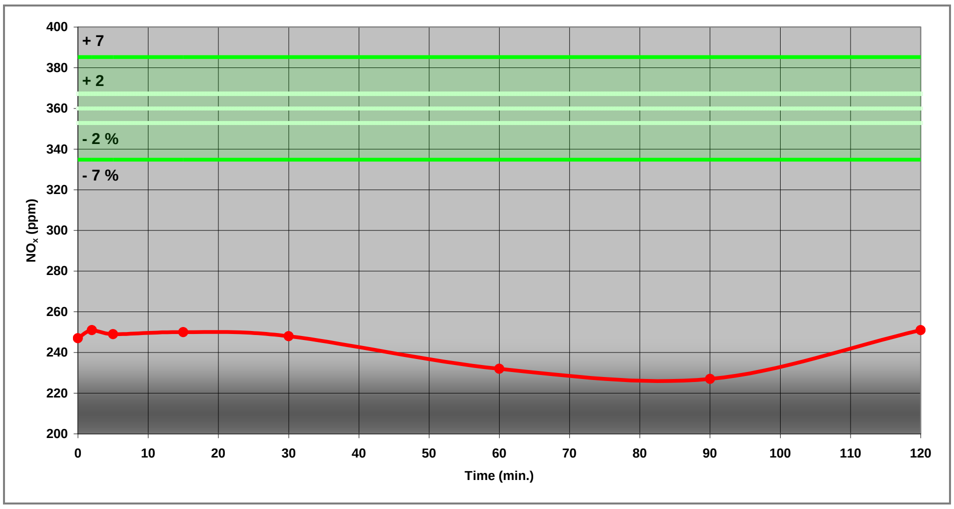

Figure G4: Stability – Capelec CAP3800 (NO_2). Span gas = 360 ppm.

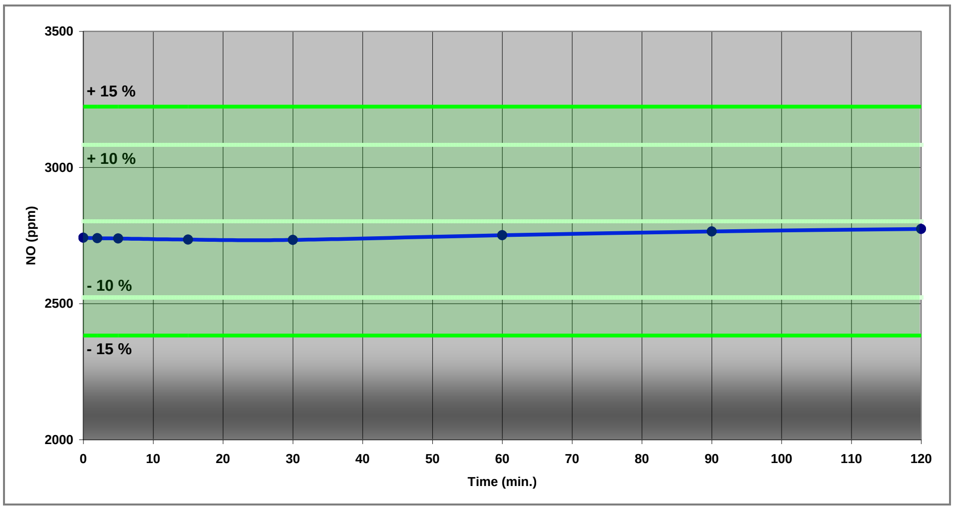

Figure G6: Stability – Junkalor Infralyt ELD (NO). Span gas =2803 ppm.

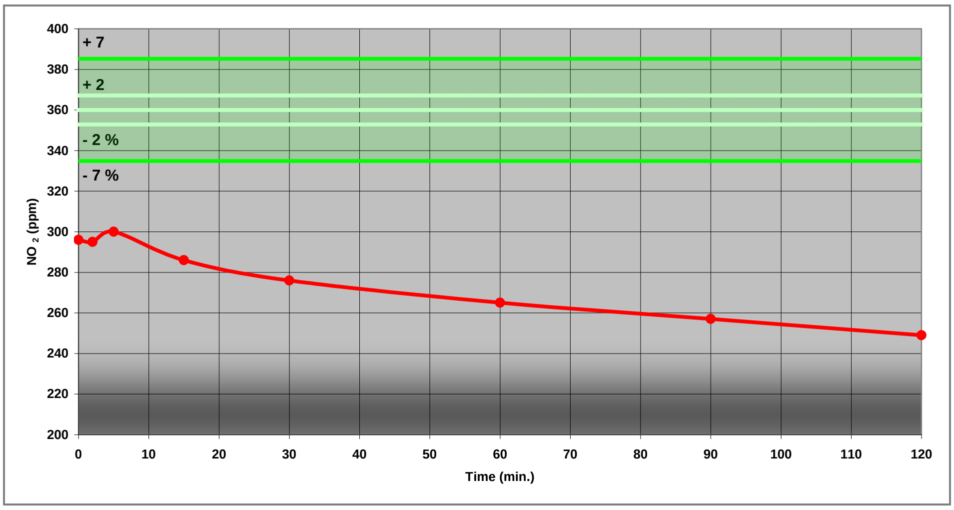

Figure G9: Stability - Infralyt ELD (NO_2). Span gas = 360 ppm.

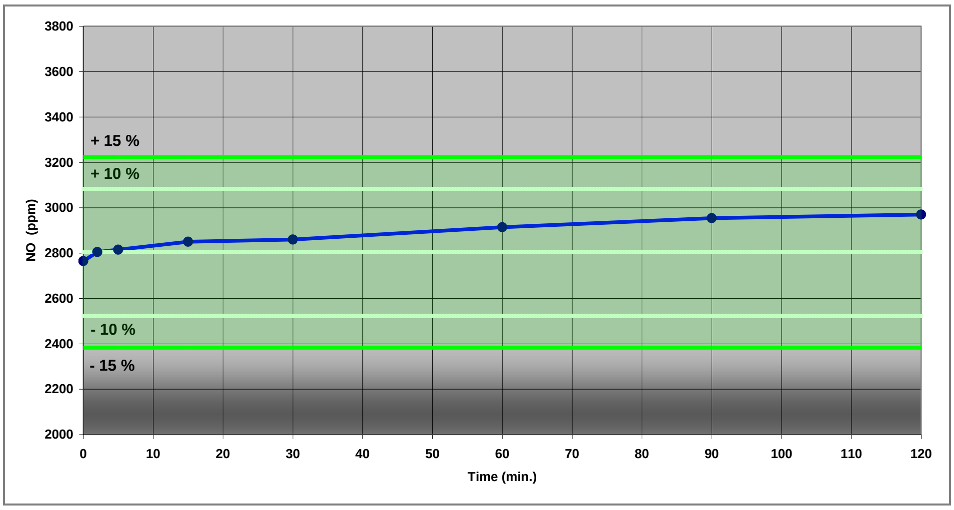

Figure G10: Stability – MAHA MET 6.1 (NO). Span gas = 2803 ppm.

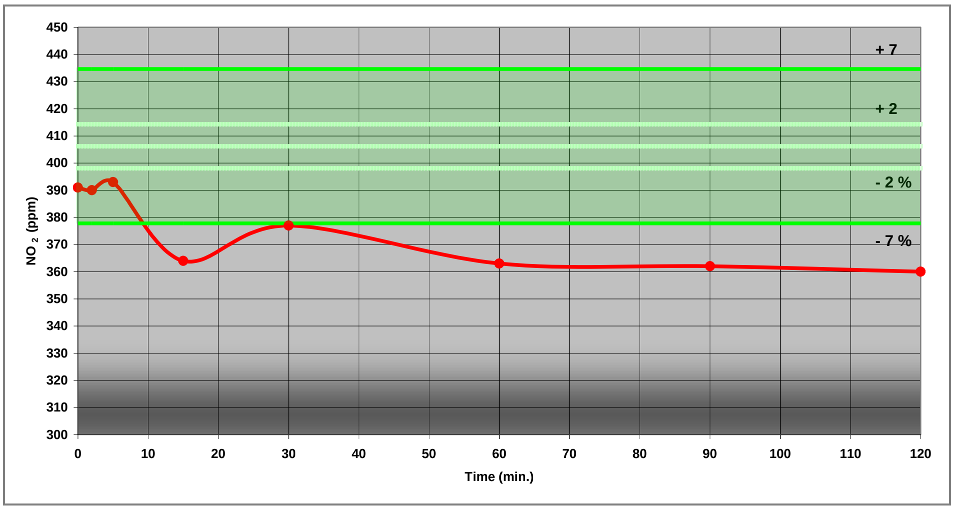

Figure G12: Stability – MAHA MET 6.1 (NO_2). Span gas = 406.2 ppm.

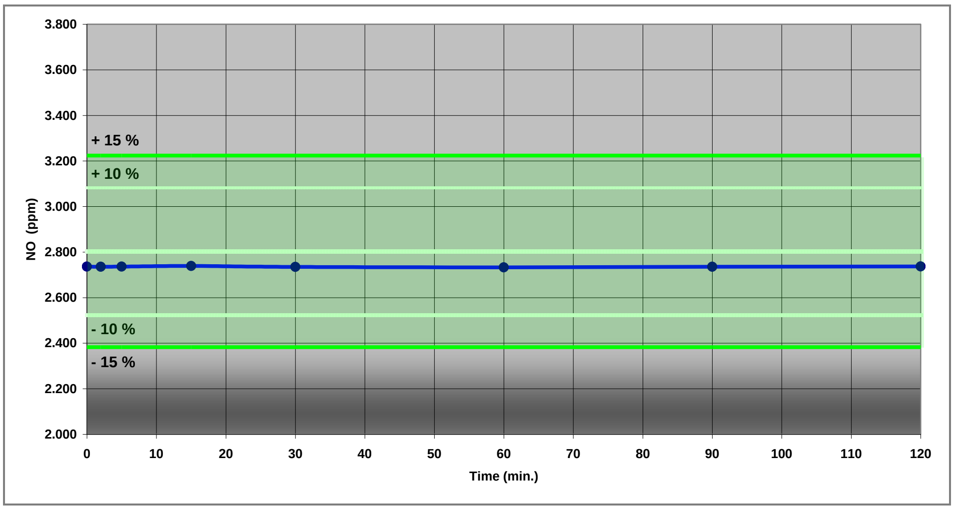

Figure G14: Stability – SEMTECH-DS (NO). Span gas = 2803 ppm.

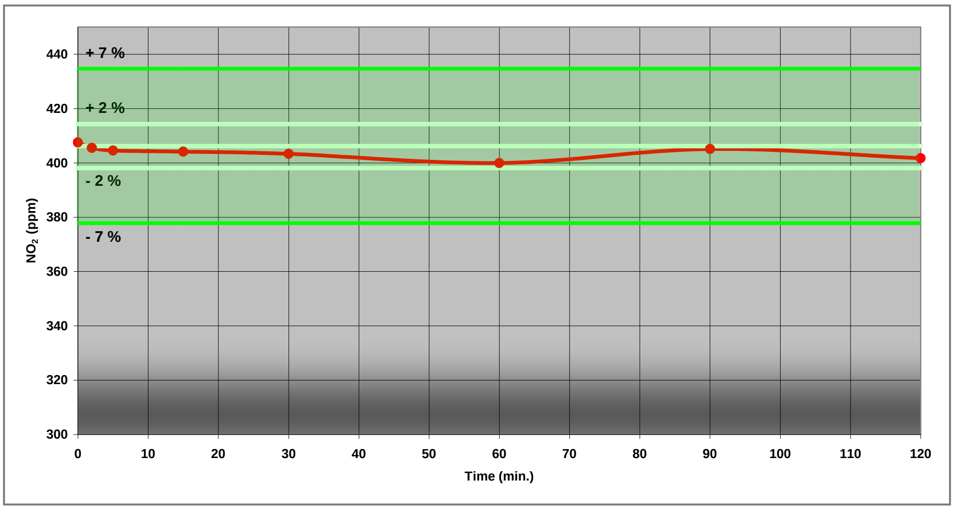

Figure G16: Stability – SEMTECH-DS (NO_2). Span gas = 406.2 ppm.

G2 Dynamic behaviour – step function response

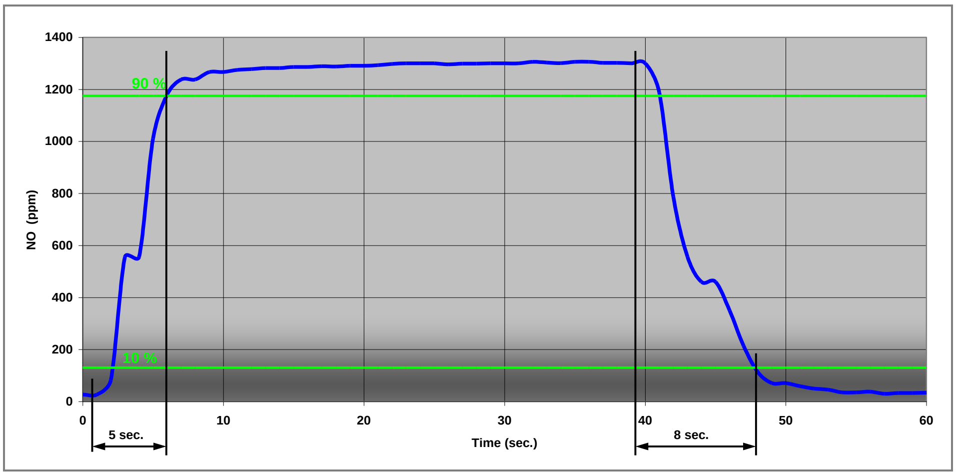

Figure G18: Dynamic response, step function – Autocal P550 (NO, 499.3 ppm span gas).

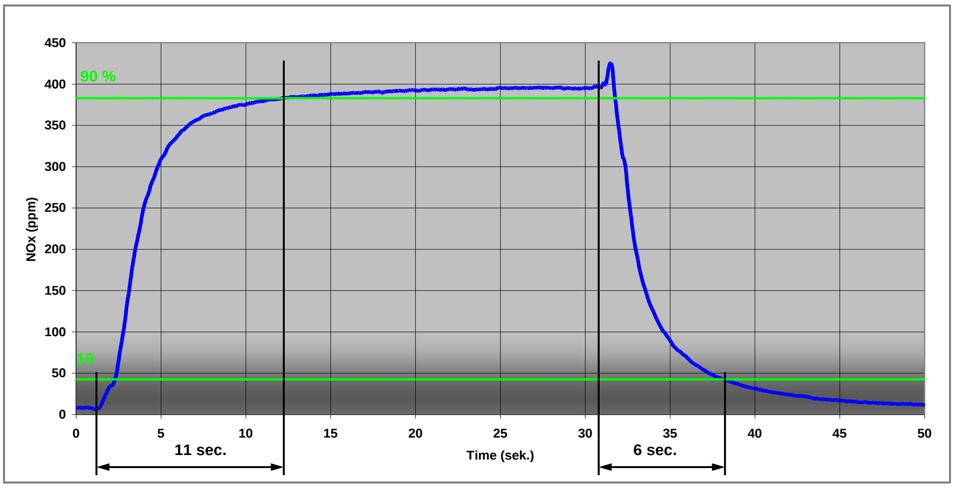

Figure G19: Dynamic response, step function – Capelec CAP3800 (NO_x, 499.7 ppm span gas).

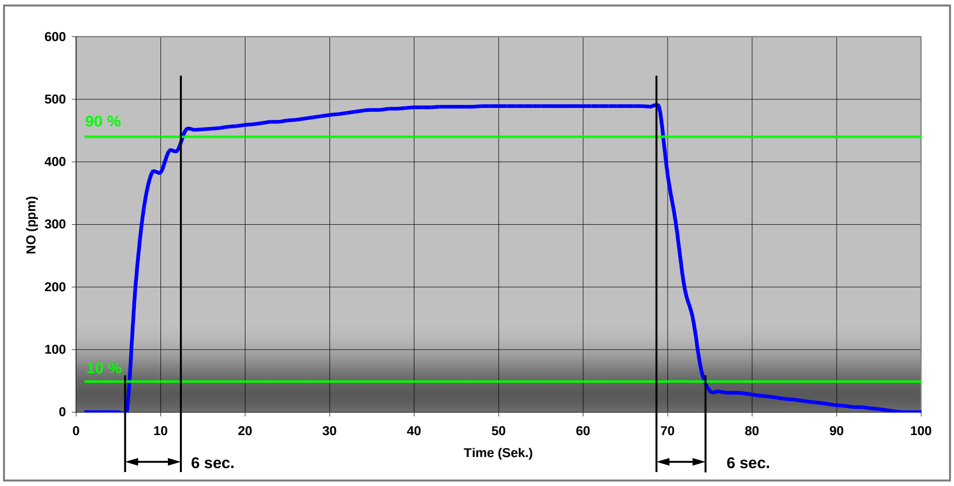

Figure G20: Dynamic response, step function – Junkalor Infralyt ELD (NO, 499.3 ppm span gas).

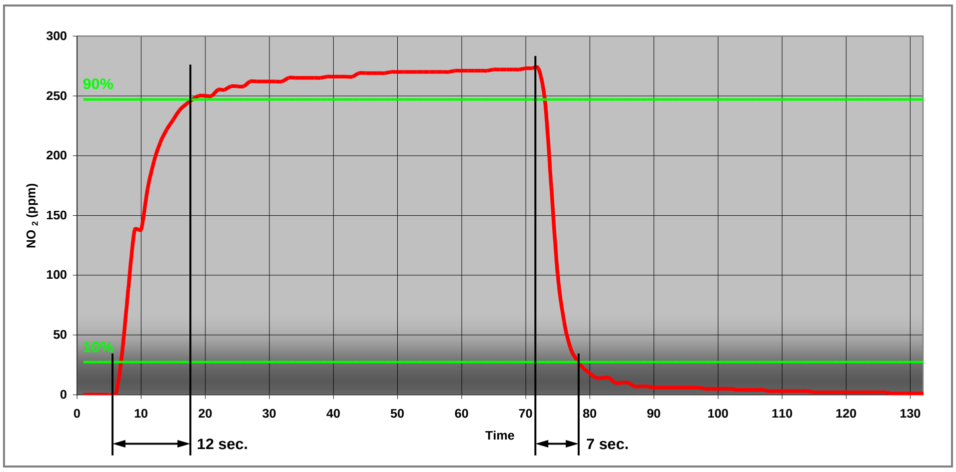

Figure G21: Dynamic response, step function – Junkalor Infralyt ELD (NO_2, 360 ppm span gas).

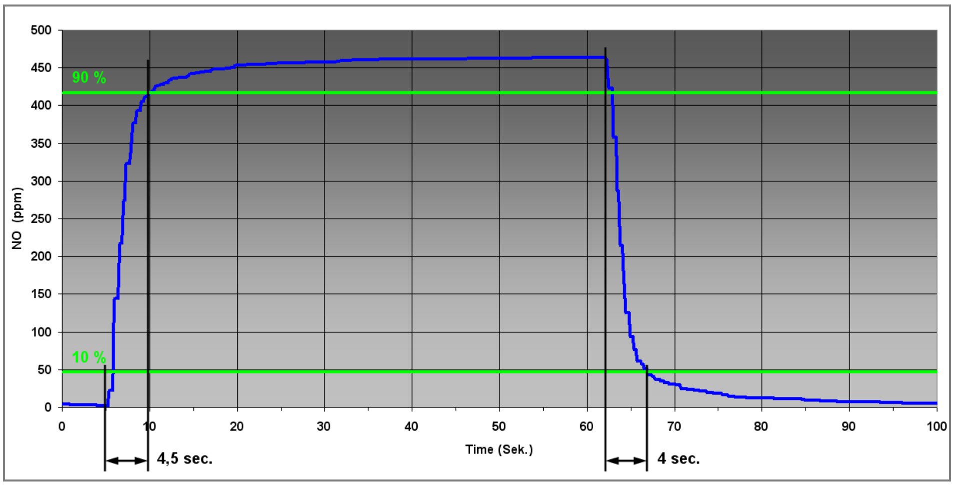

Figure G22: Dynamic response, step function – MAHA MET 6.1 (NO, 499.3 ppm span gas).

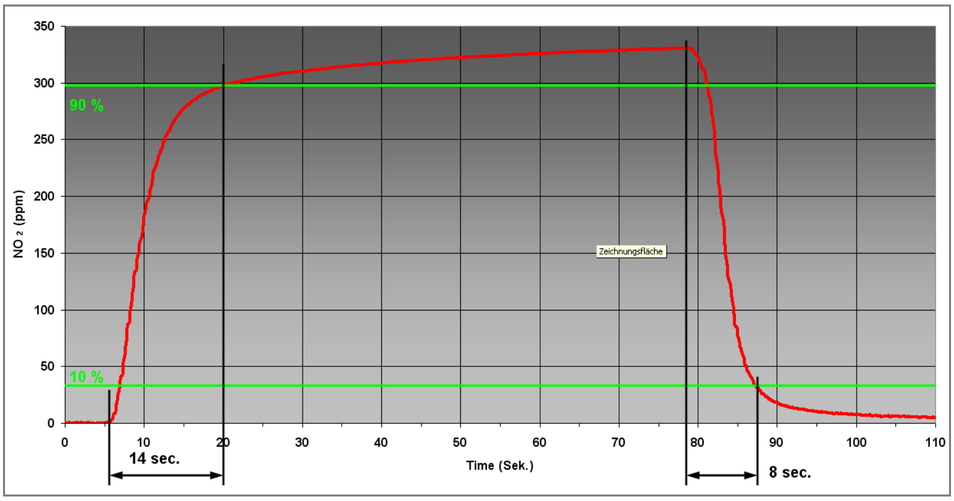

Figure G23: Dynamic response, step function – MAHA MET 6.1 (NO_2, 360 ppm span gas).

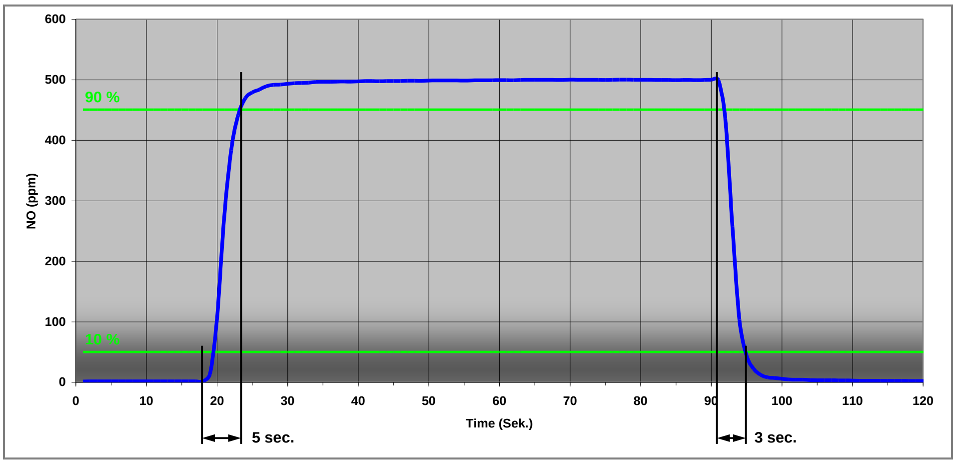

Figure G24: Dynamic response, step function – Sensors Inc. SEMTECH-DS (NO, 499.7 ppm span gas).

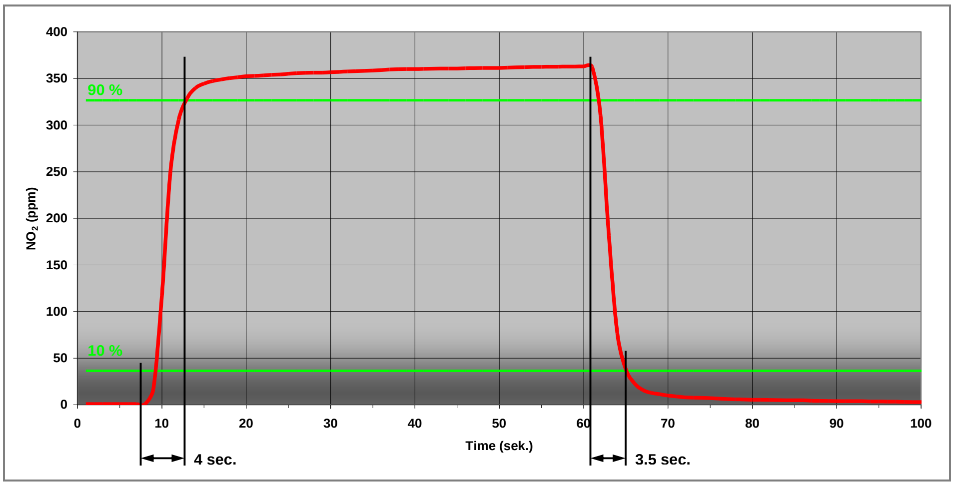

Figure G25: Dynamic response, step function – Sensors Inc. SEMTECH-DS (NO_2, 360 ppm span gas).

G3 Dynamic behaviour - free acceleration tests

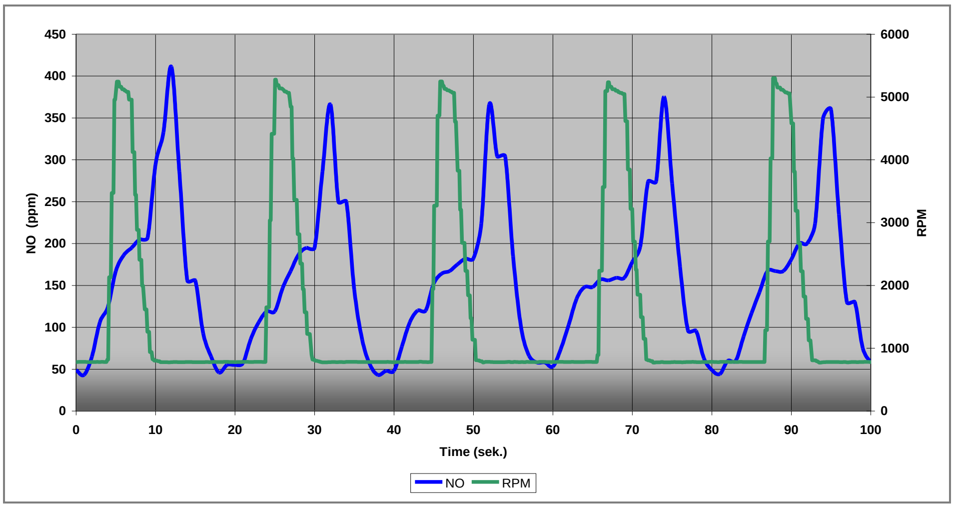

Figure G26: Dynamic response, free acceleration test – Autocal P550.

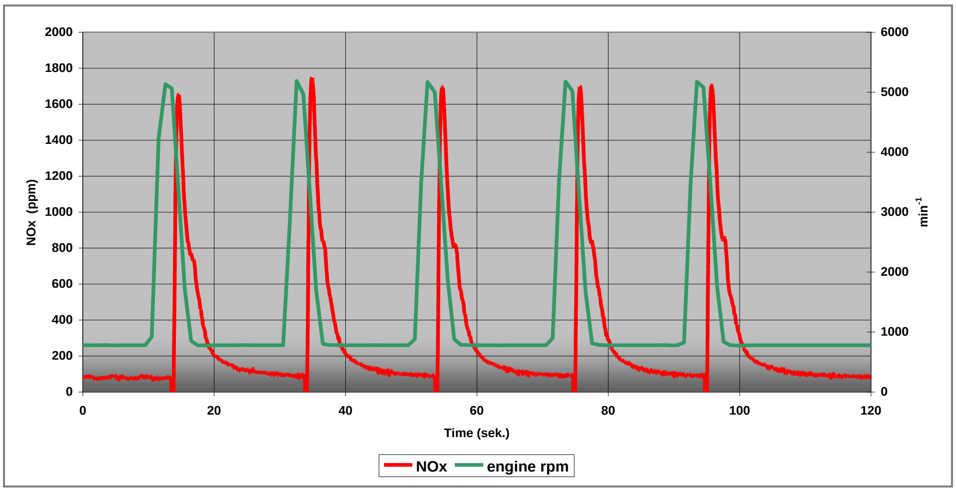

Figure G27: Dynamic response, free acceleration test – Capelec CAP3800.

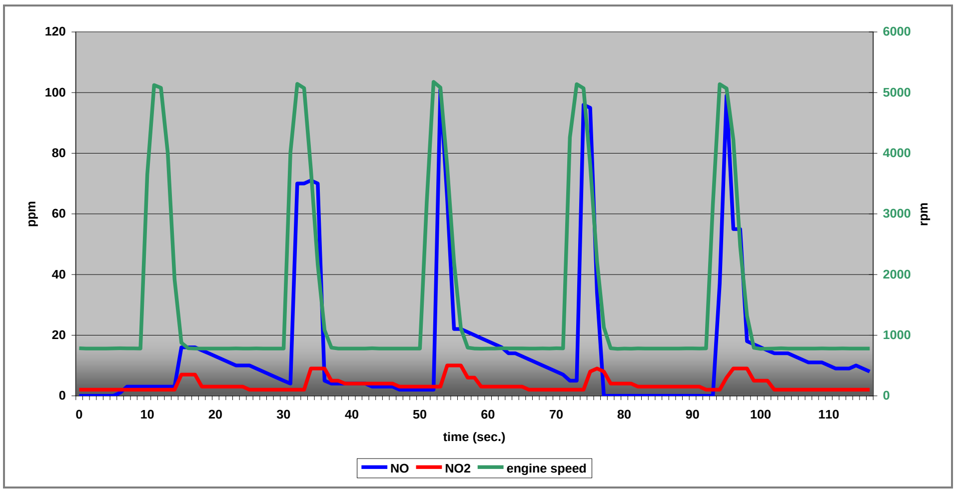

Figure G28: Dynamic response, free acceleration test – Junkalor Infralyt ELD.

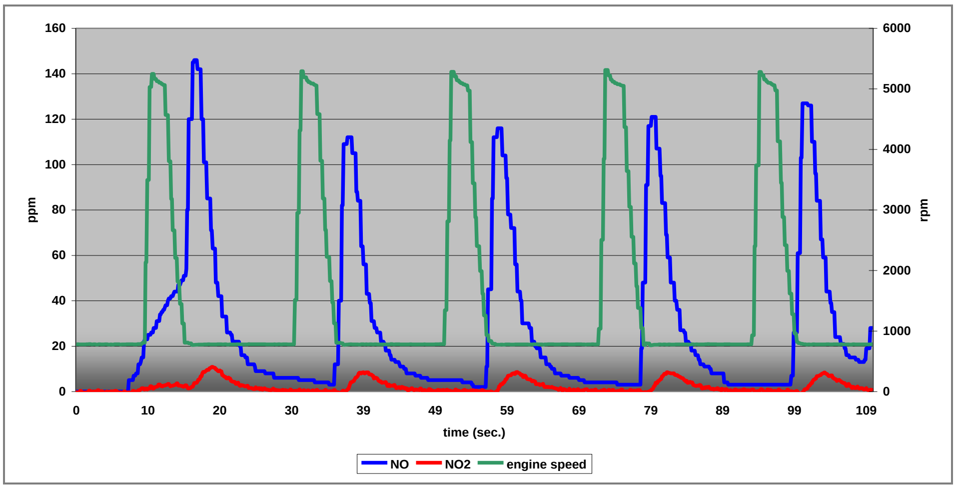

Figure G29: Dynamic response, free acceleration test – MAHA MET 6.1.

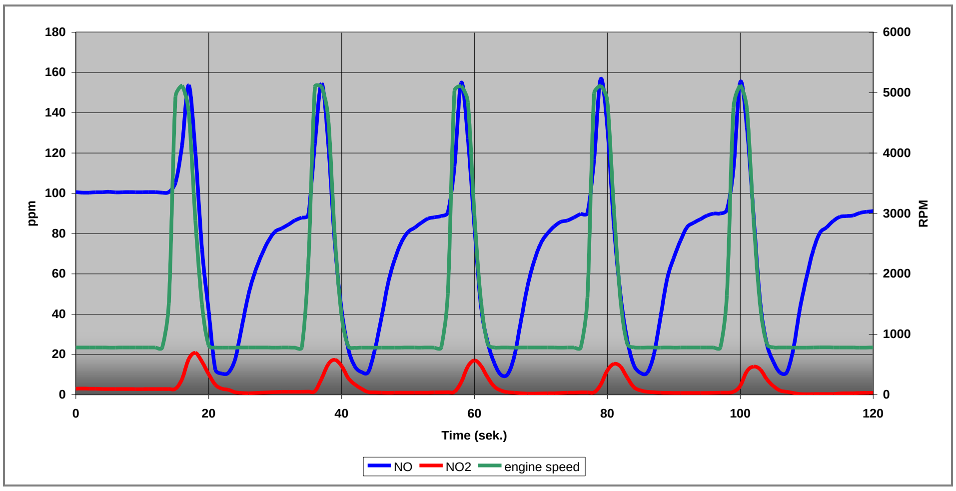

Figure G30: Dynamic response, free acceleration test – Sensors Inc. SEMTEC-DS (unheated probe).

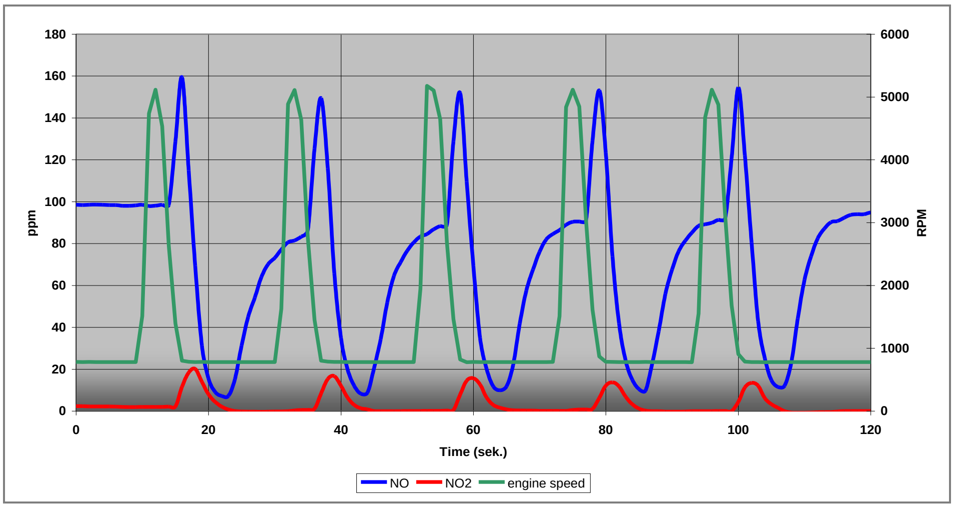

Figure G31: Dynamic response, free acceleration test – Sensors Inc. SEMTEC-DS (heated probe).

Appendix H: Results of vehicle and engine tests

H1 Results for NO and NO_2

In this section any mass emission rates for NO are stated as NO_2-equivalents.

H1.1 Vehicle 1

Table H1: Emissions over NEDC, vehicle 1.

Vehicle condition	CO (mg/km)	NO (mg/km)	NO_2 (mg/km)	NO_x (mg/km)	NO_2/NO_x [(a)]	THC+NO_x (mg/km)	PM		OBD	
							(mg/km)	*(% of E5 limit)*	MIL	DTC
Initial state	46.2	91.1	81.2	172.3	0.47	186.9	0.3	*6.0*	Off	None
DPF defect	385.5	143.9	18.4	162.3	0.11	234.9	5.06	*101.2*	Off	None
Crankcase breather removed	26.1	213.6	179.5	393.1	0.47	403.6	0.3	*6.0*	Off	None
Air mass flow meter manipulated	96.2	58.3	49.1	107.4	0.46	136.0	0.4	*8.0*	Off	None
Limit value	*500*	-	-	*250*	-	*300*	*5.0* [(b)]	*100*	-	-

(a) Mass ratio.

(b) Euro 5 limit. Vehicle was certified to Euro 4 without a DPF, but was fitted with a DPF because of national advancements and was therefore compliant with the Euro 5 limits.

Table H2: NO and NO_2 results for idle speed, vehicle 1.

Vehicle condition	Instrument	NO (ppm)	NO_2 (ppm)	NO_x (ppm)	NO_2/NO_x [(a)]
Initial state	*Pierburg (CLD)*	*30.8*	*26.6*	*57.4*	*0.46*
	MAHA MET 6.1	26.5	19.1	45.6	0.42
	Saxon-Junkalor Infralyt ELD	0.00	12.9	12.9	1.00
	Sensors Inc. SEMTECH-DS	- [(b)]	- [(b)]	- [(b)]	- [(b)]
DPF defect	*Pierburg (CLD)*	*133.4*	*23.2*	*156.6*	*0.15*
	MAHA MET 6.1	6.1	0.1	6.2	0.02
	Saxon-Junkalor Infralyt ELD	0.0	0.0	0	-
	Sensors Inc. SEMTECH-DS	- [(c)]	- [(c)]	- [(c)]	- [(c)]
Crankcase breather removed	*Pierburg (CLD)*	*54.7*	*42.2*	*96.9*	*0.44*
	MAHA MET 6.1	43.6	37.0	80.6	0.46
	Saxon-Junkalor Infralyt ELD	7.9	22.2	30.1	0.74
	Sensors Inc. SEMTECH-DS	47.9	57.5	105.4	0.55
Air mass flow meter manipulated	*Pierburg (CLD)*	*30.7*	*23.9*	*54.6*	*0.44*
	MAHA MET 6.1	26.0	18.5	44.5	0.42
	Saxon-Junkalor Infralyt ELD	0.0	11.8	11.8	1.00
	Sensors Inc. SEMTECH-DS	30.0	32.3	62.3	0.52

(a) Volume ratio. (b) Because of necessary repair, device not available at time of measurement.
(c) Device shows no constant values. See (b).

Table H3: NO and NO_2 results for high idle speed (2,500 rpm), vehicle 1.

Vehicle condition	Instrument	NO (ppm)	NO_2 (ppm)	NO_x (ppm)	NO_2/NO_x(a)
Initial state	*Pierburg (CLD)*	*112.2*	*13.2*	*125.4*	*0.11*
	MAHA MET 6.1	118.6	9.2	127.8	0.07
	Saxon-Junkalor Infralyt ELD	58.3	10.3	68.6	0.15
	Sensors Inc. SEMTECH-DS	-(b)	-(b)	-(b)	-(b)
DPF defect	*Pierburg (CLD)*	*144.3*	*13.4*	*157.7*	*0.08*
	MAHA MET 6.1	165.2	13.0	178.2	0.07
	Saxon-Junkalor Infralyt ELD	126.4	10.3	136.7	0.08
	Sensors Inc. SEMTECH-DS	-(c)	-(c)	-(c)	-(c)
Crankcase breather removed	*Pierburg (CLD)*	*127.7*	*11.0*	*138.7*	*0.08*
	MAHA MET 6.1	140.3	9.0	149.3	0.06
	Saxon-Junkalor Infralyt ELD	87.6	6.1	93.7	0.07
	Sensors Inc. SEMTECH-DS	135.6	7.6	143.2	0.05
Air mass flow meter manipulated	*Pierburg (CLD)*	*108.4*	*14.3*	*122.7*	*0.12*
	MAHA MET 6.1	124.1	11.1	135.2	0.08
	Saxon-Junkalor Infralyt ELD	77.7	7.2	84.9	0.08
	Sensors Inc. SEMTECH-DS	116.4	11.8	128.2	0.09

(a) Volume ratio. (b) Because of necessary repair, device not available at time of measurement.
(c) Device shows no constant values. See (b).

Table H4: NO and NO_2 results for free acceleration test, vehicle 1.

Vehicle condition	Instrument	NO (ppm)	NO_2 (ppm)	NO_x (ppm)	NO_2/NO_x(a)
Initial state	*Pierburg (CLD)*	*377.6*	*90.4*	*468*	*0.19*
	MAHA MET 6.1	243.2	62.7	305.9	0.20
	Saxon-Junkalor Infralyt ELD	161.3	45.0	206.3	0.22
	Sensors Inc. SEMTECH-DS	-(b)	-(b)	-(b)	-(b)
DPF defect	*Pierburg (CLD)*	*434.3*	*40.4*	*474.7*	*0.09*
	MAHA MET 6.1	368.8	19.4	388.2	0.05
	Saxon-Junkalor Infralyt ELD	275.3	14.0	289.3	0.05
	Sensors Inc. SEMTECH-DS	-(c)	-(c)	-(c)	-(c)
Crankcase breather removed	*Pierburg (CLD)*	*419.9*	*117.7*	*537.6*	*0.22*
	MAHA MET 6.1	302.4	63.9	366.3	0.17
	Saxon-Junkalor Infralyt ELD	235.6	38.8	274.4	0.14
	Sensors Inc. SEMTECH-DS	240.5	74.2	314.7	0.24
Air mass flow meter manipulated	*Pierburg (CLD)*	*414.1*	*111.1*	*525.2*	*0.21*
	MAHA MET 6.1	269.8	68.5	338.3	0.20
	Saxon-Junkalor Infralyt ELD	170.2	42.6	212.8	0.20
	Sensors Inc. SEMTECH-DS	224.2	105.7	329.9	0.32

(a) Volume ratio. (b) Because of necessary repair, device not available at time of measurement.
(c) Device shows no constant values. See (b).

Table H5: NO and NO_2 results for Norris-A test, vehicle 1.

Vehicle condition	Instrument	NO (ppm)	NO_2 (ppm)	NO_x (ppm)	NO_2/NO_x[(a)]
Initial state	*Pierburg (CLD)*	*160.7*	*88.5*	*249.2*	*0.36*
	MAHA MET 6.1	174.0	92.8	266.8	0.35
	Saxon-Junkalor Infralyt ELD	133.0	54.0	187	0.29
	Sensors Inc. SEMTECH-DS	-(b)	-(b)	-(b)	-(b)
DPF defect	*Pierburg (CLD)*	*245.3*	*29.6*	*274.9*	*0.11*
	MAHA MET 6.1	358.0	18.24	376.24	0.05
	Saxon-Junkalor Infralyt ELD	223.0	10.5	233.5	0.04
	Sensors Inc. SEMTECH-DS	-(c)	-(c)	-(c)	-(c)
Crankcase breather removed	*Pierburg (CLD)*	*204.7*	*85.3*	*290*	*0.29*
	MAHA MET 6.1	208.5	58.2	266.7	0.22
	Saxon-Junkalor Infralyt ELD	172.0	42.5	214.5	0.20
	Sensors Inc. SEMTECH-DS	198.3	103.5	301.8	0.34
Air mass flow meter manipulated	*Pierburg (CLD)*	*171.1*	*90.1*	*261.2*	*0.34*
	MAHA MET 6.1	191.0	70.4	261.4	0.27
	Saxon-Junkalor Infralyt ELD	138.5	46	184.5	0.25
	Sensors Inc. SEMTECH-DS	180.4	100.9	281.3	0.36

(a) Volume ratio. (b) Because of necessary repair, device not available at time of measurement.
(c) Device shows no constant values. See (b).

Table H6: NO and NO_2 results for INCOLL test, vehicle 1.

Vehicle condition	Instrument	NO (ppm)	NO_2 (ppm)	NO_x (ppm)	NO_2/NO_x[(a)]
Initial state	*Pierburg (CLD)*	*275.9*	*153.0*	*428.9*	*0.36*
	MAHA MET 6.1	185.4	95.16	280.56	0.34
	Saxon-Junkalor Infralyt ELD	131.9	66.0	197.9	0.33
	Sensors Inc. SEMTECH-DS	-(b)	-(b)	-(b)	-(b)
DPF defect	*Pierburg (CLD)*	*387.9*	*49.0*	*436.9*	*0.11*
	MAHA MET 6.1	295.8	35.7	331.5	0.11
	Saxon-Junkalor Infralyt ELD	219.1	29.0	248.1	0.12
	Sensors Inc. SEMTECH-DS	-(c)	-(c)	-(c)	-(c)
Crankcase breather removed	*Pierburg (CLD)*	*284.8*	*173.2*	*458*	*0.38*
	MAHA MET 6.1	193.6	91.2	284.8	0.32
	Saxon-Junkalor Infralyt ELD	134.8	39.5	174.3	0.23
	Sensors Inc. SEMTECH-DS	146.8	110.4	257.2	0.43
Air mass flow meter manipulated	*Pierburg (CLD)*	*329.8*	*152.4*	*482.2*	*0.32*
	MAHA MET 6.1	194.1	96.5	290.6	0.33
	Saxon-Junkalor Infralyt ELD	136.8	61.4	198.2	0.31
	Sensors Inc. SEMTECH-DS	153.2	114.3	267.5	0.43

(a) Volume ratio. (b) Because of necessary repair, device not available at time of measurement.
(c) Device shows no constant values. See (b).

Table H7: NO and NO_2 results for 50 km/h constant speed, vehicle 1.

Vehicle condition	Instrument	NO (ppm)	NO_2 (ppm)	NO_x (ppm)	NO_2/NO_x[(a)]
Initial state	*Pierburg (CLD)*	*27.0*	*28.9*	*55.9*	*0.52*
	MAHA MET 6.1	26.5	54.2	80.7	0.67
	Saxon-Junkalor Infralyt ELD	2.0	28.7	30.7	0.93
	Sensors Inc. SEMTECH-DS	-[(b)]	-[(b)]	-[(b)]	-[(b)]
DPF defect	*Pierburg (CLD)*	*51.4*	*21.7*	*73.1*	*0.30*
	MAHA MET 6.1	61.0	17.3	78.3	0.22
	Saxon-Junkalor Infralyt ELD	39.6	19.3	58.9	0.33
	Sensors Inc. SEMTECH-DS	-[(c)]	-[(c)]	-[(c)]	-[(c)]
Crankcase breather removed	*Pierburg (CLD)*	*21.6*	*81.0*	*102.6*	*0.79*
	MAHA MET 6.1	36.1	69.2	105.3	0.66
	Saxon-Junkalor Infralyt ELD	0.8	40.0	40.8	0.98
	Sensors Inc. SEMTECH-DS	33.2	102.1	135.3	0.75
Air mass flow meter manipulated	*Pierburg (CLD)*	*23.5*	*50.9*	*74.4*	*0.68*
	MAHA MET 6.1	25.4	50.9	76.3	0.67
	Saxon-Junkalor Infralyt ELD	4.6	33.2	37.8	0.88
	Sensors Inc. SEMTECH-DS	-[(c)]	-[(c)]	-[(c)]	-[(c)]

(a) Volume ratio. (b) Because of necessary repair, device not available at time of measurement.
(c) Device shows no constant values. See (b).

Table H8: NO and NO_2 results for 80 km/h constant speed, vehicle 1.

Vehicle condition	Instrument	NO (ppm)	NO_2 (ppm)	NO_x (ppm)	NO_2/NO_x[(a)]
Initial state	*Pierburg (CLD)*	*121.0*	*155.4*	*276.4*	*0.56*
	MAHA MET 6.1	132.9	198.6	331.5	0.60
	Saxon-Junkalor Infralyt ELD	92.9	109.7	202.6	0.54
	Sensors Inc. SEMTECH-DS	-[(b)]	-[(b)]	-[(b)]	-[(b)]
DPF defect	*Pierburg (CLD)*	*213.5*	*64.7*	*278.2*	*0.23*
	MAHA MET 6.1	227.6	64.0	291.6	0.22
	Saxon-Junkalor Infralyt ELD	202.4	58.9	261.3	0.23
	Sensors Inc. SEMTECH-DS	-[(c)]	-[(c)]	-[(c)]	-[(c)]
Crankcase breather removed	*Pierburg (CLD)*	*96.7*	*181.1*	*277.8*	*0.65*
	MAHA MET 6.1	139.0	170.6	309.6	0.55
	Saxon-Junkalor Infralyt ELD	91.3	115.8	207.1	0.56
	Sensors Inc. SEMTECH-DS	118.4	221.2	339.6	0.65
Air mass flow meter manipulated	*Pierburg (CLD)*	*104.7*	*191.1*	*295.8*	*0.65*
	MAHA MET 6.1	127.3	189.2	316.5	0.60
	Saxon-Junkalor Infralyt ELD	92.0	108.7	200.7	0.54
	Sensors Inc. SEMTECH-DS	-[(c)]	-[(c)]	-[(c)]	-[(c)]

(a) Volume ratio. (b) Because of necessary repair, device not available at time of measurement.
(c) Device shows no constant values. See (b).

Table H9: DT80 results, vehicle 1.

Vehicle condition	CO (mg/km)	NO (mg/km)	NO_2 (mg/km)	NO_x (mg/km)	NO_2/ NO_x(a)	THC+NO_x (mg/km)	ØPM (mg/m³)	OBD	
								MIL	DTC
Initial state	1.8	1038.8	1229.2	2268	0.54	568.9	0,1	Off	None
DPF defect	18.6	1754.0	487.2	2240	0.22	568.1	22	Off	None
Crankcase breather (blow-by) removed	1.7	1062.0	1326.0	2388	0.56	598.5	0,1	Off	None
Air mass flow meter manipulated	2.6	1068.4	1256.0	2325	0.54	584.7	0,1	Off	None

(a) Mass ratio
Ø = average peak value

Table H10: AC5080 results, vehicle 1.

Vehicle condition	CO (mg/km)	NO (mg/km)	NO_2 (mg/km)	NO_x (mg/km)	NO_2/ NO_x(a)	THC+NO_x (mg/km)	ØPM (mg/m³)	OBD	
								MIL	DTC
Initial state	0.7	522	606	1128	0.54	283.5	0.1	Off	0
DPF defect	12.9	854.4	243.2	1097	0.22	280.7	19	Off	0
Crankcase breather (blow-by) removed	1.8	504.4	698	1202	0.58	302.9	0.1	Off	0
Air mass flow meter manipulated	0.8	453.2	684.8	1138	0.60	286.1	0.1	Off	0

(a) Mass ratio
Ø = average peak value

H1.2 Vehicle 2

Table H11: Emissions over NEDC, vehicle 2.

Vehicle condition	CO (mg/km)	NO (mg/km)	NO_2 (mg/km)	NO_x (mg/km)	NO_2/ NO_x(a)	THC+NO_x (mg/km)	PM		OBD	
							(mg/km)	*(% of E5 limit)*	MIL	DTC
Initial state	240.3	157.3	15.1	172.4	0.09	216.2	0.74	*14*	Off	None
DPF defect	239.0	158.1	6.4	164.4	0.04	218.4	36.00	*720*	Off	None
Crankcase breather (blow-by) removed	232.8	161.7	34.2	195.9	0.47	220.9	0.31	*6.2*	Off	None
DOC defect	904.0	163.3	19.4	182.7	0.11	304.9	0.83	*16.6*	Off	None
Limit value	*500*	-	-	*180*	-	*230*	*5.0*	*100*	-	-

(a) Mass ratio.

Table H12: NO and NO_2 results for idle speed, vehicle 2.

Vehicle condition	Instrument	NO (ppm)	NO_2 (ppm)	NO_x (ppm)	NO_2/NO_x [(a)]
Initial state (repaired)	*Pierburg (CLD)*	*73.9*	*23.8*	*97.7*	*0.24*
	MAHA MET 6.1	69.3	22.3	91.6	0.24
	Saxon-Junkalor Infralyt ELD	30.1	15.5	45.6	0.34
	Sensors Inc. SEMTECH-DS	-[(b)]	-[(b)]	-[(b)]	-[(b)]
DPF defect	*Pierburg (CLD)*	*125.9*	*15.1*	*141*	*0.11*
	MAHA MET 6.1	155.2	22.1	177.3	0.12
	Saxon-Junkalor Infralyt ELD	125.2	12.7	137.9	0.09
	Sensors Inc. SEMTECH-DS	126.8	17.1	143.9	0.12
Crankcase breather removed	*Pierburg (CLD)*	*136.2*	*9.1*	*145.3*	*0.06*
	MAHA MET 6.1	142.4	8.1	150.5	0.05
	Saxon-Junkalor Infralyt ELD	90.3	4.0	94.3	0.04
	Sensors Inc. SEMTECH-DS	177.4	6.7	184.1	0.04
DOC defect	*Pierburg (CLD)*	*53.1*	*33.7*	*86.8*	*0.39*
	MAHA MET 6.1	-[(b)]	-[(b)]	-[(b)]	-[(b)]
	Saxon-Junkalor Infralyt ELD	-[(b)]	-[(b)]	-[(b)]	-[(b)]
	Sensors Inc. SEMTECH-DS	-[(b)]	-[(b)]	-[(b)]	-[(b)]

(a) Volume ratio.
(b) Instrument defective at time of measurement.

Table H13: NO and NO_2 results for high idle speed (2,500 rpm), vehicle 2.

Vehicle condition	Instrument	NO (ppm)	NO_2 (ppm)	NO_x (ppm)	NO_2/NO_x [(a)]
Initial state (repaired)	*Pierburg (CLD)*	*100.7*	*5.9*	*106.6*	*0.06*
	MAHA MET 6.1	109.3	7.1	116.4	0.06
	Saxon-Junkalor Infralyt ELD	75.5	4.2	79.7	0.05
	Sensors Inc. SEMTECH-DS	-[(b)]	-[(b)]	-[(b)]	-[(b)]
DPF defect	*Pierburg (CLD)*	*71.1*	*21.0*	*92.1*	*0.23*
	MAHA MET 6.1	78.4	26.3	104.7	0.25
	Saxon-Junkalor Infralyt ELD	39.9	15.9	55.8	0.28
	Sensors Inc. SEMTECH-DS	54.4	26.3	80.7	0.33
Crankcase breather removed	*Pierburg (CLD)*	*92.5*	*3.6*	*96.1*	*0.04*
	MAHA MET 6.1	103.1	2.3	105.4	0.02
	Saxon-Junkalor Infralyt ELD	64.2	1.0	65.2	0.02
	Sensors Inc. SEMTECH-DS	133.6	0.0	133.6	0.00
DOC defect	*Pierburg (CLD)*	*68.5*	*22.2*	*90.7*	*0.24*
	MAHA MET 6.1	-[(b)]	-[(b)]	-[(b)]	-[(b)]
	Saxon-Junkalor Infralyt ELD	-[(b)]	-[(b)]	-[(b)]	-[(b)]
	Sensors Inc. SEMTECH-DS	-[(b)]	-[(b)]	-[(b)]	-[(b)]

(a) Volume ratio.
(b) Instrument defective at time of measurement.

Table H14: NO and NO_2 results for free acceleration test, vehicle 2.

Vehicle condition	Instrument	NO (ppm)	NO_2 (ppm)	NO_x (ppm)	NO_2/NO_x[(a)]
Initial state (repaired)	*Pierburg (CLD)*	*221.8*	*27.2*	249	0.11
	MAHA MET 6.1	194.5	16.4	210.9	0.08
	Saxon-Junkalor Infralyt ELD	110.7	10.7	121.4	0.09
	Sensors Inc. SEMTECH-DS	-(b)	-(b)	-(b)	-(b)
DPF defect	*Pierburg (CLD)*	*284.2*	*31.5*	*315.7*	*0.10*
	MAHA MET 6.1	247.8	20.5	268.3	0.08
	Saxon-Junkalor Infralyt ELD	195.6	11.0	206.6	0.05
	Sensors Inc. SEMTECH-DS	205.3	17.5	222.8	0.08
Crankcase breather removed	*Pierburg (CLD)*	*320.7*	*20.4*	*341.1*	*0.06*
	MAHA MET 6.1	208.0	9.8	217.8	0.04
	Saxon-Junkalor Infralyt ELD	150.0	3.8	153.8	0.02
	Sensors Inc. SEMTECH-DS	227.0	6.4	233.4	0.03
DOC defect	*Pierburg (CLD)*	*266.7*	*69.8*	*336.5*	*0.21*
	MAHA MET 6.1	-(b)	-(b)	-(b)	-(b)
	Saxon-Junkalor Infralyt ELD	-(b)	-(b)	-(b)	-(b)
	Sensors Inc. SEMTECH-DS	-(b)	-(b)	-(b)	-(b)

(a) Volume ratio.
(b) Failure with measurement or data logging.

Table H15: NO and NO_2 results for Norris-A test, vehicle 2.

Vehicle condition	Instrument	NO (ppm)	NO_2 (ppm)	NO_x (ppm)	NO_2/NO_x[(a)]
Initial state (repaired)	*Pierburg (CLD)*	*297.3*	*45.2*	*342.5*	*0.13*
	MAHA MET 6.1	204.0	21.8	225.8	0.10
	Saxon-Junkalor Infralyt ELD	140.5	15.5	156	0.10
	Sensors Inc. SEMTECH-DS	-(b)	-(b)	-(b)	-(b)
DPF defect	*Pierburg (CLD)*	*214.7*	*21.9*	*236.6*	*0.09*
	MAHA MET 6.1	191.0	19.2	210.2	0.09
	Saxon-Junkalor Infralyt ELD	145.5	10.5	156	0.07
	Sensors Inc. SEMTECH-DS	147.5	14.4	161.9	0.09
Crankcase breather removed	*Pierburg (CLD)*	*116.2*	*21.2*	*137.4*	*0.15*
	MAHA MET 6.1	129.0	19.4	148.4	0.13
	Saxon-Junkalor Infralyt ELD	82.5	8.5	91	0.09
	Sensors Inc. SEMTECH-DS	167.7	21.1	188.8	0.11
DOC defect	*Pierburg (CLD)*	*345.4*	*118.2*	*463.6*	*0.25*
	MAHA MET 6.1	-(b)	-(b)	-(b)	-(b)
	Saxon-Junkalor Infralyt ELD	-(b)	-(b)	-(b)	-(b)
	Sensors Inc. SEMTECH-DS	-(b)	-(b)	-(b)	-(b)

(a) Volume ratio.
(b) Failure with measurement or data logging.

Table H16: NO and NO_2 results for INCOLL test, vehicle 2.

Vehicle condition	Instrument	NO (ppm)	NO_2 (ppm)	NO_x (ppm)	NO_2/NO_x[(a)]
Initial state (repaired)	*Pierburg (CLD)*	*322.0*	*43.7*	*365.7*	*0.12*
	MAHA MET 6.1	213.7	27.8	241.5	0.12
	Saxon-Junkalor Infralyt ELD	149.8	20.5	170.3	0.12
	Sensors Inc. SEMTECH-DS	-[(b)]	-[(b)]	-[(b)]	-[(b)]
DPF defect	*Pierburg (CLD)*	*280.9*	*30.7*	*311.6*	*0.10*
	MAHA MET 6.1	180.7	18.1	198.8	0.09
	Saxon-Junkalor Infralyt ELD	140.0	8.4	148.4	0.06
	Sensors Inc. SEMTECH-DS	143.5	11.2	154.7	0.07
Crankcase breather removed	*Pierburg (CLD)*	*233.7*	*52.9*	*286.6*	*0.18*
	MAHA MET 6.1	181.6	17.4	199	0.09
	Saxon-Junkalor Infralyt ELD	121.4	11.2	132.6	0.08
	Sensors Inc. SEMTECH-DS	197.0	19.0	216	0.09
DOC defect	*Pierburg (CLD)*	*218.6*	*72.8*	*291.4*	*0.25*
	MAHA MET 6.1	-[(b)]	-[(b)]	-[(b)]	-[(b)]
	Saxon-Junkalor Infralyt ELD	-[(b)]	-[(b)]	-[(b)]	-[(b)]
	Sensors Inc. SEMTECH-DS	-[(b)]	-[(b)]	-[(b)]	-[(b)]

(a) Volume ratio.
(b) Failure with measurement or data logging.

Table H17: NO and NO_2 results for 50 km/h constant speed, vehicle 2.

Vehicle condition	Instrument	NO (ppm)	NO_2 (ppm)	NO_x (ppm)	NO_2/NO_x[(a)]
Initial state (repaired)	*Pierburg (CLD)*	*77.4*	*13.8*	*91.2*	*0.15*
	MAHA MET 6.1	93.6	20.4	114	0.18
	Saxon-Junkalor Infralyt ELD	67.0	16.6	83.6	0.20
	Sensors Inc. SEMTECH-DS	-[(b)]	-[(b)]	-[(b)]	-[(b)]
DPF defect	*Pierburg (CLD)*	*94.4*	*9.2*	*103.6*	*0.09*
	MAHA MET 6.1	118.6	0.3	118.9	0.00
	Saxon-Junkalor Infralyt ELD	83.1	8.2	91.3	0.09
	Sensors Inc. SEMTECH-DS	100.5	7.9	108.4	0.07
Crankcase breather removed	*Pierburg (CLD)*	*62.4*	*20.6*	*83*	*0.25*
	MAHA MET 6.1	81.8	22.0	103.8	0.21
	Saxon-Junkalor Infralyt ELD	49.4	13.5	62.9	0.21
	Sensors Inc. SEMTECH-DS	-[(b)]	-[(b)]	-[(b)]	-[(b)]
DOC defect	*Pierburg (CLD)*	*54.9*	*26.7*	*81.6*	*0.33*
	MAHA MET 6.1	77.8	32.8	110.6	0.30
	Saxon-Junkalor Infralyt ELD	59.4	30.2	89.6	0.34
	Sensors Inc. SEMTECH-DS	-[(c)]	-[(c)]	-[(c)]	-[(c)]

(a) Volume ratio.
(b) Device shows no constant values.
(c) Because of necessary repair, device not available at time of measurement.

Table H18: NO and NO_2 results for 80 km/h constant speed, vehicle 2.

Vehicle condition	Instrument	NO (ppm)	NO_2 (ppm)	NO_x (ppm)	NO_2/NO_x (a)
Initial state (repaired)	*Pierburg (CLD)*	*155.2*	*32.2*	*187.4*	*0.17*
	MAHA MET 6.1	178.9	29.3	208.2	0.14
	Saxon-Junkalor Infralyt ELD	137.1	22.1	159.2	0.14
	Sensors Inc. SEMTECH-DS	- (b)	- (b)	- (b)	- (b)
DPF defect	*Pierburg (CLD)*	*166.4*	*27.1*	*193.5*	*0.14*
	MAHA MET 6.1	183.9	16.0	199.9	0.08
	Saxon-Junkalor Infralyt ELD	147.2	19.0	166.2	0.11
	Sensors Inc. SEMTECH-DS	156.0	25.9	181.9	0.14
Crankcase breather removed	*Pierburg (CLD)*	*122.9*	*40.6*	*163.5*	*0.25*
	MAHA MET 6.1	139.9	43.4	183.3	0.24
	Saxon-Junkalor Infralyt ELD	99.8	29.2	129	0.23
	Sensors Inc. SEMTECH-DS	- (b)	- (b)	- (b)	- (b)
DOC defect	*Pierburg (CLD)*	*109.0*	*57.6*	*166.6*	*0.35*
	MAHA MET 6.1	119.7	51.2	170.9	0.30
	Saxon-Junkalor Infralyt ELD	97.6	41.2	138.8	0.30
	Sensors Inc. SEMTECH-DS	- (c)	- (c)	- (c)	- (c)

(a) Volume ratio.
(b) Device shows no constant values.
(c) Because of necessary repair, device not available at time of measurement.

Table H19: DT80 results, vehicle 2.

Vehicle condition	CO (mg/km)	NO (mg/km)	NO_2 (mg/km)	NO_x (mg/km)	NO_2/NO_x (a)	THC+NO_x (mg/km)	ØPM (mg/m³)	OBD	
								MIL	DTC
Initial state	1.8	431.7	111.8	543.5	0.21	547.5	0.45	Off	None
DPF defect	4.31	286.3	43.5	329.7	0.13	387.4	20	Off	None
Crankcase breather removed	2.01	389.2	146.6	536.0	0.27	538.7	0.2	Off	None
DOC defect	41.6	438.4	114.1	552.5	0.21	559.6	-	Off	None

(a) Mass ratio.
Ø = average peak value

Table H20: AC5080 results, vehicle 2.

Vehicle condition	CO (mg/km)	NO (mg/km)	NO_2 (mg/km)	NO_x (mg/km)	NO_2/NO_x (a)	THC+NO_x (mg/km)	ØPM (mg/m³)	OBD	
								MIL	DTC
Initial state	1.2	182.6	39.7	222.3	0.18	225.9	0.2	Off	None
DPF defect	3.5	197.4	24.6	221.9	0.11	234.4	14.8	Off	None
Crankcase breather removed	0.60	175.1	54.0	229.1	0.24	232.8	0.2	Off	None
DOC defect	67.3	192.4	41.5	233.9	0.18	248.9	-	Off	None

(a) Mass ratio.
Ø = average peak value

H1.3 Vehicle 3

Table H21: Emissions over NEDC, vehicle 3.

Vehicle condition	CO (mg/km)	NO (mg/km)	NO_2 (mg/km)	NO_x (mg/km)	NO_2/NO_x[(a)]	THC+NO_x (mg/km)	PM		OBD	
							(mg/km)	*(% of E5 limit)*	MIL	DTC
Initial state	59.7	78.2	55.4	133.6	0.41	141.6	0.23	*4.6*	Off	None
Unloaded DPF	0.0[(b)]	77.7	65.4	143.1	0.46	150.3	1.18	*23.6*	Off	None
DOC removed	113.9	123.4	7.3	130.7	0.47	168.6	0.64	*12.8*	Off	None
Unloaded DPF + DOC removed	844.3	100.9	43.6	144.5	0.30	306.3	*4.52*	*90.4*	Off	None
Limit value	*500*	-	-	*180*	-	*230*	*5.0*	*100*	-	-

(a) Mass ratio.
(b) Bag concentration lower then ambient concentration

Table H22: NO and NO_2 results for idle speed, vehicle 3.

Vehicle condition	Instrument	NO (ppm)	NO_2 (ppm)	NO_x (ppm)	NO_2/NO_x[(a)]
Initial state	*Siemens (CLD)*	*74.8*	*51*	*125.8*	*0.41*
	MAHA MET 6.1	115	49.8	164.8	0.30
	Saxon-Junkalor Infralyt ELD	-[(b)]	-[(b)]	-[(b)]	-[(b)]
Unloaded DPF	*Siemens (CLD)*	*34.1*	*64*	*98.1*	*0.65*
	MAHA MET 6.1	116.4	79	195.4	0.40
	Saxon-Junkalor Infralyt ELD	-[(b)]	-[(b)]	-[(b)]	-[(b)]
DOC removed	*Siemens (CLD)*	*138.8*	*7.9*	*146.7*	*0.05*
	MAHA MET 6.1	170	8	178	0.04
	Saxon-Junkalor Infralyt ELD	102	7	109	0.06
Unloaded DPF + DOC removed	*Siemens (CLD)*	*127.4*	*30.9*	*158.3*	*0.20*
	MAHA MET 6.1	157	25	182	0.14
	Saxon-Junkalor Infralyt ELD	94	22	116	0.19

(a) Volume ratio
(b) Instrument defective at time of measurement.

Table H23: NO and NO_2 results for high idle speed (2,500 rpm), vehicle 3.

Vehicle condition	Instrument	NO (ppm)	NO_2 (ppm)	NO_x (ppm)	NO_2/NO_x(a)
Initial state	*Siemens (CLD)*	*81.1*	*11.4*	*92.5*	*0.12*
	MAHA MET 6.1	127	10.4	137.4	0.08
	Saxon-Junkalor Infralyt ELD	-(b)	-(b)	-(b)	-(b)
Unloaded DPF	*Siemens (CLD)*	*105.7*	*27.7*	*133.4*	*0.21*
	MAHA MET 6.1	134	18	152	0.12
	Saxon-Junkalor Infralyt ELD	-(b)	-(b)	-(b)	-(b)
DOC removed	*Siemens (CLD)*	*116.9*	*2.9*	*119.8*	*0.02*
	MAHA MET 6.1	148	1	149	0.01
	Saxon-Junkalor Infralyt ELD	83	0	83	0.00
Unloaded DPF + DOC removed	*Siemens (CLD)*	*66.4*	*64.7*	*131.1*	*0.49*
	MAHA MET 6.1	87	43	130	0.33
	Saxon-Junkalor Infralyt ELD	37	41	78	0.53

(a) Volume ratio
(b) Instrument defective at time of measurement.

Table H24: NO and NO_2 results for free acceleration test, vehicle 3.

Vehicle condition	Instrument	NO (ppm)	NO_2 (ppm)	NO_x (ppm)	NO_2/NO_x(a)
Initial state	*Siemens (CLD)*	*287.63*	*169.95*	*457.58*	*0.37*
	MAHA MET 6.1	338.08	32.90	370.98	0.09
	Saxon-Junkalor Infralyt ELD	-(b)	-(b)	-(b)	-(b)
Unloaded DPF	*Siemens (CLD)*	*190.98*	*276.10*	*467.08*	*0.59*
	MAHA MET 6.1	257.50	81.50	339	0.24
	Saxon-Junkalor Infralyt ELD	-(b)	-(b)	-(b)	-(b)
DOC removed	*Siemens (CLD)*	*278.83*	*171.00*	*449.83*	*0.38*
	MAHA MET 6.1	346.40	6.55	352.95	0.02
	Saxon-Junkalor Infralyt ELD	221.25	5.50	226.75	0.02
Unloaded DPF + DOC removed	*Siemens (CLD)*	*303.38*	*84.20*	*387.58*	*0.22*
	MAHA MET 6.1	340.10	36.80	376.9	0.10
	Saxon-Junkalor Infralyt ELD	227.25	41.50	268.75	0.15

(a) Volume ratio
(b) Instrument defective at time of measurement.

Table H25: NO and NO_2 results for Norris-A test, vehicle 3.

Vehicle condition	Instrument	NO (ppm)	NO_2 (ppm)	NO_x (ppm)	NO_2/NO_x[a]
Initial state	*Siemens (CLD)*	*261.55*	*176.30*	*437.85*	*0.40*
	MAHA MET 6.1	349.43	67.53	416.96	0.16
	Saxon-Junkalor Infralyt ELD	-[b]	-[b]	-[b]	-[b]
Unloaded DPF	*Siemens (CLD)*	*257.50*	*114.60*	*372.1*	*0.31*
	MAHA MET 6.1	264.75	98.50	363.25	0.27
	Saxon-Junkalor Infralyt ELD	-[b]	-[b]	-[b]	-[b]
DOC removed	*Siemens (CLD)*	*336.30*	*38.18*	*374.48*	*0.10*
	MAHA MET 6.1	388.58	36.80	425.38	0.09
	Saxon-Junkalor Infralyt ELD	260.75	40.75	301.5	0.14
Unloaded DPF + DOC removed	*Siemens (CLD)*	*390.10*	*136.93*	*527.03*	*0.26*
	MAHA MET 6.1	405.58	35.80	441.38	0.08
	Saxon-Junkalor Infralyt ELD	280.25	39.75	320	0.12

(a) Volume ratio
(b) Instrument defective at time of measurement.

Table H26: NO and NO_2 results for INCOLL test, vehicle 3.

Vehicle condition	Instrument	NO (ppm)	NO_2 (ppm)	NO_x (ppm)	NO_2/NO_x[a]
Initial state	*Siemens (CLD)*	*307.1*	*233.4*	*540.5*	*0.43*
	MAHA MET 6.1	367	94.7	461.7	0.21
	Saxon-Junkalor Infralyt ELD	-[b]	-[b]	-[b]	-[b]
Unloaded DPF	*Siemens (CLD)*	*259.3*	*264.1*	*523.4*	*0.50*
	MAHA MET 6.1	214	108	322	0.34
	Saxon-Junkalor Infralyt ELD	-[b]	-[b]	-[b]	-[b]
DOC removed	*Siemens (CLD)*	*369.4*	*183.7*	*553.1*	*0.33*
	MAHA MET 6.1	383.5	65.8	449.3	0.15
	Saxon-Junkalor Infralyt ELD	241	72	313	0.23
Unloaded DPF + DOC removed	*Siemens (CLD)*	*402.9*	*139.3*	*542.2*	*0.26*
	MAHA MET 6.1	450.5	33.4	483.9	0.07
	Saxon-Junkalor Infralyt ELD	319	57	376	0.15

(a) Volume ratio
(b) Instrument defective at time of measurement.

Table H27: NO and NO_2 results for 50 km/h constant speed, vehicle 3.

Vehicle condition	Instrument	NO (ppm)	NO_2 (ppm)	NO_x (ppm)	NO_2/NO_x [(a)]
Initial state	*Siemens (CLD)*	*20.6*	*35.3*	*55.9*	*0.63*
	MAHA MET 6.1	28	22.3	50.3	0.44
	Saxon-Junkalor Infralyt ELD	-(b)	-(b)	-(b)	-(b)
Unloaded DPF	*Siemens (CLD)*	*12.4*	*77.1*	*89.5*	*0.86*
	MAHA MET 6.1	18	57	75	0.76
	Saxon-Junkalor Infralyt ELD	-(b)	-(b)	-(b)	-(b)
DOC removed	*Siemens (CLD)*	*93.2*	*21.3*	*114.5*	*0.19*
	MAHA MET 6.1	111	17	128	0.13
	Saxon-Junkalor Infralyt ELD	56	16	72	0.22
Unloaded DPF + DOC removed	*Siemens (CLD)*	*84.5*	*34.5*	*119*	*0.29*
	MAHA MET 6.1	106	25	131	0.19
	Saxon-Junkalor Infralyt ELD	55	22	77	0.29

(a) Volume ratio

(b) Instrument defective at time of measurement.

Table H28: NO and NO_2 results for 80 km/h constant speed, vehicle 3.

Vehicle condition	Instrument	NO (ppm)	NO_2 (ppm)	NO_x (ppm)	NO_2/NO_x [(a)]
Initial state	*Siemens (CLD)*	*13.1*	*16.5*	*29.6*	*0.56*
	MAHA MET 6.1	17	9.2	26.2	0.35
	Saxon-Junkalor Infralyt ELD	-(b)	-(b)	-(b)	-(b)
Unloaded DPF	*Siemens (CLD)*	*13.1*	*87.8*	*100.9*	*0.87*
	MAHA MET 6.1	24	51	75	0.68
	Saxon-Junkalor Infralyt ELD	-(b)	-(b)	-(b)	-(b)
DOC removed	*Siemens (CLD)*	*85.5*	*23.5*	*109*	*0.22*
	MAHA MET 6.1	104	18	122	0.15
	Saxon-Junkalor Infralyt ELD	51	17	68	0.25
Unloaded DPF + DOC removed	*Siemens (CLD)*	*84.5*	*22.5*	*107*	*0.21*
	MAHA MET 6.1	130	16	146	0.11
	Saxon-Junkalor Infralyt ELD	59	14	73	0.19

(a) Volume ratio

(b) Instrument defective at time of measurement.

Table H29: DT80 results, vehicle 3.

Vehicle condition	CO (mg/km)	NO (mg/km)	NO_2 (mg/km)	NO_x (mg/km)	NO_2/ NO_x[(a)]	THC+NO_x (mg/km)	PM (mg/km)	OBD	
								MIL	DTC
Initial state	18.3	1621.9	846.0	2467.8	0.34	2468.3	19.62	Off	None
Unloaded DPF	23.4	1645.9	987.6	2633.5	0.38	2658.5	15.14	Off	None
DOC removed	48.8	2049.9	735.4	2785.3	0.26	2797.3	15.75	Off	None
Unloaded DPF + DOC removed	1020.9	2303.9	627.2	2931.1	0.21	3072.5	26.11	Off	None

(a) Mass ratio.

Table H30: AC5080 results, vehicle 3.

Vehicle condition	CO (mg/km)	NO (mg/km)	NO_2 (mg/km)	NO_x (mg/km)	NO_2/ NO_x[(a)]	THC+NO_x (mg/km)	PM (mg/km)	OBD	
								MIL	DTC
Initial state	27.8	318.9	218.9	537.8	0.41	542.7	0.77	Off	None
Unloaded DPF	0.20	281.4	370.0	651.4	0.57	655.1	4.39	Off	None
DOC removed	7.81	512.4	177.9	690.3	0.26	692.3	1.36	Off	None
Unloaded DPF + DOC removed	443.9	613.7	124.3	738.0	0.17	822.4	4.67	Off	None

(a) Mass ratio.

H1.4 Vehicle 4

Table H31: Emissions over NEDC, vehicle 4.

Vehicle condition	CO (mg/km)	NO (mg/km)	NO_2 (mg/km)	NO_x (mg/km)	NO_2/ NO_x[(a)]	THC+NO_x (mg/km)	PM		OBD	
							(mg/km)	*(% of E5 limit)*	MIL	DTC
Initial state	130.7	109.7	44.4	154.1	0.29	163.2	0.6	*12.0*	Off	None
Unloaded DPF	75.7	87.6	51.4	139	0.37	144.7	0.86	*17.2*	Off	None
Unloaded DPF + DOC removed	982.9	98.6	30	128.6	0.23	242.4	*2.27*	*54.0*	Off	None
DPF defect	82.8	76.6	58.9	135.5	0.43	137.9	*6.52*	*130.4*	Off	None
Limit value	*500*	-	-	*180*	-	*230*	*5*	*100.0*	-	-

(a) Mass ratio.

Table H32: NO and NO_2 results for free acceleration test, vehicle 4.

Vehicle condition	Instrument	NO (ppm)	NO_2 (ppm)	NO_x (ppm)	NO_2/NO_x[(a)]
Initial state	*Siemens (CLD)*	*283*	*140*	*423*	*0.33*
	Saxon-Junkalor Infralyt ELD	212	157	*369*	*0.43*
Unloaded DPF	*Siemens (CLD)*	*319*	*69*	*388*	*0.18*
	Saxon-Junkalor Infralyt ELD	217	133	*350*	*0.38*
Unloaded DPF + DOC removed	*Siemens (CLD)*	*442*	*94*	*536*	*0.18*
	Saxon-Junkalor Infralyt ELD	305	63	*368*	*0.17*
DPF defect	*Siemens (CLD)*	*363*	*97*	*460*	*0.21*
	Saxon-Junkalor Infralyt ELD	224	109	*333*	*0.33*

(a) Volume ratio.

Table H33: NO and NO_2 results for Norris-A test, vehicle 4.

Vehicle condition	Instrument	NO (ppm)	NO_2 (ppm)	NO_x (ppm)	NO_2/NO_x[(a)]
Initial state	*Siemens (CLD)*	*336*	*72*	*408*	*0.18*
	Saxon-Junkalor Infralyt ELD	249	177	*426*	*0.42*
Unloaded DPF	*Siemens (CLD)*	*402*	*188*	*590*	*0.32*
	Saxon-Junkalor Infralyt ELD	233	203	*436*	*0.47*
Unloaded DPF + DOC removed	*Siemens (CLD)*	*429*	*44*	*473*	*0.09*
	Saxon-Junkalor Infralyt ELD	274	56	*330*	*0.17*
DPF defect	*Siemens (CLD)*	*345*	*92*	*437*	*0.21*
	Saxon-Junkalor Infralyt ELD	228	164	*392*	*0.42*

(a) Volume ratio.

Table H34: NO and NO_2 results for INCOLL test, vehicle 4.

Vehicle condition	Instrument	NO (ppm)	NO_2 (ppm)	NO_x (ppm)	NO_2/NO_x[(a)]
Initial state	*Siemens (CLD)*	*321*	*147*	*468*	*0.31*
	Saxon-Junkalor Infralyt ELD	212	190	*402*	*0.47*
Unloaded DPF	*Siemens (CLD)*	*527*	*41*	*568*	*0.07*
	Saxon-Junkalor Infralyt ELD	299	189	*488*	*0.39*
Unloaded DPF + DOC removed	*Siemens (CLD)*	*549*	*12*	*561*	*0.02*
	Saxon-Junkalor Infralyt ELD	389	67	*456*	*0.15*
DPF defect	*Siemens (CLD)*	*409*	*155*	*564*	*0.27*
	Saxon-Junkalor Infralyt ELD	299	176	*475*	*0.37*

(a) Volume ratio.

H1.5 Vehicle 5

Table H35: Emissions over NEDC, vehicle 5.

Vehicle condition	CO (mg/km)	NO (mg/km)	NO_2 (mg/km)	NO_x (mg/km)	NO_2/ NO_x(a)	THC+NO_x (mg/km)	PM		OBD	
							(mg/km)	*(% of E5 limit)*	MIL	DTC
Initial state	25.51	43.53	15.61	59.14	0.26	71.11	0.36	8.1	Off	None
DPF defect	489.4	61.64	33.08	94.72	0.35	163.39	8.87	197	Off	None
SCR catalyst aged	69.65	58.75	34.09	92.84	0.37	109.39	0.22	4.9	Off	None
SCR catalyst damaged	68.47	45.59	30.07	75.66	0.40	91.99	0.41	9	Off	None
Limit value	*500*	*-*	*-*	*80*	*-*	*170*	*4.5*	*100*	-	-

(a) Mass ratio.

Table H36: NO and NO_2 results for idle speed, vehicle 5.

Vehicle condition	Instrument	NO (ppm)	NO_2 (ppm)	NO_x (ppm)	NO_2/NO_x(a)
Initial state	*Pierburg (CLD)*	*5.16*	*6.89*	*12.05*	*0.57*
	Sensors Inc. SEMTECH-DS	3.05	10.11	13.16	0.77
DPF defect	*Pierburg (CLD)*	*6.28*	*0.06*	*6.34*	*0.01*
	Sensors Inc. SEMTECH-DS	4.2	0.2	4.4	0.05
SCR catalyst aged	*Pierburg (CLD)*	*0.5*	*0.37*	*0.87*	*0.43*
	Sensors Inc. SEMTECH-DS	1.2	0.9	2.1	0.43
SCR catalyst damaged	*Pierburg (CLD)*	*25.32*	*1.96*	*27.28*	*0.07*
	Sensors Inc. SEMTECH-DS	46.1	7.1	53.2	0.13

(a) Volume ratio.

Table H37: NO and NO_2 results for high idle speed (2,500 rpm), vehicle 5.

Vehicle condition	Instrument	NO (ppm)	NO_2 (ppm)	NO_x (ppm)	NO_2/NO_x(a)
Initial state	*Pierburg (CLD)*	*37.32*	*22.55*	*59.87*	*0.38*
	Sensors Inc. SEMTECH-DS	37.68	29.22	66.9	0.44
DPF defect	*Pierburg (CLD)*	*20.46*	*0.61*	*21.07*	*0.03*
	Sensors Inc. SEMTECH-DS	19.6	0.7	20.3	0.03
SCR catalyst aged	*Pierburg (CLD)*	*87.95*	*5.14*	*93.09*	*0.06*
	Sensors Inc. SEMTECH-DS	9.7	3.3	13	0.25
SCR catalyst damaged	*Pierburg (CLD)*	*67.67*	*3.93*	*71.6*	*0.05*
	Sensors Inc. SEMTECH-DS	71.2	4.8	76	0.06

(a) Volume ratio.

Table H38: NO and NO_2 results for free acceleration test, vehicle 5.

Vehicle condition	Instrument	NO (ppm)	NO_2 (ppm)	NO_x (ppm)	NO_2/NO_x (a)
Initial state	*Pierburg (CLD)*	*100.67*	*138*	*238.67*	*0.58*
	Sensors Inc. SEMTECH-DS	77.4	42.52	119.92	0.35
DPF defect	*Pierburg (CLD)*	*167*	*128.93*	*295.93*	*0.44*
	Sensors Inc. SEMTECH-DS	84.3	2.9	87.2	0.03
SCR catalyst aged	*Pierburg (CLD)*	*137.96*	*123.69*	*261.65*	*0.47*
	Sensors Inc. SEMTECH-DS	85.6	29.1	114.7	0.25
SCR catalyst damaged	*Pierburg (CLD)*	*147.5*	*83*	*230.5*	*0.36*
	Sensors Inc. SEMTECH-DS	109.5	10.3	119.8	0.09

(a) Volume ratio.

Table H39: NO and NO_2 results for Norris-A test, vehicle 5.

Vehicle condition	Instrument	NO (ppm)	NO_2 (ppm)	NO_x (ppm)	NO_2/NO_x (a)
Initial state	*Pierburg (CLD)*	*75.73*	*59.5*	*135.23*	*0.44*
	Sensors Inc. SEMTECH-DS	67.2	38.55	105.75	0.36
DPF defect	*Pierburg (CLD)*	*110.35*	*57.35*	*167.7*	*0.34*
	Sensors Inc. SEMTECH-DS	83.7	2.9	86.6	0.03
SCR catalyst aged	*Pierburg (CLD)*	*101.42*	*106.72*	*208.14*	*0.51*
	Sensors Inc. SEMTECH-DS	79.6	39.2	118.8	0.33
SCR catalyst damaged	*Pierburg (CLD)*	*121.73*	*28.9*	*150.63*	*0.19*
	Sensors Inc. SEMTECH-DS	97.4	11.2	108.6	0.10

(a) Volume ratio.

Table H40: NO and NO_2 results for INCOLL test, vehicle 5.

Vehicle condition	Instrument	NO (ppm)	NO_2 (ppm)	NO_x (ppm)	NO_2/NO_x (a)
Initial state	*Pierburg (CLD)*	*120.7*	*134.75*	*255.45*	*0.53*
	Sensors Inc. SEMTECH-DS	71.7	34.9	106.6	0.33
DPF defect	*Pierburg (CLD)*	*166.17*	*90.14*	*256.31*	*0.35*
	Sensors Inc. SEMTECH-DS	96.1	6.9	103	0.07
SCR catalyst aged	*Pierburg (CLD)*	*153.76*	*118.73*	*272.49*	*0.44*
	Sensors Inc. SEMTECH-DS	79.8	39.6	119.4	0.33
SCR catalyst damaged	*Pierburg (CLD)*	*183.88*	*69.68*	*253.56*	*0.27*
	Sensors Inc. SEMTECH-DS	100.3	28.7	129	0.22

(a) Volume ratio.

Table H41: NO and NO_2 results for 50 km/h constant speed, vehicle 5.

Vehicle condition	Instrument	NO (ppm)	NO_2 (ppm)	NO_x (ppm)	NO_2/NO_x[(a)]
Initial state	*Pierburg (CLD)*	*3.78*	*8.77*	*12.55*	*0.70*
	Sensors Inc. SEMTECH-DS	1.13	15.8	16.93	0.93
DPF defect	*Pierburg (CLD)*	*9.07*	*17.99*	*27.06*	*0.66*
	Sensors Inc. SEMTECH-DS	24.4	12.3	36.7	0.34
SCR catalyst aged	*Pierburg (CLD)*	*4.91*	*13.64*	*18.55*	*0.74*
	Sensors Inc. SEMTECH-DS	1.9	19.2	21.1	0.91
SCR catalyst damaged	*Pierburg (CLD)*	*7.69*	*14.69*	*22.38*	*0.66*
	Sensors Inc. SEMTECH-DS	4.3	20.8	25.1	0.83

(a) Volume ratio.

Table H42: NO and NO_2 results for 80 km/h constant speed, vehicle 5.

Vehicle condition	Instrument	NO (ppm)	NO_2 (ppm)	NO_x (ppm)	NO_2/NO_x[(a)]
Initial state	*Pierburg (CLD)*	*4.58*	*17.52*	*22.1*	*0.79*
	Sensors Inc. SEMTECH-DS	2.13	22.27	24.4	0.91
DPF defect	*Pierburg (CLD)*	*8.68*	*22.81*	*31.49*	*0.72*
	Sensors Inc. SEMTECH-DS	34.5	12.3	46.8	0.26
SCR catalyst aged	*Pierburg (CLD)*	*7.51*	*23.73*	*31.24*	*0.76*
	Sensors Inc. SEMTECH-DS	4.5	23.2	27.7	0.84
SCR catalyst damaged	*Pierburg (CLD)*	*9.36*	*21.76*	*31.12*	*0.70*
	Sensors Inc. SEMTECH-DS	5.4	32.3	37.7	0.86

(a) Volume ratio.

Table H43: AC5080 results, vehicle 5.

Vehicle condition	CO (mg/km)	NO (mg/km)	NO_2 (mg/km)	NO_x (mg/km)	NO_2/NO_x[(a)]	$THC+NO_x$ (mg/km)	Ø PM (mg/m^3)	OBD	
								MIL	DTC
Initial state	0.01	24.23	18.52	42.75	0.43	43.42	0.26	Off	None
DPF defect	24.52	38.32	21.46	59.78	0.36	62.11	4.10	Off	None
SCR catalyst aged	0.12	28.51	16.57	45.08	0.37	45.99	0.27	Off	None
SCR catalyst damaged	0.48	20.78	18.46	39.23	0.47	39.55	0.34	Off	None

(a) Mass ratio.
Ø = average peak value

H1.6 Heavy-duty engine

Table H44: Emissions over ESC, heavy-duty engine.

	CO (g/kWh)	HC (g/kWh)	NO (g/kWh)	NO_2 (g/kWh)	NO_x (g/kWh)	NO_2/NO_x[(a)]	PM (g/kWh)
Test result	0.73	0.011	0.913	0.035	0.948	0.04	0.016
Limit value	*1.5*	*0.46*	-	-	*2.0*	-	*0.02*

(a) Mass ratio.

Table H45: Emissions over ETC, heavy-duty engine.

Engine condition	CO (g/kWh)	HC (g/kWh)	NO (g/kWh)	NO_2 (g/kWh)	NO_x (g/kWh)	NO_2/NO_x[(a)]	PM (g/kWh)
Initial state	1.5325	0.02	1.1816	0.0183	1.1999	0.02	0.0276
Intermittent reagent dosing	1.5504	0.02	6.0904	0.036	6.1264	0.01	0.0299
Empty reagent reservoir	1.6056	0.02	7.2943	0.0606	7.3549	0.01	0.0287
Reagent diluted with 50 % H_2O	1.5224	0.02	3.3718	0.0933	3.4651	0.03	0.0276
Limit value	*4.0*	*0.55*	-	-	*2.0*	-	*0.03*

(a) Mass ratio.

Table H46: NO and NO_2 emissions over ETC, heavy-duty engine in initial state and with faults (average value ppm/test).

Condition	Instrument	NO (ppm)	NO_2 (ppm)	NO_x (ppm)	NO_2/NO_x[(a)]
Initial state	*Pierburg AMA 4000 (CLD)*	*62.84*	*1.20*	*64.04*	*0.02*
	MAHA MET 6.1	86.75	0.03	86.78	0.00
	Saxon Junkalor Infralyt ELD	13.36	0.00	13.36	0.00
Intermittent reagent dosing	*Pierburg AMA 4000 (CLD)*	*341.86*	*1.09*	*342.95*	*0.00*
	MAHA MET 6.1	438.69	5.61	444.30	0.01
	Saxon Junkalor Infralyt ELD	238.62	5.32	243.94	0.02
Empty reagent	*Pierburg AMA 4000 (CLD)*	*399.28*	*2.25*	*401.53*	*0.01*
	MAHA MET 6.1	497.08	7.66	504.74	0.02
	Saxon Junkalor Infralyt ELD	374.79	7.51	382.30	0.02
Diluted reagent	*Pierburg AMA 4000 (CLD)*	*185.04*	*5.58*	*190.62*	*0.03*
	MAHA MET 6.1	225.87	0.93	226.80	0.00
	Saxon Junkalor Infralyt ELD	66.71	1.61	68.32	0.02

(a) Volume ratio.

Table H47: NO and NO_2 emissions during idle test – initial state only (average value ppm/test).

Instrument	NO (ppm)	NO_2 (ppm)	NO_x (ppm)	NO_2/ NO_x (a)
Pierburg AMA 4000 (CLD)	*283.04*	*6.68*	*289.72*	*0.02*
MAHA MET 6.1	316.90	16.05	332.95	0.05
Saxon Junkalor Infralyt ELD	240.24	16.94	257.18	0.07

(a) Volume ratio.

Table H48: NO and NO_2 emissions during high idle test – initial state only (average value ppm/test).

Instrument	NO (ppm)	NO_2 (ppm)	NO_x (ppm)	NO_2/ NO_x (a)
Pierburg AMA 4000 (CLD)	*375.85*	*0.96*	*376.81*	*0.00*
MAHA MET 6.1	416.98	15.77	432.75	0.04
Saxon Junkalor Infralyt ELD	30.39	6.45	36.84	0.08

(a) Volume ratio.

Table H49: NO and NO_2 emissions during free acceleration test, heavy-duty engine – initial state only (moving average value ppm/test).

Instrument	NO (ppm)	NO_2 (ppm)	NO_x (ppm)	NO_2/ NO_x (a)
Pierburg AMA 4000 (CLD)	*151.40*	*6.69*	*158.09*	*0.04*
MAHA MET 6.1	159.66	2.23	161.89	0.01
Saxon Junkalor Infralyt ELD	45.17	1.67	46.84	0.04

(a) Volume ratio.

Table H50: NO and NO_2 emissions during INCOLL test, heavy-duty engine – initial state only (moving average value ppm/test).

Instrument	NO (ppm)	NO_2 (ppm)	NO_x (ppm)	NO_2/ NO_x (a)
Pierburg AMA 4000 (CLD)	*154.02*	*0.89*	*154.91*	*0.01*
MAHA MET 6.1	162.47	1.52	163.99	0.01
Saxon Junkalor Infralyt ELD	48.2	1.85	50.05	0.04

(a) Volume ratio.

Table H51: NO and NO_2 emissions during constant speed/torque tests, heavy-duty engine (average value ppm/test).

Condition	Test Speed (rpm)	Test Torque (Nm)	Instrument	NO (ppm)	NO_2 (ppm)	NO_X (ppm)	NO_2/NO_x[(a)]
Initial state	1430	416	*Pierburg AMA 4000 (CLD)*	*63.81*	*0.22*	*64.03*	*0.00*
			MAHA MET 6.1	65.23	0.41	65.64	0.01
			Saxon Junkalor Infralyt ELD	30.6	0	30.6	0.00
	1700	450	*Pierburg AMA 4000 (CLD)*	*73.57*	*3.33*	*76.9*	0.04
			MAHA MET 6.1	90.03	0.12	90.15	0.00
			Saxon Junkalor Infralyt ELD	41.7	0	41.7	0.00
Intermittent reagent dosing	1430	416	*Pierburg AMA 4000 (CLD)*	-[(b)]	-[(b)]	412.36	-[(b)]
			MAHA MET 6.1	-[(b)]	-[(b)]	-[(b)]	-[(b)]
			Saxon Junkalor Infralyt ELD	-[(b)]	-[(b)]	-[(b)]	-[(b)]
	1700	416	*Pierburg AMA 4000 (CLD)*	-[(b)]	-[(b)]	428.73	-[(b)]
			MAHA MET 6.1	-[(b)]	-[(b)]	-[(b)]	-[(b)]
			Saxon Junkalor Infralyt ELD	-[(b)]	-[(b)]	-[(b)]	-[(b)]
Empty reagent	1430	416	*Pierburg AMA 4000 (CLD)*	*468.13*	*5.32*	*473.45*	*0.01*
			MAHA MET 6.1	549.95	9.79	559.74	0.02
			Saxon Junkalor Infralyt ELD	416.09	8.71	424.8	0.02
	1700	416	*Pierburg AMA 4000 (CLD)*	*500.14*	*2.42*	*502.56*	0.00
			MAHA MET 6.1	593.06	8.88	601.94	0.01
			Saxon Junkalor Infralyt ELD	438.79	9	447.79	0.02
Diluted reagent	1430	416	*Pierburg AMA 4000 (CLD)*	*211.22*	*4.35*	*215.57*	*0.02*
			MAHA MET 6.1	246.65	2.23	248.88	0.01
			Saxon Junkalor Infralyt ELD	193.67	0	193.67	0.00
	1700	416	*Pierburg AMA 4000 (CLD)*	*162.09*	*3.07*	*165.16*	0.02
			MAHA MET 6.1	311.21	2.62	313.83	0.01
			Saxon Junkalor Infralyt ELD	115.96	0	115.96	0.00

(a) Volume ratio.
(b) Data unavailable.

H2 Results for PM

H2.1 Vehicle 1

PM emissions over the loaded transient tests were provided in section H1.1.

Table H52: PM results over loaded steady-state and unloaded tests, vehicle 1.

Vehicle condition	Instrument	Ø PM (mg/m³)						
		50 km/h	80 km/h	Idle	High idle	Free accel.	Norris A	INCOLL
Initial state	MAHA MET 6.1	-	0.1	-	-	-	-	-
	MAHA MET 6.2	0.1	-	-	0.1	0.39	0.14	0.11
DPF defect	MAHA MET 6.1	-	0.95	-	-	-	-	-
	MAHA MET 6.2	0.9	-	-	0.3	7.41	2.85	3.5
Crankcase breather removed	MAHA MET 6.1	-	0.1	-	-	-	-	0.13
	MAHA MET 6.2	0.1	-	-	0.11	0.14	0.13	-
Air mass flow meter manipulated	MAHA MET 6.1	0.1	0.1	-	0.13	-	-	0.12
	MAHA MET 6.2	-	-	-	-	0.12	0.12	-

Ø = average peak value

Table H53: PM results for free acceleration test, vehicle 1 (mean of last three measurements).

Vehicle condition	Instrument	k (m^{-1})	PM (mg/m³)
Initial state	*AVL 439*	*0.022*	-(a)
	MAHA MET 6.2	-	0.39
	AVL 2000	-	0.64
DPF defect	*AVL 439*	*0.037*	-(a)
	MAHA MET 6.2	-	7.41
	AVL 2000	-	24.92

(a) Not relevant

Table H54: PM results for Norris test, vehicle 1 (mean of two measurements).

Vehicle condition	Instrument	k (m^{-1})	PM (mg/m³)
Initial state	*AVL 439*	*0.019*	-(a)
	MAHA MET 6.2	-	0.21
	AVL 2000	-	0.20
DPF defect	*AVL 439*	*0.028*	-(a)
	MAHA MET 6.2	-	2.85
	AVL 2000	-	6.10

(a) Not relevant

Table H55: PM results for INCOLL test, vehicle 1 (mean of all measurements).

Vehicle condition	Instrument	k (m^{-1})	PM (mg/m^3)
Initial state	*AVL 439*	*0.038*	-(a)
	MAHA MET 6.2	-	0.24
	AVL 2000	-	0.35
DPF defect	*AVL 439*	*0.043*	-(a)
	MAHA MET 6.2	-	3.65
	AVL 2000	-	11.62

(a) Not relevant

H2.2 Vehicle 2

PM emissions over the loaded transient tests were provided in section H1.2.

Table H56: PM results over loaded steady-state and unloaded tests, vehicle 2.

Vehicle condition	Instrument	Ø PM (mg/m^3)						
		50 km/h	80 km/h	Idle	High idle	Free accel.	Norris A	INCOLL
Initial state	MAHA MET 6.1	-	-	-	-	-	0.14	-
	MAHA MET 6.2	0	0	-	0	0.41	-	0.19
DPF defect	MAHA MET 6.1	-	-	-	-	-	73.5	-
	MAHA MET 6.2	3.8	4.1	-	2.1	128.89	-	61.12
Crankcase breather removed	MAHA MET 6.1	-	-	-	-	-	0.16	-
	MAHA MET 6.2	0	0	-	0	0.32	-	0.18
DOC defect	MAHA MET 6.1	-	-	-	-	-	0.11	-
	MAHA MET 6.2	-	-	-	-	0.12	-	0.16

Ø = average peak value

Table H57: PM results for free acceleration test, vehicle 2 (mean of last three measurements).

Vehicle condition	Instrument	k (m^{-1})	PM (mg/m^3)
Initial state	*AVL 439*	*0.010*	-(a)
	MAHA MET 6.2	-	0.41
	AVL 2000	-	0.55
DPF defect	*AVL 439*	*0.242*	-(a)
	MAHA MET 6.2	-	128.89
	AVL 2000	-	134.43

(a) Not relevant

Table H58: PM results for Norris test, vehicle 2 (mean of two measurements).

Vehicle condition	Instrument	k (m^{-1})	PM (mg/m^3)
Initial state	*AVL 439*	*0.009*	-[(a)]
	MAHA MET 6.2	-	0.14
	AVL 2000	-	0.16
DPF defect	*AVL 439*	*0.115*	-[(a)]
	MAHA MET 6.2	-	73.50
	AVL 2000	-	80.34

(a) Not relevant

Table H59: PM results for INCOLL test, vehicle 2 (mean of all measurements).

Vehicle condition	Instrument	k (m^{-1})	PM (mg/m^3)
Initial state	*AVL 439*	*0.009*	-[(a)]
	MAHA MET 6.2	-	0.19
	AVL 2000	-	0.21
DPF defect	*AVL 439*	*0.282*	-[(a)]
	MAHA MET 6.2	-	61.12
	AVL 2000	-	83.20

(a) Not relevant

H2.3 Vehicle 3

PM emissions over the loaded transient tests were provided in section H1.3.

Table H60: PM results for free acceleration test with simulated faults, vehicle 3 (average of four tests).

Vehicle condition	Instrument	k (m^{-1})	PM (mg/m^3)
Initial state	*AVL 439*	0.024	-[(a)]
	MAHA MET 6.2	-	0.000
	AVL 2000	-	0.003
	Bosch BEA 080	-	0.087
Unloaded DPF	*AVL 439*	0.044	-[(a)]
	MAHA MET 6.2	-	0.000
	AVL 2000	-	0.249
	Bosch BEA 080	-	0.004
DOC removed	*AVL 439*	0.020	-[(a)]
	MAHA MET 6.2	-	1.242
	AVL 2000	-	2.931
	Bosch BEA 080	-	0.987
Unloaded DPF + DOC removed	*AVL 439*	0.015	-[(a)]
	MAHA MET 6.2	-	0.087
	AVL 2000	-	0.286
	Bosch BEA 080	-	0.079

(a) Not relevant

H2.4 Vehicle 4

PM emissions over the loaded transient tests were provided in section H1.4.

Table H61: PM results over loaded steady-state and unloaded tests, vehicle 4 (average of four tests).

Vehicle condition	Instrument	Ø PM (mg/m^3)		
		Free acceleration	Norris A	INCOLL
Initial state	AVL 2000	0.24	0.02	1.72
	Bosch BEA 080	0.34	0.03	0.92
Unloaded DPF	AVL 2000	1.96	0.26	0.65
	Bosch BEA 080	1.83	0.00	0.87
Unloaded DPF + DOC removed	AVL 2000	0.24	0.10	0.33
	Bosch BEA 080	0.37	0.00	0.54
DPF defect	AVL 2000	59.84	5.15	24.10
	Bosch BEA 080	12.14	4.06	14.47

Ø = average peak value

H2.5 Vehicle 5

PM emissions over the loaded transient tests were provided in section H1.5.

Table H62: PM results over loaded steady-state and unloaded tests, vehicle 5.

Vehicle condition	Instrument	Ø PM (mg/m^3)						
		50 km/h	80 km/h	Idle	High idle	Free accel.	Norris A	INCOLL
Initial state	AVL 2000	0.09	0.09	0.09	0.08	0.46	0.16	0.24
	MAHA MET 6.1	0.22	0.22	0.15	0.18	1.23	0.33	0.72
DPF defect	AVL 2000	3.81	7.01	4.25	5.25	20.49	6.65	10.38
	MAHA MET 6.1	1.89	3.35	2.11	2.24	10.83	3.72	4.58
SCR catalyst aged	AVL 2000	-(a)	-(a)	-(a)	-(a)	-(a)	-(a)	-(a)
	MAHA MET 6.1	0.23	0.24	0.1	0.14	0.27	0.24	0.27
SCR catalyst damaged	AVL 2000	-(a)	-(a)	-(a)	-(a)	-(a)	-(a)	-(a)
	MAHA MET 6.1	0.16	0.17	0.14	0.17	2.96	1.12	1.29

(a) Data unavailable.

Ø = average peak value.

H2.6 Heavy-duty engine

PM emissions over the ETC were provided in section H1.6.

Table H63: Opacity results for ELR, heavy-duty engine (initial state only).

Test procedure	Instrument	k (m^{-1})
ELR	AVL 439	0.106
	Limit	*0.5*

Table H64: PM results for free acceleration test, heavy-duty engine.

Condition	Instrument	k (m^{-1})[a]	PM (mg/m^3)
Initial state	*AVL 439*	0.116	-[b]
	MAHA MET 6.2	0.123	27.83
	AVL 2000	0.189	44.91
	Bosch BEA 080	0	0.016
Intermittent reagent dosing	*AVL 439*	0.117	-[b]
Empty reagent reservoir	*AVL 439*	0.118	-[b]
Reagent diluted with 50 % H_2O	*AVL 439*	0.116	-[b]

(a) Average of four tests.
(b) Not relevant

Appendix I: Cost-benefit analysis results

I1 Emission results and potential changes in emissions

In the following tables n.o. = not observed.

Table I1: Emission results for tested vehicle 1.

		Initial State	DPF defect (Case 1)	Crankcase breather removed (Case 2)	Air mass flow meter manipulated (Case 3)	Catalytic converter fault (Case 4)	Without catalyst, new DPF (Case 5)	Without catalyst, unl. DPF (Case 6)	SCR catalyst aged (Case7)	SCR catalyst damaged (Case8)
Emissions in mg/km	CO	46.2	385.5	26.1	96.2	n.o.	n.o	n.o	n.o	n.o
	NO	91.1	143.9	213.6	58.3	n.o	n.o	n.o	n.o	n.o
	NO_2	81.2	18.4	179.5	49.1	n.o	n.o	n.o	n.o	n.o
	NO_x	172.3	162.3	393.1	107.4	n.o	n.o	n.o	n.o	n.o
	THC	14.6	72.6	10.5	31.3	n.o	n.o	n.o	n.o	n.o
	PM	0.3	5.06	0.3	0.4	n.o	n.o	n.o	n.o	n.o

Table I2: Possible emission changes for tested vehicle 1.

		Delta Case 1	Delta Case 2	Delta Case 3	Delta Case 4	Delta Case 5	Delta Case 6	Delta Case 7	Delta Case 8
Emissions in mg/km	CO	339.3	-20.1	50	n.o.	n.o.	n.o.	n.o.	n.o.
	NO	52.8	122.5	-32.8	n.o.	n.o.	n.o.	n.o.	n.o.
	NO_2	-62.8	98.3	-32.1	n.o.	n.o.	n.o.	n.o.	n.o.
	NO_x	-10	220.8	-64.9	n.o.	n.o.	n.o.	n.o.	n.o.
	THC	58	-4.1	16.7	n.o.	n.o.	n.o.	n.o.	n.o.
	PM	4.76	0	0.1	n.o.	n.o.	n.o.	n.o.	n.o.

Table I3: Emission results for tested vehicle 2.

		Initial State	DPF defect (Case 1)	Crankcase breather removed (Case 2)	Air mass flow meter manipulated (Case 3)	Catalytic converter fault (Case 4)	Without catalyst, new DPF (Case 5)	Without catalyst, unl. DPF (Case 6)	SCR catalyst aged (Case7)	SCR catalyst damaged (Case8)
Emissions in mg/km	CO	240.3	239.0	232.8	n.o.	904.0	n.o.	n.o	n.o	n.o
	NO	157.3	158.1	161.7	n.o.	163.3	n.o.	n.o	n.o	n.o
	NO_2	15.1	6.4	34.2	n.o.	19.4	n.o.	n.o	n.o	n.o
	NO_x	172.4	164.4	195.9	n.o.	182.7	n.o.	n.o	n.o	n.o
	THC	43.8	54.0	220.9	n.o.	122.2	n.o.	n.o	n.o	n.o
	PM	0.74	36.0	0.31	n.o.	0.83	n.o.	n.o	n.o	n.o

Table I4: Possible emission changes for tested vehicle 2.

		Delta Case 1	Delta Case 2	Delta Case 3	Delta Case 4	Delta Case 5	Delta Case 6	Delta Case 7	Delta Case 8
Emissions in mg/km	CO	-1.3	-7.5	n.o.	663.7	n.o.	n.o.	n.o.	n.o.
	NO	0.8	4.4	n.o.	6	n.o.	n.o.	n.o.	n.o.
	NO_2	-8.7	19.1	n.o.	4.3	n.o.	n.o.	n.o.	n.o.
	NO_x	-8	23.5	n.o.	10.3	n.o.	n.o.	n.o.	n.o.
	THC	10.2	177.1	n.o.	78.4	n.o.	n.o.	n.o.	n.o.
	PM	35.26	-0.43	n.o.	0.09	n.o.	n.o.	n.o.	n.o.

Table I5: Emission results for tested vehicle 3.

		Initial State	DPF defect (Case 1)	Crankcase breather removed (Case 2)	Air mass flow meter manipulated (Case 3)	Catalytic converter fault (Case 4)	Without catalyst, new DPF (Case 5)	Without catalyst, unl. DPF (Case 6)	SCR catalyst aged (Case7)	SCR catalyst damaged (Case8)
Emissions in mg/km	CO	59.7	82.8	n.o.	n.o.	982.9	113.9	844.3	n.o	n.o
	NO	78.2	76.6	n.o.	n.o.	98.6	123.4	100.9	n.o	n.o
	NO_2	55.4	58.9	n.o.	n.o.	30	7.3	43.6	n.o	n.o
	NO_x	133.6	135.5	n.o.	n.o.	128.6	130.7	144.5	n.o	n.o
	THC	8.0	2.4	n.o.	n.o.	113.8	37.9	161.8	n.o	n.o
	PM	0.23	6.52	n.o.	n.o.	4.82	0.64	4.52	n.o	n.o

Table I6: Possible emission changes for tested vehicle 3.

		Delta Case 1	Delta Case 2	Delta Case 3	Delta Case 4	Delta Case 5	Delta Case 6	Delta Case 7	Delta Case 8
Emissions in mg/km	CO	23.1	n.o.	n.o.	923.2	54.2	784.6	n.o.	n.o.
	NO	-1.6	n.o.	n.o.	20.4	45.2	22.7	n.o.	n.o.
	NO_2	3.5	n.o.	n.o.	-25.4	-48.1	-11.8	n.o.	n.o.
	NO_x	1.9	n.o.	n.o.	-5	-2.9	10.9	n.o.	n.o.
	THC	-5.6	n.o.	n.o.	105.8	29.9	153.8	n.o.	n.o.
	PM	6.29	n.o.	n.o.	4.59	0.41	4.29	n.o.	n.o.

Table I7: Emission results for tested vehicle 4.

		Initial State	DPF defect (Case 1)	Crankcase breather removed (Case 2)	Air mass flow meter manipulated (Case 3)	Catalytic converter fault (Case 4)	Without catalyst, new DPF (Case 5)	Without catalyst, unl. DPF (Case 6)	SCR catalyst aged (Case7)	SCR catalyst damaged (Case8)
Emissions in mg/km	CO	59,7	n.o.	n.o.	n.o.	844,3	113,9	*	n.o.	n.o
	NO	78,2	n.o.	n.o.	n.o.	100,9	123,4	77,7	n.o	n.o
	NO_2	55,4	n.o.	n.o.	n.o.	43,6	7,3	65,4	n.o	n.o
	NO_x	133,6	n.o.	n.o.	n.o.	144,5	130,7	143,1	n.o	n.o
	THC	8	n.o.	n.o.	n.o.	161,8	37,9	7,2	n.o	n.o
	PM	0,23	n.o.	n.o.	n.o.	4,52	0,64	1,18	n.o	n.o

Table I8: Possible emission changes for tested vehicle 4.

		Delta Case 1	Delta Case 2	Delta Case 3	Delta Case 4	Delta Case 5	Delta Case 6	Delta Case 7	Delta Case 8
Emissions in mg/km	CO	n.o	n.o	n.o	784,6	54,2	*	n.o	n.o
	NO	n.o	n.o	n.o	22,7	45,2	-0,5	n.o	n.o
	NO_2	n.o	n.o	n.o	-11,8	-48,1	10	n.o	n.o
	NO_x	n.o	n.o	n.o	10,9	-2,9	9,5	n.o	n.o
	THC	n.o	n.o	n.o	153,8	29,9	-0,8	n.o	n.o
	PM	n.o	n.o	n.o	4,29	0,41	0,95	n.o	n.o

Table I9: Emission results for tested vehicle 5.

		Initial State	DPF defect (Case 1)	Crankcase breather removed (Case 2)	Air mass flow meter manipulated (Case 3)	Catalytic converter fault (Case 4)	Without catalyst, new DPF (Case 5)	Without catalyst, unl. DPF (Case 6)	SCR catalyst aged (Case7)	SCR catalyst damaged (Case8)
Emissions in mg/km	CO	25.51	489.40	n.o.	n.o.	n.o.	n.o.	n.o.	69.65	68.47
	NO	43.53	61.64	n.o.	n.o.	n.o.	n.o.	n.o.	58.75	45.59
	NO_2	15.61	33.08	n.o.	n.o.	n.o.	n.o.	n.o.	34.09	30.07
	NO_x	59.14	94.72	n.o.	n.o.	n.o.	n.o.	n.o.	92.84	75.66
	THC	11.97	74.67	n.o.	n.o.	n.o.	n.o.	n.o.	16.56	16.33
	PM	0.36	8.87	n.o.	n.o.	n.o.	n.o.	n.o.	0.22	0.41

Table I10: Possible emission changes for tested vehicle 5.

		Delta Case 1	Delta Case 2	Delta Case 3	Delta Case 4	Delta Case 5	Delta Case 6	Delta Case 7	Delta Case 8
Emissions in mg/km	CO	463.89	n.o.	n.o.	n.o.	n.o.	n.o.	44.14	42.96
	NO	18.11	n.o.	n.o.	n.o.	n.o.	n.o.	15.22	2.06
	NO_2	17.47	n.o.	n.o.	n.o.	n.o.	n.o.	18.48	14.46
	NO_x	35.58	n.o.	n.o.	n.o.	n.o.	n.o.	33.7	16.52
	THC	62.7	n.o.	n.o.	n.o.	n.o.	n.o.	4.59	4.36
	PM	8.51	n.o.	n.o.	n.o.	n.o.	n.o.	-0.14	0.05

I2 Calculated changes in emissions by fault case

Table I11: Changes in NO_x emissions in tonnes in 2010.

EU Member States		Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7	Case 8
Belgium	BE	93.8	160.6	-56.6	281.5	30.0	89.9	14.5	8,3
Denmark	DK	19.0	32.6	-11.5	57.1	6.1	18.2	2.9	1,7
Germany	DE	357.7	612.1	-215.6	1,072.9	114.4	342.5	55.3	31,5
Greece	EL	4.4	7.6	-2.7	13.3	1.4	4.2	0.7	0,4
Spain	ES	354.8	607.2	-213.9	1,064.4	113.5	339.8	54.9	31,2
France	FR	472.3	808.2	-284.7	1,416.6	151.0	452.3	73.0	41,6
Ireland	IE	11.0	18.9	-6.7	33.1	3.5	10.6	1.7	1,0
Italy	IT	285.6	488.7	-172.2	856.6	91.3	273.5	44.1	25,1
Luxembourg	LU	7.5	12.8	-4.5	22.4	2.4	7.2	1.2	0,7
Netherlands	NL	81.2	138.9	-48.9	243.5	26.0	77.7	12.5	7,1
Austria	AT	66.8	114.3	-40.3	200.4	21.4	64.0	10.3	5,9
Portugal	PT	44.9	76.8	-27.0	134.6	14.3	43.0	6.9	3,9
Finland	FI	21.0	35.9	-12.7	63.0	6.7	20.1	3.2	1,8
Sweden	SE	22.6	38.7	-13.6	67.8	7.2	21.7	3.5	2,0
United Kingdom	UK	290.8	497.6	-175.3	872.2	93.0	278.5	44.9	25,6
Czech Republic	CZ	32.1	54.9	-19.3	96.2	10.3	30.7	5.0	2,8
Estonia	EE	1.3	2.2	-0.8	3.8	0.4	1.2	0.2	0,1
Cyprus	CY	0.4	0.6	-0.2	1.1	0.1	0.4	0.1	0,0
Latvia	LV	3.3	5.7	-2.0	10.0	1.1	3.2	0.5	0,3
Lithuania	LT	7.2	12.3	-4.3	21.6	2.3	6.9	1.1	0,6
Hungary	HU	12.3	21.1	-7.4	37.0	3.9	11.8	1.9	1,1
Malta	MT	0.4	0.6	-0.2	1.1	0.1	0.3	0.1	0,0
Poland	PL	55.8	95.5	-33.6	167.4	17.8	53.5	8.6	4,9
Slovenia	SI	6.9	11.8	-4.2	20.7	2.2	6.6	1.1	0,6
Slovakia	SK	7.8	13.3	-4.7	23.3	2.5	7.4	1.2	0,7
Romania	RO	14.0	24.0	-8.4	42.0	4.5	13.4	2.2	1,2
Bulgaria	BG	17.4	29.8	-10.5	52.3	5.6	16.7	2.7	1,5
Total EU 27		**2,292.3**	**3,922.7**	**-1,381.0**	**6,876.9**	**7,330.0**	**2,195.3**	**354.3**	**201.6**
EU 27 Average		**84.9**	**145.3**	**-51.2**	**254.7**	**610.8**	**81.3**	**13.1**	**7.5**

Positive value = emission savings
Negative value = unavoidable increases in emissions

Table I12: Changes in PM emissions in tonnes in 2010.

EU Member States		Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7	Case 8
Belgium	BE	460.3	-0.5	0.1	3.3	0.3	0.5	-0.0	0,0
Denmark	DK	93.3	-0.1	0.0	0.7	0.1	0.1	-0.0	0,0
Germany	DE	1,754.5	-1.8	0.5	12.4	1.1	1.9	-0.2	0,1
Greece	EL	21.7	-0.0	0.0	0.2	0.0	0.0	-0.0	0,0
Spain	ES	1,740.7	-1.7	0.5	12.3	1.1	1.9	-0.2	0,1
France	FR	2,316.7	-2.3	0.7	16.4	1.5	2.5	-0.3	0,1
Ireland	IE	54.1	-0.1	0.0	0.4	0.0	0.1	-0.0	0,0
Italy	IT	1,400.9	-1.4	0.4	9.9	0.9	1.5	-0.2	0,1
Luxembourg	LU	36.6	-0.0	0.0	0.3	0.0	0.0	-0.0	0,0
Netherlands	NL	398.2	-0.4	0.1	2.8	0.3	0.4	-0.0	0,0
Austria	AT	327.7	-0.3	0.1	2.3	0.2	0.3	-0.0	0,0
Portugal	PT	220.1	-0.2	0.1	1.6	0.1	0.2	-0.0	0,0
Finland	FI	103.0	-0.1	0.0	0.7	0.1	0.1	-0.0	0,0
Sweden	SE	111.0	-0.1	0.0	0.8	0.1	0.1	-0.0	0,0
United Kingdom	UK	1,426.3	-1.4	0.4	10.1	0.9	1.5	-0.2	0,1
Czech Republic	CZ	157.3	-0.2	0.0	1.1	0.1	0.2	-0.0	0,0
Estonia	EE	6.2	-0.0	0.0	0.0	0.0	0.0	-0.0	0,0
Cyprus	CY	1.8	-0.0	0.0	0.0	0.0	0.0	-0.0	0,0
Latvia	LV	16.4	-0.0	0.0	0.1	0.0	0.0	-0.0	0,0
Lithuania	LT	35.3	-0.0	0.0	0.2	0.0	0.0	-0.0	0,0
Hungary	HU	60.5	-0.1	0.0	0.4	0.0	0.1	-0.0	0,0
Malta	MT	1.8	-0.0	0.0	0.0	0.0	0.0	-0.0	0,0
Poland	PL	273.8	-0.3	0.1	1.9	0.2	0.3	-0.0	0,0
Slovenia	SI	33.8	-0.0	0.0	0.2	0.0	0.0	-0.0	0,0
Slovakia	SK	38.1	-0.0	0.0	0.3	0.0	0.0	-0.0	0,0
Romania	RO	68.7	-0.1	0.0	0.5	0.0	0.1	-0.0	0,0
Bulgaria	BG	85.5	-0.1	0.0	0.6	0.1	0.1	-0.0	0,0
Total EU 27		**11,244.3**	**-11.2**	**3.0**	**79.5**	**7.1**	**11.9**	**-1.1**	**0.5**
EU 27 Average		**416.5**	**-0.4**	**0.1**	**2.9**	**0.26**	**0.5**	**-0.04**	**0.02**

Positive value = emission savings
Negative value = unavoidable increases in emissions

I3 Calculated benefits by fault case

Table I13: Total emission benefits - Case 1.

EU Member States		Benefits of NO_x savings per year in Euro	Benefits of PM savings per year in Euro	Total benefits from emission savings per year in Euro
Belgium	BE	439,203	42,600,472	43,039,676
Denmark	DK	89,033	8,635,789	8,724,823
Germany	DE	1,674,033	162,372,547	164,046,580
Greece	EL	20,741	2,011,759	2,032,500
Spain	ES	1,660,851	161,094,011	162,754,863
France	FR	2,210,450	214,402,230	216,612,680
Ireland	IE	51,651	5,009,870	5,061,521
Italy	IT	1,336,643	129,647,495	130,984,138
Luxembourg	LU	34,945	3,389,501	3,424,446
Netherlands	NL	379,961	36,854,297	37,234,258
Austria	AT	312,638	30,324,319	30,636,957
Portugal	PT	209,987	20,367,688	20,577,676
Finland	FI	98,245	9,529,262	9,627,507
Sweden	SE	105,864	10,268,301	10,374,166
United Kingdom	UK	1,360,915	132,001,774	133,362,689
Czech Republic	CZ	14,515,294	14,735,474	14,703,373
Estonia	EE	569,831	578,475	577,215
Cyprus	CY	166,751	169,280	168,911
Latvia	LV	1,516,718	1,539,725	1,536,370
Lithuania	LT	3,256,786	3,306,188	3,298,985
Hungary	HU	5,580,458	5,665,107	5,652,766
Malta	MT	162,248	164,709	164,350
Poland	PL	25,272,386	25,655,738	25,599,848
Slovenia	SI	3,117,794	3,165,087	3,158,192
Slovakia	SK	3,515,655	3,568,983	3,561,208
Romania	RO	6,337,517	6,433,650	6,419,634
Bulgaria	BG	7,890,683	8,010,375	7,992,925
Total EU 27		**81,887,281**	**1,041,502,106**	**1,051,328,257**

Table I14: Total emission benefits - Case 2.

EU Member States		Benefits of NO_x savings per year in Euro	Benefits of PM savings per year in Euro	Total benefits from emission savings per year in Euro
Belgium	BE	751,594	-42,532	709,063
Denmark	DK	152,360	-8,622	143,738
Germany	DE	2,864,716	-162,110	2,702,606
Greece	EL	35,493	-2,009	33,485
Spain	ES	2,842,159	-160,834	2,681,325
France	FR	3,782,669	-214,056	3,568,613
Ireland	IE	88,388	-5,002	83,387
Italy	IT	2,287,353	-129,438	2,157,915
Luxembourg	LU	59,800	-3,384	56,416
Netherlands	NL	650,215	-36,795	613,420
Austria	AT	535,008	-30,275	504,732
Portugal	PT	359,344	-20,335	339,010
Finland	FI	168,123	-9,514	158,610
Sweden	SE	181,162	-10,252	170,910
United Kingdom	UK	2,328,889	-131,789	2,197,100
Czech Republic	CZ	256,762	-14,530	242,233
Estonia	EE	10,080	-570	9,509
Cyprus	CY	2,950	-167	2,783
Latvia	LV	26,829	-1,518	25,311
Lithuania	LT	57,610	-3,260	54,350
Hungary	HU	98,713	-5,586	93,127
Malta	MT	2,870	-162	2,708
Poland	PL	447,046	-25,298	421,748
Slovenia	SI	55,151	-3,121	52,030
Slovakia	SK	62,189	-3,519	58,670
Romania	RO	112,105	-6,344	105,761
Bulgaria	BG	139,579	-7,899	131,680
Total EU 27		**18,359,157**	**-1,038,921**	**17,320,240**

Table I15: Total emission benefits - Case 3.

EU Member States		Benefits of NO_x savings per year in Euro	Benefits of PM savings per year in Euro	Total benefits from emission savings per year in Euro
Belgium	BE	-264,793	13,188	-251,605
Denmark	DK	-53,678	2,673	-51,004
Germany	DE	-1,009,264	50,267	-958,997
Greece	EL	-12,505	623	-11,882
Spain	ES	-1,001,317	49,871	-951,446
France	FR	-1,332,666	66,374	-1,266,293
Ireland	IE	-31,140	1,551	-29,589
Italy	IT	-805,854	40,136	-765,718
Luxembourg	LU	-21,068	1,049	-20,019
Netherlands	NL	-229,076	11,409	-217,667
Austria	AT	-188,488	9,388	-179,100
Portugal	PT	-126,600	6,305	-120,295
Finland	FI	-59,231	2,950	-56,281
Sweden	SE	-63,825	3,179	-60,646
United Kingdom	UK	-820,487	40,865	-779,623
Czech Republic	CZ	-90,460	4,505	-85,954
Estonia	EE	-3,551	177	-3,374
Cyprus	CY	-1,039	52	-987
Latvia	LV	-9,452	471	-8,981
Lithuania	LT	-20,296	1,011	-19,285
Hungary	HU	-34,778	1,732	-33,045
Malta	MT	-1,011	50	-961
Poland	PL	-157,498	7,844	-149,654
Slovenia	SI	-19,430	968	-18,462
Slovakia	SK	-21,910	1,091	-20,818
Romania	RO	-39,496	1,967	-37,528
Bulgaria	BG	-49,175	2,449	-46,726
Total EU 27		**-6,468,088**	**322,145**	**-6,145,940**

Table I16: Total emission benefits - Case 4.

EU Member States		Benefits of NO_x savings per year in Euro	Benefits of PM savings per year in Euro	Total benefits from emission savings per year in Euro
Belgium	BE	1,171,580	311,569	1,483,149
Denmark	DK	237,498	63,160	300,658
Germany	DE	4,465,501	1,187,552	5,653,053
Greece	EL	55,327	14,713	70,040
Spain	ES	4,430,339	1,178,201	5,608,540
France	FR	5,896,399	1,568,084	7,464,483
Ireland	IE	137,779	36,641	174,420
Italy	IT	3,565,510	948,209	4,513,719
Luxembourg	LU	93,217	24,790	118,007
Netherlands	NL	1,013,551	269,543	1,283,094
Austria	AT	833,966	221,784	1,055,751
Portugal	PT	560,143	148,964	709,108
Finland	FI	262,070	69,695	331,764
Sweden	SE	282,394	75,100	357,494
United Kingdom	UK	3,630,256	965,428	4,595,684
Czech Republic	CZ	400,239	106,439	506,679
Estonia	EE	15,712	4,179	19,891
Cyprus	CY	4,598	1,223	5,821
Latvia	LV	41,821	11,122	52,943
Lithuania	LT	89,801	23,882	113,683
Hungary	HU	153,874	40,921	194,795
Malta	MT	4,474	1,190	5,664
Poland	PL	696,852	185,320	882,172
Slovenia	SI	85,969	22,863	108,831
Slovakia	SK	96,939	25,780	122,719
Romania	RO	174,748	46,472	221,221
Bulgaria	BG	217,575	57,862	275,437
Total EU 27		**28,618,132**	**7,610,686**	**36,228,820**

Table I17: Total emission benefits - Case 5.

EU Member States		Benefits of NO_x savings per year in Euro	Benefits of PM savings per year in Euro	Total benefits from emission savings per year in Euro
Belgium	BE	140,442	27,036	167,478
Denmark	DK	28,470	5,481	33,950
Germany	DE	535,299	103,047	638,346
Greece	EL	6,632	1,277	7,909
Spain	ES	531,084	102,235	633,319
France	FR	706,827	136,067	842,893
Ireland	IE	16,516	3,179	19,696
Italy	IT	427,413	82,278	509,692
Luxembourg	LU	11,174	2,151	13,325
Netherlands	NL	121,499	23,389	144,888
Austria	AT	99,971	19,245	119,216
Portugal	PT	67,147	12,926	80,073
Finland	FI	31,415	6,048	37,463
Sweden	SE	33,852	6,517	40,368
United Kingdom	UK	435,175	83,773	518,947
Czech Republic	CZ	47,978	9,236	57,214
Estonia	EE	1,884	363	2,246
Cyprus	CY	551	106	657
Latvia	LV	5,013	965	5,978
Lithuania	LT	10,765	2,072	12,837
Hungary	HU	18,445	3,551	21,996
Malta	MT	536	103	640
Poland	PL	83,535	16,081	99,615
Slovenia	SI	10,305	1,984	12,289
Slovakia	SK	11,621	2,237	13,858
Romania	RO	20,948	4,033	24,980
Bulgaria	BG	26,082	5,021	31,102
Total EU 27		**3,430,579**	**660,401**	**4,090,975**

Table I18: Total emission benefits - Case 6.

EU Member States		Benefits of NO_x savings per year in Euro	Benefits of PM savings per year in Euro	Total benefits from emission savings per year in Euro
Belgium	BE	813,568	28,289	841,856
Denmark	DK	164,923	5,735	170,658
Germany	DE	3,100,929	107,822	3,208,751
Greece	EL	38,420	1,336	39,756
Spain	ES	3,076,512	106,973	3,183,485
France	FR	4,094,572	142,372	4,236,944
Ireland	IE	95,677	3,327	99,003
Italy	IT	2,475,959	86,091	2,562,050
Luxembourg	LU	64,731	2,251	66,982
Netherlands	NL	703,829	24,473	728,302
Austria	AT	579,122	20,137	599,259
Portugal	PT	388,974	13,525	402,499
Finland	FI	181,986	6,328	188,314
Sweden	SE	196,100	6,819	202,919
United Kingdom	UK	2,520,920	87,655	2,608,574
Czech Republic	CZ	277,934	9,664	287,598
Estonia	EE	10,911	379	11,290
Cyprus	CY	3,193	111	3,304
Latvia	LV	29,042	1,010	30,051
Lithuania	LT	62,360	2,168	64,528
Hungary	HU	106,853	3,715	110,568
Malta	MT	3,107	108	3,215
Poland	PL	483,907	16,826	500,733
Slovenia	SI	59,698	2,076	61,774
Slovakia	SK	67,317	2,341	69,657
Romania	RO	121,349	4,219	125,568
Bulgaria	BG	151,088	5,253	156,342
Total EU 27		**19,872,981**	**691,003**	**20,563,980**

Table I19: Total emission benefits - Case 7.

EU Member States		Benefits of NO_x savings per year in Euro	Benefits of PM savings per year in Euro	Total benefits from emission savings per year in Euro
Belgium	BE	67,895	-4,616	63,279
Denmark	DK	13,763	-936	12,828
Germany	DE	258,782	-17,593	241,189
Greece	EL	3,206	-218	2,988
Spain	ES	256,745	-17,455	239,290
France	FR	341,705	-23,231	318,474
Ireland	IE	7,985	-543	7,442
Italy	IT	206,627	-14,048	192,579
Luxembourg	LU	5,402	-367	5,035
Netherlands	NL	58,737	-3,993	54,744
Austria	AT	48,330	-3,286	45,044
Portugal	PT	32,461	-2,207	30,254
Finland	FI	15,187	-1,033	14,155
Sweden	SE	16,365	-1,113	15,253
United Kingdom	UK	210,379	-14,303	196,076
Czech Republic	CZ	23,194	-1,577	21,618
Estonia	EE	911	-62	849
Cyprus	CY	266	-18	248
Latvia	LV	2,424	-165	2,259
Lithuania	LT	5,204	-354	4,850
Hungary	HU	8,917	-606	8,311
Malta	MT	259	-18	242
Poland	PL	40,384	-2,745	37,638
Slovenia	SI	4,982	-339	4,643
Slovakia	SK	5,618	-382	5,236
Romania	RO	10,127	-688	9,438
Bulgaria	BG	12,609	-857	11,752
Total EU 27		**1,658,464**	**-112,753**	**1,545,714**

Table I20: Total emission benefits - Case 8.

EU Member States		Benefits of NO_x savings per year in Euro	Benefits of PM savings per year in Euro	Total benefits from emission savings per year in Euro
Belgium	BE	38,667	1,649	40,315
Denmark	DK	7,838	334	8,173
Germany	DE	147,378	6,283	153,662
Greece	EL	1,826	78	1,904
Spain	ES	146,218	6,234	152,452
France	FR	194,604	8,297	202,900
Ireland	IE	4,547	194	4,741
Italy	IT	117,675	5,017	122,692
Luxembourg	LU	3,077	131	3,208
Netherlands	NL	33,451	1,426	34,877
Austria	AT	27,524	1,173	28,698
Portugal	PT	18,487	788	19,275
Finland	FI	8,649	369	9,018
Sweden	SE	9,320	397	9,717
United Kingdom	UK	119,812	5,108	124,920
Czech Republic	CZ	13,209	563	13,773
Estonia	EE	519	22	541
Cyprus	CY	152	6	158
Latvia	LV	1,380	59	1,439
Lithuania	LT	2,964	126	3,090
Hungary	HU	5,078	217	5,295
Malta	MT	148	6	154
Poland	PL	22,999	981	23,979
Slovenia	SI	2,837	121	2,958
Slovakia	SK	3,199	136	3,336
Romania	RO	5,767	246	6,013
Bulgaria	BG	7,181	306	7,487
Total EU 27		**944,506**	**40,267**	**984,775**

Appendix J: Summary of stakeholder meeting

A meeting with stakeholders was held at DG-MOVE on 8 November 2011. In total, 49 people attended the meeting, with the participants representing a wide range of organisations, including:

- The European Commission (DG-MOVE, DG-ENTERPRISE, DG-CLIMA)
- The CITA Bureau Permanent and Secretariat
- CITA members
- National ministries
- Vehicle manufacturers
- Equipment manufacturers
- Associations

The aim of the meeting was to understand the views of stakeholders, and to ensure that the recommendations from the project represent these views and are realistic. Each item on the agenda is summarised separately below.

The participants were divided into three groups, and each group was invited to respond to the following three questions:

- Question 1: Do you think that the 'enhanced' measurement of PM – as presented – is sufficient on its own for the PTI emission test for diesel?
- Question 2: Should NO, NO_2 or NO_x measurement be considered as a further step?
- Question 3: Should the measurement of other pollutants (e.g. CO or HC) be considered to ensure that faults in all after-treatment systems are covered?

The responses to these questions are summarised below.

Question 1

All three groups returned a clear 'yes' response to this question, as correlations with type approval are good and the cost-benefit analysis showed it to be cost-effective. Comments relating specifically to the procedure and instruments included the following:

- The proposed metric will be PM mass concentration (mg/m^3). It will be important to define thresholds carefully.
- There will be a need to address the use of acceleration limiters (rpm and rpm gradient). Engine protection limits will need to be discussed with OEMs.
- The overall costs of new PM instruments should not be higher than those of existing systems. The manufacturers agreed that this possible as long as calibration costs (see below) can be kept down.
- The cost of instrument calibration should not be too high. A simple calibration method is required, and this is currently under development.
- The additional use of the OBD system should also be considered.

Other comments:

- The topic of particle number measurement was raised as this is relevant to health, but it was agreed that costs would be high and accuracy would have to be evaluated.

- Direct-injection petrol engines solutions should also be covered by the new approach for diesel engines, as these have similar emission characteristics to modern diesel engines.
- The new approach would be used for older vehicles as well as newer ones.
- There could be a phased introduction of the method, with the use of advanced opacimeters at the start followed by stepwise improvements.
- New opacity instruments will be required, as the old instruments are at their limits of detection for new vehicles. These will have a narrow measurement range (up to around 2-3 m^{-1} rather than 9.99 m^{-1}).

Question 2

There was a general agreement that NO_x and NO_2 are important from an environmental perspective. The groups did not, however, think that NO_x, NO or NO_2 should be included in the PTI tests at present for the following reasons:

- The NO/NO_2 ratio is not useful for identifying catalyst problems, and is very sensitive to the actual after-treatment technology used in different vehicles.
- The measurements from PTI instruments are not sufficiently reliable at present stable.
- The correlation between PTI results and type approval results is poor.
- Other comments:
- There should be an emphasis on the measurement of absolute NO_x rather than the NO/NO_2 ratio. This should also be 'real' NO_x (i.e. with both NO and NO_2 being measured).
- There should be a focus on OBD II, with tight thresholds for NO_x detection. NO_x effects can be detected by OBD surveillance, and systems like EGR and advanced after-treatment devices can be monitored. However, it was noted that there are many faulty EGR valves in the field which are not currently being identified by OBD.

Question 3

The responses to this question were mixed. There was tendency towards a 'no' response. Comments included:

- Further research is required to establish whether CO and THC measurement during PTI can be used to identify emission-related faults.
- For Euro 5+ vehicles in-use compliance testing may be sufficient, but this is addressed to the vehicle manufacturer not PTI, which is more relevant to the vehicle owner.
- Developments in the measurement of NH_3 and N_2O should be monitored.
- The most efficient solutions should always be sought, and in this sense OBD can provide a positive contribution to future emission testing procedures within PTI. However, further development is needed. In addition, there is a need to address how drivers react to OBD MIL illumination. For example, is there a need for legislation to prevent driving with MIL on?

There was a question-and-answer session following the presentation of the measurement programme, and questions were also posed at other points during the meeting. These are summarised below.

Q: The number of vehicles equipped with acceleration limiters is increasing, so how can vehicle manufacturers be brought on board concerning the requirements of free acceleration tests?

A: A solution to this clearly needs to be identified with ACEA, otherwise dynamometer-based testing may be required for PTI. New vehicle models do not appear to have a manual override for this.

Q: Why was the NO/NO_2 ratio used, and not absolute NO_x? The ratio is technology-dependent and not very meaningful – even car manufacturers cannot use it. It is highly dependent on soot oxidation and DPF regeneration. In addition, it gives no indication of absolute NO_x. With SCR, for example, we might expect a NO_2/NO_x ratio of 50%, but absolute levels would be very low.

A: The ratio does depend on the type of after-treatment used. Consideration is also being given to absolute NO_x (in combination with OBD) in the analysis of the data from the TEDDIE measurement programme.

Q: Why is more use not being made of OBD?

A: OBD did not identify emission-related failures in the TEDDIE tests (no DTCs were stored and no MILs were illuminated). This reflects the findings of the German Emission Test programme, which noted that the OBD thresholds are set too high.

Q: In the German test programme, why were holes drilled in the DPF? The OBD would not be looking for this as a 'fault', and the MIL would therefore always be off.

A: OBD can detect a DPF failure only if PM emissions exceed the type approval limit of 50 mg/km, at which point the MIL is illuminated. The failure of a DPF typically involves mechanical cracking of the monolith – partly or in total after a longer period of time, and in some cases this can be detected by OBD. However, under the simulated failure conditions tested – whatever the reason for the high emission levels – the MIL was not illuminated.

Q: In Work Package 3 cross-sensitivity to other exhaust components was examined, but what about interference from water vapour?

A: Interference from water vapour is well known, but was not investigated in detail. The effect is generally within the accuracy range of the instruments.

Q: Can a general PM limit for all vehicles with full-flow filters be defined? Does it need another study?

A: The current limits in regulation (and plate values) are in some cases not sufficient because of the relative high values stated at type approval. Updated procedures for the calculation of these plate values/thresholds are required. The main focus might be to have thresholds for closed filter solutions; relatively few so-called open filters are now used.

Q: Can the cost-benefit analysis be extended to include future years?

A: This would be very useful, but is beyond the scope of the TEDDIE project.

Q: Are repair costs included in the cost-benefit analysis?

A: No. According to accepted economic valuation methods these costs are not included in cost-benefit analysis.