Swedish In-Service Testing Program

On Emissions from Heavy-Duty Vehicles

Report for the Swedish Transport Agency

Certification & Regulation Compliance
AVL

#OMT2006
2014

Content

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List of Abbreviations

BS	Brake Specific
CAN	Controller Area Network
CD	Chassis dynamometer
CF	Conformity Factor
CFV	Critical Flow Venturi
CH4	Methane
CNG	Compressed Natural Gas
CO	Carbon monoxide
CO_2	Carbon dioxide
COP	Conformity of Production
CPC	Condensation Particle Counter
CVS	Constant Volume Sampling
DOC	Diesel Oxidation Catalyst
DPF	Diesel Particulate Filter
DS	Distance Specific
ECU	Engine Control Unit
ED95	Ethanol Diesel
EEV	Environmentally Enhanced Vehicle
EGR	Exhaust Gas Recirculation
ELR	European Load Response
ESC	European Stationary Cycle
ETC	European Transient Cycle
FC	Fuel consumption
FTIR	Fourier transform infrared spectroscopy
GFM	Gravimetric Filter Module
HC	Total hydrocarbons (THC)
HDV/HD	Heavy Duty Vehicle/ Heavy Duty
HFID	Heated Flame Ionization Detector
IUC	In Use Compliance
JRC	Joint Research Centre
MK1	Environmental class 1
MSS	Micro Soot Sensor
NDIR	Non-Dispersive Infrared
NDUV	Non-Dispersive Ultraviolet
NH4	Ammonia
NMHC	Non Methane HydroCarbons
NO	Nitrogen oxides
NO_2	Nitrogen dioxides
NOx	Nitrogen oxides
OBD	On board Diagnostics
PASS	Photo-Acoustic principle
PEMS	Portable Emission Measurement System
PLU	Fuel mass flow metering device
PM	Particulate Matter
PN	Particulate Number
SCR	Selective Catalytic Reduction
SEPA	Swedish Environmental Protection Agency
SRA	Swedish Road Administration
STA	The Swedish Transport Agency
THC	Total Hydrocarbons
TWC	Three way catalyst
WBW	Work Based Window
WHSC	World Harmonized Stationary Cycle
WHTC	World Harmonized Transient Cycle
WHVC	World Harmonized Vehicle Cycle

Summary

AVL MTC AB has on the commission of The Swedish Transport Agency (STA) carried out The Swedish In-Service Testing Programme on Emissions from Heavy-Duty (HD) Vehicles. Nine of these vehicles have been tested on chassis dynamometer according to the Fige (chassis dynamometer version of European Transient Cycle (ETC)) and the WHVC (Worldwide Harmonized Vehicle Cycle, chassis dynamometer version of WHTC - Worldwide harmonized Transient Cycle). In addition were eight vehicles also tested on road using Portable Emissions Measurement System (PEMS). The emission measurement methods used in the programme meet the requirements of regulation (EU) NO. 582/2011 Annex II and (EU) No. 64/2012. The selection of the vehicles was based on Euro IV and VI standard.

The scope of the investigation was, beside in use compliance, to generate emission factors from commercial vehicles tested as commanded in the new directive for Euro VI vehicles. In addition aspects of alternative fuels and technologies, driving pattern, temperatures and loads were taken into consideration.

The vehicles are denoted A – H in this report.

The selection of the test vehicle was done in cooperation with the Swedish Transport Agency.

Vehicle A was a heavy-duty gas engine truck which was tested on Chassis dynamometer. The vehicle was of euro standard VI and equipped with Wastegate turbo, EGR and TWC. The fuel used during the tests was commercially available CNG. The gaseous emissions, CO, NOx and THC were well below the Euro VI emission limits. Neither the NMHC nor the CH_4 emission limits were exceeded in any test. The PM level of the test vehicle was low and below the EUVI limit in all tests. PN levels exceeded the Euro VI PN limit applicable for Diesel engines in the WHVC tests. Some ammonia emissions where detected but the weighted result was below the Euro VI 10 ppm limit.

Vehicle B was a Heavy Duty crane truck which was tested on road as well as on chassis dynamometer. The vehicle was of euro standard VI equipped with a SCRT® filter and the fuel used during the tests was MK1. No emissions of THC were measured on CD and very low levels on the road. Emissions of CO were below the EUVI emission limit on both chassis dynamometer and on the road. Emissions of NOx measured on chassis dynamometer exceeded the WHTC engine test emission limit. The results from the PEMS testing and the FIGE test cycle showed more moderate NOx emissions passing the applicable Euro VI emission limit. The vehicle passed the EUVI ISC conformity factor limits for all gaseous emissions. PM emissions were high and the WHTC engine test limit was exceeded in all CD tests. No PEMS IUC conformity factor limit for PM is yet established but the PM level could be considered high also in the road tests.The PN levels did not exceed the Euro VI applicable PN limit on CD. Some ammonia emissions were measured but the limit was not exceeded.

Vehicle C was a small distribution truck which was tested on road as well as on chassis dynamometer. The vehicle was of euro standard VI equipped with EGR, DOC, SCR and DPF. The fuel used during the tests was Mk1 diesel. Emissions of THC, CO and PM were below the EU VI emission limits both on chassis dynamometer and on the road. Emissions of NOx measured on chassis dynamometer exceeded the WHTC engine test emission limit. Also the “all events” results from the PEMS testing showed high NOx emissions, not passing the applicable Euro VI emission limit. The vehicle did however pass the EU VI ISC conformity factor limits for all gaseous emissions. The weighted PN emission result did not exceed the PN emission limit. The ammonia emissions measured were low.

Vehicle D was a small bus which was tested on road as well as on chassis dynamometer. The vehicle was of euro standard VI, equipped with a SCR system and a DPF. The fuel used during the tests was Mk1 diesel. Emissions of THC, CO and PM were below the EUVI emission limits on both chassis dynamometer and on the road. Emissions of NOx measured on chassis dynamometer exceeded the WHTC engine test emission limit. The “all events” results from the PEMS testing showed lower NOx emissions, passing the applicable Euro VI emission limit. In one road test the vehicle failed the EUVI ISC conformity factor limits for NOx emissions.

Vehicle E was a distribution truck which was tested on road as well as on chassis dynamometer. The vehicle was of euro standard IV equipped with an EGR system and the fuel used during the tests was

Mk1 diesel. The results from the emissions testing show that the Euro IV applicable emissions limits of NOx and PM were exceeded. A large deviation in energy consumption between the tests on the chassis dynamometer and the on-road tests could be observed. This might be explained by that different methods to measure work were applied and by differences in operational conditions. Poor accuracy of the ECU signal could also be a part of the explanation of the large differences in energy consumption. No malfunction was indicated by the OBD system. The Euro VI PN limits were exceeded by about 200 times.

Vehicle F was a distribution truck equipped with a SCR system. The vehicle was tested on road as well as on chassis dynamometer. The fuel used during the tests was Mk1 diesel. The results from the emissions testing show that the Euro IV applicable emissions limits of NOx and PM were exceeded by a factor of two and 57, respectively. The NOx emissions appeared to be insensitive to the exhaust temperature which indicates a malfunctioning exhaust after treatment system. Moreover, the extremely high PM emissions could be a result of NH3/urea slip due to incorrect urea dosing. The PM filter sampling showed a bluish shimmering tone which may be an indication of that a considerable amount of the PM sample comprise NH3 and/or urea. The Euro VI PN limits were exceeded by about 100 times. No malfunction was indicated by the OBD system.

Vehicle G was a truck which was tested on road as well as on chassis dynamometer. The vehicle was of euro standard VI, equipped with a DOC, DPF and SCR and the fuel used during the tests was Mk1 diesel. The vehicle met all the European applicable emission limits during the test, both during real world driving and on the chassis dynamometer.

Vehicle H was a N3 Euro VI truck, model year 2014. Testing was performed on a chassis dynamometer and on Swedish roads using a portable emissions measurement system (PEMS).
The vehicle, equipped with a DOC, EGR, SCR and a DPF after treatment system, was tested with the both environmental class 1 (MK1) as well as European EN 590 diesel qualities on chassis dynamometer and with MK1 during the on-road measurements. The vehicle was driven according to the WHVC test cycle on a chassis dynamometer. Regulated exhausts, CO2 as well as unregulated pollutants i.e. PAH and aldehydes were measured. Tests were carried out with both cold start as well as hot start engine.
The investigation shows that there are no significant differences on emission level between these two fuels when tested on a Euro VI vehicle with a fully warmed up engine. However, when taken the engine cold start test into consideration there are still some discrepancies. All regulated components (except particle number) as well as formaldehyde and polycyclic aromatic hydrocarbons are higher when using the MK3 quality compared to MK1.However, it must be emphasized that the emission levels are very low and close to detection limit.
Emissions of all regulated pollutants were below the EUVI emission limits both on chassis dynamometer and on the road. The vehicle did pass the EUVI ISC conformity factor limits for all gaseous emissions during the on-road tests both during hot as well as cold start.

Introduction

In Europe as well as in USA methods for verifying emission performance have been developed using portable emission measurement system (PEMS), where emissions are measured on board a vehicle during real life operation. The main objective with on board measurement is to find a robust method for verification whether a HD vehicle is meeting set emission requirement.

In Europe, activities to develop suitable test methods for on-road measurements and associated test protocol have been organized and coordinated by EU Joint Research Centre (JRC). JRC launched a pilot project for measurements of gaseous emissions in 2006 where manufacturer of engines/vehicles, manufacturer of instrument, approval authorities and technical services was invited to participate. The activity was called EU-PEMS project. The Swedish Road administration and then later, The Swedish Transport Agency (STA) participated in the pilot project using data from the In-Service Testing Program as input. The EU-PEMS Pilot project is now finalized and findings, conclusions and comments from stakeholders have been considered and are now included in the European Euro VI emission requirements (Regulation No 595/2009 and EU Regulation No 582/2011). Further, a common way to calculate and present results from measurements have been introduced by JRC and a standardized test protocol has been established (EMROAD). The protocol is used to verify whether tested vehicles/engines meet the set requirements. The protocol also specifies the measurement points to be used for the calculation.

The result from national activities carried out 2014 is presented in this report.

Test program

Nine vehicles have been tested on chassis dynamometer. In addition, eight of these vehicles (B-I) have also been tested on road by a portable exhaust measurement system (PEMS). The aim of the study was not to pinpoint specific manufacturer thus, the vehicles in this report will be denoted A – H and the engine power is presented as an approximate figure.

Selection of test vehicles

The vehicle selection has been performed in cooperation with the STA. The vehicle type chosen for testing was based on Euro IV and VI, technology. The vehicles tested have been served in accordance to the manufacturer specification on a regular basis.

Table 1 EU Emission Standards for HD Diesel Engines

Dates for first registration. entry into service	CO [g/kWh]	HC [g/kWh]	NO_x [g/kWh]	PM [g/kWh]	Smoke m^{-1}
Euro IV – 2006.10 – 2009.09					
European Stationary Cycle (ESC) and European Load Response (ELR)	1.5	0.46	3.5	0.02	0.5
European Transient Cycle (ETC)	4	0.55	3.5	0.03	
Euro V - 2009.10 – 2013.12					
European Stationary Cycle (ESC) and European Load Response (ELR)	1.5	0.46	2	0.02	0.5
European Transient Cycle (ETC)	4	0.55	2	0.03	
Euro VI[1] - 2014.01 –					
Worldwide Harmonized Stationary Cycle (WHSC)	1.5	0.13	0.4	0.01	
Worldwide Harmonized Transient Cycle (WHTC)	4	0.16	0.4	0.01	

[1] Euro VI also include (for Diesel engines) maximum particle number requirements which are $8.0*10^{11}$ #/kWh (WHSC) and $6.0*10^{11}$ #/kWh (WHTC)

Testing on chassis dynamometer

Chassis dynamometer test cell

The chassis dynamometer is a cradle dynamometer with 515 mm roller diameters. The maximum permitted axle load is 13 000 kg. Vehicle inertia is simulated by flywheels in steps of 226 kg from 2 500 kg to 20 354 kg. The maximum speed is 120 km/h without flywheels and 100 km/h with flywheels.

Two DC motors, each 200 kW maximum load, and separate control system serves as power absorption units. The DC motors and their computer-controlled software enable an excellent road load simulation capability. The software sets the desired road load curve through an iterative coast down procedure with test vehicle on the dynamometer.

An AVL PUMA computer system is used as a superior test cell computer for engine monitoring and also for the measurement and collection of all data emanating from the vehicle, emission measurement system and test cell.

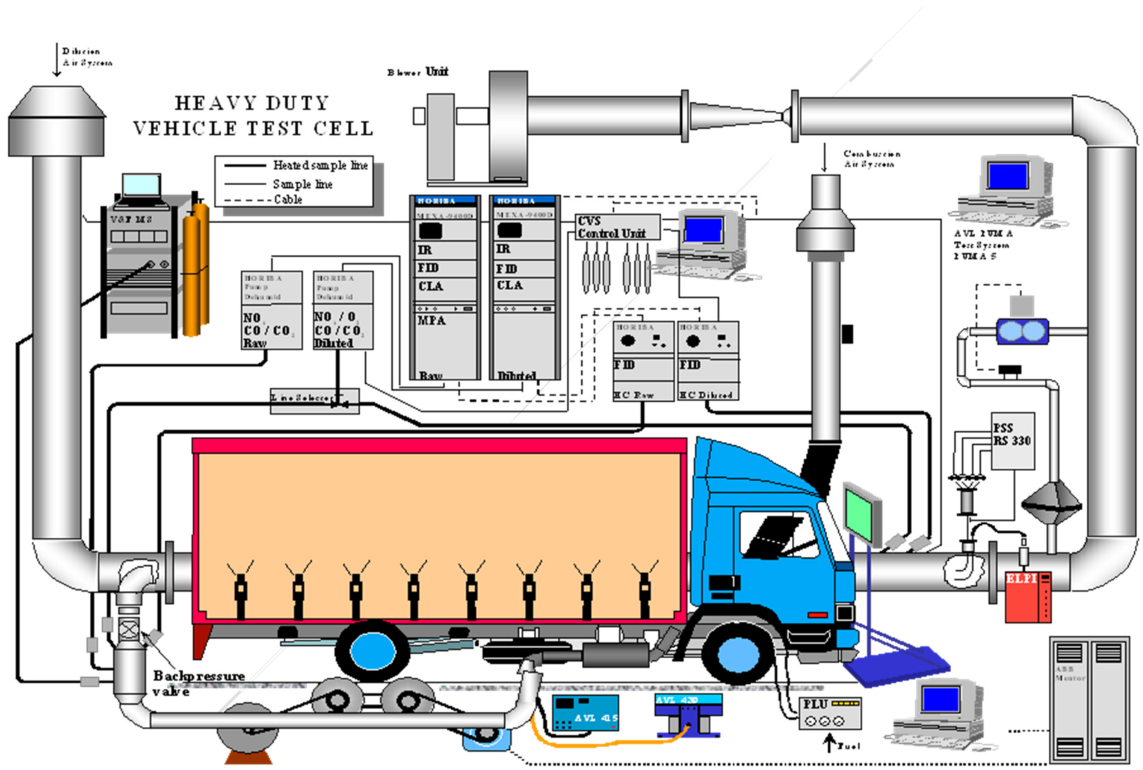

Figure 1 A schematic description of the test cell.

<u>Engine power</u>
The engine power was estimated by adding the integrated signals from measured acceleration force of the inertia used and the road load. No fan correction has been applied to the calculations. The integrated power is then used to calculate the total estimated work (kWh) during the test cycle which is used to calculate emissions in g/kWh.

<u>Regulated gaseous emissions and CO_2</u>
The sampling- and analysing equipment are based on full flow dilution systems, i.e. the total exhaust is diluted using the CVS (Constant Volume Sampling) concept. The total volume of the mixture of exhaust and dilution air is measured by a CFV (Critical Flow Venturi) system. For the subsequent collection of particulates, a sample of the diluted exhaust is passed to the particulate sampling system. The sample is here diluted once more in the secondary dilution tunnel, a system referred to as full flow double dilution.

According to the regulations for transient tests the diluted exhaust gases are both bagsampled and sent for further analysis *and* on-line sampled. Through the CVS system a proportional sampling is guaranteed.

The equipment used for analysing the gaseous regulated emissions consist of double Horiba 9400D systems. Hereby exists the possibility to measure both diluted and raw exhaust emissions on-line simultaneously. The sampling system fulfils the requirements of Regulation (EU) 582/2011 in terms of sampling probes and heated lines etc.

The measured components and measurement principles are specified in **Error! Reference source not found.**.

Table 2 Measured components and measurement principles.

Component	Measurement principle
Total hydrocarbons (THC)	HFID (heated flame ionization detector) (190℃)
Carbon monoxide (CO)	NDIR (non-dispersive infrared analyzer)
Carbon dioxide (CO_2)	NDIR
Nitrogen oxides (NO_X)	CL (chemiluminescence)
Ammonia (NH_3)	FTIR (Fourier Transform InfraRed)
Fuel consumption (FC)	Carbon balance of HC, CO and CO_2

Fuel consumption

The total fuel consumption (Fc) was calculated using the carbon balance method. The diesel consumption was also measured with a PLU (fuel mass flow meter measuring device).

Particulate emissions

The particulate emissions were analyzed gravimetrically, by number and by size distribution.

Particulate mass

The particulate mass was measured gravimetrically by the use of glass fibre filters. For the collection of particle matter (PM), a sample of the diluted exhaust is passed to the particulate sampling system. The sample is then diluted once more in the secondary dilution tunnel, a system referred to as full flow double dilution. The particles are collected on Teflon-coated Pallflex™ filter and measured gravimetrically. The sampling of particle matter is in accordance with Directive 2005/55/EEC.

Particle number

The particle number is measured in a Condensation Particle Counter (CPC) with a size range of 23nm to 2.5µm. The particle number is limited for heavy duty diesel engines from emission standard Euro VI (limits for positive ignited engines are not yet decided).

In the counter, the particles are enlarged by condensation of butanol and are thereafter detected and counted using a light-scattering method. A schematic description of the detector is presented in Figure 2.

In order to count non-volatile particles, a special sampling method has been developed. A pump draws the exhaust gas into a sampling probe which eliminates all particles >2.5 µm due to its special shape. The sampled exhaust gas is then diluted with cleaned hot air at a temperature of 150℃. This stabilizes the particle number concentration and reduces the concentration so that agglomerations and particle deposits are largely prevented.

After the hot primary dilution, the diluted exhaust gas is further heated up to a temperature of 300℃ to 400℃ in an evaporation tube in order to convert all volatile particles into gaseous phase. A secondary dilution is then performed to prevent further condensation or adsorption of volatile substances and to ensure that the maximum inlet temperature of 35°C is not exceeded. The particle number concentration is measured in the Condensation Particle Counter (with a size range of 23nm to 2.5µm according to UNECE-R83 specifications). The particles are enlarged due to the condensation of butanol and are detected and counted using the lightscattering.method.

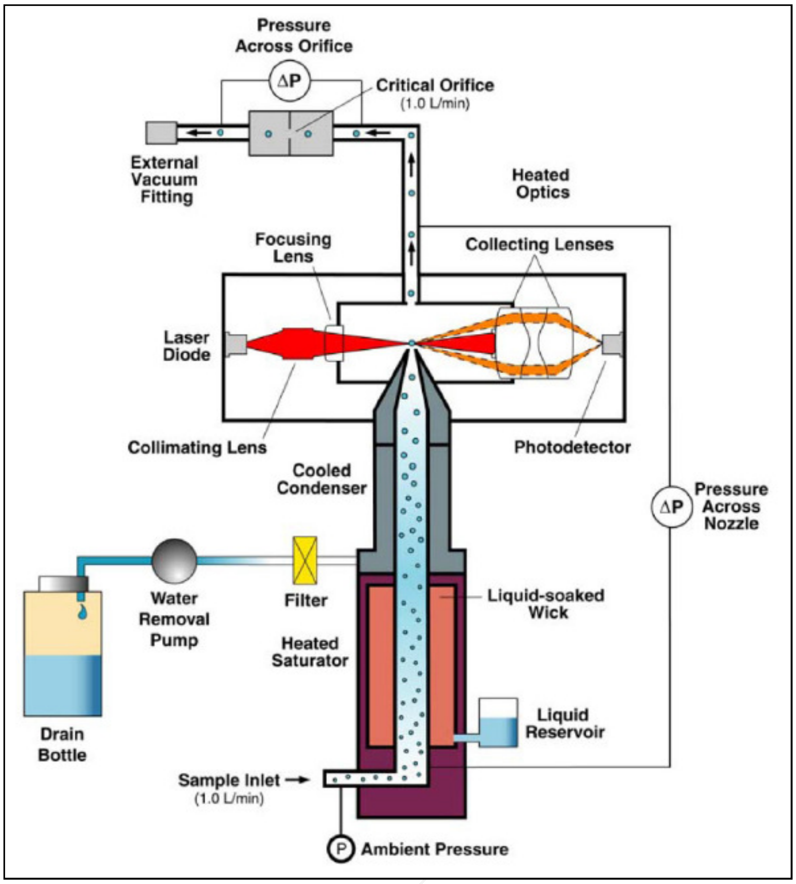

Figure 2 Schematic description of the detector in the Condensation Particle Counter.

Chassis dynamometer test cycles

The ETC/FIGE driving cycle

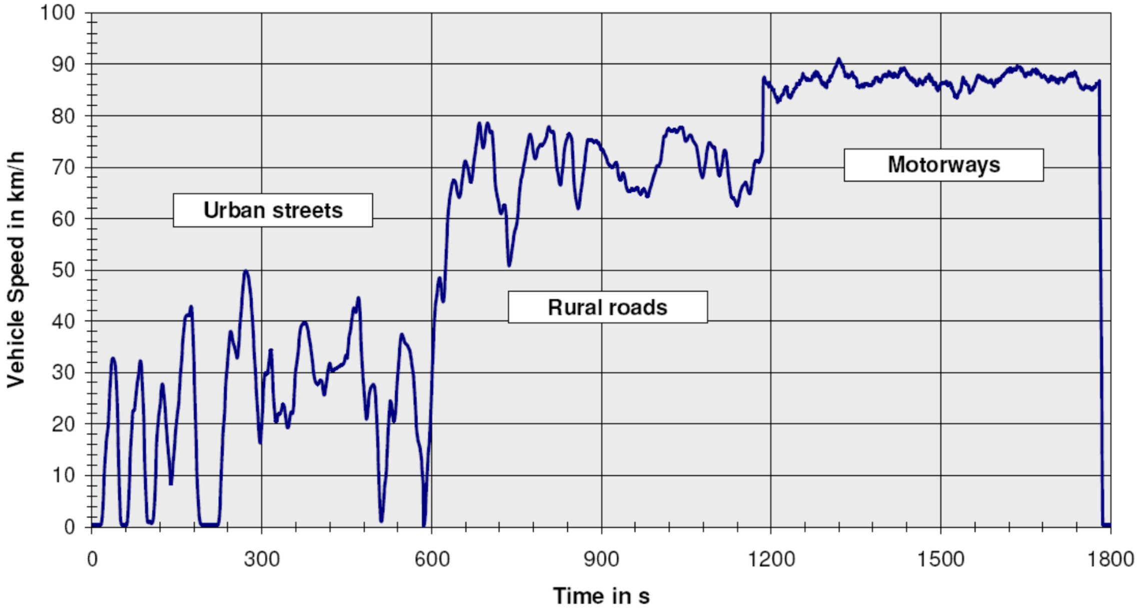

Figure 3 The FIGE driving cycle

The FIGE test cycle has been developed by the FIGE Institute, Aachen, Germany, based on real road cycle measurements of heavy duty vehicles. FIGE Institute developed the cycle in two variants: as a chassis and an engine dynamometer test. The engine dynamometer version of the test is the so called ETC cycle (European Transient Cycle) which today is used for certification purposes of diesel engines to be used in heavy duty vehicles. The chassis dynamometer version is normally referred to as the FIGE test cycle.

Different driving conditions are represented by three parts of the ETC/FIGE cycle, including urban, rural and motorway driving.

The duration of the entire cycle is 1800s. The duration of each part is 600s.

- Part one represents city driving with a maximum speed of 50 km/h, frequent starts, stops, and idling.
- Part two is rural driving starting with a steep acceleration segment. The average speed is about 72 km/h
- Part three is motorway driving with average speed of about 88 km/h.

The WHVC/WHTC test cycle

The WHTC (World Harmonized Transient Cycle) test cycle will become the future test cycle for certification of engines. The WHVC (World Harmonized Vehicle Cycle) test cycle, which can be used for testing entire vehicles on a chassis dynamometer, is the test cycle from which the WHTC was developed. The WHVC is not identical to the WHTC since it was only an intermediate step from data collection to engine test bench cycle, but it is the closest there is today.

The test procedures for chassis dynamometer testing are not identical to the procedures used for engine dynamometer testing, but the results using the WHVC test cycle can be used in order to compare the emission levels from a vehicle with the emissions levels of an engine tested with the WHTC test cycle. The emission results are presented in g/km but also converted from g/km to g/kWh using estimations of executed work during the transient test cycle.

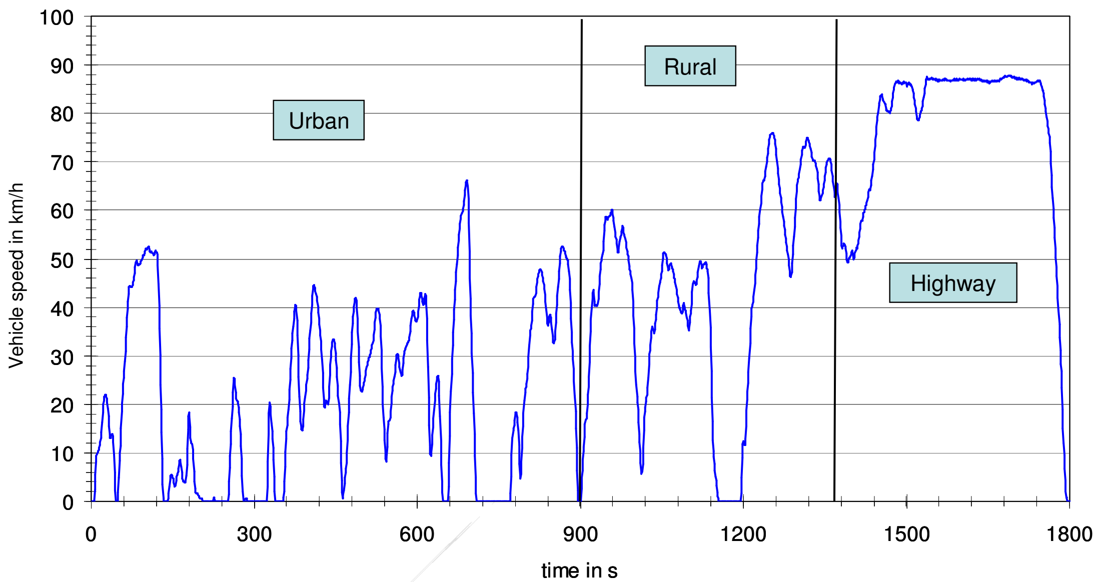

Figure 4 The WHVC test cycle

The transient cycle used in the test was the "WHVC" test cycle (unofficial).

The WHVC is a transient test of 1800 s duration, with several motoring segments.

Different driving conditions are represented by three parts of the WHVC cycle, including urban, rural and highway driving.

The duration of the entire cycle is 1800s.

- The first 900 seconds represents urban driving with an average speed of 21 km/h, maximum speed of 66 km/h. This part includes frequent starts, stops and idling.
- The following 468 seconds represents rural driving with an average speed of 43 km/h and maximum speed of 76 km/h.
- The last 432 seconds are defined as highway driving with average speed of about 76 km/h.

On-road measurement

Portable Emissions Measurement System (PEMS)

The M.O.V.E is developed by AVL for testing of vehicles and equipment under real-world operating conditions. The instrument is an on-board emissions analyzer which enables tailpipe emissions to be measured and recorded simultaneously while the vehicle/machine is in operation.
The following measurement subsystems are included in the AVL M.O.V.E GAS PEMS emission analyzer:

- Heated Flame Ionization Detector (HFID) for total hydrocarbon (THC) measurement.
- Non-Dispersive Ultraviolet (NDUV) analyzer for nitric oxide (NO) and nitrogen dioxide (NO_2) measurement.
- Non-Dispersive Infrared (NDIR) analyzer for carbon monoxide (CO) and carbon dioxide (CO_2) measurement.
- Electrochemical sensor for oxygen (O_2) measurement.

Table 3

An AVL M.O.V.E GAS PEMS 493	
Inputs/Outputs electrical	Heated line connectors (3 heating circles with 2 x PT100); 1 x Ethernet (TCP/IP); 1 x CAN (CAN bus monitoring); 8 x analog out; 4 x analog In, 4 x digital Out (DC-isolated); 5 x digital In (DC-isolated)
Measurement Range	**THC:** 0-30,000 ppmC1 **NO/ NO2:** 0-5000 ppm (NO) 0-2500 ppm (NO2) **CO/ CO2:** 0-5 vol% (CO), 0-20 vol% (CO2)
Zero Drift	**THC:** < 1,5 ppmC1/8h **NO/ NO2:** 2ppm/8h **CO:** 20ppm/8h **CO2:** 0,1 vol%/8h
Sample flow rate	< 3.5l/min
Pneumatics Inputs/ Outputs	ZERO gas, SPAN gas, burner gas for HFID, sample gas IN, exhaust and drainage OUT

The AVL M.O.V.E PM PEMS combines the time resolved photo-acoustic soot measurement principle with a gravimetric PM measurement which operates with a gravimetric filter. The time-resolved particulate (PM) emissions are calculated by weighing the loaded gravimetric filter after the end of the test and using additionally the time resolved soot signal and the exhaust mass flow as inputs.
The instrument consists of below main components:

- The Micro Soot Sensor measuring unit (MSS) which is designed for continuous measurement of soot concentrations

Table 4

AVL 483 Micro Soot Sensor	
MEASURING UNIT	
Measured value:	Concentration of soot (mg/m3, µg/m3) in the diluted exhaust gas
Measuring range:	0 – 50 mg/m3
Display resolution:	0,001 mg/m3
Detection limit:	~ 5 µg/ m3
Turndown ratio:	1 : 5.000
Data rate:	Digital: 10 Hz Analog: 100 Hz
Rise time:	≤ 1 sec
Operation temperature:	5°C to 43°C
Probe/Bypass flow:	~ 2 + 2 l/min
Interfaces:	RS232, Digital I/O, Analog I/O, Ethernet
Laser class:	Class 1 laser product
CONDITIONING UNIT	
Dilution ratio (DR): The actual DR will be displayed with the	Adjustable from 2 – 10 and from 10 – 20 accuracy noted below
Data rate:	Digital: max. 5 Hz Analog: 50 Hz
Accuracy (DR display):	max. ± 3% in the range of DR [2..10], max. ± 10 % in the range of DR [10..20]
Power supply:	90…230V, 50/60 Hz
Pressurized air:	Input pressure 1 ± 0,2 bar over pressure Flow: > 41/min
Exhaust gas temperature:	Up to 1000°C
Exhaust gas back pressure	Up to 2000 mbar
Pressure pulsation:	± 1000 mbar, but max. 50% of exhaust gas back pressure (intermediate pressure)
Blow by amount:	Dep. on pressure, ~ 20 l/min at 1000 mbar
Power supply:	90…240V AC, 50/60Hz, 500VA
Unit dimensions:	Measuring unit: W x H x D ~ 19" x 5HE x 530 mm Conditioning unit: W x H x D ~ 19" x 5HE x 530 mm
Unit weight:	Measuring unit: ~20 kg Conditioning unit: ~ 12 kg

- The Gravimetric Filter Module (GFM) which provides total PM using the gravimetric filter method.

Table 5

AVL M.O.V.E PM PEMS 494	
Operating temperature	5 to 40°C
Storage temperature	-40 to +70°C
Ambient rel. humidity	Corr. max. humidity of 95% at 25°C
Dimensions	appr. 19"*430*540 mm (w*h*d*)
Weight	appr. 45 kg
Warm-up time at 20°C ambient temperature	<<1/2 hr
Power Demand/Operating Voltage	appr. 400W (after warm-up), the PM PEMS can be operated either with 24 VDC or 110 VAC
Exhaust inlet pressure tolerance:	-80 mbar to +60 mbar (for higher pressures an optional available high pressure reduction module is required)
Data logging frequency	1 Hz standard, 5 Hz for selected values
Interfaces	Analog (0 -10V, 4 Out/ 2 In), 4 Digital In, 4 Digital out, 1 TCP/IP
Dilution ratio (constant)	up to DR=20
Dilution ratio (proportional)	DR=2 to 100
Sample flow over filter	6 lpm
Filter holder	47mm, measurement and backup filter; Geometry acc. to CFR 40 §1056
Soot measuring range	up to 1000 mg/m3 (at DR=20)
Soot detection limit	~ 5 µg/m³
rise time of soot signal	≥ 1 sec

The instruments are operated in combination with an electronic vehicle exhaust flow meter, Sensors EFM-HS. The M.O.V.E. instrument uses the flow data together with exhaust component concentrations to calculate instantaneous and total mass emissions. The flow meter is available in different sizes depending on engine size of the tested machine.

Weighing room Temperature and humidity controlled clean environment
AVL FILTER WEIGHING CHAMBER EPA 1065 Provides in a restricted area the climatic conditions which are required by legislation for the conditioning and weighing of filter wavers for particle sampling.
Analysis scale, Sartorius SE2 capacity 2.1 g readability 1 µg reproducibility 1 µg
Analysis scale, Sartorius R 200 D (located in weighing room) Measuring range: 0-42 / 0-200 g; d = 0,01 / 0,1 mg
Analysis scale, Sartorius MC 5 (located in weighing room) Measuring range: 0-5,1 g; d = 0,001 mg

On-road measurement test routes

Euro VI route 1

Euro VI route 1 is designed to meet the requirements specified by the regulation for all N_3 vehicles. The route has the following main data:

- Approximate trip duration: 23300 seconds
- Average trip distance: 343 km
- Average speed: 53 km/h (of course dependent on traffic situation)
- Trip composition:
    - Urban driving: 24%
    - Rural driving: 23%
    - Highway driving: 53%
    - Idle: 14%

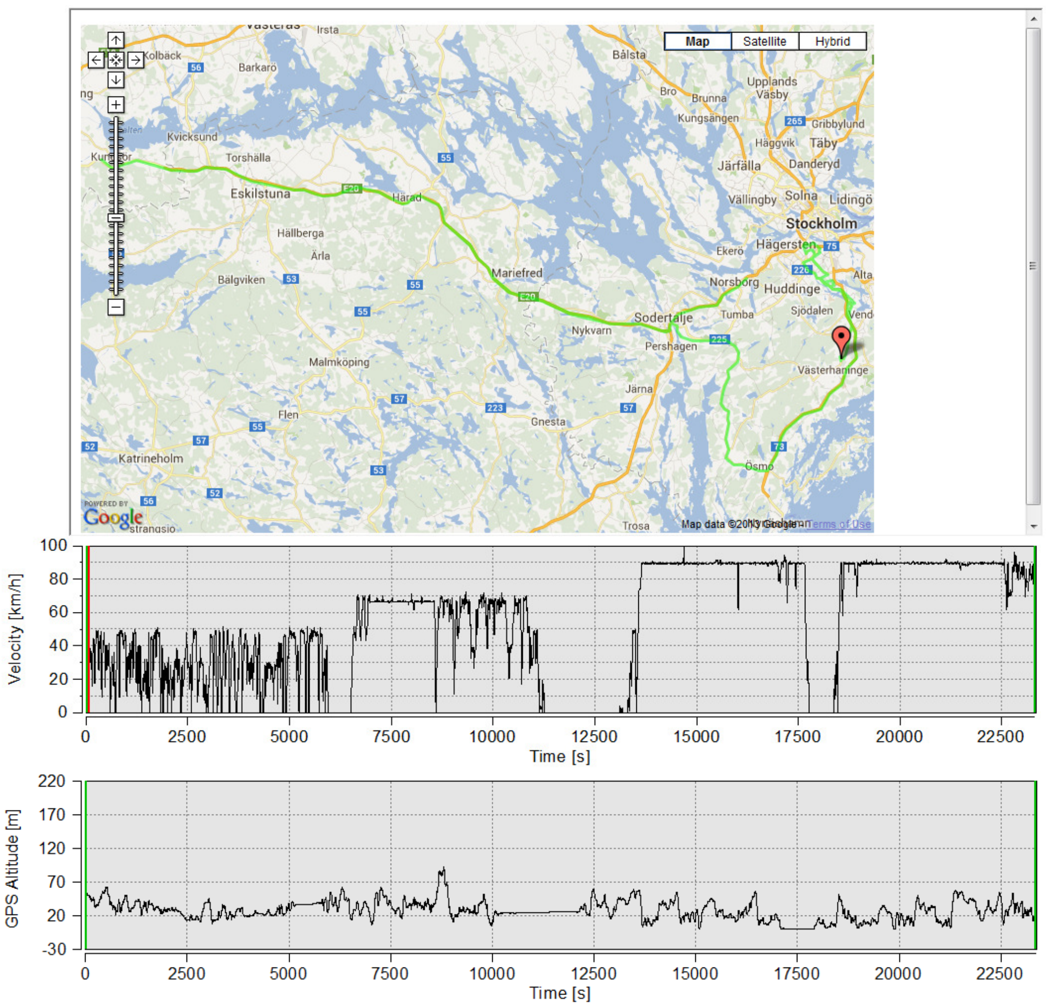

Figure 5 Characteristics of the Euro VI route 1

Euro VI route 2

Euro VI route 2 is also designed to meet the Euro VI requirements but shorter than Euro VI route 1.

The route has the following main data:

- Approximate trip duration: 15500 seconds
- Average trip distance: 242 km
- Average speed: 56 km/h (of course dependent on traffic situation)
- Trip composition:
    - Urban driving: 23%
    - Rural driving: 27%
    - Highway driving: 50%
    - Idle: 12%

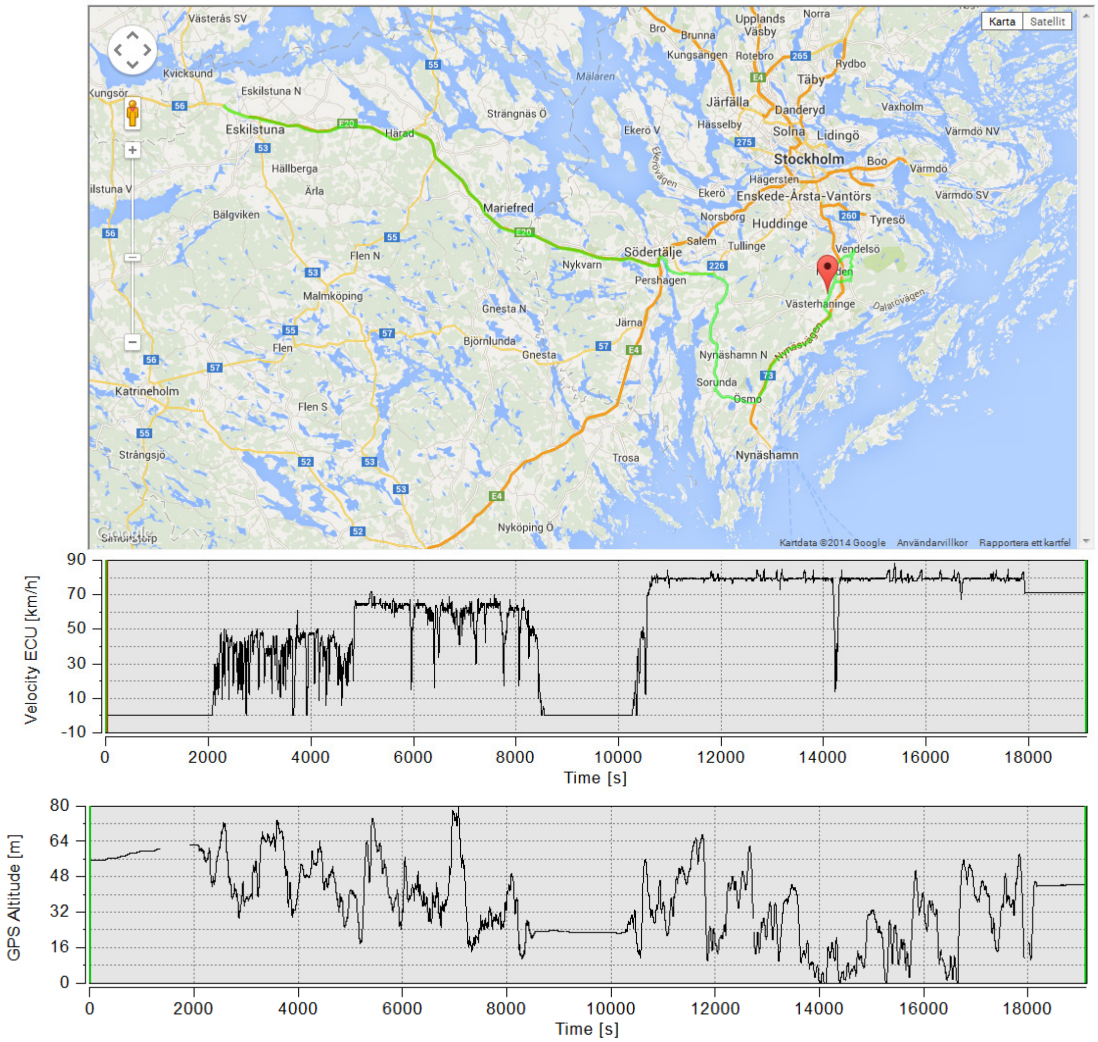

Figure 6 Characteristics of the Euro VI route 2

Euro VI route 3

The so called "Euro VI route 3" is a test route designed for vehicles of category N2 and M2 and starts at Armaturvägen 1 in Haninge (at AVL MTC Motortestcenter AB). The first part consists of urban driving is carried out in the central part of Haninge (Figure 7). Thereafter, the rural driving is achieved by driving from Haninge towards Dalarö and return after a short stop. The last part of the trip (motorway) is completed by driving towards Nynäshamn, turning on the motorway and driving back, past Haninge and continuing to Farsta where vehicle again turns on the motorway before returning to AVL where the trip ends. The Euro VI route 3 was developed to comply with the Euro VI In Service Conformity tests, i.e. "*The minimum test duration shall be long enough to complete five times the work performed during the WHTC or produce five times the CO_2 reference mass in kg/cycle from the WHTC as applicable*" and "*For M2 and M3 vehicles the trip shall consist of approximately 45 per cent urban, 25 per cent rural and 30 per cent motorway operation*" (on time basis). Nonetheless, the trip composition is sensitive to driver behavior, ambient conditions, traffic situation and the GVM to Engine-power ratio.

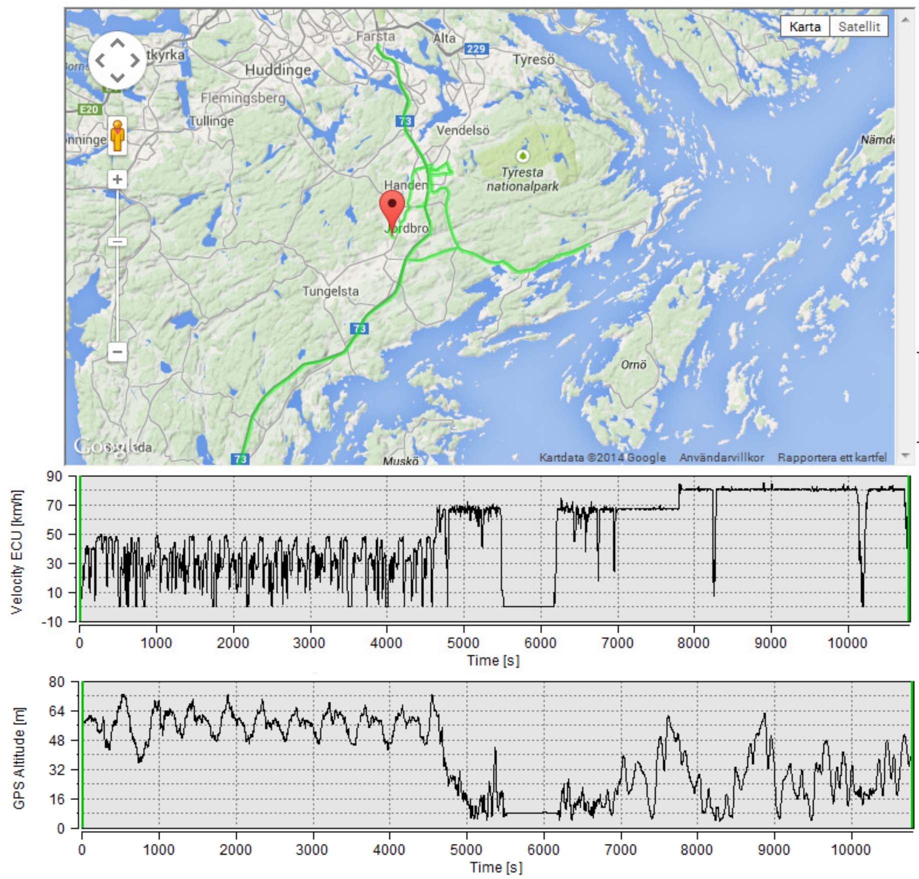

Figure 7 Map showing the EuroVI route 3. The red mark indicates the starting point. The diagram below the map shows the terrain profile and typical vehicle velocities.

Main characteristics of Euro VI route 3:

- Approximate trip duration: 9 650 seconds (approx. 2h, 40 min)
- Average trip distance: 137 km
- Average speed: 51 km/h (dependent on traffic situation)
- Average trip composition (dependent on traffic situation):
    - Urban driving: 44 % (goal 45%)
    - Rural driving: 25 % (goal 25 %)
    - Highway driving: 31 % (goal 30%)
    - Idle: 4 % (included in Urban driving)

PEMS Pilot route (Euro V)

The route has the following main data:

- Approximate trip duration: 5 000 seconds
- Average trip distance: 77 km
- Average speed: 55 km/h (of course dependent on traffic situation)
- Trip composition:
    - Urban driving: 43%
    - Rural driving: 17%
    - Highway driving: 40%
    - Idle: 7%

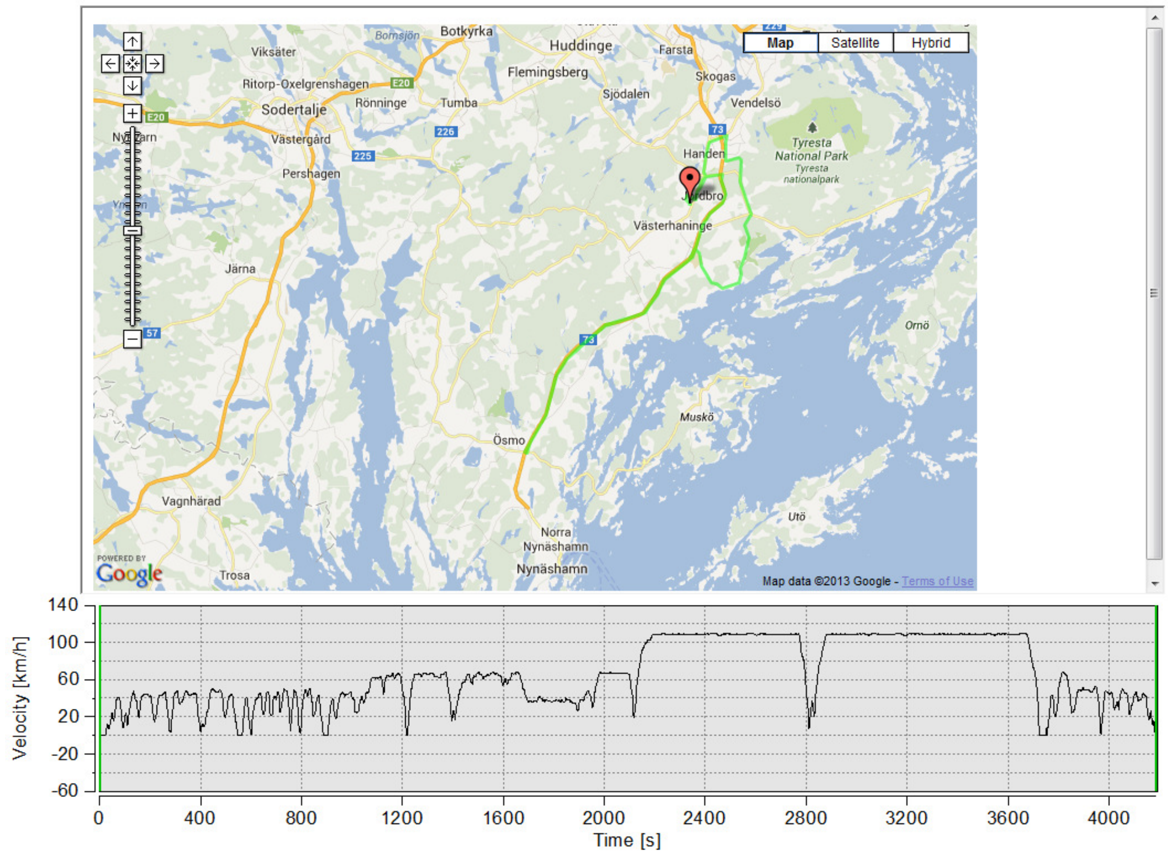

Figure 8 Characteristics of the PEMS Pilot route

Test Fuel

Commercially available fuels fulfilling the specification of Environmental class 1 diesel (Mk1) has been used. Swedish MK1 fuel is a low sulphur diesel i.e. less than 10 ppm, and has a boiling point interval of 180-290℃. The fuel consists of 50-70% parafines, 30-45% naphtenes and 3-5% aromatics.

CNG (Compressed Natural Gas), commercially available CNG which consists of ~77% methane. CNG has an energy content of 35-39 MJ/Nm^3.

Vehicle A

Vehicle A was a heavy-duty gas engine truck of euro standard VI equipped with Wastegate turbo, EGR and TWC. The fuel used during the tests was commercially available Compressed Natural Gas (CNG).

Presentation of vehicle:

Model year:	2014
Vehicle category (2007/46/EC):	N3
Vehicle type:	Garbage truck
Mileage:	9790 km
Engine:	SI, 5-cylinder
Displacement:	9,3 litres
Fuel:	CNG
Power:	250 kW
Exhaust after treatment:	Wastegate turbo, EGR, TWC
Transmission:	automatic, 6 speed
Gross Vehicle Mass (GVM)*:	26500 kg
Mass in running order:	17370kg
Maximum payload:	9130 kg
Emission standard:	Euro VI

Test program

The vehicle has been tested on a chassis dynamometer. More information about test equipment can be found in Chassis dynamometer test cell

For chassis dynamometer test have the WHVC (World Harmonized Vehicle Cycle) test cycle been used (warm and cold start) as well as the FIGE test cycle (warm start). More information about the test cycles (CD) can be found in Chassis dynamometer test cycles

Before the actual test was started, the vehicle was pre-conditioned on the chassis dynamometer by driving the vehicle on the dynamometer with a steady speed for a specific time to reach the exhaust gas temperature of approximately 230℃ measured about 3 meters after tailpipe.

Table 6 Test program on chassis dynamometer

Test	Cold start	Hot start	Inertia	Vehicle Payload
FIGE	-	2	20354	3000
WHVC	3	2	20354	3000

The inertia, which is the maximum possible of the chassis dynamometer, simulated a vehicle payload corresponding to 33% of the maximum payload.

There were no diagnostic trouble codes from the OBD system.

Test results

The test results are presented in Figure 9 to Figure 14. The weighted emissions are calculated as 86% of the warm test result added to 14% of the cold start test result. The gaseous emissions, CO, NOx and THC are well below the Euro VI emission limits.

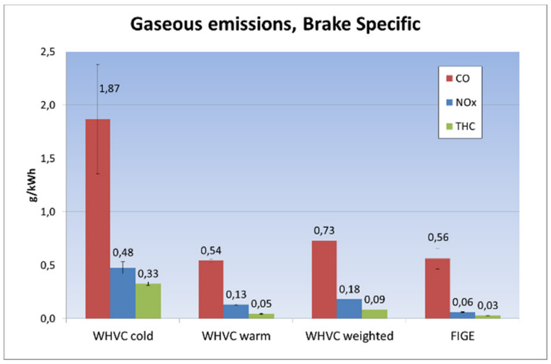

Figure 9 Brake specific gaseous emissions

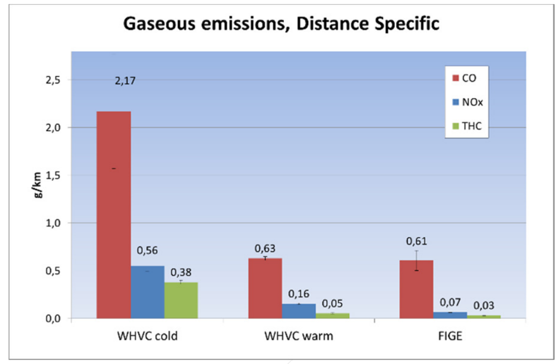

Figure 10Distance specific gaseous emissions

Emissions of methane and NMHC are as expected significantly higher during the cold start tests compared to the tests with warm start. Since methane is one of the most stable hydrocarbons and the NMHC most likely will be reduced first by the catalyst, the higher NMHC results compared to methane during the warm start tests are probably a measurement error caused by measurement of these components outside or partly outside the linear range of the detector. However, neither the NMHC nor the CH_4 emission limits (NMHC=0.16 g/kWh, CH4=0.5 g/kWh) were exceeded in any test.

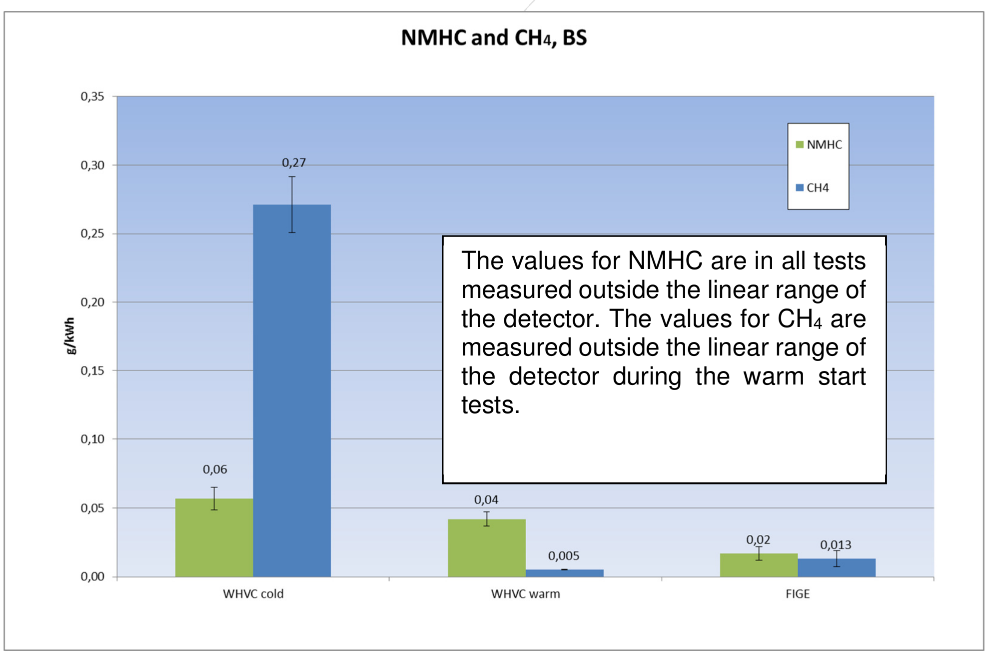

Figure 11 Emissions of HC

The PM level of the test vehicle was low and below the EUVI limit in all tests. PN levels however exceeded the Euro VI applicable PN limit for Diesel engines in both the WHVC cold start test and the WHVC warm start (Figure 12).

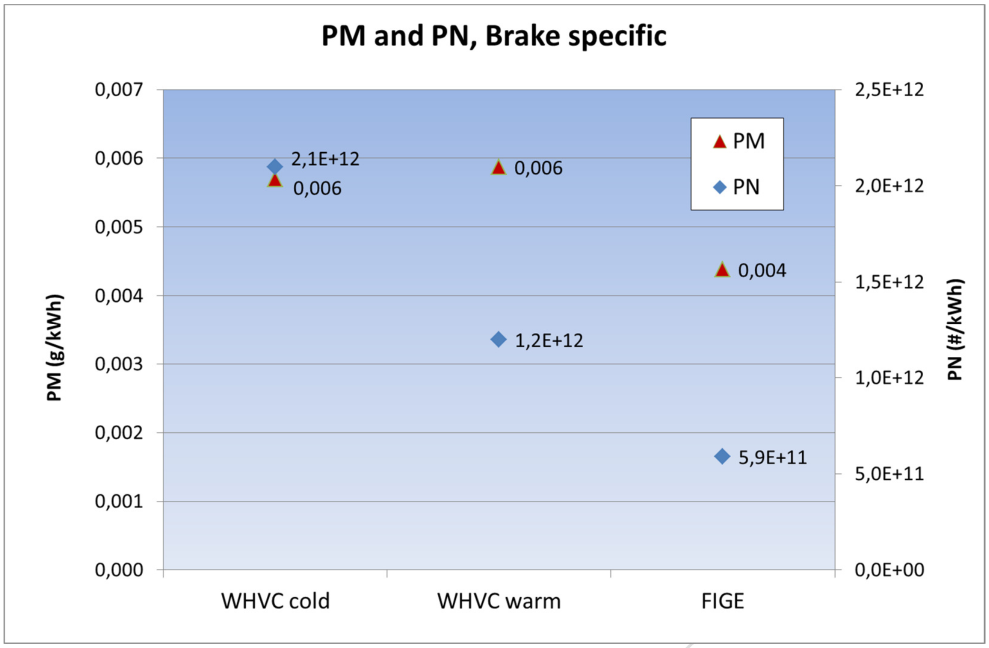

Figure 12 Emissions of PM and PN

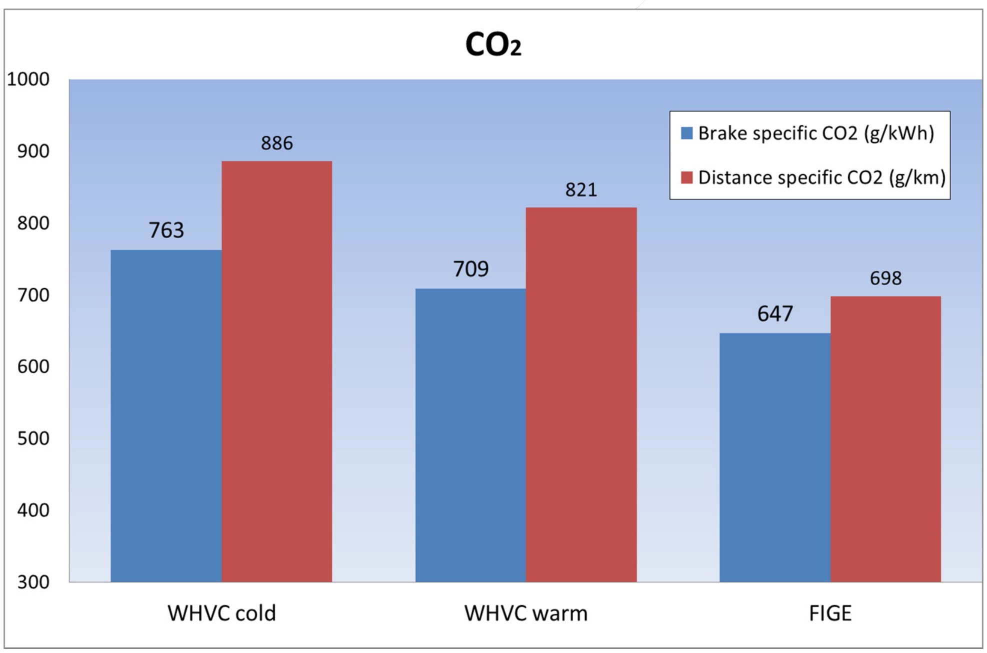

Figure 13 Emissions of CO_2

The weighted ammonia emissions were below the Euro VI 10 ppm limit.

In a vehicle with a positive ignited engine and a three-way catalyst, ammonia may be formed as a secondary pollutant during the NO_x reduction process over the three-way catalyst.

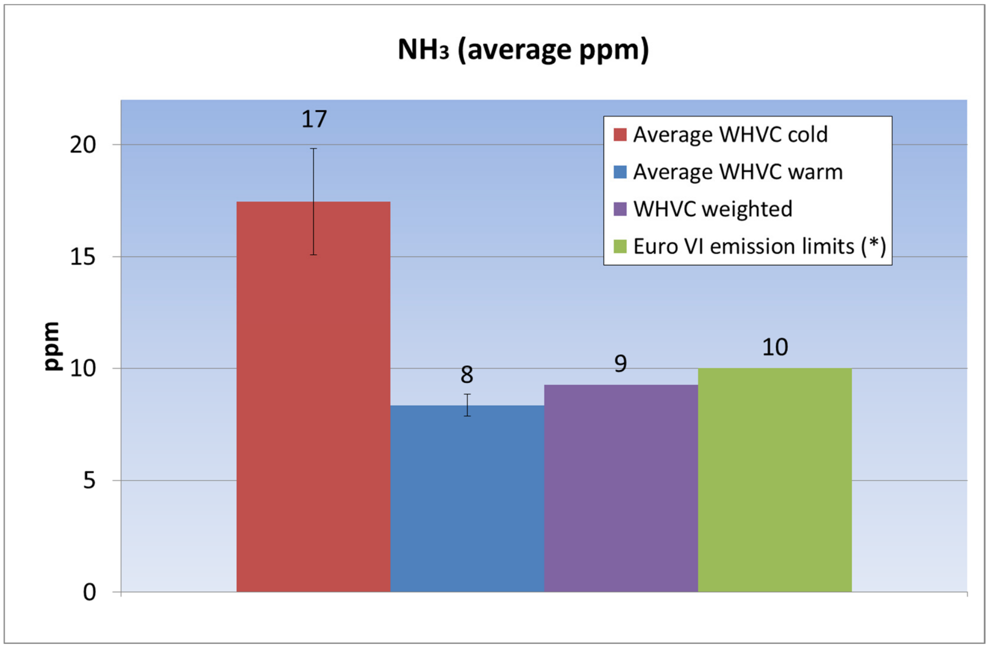

Figure 14 Emissions of NH_3

(*) Engine testing, WHTC cycle

Vehicle B.

Vehicle B was a Heavy Duty crane truck of euro standard VI equipped with a SCRT® filter. The test fuel used during the tests was commercially available Environmental class 1 diesel (MK1). The vehicle has been tested both on chassis dynamometer and on road.

Presentation of vehicle:

Model year:	2014
Vehicle category:	N3
Vehicle type:	Crane
Mileage:	7562 km
Engine:	CI, 6-cylinder
Displacement:	10.5 litres
Fuel:	Diesel
Power:	235 kW
Exhaust after treatment:	SCRT®
Transmission:	automatic
Gross Vehicle Mass (GVM)*:	28000 kg
Mass in running order:	14043kg
Maximum payload:	13 957 kg
Emission standard:	Euro VI

Test program

The on-road testing was performed on the 2nd and 3rd of July 2014. Tests on the chassis dynamometer were performed on the 9th and 10th of July 2014.

Table 7 Test program. Inertia is simulated inertia by the chassis dynamometer. The vehicle payload is reproduced by loading the vehicle with large concrete blocks during on-road tests.

Test	Cold start	Hot start	Inertia [kg]	Vehicle Payload [kg]
FIGE	-	1	20354	(~6300)
WHVC	1	3	20354	(~6300)
PEMS Euro VI N3 route		2		7000

The vehicle payload, during the on-road tests using PEMS, made 50% of the maximum payload. The simulated vehicle payload during the tests on the chassis dynamometer made 45% of the maximum payload.

Test results

The ISC test results from the PEMS tests are presented in Figure 15 and Figure 16. No emissions of CO were detected in any PEMS test and the emissions of THC and NOx were below the conformity factor limits. A conformity factor limit for PM has not yet been established, but the PM level of this vehicle seems high.

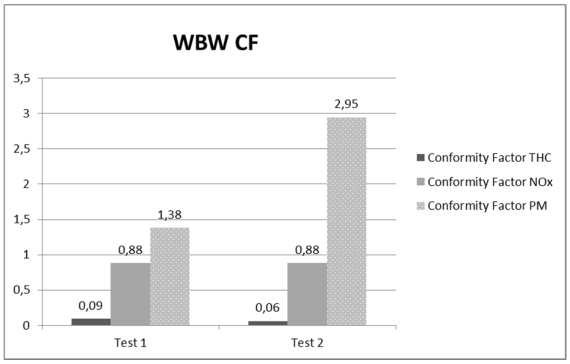

Figure 15 Work based window Conformity Factors

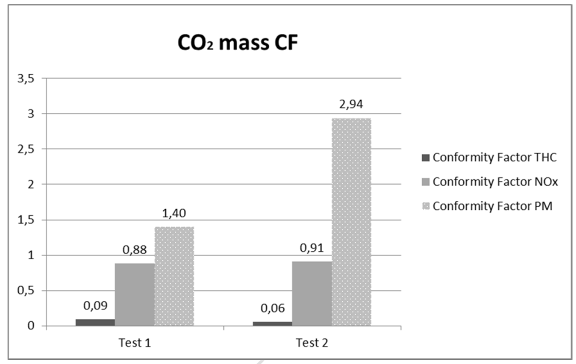

Figure 16 CO2 mass method Conformity Factors

The results presented in Figure 17 to Figure 30 were recorded over the whole PEMS route (all events) or CD test cycle. In cases where the test cycles/routes were repeated the results are presented as average values with standard deviation.

The CO emissions (Figure 17 and Figure 18) varied significantly between the different test cycles and the test route. However, all tests resulted in CO emissions well below the Euro VI emission limit (4 g/kWh).

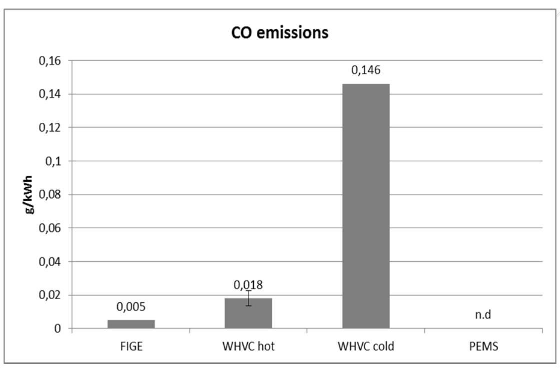

Figure 17 Brake specific CO emissions.

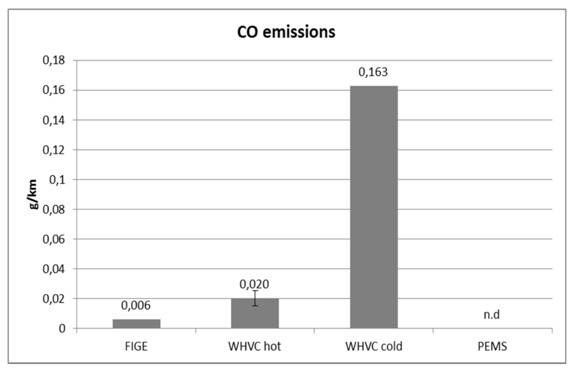

Figure 18 Distance specific CO emissions.

In this study the total hydrocarbon emissions (THC) were measured. In the Euro VI standard methane is excluded from the hydrocarbon emission limit (*i.e. Non Methane HydroCarbons* [NMHC]). Methane emissions were expected to be insignificant since the vehicle under study was equipped with a diesel fuelled engine. Very low levels of HC were measured on road and no emissions of HC were detected on CD.

The NO_x emissions measured during the tests on the chassis dynamometer were in the WHVC cycles rather high (Figure 19 and Figure 20) and the Euro IV emission limit (0,46 g/kWh) was exceeded in the WHVC test cycle. The results from the PEMS testing (all events) and the FIGE test cycle showed more moderate NOx emissions passing the applicable Euro VI emission limit. Relatively high ammonia emissions were measured (Figure 21).

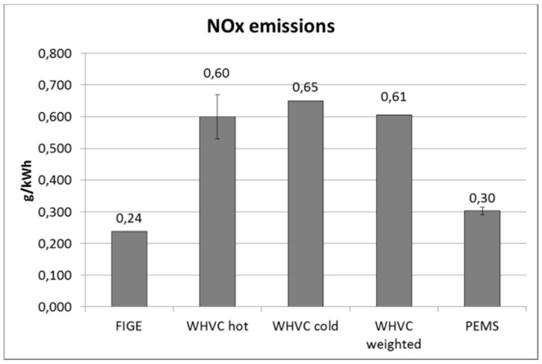

Figure 19 Brake specific NOx emissions.

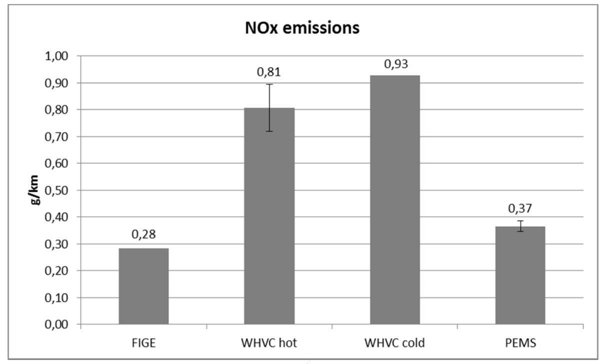

Figure 20 Distance specific NOx emissions.

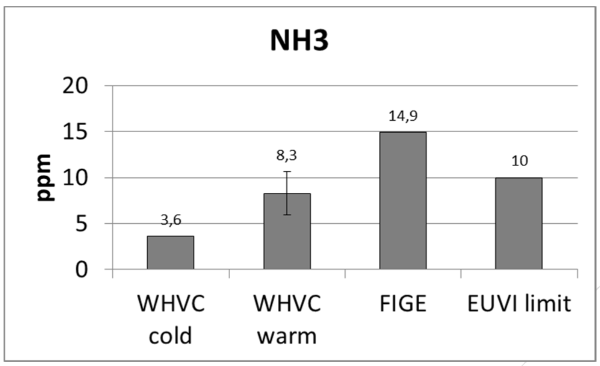

Figure 21 Emissions of ammonia

The Euro IV PM Emission limit was exceeded in all tests (Figure 22). The PN levels did not exceed the Euro VI applicable PN limit (Figure 24).

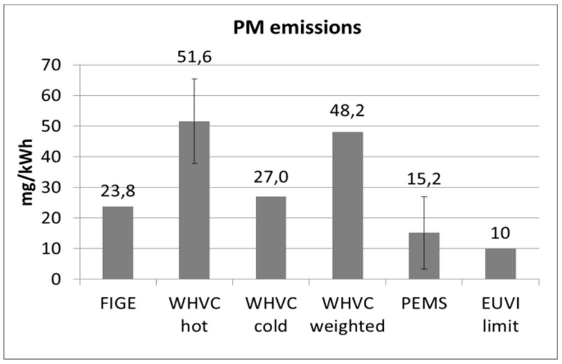

Figure 22 Brake specific PM emissions.

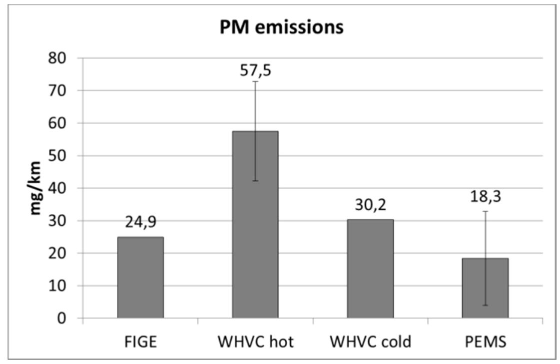

Figure 23 Distance specific PM emissions.

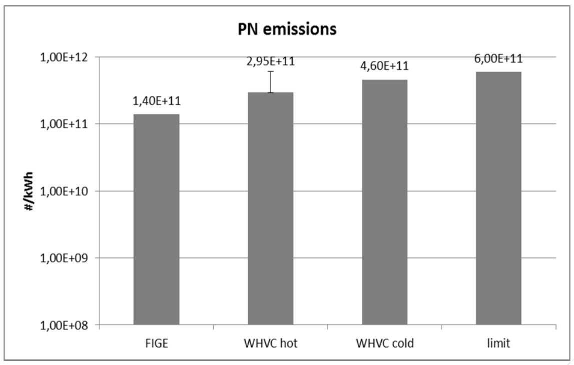

Figure 24 Brake specific PN emissions.

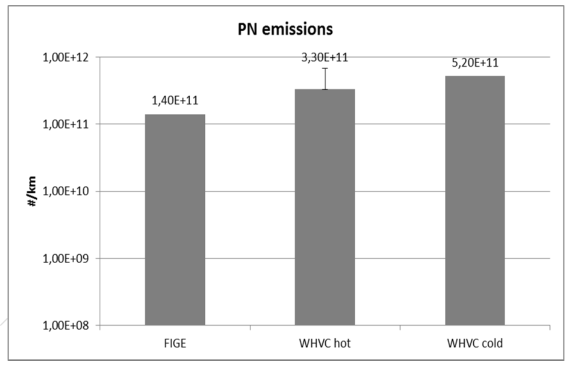

Figure 25 Distance specific PN emissions

The CO_2 emissions and fuel consumption followed the same trend (Figure 26, Figure 27 and Figure 28, Figure 29).

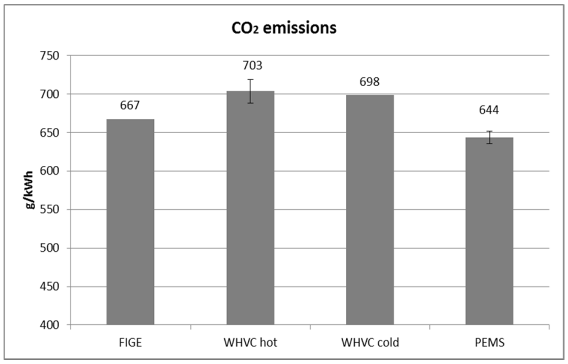

Figure 26 Brake specific CO_2 emissions.

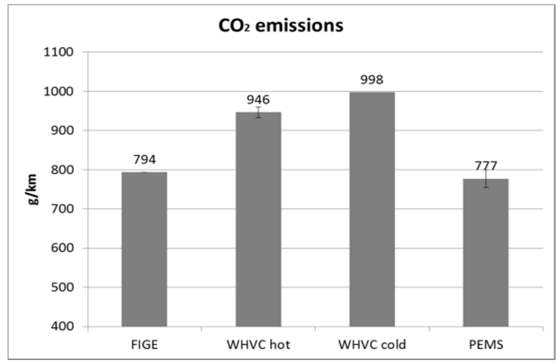

Figure 27 Distance specific CO_2 emissions.

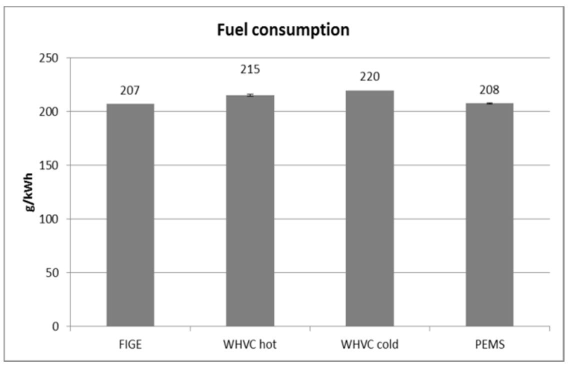

Figure 28 Brake specific fuel consumption.

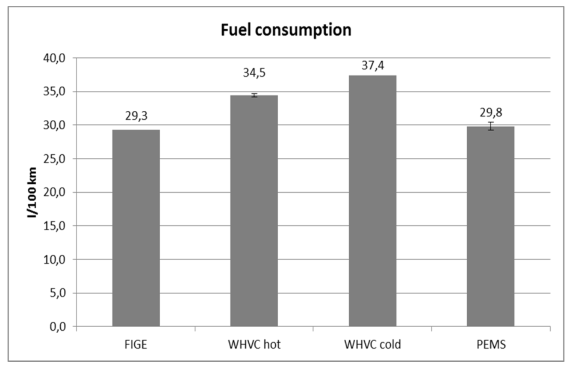

Figure 29 Distance specific fuel consumption

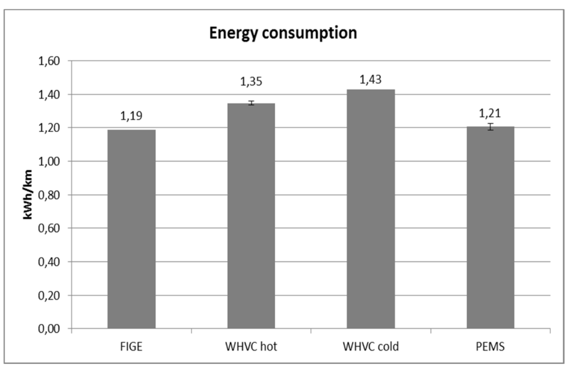

Figure 30 Energy consumption.

Comments/Conclusions

No emissions of THC were measured on CD and very low levels on the road. Emissions of CO were below the EUVI emission limit on both chassis dynamometer and on the road. Emissions of NOx measured on chassis dynamometer exceeded the WHTC engine test emission limit. The results from the PEMS testing and the FIGE test cycle showed more moderate NOx emissions passing the applicable Euro VI emission limit. The vehicle passed the EUVI ISC conformity factor limits for all gaseous emissions. PM emissions were high and the WHTC engine test limit was exceeded in all CD tests. No PEMS IUC conformity factor limits for PM is yet established but the PM level can be considered high.The PN levels did not exceed the Euro VI applicable PN limit on CD. Relatively high ammonia emissions were measured.

No malfunction was indicated by the OBD system.

Vehicle C.

Test vehicle C was a small distribution truck of emission standard Euro VI, equipped with EGR, DOC, a SCR system DPF. The test fuel used during the tests was commercially available Environmental class 1 diesel (MK1). The vehicle has been tested both on chassis dynamometer and on road.

Presentation of vehicle:

Model year:	2014
Vehicle category:	N2
Vehicle type:	Rigid truck
Mileage:	10368 km
Engine:	CI, 6-cylinder
Displacement:	7.7 litres
Fuel:	Diesel
Power:	175 kW
Exhaust after treatment:	EGR, DOC, SCR, DPF
Transmission:	automatic
Gross Vehicle Mass (GVM)*:	11 990 kg
Mass in running order:	8 235 kg
Maximum payload:	3 755 kg
Emission standard:	Euro VI

(* = *technically permissible maximum laden mass of the vehicle)*

Test program

The on-road testing was performed between the 5th and 11th of November 2014. Tests on the chassis dynamometer were performed between the 17th and 20th of November 2014.

Table 8 Test program. Inertia is simulated inertia by the chassis dynamometer. The vehicle payload is reproduced by loading the vehicle with large concrete blocks during on-road tests.

Test	Cold start	Hot start	Inertia [kg]	Vehicle Payload [kg]
FIGE	-	1	10184	(~1950)
WHVC	2	3	10184	(~1950)
PEMS Euro VI N3 route	2	2		2000

The vehicle payload, during the on-road tests using PEMS, made 53% of the maximum payload. The simulated vehicle payload during the tests on the chassis dynamometer made 52% of the maximum payload.

Test results

The ISC test results from the PEMS tests are presented in Figure 15 and Figure 16. No emissions of CO or HC were detected in any PEMS test. The NOx emissions were relatively high, however passing the conformity factor limit in all tests except one cold start. The CO2 mass results for NOx were higher and above the CF limit. A conformity factor limit for PM has not yet been established, but the PM emission of this vehicle was low.

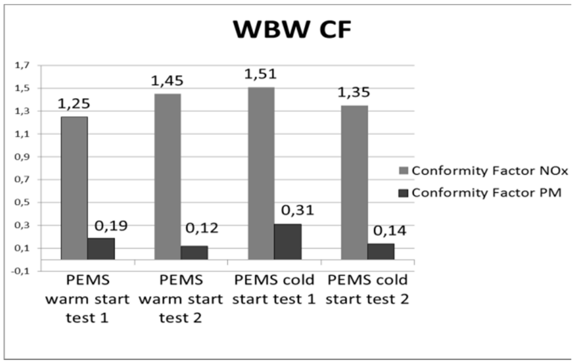

Figure 31

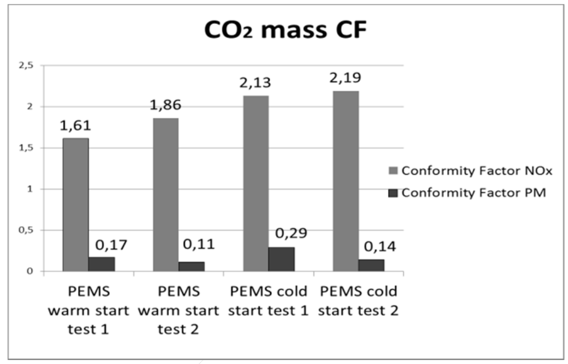

Figure 32

The results presented in Figure 17 to Figure 48 were recorded over the whole PEMS route (all events) or test cycle. The weighted emissions are calculated as 86% of the warm test result added to 14% of the cold start test result. In cases where the test-cycles/routes were repeated the results are presented as average values with standard deviation.

The CO emissions (Figure 17 and Figure 18) varied significantly between the different test cycles and the test route. However, all tests resulted in CO emissions well below the Euro VI emission limit (4 g/kWh).

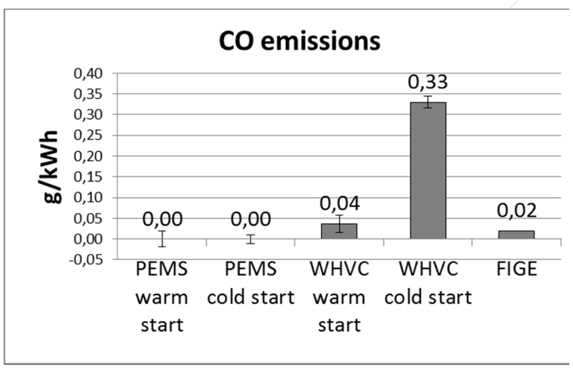

Figure 33 Brake specific CO emissions.

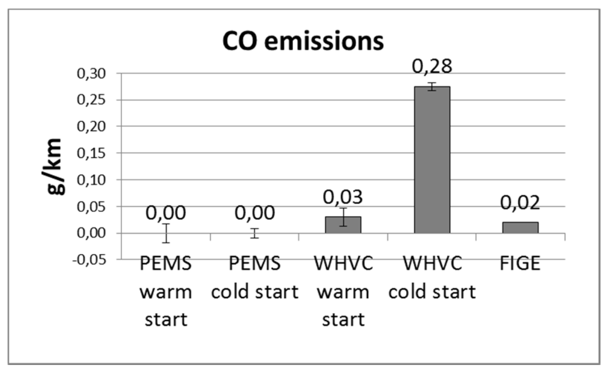

Figure 34 Distance specific CO emissions.

In this study the total hydrocarbon emissions (THC) were measured. In the Euro VI standard methane is excluded from the hydrocarbon emission limit (*i.e. Non Methane HydroCarbons* [NMHC]). Methane emissions were expected to be insignificant since the vehicle under study was equipped with a diesel fuelled engine. Figure 35 shows that the emissions of THC from all tests were well below the Euro IV NMHC emission limit (0,16 g/kWh).

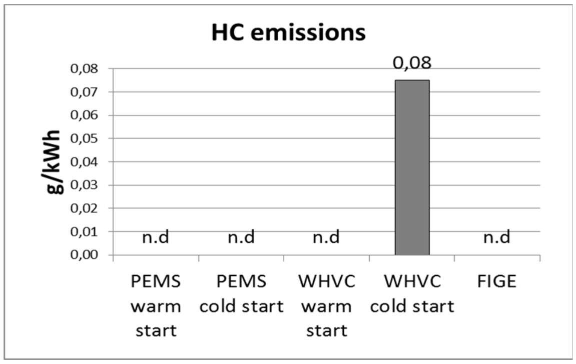

Figure 35 Brake specific THC emissions.

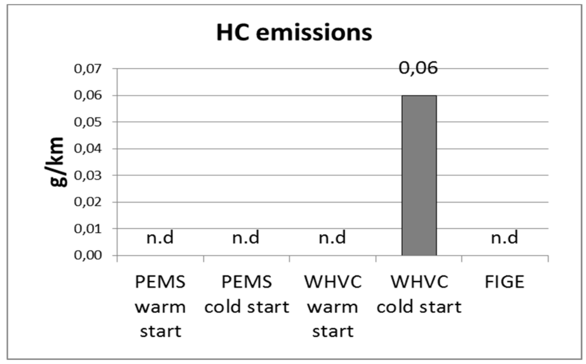

Figure 36 Distance specific THC emissions.

The NOx emissions measured during the tests on the chassis dynamometer were in the WHVC cycles rather high (Figure 19 and Figure 38) and the Euro IV emission limit (0,46 g/kWh) was exceeded. Also the “all events” results from the PEMS testing showed high NOx emissions, not passing the applicable Euro VI emission. The ammonia emissions measured were low (Figure 39).

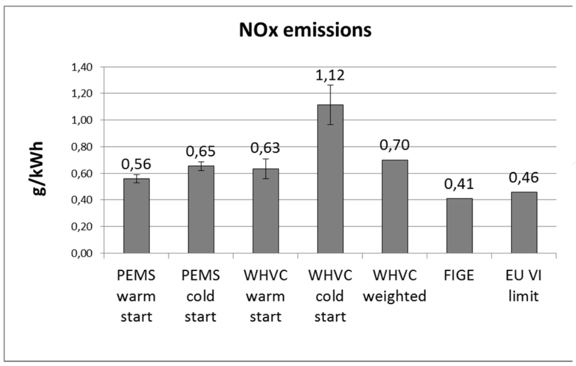

Figure 37 Brake specific NOx emissions.

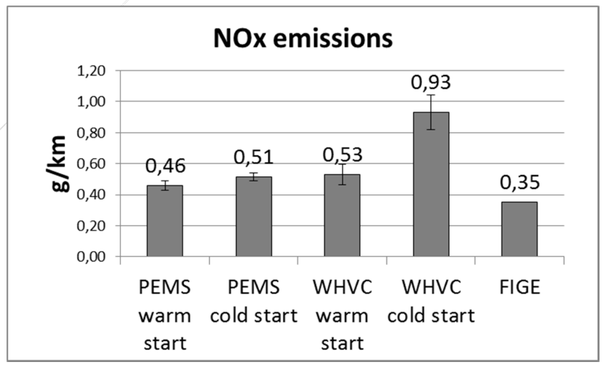

Figure 38 Distance specific NOx emissions.

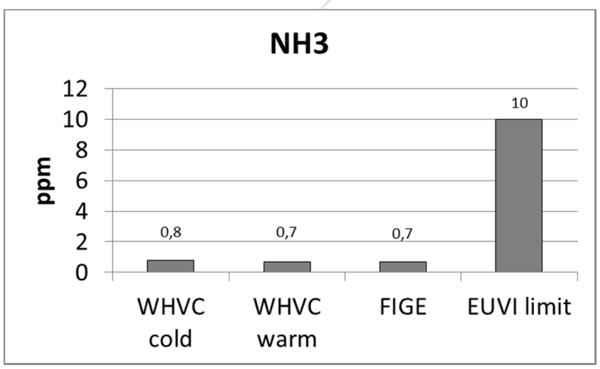

Figure 39 Emissions of ammonia

The PM level of the test vehicle was low and below the EUVI limit in all tests (Figure 22). PN levels did exceed the Euro VI applicable PN limit in the cold start test but the weighted result was below the limit (Figure 24).

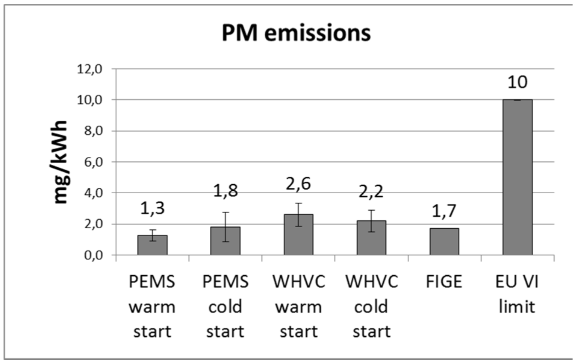

Figure 40 Brake specific PM emissions.

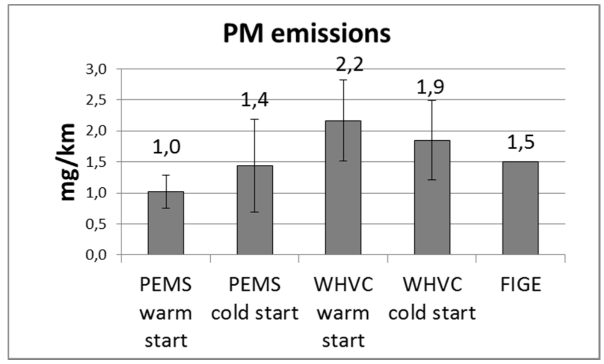

Figure 41 Distance specific PM emissions.

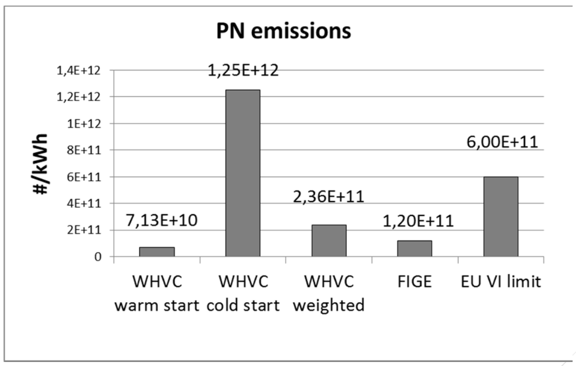

Figure 42 Brake specific PN emissions.

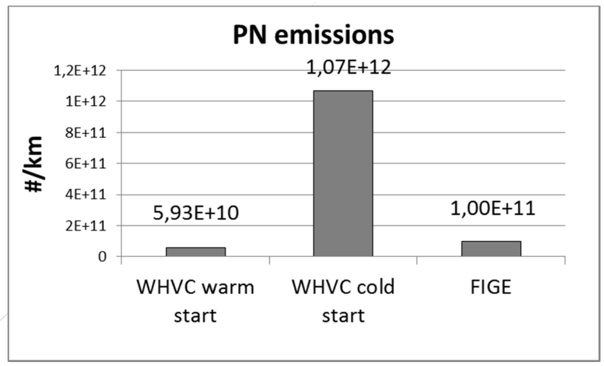

Figure 43 Distance specific PN emissions

The CO_2 emissions and fuel consumption followed the same trend (Figure 26, Figure 27 and Figure 28, Figure 29).

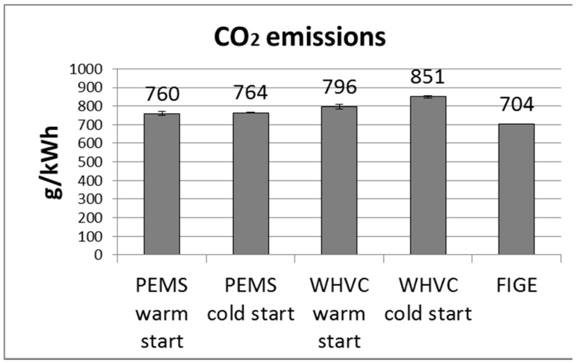

Figure 44 Brake specific CO_2 emissions.

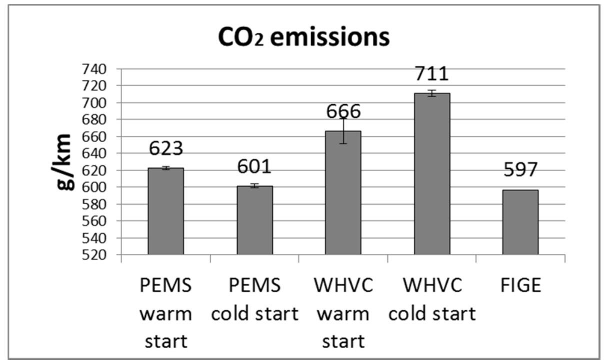

Figure 45 Distance specific CO_2 emissions.

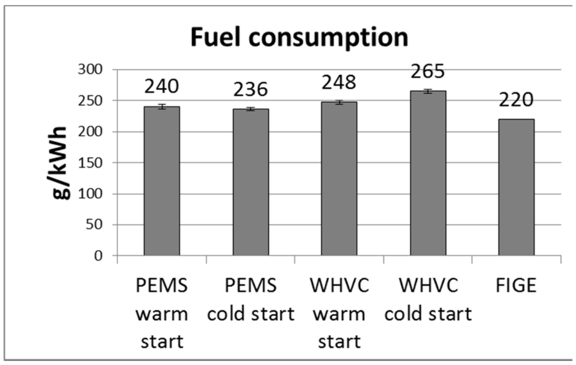

Figure 46 Brake specific fuel consumption.

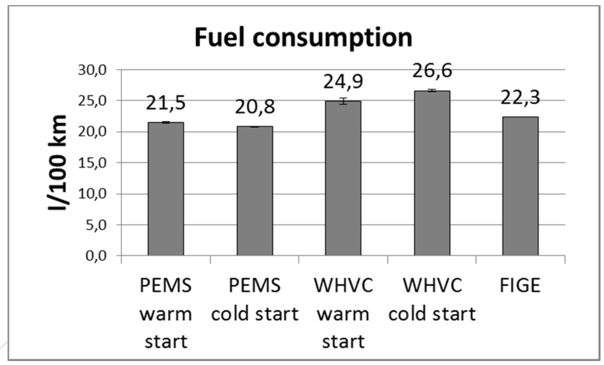

Figure 47 Distance specific fuel consumption

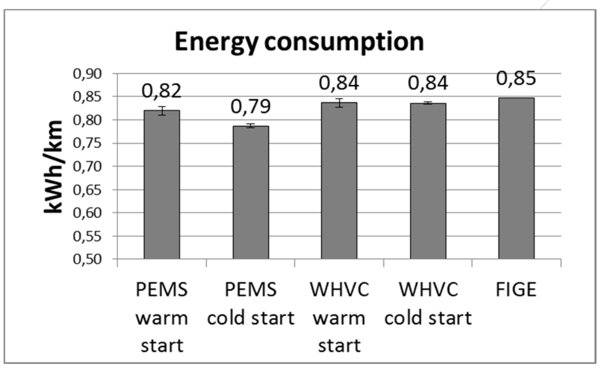

Figure 48 Energy consumption.

Comments/Conclusions

Emissions of THC, CO and PM were below the EUVI emission limits on both chassis dynamometer and on the road. Emissions of NOx measured on chassis dynamometer exceeded the WHTC engine test emission limit. Also the “all events” results from the PEMS testing showed high NOx emissions, not passing the applicable Euro VI emission limit. The vehicle did however pass the EUVI ISC conformity factor limits for all gaseous emissions. The weighted PN emission result did not exceed the PN emission limit. The ammonia emissions measured were low.

No malfunction was indicated by the OBD system.

Vehicle D

Test vehicle D was a small bus of emission standard Euro VI, equipped with a SCR system and a DPF. The test fuel used during the tests was commercially available Environmental class 1 diesel (MK1). The vehicle has been tested both on chassis dynamometer and on road.

Presentation of vehicle:

Model year:	*2014*
Vehicle category:	*M2*
Vehicle type:	*Bus*
Mileage (km):	*986*
Engine:	*CI, 4-cylinder*
Displacement:	*2.1 litres*
Fuel:	*Diesel*
Power:	*120 kW*
Exhaust after treatment:	*DPF, SCR*
Transmission:	*Automatic*
Gross Vehicle Mass (GVM)*:	*5 000 kg*
Mass in running order:	*2560 kg**/3590 kg****
Maximum payload:	*2440 kg*
Emission standard:	*Euro VI*

* *Technically permissible maximum laden mass of the vehicle*
*** According to information on The Swedish Transport Agency's homepage*
**** Actual weight*

Test program

The on-road testing was performed between the 1 and 3[d] of September 2014. Tests on the chassis dynamometer were performed on the 28[th] and 29[th] of August 2014.

Table 9 Test program. Inertia is simulated inertia by the chassis dynamometer. The vehicle payload is reproduced by loading the vehicle a tank of water during on-road tests.

Test	Cold start	Hot start	Inertia	Vehicle Payload
FIGE	-	1	2270	(~0)
WHVC	1	2	2270	(~0)
PEMS Euro VI M2 route	2	3		1500

Due to underestimation of vehicle curb weight the vehicle was loaded with approximately 1,5 tonnes during the road tests which corresponds to 100% of maximum permissible load. The chassis dynamometer inertia was the maximum possible of the dynamometer which unfortunately corresponds to less than the actual vehicle weight.

Test results

The ISC test results from the PEMS tests are presented in Figure 50. Only the worked based window method is presented since the amount of valid windows were too few in the CO_2 mass method. Also in the work based window method were the amount of valid windows close to 50% which for this vehicle means that the engine load during the entire urban and rural part is below the 20% power threshold and is eliminated from the test result (Figure 49).

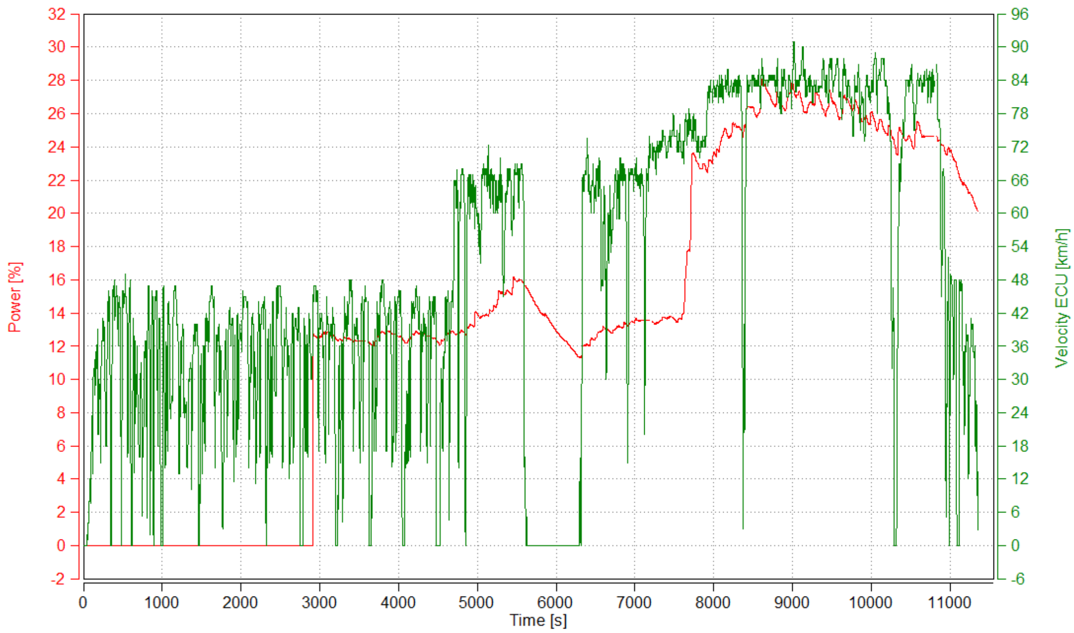

Figure 49 Engine power during one PEMS test

No emissions of CO were detected in any PEMS test and the conformity factor for THC was 0,01 in all tests. A conformity factor limit for PM has not yet been established, but the PM level of this vehicle is low in all tests. The NOx emissions are rather high, in one test exceeding the Euro VI conformity factor limit. The exhaust gas temperature, measured approximately 3 meters after the engine, is below 190°C during the whole test and it may be possible that the catalyst has problems to reach light off temperature during at least parts of the test. During warm test no 3, DPF regeneration occurs during the urban part of the test. This does not influence the test result since the vehicle does not work over the 20% power threshold during this part of the test and the emissions are not included.

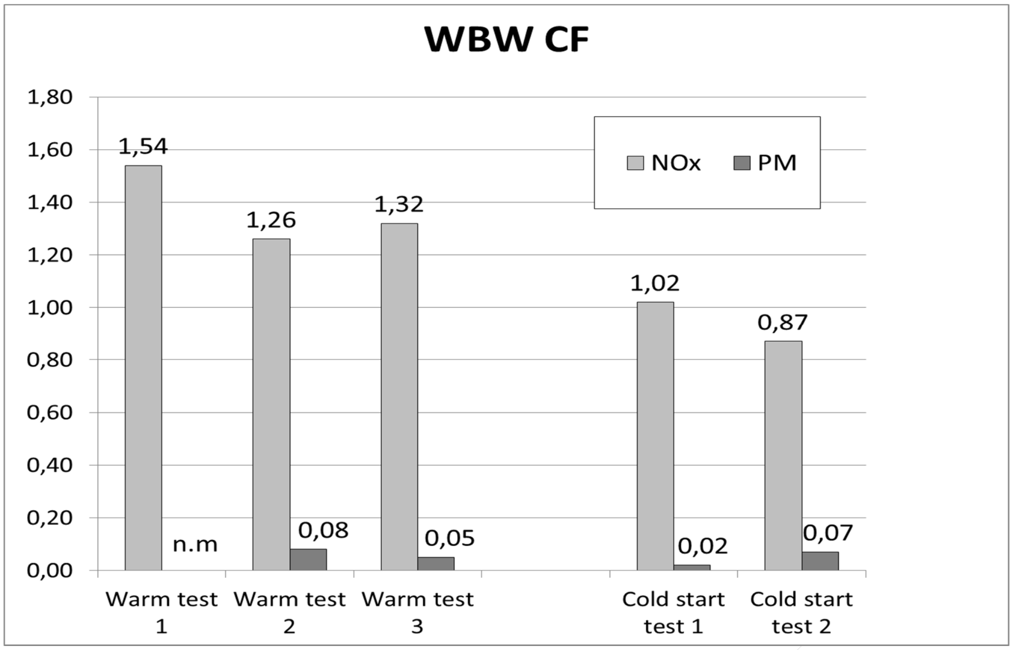

Figure 50 Work based windows, NOx and PM conformity factors

The results presented in Figure 51-Figure 63 were recorded over the whole PEMS route or test cycle. In cases where the test-cycles/routes were repeated the results are presented as average values with standard deviation. Warm test no 3 with DPF regeneration is not included in any average value. ECU data was used to calculate the engine work both on chassis dynamometer and road tests. For the chassis dynamometer tests have the vehicle payload been lower compared to the road tests.

The CO emissions (Figure 51, Figure 52) varied between the different test cycles and the test route. However, all tests resulted in CO emissions well below the Euro VI emission limit of 4,0 g/kWh.

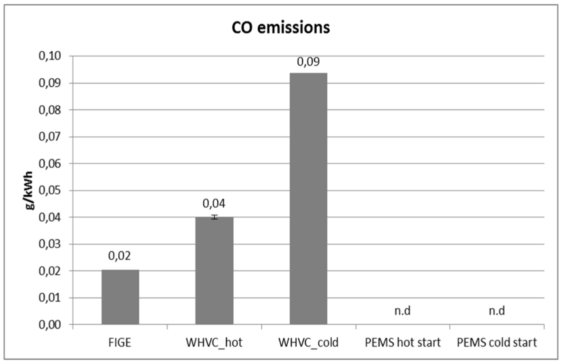

Figure 51 Brake specific CO emissions.

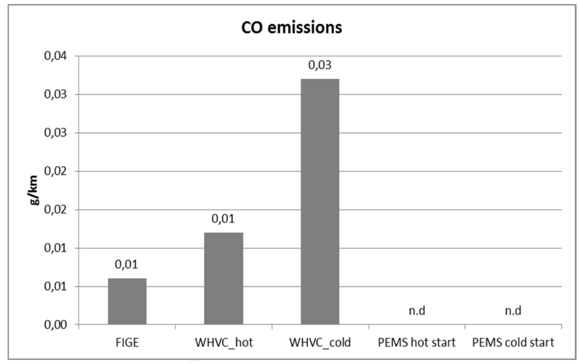

Figure 52 Distance specific CO emissions.

In this study the total hydrocarbon emissions (THC) were measured. In the Euro VI standard methane is excluded from the hydrocarbon emission limit (*i.e. Non Methane HydroCarbons* [NMHC]). Methane emissions were expected to be insignificant since the vehicle under study was equipped with a diesel fuelled engine. Figure 53 shows that the emissions of THC from all tests were well below the Euro VI NMHC emission limit of 0,16 g/kWh.

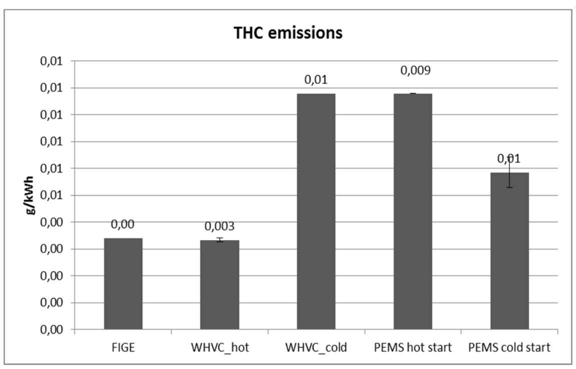

Figure 53 Brake specific THC emissions.

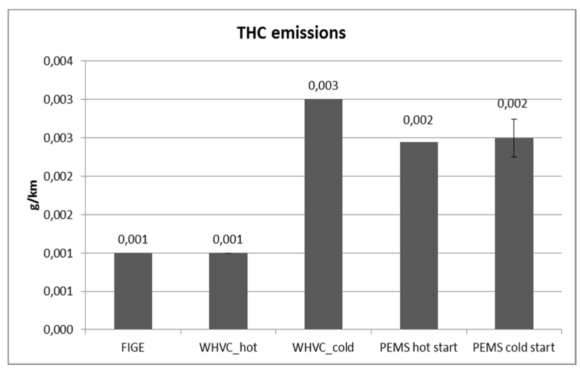

Figure 54 Distance specific THC emissions.

The NO_x emissions measured during the tests on the chassis dynamometer were generally rather high (Figure 55, Figure 56) and the Euro IV emission limit were exceeded in all tests on chassis dynamometer. The weighted NOx test result exceeded the limit by more than 100%. The results from the PEMS testing showed lower NOx emissions below the applicable Euro VI emission limit.

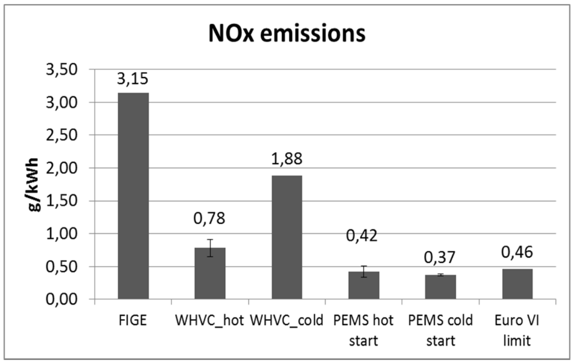

Figure 55 Brake specific NOx emissions.

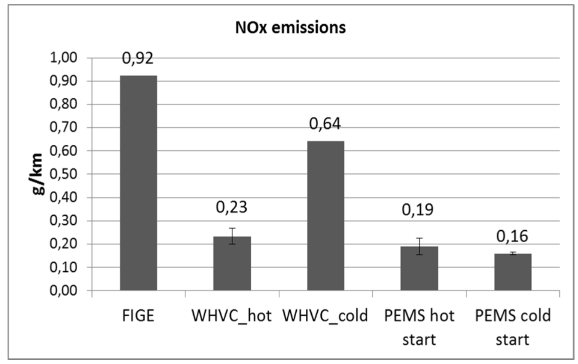

Figure 56 Distance specific NOx emissions.

The PM emissions where low and well below the Euro VI PM emission limit (10 mg/kWh).

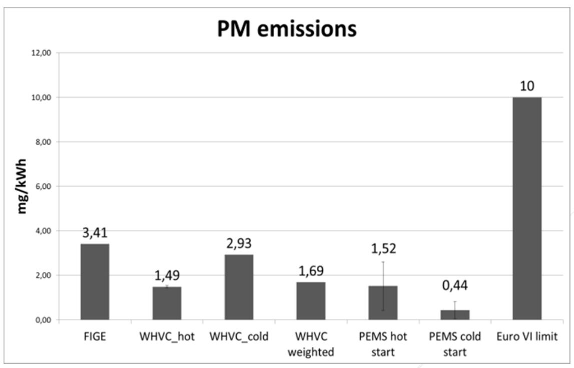

Figure 57 Brake specific PM emissions.

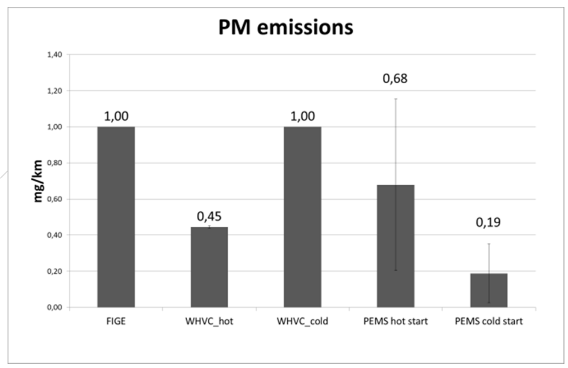

Figure 58 Distance specific PM emissions.

The CO_2 emissions and fuel consumption followed the same trend (Figure 59-Figure 62). The brake specific CO_2 and break specific fuel consumption are on the same level for all tests, both on the road and on chassis dynamometer. The distance specific emissions, however, are significantly higher on the road compared to chassis dynamometer which is a result of the difference in payload.

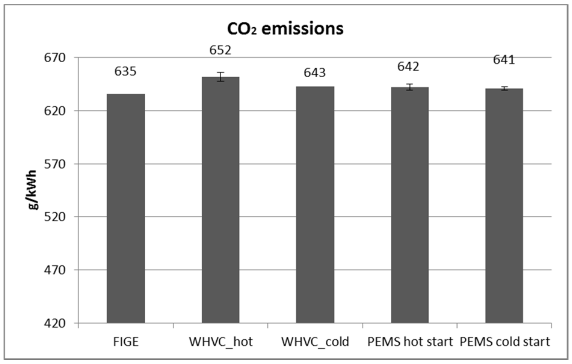

Figure 59 Brake specific CO_2 emissions.

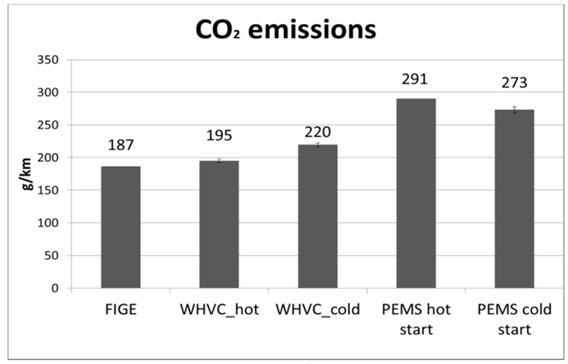

Figure 60 Distance specific CO_2 emissions.

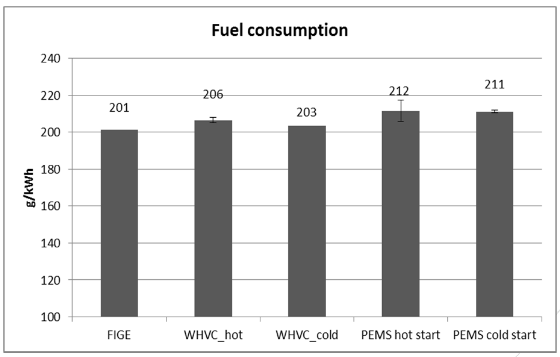

Figure 61 Brake specific fuel consumption.

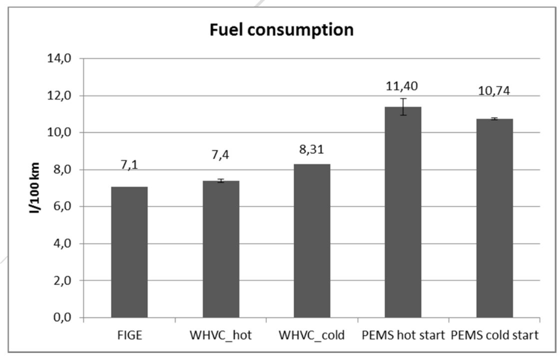

Figure 62 Distance specific fuel consumption

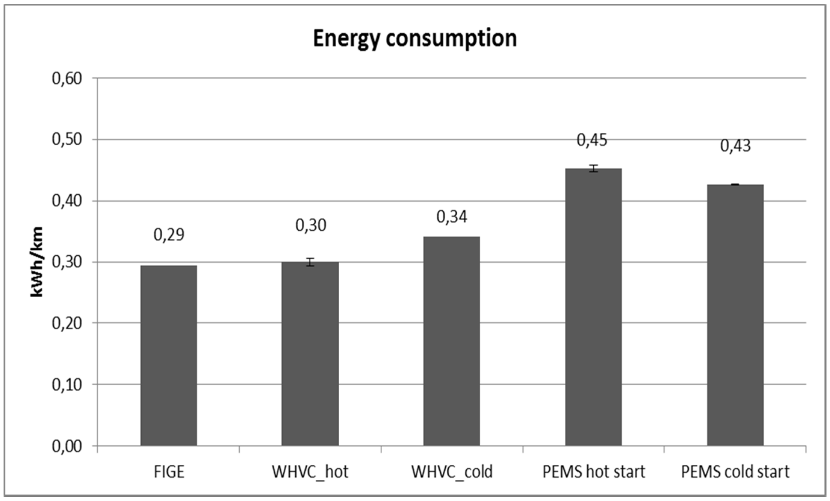

Figure 63 Energy consumption.

For these tests, ECU data has been used to measure the work also on chassis dynamometer. The difference in vehicle payload on chassis dynamometer compared to PEMS is clearly reflected in the results.

Comments/Conclusions

Emissions of THC, CO and PM were below the EUVI emission limits on both chassis dynamometer and on the road. Emissions of NOx measured on chassis dynamometer exceeded the WHTC engine test emission limit. The “all events” results from the PEMS testing showed lower NOx emissions, passing the applicable Euro VI emission limit. In one road test the vehicle failed the EUVI ISC conformity factor limits for NOx emissions.

No malfunction was indicated by the OBD system.

Vehicle E

Test vehicle E was a distribution truck of emission standard Euro IV, equipped with EGR. The vehicle was also tested in 2012. Now, approximately 2 years later, the same vehicle has been retested in order to verify the emission performance over time. The test fuel used during the tests was commercially available Environmental class 1 diesel (MK1). The vehicle has been tested both on chassis dynamometer and on road. Due to differences in PEMS test route, the comparison has been done only with chassis dynamometer test results.

Presentation of vehicle:

Model year:	*2007*
Vehicle category:	*N3*
Vehicle type:	*Rigid*
Mileage:	*391 252,6 km*
Engine:	*CI, 6-cylinder*
Displacement:	*11.7 litres*
Fuel:	*Diesel*
Power:	*353 kW*
Exhaust after treatment:	*EGR*
Transmission:	*manual*
Gross Vehicle Mass (GVM)*:	*27 000 kg*
Mass in running order:	*10 860 kg*
Maximum payload:	*14 140 kg*
Emission standard:	*Euro IV*

(* = *technically permissible maximum laden mass of the vehicle)*

Test program

The on-road testing was performed on the 27th and 28th of May 2014. Tests on the chassis dynamometer were performed on the 20th and 23th of May 2014.

Table 10 Test program.

Test	Cold start	Hot start	Vehicle payload
Fige	2	3	8138 kg*
WHVC	–	3	8138 kg*
PEMS EuroVI route2	–	2	7000 kg

Inertia is simulated inertia by the chassis dynamometer. The vehicle payload is reproduced by loading the vehicle with large concrete blocks during on-road tests.
(Vehicle payload = Inertia – Mass in running order)*

The vehicle payload, during the on-road tests using PEMS, made 50% of the maximum payload. The simulated vehicle payload during the tests on the chassis dynamometer made 58% of the maximum payload.

Test results 2014

The results presented in Figure 64 to Figure 78 were recorded over the whole PEMS route or test cycle. In cases where the test-cycles/routes were repeated the results are presented as average values.

The CO emissions (Figure 64, Figure 65) varied significantly between the different test cycles and the test route. However, all tests resulted in CO emissions well below the Euro IV emission limits.

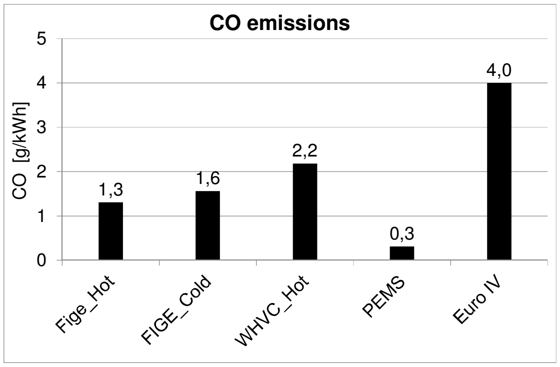

Figure 64 Brake specific CO emissions.

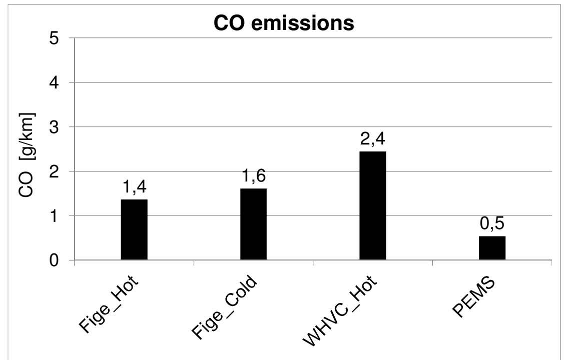

Figure 65 Distance specific CO emissions.

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In this study the total hydrocarbon emissions (THC) were measured. In the Euro IV standard methane is excluded from the hydrocarbon emission limit (*i.e. Non Methane HydroCarbons [*NMHC]). Methane emissions were expected to be insignificant since the vehicle under study was equipped with a diesel fuelled engine. Figure 66 shows that the emissions of THC from all tests were well below the Euro IV NMHC emission limit.

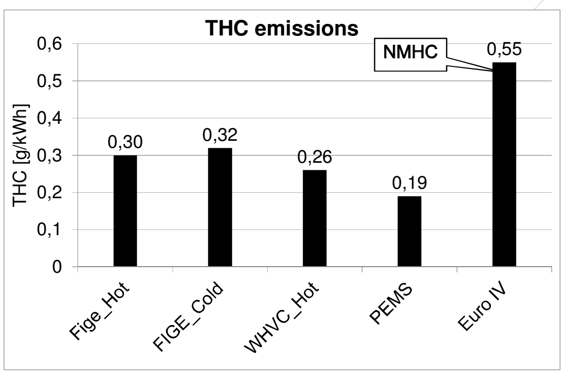

Figure 66 Brake specific THC emissions.

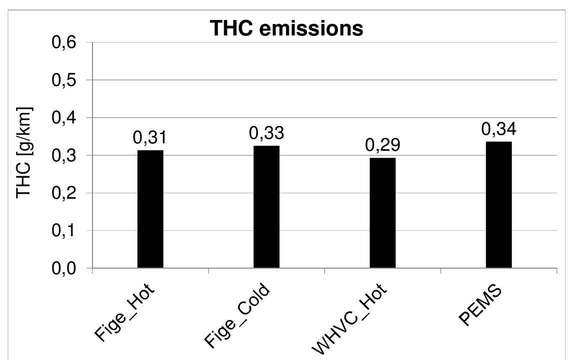

Figure 67 Distance specific THC emissions.

The NO_x emissions measured during the tests on the chassis dynamometer were generally very high (Figure 68, Figure 69) and the Euro IV emission limit were exceeded by a factor of about 1.8. The results from the PEMS testing showed more moderate NOx emissions but still exceeding the applicable Euro VI emission limit.

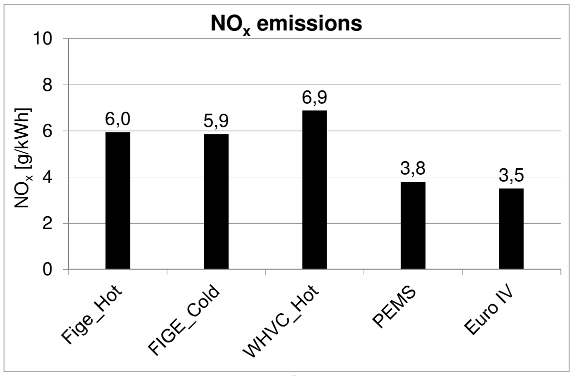

Figure 68 Brake specific NOx emissions.

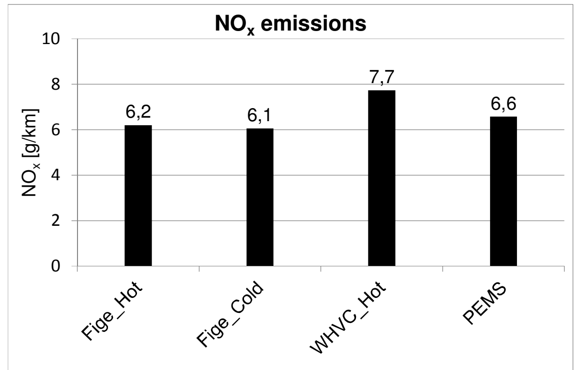

Figure 69 Distance specific NOx emissions.

The Euro IV PM emission limit was exceeded by a factor of up to two. The results from the PEMS on-road measurements indicated that the soot fraction was relatively low (*c.f.* Figure 70, Figure 71). PN levels exceeded the Euro VI applicable PN limit by a factor somewhere between 100 and 200 (*c.f.* Figure 72).

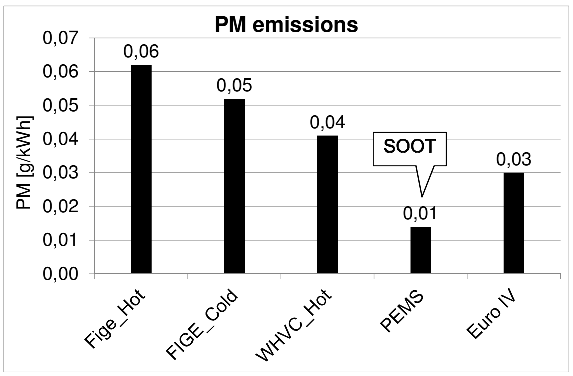

Figure 70 Brake specific PM emissions.

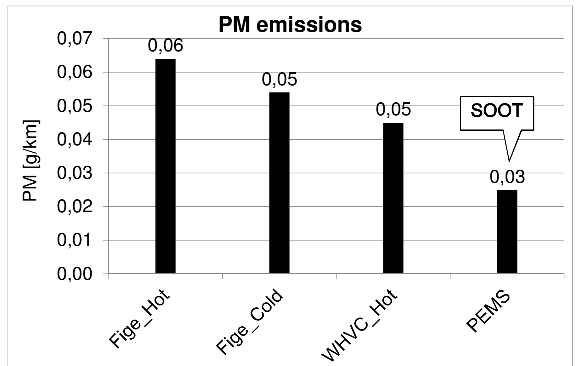

Figure 71 Distance specific PM emissions.

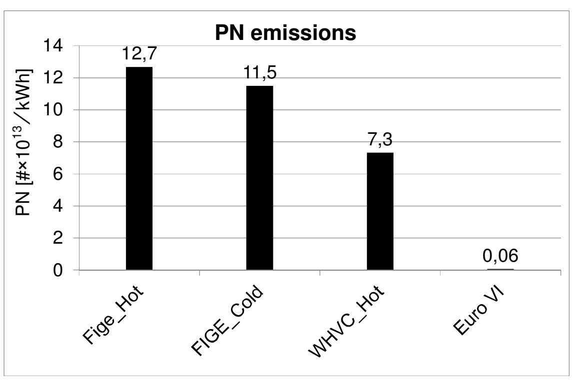

Figure 72 Brake specific PN emissions.

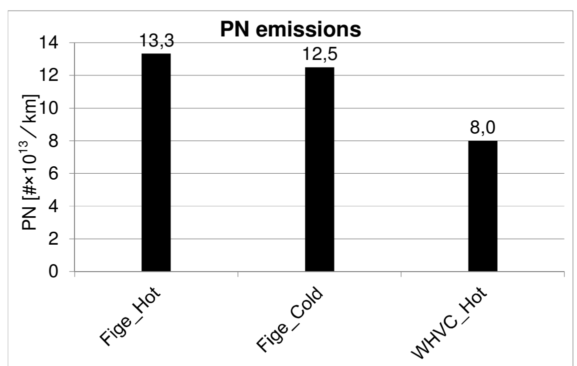

Figure 73 Distance specific PN emissions

The CO_2 emissions and fuel consumption followed the same trend (*c.f.* Figure 74, Figure 75and Figure Figure 76, Figure 77). The Brake specific CO_2 and Brake specific fuel consumption of the WHVC tests and Fige cycle stayed at level of about 90 % higher than the on-road tests (PEMS). On the other hand, all results of the distance specific calculations showed deviations from the mean value (all tests) of less than ±12%.

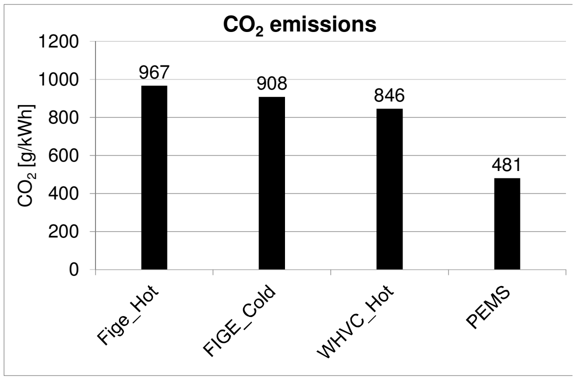

Figure 74 Brake specific CO2 emissions.

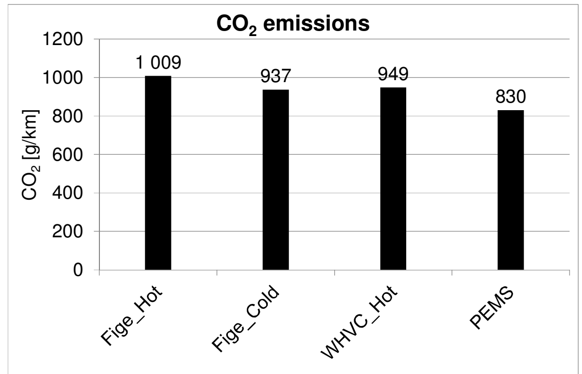

Figure 75 Distance specific CO2 emissions.

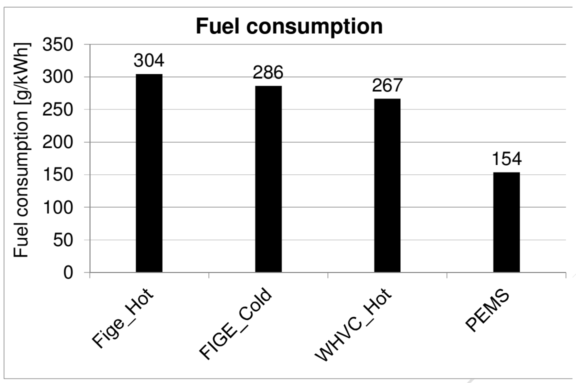

Figure 76 Brake specific fuel consumption.

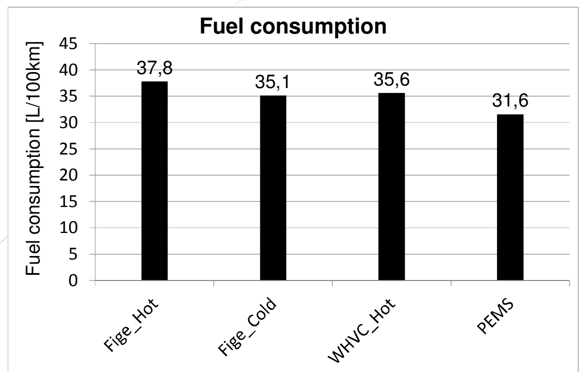

Figure 77 Distance specific fuel consumption

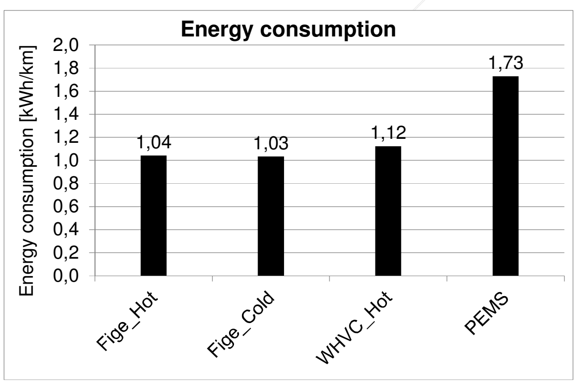

Figure 78 Energy consumption

The difference between the results of the test cycles and the on-road measurements for the distance specific results was much smaller than for the results calculated on Brake specific basis. This could be explained by that the energy consumption (kWh/km) was higher for the on-road tests than for the tests on the chassis dynamometer (*c.f.* Figure 78). The difference in energy consumption is partly a result of that the work performed on the chassis dynamometer and the on-road testing are calculated by using different methods. The calculation of performed work of the chassis dynamometer testing is based on the force exerted by the wheels on the rolls of the chassis dynamometer. Work performed during the on-road tests is calculated for the crank axle. This means, in contrast to the chassis dynamometer testing that the loss of energy, due to friction of the transmission and tire power consumption, is not accounted for during the on-road tests. Still, the difference in energy consumption was so large, between laboratory testing and on-road tests, that it could not be explained by the energy losses in the transmission and tires solely. The energy consumption is also affected by the operational conditions which differed between the different test cycles and the on-road test routs. It is also possible that the ECU of the vehicle may have delivered inaccurate data on the engine load. It should be stressed that there are no legal requirements of access to ECU data from Euro IV engines.

Emission performance over time

All regulated emissions increased significantly between 2012 and 2014. CO and THC increased by more than 50%, however the Euro IV emission limit was still not exceeded. PM increased by approximately 30% and did in 2014 no longer pass the Euro IV limit as it did in 2012. NOx increased on average 7% and was, in 2014 as well as in 2012, far above the Euro IV limit.

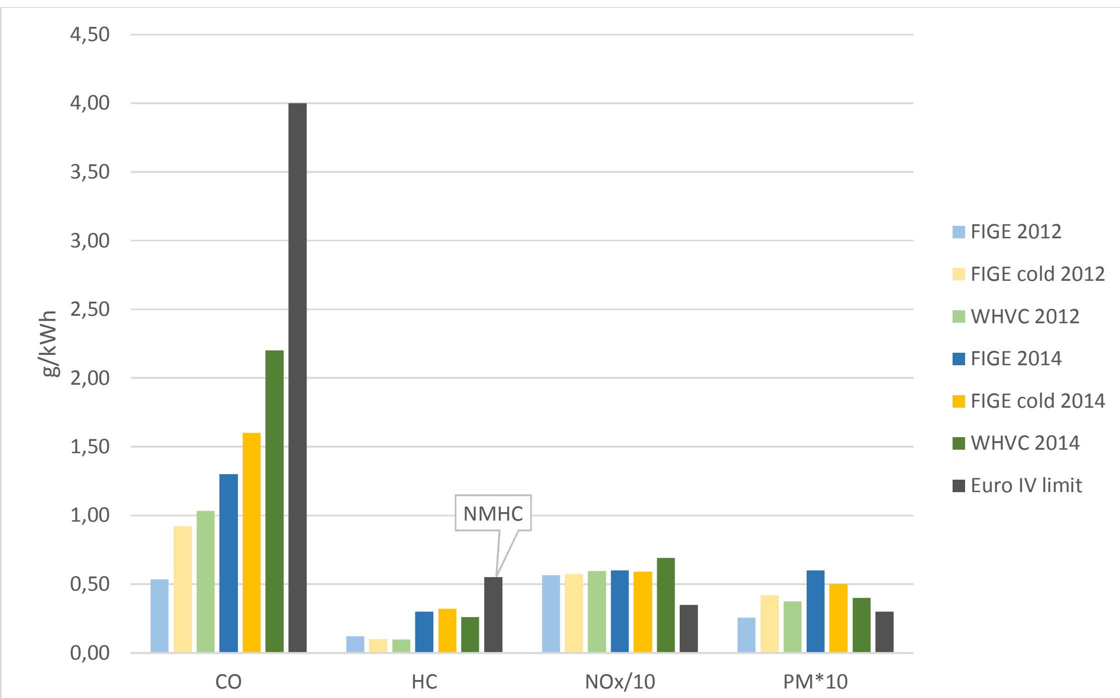

Figure 79 Comparison of emission performance between year 2012 and 2014

Comments/Conclusions

The results from the emissions testing show that the Euro IV applicable emissions limits of NO_x and PM were exceeded. A large deviation in energy consumption between the tests on the chassis dynamometer and the on-road tests could be observed. This might be explained by that different methods to measure work were applied and by differences in operational conditions. Poor accuracy of the ECU signal could also be a part of the explanation of the large differences in energy consumption. No malfunction was indicated by the OBD system. The Euro VI PN limits were exceeded by about 200 times. All regulated emissions increased significantly between 2012 and 2014.

Vehicle F

Test vehicle F was a distribution truck of emission standard Euro IV, equipped with SCR. The test fuel used during the tests was commercially available Environmental class 1 diesel (MK1). The vehicle has been tested both on chassis dynamometer and on road.

Presentation of vehicle:

Model year:	*2007*
Vehicle category:	*N3*
Vehicle type:	*Rigid*
Mileage:	*334 305 km*
Engine:	*CI, 6-cylinder*
Displacement:	*9.365 litres*
Fuel:	*Diesel*
Power:	*226 kW*
Exhaust after treatment:	*SCR*
Transmission:	*manual*
Gross Vehicle Mass (GVM)*:	*26 000 kg*
Mass in running order:	*11 520 kg*
Maximum payload:	*13 480 kg*
Emission standard:	*Euro IV*

(* = *technically permissible maximum laden mass of the vehicle)*

Test program

The on-road testing was performed on the 7th and 8th of May 2014. Tests on the chassis dynamometer were performed on the 14th and 15th of May 2014.

Table 11 Test program.

Test	Cold start	Hot start	Inertia/Vehicle payload
Fige	–	2	18 998 kg
WHVC	1	2	18 998 kg
PEMS EuroVI route2	–	2	6000 kg

Inertia is simulated inertia by the chassis dynamometer. The vehicle payload is reproduced by loading the vehicle with large concrete blocks.

The vehicle payload made about 45% of the maximum payload. The simulated vehicle payload during the tests on the chassis dynamometer made about 55% of the maximum payload.

Test results

The results presented in Figure 80 to Figure 94 were recorded over the whole PEMS route or test cycle. In cases where the test-cycles/routes were repeated the results are presented as average values.

The CO emissions (Figure 80, Figure 81) showed a large variation between the different test cycles. The Fige hot start cycle, as well as the on-road tests, resulted in CO emissions well below the Euro IV emission limits. The WHVC cycles on the other hand, exceeded the Euro IV standard for CO.

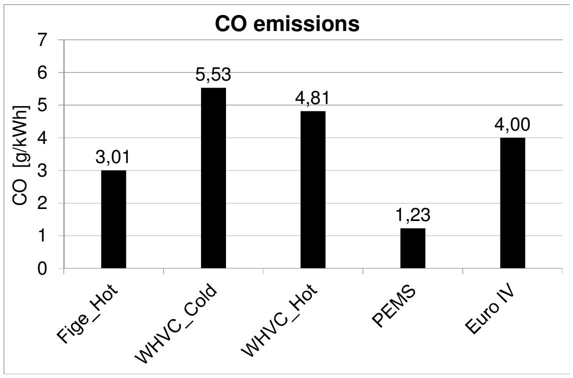

Figure 80 Brake specific CO emissions.

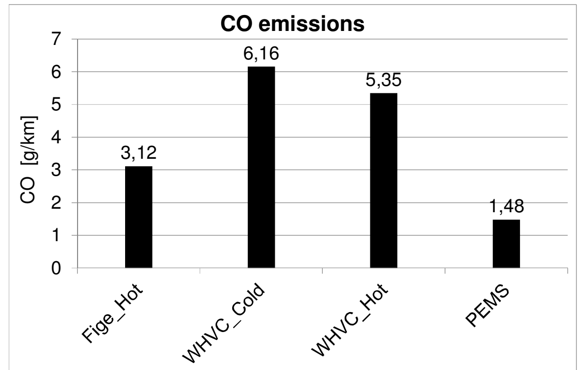

Figure 81 Distance specific CO emissions

The hydrocarbon emission limit of the Euro IV standard excludes methane. In this study the total hydrocarbon emissions (THC) were measured. Since the vehicle under study was equipped with a diesel fuelled engine, methane emissions were expected to be insignificant. As can be seen in Figure 82 the emissions of THC from all tests were well below the Euro IV NMHC emission limit.

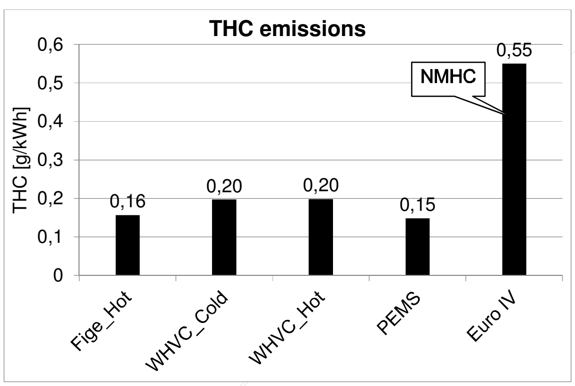

Figure 82 Brake specific THC emissions.

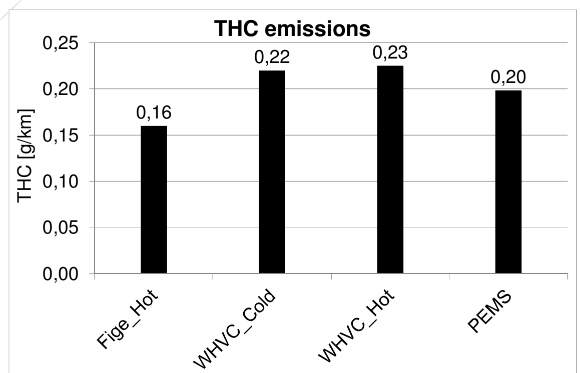

Figure 83 Distance specific THC emissions

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During all test, the NO_x emissions were very high (Figure 84, Figure 85) and the Euro IV emission limit were generally exceeded by a factor of two. At the same time extremely high PM emissions could be observed while the soot stayed low. This indicated that the high NO_x could have been caused by a malfunctioning urea injection control system. Incorrect urea injections may have led to an extensive urea and/or NH_3 slip causing extremely high PM levels (*c.f.* Figure 86, Figure 87) and poor NO_x reduction. Moreover, the PM collected on the TX40 filter had an unusual bluish shimmering tone. PN levels exceeded the Euro VI applicable PN limit by a factor of around 100 (*c.f.* Figure 88).

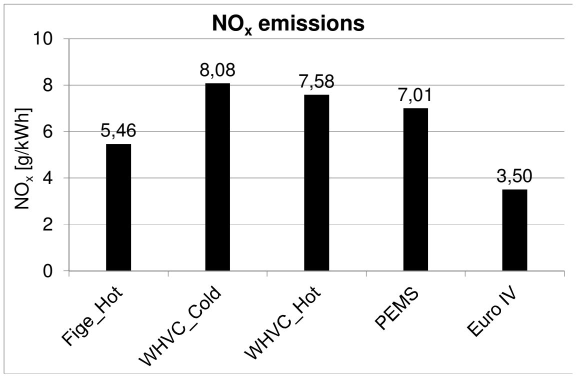

Figure 84 Brake specific NOx emissions.

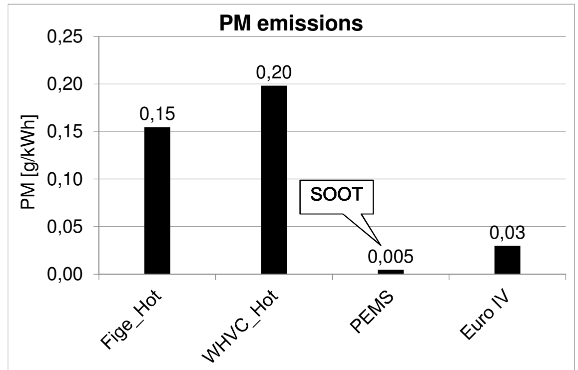

Figure 86 Brake specific PM emissio

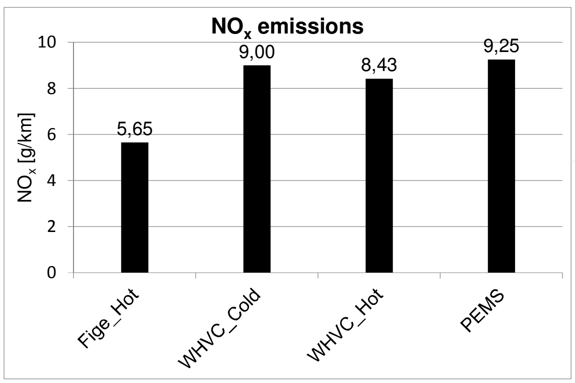

Figure 85 Distance specific NOx emissions

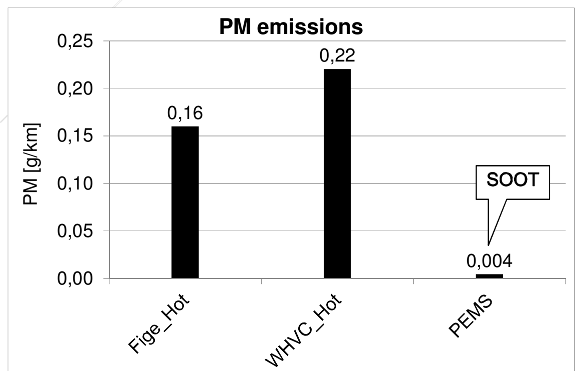

Figure 87 Distance specific PM emissions.

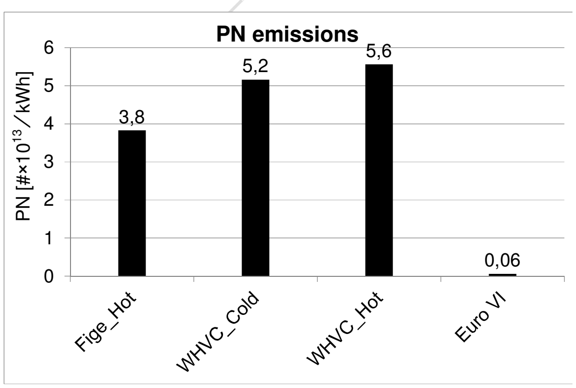

Figure 88 Brake specific PN emissions.

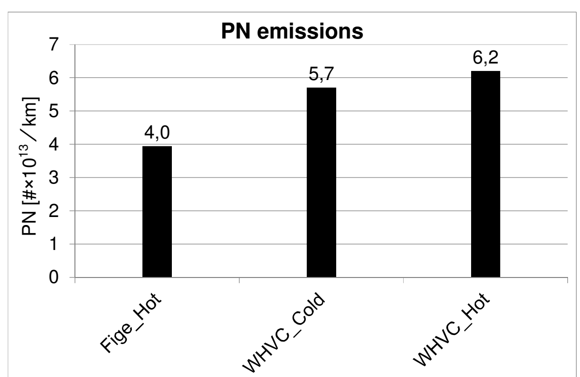

Figure 89 Distance specific PN emissions

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The CO_2 emissions and fuel consumption followed the same trend. The results from the Fige- and the on-road tests agreed well. The results of the CO_2 and fuel consumption measurements of the on-road tests and Fige cycle stayed at level of about 20 % lower than the WHVC tests.

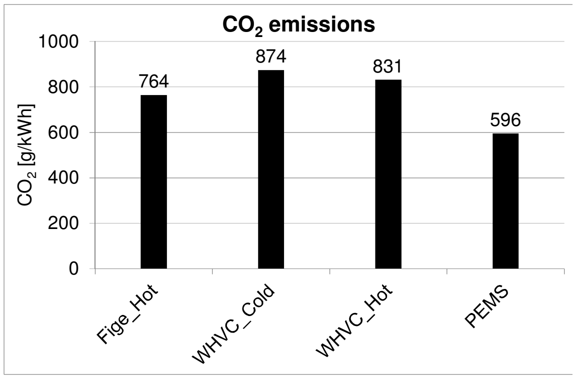

Figure 90 Brake specific CO2 emissions.

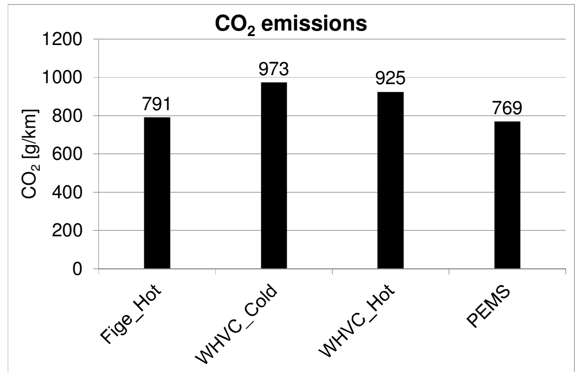

Figure 91 Distance specific CO2 emissions.

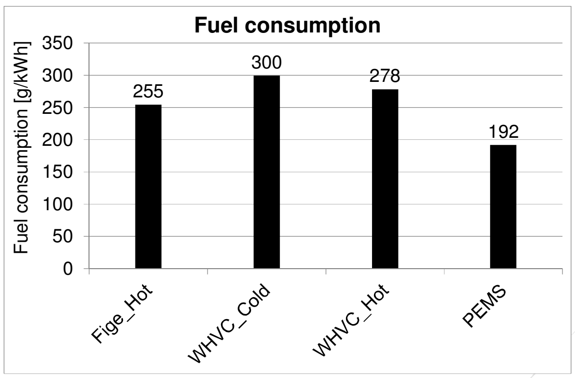

Figure 92 Brake specific fuel consumption.

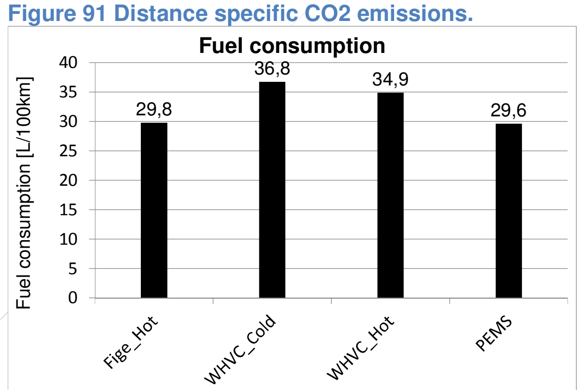

Figure 93 Distance specific fuel consumption

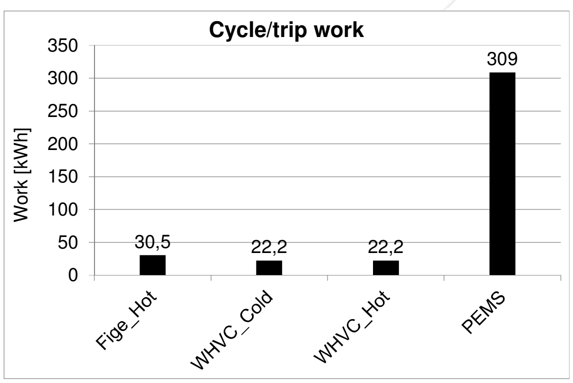

Figure 94 Cycle work

During the two on-road tests the average temperatures of the ambient air differed by 1.6°C. The average relative humidity differed by 30 percentage points, but still, the exhaust temperatures agreed fairly well (Figure 95). The tailpipe exhaust temperature remained at temperatures between 200 and 280°C. However, despite the relatively high tailpipe temperatures the SCR system did not seem to reach light off. As can be seen in Figure 95 the accumulation rate of NO_x rather increases with increased temperature than showing any signs of improvement of the NO_x conversion efficiency.

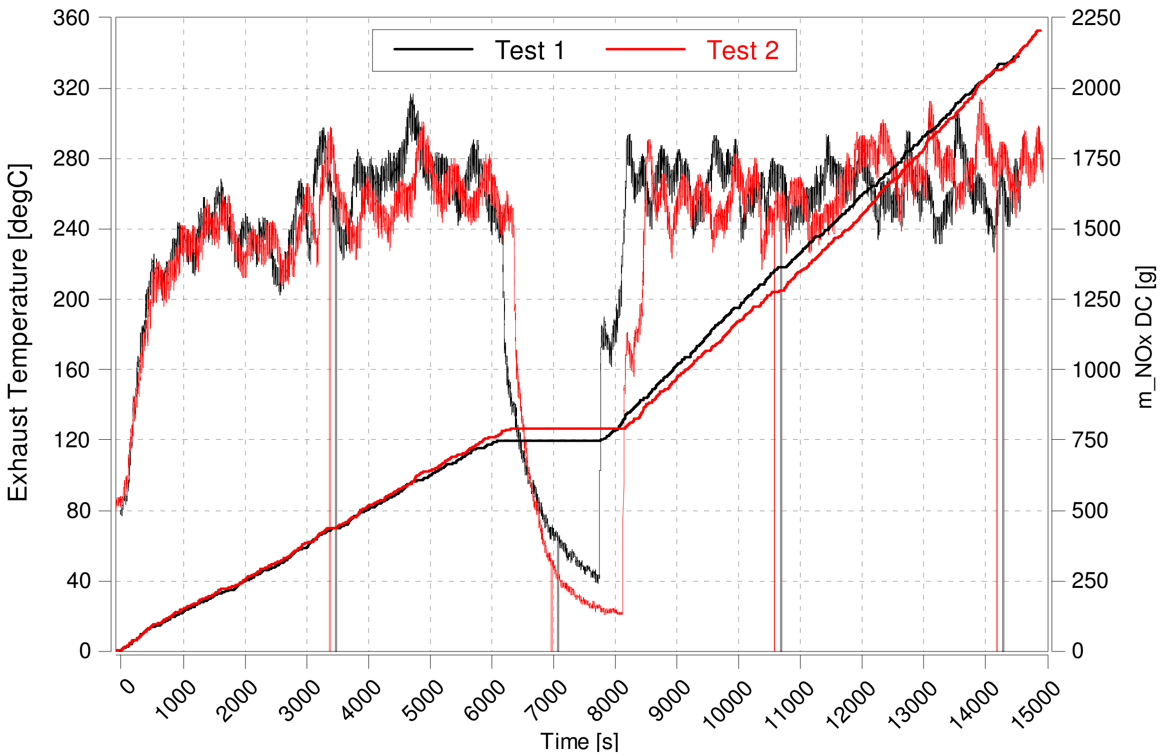

Figure 95 Tailpipe exhaust temperature and accumulated NOx during test 1 and 2 on the Euro VI route2.

Emission performance over time

Emissions of CO and THC increased significantly between 2012 and 2014. CO increased by approximately 45% on average passing the Euro IV CO emission limit in the FIGE test cycle but was above 4 g/kWh in the WHVC. THC increased by more than 80% on average but was still far below the limit. NOx decreased slightly between 2012 and 2014 but was still above the Euro IV limit.

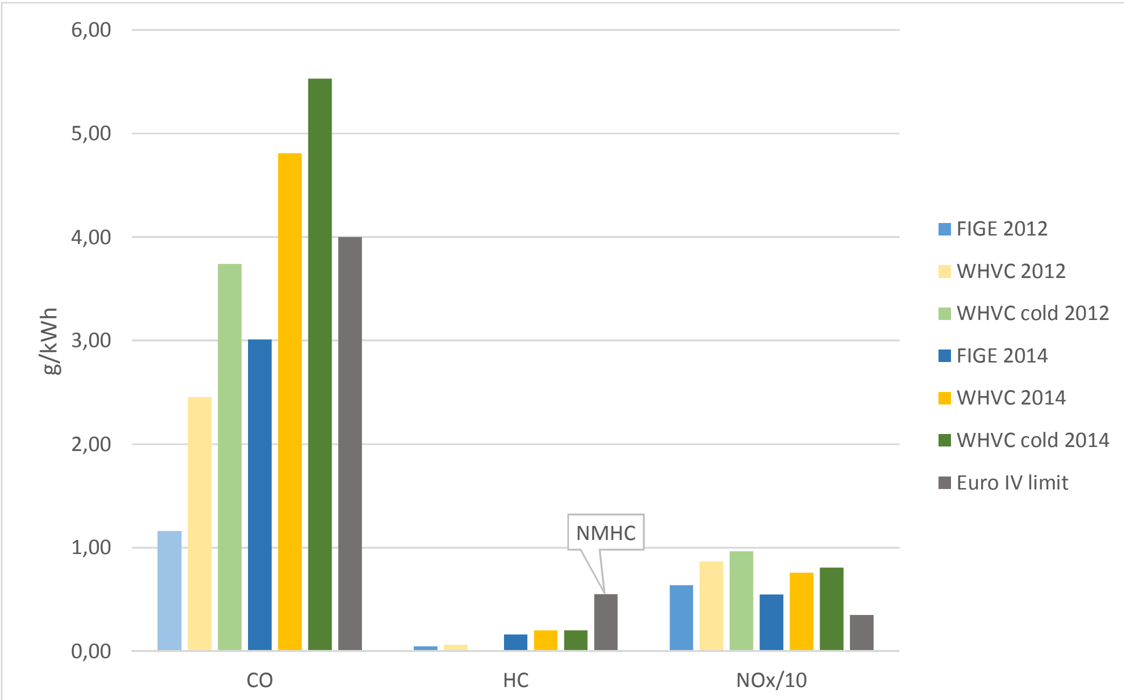

Figure 96 Comparison of emission performance between year 2012 and 2014

Comments/Conclusions

The results from the emissions testing show that the Euro IV applicable emissions limits of NO_x and PM were exceeded by a factor of two and 57, respectively. The NOx emissions appeared to be insensitive to the exhaust temperature which indicates a malfunctioning exhaust after treatment system. Moreover, the extremely high PM emissions could be a result of NH3/urea slip due to incorrect urea dosing. The PM filter sampling showed a bluish shimmering tone which may be an indication of that a considerable amount of the PM sample comprise NH3 and/or urea. The Euro VI PN limits were exceeded by about 100 times. No malfunction was indicated by the OBD system.

Emissions of CO and THC increased significantly between 2012 and 2014. NOx decreased slightly but remained above the Euro IV emission limit.

Vehicle G

Vehicle G was a truck which was tested on road as well as on chassis dynamometer. The vehicle was of euro standard VI, equipped with a DOC, DPF and SCR and the fuel used during the tests was Mk1 diesel.

Presentation of vehicle:

Model year:	*2014*
Vehicle category:	*N3*
Vehicle type:	*Rigid*
Mileage:	*≈ 150 km*
Engine:	*CI, 6-cylinder*
Displacement:	*10,837 litres*
Fuel:	*Diesel*
Power:	*271 kW*
Exhaust after treatment:	*DOC/SCR/DPF*
Transmission:	*manual*
Gross Vehicle Mass (GVM)*:	*28 000 kg*
Mass in running order:	*12 165 kg*
Maximum payload:	*15 835 kg*
Emission standard:	*Euro VI*

(* = *technically permissible maximum laden mass of the vehicle)*

Test program

The on-road testing was performed between the 3rd and 9th of October 2014. Tests on the chassis dynamometer were performed between 25th and 29th of October 2014.

Table 12 Test program.

Test	Cold start	Hot start	Vehicle payload
Fige	-	1	6833 kg*
WHVC	1	2	6833 kg*
PEMS EuroVI route2	1	3	7000 kg

The vehicle payload was achieved by loading the vehicle with large concrete blocks during on-road tests.
(Vehicle payload = Inertia simulated by the CD – Mass in running order)*

The vehicle payload, during the on-road tests using PEMS, made 43% of the maximum payload. The simulated vehicle payload during the tests on the chassis dynamometer (CD) made 44% of the maximum payload. According to UNECE R49 the vehicle payload shall be 50 - 60 per cent of the maximum vehicle payload. Unfortunately it was not possible mount an adequate amount of concrete blocks safely on the vehicle to meet the requirements of UNECE R49.

Test results

The results presented in Figure 98 to Figure 14 were recorded over the whole PEMS route or test cycle. In cases where the test-cycles/routes were repeated the results are presented as average values.

The CO emissions (Figure 97, Figure 98) were generally very low and significantly below the Euro VI emission limits. CO emissions could not be quantified safely during the PEMS measurements because of the low emission level.

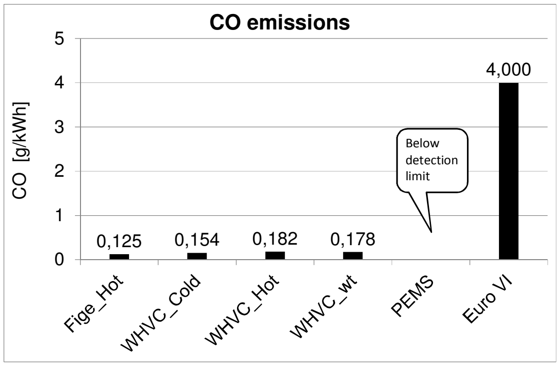

Figure 97 Brake specific CO emissions.

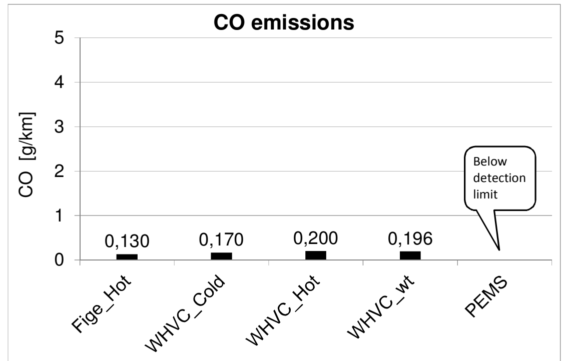

Figure 98 Distance specific CO emissions

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Figure 6a shows that the emissions of THC from all tests were well below the Euro VI THC emission limit. The THC emissions during the tests on chassis dynamometer were extremely low and could not be detected.

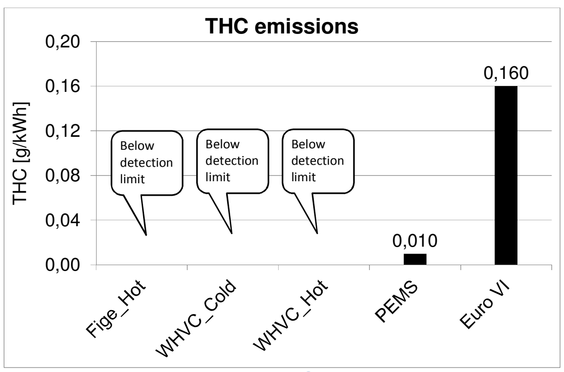

Figure 99 Brake specific THC emissions.

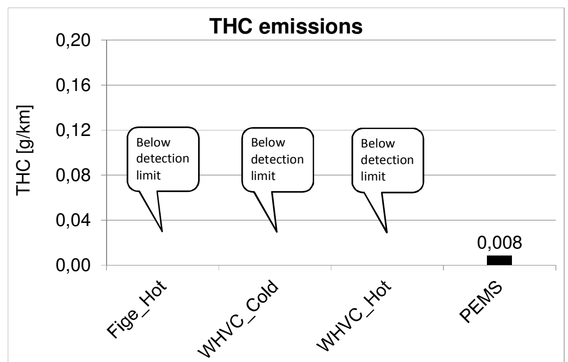

Figure 100 Distance specific THC emissions

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The NO_x emissions complied with the requirements of Euro VI (Figure 101, Figure 102). The weighted results (wt) of the WHVC (0.86×Hot start + 0.14×Cold start) were far below the Euro VI limit while the average of the PEMS measurements were a bit closer to the emission limit. The PEMS testing was performed under different operational conditions and evaluated according to the ISC regulation or as whole tests. The difference between results of the chassis dynamometer tests and real world test could partly be explained by differences in driving pattern and ambient conditions (*eg.* wind chill on after treatment system).

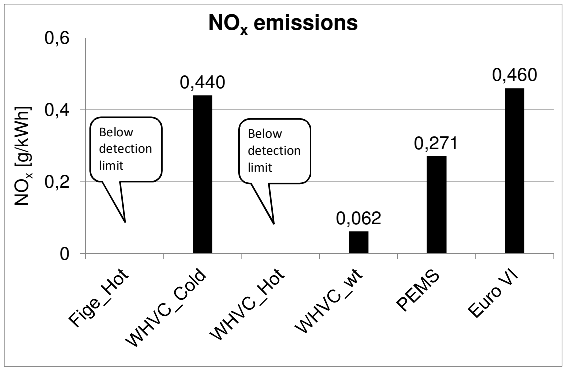

Figure 101 Brake specific NOx emissions.

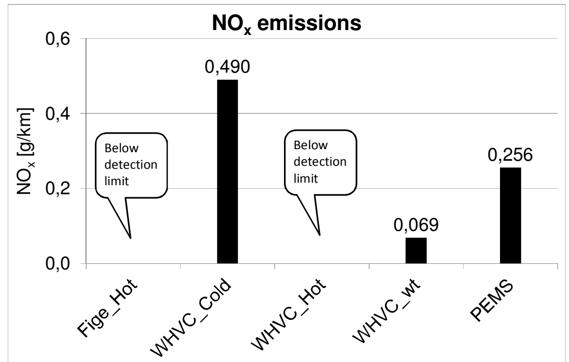

Figure 102 Distance specific NOx emissions

The object under study was equipped with a DPF and hence, the PN and PM emissions were very low, roughly one fifth of the applicable limits of Euro VI (*c.f.* Figure 103, Figure 104 and Figure 105, Figure 106).

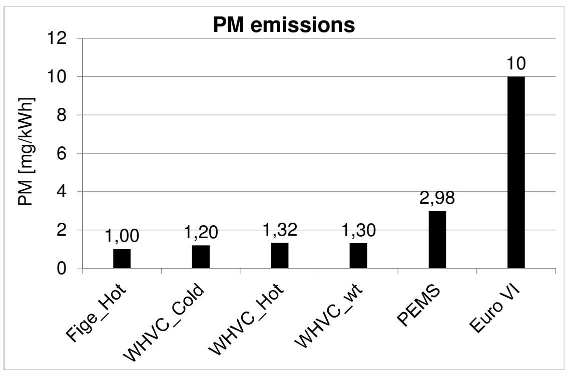

Figure 103 Brake specific PM emissions.

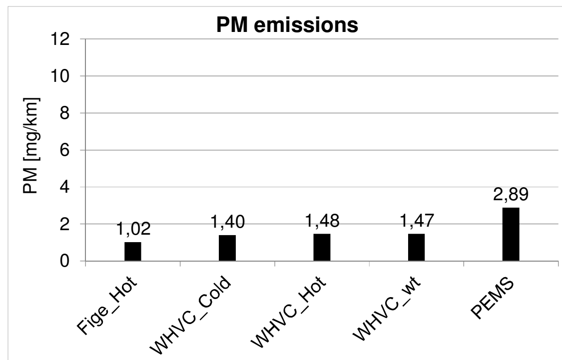

Figure 104 Distance specific PM emissions

The emissions of PN during WHVC cold starts were about two times higher than during the WHVC hot starts (*c.f.* Figure 105, Figure 106).

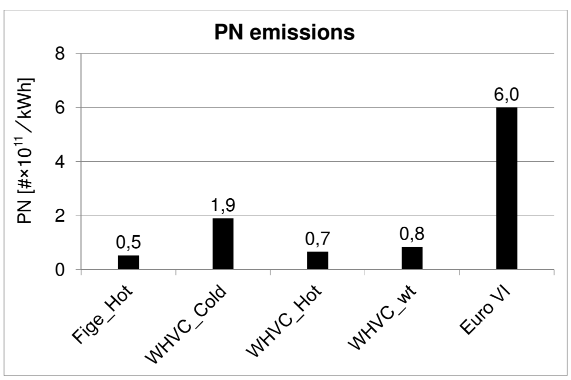

Figure 105 Brake specific PN emissions.

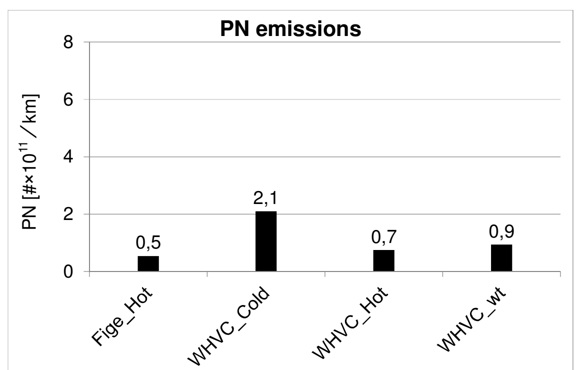

Figure 106 Distance specific PN emissions

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Considering brake specific CO_2 emissions, good agreement between PEMS on-road tests and the WHVC weighted test (WHVC_wt) could be observed (Figure 107, Figure 108). The Fige hot start was about 12 % lower in brake specific CO_2 emissions and the WHVC cold start about 6 % higher, than the WHVC_wt and PEMS. However, the distance specific CO_2 emissions measured during WHVC testing on the chassis dynamometer generally exceeded the PEMS results by more than 20 %. Fige hot start and PEMS showed virtually the same distance specific results.

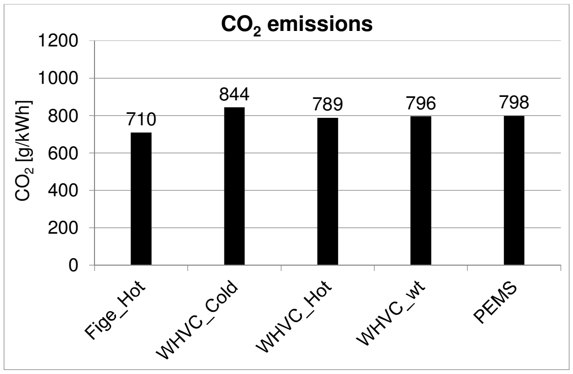

Figure 107 Brake specific CO2 emissions.

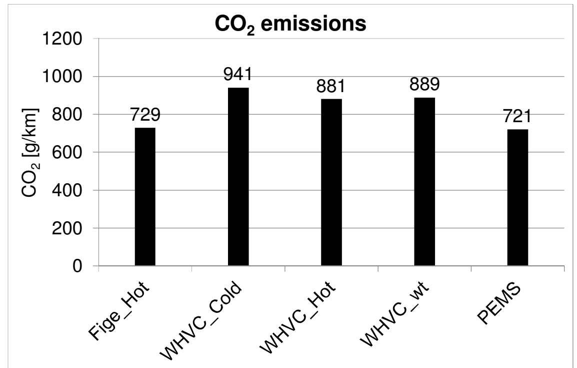

Figure 108 Distance specific CO2 emissions

Fuel consumption (Figure 109, Figure 110) and CO_2 emissions showed the same pattern but the difference between the various tests performed was bigger for fuel consumption.

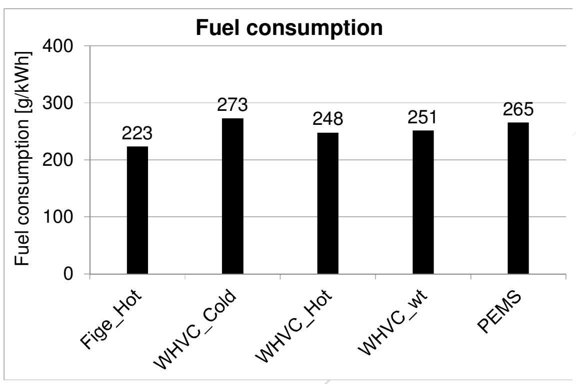

Figure 109 Brake specific fuel consumption

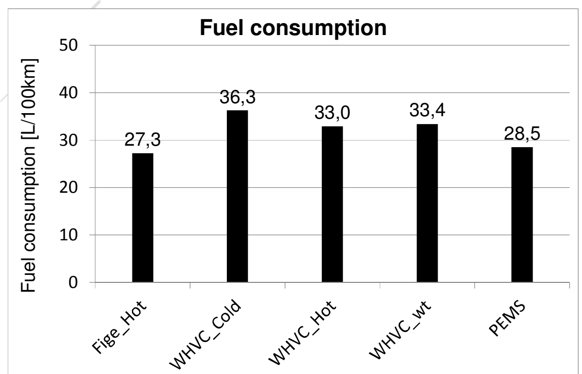

Figure 110 Distance specific fuel consumption

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The different chassis dynamometer test cycles and the on-road test routes all have different characteristics considering vehicle speed causing differences in emissions and fuel consumption. Furthermore, the difference in distance specific results between the chassis dynamometer and the on-road tests could be explained by the fact that the Fige and WHVC is based on simulation of driving on a flat road and no wind while the on-road tests were performed up- and downhill in windy conditions. This will affect the operational conditions of the engine causing different results, in particular for the distance specific results but also for the brake specific results. The results of energy consumption measurements (Figure 111) indicates that real driving is more energy efficient than driving according to test cycles on the chassis dynamometer. Moreover, the energy measurement on the chassis dynamometer is based on the force exerted by the wheels on the rolls, while the PEMS calculates the energy produced at the crank axle. This implicates that energy consumption measurement by PEMS excludes energy losses due to friction in the transmission and tires. By normalizing the calculations for energy losses the difference in energy consumption between PEMS and CD would increase.

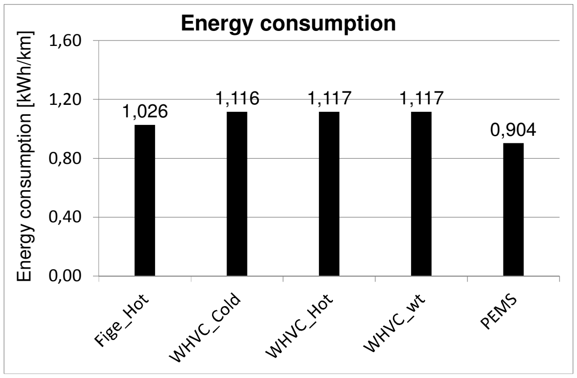

Figure 111 Energy consumption

Ammonia (NH_3) concentrations were measured with Fourier Transform Infra-Red Spectroscopy during the tests on the chassis dynamometer. The average concentrations were all clearly below the applicable limit of Euro VI (10 ppm), *cf.* Figure 112.

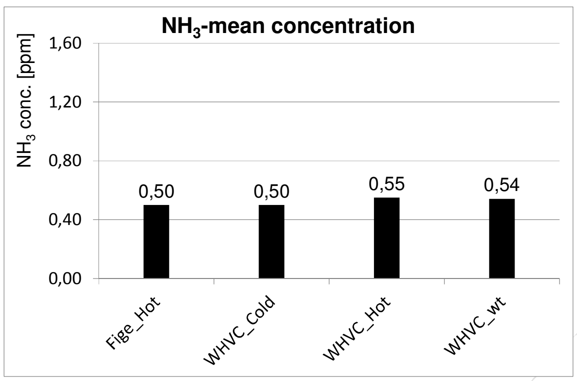

Figure 112 NH_3 test cycle mean concentration in exhaust gas.

PEMS results in detail

PEMS testing was performed on the Euro VI route2. Tests were performed by “normal” In Service Conformity” (ISC) procedures, unladen, cold start and test with a segment of DPF regeneration. None of the tests showed any CO emissions above the detection limit.

Two hot start tests (Hot start_1, Hot start_2) at different start tailpipe exhaust temp were performed, both in agreement with UNECE R49. The start tailpipe temp was about 90°C during Hot start_1 and 145°C during Hot start_2. To demonstrate the effect of load on the emissions a hot start test where the vehicle was unloaded (Hot start, unl.) was carried out. The test programme also comprised a Cold start test including an event where the DPF was regenerated actively (Cold start, reg. and Cold start, reg. wh.t).

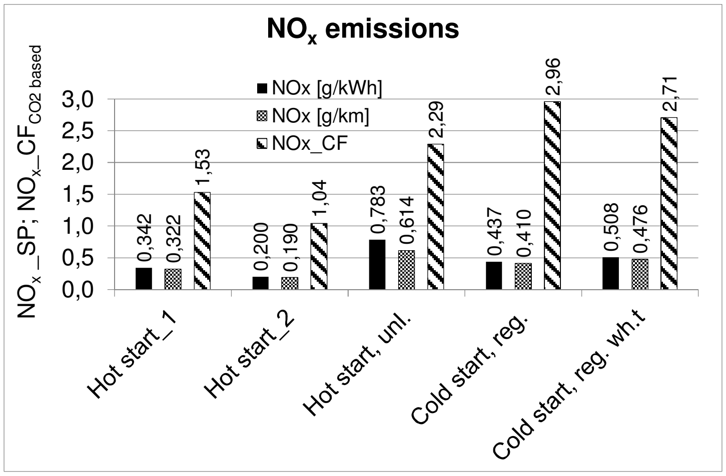

Figure 113 Real world NOx emissions.

The impact on start exhaust temperature on NO_X emissions is relatively strong as can be seen by comparing Hot start_1 and Hot start_2. This implies that the preconditioning procedure of the vehicle is of great importance to obtain high repeatability between tests. Higher start exhaust temperatures means that the light off temperature of the exhaust after treatment system will be reached earlier and with that, lower emissions. The load is also of great importance to the emissions of NO_X. In Figure 113 it is shown that Hot start, unl. generated significantly more NO_X than Hot start_1 and Hot start_2. A likely explanation to this is that higher load leads to a higher power demand and consequently increased exhaust temperatures and thereby lower emissions. Cold start, reg. gives an indication of that regeneration of the DPF has a “negative” effect on the NO_X emissions. The Conformity Factor (CF) of NO_X for Hot start_1 just exceeded the legal requirement of 1.50 by 0.03 units and Hot start_2 was undoubtedly below the requirements. The other tests which were not following the European ISC test procedure exceeded the legal limit of 1.5 by far.

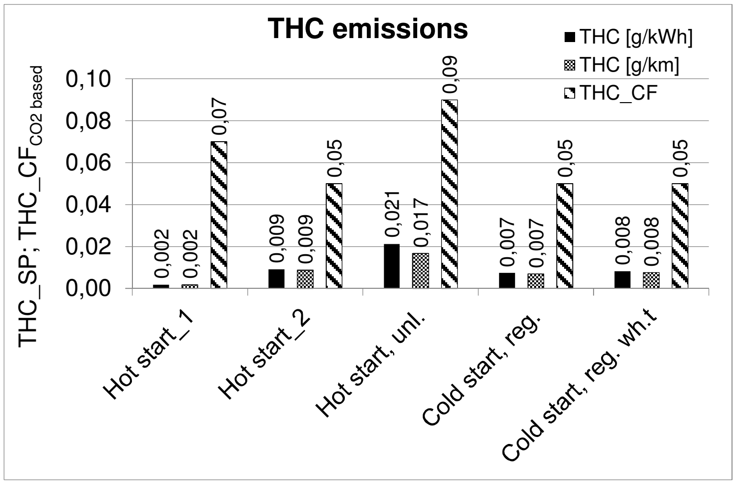

Figure 114 Real world THC emissions.

The THC emissions were generally very low with CFs far below the legal requirements of 1.5.

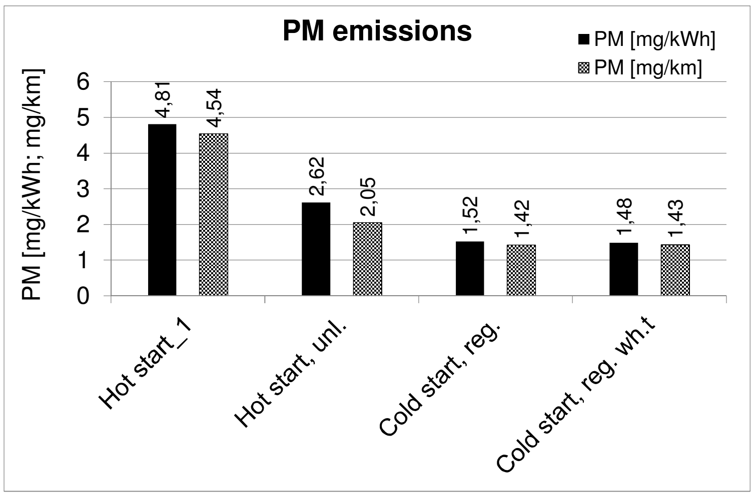

Figure 115 Real world PM emissions.

PM measurements of the hot starts were performed using a Proportional Dilution System (PDS) while the Cold start, reg was performed using a Constant Dilution System (CDS). The PDS approach for PM measurement is of the same type as described in UNECE R49 meant for engine test beds. The result of the PDS PM-filter measurement is not only used to determine the overall test PM emissions but also used to determine a scaling factor between PM and Soot. The scaling factor is applied to the signal of a real time Soot sensor to estimate a real time PM signal used for determination of CF according to ISC of UNECE R49. In contrast, the CDS uses the PM sample only for determination of the scaling factor between PM and Soot. Hence, the CDS only produces PM results based on a scaled soot signal. In Figure 115 it is shown that PM emissions of the hot start test is higher than the cold start test. The big difference between the cold start test and hot starts in Figure 115 could partly be explained by that the Soot to PM scaling factors were very high, ranging between 6 and 53. This means that the correlation between Soot- and PM emissions, which, if it exists at all, is extremely weak. Under these circumstances the PM emissions measured by the CDS, which relies on the scaled soot signal, could not be considered reliable.

Comments/Conclusions

The vehicle met all the European applicable emission limits during the test, both during real world driving and on the chassis dynamometer. CD tests report higher energy consumption than PEMS by about 24%. The main reason for this is that the net work done by the entire powertrain is measured by the CD while PEMS calculates the work performed by the crank axel (*i.e* losses in the transmission and driveline are not included). However, differences in driving conditions also impact on the energy consumption. The PEMS PM cold start emissions were much lower than the hot start emissions. A plausible explanation to this result is that the soot to PM scaling factors were very high, between 6 and 53, indicating poor correlation between soot and PM. Therefore, since the PM cold start emissions of the PEMS test were calculated indirectly by using the soot sensor signal as tracer (*i.e.* CDS), dislike the hot starts, these results should be treated with skepticism. However, the use of the soot sensor as a tracer for PM is compliant with US regulation title 40 CFR 1065.

No malfunction was indicated by the OBD system.

Vehicle H

Vehicle H was a N3 Euro VI truck, model year 2014. Testing was performed on a chassis dynamometer and on Swedish roads using a portable emissions measurement system (PEMS).
The vehicle, equipped with a DOC, EGR, SCR and a DPF after treatment system, was tested with the both environmental class 1 (MK1) as well as European EN 590 diesel qualities on chassis dynamometer and with MK1 during the on-road measurements. The vehicle was driven according to the WHVC test cycle on a chassis dynamometer. Regulated exhausts, CO2 as well as unregulated pollutants i.e. PAH and aldehydes were measured. Tests were carried out with both cold start as well as hot start engine.

Presentation of vehicle:

Model year:	2014
Vehicle category:	N3
Vehicle type:	Rigid truck
Mileage:	1500 km
Engine:	CI, 6-cylinder
Displacement:	7.7 litres
Fuel:	Diesel
Power:	175 kW
Exhaust after treatment:	EGR, DOC, SCR, DPF
Transmission:	automatic
Gross Vehicle Mass (GVM)*:	18 000 kg
Mass in running order:	9 502 kg
Maximum payload:	8 498 kg
Emission standard:	Euro VI

Test program

The on-road testing was performed between the 22^{d} and 28th of October 2014. Tests on the chassis dynamometer were performed between the 8th and 14th of October 2014.

Table 13 Test program. Inertia is simulated inertia by the chassis dynamometer. The vehicle payload is reproduced by loading the vehicle with large concrete blocks during on-road tests.

Test	Cold start	Hot start	Inertia [kg]	Vehicle Payload [kg]
FIGE	-	1	14 478	(~5000)
WHVC	2	3	14 478	(~5000)
PEMS Euro VI N3 route	2	2		5000

The diesel fuels used during chassisdynamometer testing in this study were according to the standards Swedish Environmental class 1 and European diesel standard EN590, hereafter called MK1 and MK3 respectively.

When the Swedish MK1 fuel was introduced the differences compared to the European MK3 were extensive, especially considering the sulphur level in the fuels but also regarding aromatic content. Today, the differences between the fuels are much smaller.
One remaining difference is the aromatic content, where the MK1 fuel has much stricter requirements. Aromatics increase the emissions of PAH, of which several are considered to be probable or possible carcinogen to human.

The cetane number indicates the ignition delay of the fuel. A higher value correlates with a shorter ignition delay time. Increased cetane number generally decreases the NOx emissions.

The MK1 has a lower density compared to MK3. This, in combination with distillation curve, reduces the high boiling components. The reduction of high boiling components reduces soot and heavy PAH emissions.

Test results

Chassis dynamometer test results.

Below are the results presented as mean values in bar charts diagram with standard deviations, Figure 116-125. The emissions of THC were in all tests below the detection limit and thus not reported. During one cold start WHVC the vehicle exhaust aftertreatment system starts a regeneration cycle for particulate. That test was considered to be a fail test. However, the results are presented as a comparison.

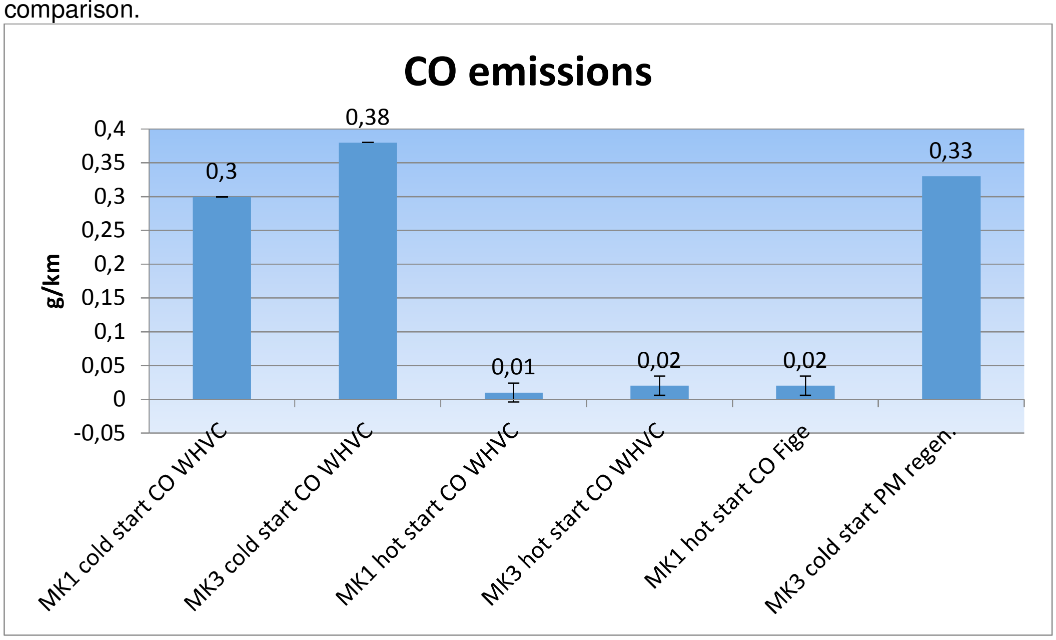

Figure 116 CO emissions g/km.

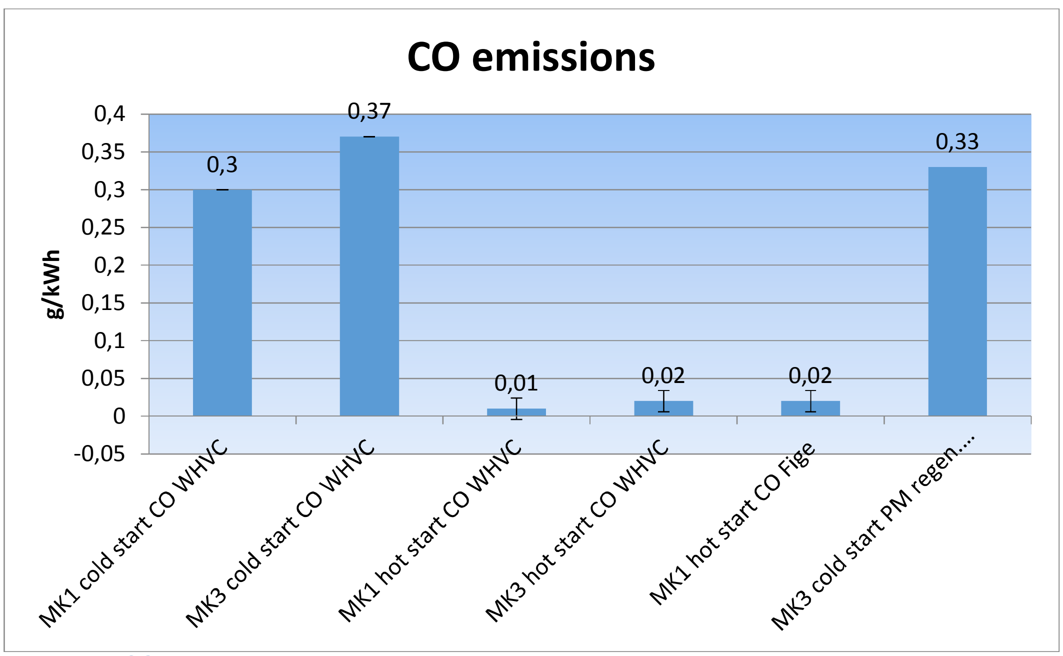

Figure 117 CO emissions g/kWh.

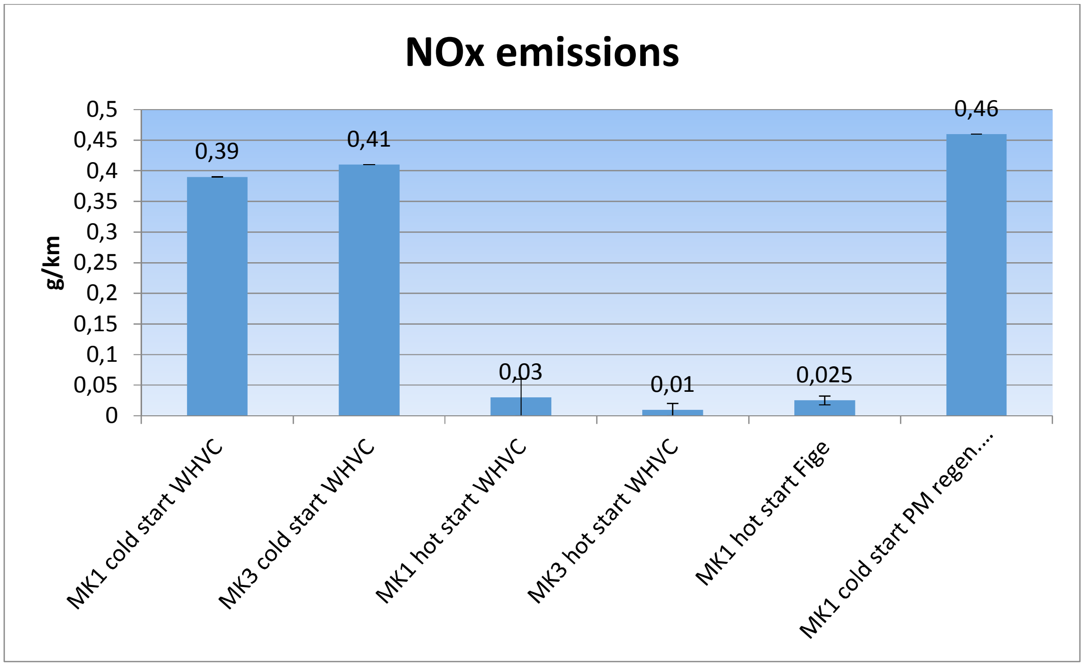

Figure 118 NOx emissions g/km.

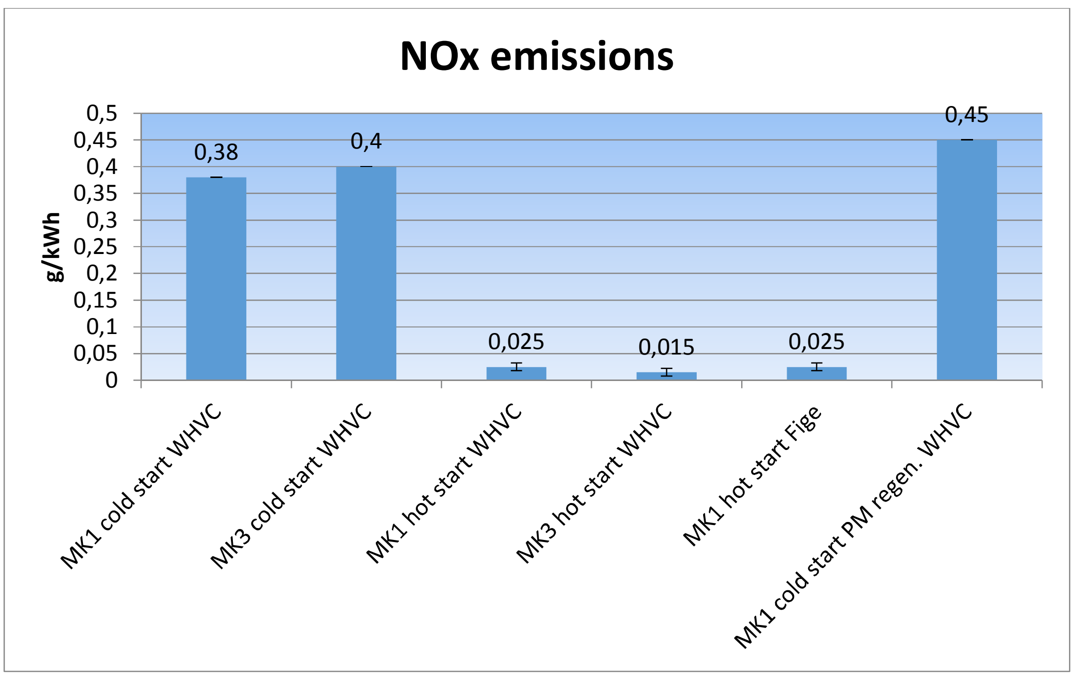

Figure 119 NOx emissions g/kWh.

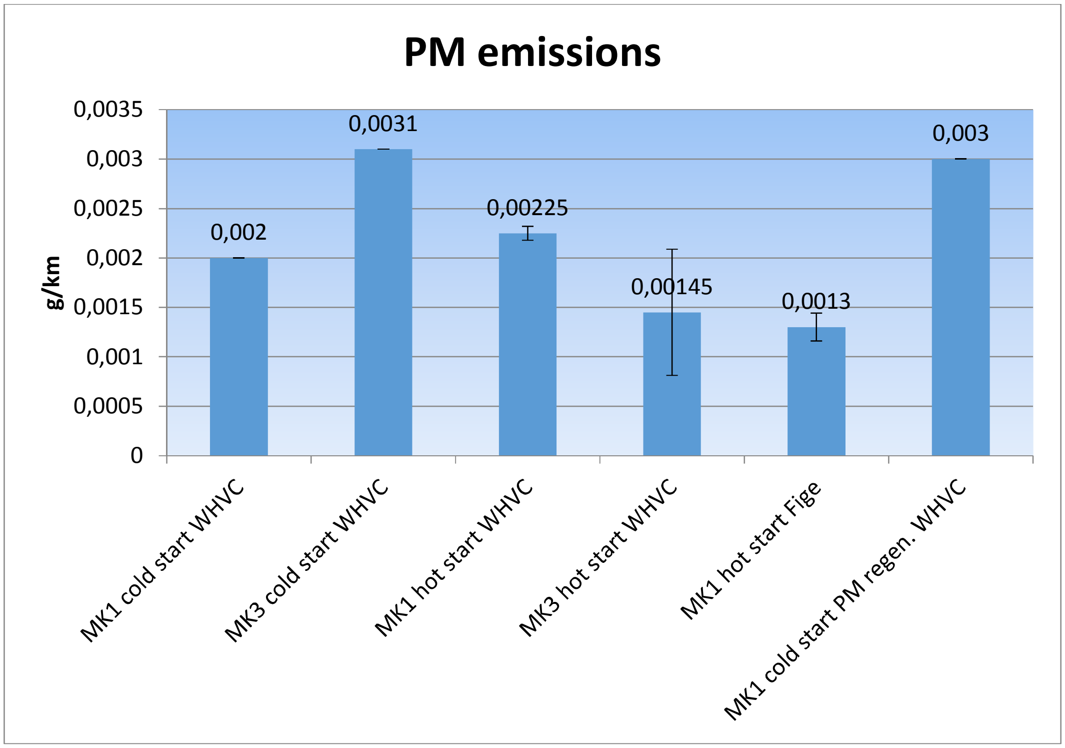

Figure 120 Particle mass emissions g/km.

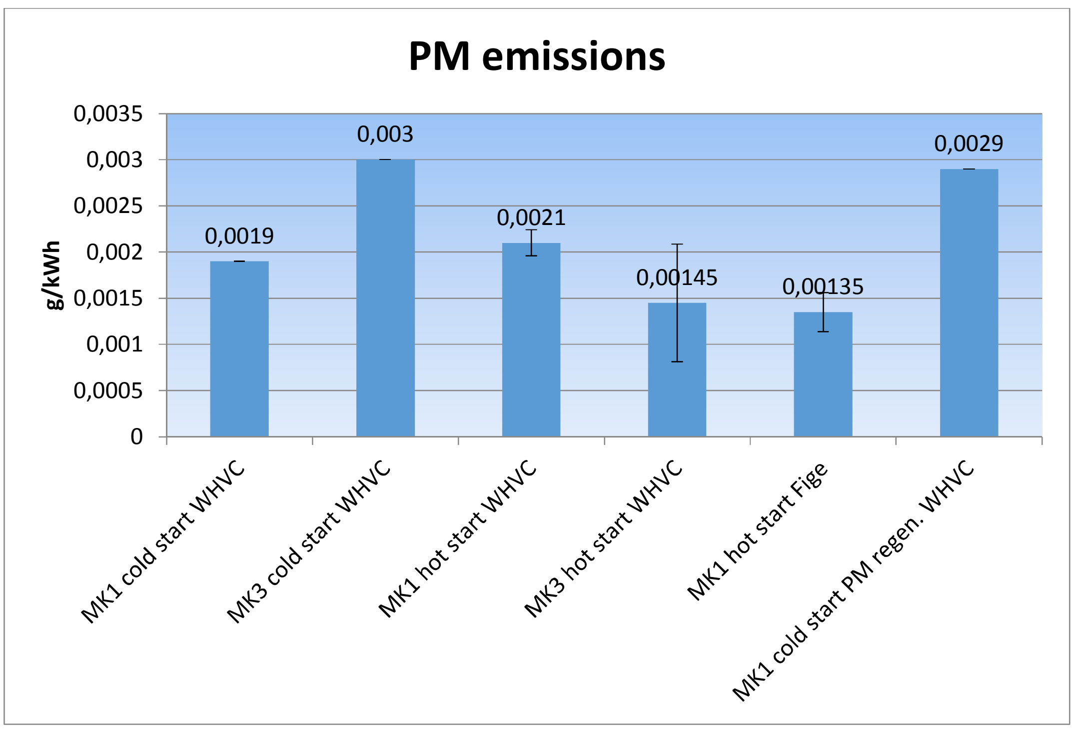

Figure 121 Particle mass emissions g/kWh.

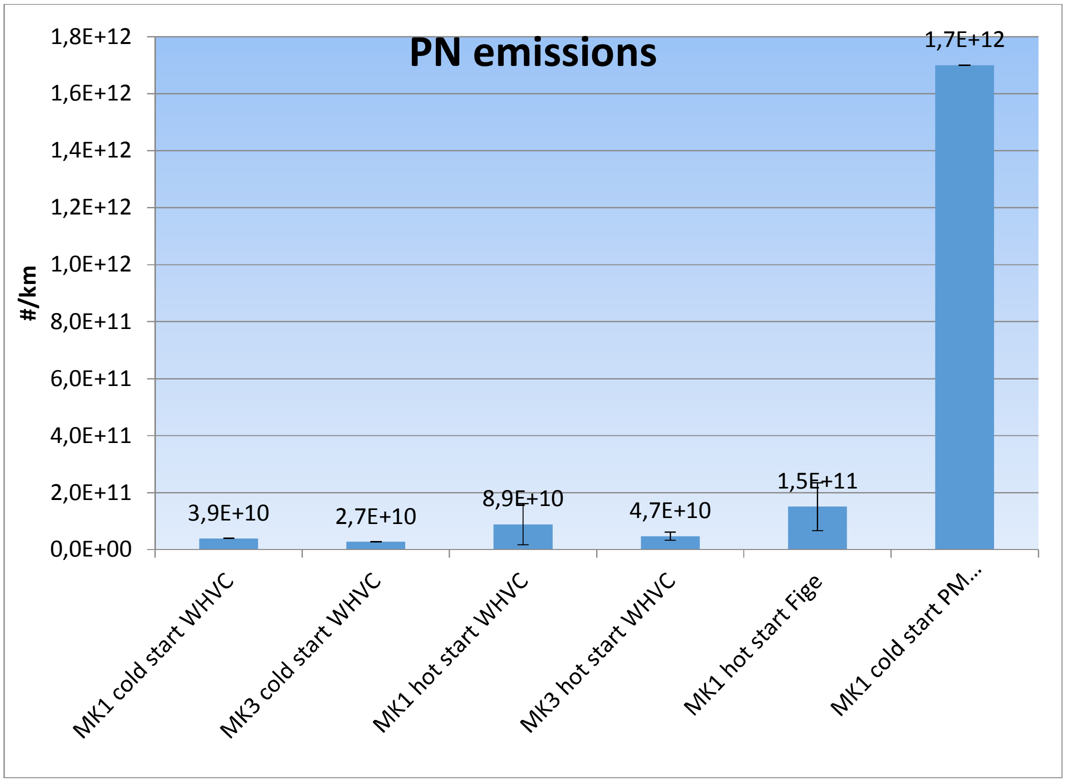

Figure 122 Particle number emissions g/km.

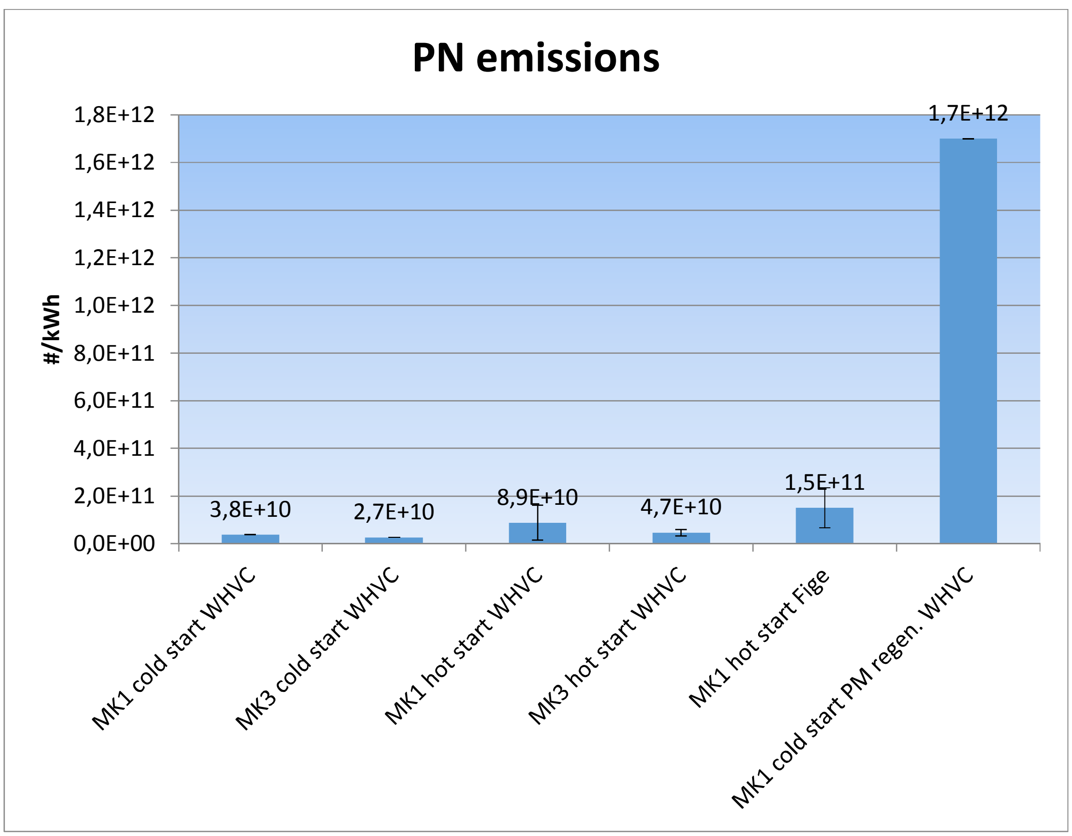

Figure 123 Particle number emissions g/kWh.

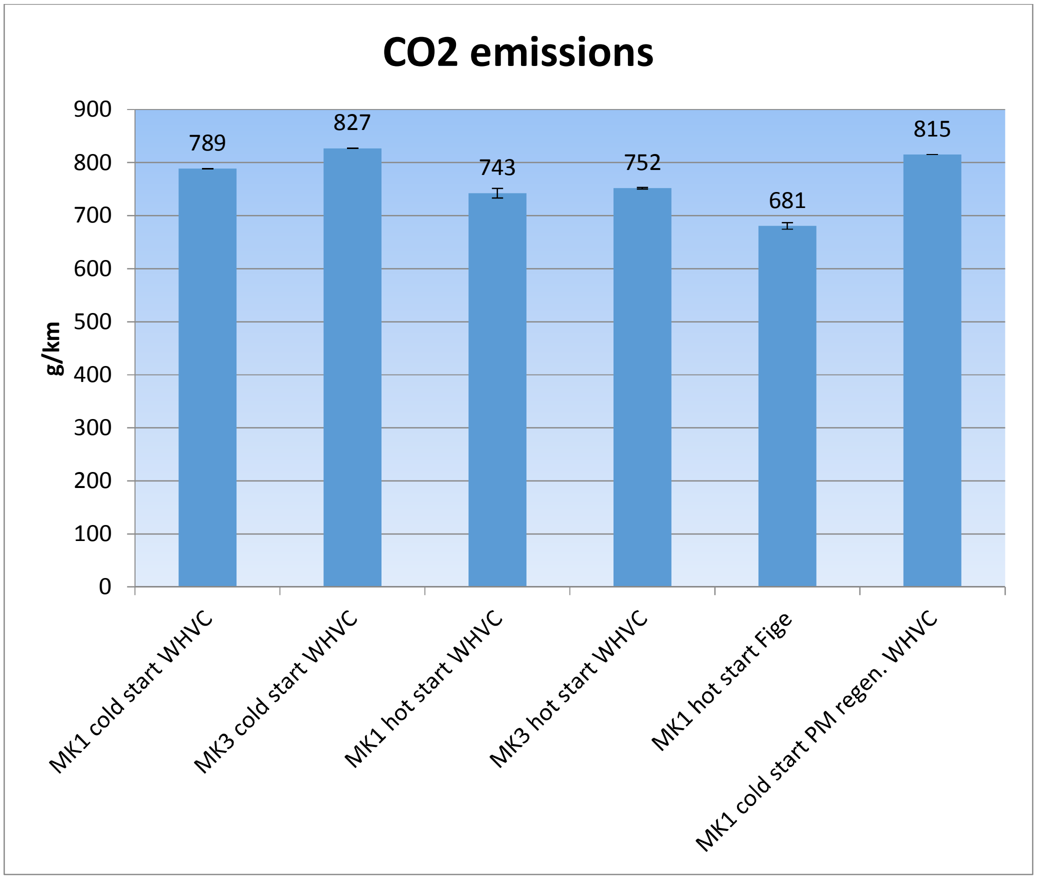

Figure 124 CO2 emissions g/km.

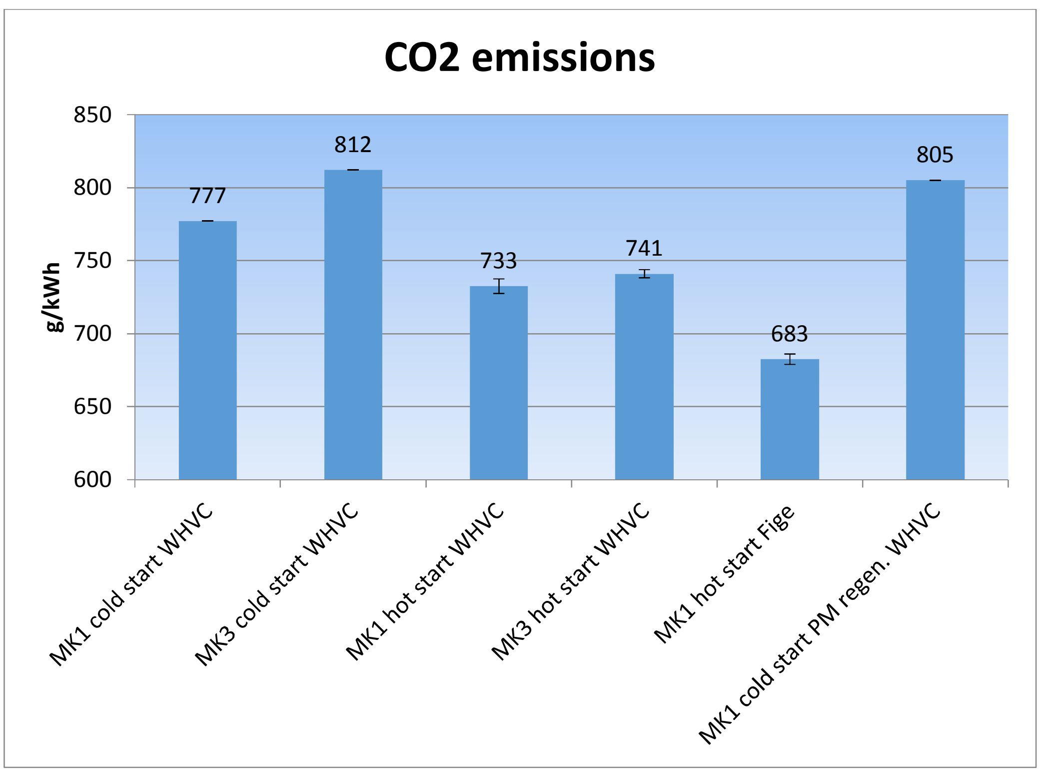

Figure 125 CO2 emissions g/kWh.

All of the measured regulated emission components were significantly higher when using the MK3 fuel compared with the MK1 fuel during cold start testing except the PN emissions. No significant differences could be detected during the hot start tests.
The unregulated emission results are presented as bar charts in Figure 126-129. Unregulated emissions were only measured during VHVC hot and cold start.

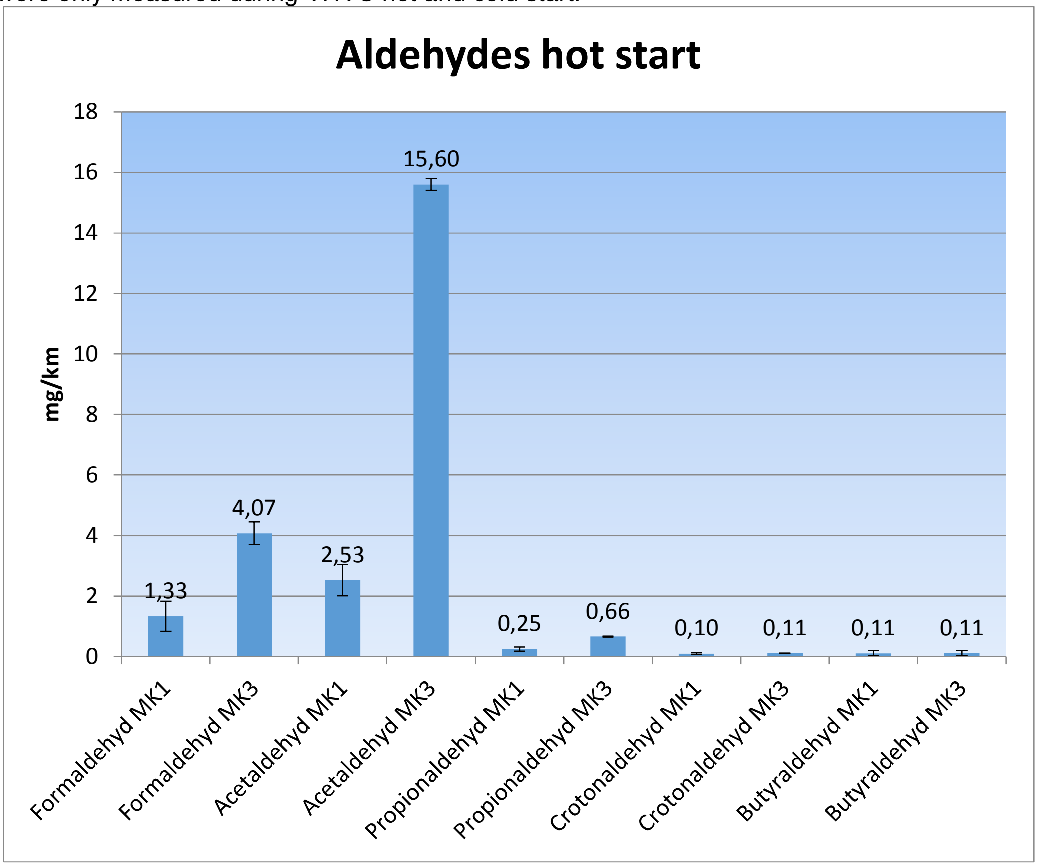

Figure 126 Aldehyde emissions g/km.

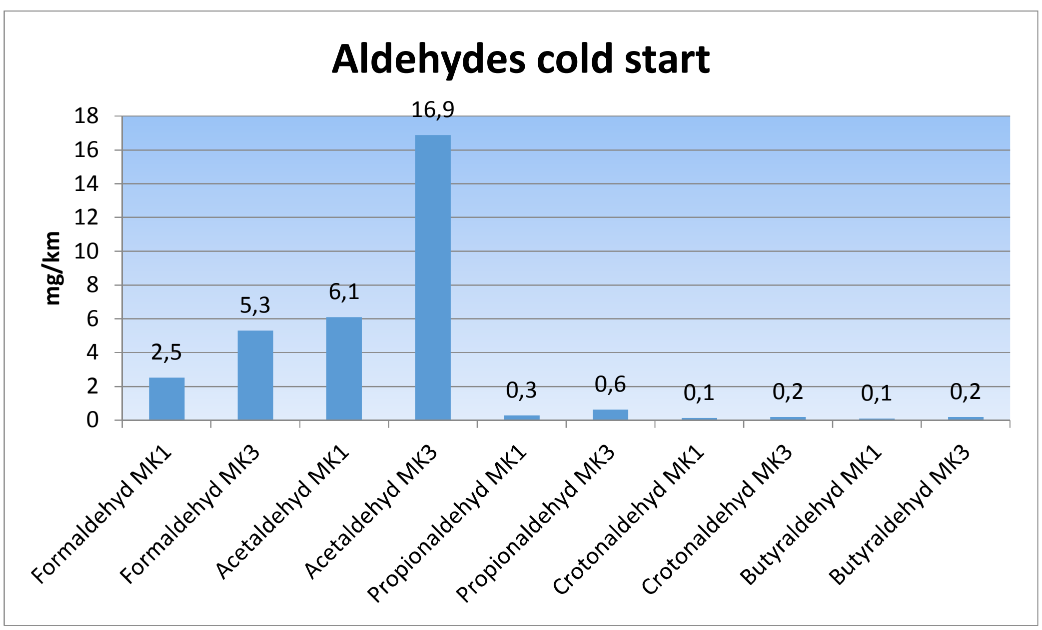

Figure 127 Aldehyde emissions g/kWh.

Some of the individual aldehydes i.e. formaldehyde and acetaldehyde are higher when using MK3 compared to MK1 during both cold as well as hot start. Acetaldehyde and formaldehyde are listed as probable and human carcinogen respectively by the US. EPA.

PAH results from filter and semivolatile phase are presented in Figure 128- 129

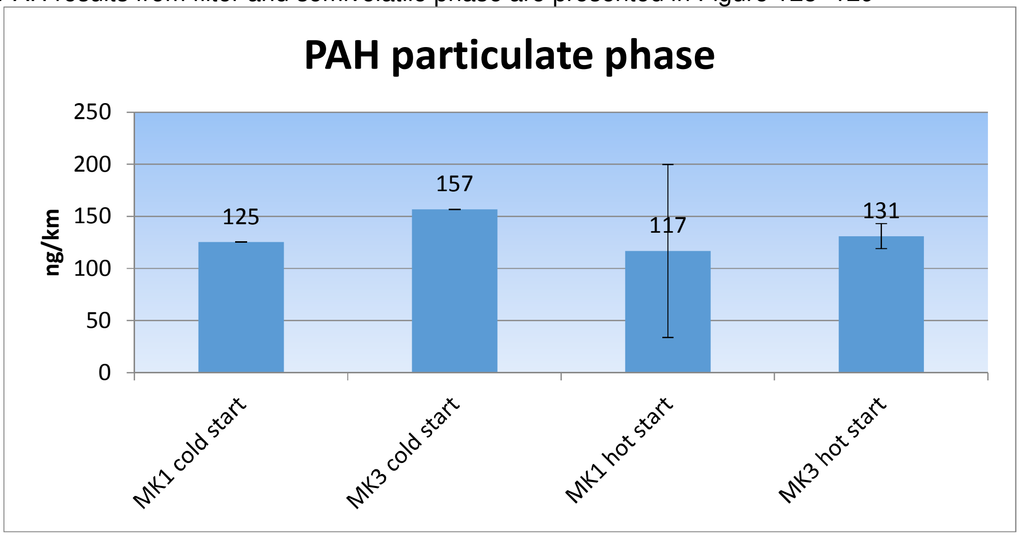

Figure 128 PAH particulate phase.

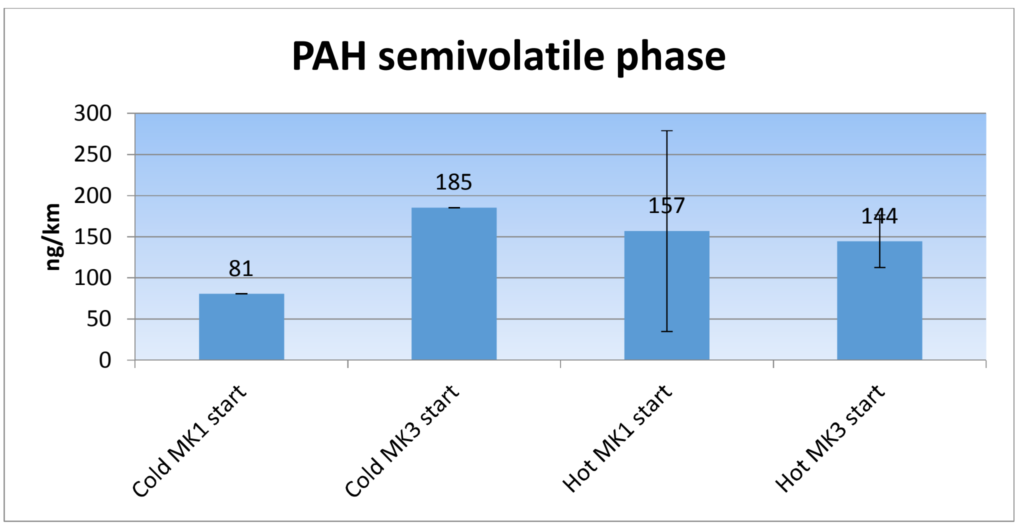

Figure 129 PAH semivolatile phase.

The PAH in the emissions can be derived from unburned residues of fuel and as a byproduct from the combustion. The MK3 fuel contains higher amounts of PAH which is also reflected in the engine out exhaust emissions i.e cold start testing. There are higher levels of PAH both in the semivolatile phase and in the particulate phase for the MK3 fuel. However, no significant differences can be seen during the hot start test. A large standard deviation for the hot start MK1 tests was obtained due to the results of Phenantrene

On-board measurement results.

The ISC test results from the PEMS tests are presented in 131 – 1134 as g/km and in in g/kWh. As can be seen from the confirmatory factors (CF), Figure 130, all measured components were well below 1.5 with regard to both hot as well as cold start.

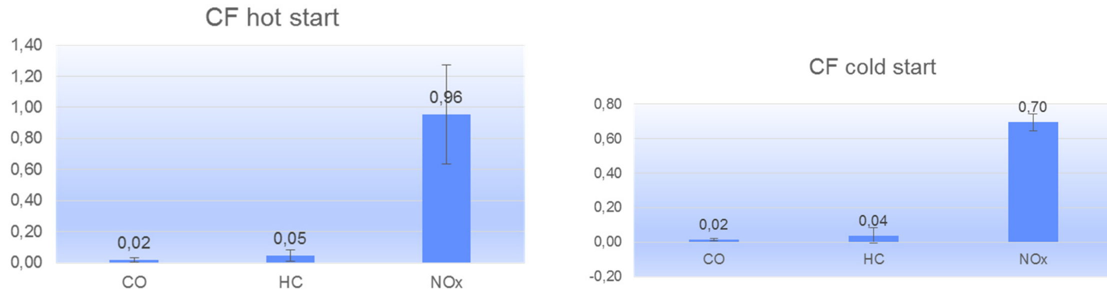

Figure 130 Confirmatory factors hot and cold start

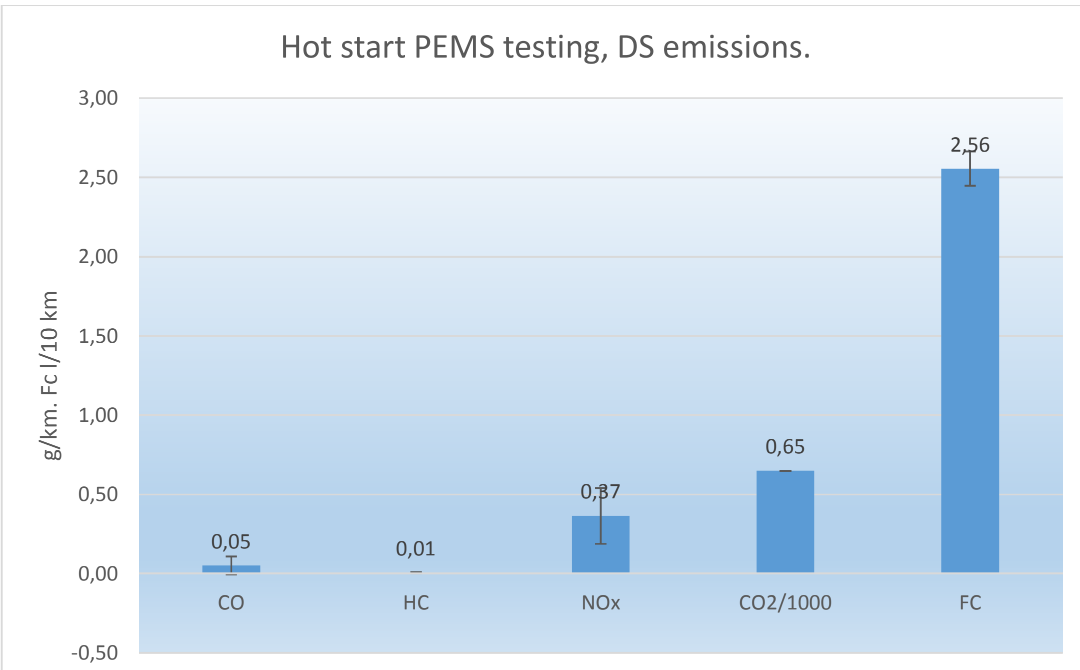

Figure 131 Distance specific emissions, hot start.

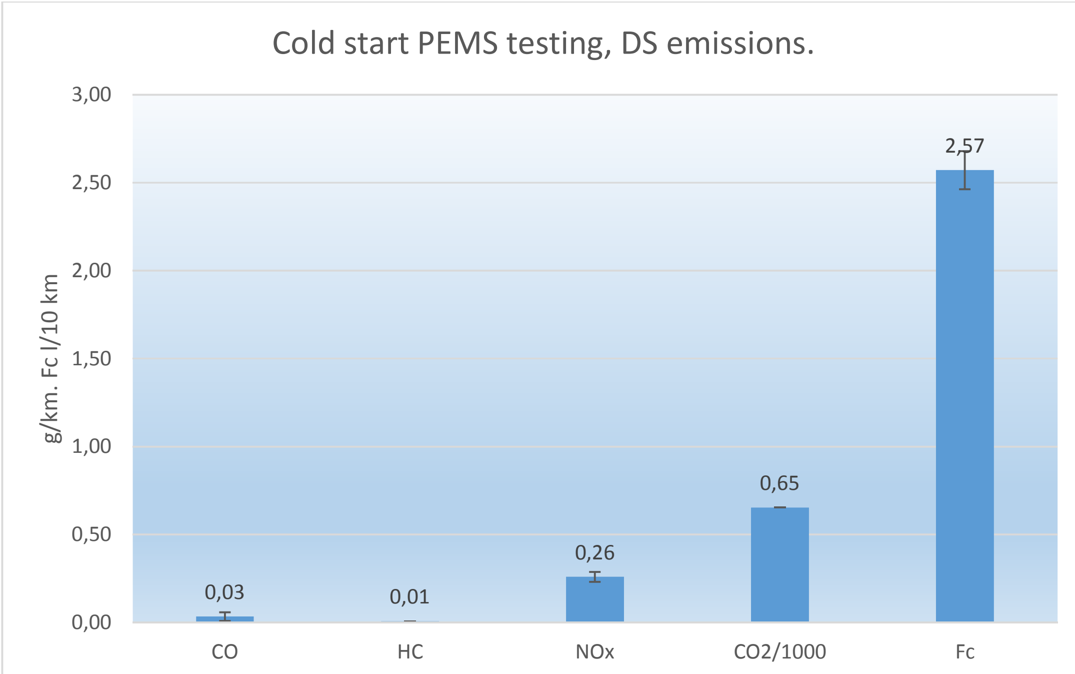

Figure 132 Distance specific emissions, cold start.

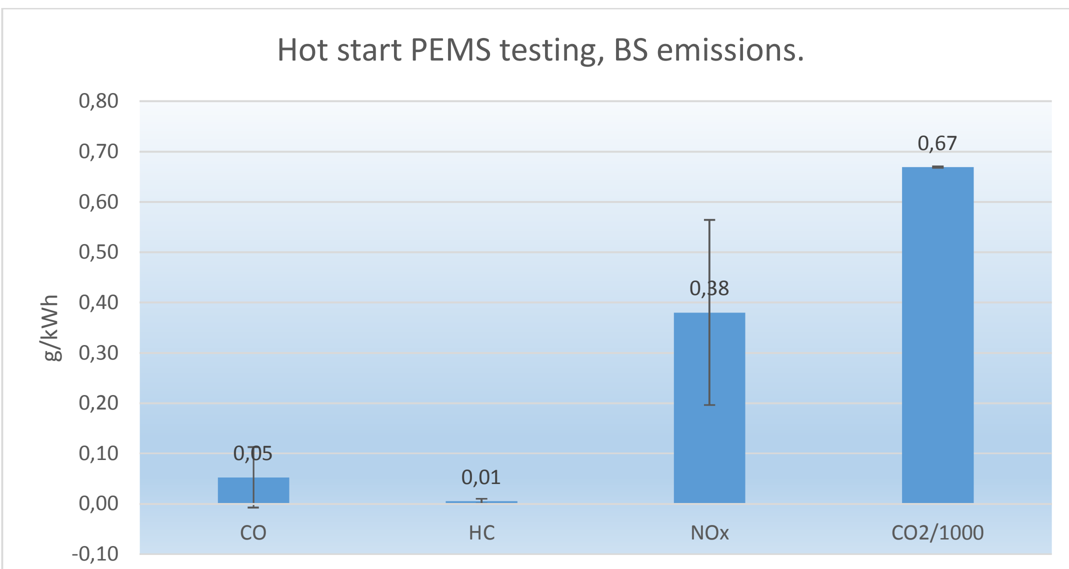

Figure 133 Brake specific emissions, hot start.

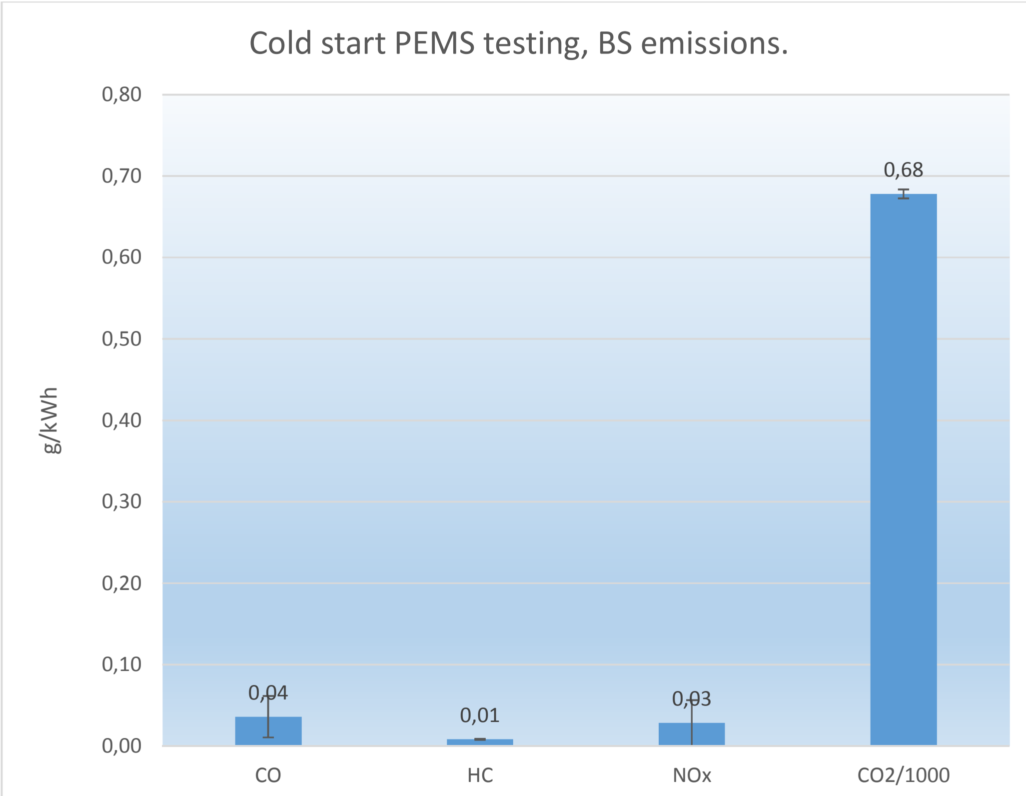

Figure 134 Brake specific emissions, cold start.

Comments

The investigation shows that there are no significant differences on emission level between these two fuels when tested on a Euro VI vehicle with a fully warmed up engine. However, when taken the engine cold start test into consideration there are still some discrepancies. All regulated components (except particle number) as well as formaldehyde and polycyclic aromatic hydrocarbons are higher when using the MK3 quality compared to MK1.However, it must be emphasized that the emission levels are very low and close to detection limit.
Emissions of all regulated pollutants were below the EUVI emission limits both on chassis dynamometer and on the road. The vehicle did pass the EUVI ISC conformity factor limits for all gaseous emissions during the on-road tests both during hot as well as cold start.

Appendix, PEMS system approval

TÜV HESSEN - QUALITY

AUTOMOTIVE

CERTIFICATE

AVL M.O.V.E SYSTEM GAS PEMS 493

Hard- and Software Release May 2013

The TÜV®-tested PEMS system meets the requirements

of the regulation

(EU) No. 582/2011 Annex II
and (EU) No. 64/2012/EC

The Certificate is based on the test reports TÜH TB 2013 – S9.00 and TÜH TB 2013 - S10.00 dated May, 29th, 2013 and references the release of the hard- and software, and the results of the tests performed .

Certificate No.:	2013-06-03-AM-Z.01
Annexes:	Annex 1 – PEMS System
Issued:	June, 3rd 2013
Valid until:	June, 3rd 2015

Ottmar Degrell

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TÜV HESSEN - QUALITY

AUTOMOTIVE

CERTIFICATE

AVL Concerto PEMS, Version 4.5

Software Release May 2013

The TÜV®-tested PEMS data evaluation software meets the requirements

of the regulation

(EU) No. 582/2011 Annex II
and (EU) No. 64/2012

The Certificate is based on the test report TÜH TB 2013 - S10.00 dated May, 29th, 2013 and references the release of the software, and the results of the tests performed .

Certificate No.:	2013-06-03-AM-Z.02
Annexes:	Annex 1 – PEMS Software
Issued:	June, 3rd 2013
Valid until:	June, 3rd 2015

TÜV Technische Überwachung Hessen GmbH · Automotive · 57000

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