Volkswagen Recall Evaluation

Fuel Efficiency, Emissions, Performance

Prepared for The Australian Automobile Association - 2017

ABMARC

FIA

Australian Automobile Association

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Volkswagen Recall Evaluation

Fuel Efficiency, Emissions, Performance

REPORT **August 2017**

For the Australian Automobile Association

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EXECUTIVE SUMMARY

OVERVIEW

This report presents the emissions, fuel consumption and performance test results of a Euro 5 model year 2010 2.0 litre turbo diesel Volkswagen Golf wagon. Emissions and fuel consumption were measured with a Portable Emissions Measurement System (PEMS) on Australian roads. Testing was conducted by ABMARC for the Australian Automobile Association generally in accordance with EC 2016/427 and the draft Real Driving Emissions (RDE) procedure, adapted to suit Australia's unique roads and driving conditions. The VW Golf was tested before the NO_x emissions 23R7 Recall fix, and again after the fix, with one cold start and one warm start test per configuration. The testing was conducted on Melbourne roads during June and July 2017. In addition, the vehicle's performance was assessed on the road and on a chassis dynamometer before and after the recall fix.

PROJECT BACKGROUND

Noxious emissions, CO_2, and fuel consumption standards are regularly reviewed and tightened globally. Despite increasingly strict regulations, air quality monitoring by various agencies in Europe and the USA over time has not shown the air quality improvements that were anticipated by the respective legislation.

A 2011 EC JRC study of the real driving emissions of a range of cars made clear that diesel passenger vehicles were emitting significantly higher levels of NO_x in the real world than in the laboratory.

Vehicles undergo a standard laboratory test (called the New European Drive Cycle) to determine their "official" emissions and fuel consumption figures. NEDC testing is conducted in a laboratory on a dynamometer. The NEDC has been criticised for many years for not representing real world driving conditions and driving styles well. The 2011 JRC study was the key driver for the development and implementation of RDE regulation for light duty vehicles utilising Portable Emissions Measurement Systems (PEMS) to quantify the real-world emissions of vehicles and ensure they comply with new regulatory limits for real driving emissions.

In 2014, real world emissions testing of Volkswagen and Audi vehicles by researchers from West Virginia University, in partnership with the International Council on Clean Transportation (ICCT), revealed that the NO_x emissions from these vehicles were significantly higher than expected when compared to the laboratory limit. These were presented to the Environmental Protection Agency (EPA) and California Air Resources Board (CARB). In September 2015, after further investigation as a result of the initial testing, it was announced that Volkswagen had installed "defeat device" software on diesel vehicles produced between 2008 and 2015.

The software was purposely designed to detect the conditions of a laboratory test and alter the engine emission control strategies during a certification test, ensuring emissions were below required limits. This made the vehicles appear cleaner and more efficient than the reality when operated on the road. In March 2017 Volkswagen pleaded guilty to conspiracy to commit fraud, obstruction and entry of goods by false statement charges in the United States, and it plans to recall up to 11 million cars worldwide to bring the effected vehicles back in line with the regulated limits. The Volkswagen "defeat device scandal" was a key influence in the RDE regulation coming in to force sooner rather than later as there had been significant lobbying by industry to delay its introduction and this had been gaining traction.

It has been anecdotally reported by some Volkswagen owners affected by this recall that significant decreases in vehicle performance and higher fuel consumption have been experienced after having the "fix" implemented. In response to these claims, the Australian Automobile Association (AAA) has contracted ABMARC on behalf of the Fédération Internationale de l'Automobile (FIA) to conduct real world testing of emissions, fuel consumption and performance, pre-and post-recall, of one Volkswagen vehicle affected by the "defeat device" recall: a Euro 5, 2010 2.0 Litre Diesel VW Golf wagon.

TEST MEASUREMENTS

The following variables were measured in order to accurately determine the vehicle emissions and fuel consumption.

Emissions

Emissions were measured with a Portable Emissions Measurement System (PEMS), providing repeatability of 1% or better and complying with EC 2016/427 and European RDE draft regulations.

- **Gaseous:** Total Hydrocarbons, Carbon Monoxide (CO), Carbon Dioxide (CO_2), Nitric Oxide (NO) and Nitrogen Dioxide (NO_2).
- **Particulate Matter (PM):** Collected on gravimetric filter with real time photo acoustic sensor for second by second data.

The exhaust gas sample was taken from probes in the exhaust extension and transferred via heated sample lines to the gaseous analysers and gravimetric filter.

Fuel Consumption

Fuel consumption was derived using the carbon balance method by utilising an exhaust flow meter as specified in EC 2016/427 Appendix 2 Paragraph 7. Fuel properties were determined as per ASTM 4052 (density) to correct emissions and fuel consumption to standard fuel data.

Vehicle Information

An OBD data logger was used to record engine parameters via CAN-Bus (SAE J1979) according to EC 2016/427 Appendix 1 Paragraph 3.4.5.

Ambient Conditions

Ambient conditions, humidity, pressure & temperature were recorded according to EC 2016/427 Appendix 2 Paragraph 8.

Location & Vehicle Speed

Vehicle speed and vehicle location was recorded via GPS, according to EC 2016/427 Appendix 1 Paragraph 4.7.

OUTPUT

For each test, the following were measured and/or calculated from measured values and have been reported:

- Grams of emissions per kilometre travelled (g/km)
- Litres of fuel per 100 kilometres travelled (L/100km)

The emissions data processing and calculations were performed in accordance with prescribed methodologies conforming to EC 2016/427 Annex IIIA Appendix 4, for the analysis of RDE measurement data.

The purpose of this study is to determine the impact of the recall fix by comparing the real world pollutant emissions of the test vehicle to the respective laboratory limits and the fuel consumption to the 'official' figures before and after the recall fix.

EMISSIONS TEST PROCEDURE

Tests were conducted by driving the vehicle on a route in Melbourne, Victoria. The route consisted of urban, extra-urban and freeway driving, with approximately one third of the test being driven in each segment. Each real-world test is driven in normal traffic conditions and accumulates more than seven times the equivalent distance of the NEDC for the laboratory test.

The test route was devised to satisfy the current Real Driving Emissions test procedure developed by the Joint Research Council (JRC), and meets requirements specified by the draft RDE procedure and EC 2016/427 Annex IIIA Part 6. As allowed under the regulation, some minor changes to the drive route specifications were made to conform with Australia's unique road conditions, specifically:

- Maximum speed was limited to 100 km/h which inhibits the ability to achieve at least 5 minutes' driving in excess of 100 km/h for RDE.
- Urban average vehicle speed in Australia is around 25 – 50 km/h, compared to 15 – 30 km/h in Europe, due to different city speed limits.

In line with the European RDE procedure, no less than 16 kilometres must be travelled in each of the urban, extra-urban and freeway test segments. The actual trip distance was approximately 80 km, and duration was between 91 and 97 minutes. An overview of the Drive Route is shown below in Figure 1.

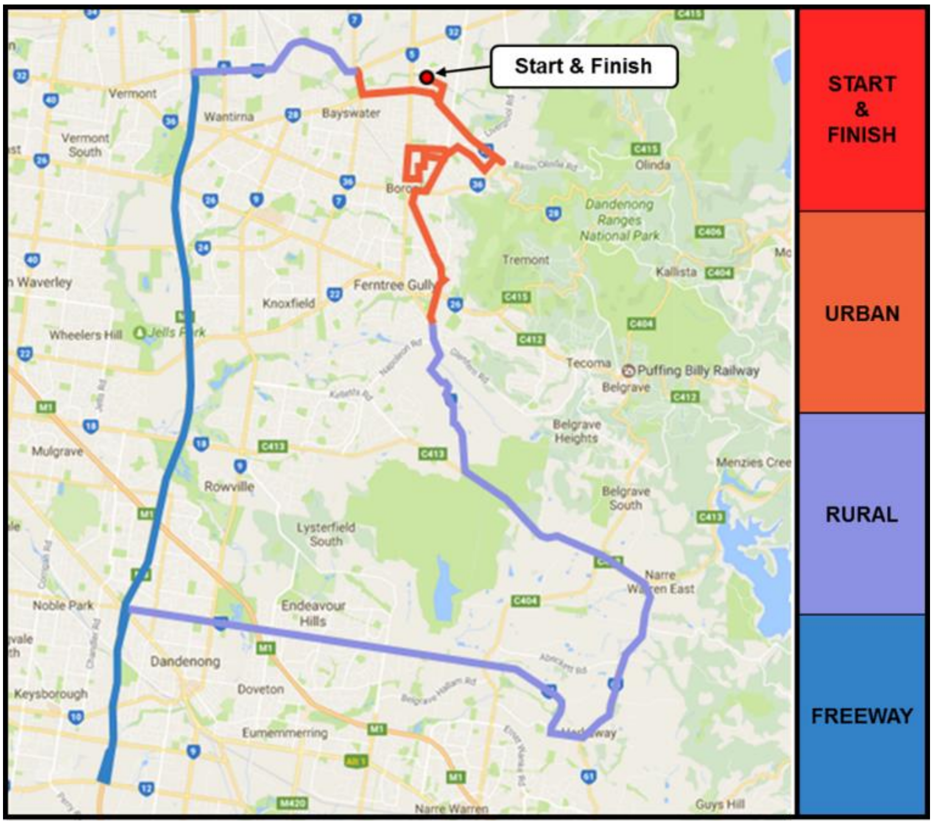

Figure 1 – Test Route Overview

TEST ROUTE REPEATABILITY

An evaluation of the test to test fuel consumption repeatability has been conducted over the drive route with more than 20 vehicles. This test to test analysis compares the variation in fuel consumption between a warm start and a cold start test condition. It has been found that the typical repeatability of vehicle fuel consumption on this route with these start conditions is excellent, and on average 3.1%.

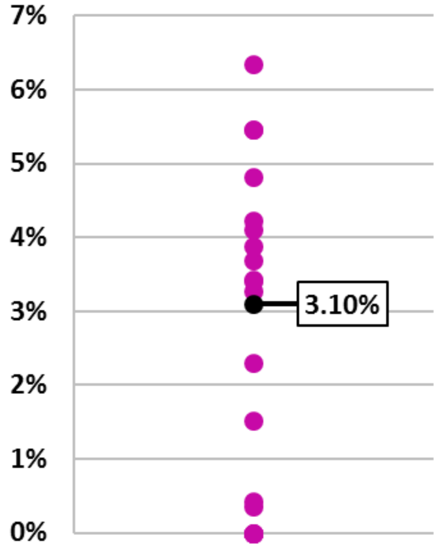

Chart 1 – Typical Fuel Consumption Test Variation (cold start compared to warm start)

RECALL EVALUATION TEST VEHICLE

A Euro 5 model year 2010 2.0 litre turbo diesel VW Golf wagon, shown in Figure 2, was tested in two configurations (pre-and post-fix). The vehicle was taken from the general service fleet. Further vehicle information can be found in the Test Vehicle section of this report.

Figure 2 – Test Vehicle

FUEL CONSUMPTION AND EMISSIONS RESULTS

A summary of the pre-and post-recall test results are shown below in Chart 2. The warm start fuel consumption increased by 7% post recall. Comparing the warm start tests, reductions in pollutant emissions were seen across all pollutants. NO_x and PM decreased by 41% and 33% respectively post recall. CO and THC decreased by 13% and 25% post recall in the warm start test.

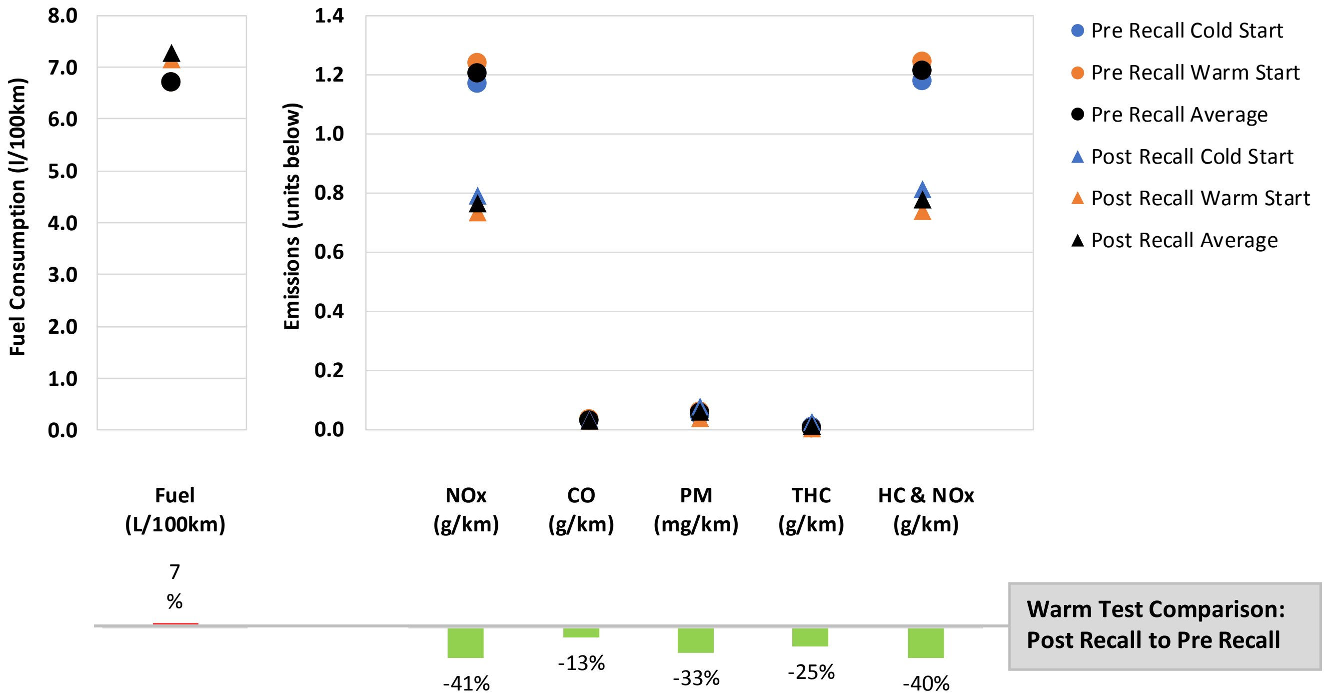

Chart 2 – Summary of Results

Table 1 provides a summary of the real world noxious emissions and fuel consumption compared to their limit (emissions) or official figures (fuel consumption). Note that the fuel consumption results have the regulation Ki factor of 1.05 applied to account for particulate filter regeneration (with the exception of the post-recall cold start test where regeneration occurred during the test). Green shading indicates that the real world emissions or fuel consumption are within the laboratory based limit, and red shading indicates that the emission or fuel consumption exceeds the limit. Only the pollutants that have an applicable regulation limit are shown.

The warm start NO_x emissions decreased to 4.11 times the laboratory limit after the recall, from 6.91 times the laboratory limit pre-recall. CO and PM were well below the laboratory limit in all tests. Warm start test fuel consumption increased after the recall to be 1.26 times the official combined NEDC figure, increasing from the pre-recall fuel consumption result of 1.18 times.

Test Results Compared to Limits & NEDC Combined Fuel Consumption						
	Test	NOx	CO	PM	HC & NOx	Fuel
Pre Recall	Cold Start	652%	6%	1%	513%	118%
	Warm Start	691%	7%	1%	543%	118%
Post Recall	Cold Start	440%	7%	2%	355%	130%
	Warm Start	411%	6%	1%	323%	126%

Table 1 – Results Compared to the Applicable Euro 5 Emissions Limits & the Official Fuel Consumption Figures (Combined NEDC)

PERFORMANCE RESULTS

Vehicle performance was compared pre-and post-recall. Peak power and torque were measured on a chassis dynamometer (note: the test facility was not certified). Over the range of RPM measured which was limited due to the automatic transmission overriding gear selection, it was observed that both power and torque had increased slightly after the recall fix was applied. Vehicle acceleration performance was compared from standing starts and rolling starts over a range of speeds. No detrimental effects to the acceleration were observed after the recall.

EMISSION AND FUEL CONSUMPTION RESULTS

The warm start test fuel consumption in each drive route segment is shown below in Chart 3. The urban section of the drive route shows the smallest change in fuel consumption at 2% higher post recall. The rural segment had increased fuel consumption by 7%, while the motorway segment showed the highest increase in fuel consumption to 14% greater than the pre-recall test.

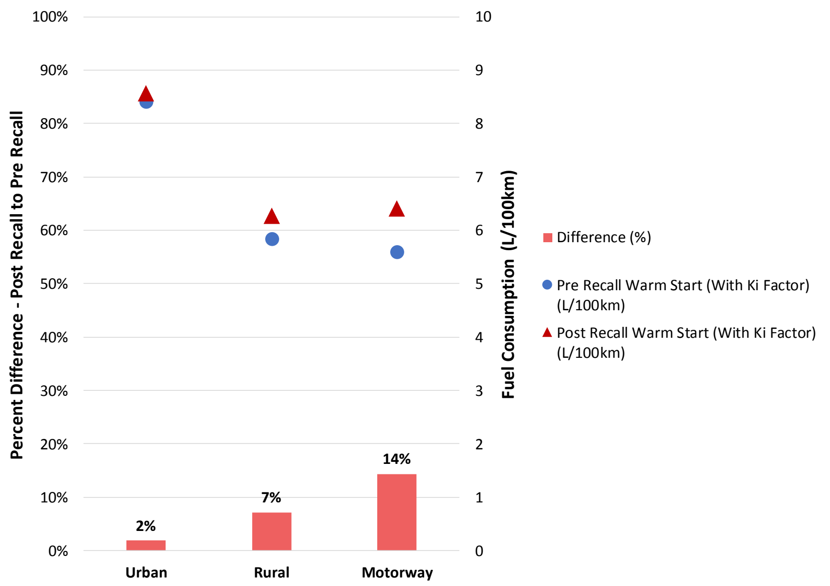

Chart 3 – Warm Start Fuel Consumption by Drive Segment

The warm start test NO_x in each drive route segment is shown below in Chart 4. In the urban section of the drive route NO_x decreased by 38%. While the rural segment had the smallest change at 27% lower than the pre-recall test. The motorway segment showed the highest decrease in NO_x with a result 60% lower than that measured in the pre-recall test.

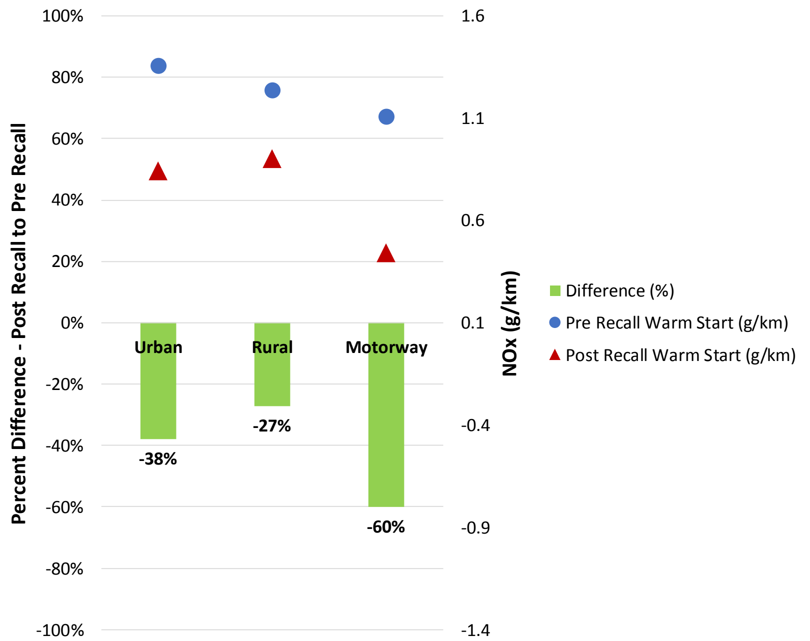

Chart 4 – Warm Start NO_x by Drive Route Segment

CONCLUSION

This program has determined that:

- The recall fix has not detrimentally impacted vehicle performance. A slight increase in power and torque was observed post-fix. The on-road performance from standing and rolling starts was not affected.
- The real world warm start average fuel consumption was 7% higher after the recall fix was applied, at 1.26 times the official figures, up from 1.18 times the official figures pre-recall.
- The pre-recall real world average NO_x emissions were 6.71 times the laboratory limit.
- The real-world NO_x emissions were reduced post recall by 41% when comparing warm tests. However, the NO_x emissions were still 4.11 times the laboratory limit after the recall when tested under real driving conditions.
- Real world CO and PM emissions were below the laboratory limit pre-and post-recall. No significant change was measured in the CO emissions.
- The real-world PM results decreased by 33% post recall, although the PM was very low pre- and post-recall at less than 0.1 mg/km.

ACRONYMS

AAA	Australian Automobile Association
ADR	Australian Design Rule
AS	Australian Standards
ASTM	American Society for Testing and Materials
Avg	Average
BSFC	Brake Specific Fuel Consumption
CAN	Controller Area Network
CARB	California Air Resources Board
CF	Conformity Factor
CI	Compression-Ignition Engine (Diesel)
CO	Carbon Monoxide
CO_2	Carbon Dioxide
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DPF	Diesel Particulate Filter
EC	European Council
ECU	Engine Control Unit
EEV	Enhanced Environmentally Friendly Vehicle
EPA (US)	Environmental Protection Agency
EPA (AUS)	Environment Protection Authority
EGR	Exhaust Gas Recirculation
EGT	Exhaust Gas Temperature
EU	European Union
FID	Flame Ionization Detector
FIA	Fédération Internationale de l'Automobile
GCM	Gross Combination Mass
GFM	Gravimetric Filter Module
GPS	Global Positioning System
GVM	Gross Vehicle Mass
ISO	International Organization for Standardization
ICCT	International Council on Clean Transportation
JRC	Joint Research Centre
LDV	Light Duty Vehicle
LPG	Liquefied Petroleum Gas
MAP	Manifold Absolute Pressure
MAW	Moving Average Window
MIL	Malfunction Indicator Lamp
NATA	National Association of Testing Authorities
N/A	Not Applicable
NDIR	Non-Dispersive Infrared
NDUV	Non-Dispersive Ultra-Violet
NEDC	New European Drive Cycle
NMHC	Non-Methane Hydrocarbons
NRMM	Non-Road Mobile Machinery
NO	Nitric Oxide
NO_X	Oxides of Nitrogen
NO_2	Nitrogen Dioxide
NTE	Not To Exceed
NSW	New South Wales
OBD	On-board Diagnostic
OEM	Original Equipment Manufacturer
PEMS	Portable Emissions Measurement System
PI	Positive Ignition Engine (Petrol)
PID	Vehicle Data Parameter Identifier
PM	Particulate Matter
PPM	Parts Per Million
RDE	Real Driving Emissions
RPM	Revolutions per Minute
SAE	Society of Automotive Engineers
Temp.	Temperature
THC	Total Hydrocarbons
UN	United Nations
UV	Ultra Violet
VIC	Victoria
VW	Volkswagen AG
WLTC	Worldwide Harmonized Light-duty Test Cycle
WLTP	Worldwide Harmonized Light-duty Vehicles Testing Procedure

GLOSSARY OF TERMS

Dilution Air: Conditioned and filtered air used to dilute the exhaust sample entering the particulate matter emissions measurement device.
Particulate Matter Dilution Ratio: Ratio of dilution air to exhaust gas sample that is used for particulate matter measurement.
Drift: Drift is the amount of change in the reading of a measurement instrument over time.
Gaseous Emissions: Engine emissions in gaseous form, includes oxides of nitrogen, carbon monoxide, carbon dioxide and total hydrocarbons.
Particulate Emissions: Referred to as Particulate Matter (PM). A complex mixture of small solid and liquid particles suspended in the exhaust gas, often visible as soot and smoke being ejected from the exhaust. In emission standards for internal combustion engines, PM is defined as the material collected on a filter when the exhaust gas is diluted to a temperature of not more than 52°C and passed through a filter.
Real World: Real World refers to on-road testing using PEMS, as opposed to NEDC testing in the laboratory.
Run in: The period of time to bed in/stabilise new components.
Span Gas: A gas of known composition used to calibrate the emissions testing devices and determine the drift (if any).
Euro I – VI: European emission standards define the acceptable limits for exhaust emissions of new vehicles sold in EU member states.

ABBREVIATIONS

ºC	Degrees Celsius
g	Gram
g/kWhr	Grams per Kilowatt Hour
mg/km	Milligrams per Kilometre
g/km	Grams per Kilometre
g/s	Grams per Second
h	Hour
kg/l	Kilograms per Litre
L/100km	Litres per 100 Kilometres
km	Kilometre
kW	Kilo Watt
L	Litre
L/min	Litre per Minute
m	Metre
mm	Millimetre
min	Minute
MJ/kg	Mega Joule per Kilogram
MJ/kWhr	Mega Joule per Kilowatt Hour
Nm	Newton Metre
Pa	Pascal
ppm	Parts per Million
RPM	Revolutions per Minute
s	Seconds

VOLKSWAGEN RECALL EVALUATION

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OVERVIEW

Some Volkswagen owners affected by this recall have reported that they have experienced significant decreases in vehicle performance and higher fuel consumption after having the “recall fix” implemented on their vehicles. In response to these anecdotal reports the Australian Automobile Association (AAA), on behalf of the Fédération Internationale de l'Automobile (FIA), has contracted ABMARC to conduct real world pre- and post-recall emissions, fuel consumption and performance testing on a Volkswagen vehicle affected by the “defeat device” recall.

The AAA asked ABMARC to determine whether the software fix associated with recall campaign 23R7 reduced the real world emissions on a test vehicle, with particular focus on NO_x emissions. Further, the AAA asked ABMARC to determine whether the software upgrade impacted the vehicle’s on-road performance, specifically in relation to fuel consumption. Additionally, ABMARC was asked to evaluate the test vehicle’s acceleration and power/torque before and after the “recall fix”.

The test vehicle was a privately-owned car, selected from the general Australian vehicle fleet. The test vehicle was a Euro 5, 2010 2.0 Litre Diesel VW Golf Wagon. It had accumulated approximately 113,000 kilometres at the time of testing and was in a standard condition (i.e. it had not been modified). The vehicle log book showed a regular scheduled maintenance history at Volkswagen dealerships. Testing was conducted between June 2017 and July 2017 in Melbourne, Australia.

According to Volkswagen, this vehicle only required a software update to enable the emissions to meet the regulations. Not all Volkswagen vehicles are affected by the recall in the same way; some models require software changes only, some models require both hardware and software changes. The specifications of the test vehicle are outlined in Table 2 – Vehicle Specifications.

Real world vehicle emissions, fuel consumption and performance were tested before and after the software update was installed to enable pre-and post-modification comparisons to be made. Comparisons with the regulated laboratory emissions limits and the official fuel consumption figures were made.

Emissions and fuel consumption testing was conducted on-road with a Portable Emissions Measurement System (PEMS).

BACKGROUND

Noxious emissions, CO_2 and fuel consumption standards are regularly reviewed and tightened globally. Typically, the regulated pollutants are: carbon monoxide (CO), oxides of nitrogen (NO_X), hydrocarbons (HC), and particulates (PM). Despite increasingly strict regulations, air quality monitoring by various agencies in Europe and the USA over time has not shown the air quality improvements that were anticipated by the respective legislation.

Chart 5 presents the results of a JRC study (2011) for NO_x emissions. From this study, it became clear that diesel passenger vehicles were emitting significantly higher levels of NO_x in the real world than in the laboratory.

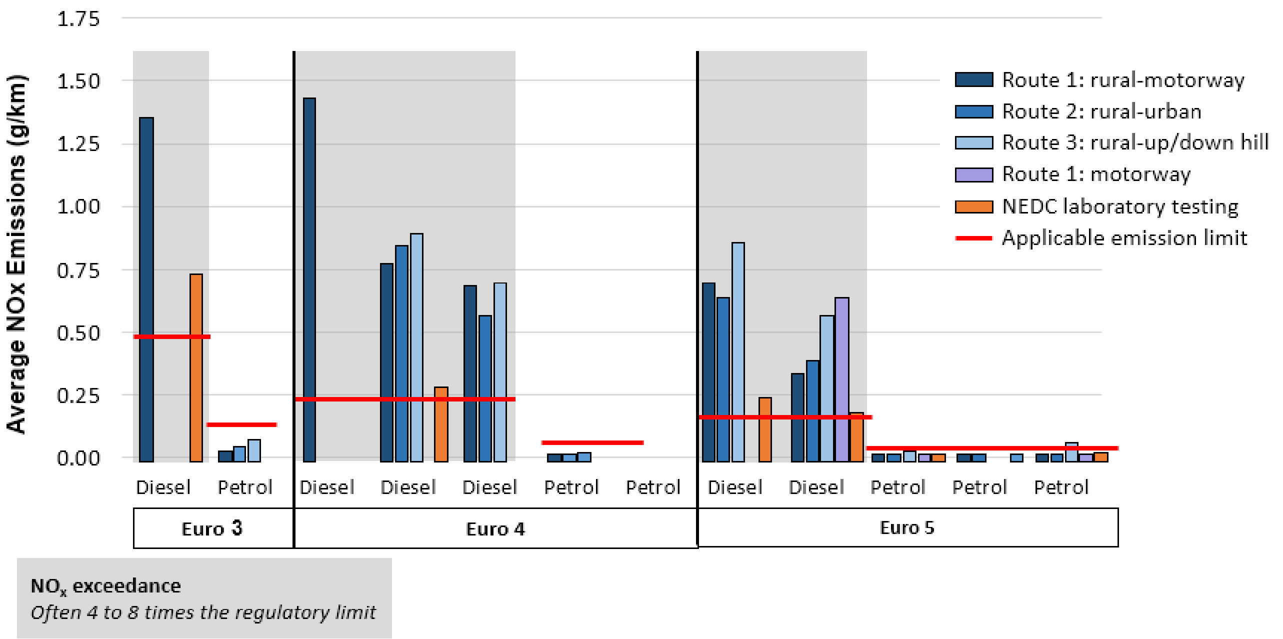


Chart 5 – 2011 EC JRC Study Average NO_x Exceedance in g/km on European Roads

Vehicles undergo a standard test (called the New European Drive Cycle, or NEDC) to determine their "official" emissions and fuel consumption. These are the figures provided to consumers when purchasing a new vehicle. NEDC testing is conducted in a laboratory on a dynamometer. The NEDC has been criticised for many years for not representing real world driving conditions and driving styles well. Chart 6 compares the NEDC "urban segment" engine load and RPM with real world urban driving in Brisbane, Australia (ABMARC RWE test, 2014). It can be seen that real world driving resulted in a much broader range of engine load and RPM than can be seen in the simulated NEDC test.

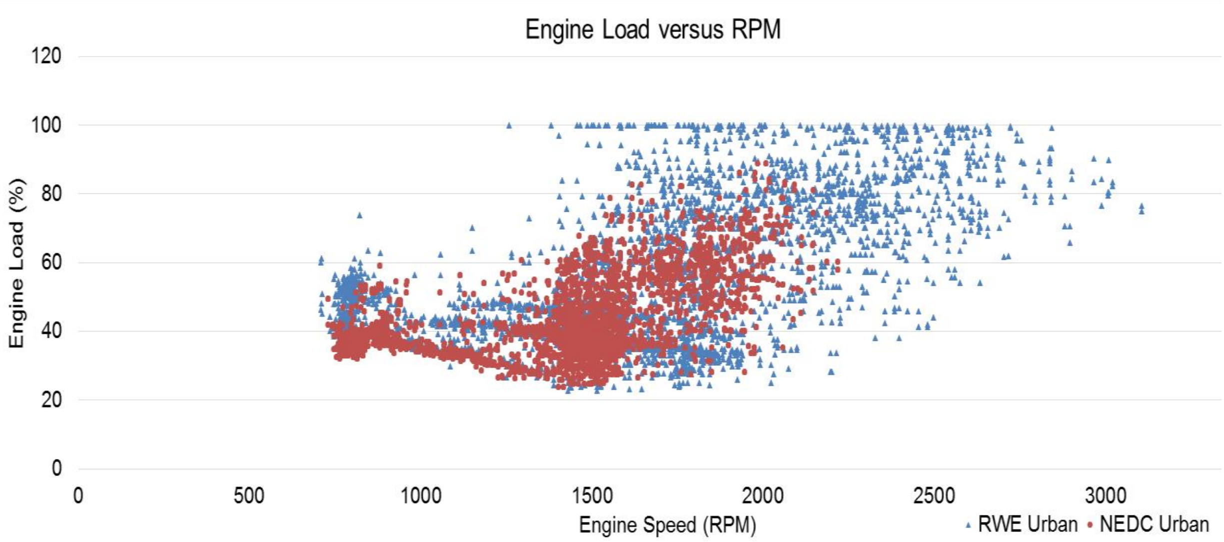


Chart 6 – Brisbane City Real World Drive Engine Load Comparison to NEDC

Additionally, it can be seen that in the real world test the vehicle accelerated many more times and at much higher rates than on the NEDC urban test. Chart 7 compares real world vehicle speed and acceleration to the NEDC urban segment.

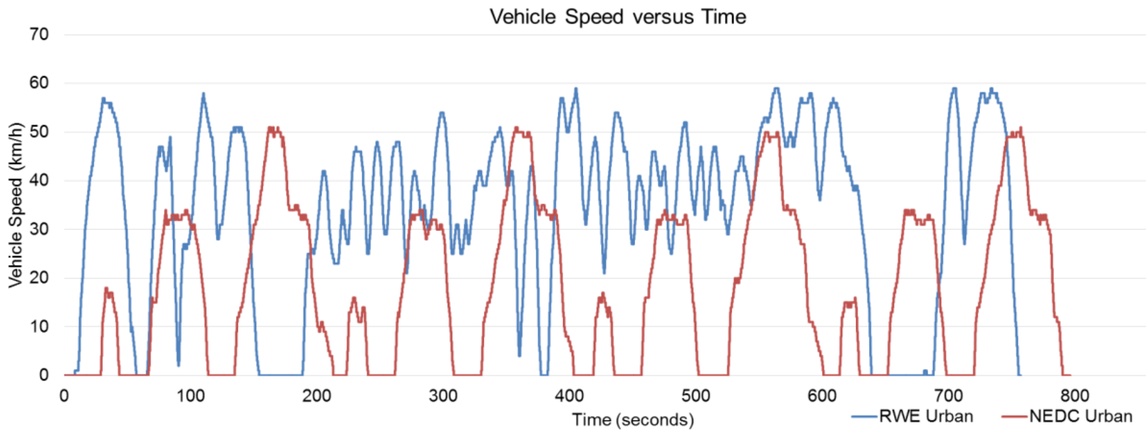


Chart 7 – Brisbane City Real World Drive Vehicle Speed Comparison to NEDC

The 2011 JRC study was the key driver for the development and implementation of Real Driving Emissions (RDE) regulation for light duty vehicles utilising Portable Emissions Measurement Systems (PEMS) to quantify the real-world emissions of vehicles and to ensure they comply with new regulatory limits to ensure improved health outcomes.

In 2014, real world emissions testing of Volkswagen and Audi vehicles by researchers from West Virginia University, in partnership with the International Council on Clean Transportation (ICCT), revealed that the NO_x emissions from these vehicles were significantly higher than expected when compared to the laboratory limit. These were presented to the Environmental Protection Agency (EPA) and California Air Resources Board (CARB). In September 2015, after further investigation as a result of the initial testing, it was announced that Volkswagen had installed "defeat device" software on diesel vehicles produced between 2008 and 2015.

The software was purposely designed to detect the conditions of a laboratory test and alter the engine emission control strategies during a certification test, ensuring emissions were below required limits. This made the vehicles appear cleaner and more efficient than the reality when operated on the road. In March 2017 Volkswagen pleaded guilty to conspiracy to commit fraud, obstruction and entry of goods by false statement charges in the United States, and it plans to recall up to 11 million cars worldwide to bring the effected vehicles back in line with the regulated limits. The Volkswagen "defeat device scandal" was a key influence in the RDE regulation coming in to force sooner rather than later as there had been significant lobbying by industry to delay its introduction and this had been gaining traction.

On-road emissions are measured with calibrated laboratory equipment that has been ruggedized for use in vehicles. This equipment has the same accuracy and specifications as the fixed laboratory equipment, and provides high levels of repeatability. Test to test variation in a single vehicle is typically a function of the actual traffic or temperature conditions experienced on the test, a phenomenon recognised by the EC.

Figure 3 – Vehicles with PEMS Installed and Examples of Real World Driving Road Conditions

TEST VEHICLE

A 2010 Volkswagen Golf 2.0 TDI Wagon affected by the NO_x emissions recall number 23R7 was tested. The vehicle specifications are provided in Table 2 below. The recall for this vehicle specified a software calibration change only.

Make	Volkswagen
Model	Golf 2.0 TDI Wagon
Badge	103TDI Comfortline
Model Code	AJ5 36M
Series	VI
Transmission	Sports Automatic Dual Clutch
Number of Gears	6
Drive	Front Wheel Drive
Fuel Type	Diesel
Release Year	2010
Engine Code	CBD I98067
Engine Size (cc) (cc)	1968
Induction	Turbo Intercooled
Engine Configuration	In-line 4 cylinder
Power	103 kW @ 4,000 rpm
Torque	320 Nm @ 1,750-2,500 rpm
Emission Standard	Euro 5
Recall Code Label	VW000010006

Pre-Recall Odometer	113,093 km
Post-Recall Odometer	113,346 km

Table 2 – Vehicle Specifications

Figure 4 – Volkswagen Golf Test Vehicle

EMISSIONS LIMITS

The emissions limits for the 2010 VW Golf diesel are listed Table 3 below. At the time of introduction of the 2010 VW Golf the emission standard in Australia was Euro 4, however, the 2010 VW Golf was certified to Euro 5. The current new vehicle emissions standard in Australia for passenger cars is Euro 5.

Introduction Period (Aust.)	Stage	Combustion Type	Test Cycle	CO [g/km]	NOx [g/km]	HC [g/km]	NHMC [g/km]	PM [g/km]	HC & NOx [g/km]
2008 to 2010 For reference	**Euro 4**	Diesel	NEDC	0.5	0.25	N/A	N/A	0.025	0.3
2013 to 2016	**EURO 5a**	Diesel	NEDC	0.5	0.18	N/A	N/A	0.005	0.23

Table 3 – Emissions Limits

PROJECT TIMING AND SEQUENCE

Testing took place between June and July 2017. The project Schedule was developed in conjunction with AAA according to the test vehicle availability. The testing comprised two phases: pre-and post-recall. One cold and one warm start test was completed in each phase of testing. A vehicle conditioning drive was completed before each emissions test sequence.

The project sequence and timing is outlined below in Table 4.

	Project Sequence		
	Activity		**Date**
Pre Recall	**1**	Vehicle received	16-June-2017
Pre Recall	**2**	Filled with fuel (density analysed)	16-June-2017
Pre Recall	**3**	Vehicle conditioning drive	22-June-2017
Pre Recall	**4**	Emisisons test cold start	05-July-2017
Pre Recall	**5**	Emisisons test warm start	05-July-2017
	6	Recall fix	07-July-2017
Post Recall	**7**	Vehicle conditioning drive (from service centre)	07-July-2017
Post Recall	**8**	Vehicle conditioning drive	10-July-2017
Post Recall	**9**	Emisisons test cold start	13-July-2017
Post Recall	**10**	Emisisons test warm start	13-July-2017
Post Recall	**11**	Return	17-July-2017

Table 4 – Project Timing

TEST METHODOLOGY

PROCEDURE

A PEM System is fitted to the test vehicle and measures the tailpipe emissions of NO, NO_2, CO, CO_2, THC and PM. The PEMS test procedure requires that the emissions and fuel data are continuously logged at a minimum rate of 1 Hz. The maximum test duration is limited to 2 hours. The test meets the requirements specified in EC 2016/42, with the exception of adaptations for Australian road conditions, listed under the variations column of Table 5 and Table 6.

Constant dilution sampling of the exhaust gas for PM measurement was used. Gravimetric filters were utilised for particulate mass measurement. The conditioning and weighing of gravimetric filters pre-and post-test (PM loading) occurred at CSIRO's automated weighing facility in North Ryde, NSW.

The vehicle was tested twice in each phase as follows:

Test 1 – Cold Start Test
Test 2 – Warm Start Test

Testing was conducted using commercially available diesel fuel meeting the requirements of the current Australian Fuel Quality Standards Act.

Fuel was tested for density, the fuel test results are listed in Appendix A.

Prior to conducting each test sequence:

a) The vehicle is checked to ensure roadworthy condition prior to testing.
b) The emissions and fuel sampling equipment is checked to confirm that it meets the requirements of EC 2016/427.
c) It is ensured that the vehicle has no maintenance issues, i.e. that there are no "check engine" codes present, reading vehicle information using the On-Board Diagnostic (OBD) system.
d) If during (or immediately after the test) a "check engine" code is set, the test is deemed to be invalid and the vehicle is required to be repaired prior to re-testing.

The test process, shown in Figure 5, is used to ensure the correct vehicle set-up and test methodology is applied for accurate and repeatable Real Driving Emissions testing in conformance with the regulation. This process was developed in accordance with RDE draft regulations and the procedures set out in EC 2016/427, Annex IIIA, Appendix 1, and is followed each time a test is conducted.

A Ki factor of 1.05 has been applied to the fuel consumption results of tests when the DPF was not active. A Ki factor is a regulation requirement for the official fuel consumption results determined from the laboratory test (the Ki factor can be the regulation number of 1.05 or determined by the vehicle manufacturer based on actual vehicle performance). Emissions results have not had a factor applied.

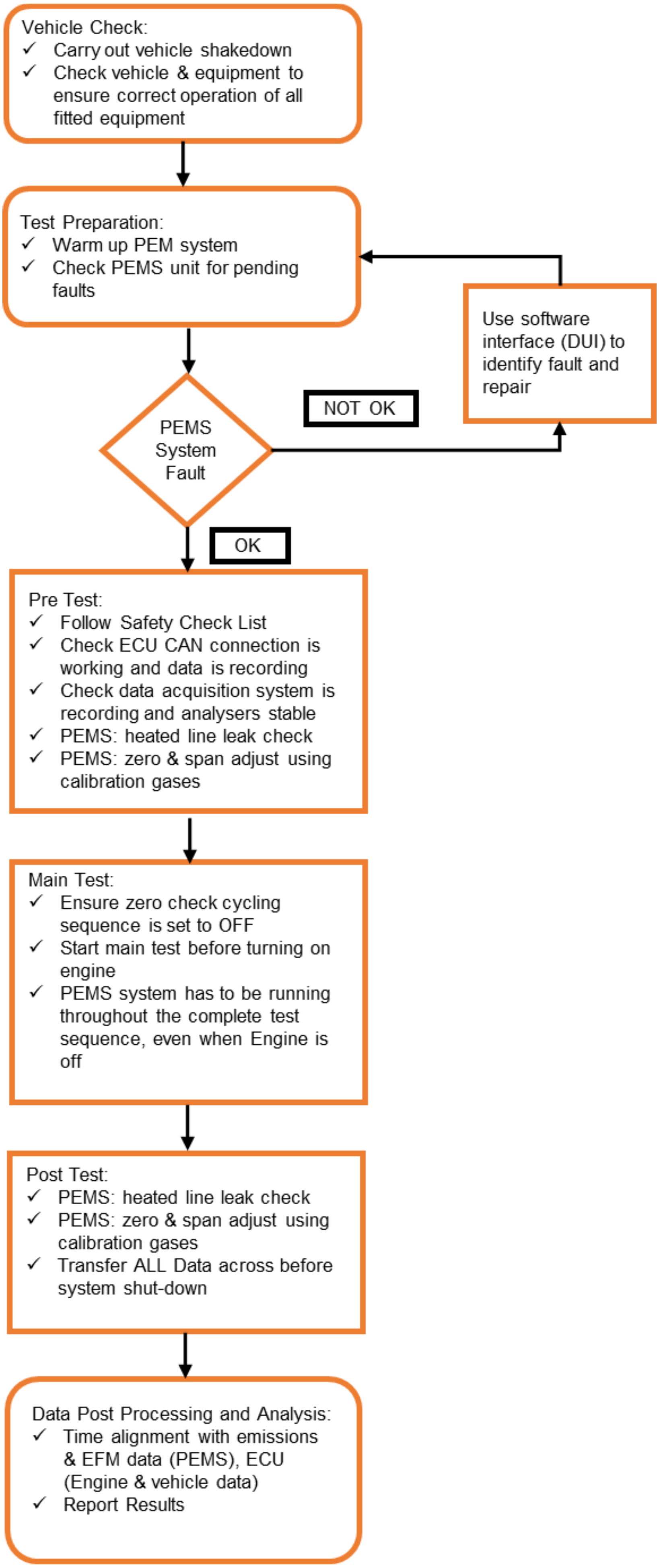


Figure 5 – PEMS Test Procedure

TEST REQUIREMENTS

The test criteria summary of the draft European RDE regulation 2016/427, is shown below in Table 5 and Table 6.

Modification of the drive route is allowed under the regulation with approval from the regulator. ABMARC consulted with JRC, who developed the European RDE test, to ensure appropriate test and drive route conditions were met for Australian conditions. The only variations to the drive route specification were the time over 100 km/h (no time) and the average urban vehicle speed (higher than in Europe).

The test was carried out generally according to the regulation and guidelines as per EC 2016/427, for example:

- All data recording needs to start prior to engine running
- The test cannot be interrupted once started
- Data is required to be continuously recorded
- If the engine stalls during the test, the engine can be restarted
- The emission sampling and vehicle data recording cannot be stopped or paused during the test, otherwise the test is considered void
- Data cannot be combined from different data sets, modified or deleted
- The test is to be conducted on sealed roads

Test Trip Requirements				
Test Conditions	**Route Requirement**	**Variations**	**Comments**	**Potential Impact**
Test route sequence	Urban › Rural › Freeway	Urban › Rural › Freeway › Rural › Urban	The sequence is conducted in a loop.	
Drive route percentage: Urban, Rural, Freeway	34% / 33% / 33% Tolerance (+/- 10% and Urban not < 29% of the total trip distance)	None		
Urban vehicle speeds	< 60 km/h	None		
Rural vehicle speeds	60 to 90 km/h	60 to 80 km/h	Australian roads	Meets technical requirements
Freeway vehicle speeds	> 90 km/h	> 80 km/h	Range adjusted to above 80 km/h to achieve dynamicity requirements.	
Max vehicle velocity	145 km/h	Yes	Limited to 100 km/h	Possible lower average fuel consumption and pollutants on motorways in Australia due to lower engine operating loads.
Urban avg. vehicle speed	15-30 km/h	Average actual vehicle speed is 40 to 50 km/h	European city speeds are typically 30 km/h compared to Australia's minimum of 40 km/h around schools and 50 km/h elsewhere.	Higher pollutants emitted in urban areas in Australia due to higher engine operating loads.
Freeway vehicle speed range	90 - 110 km/h at least 5 minutes above 100 km/h	No test time above 100 km/h	Max. vehicle speed will not be achieved to satisfy the trip requirement as the majority of Victorian freeways close to urban areas are speed limited to 100 km/h.	

Table 5 – RDE Test Route Requirements and Variations

Test Requirements				
Test Conditions	**Test Requirement**	**Variations**	**Comments**	**Potential Impact**
Test duration (minutes)	90 - 120 minutes	None	Typical test time on this selected route is 95 min.	
Altitude	<=700 m above sea level. The start and end point should not differ more than 100 m. Elevation gain limit is 1200 m/100 km	None		
Minimum trip distance (km)	Total trip distance a min. of 48 km (min. of 16 m for each urban, rural and freeway)	None		
Cold start	Driven for at least 30 min and then parked in key-off engine status between 6 and 56 hours	Test sequence consists of a cold start followed by a warm start	Additional test for verification and assessment at warm start	Highly dependent on vehicle, emissions system and strategy
Ambient temperature	Normal operating range 0 °C to 30 °C *Extended temperature range is -7 °C to + 35 °C*			
Fuel	Market fuel			
Payload	Driver, witness & test equipment plus additional weight to maximum 90% of the sum of "passenger mass" and "pay mass"	Driver, Test equipment and fuel	Average payload mass is 215 kg + driver and fuel	
Auxiliary system operation	Air-conditioning and other auxiliary devices operational compatible with possible consumer use while driving on the road		All performance options (if any) set to standard/normal ac on with fan setting low, lights on and radio off	
Regeneration system (if applicable)	If regeneration occurs, exclusion of that test is permitted & one further test may be completed			
PEMS set up in vehicle	Minimise impact on emissions			
Test day selection	Normal working day		Tests have been conducted to avoid peak hour traffic	

Table 6 – RDE Test Requirements and Variations

TEST ROUTE

In line with the European RDE procedure, the drive routes consist of approximately one third urban, one third rural, and one third freeway driving, with no less than 16 km distance travelled in each of the three segments, and a duration between 90 and 120 minutes. The total actual test time on this real driving route is 5 NEDC tests. The percentage of total distance travelled in each test segment is in Table 7. A tolerance of +/- 10% is allowed, with the exception of urban being not less than 29% of the total trip distance.

The test route is representative of average Australian drive conditions, covering a wide variety of:

- Topography
- Road Conditions
- Traffic Density

The RDE trip distance on the selected route was approximately 80 km with an average test duration of 94 minutes. The minimum and maximum time to complete the testing in the VW Golf was between 91 and 97 minutes, depending on traffic and weather conditions.

TEST ROUTE

ABMARC developed the test route in accordance with the European RDE procedure. The key parameters are listed in Table 7.

The drive route was conducted around the eastern suburbs of Melbourne, starting the urban segment in Boronia, rural segment around Ferntree Gully and Lysterfield and freeway (motorway) driving on Eastlink between Keysborough and Wantirna VIC.

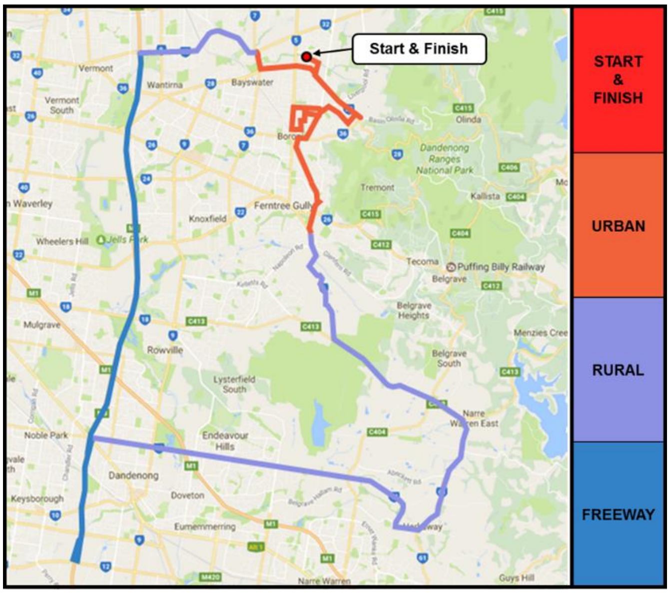


Figure 8 – Test Route Comparison

	Urban (1 to 59 km/h)	Rural (60 to 79 km/h)	Motorway (80 to 100 km/h)	Total
Average Vehicle Speed	30	71	99	49
Trip Share (% Dist)	37.3	32	30.7	
Distance (km)	29.5	25.3	24.4	79.2
Duration (min)	60	22	15	97

Table 7 – Drive Route Key Parameters – Example

URBAN DRIVE SEGMENT

The urban drive segment was conducted around the eastern suburbs of Melbourne. This segment consisted of speeds between 0 km/h and 59 km/h, during non-peak traffic conditions with regular stopping at intersections.

Figure 6 – Urban Drive Segment Example

RURAL DRIVE SEGMENT

The rural speed segment was conducted around Lysterfield in non-peak hour, medium density traffic at speeds between 60 km/h and 80 km/h.

Figure 7 – Rural Drive Segment Example

HIGHWAY DRIVE SEGMENT

The highway drive segment was conducted between speeds of 80 km/h and 100 km/h during non-peak times in low to medium traffic density on the Eastlink freeway.

Figure 8 – Highway Drive Segment Example

ROUTE REPEATABILITY

An evaluation of the test to test fuel consumption repeatability has been conducted over the drive route using the results from 20 vehicles (40 tests). It has been found that the typical repeatability of vehicle fuel consumption on this route is excellent, and on average 3.1%. This test to test repeatability includes the variation between warm start and cold start tests. We anticipate that if each test sequence was repeated in the same configuration (i.e. either warm start or cold start) then the average repeatability results would be improved further.

TYPICAL ROUTE REPEATABILITY – FUEL CONSUMPTION

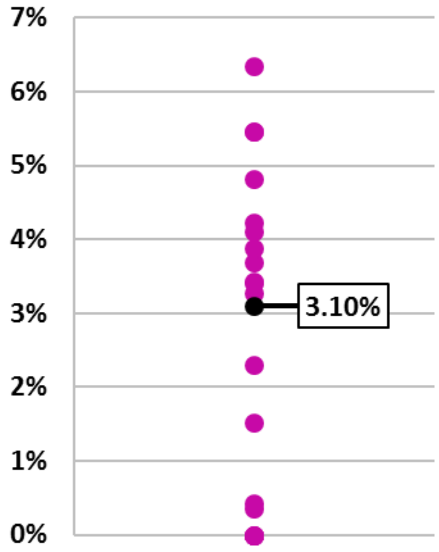


Chart 8 – Typical Fuel Consumption Test Variation Between Cold and Warm Start Tests

EMISSIONS TEST STANDARDS

Emissions and fuel consumption testing requires specific procedures to be followed pre-test, during testing and post-test. Regulations specify the measurement equipment that is permitted to be used. Testing was conducted according to the most current available draft RDE light passenger and commercial vehicle regulation, as proposed by the European Commission and adapted for Australian road conditions. The European RDE test procedure is still evolving and is conducted in conjunction with the laboratory test. The current European emissions regulations are stated in EC No 692-2008, with key amendments relating to PEMS tests being EC 2016/427 & EC 42016/646.

RDE requirements specify:

- Equipment specification and calibration
- Handling of filters pre- and post-test
- Environmental conditions of the test
- Test methodology
- Test Route & Driving Conditions
- Calculations

An overview of the emissions test and standards is in Figure 9 below.

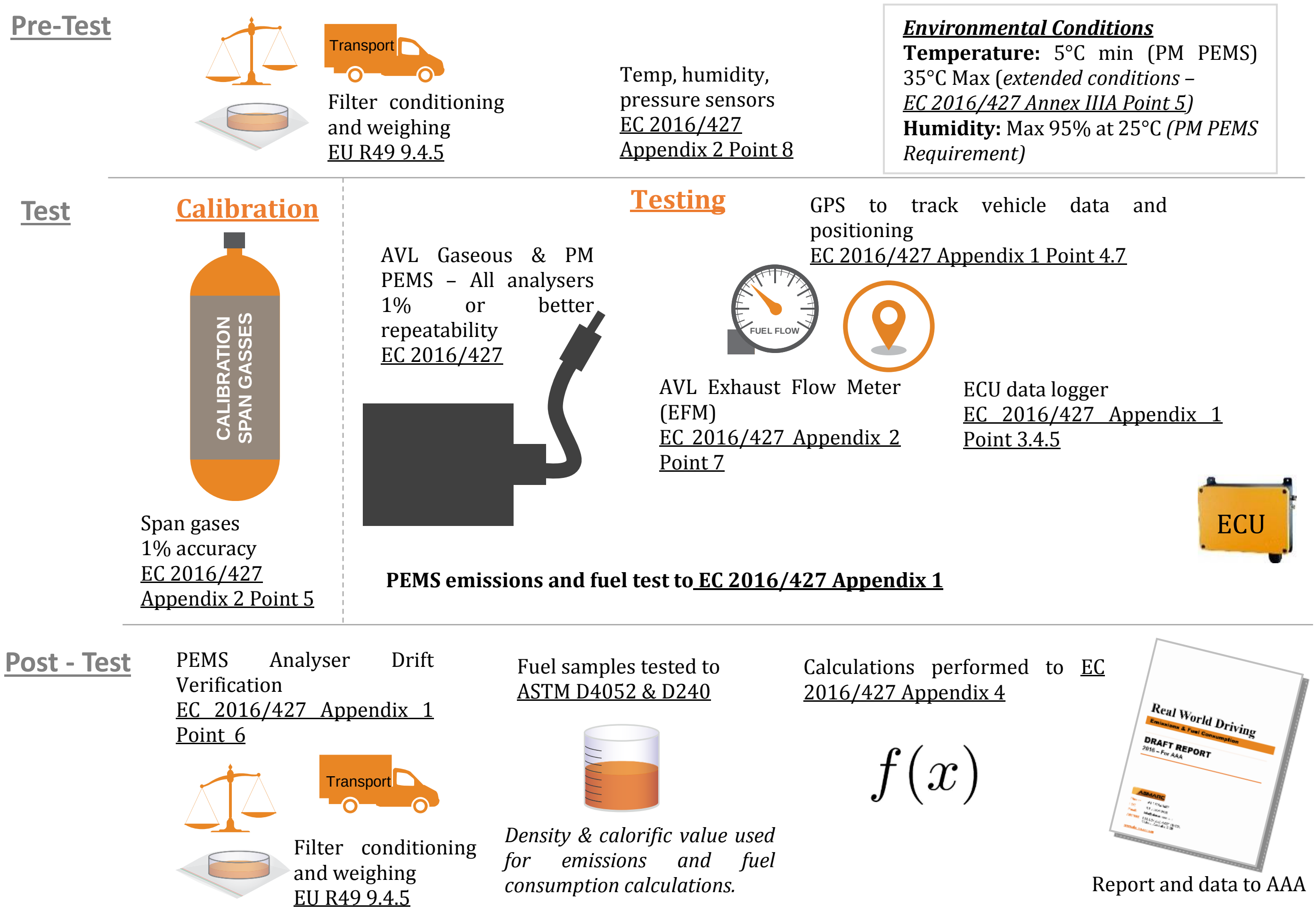


Figure 9 – Fuel and Emissions Test Standards

NOTE:

Particulate Mass measurement is not a requirement for light duty vehicle testing in Europe, however, the AAA and ABMARC view PM as an important emission to measure during this test program. Particulate matter measurement follows the heavy-duty vehicle emissions procedure and requirements as set out in EU R49 where applicable, using a constant dilution ratio rather than proportional.

SUMMARY OF MEASURED EMISSIONS

Emissions measured were: NO, NO_2, CO, CO_2, THC, and PM. The data processing includes start data (all data from the moment the engine starts).

NO_x
Oxides of nitrogen (NO_x) is the sum of nitric oxide (NO) and nitrogen dioxide (NO_2). NO_x is strongly dependent on combustion temperature, local concentration of oxygen and the duration of the combustion process. A slower ignition and lower combustion temperature tends to be beneficial for reducing NO_x emissions.

CO
Carbon monoxide (CO) formation is mainly dependent on the fuel-air equivalence ratio. CO is usually low during steady state engine operation but often increases during rich fuel operations, such as full load.

CO_2
Carbon dioxide (CO_2) is not a regulated emission in Australia at the moment, however is measured due to its contribution to greenhouse gases.

THC
Total hydrocarbons (THC) represents unburnt and partially burnt fuel.

PM
Often visible as soot and smoke ejected from an exhaust. Particulate matter (PM) is a complex mixture of small solid and liquid particles suspended in the exhaust gas which consist mainly of combustion generated carbon material (soot) on which some organic compounds (mainly from unburned fuel and lubrication oil) have been absorbed.

Fuel
Fuel consumption is expressed in Litres per 100 kilometres (L/100km). Exhaust mass flow was measured and the carbon balance method used to calculate fuel consumption.

INSTRUMENTATION

Three key areas were measured, being: vehicle emissions, exhaust flow and vehicle dynamics (speed and distance travelled). These are supplemented with the measurement of vehicle engine data and ambient conditions. This section provides an overview of the instrumentation that was used, and its installation.

OVEVIEW

Emissions measurements were performed utilising an AVL Portable Emissions Measurement System (PEMS). The PEM system consists of gaseous analysers for NO, NO_2, CO, CO_2 and THC contained in an environmentally controlled chamber and a gravimetric filter for PM measurements. A continuous sample of exhaust gas is taken via two probes located in the exhaust extension with the sample line temperature controlled to 191°C (gaseous) and 52°C (PM) as required by EC 2016/427. More information regarding the specifications of the PEM system can be found in Appendix D.

The ambient conditions, pressure, temperature and humidity, were recorded by the PEM system. All measurements were performed at a frequency of 1Hz or greater.

The PEMS equipment and driver added approximately 285 kg to the vehicle weight.

Key test equipment components are outlined in Table 8.

Key Items	
Description	**Serial Number**
Gaseous PEMS - (Gas Analysers: NO, NO2, CO, CO2, THC)	137
PM PEMS - Gravimetric Filter Module (GFM)	205
PM PEMS - Micro Soot Sensor	210
Exhaust Flow Meter	175

Table 8 – Test Equipment Part Description and Serial Numbers

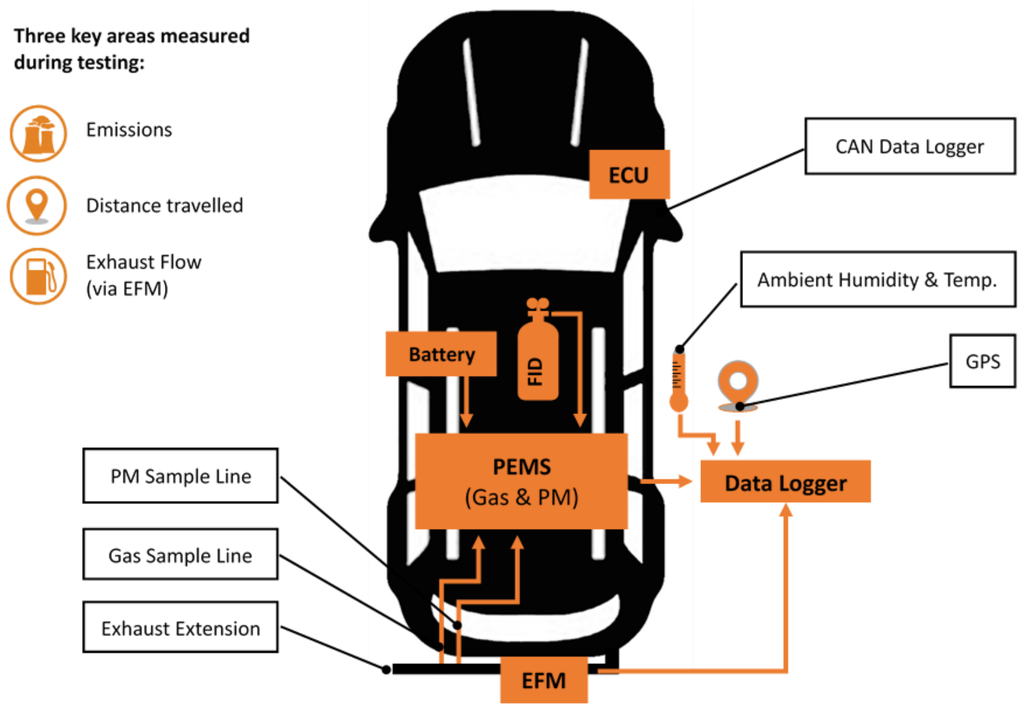


Figure 10 – Overview of Instrumentation

Emissions Test Equipment List		
Number	**Item**	**Description**
1	PEMS	The PEMS consists of: Gas analysers that measure NO, NO2, CO, CO2 and THC, and a PM gravimetric filter and soot sensor module that measure Particulate Matter.
2	FID Fuel	FID fuel is carried on board and is consumed by the hydrocarbon analyser.
3	PM Sample Line	PM sample is collected through a PM sample probe and transported through the temperature controlled PM sample line to the PM PEMS modules.
4	Gas Sample Line	Gas sample is collected through a Gas sample probe and transported through the temperature controlled Gas sample line to the Gaseous PEMS module.
5	Exhaust Extension	The exhaust pipe is extended to enable the exhaust gas to pass through the EFM and for a sample to be collected by the Gas and PM probes.
6	EFM	Exhaust gas flows through the exhaust flow meter (EFM). Exhaust mass, temperature and volume is measured and used for fuel consumption calculation.
7	Ambient Humidity, Pressure & Temperature	Ambient conditions are measured to ensure the test is compliant and to make any necessary calculations during data analysis.
8	GPS	GPS tracks the vehicle speed and drive route to ensure the test is compliant and is used for data analysis.
9	Data Logger	All data is logged second by second in real time.
10	Power Supply	Two 12 V, 180 Amp hour batteries supply the test equipment with power during the test. The PEMS is powered by mains power during warm up.
11	ECU CAN Data Logger	Available ECU data is logged for the duration of the test.

Table 9 – Emissions and Fuel Consumption Instrumentation

PEMS - EXHAUST EMISSIONS SYSTEM INSTALLATION

The PEMS was installed in the rear passenger and luggage compartment of the vehicle, as shown in Figure 11.


Figure 11 – PEMS System Installed

PM PEMS

The Gravimetric Filter Module provides the dilution air and draws the diluted exhaust gas from the dilution cell, mounted just after the sample probe, through the photo-acoustic measurement cell and then to the PM filter, providing time resolved (second by second) data. The device offers the choice between constant or proportional dilution. A constant dilution ratio was used for all testing. Ambient air is dried with a water separator and cleaned with HEPA and carbon filters for dilution air, to remove any contaminants. The PM PEM System allows time resolved (second by second) PM emissions data from its real-time photo acoustic sensor measurement in conjunction with the gravimetric filter PM mass.

Figure 12 – PM PEMS Without Any Attachments

GAS PEMS

All gas analyzers are mounted inside temperature controlled enclosures to ensure stable conditions and a high accuracy, even with changing ambient conditions. Exhaust gas flows at a rate of approximately 3.5 L/min through the 191°C temperature controlled sample line to the analysers. This prevents unaccountable losses of HC and NO_2 through condensation forming in the sample line. For each stage of testing, ABMARC used the same span gases to ensure repeatability was achieved across gaseous emissions.

Figure 13 – Gas PEMS Without Any Attachments

FID FUEL

The gas PEMS uses a Flame Ionization Detector (FID) analyser for measuring hydrocarbons. A small FID gas bottle consisting of 40% hydrogen, 60% helium was carried on board for each test.

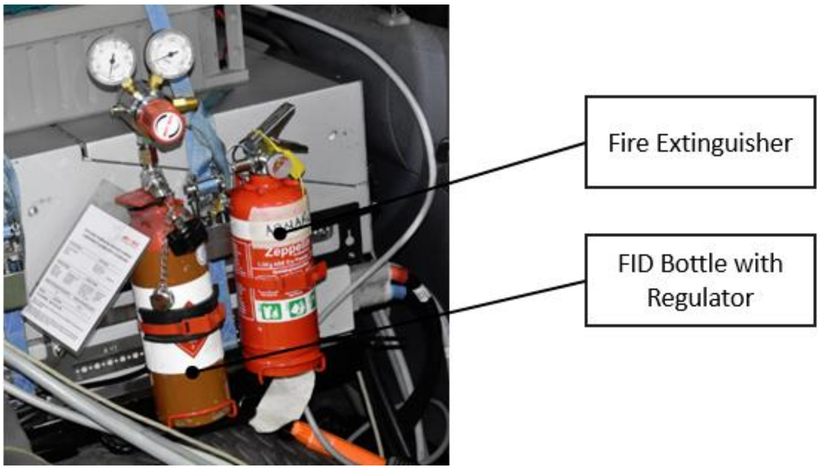


Figure 14 – FID Fuel Installation Example

SAMPLE LINES & EXHAUST EXTENSION

An exhaust extension was manufactured to suit the vehicle. The exhaust extension provides a well-mixed exhaust flow to the EFM and exhaust sample probes, and was designed to prevent leaks. The sample probes were installed according to EC 2016/427. The probe and sample line configuration is shown in Figure 15 with two sample probes installed, one for gaseous and one for PM emissions, located in the centre of the exhaust stream.

The PM probe comprises a 45-degree cut-off opening orientated into the exhaust stream. The raw PM sample gas was diluted with filtered and dried ambient air within 250mm of the sample point at a constant dilution ratio. The diluted PM exhaust sample was transferred to the gravimetric filter and soot sensor modules via a transfer line heated to 52°C.

The gaseous probe comprised a closed end probe with a number of inlet holes along its length to draw the sample gas in. The raw exhaust gas was passed to the emissions analysers via a sample line heated to 191°C.

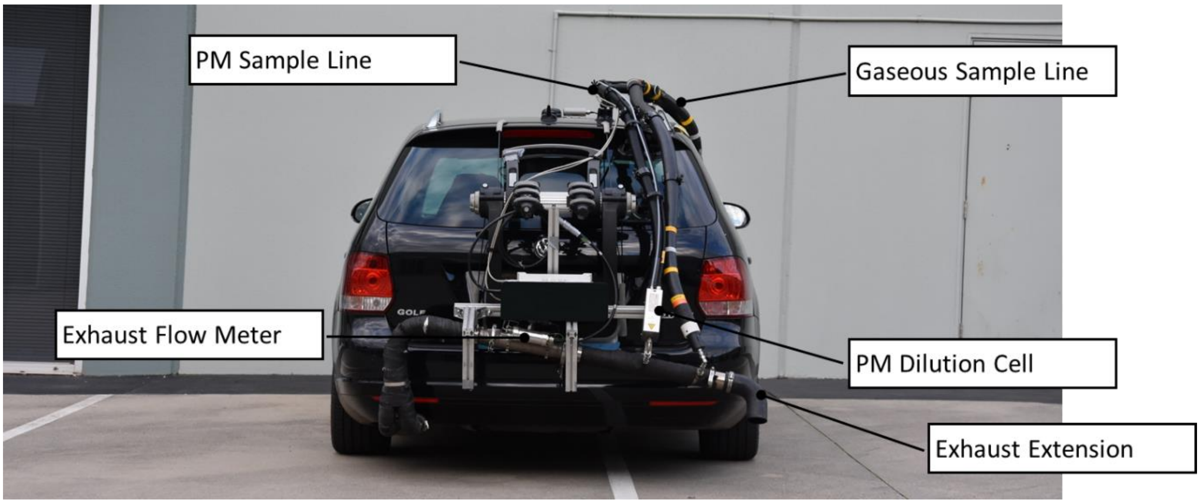


Figure 15 – Exhaust Extension and Emissions Sample Probes installed

EXHAUST FLOW METER

The EFM consists of the EFM tube, installed on the exhaust extension and the EFM control box, mounted on the rear of the test vehicle. The EFM tube measures exhaust flow using differential pressure with a pitot probe. The EFM control box consists of a dust and rain protection case enclosing temperature conditioned, high speed pressure transducers and electronics, enabling high accuracy measurements in dynamic flow conditions over a wide range of ambient conditions. The EFM measures second by second exhaust mass flow in kilograms per hour (kg/h), and exhaust temperature (°C), as well as volume flow in metres cubed per second (m^3/s). The data collected by the exhaust flow meter is used for calculating the emissions and fuel consumption results. Exhaust flow is measured according to the requirements set out in EC 2016/427 Appendix 2 Point 7.

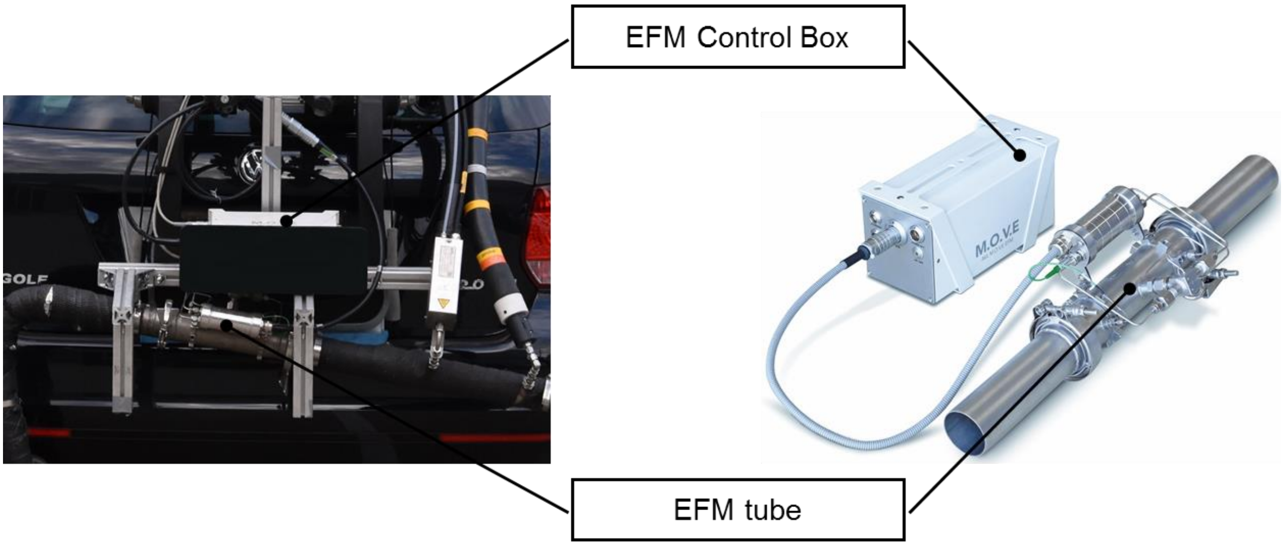


Figure 16 – Exhaust Flow Meter Installation Example

AMBIENT CONDITIONS & GPS
In addition to the instrumentation already listed the following was used:

- GPS – to record location and vehicle speed
- Ambient Air Temperature, Pressure and Humidity Sensor

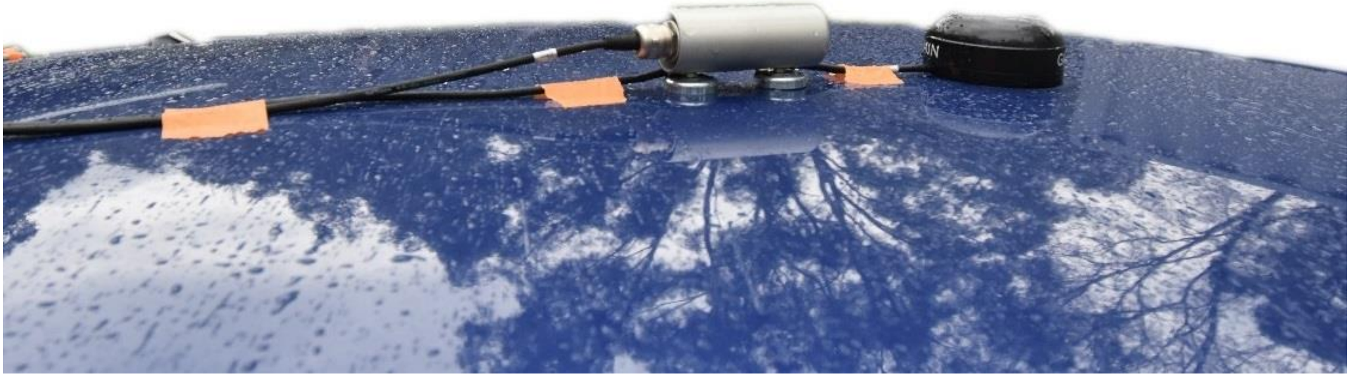


Figure 17 - Ambient Air, Temperature & Humidity Sensor (Left) & GPS (Right)

DATA LOGGING
Integrated data acquisition unit where all non-emissions signals are logged and combined into a time aligned output file.

Figure 18 – PEMS Data Logger & System Control, Installed in a Test Vehicle

PEMS INDEPENDENT POWER SUPPLY – LITHIUM BATTERIES

The electrical power to the PEM System is supplied by an independent external power supply unit, and not from a source that draws its energy either directly or indirectly from the vehicle under test. The power for the PEMS during the test is supplied through two Lithium-Ion batteries developed specifically for this project. The two 12 Volt batteries combine to supply the required 24 Volts and 180 Amp Hours. The batteries are installed in the test vehicle and connected to the PEMS as shown in Figure 19.

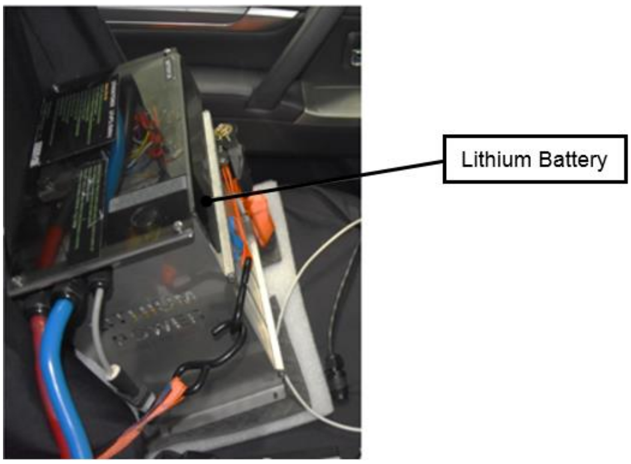


Figure 19 – Batteries for PEMS

CHARGEMASTER

The Chargemaster distributes power from multiple sources and is shown below in Figure 20. Before the test commences, the system is switched to draw power from the Lithium-Ion batteries, and the mains power is disconnected.

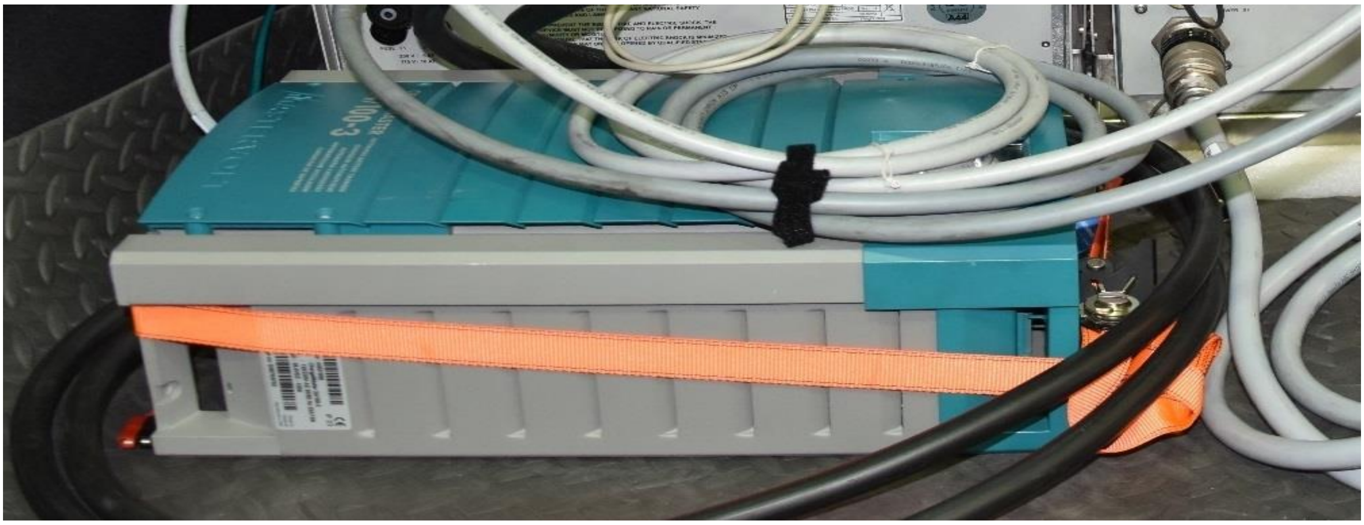


Figure 20 – Chargemaster for PEMS

VEHICLE & ENGINE DATA

A vehicle CAN data link adapter is used in conjunction with the PEMS system control unit to communicate with the vehicle OBD system. All required engine and vehicle parameters can be recorded and monitored throughout the test trip according to EC 2016/427 Appendix 1 Point 3.4.5

Figure 21 – Vehicle CAN Data Link Adapter

PARTICULATE MATTER FILTERS

The PM gravimetric filter module requires TX40 PM filters. These filters capture exhaust particulate matter during testing. After each test, they are carefully removed from the PM PEMS.

Particulate matter measurement follows the heavy-duty procedure and requirements asset out in EU R49. An example of a PM filter with soot embedded from a test is shown below in Figure 22.

Once removed from the PM PEMS, the filters are returned to their individually barcoded petri dish and sent to CSIRO to be weighed. The filter weight along with the time resolved soot signal data is used for the second by second PM results over the test.

Figure 22 – (Left) Example PM Filter After Use, (Right) Example PM Filters Inside Individually Bar-Coded Petri Dishes

FUEL PROPERTY TESTING

The fuel properties were used in the data post-processing to accurately calculate fuel consumption. Fuel samples were tested for density according to ASTM D4052. Fuel samples were delivered to a NATA approved facility for testing.

Figure 23 – Diesel Fuel Sample Ready to be Posted

RESULTS

RESULTS

OVERVIEW

The results outlined in this section were obtained during on-road vehicle testing using PEMS.

The Volkswagen Golf underwent a diesel particulate filter (DPF) regeneration event during the post-recall cold start test.

The DPF regeneration caused a significant increase in exhaust temperature, which can be noted in Chart 9.

The DPF regeneration occurred during the rural section of the drive route and lasted for approximately 15 minutes, which is slightly less than the duration of an NEDC test cycle. The DPF regeneration resulted in higher than normal fuel consumption during this period, which is typical of a DPF regeneration. This means that the post-recall cold start test results could not be compared directly to the pre-recall cold start test data.

Additionally, it is possible that DPF activation could also have resulted in higher NO_x emissions during this test. For these reasons, it was determined to use the warm start tests only in this analysis when quantifying changes between the pre-and post-recall tests.

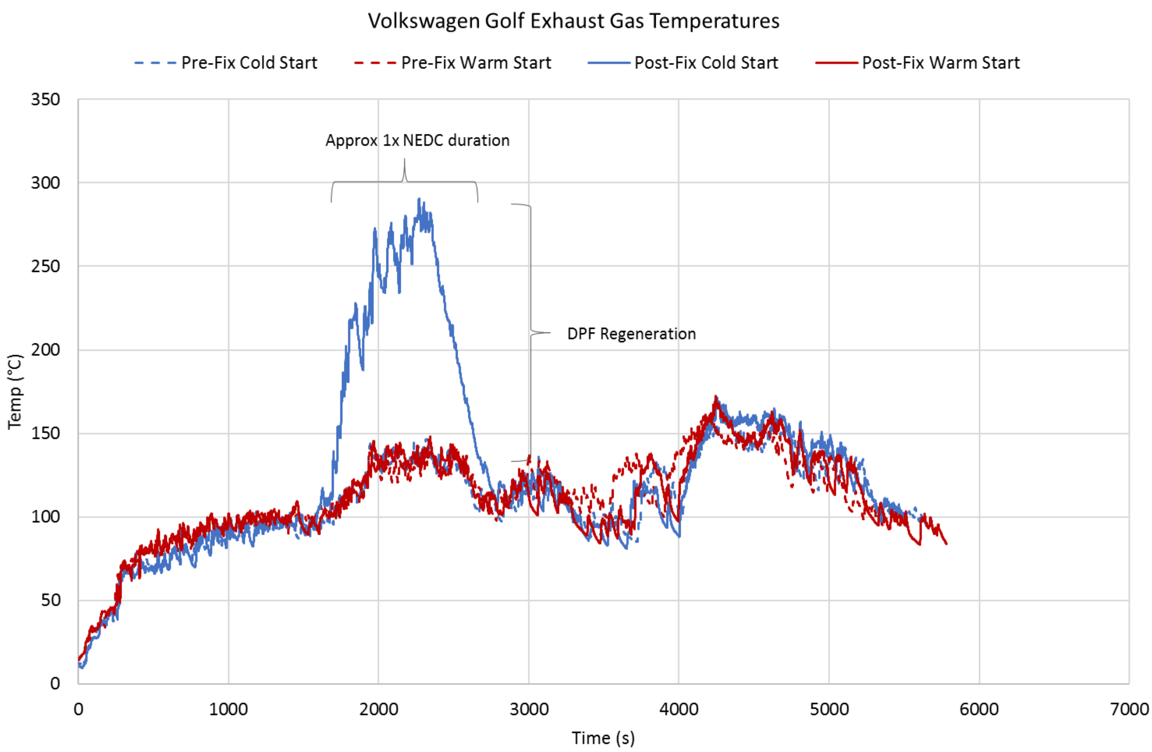


Chart 9 – DPF regeneration event on post recall cold start test

SUMMARY

The real world warm start fuel consumption increased by 7% post recall.

Comparing the warm start tests, a reduction in emissions was seen across all pollutants. NOx and PM decreased by 41% and 33% respectively post recall. CO and THC decreased by 13% and 25% post recall in the warm start test.

A summary of the pre-and post-recall test results is shown below in Chart 10.

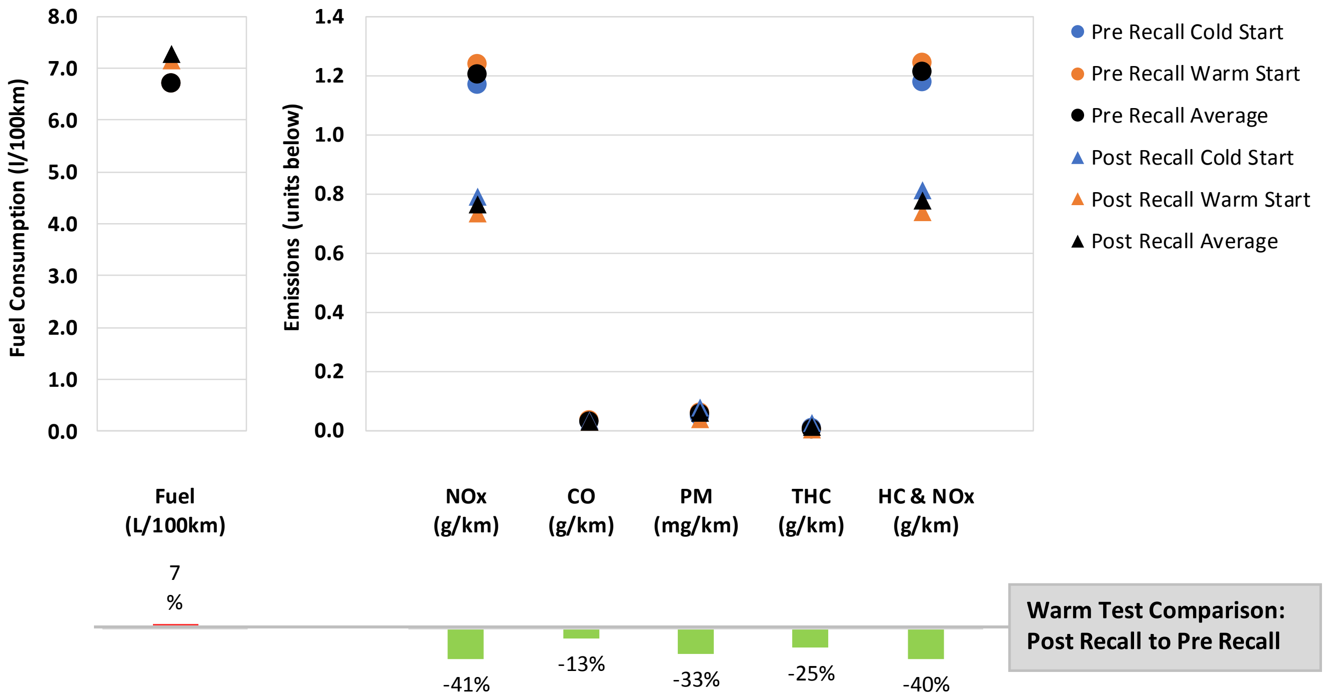


Chart 10 – Summary of Results

Table 10 provides a summary of the real world noxious emissions and fuel consumption compared to their certification limit (for emissions) and official figures (for fuel consumption). Note that the fuel consumption results where no DPF regeneration took place have the regulation Ki factor of 1.05 applied to account for particulate filter regeneration.

In Table 10, the applicable emissions limit for the 2010 VW Golf (Euro 5b) is 100%. Green shading indicates that the real world emissions or fuel consumption results are within the limit, and red shading indicates that the emissions or fuel consumption results exceeds the limit. Only the emissions results that have an applicable regulation limit are shown.

The warm start NOx emissions decreased to 4.11 times the laboratory limit after the recall, from 6.91 times the laboratory limit pre-recall. CO and PM were well below the laboratory limit in all tests.

Warm start test fuel consumption increased after the recall to be 1.26 times the official combined NEDC figure from the pre-recall fuel consumption result of 1.18 times.

Test Results Compared to Limits & NEDC Combined Fuel Consumption						
	Test	NOx	CO	PM	HC & NOx	Fuel
Pre Recall	Cold Start	652%	6%	1%	513%	118%
	Warm Start	691%	7%	1%	543%	118%
Post Recall	Cold Start	440%	7%	2%	355%	130%
	Warm Start	411%	6%	1%	323%	126%

Table 10 – Results Compared to Emission Limit & Official Fuel Consumption Figures (Combined NEDC)

AMBIENT TEST CONDITIONS

Emissions and fuel consumption testing conformed to the environmental requirements specified by Commissions Regulation (EU) 2016/427. The temperature and humidity test conditions were within the operational limits specified by test equipment manufacturers. The test environmental conditions are outlined in Figure 24 below.

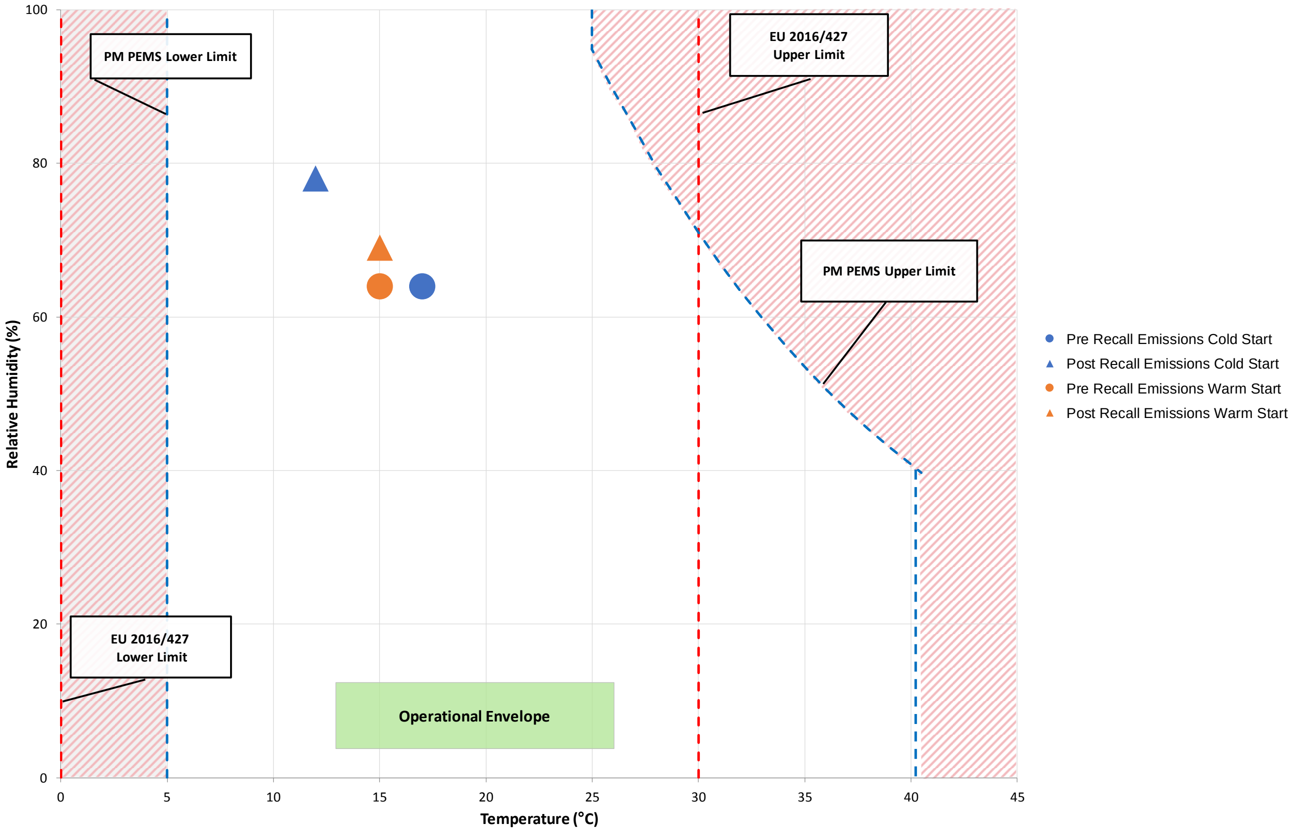


Figure 24 – Environmental Test Conditions

CHART KEY FOR FUEL CONSUMPTION AND EMISSIONS TEST RESULTS

The emissions results for the cold start and warm start tests are presented and compared to the applicable limits in the following fuel consumption and emissions results sections.

The chart key for the results in these sections is illustrated in Figure 25.

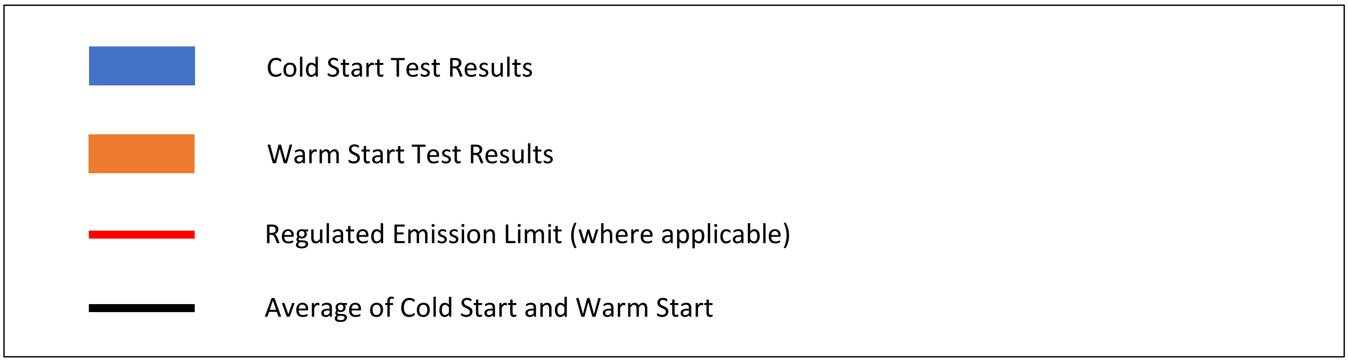


Figure 25 – Key for Emissions Results Charts

FUEL CONSUMPTION

The real world warm start test fuel consumption was 7% higher after the recall fix. The warm start test fuel consumption after the recall is 7.2 L/100km compared to 6.7 L/100km before. This is an increase of 0.5 L/100km after the recall fix.

The post-recall, real world, warm start test fuel consumption is 126% of the official figure. This is higher than the average pre-recall amount of 118% of the official figure.

As discussed previously, the cold start test results are not compared pre- and post-recall due to the diesel particulate filter regeneration that occurred during the post-recall cold start test. This is because a DPF regeneration can result in higher fuel consumption.

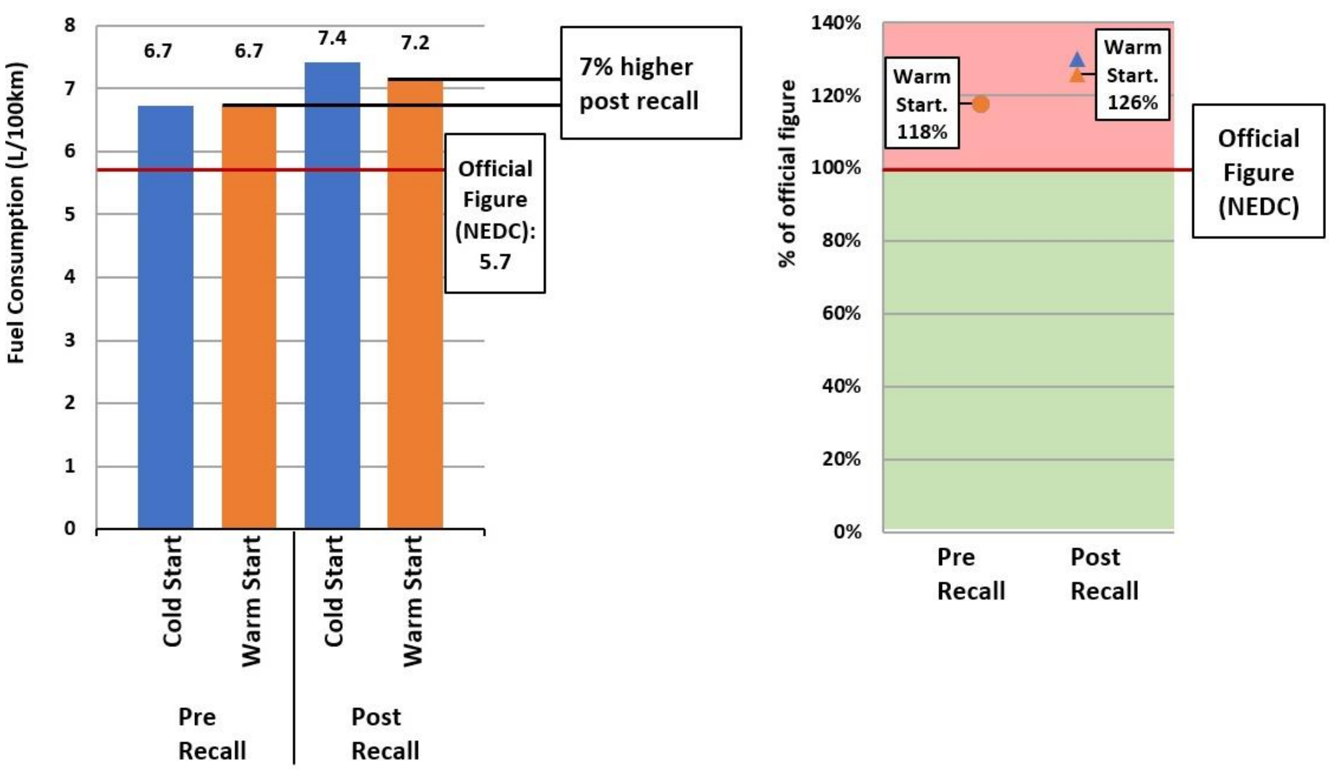


Chart 11 –Fuel Consumption Results

EMISSIONS RESULTS

The emissions results from the pre-and post-recall RDE tests were compared. These two sets of tests were also compared to the relevant regulation emission limit for each pollutant.

Emissions results are generally presented in grams of pollutant per kilometre travelled (g/km), with the exception of particulate matter, which is presented in milligrams of Particulate Matter (PM) per kilometre travelled (mg/km) due to the low weight of particulate matter emissions.

OXIDES OF NITROGEN (NO_X) EMISSIONS

The warm start test NO_x emissions were 0.50 g/km, or 41%, lower after the recall, a significant decrease. The post-recall warm start test NO_x is 0.74 g/km compared to 1.24 g/km before the recall.

Whilst the warm start test, post-recall NO_x has decreased significantly following the recall, the NO_X emissions are still higher from this real world test than the regulated laboratory limit, at 4.11 times the Euro 5 limit. Before the recall, the NO_X emissions were 6.71 times the limit.

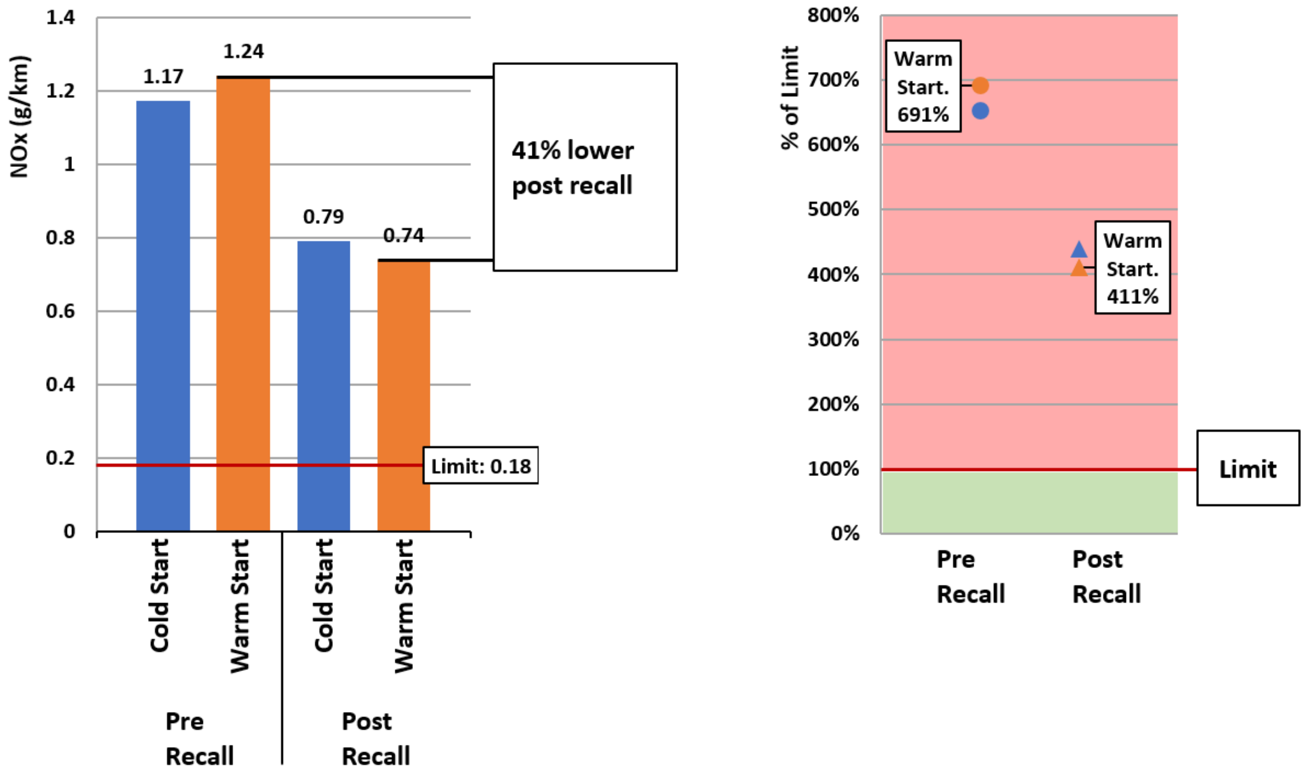


Chart 12 – Oxides of Nitrogen Emissions Results

PARTICULATE MATTER (PM)

The warm start test PM emissions were 33% lower after the recall, a significant decrease. Note that the PM measurements both pre-and post-recall were very small and both well under the Euro 5 limit. The warm start test PM after the recall is 0.04 mg/km compared to 0.06 mg/km before, 0.02 mg/km lower than the pre-recall PM emissions.

In terms of percentage of the Euro 5 limit, both the warm start tests, pre-recall and post-recall, PM emissions were only 1% of the Euro 5 limit.

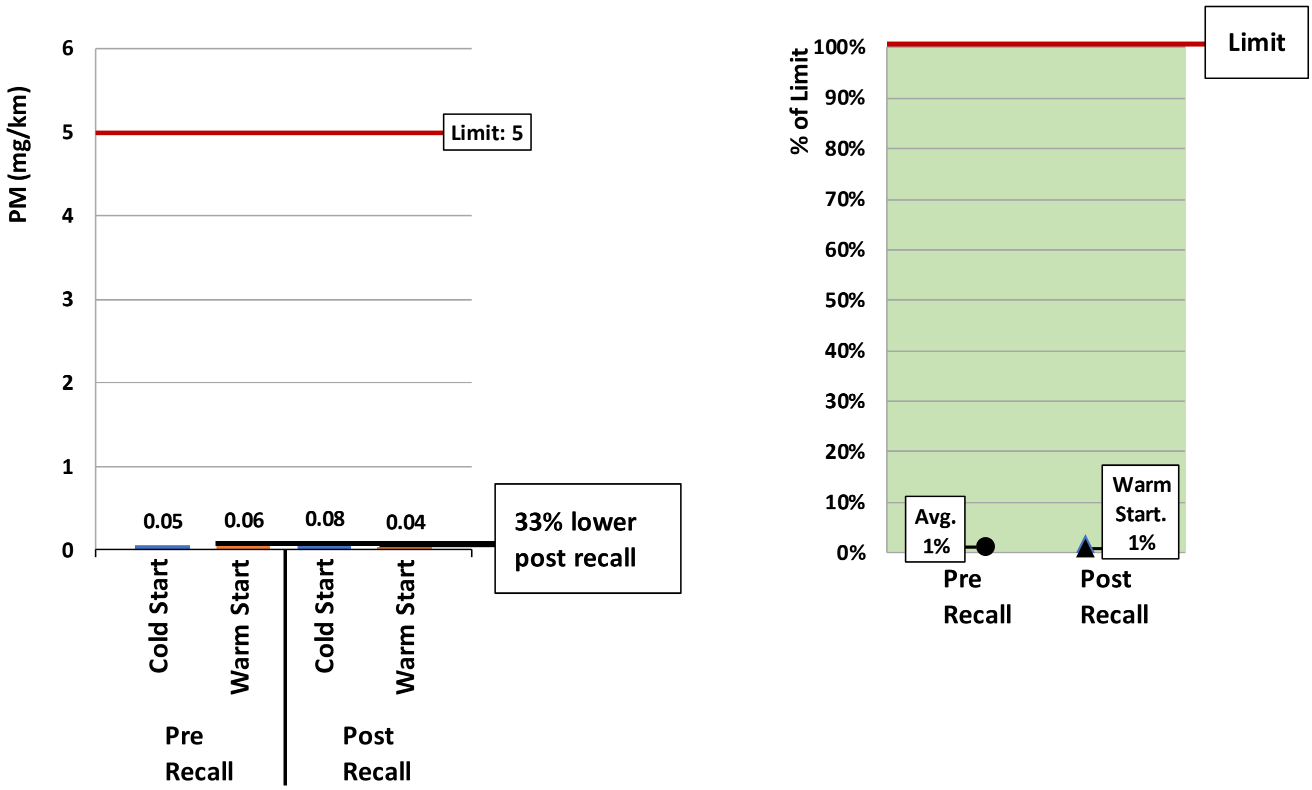
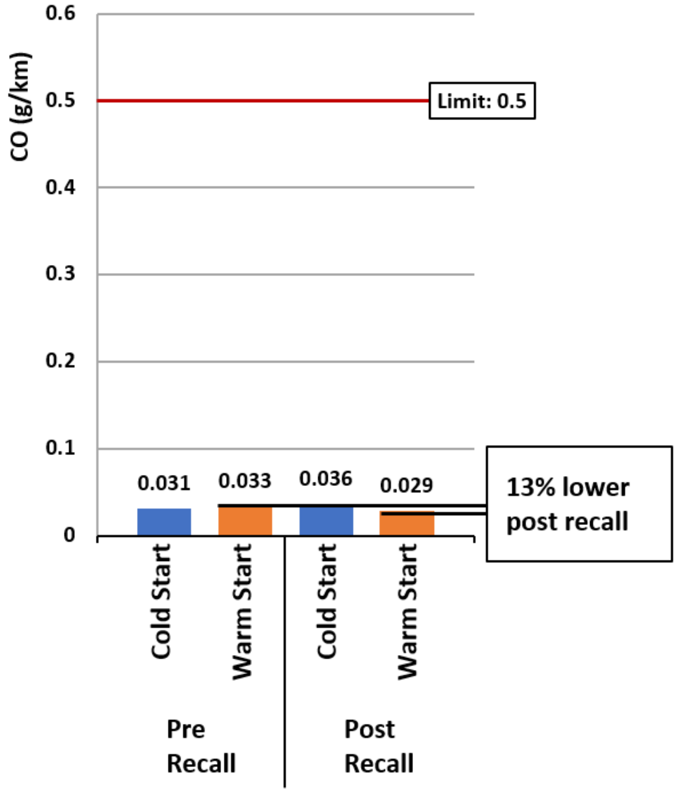


Chart 13 – Particulate Matter Emissions Results

CARBON MONOXIDE (CO)

The warm start test CO emissions were 13% lower following the recall. The warm start test CO after the recall is 0.029 g/km compared to 0.033 g/km before, 0.04 g/km lower than the pre-recall emissions.

The post-recall warm start test and pre-recall average real world CO emissions are lower than the regulated laboratory limit, at 6% of the Euro 5 limit.



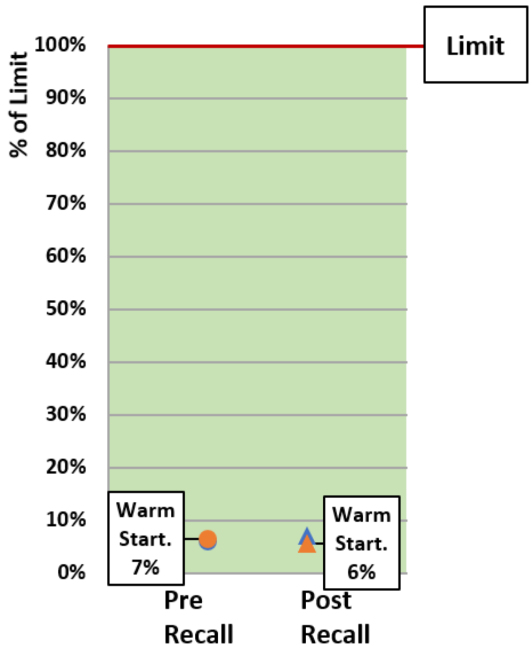


Chart 14 – Carbon Monoxide Emissions Results

CARBON DIOXIDE (CO_2)

The warm start test CO_2 emissions increased by 6% after the recall. The warm start test CO_2 after the recall is 181 g/km compared to 170 g/km before, an increase of 11g/km.

The warm start test real world post recall CO_2 is 1.21 times the official figure. This is higher than the average pre-recall amount of 1.14 times the official figure.

Note: The Ki factor was not applied to these emissions.

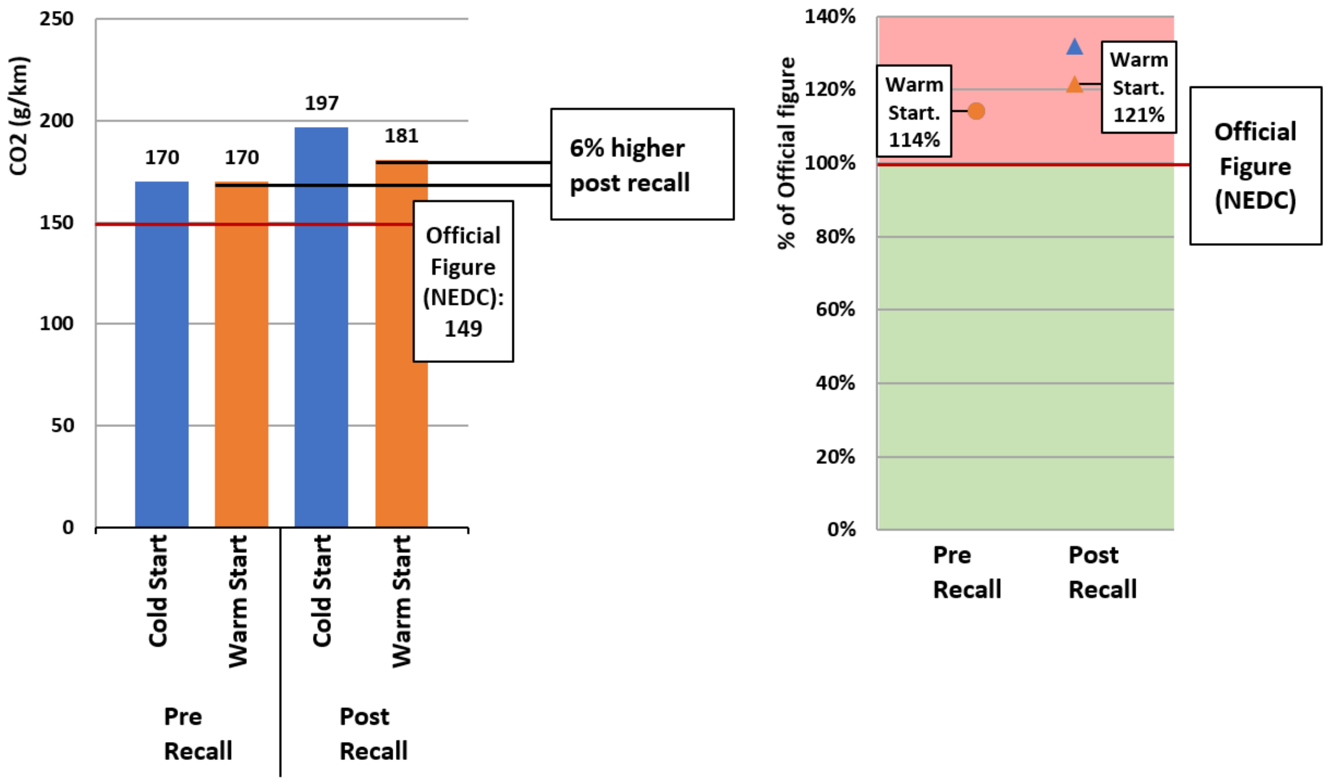


Chart 15 – Carbon Dioxide Emissions Results

TOTAL HYDROCARBONS AND OXIDES OF NITROGEN (THC & NO_X)

The warm start test HC and NO_x emissions were 40% lower after the recall, a significant decrease. These emissions are largely comprised of NO_x, with the HC contributing on average only 1% of the combined HC and NO_x results. The warm start test HC and NO_x emissions after the recall is 0.74 g/km compared to 1.25 g/km before, 0.51 g/km lower than the pre-recall HC and NO_x emissions. Whilst these emissions decreased significantly, pre- and post-recall HC and NO_X are both higher than the allowable Euro 5 laboratory limit.

The real world, post recall, warm start test HC and NO_x are higher than the regulated laboratory limit at 3.23 times the Euro 5 limit. This is lower than the average pre-recall amount of 5.28 times the limit.

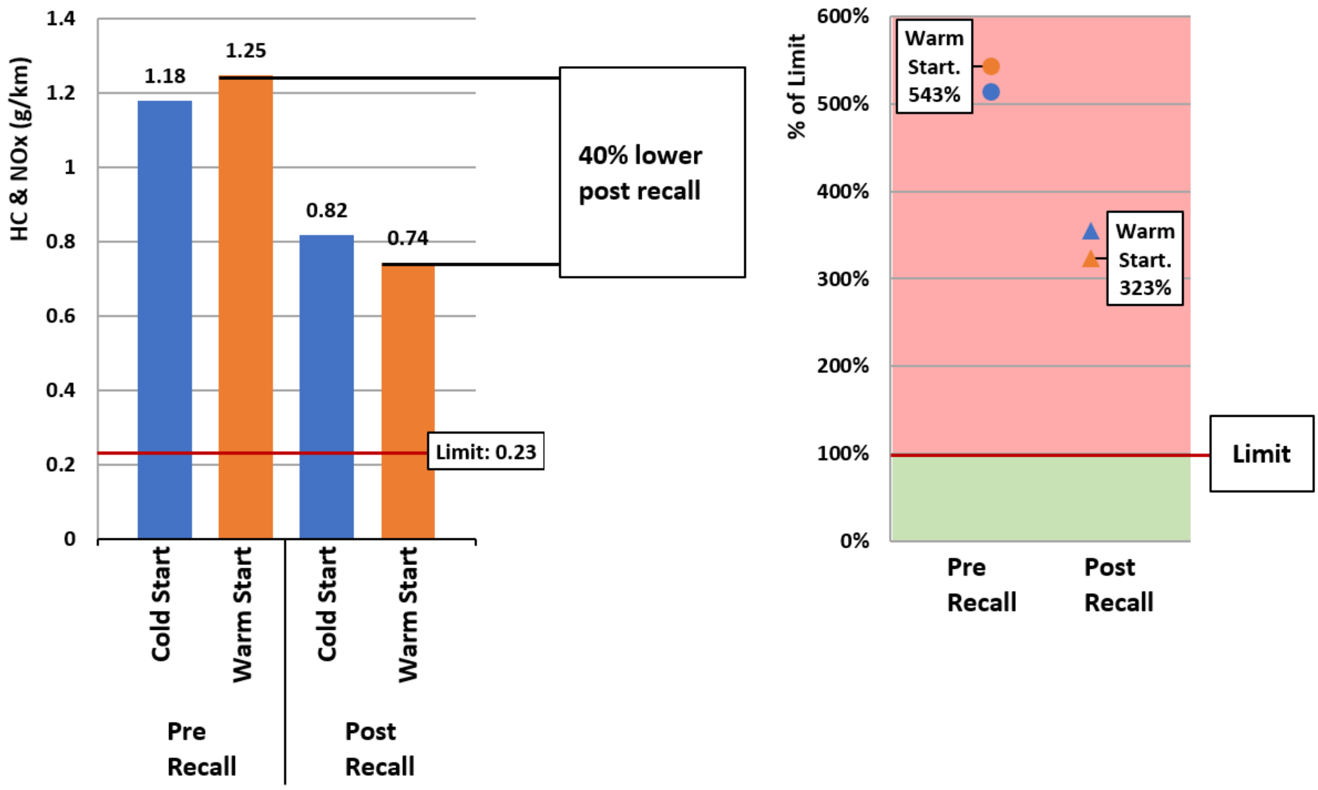


Chart 16 – Hydrocarbon and Oxides of Nitrogen Emissions Results

FURTHER ANALYSIS OF RESULTS

Vehicle performance was compared pre-and post-recall. Peak power and the corresponding torque over the engine speed range were measured on an uncertified chassis dynamometer. Over the range of RPM that power and torque could be measured (due to automatic transmission strategy overriding gear selection), it was found that both had increased slightly after the recall fix had been implemented.

The acceleration was compared from 0 km/h starts and rolling starts over a range of starting speeds. No significant difference to the acceleration rates were observed after the recall.

FUEL CONSUMPTION BY DRIVE SEGMENT

The warm start test fuel consumption in each drive route segment pre-and post-update is shown below in Chart 17. The urban section of the drive route shows the smallest change in fuel consumption at 2% higher post-recall. The rural segment had increased fuel consumption by 7%, while the motorway segment showed the highest increase in fuel consumption, being 14% greater than the pre-recall test.

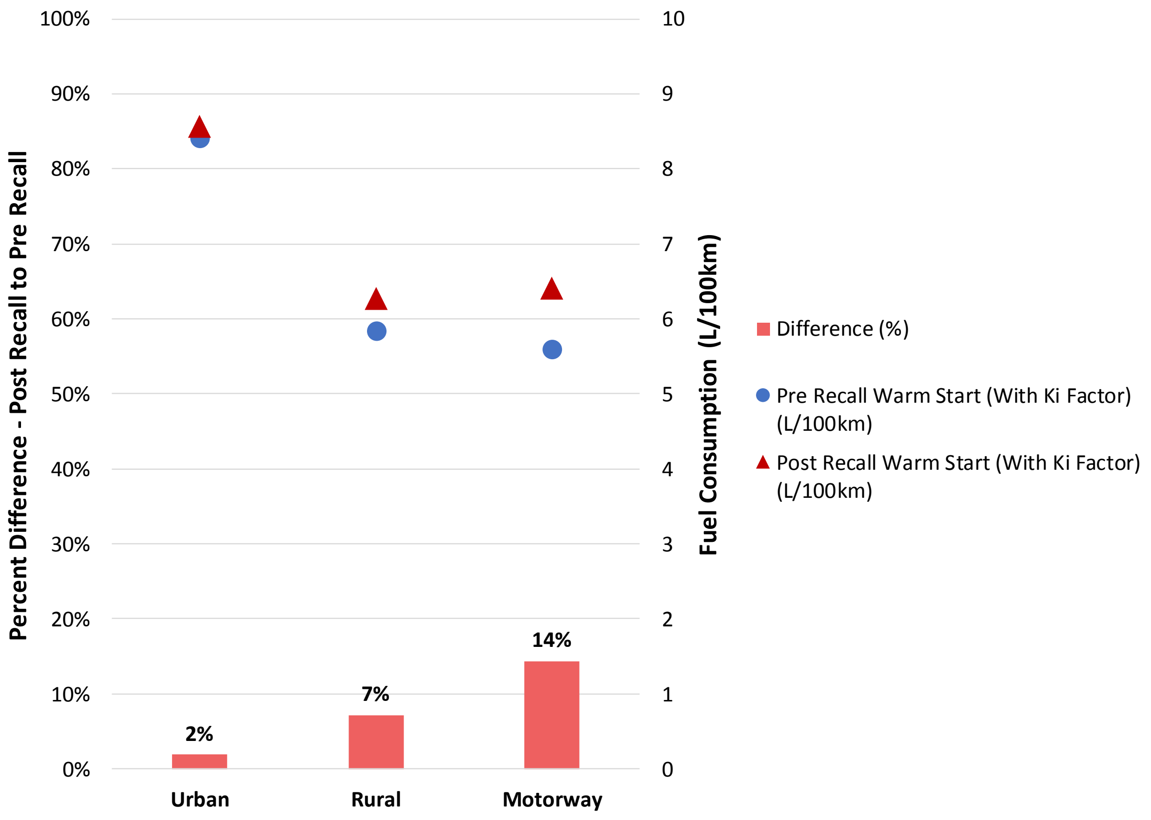


Chart 17 – Warm Start Fuel Consumption by Drive Segment

NO_X BY DRIVE SEGMENT

The warm start test NO_x in each drive route segment is shown below in Chart 18. The urban section of the drive route decreased NO_x by 38%. The rural segment had the smallest change at 27% lower than the pre-recall test. The motorway segment showed the highest decrease in NO_x to 60% lower than the pre-recall test.

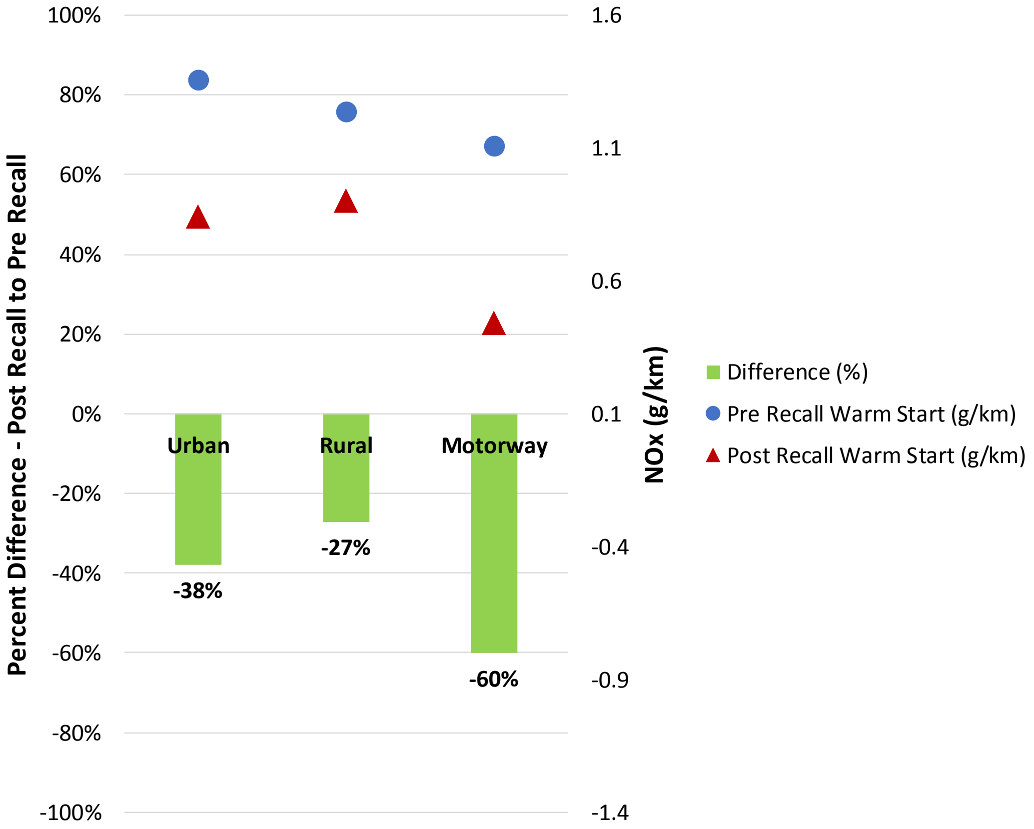


Chart 18 – Warm Start NO_x by Drive Route Segment

CUMULATIVE NO_X

The cumulative NO_x in grams is shown below in Chart 19. It appears that the DPF regeneration caused a small increase in the post recall cold start test NO_x emissions, when compared to the post recall warm start test.

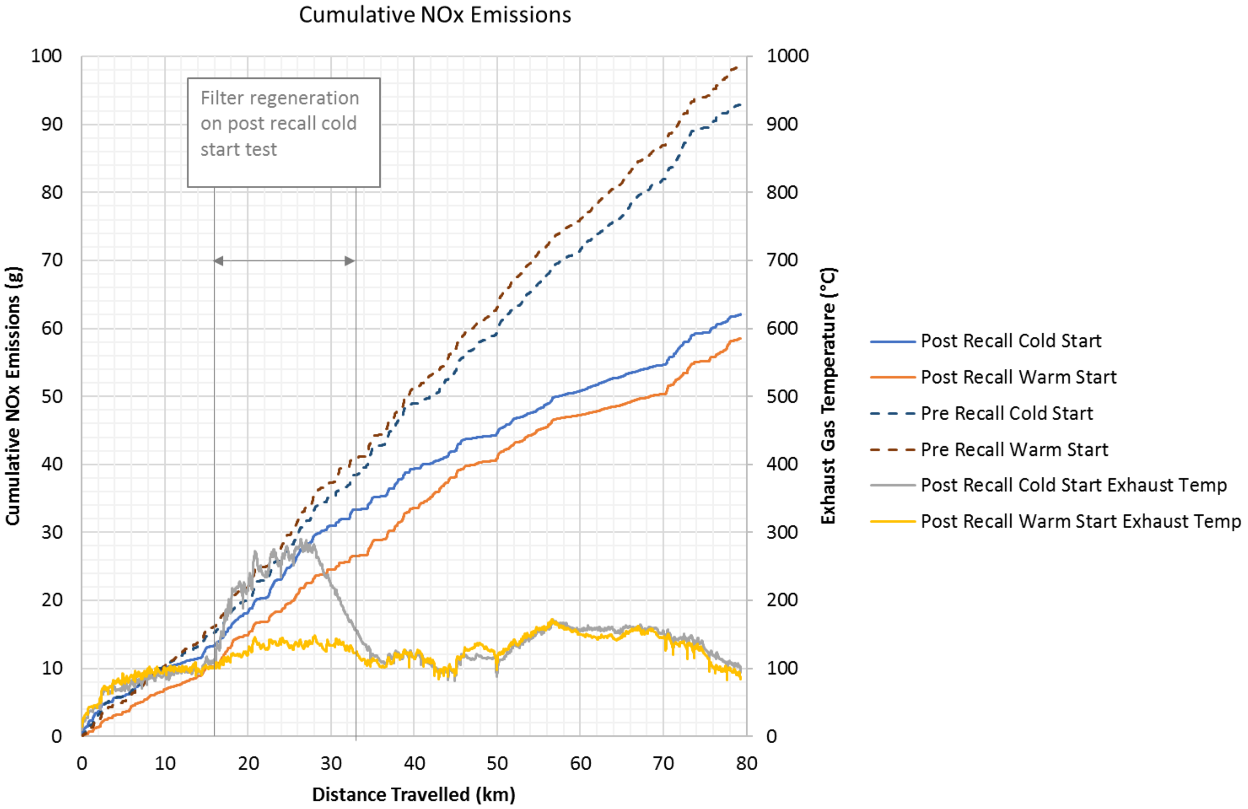


Chart 19 – Cumulative NO_x Emissions

The cumulative distance specific NO_x in grams per kilometre is shown below in Chart 20.

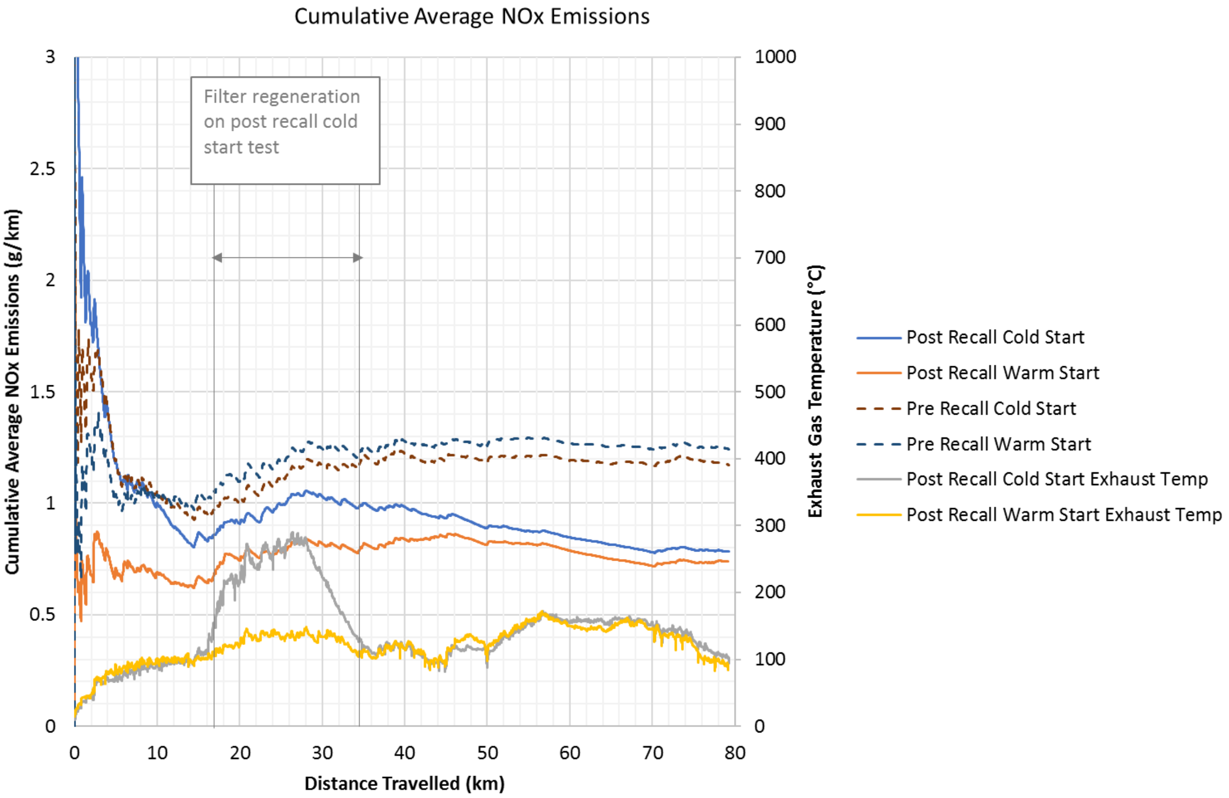


Chart 20 – Cumulative Average Distance Specific NO_x Emissions

CUMULATIVE FUEL CONSUMPTION

The cumulative fuel consumption in Litres is shown below in Chart 21. The DPF regeneration caused an increase in the post recall cold start test fuel consumption (which can be seen by an increase in the slope of the curve), when compared to the post recall warm start test.

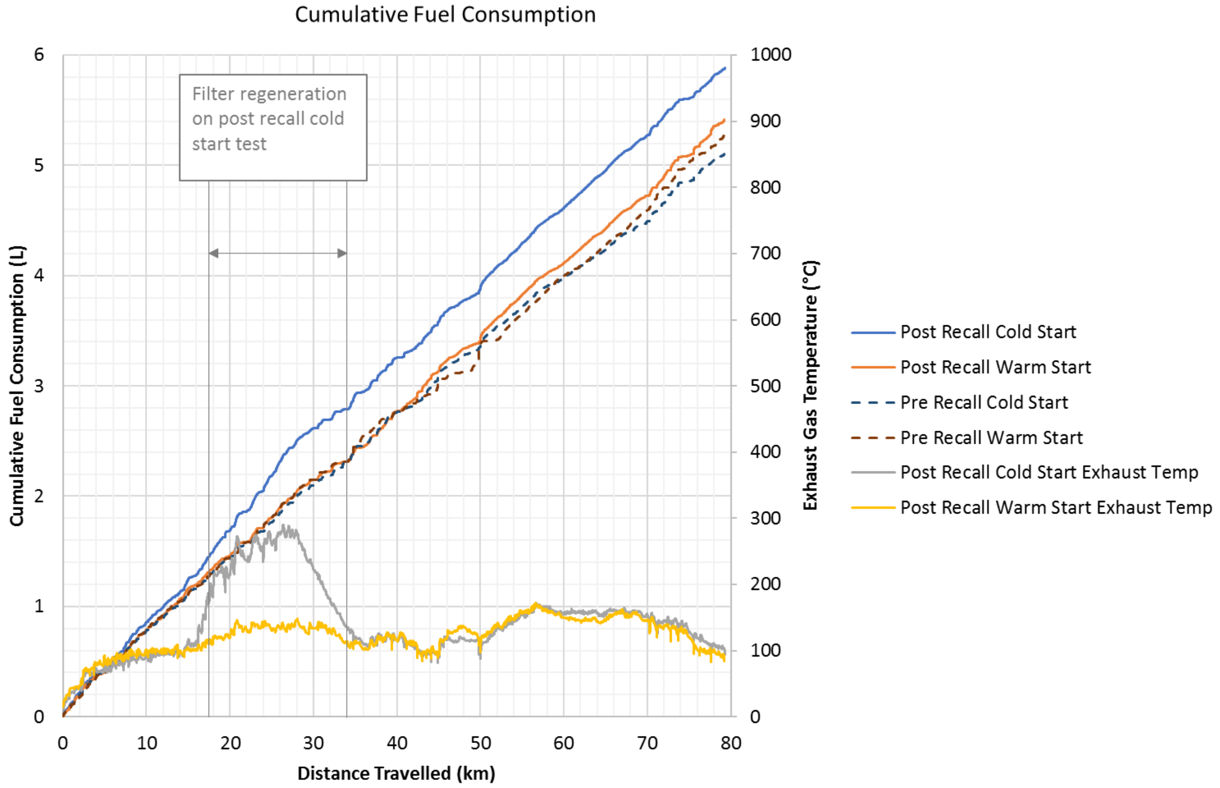


Chart 21 – Cumulative Fuel Consumption

The cumulative distance specific fuel consumption in Litres per 100 kilometres is shown below in Chart 22.

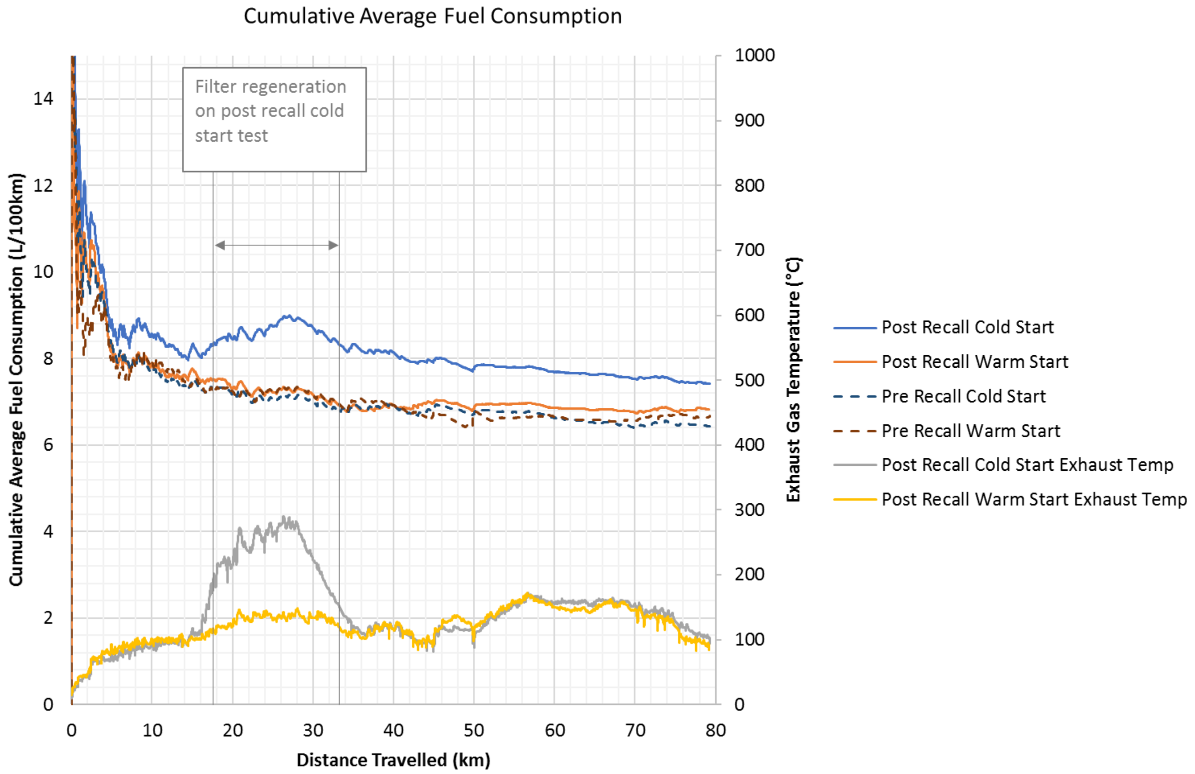


Chart 22 – Cumulative Average Distance Specific Fuel Consumption

APPENDIX

APPENDIX

A. FUEL DENSITY

Fuel consumption was corrected for fuel density. The density was obtained following the American Society for Testing and Materials standard (ASTM) D4052. All testing was conducted using the same tank of fuel. The density of the diesel fuel used was 834.5 g/L.

B. TEST PARAMETERS

The following table summarises the measurement parameters required and logged at 1Hz during a PEMS test.

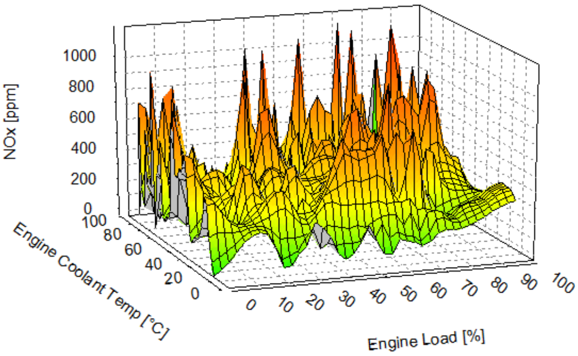
Test Parameters				
Parameters	**Unit**	**Measurement Technique**	**Measurement Technique used by ABMARC**	**Comments**
Exhaust Gas Parameters				
THC concentration	ppm	PEMS Analyser	PEMS Analyser	**Mandatory**
CH_4 concentration	ppm	PEMS Analyser	PEMS Analyser	**Mandatory**
NMHC concentration	ppm	PEMS Analyser	PEMS Analyser	**Mandatory**
CO concentration	ppm	PEMS Analyser	PEMS Analyser	**Mandatory**
NOx concentration	ppm	PEMS Analyser	PEMS Analyser	**Mandatory**
CO_2 concentration	ppm	PEMS Analyser	PEMS Analyser	**Mandatory**
Particulate Matter	g/m^3	PEMS Analyser	PEMS Analyser	**Mandatory**
Exhaust Mass Flow Rate	kg/s	EFM	EFM	**Mandatory**
Exhaust Gas Temperature	degC	EFM Sensor	EFM Sensor	**Mandatory**
Engine Parameters				
Engine Torque	Nm	ECU or Sensor	ECU	**Mandatory**
Engine Speed	RPM	ECU	ECU	**Mandatory**
Engine Coolant Temperature	degC	ECU	ECU	Is needed for data processing
Engine Intake Air Temperature	degC	Sensor	ECU & Sensor	Is needed for data processing
Engine Intake Air Flow	g/s	ECU	ECU	Is needed for data processing
Engine Fuel Flow	mm^3/s	ECU or Sensor	EFM	Is needed for data processing
Fault Status	-	ECU	Check with Diagnostic Tool	ECU Fault Status needs to be recorded prior to test
Vehicle Parameters				
Vehicle Speed	km/h	ECU or Sensor	ECU, GPS	**Mandatory**
Vehicle Latitude	degree	GPS	GPS (PEMS)	**Mandatory**
Vehicle Longitude	degree	GPS	GPS (PEMS)	**Mandatory**
Vehicle Acceleration	m/s^2	GPS	GPS (PEMS)	**Mandatory**
Distance Travelled	km	GPS	GPS (PEMS)	**Mandatory**
Ambient Conditions				
Ambient Temperature	degC	ECU or Sensor	Sensor (PEMS)	**Mandatory**
Ambient Humidity	%	Sensor	Sensor (PEMS)	**Mandatory**
Ambient Pressure	kPa	ECU or Sensor	Sensor (PEMS)	**Mandatory**

Table 11 – Mandatory Parameters for RDE Testing

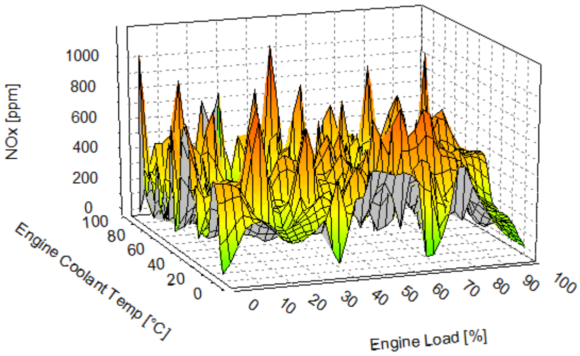
C. NO_X AND ENGINE LOAD

The following charts compare the NO_x emissions at different load and temperature points over the engine map during each real world emissions test.

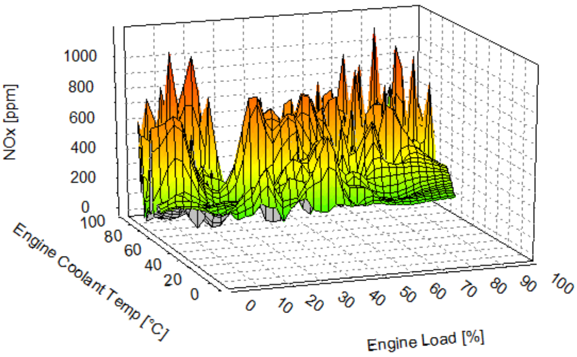
Pre-Recall – Cold Start



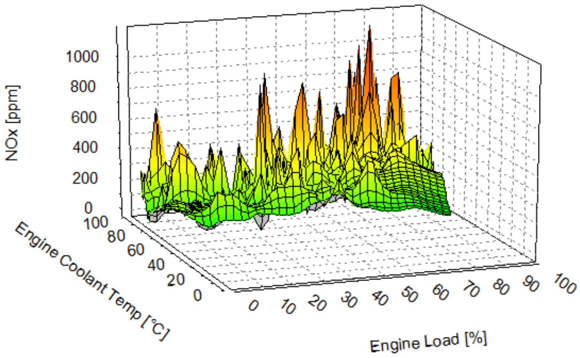
Post-Recall – Cold Start



Pre-Recall – Warm Start

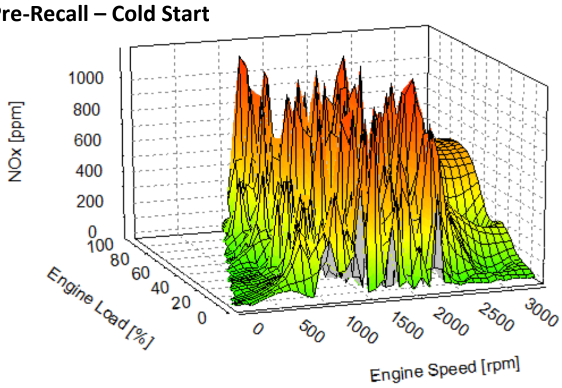


Post-Recall – Warm Start

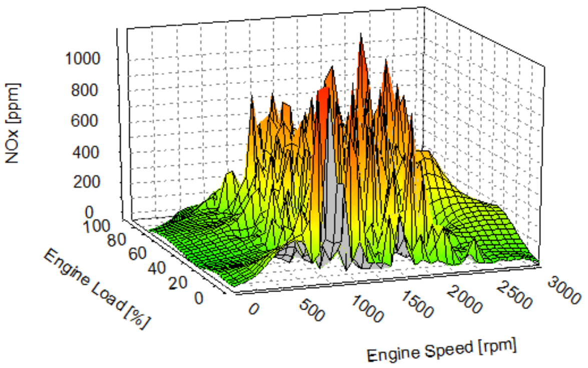


The following charts compare the NO_x emissions at different load and engine RPM points over the engine map during each real world emissions test.

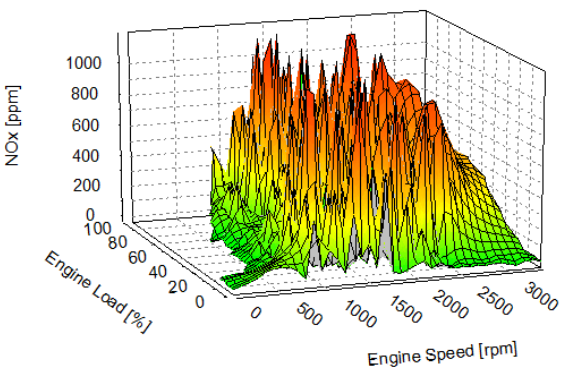
Pre-Recall – Cold Start



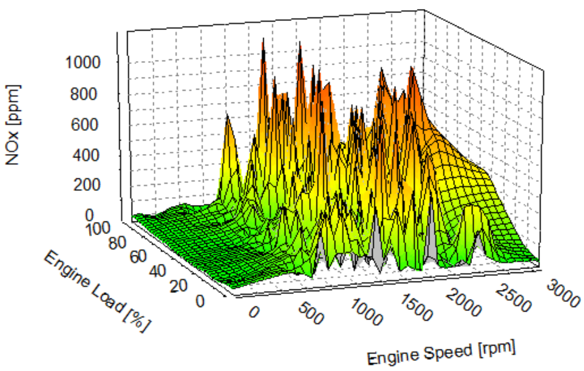
Post-Recall – Cold Start



Pre-Recall – Warm Start



Post-Recall – Warm Start



D. PEMS OVERVIEW

The AVL Gaseous PEMS meets the proposed European RDE instrumentation requirements for conformity with EC 2016/427.

The PM PEM System allows time resolved (second by second) PM emissions data from its real-time photo acoustic sensor measurement in conjunction with the gravimetric filter PM mass.

Gas PEMS

All analyzers are mounted inside temperature controlled enclosures to ensure stable conditions and a high accuracy even at changing ambient conditions. Exhaust gas flows at a rate of approximately 3.5 L/min through the 191° C temperature controlled sample line to the analysers. This prevents unaccountable losses of HC and NO_2 through condensation forming in the sample line. For each stage of testing, ABMARC used the same span gases to ensure repeatability was achieved across gaseous emissions.

PM PEMS

The Gravimetric Filter Module provides the dilution air and draws the diluted exhaust gas from the dilution cell, mounted just after the sample probe, through a PM Filter and to the photo-acoustic measurement cell, providing time resolved (second by second) data. The device offers the choice between constant or proportional dilution. Ambient air is dried with a water separator and cleaned with a HEPA and carbon filters for dilution air, to remove any contaminants.

Attribute	EC 2016/427		AVL PEMS & EFM	
	Accuracy	Repeatability	Accuracy	Repeatability
EFM	± 2%	± 1% *of max. calibration flow*	Satisfied	Satisfied
CO/CO_2	± 2%	± 1%	Satisfied	Satisfied
Hydrocarbons	± 2%	± 1%	Satisfied	± 0.5%
NOx (NO_2/NO)	± 2%	± 1%	Satisfied	± 0.5%
PM (Gravimetric)	2%	0.5 µg / 1%	Satisfied	Satisfied

Note:

1. *European RDE requirements still in development*
2. *The PEMS analyser repeatability requirement is no greater than 1 % of the full-scale concentration for a measurement range equal or above 155 ppm (or $ppmC_1$ and 2 % of the full-scale concentration for a measurement range of below 155 ppm (or (or $ppmC_1$).*
3. *The EFM accuracy is 2% of reading or 0.5% of full-scale, whichever is the greatest.*

Gas Analyser Drift Specifications

THC: Heated FID <1.5ppmC1/8hrs
NO/NO_2: NDUV 2ppm/8hrs
CO: NDIR 20ppm/8hrs
CO_2: NDIR 0.1 vol.%/8hrs

PM Analyser Specifications

Raw sample rate: 6 LPM over filter.
Face velocity: 45cm/sec
PM Filters: 47mm TX40

Gas PEMS Module

Photo-acoustic sensor

Gravimetric Filter Module

PM PEMS Modules

The combination of two PM measurement principles (gravimetric and photo-acoustic) were developed to meet US and EU in-use requirements for time resolved measurements. Gravimetric measurement delivers a single value for an entire test. The time-resolved particulate (PM) emissions are calculated by weighing the loaded gravimetric filter after the end of the test and using the time resolved soot signal and the exhaust mass flow as inputs. This enables second by second PM data to be captured during testing.

Gas Analysers

Heated Flame Ionisation Detector (FID)

The AVL Gas PEMS uses a heated FID analyzer for measuring the THC concentrations.

The flame ionization detector measures hydrocarbons through the ionization of carbon atoms in organic compounds when burned in a hydrogen flame. A supply of burner air free of hydrocarbons maintains the flame. Ionized particles are produced using the hydrogen flame to burn hydrocarbons present in the sample gas. This generates an ionization current between the two electrode shells that is directly proportional to the number of organically bound carbon atoms present within the sample gas. This ionization current is amplified electrically and converted into a calibrated voltage signal for data acquisition.

Ultra Violet (UV)

The NO and NO_2 measurement is conducted simultaneously and directly (without the need of a NO_2 to NO converter) using the UV analyzer. The UV Analyser is a dual-component UV photometer with high zero-point and end-point stability. The system reads NO and NO_2 separately, which are then combined to provide NO_x readings.

Non-Dispersive Infra-Red (NDIR)

CO and CO_2 measurements are conducted with the NDIR analyser, specially optimized for high accuracy and resolution of the CO channel at low concentrations.

Qualitative and quantitative molecular analysis is performed by infrared spectrometry. The analyser is located in a temperature controlled (±0.5 °C) compartment that is maintained even during rapid changes in ambient temperature. Under these conditions, the NDIR provides stable signals with little to no drift over hours of operation.

Heated Gas Transfer Line

PM Analysers

PM Dilution Cell and Transfer Line

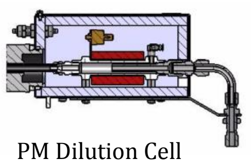
The dilution and exhaust transfer unit consists of the dilution cell at the sample probe, which receives a dilution air supply via an external hose from the Gravimetric Filter Module (GFM). The dilution cell feeds directly into the 52 °C heated transfer tube connected to the GFM.

Photo-Acoustic Sensor

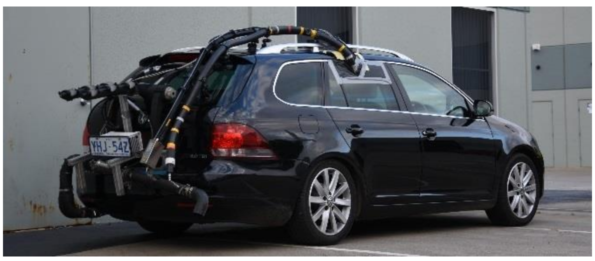
The flow rate through the photo-acoustic sensor is approximately 2L/min. Time resolved PM emissions are determined by scaling the real-time soot signal to the gravimetric filter reference. The exhaust sample is exposed to modulated light which is absorbed by the soot particles in the exhaust causing periodic warming and cooling of the particles. The resulting expansion and contraction of the carrier gas generates a sound wave that is detected by microphones. Clean air produces no signal. When the air is loaded with soot or exhaust gas, the signal rises proportionally to the concentration of soot in the measurement volume. The soot sensor does not respond to the volatile fractions of the PM.

Gravimetric Filter Module

Filter loading on the PM filter is monitored to avoid overloading. High-performance filter elements are used for filtering particulates. A filter efficiency of 99.995 % is specified for filter elements at the nominal flow rate of 5 L/min through the filter.



PM Dilution Cell



PEMS Installed on the VW Golf

D. FURTHER RESULTS

The following pages contain summary results for each test, including test conditions and result analysis according to RDE.

Real World Emissions Summary Report: VW Golf - Pre Recall

Client	AAA
Project Number	2017_01_AAA_02
Report Number	Pre-Recall Fix - VW Golf Wagon

EMISSION STANDARDS & RESULTS SUMMARY

Emission Std	Conformity Factor (CF) Applied	Fuel
Euro 5a	#N/A	Diesel

	NOx	CO	PM	THC	HC + NOx	NMHC	CO_2	Fuel
Lab	651%	6%	1%	N/A	513%	N/A	114%	113%
CF	N/A	*CF: Euro 6 permits higher real-world driving NOx emissions than lab-based limits*						

TEST OVERVIEW

These tests has been conducted generally in accordance with EC No 2016_427 & EC Regulation No 2016_646, known as Real Driving Emissions (RDE), modified for Australian roads and ambient conditions. Two tests have been conducted; one with a cold engine start and one with a warm engine start. The drive route was conducted in Victoria, starting an urban segment in the eastern suburbs of Melbourne, followed by a rural segment near Lysterfield Park, and a segment on the Eastlink Freeway.

This report compares real-world emissions and fuel consumption measurements against the noxious emissions limits and manufacturer's declared CO_2 and fuel consumption when tested in a laboratory under controlled conditions.

VEHICLE DETAILS

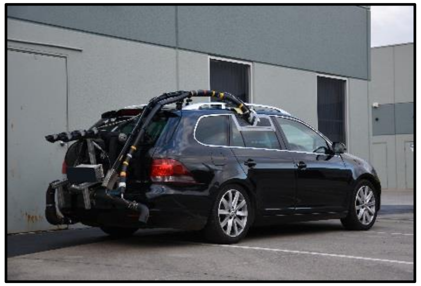
Make	VW
Model	Golf Wagon 103 TDI
Model Year	2010
Vehicle Kilometers (Start / End)	113093 km / 113173 km
Engine & Fuel Type	2.0L Turbo Diesel
OBD Check? - DiagnosticTrouble Codes (DTC)?	Yes - No DTC Active
Applicable Emissions Standard	Euro 5

TEST INFORMATION	COLD TEST	WARM TEST
Test Date	05-Jul-17	05-Jul-17
Test Trip Meets Requirements?	YES	YES
Average Ambient Temperature (°C)	13	14
Average Ambient Pressure (kPa)	100.0	99.9
Average Ambient Humidity (%)	72	61
Road Condition	Dry	Dry
Traffic Condition	Normal Traffic - No route deviation	
Fuel Sample	Sampled from tank. Density tested.	

TEST EQUIPMENT - PART DESCRIPTION	SERIAL #
Gaseous (NO, NO_2, CO, CO_2, THC)	500
Particulate Matter & Soot Sensor	205 and 210
Exhaust Flow Meter	175

VEHICLE PHOTOS AND ROUTE MAP

Test Vehicle



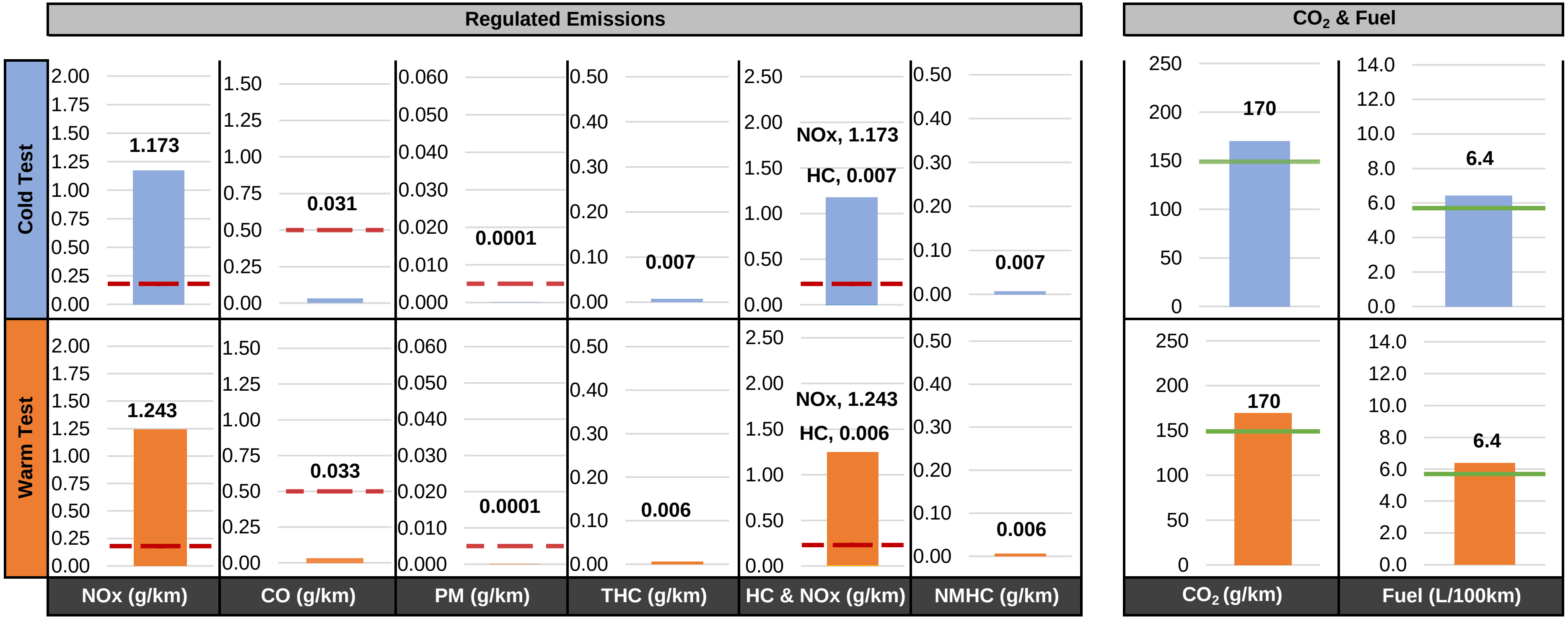
Exhaust Sampling and Flow Measurement

PEMS Equipment Installed in Vehicle

Test Route Map

Real World Emissions Summary Report: VW Golf - Pre Recall

RWE REAL WORLD ECONOMY & EMISSIONS



Euro 5a Diesel Cars - NEDC

Emissions	NOx	CO	PM	THC	HC & NOx	NMHC	CH_4	NO_2	NO
	g/km	g/km	g/km	g/km	g/km	g/km	g/km	g/km	g/km
Cold Test	1.173	0.031	0.0001	0.007	1.180	0.007	0.000	0.296	0.876
Warm Test	1.243	0.033	0.0001	0.006	1.249	0.006	0.000	0.314	0.930
Limit	0.18	0.50	0.0050	#N/A	0.23	#N/A	#N/A	#N/A	#N/A
Limit with CF	#N/A								

CO_2	Fuel
g/km	L/100km
170	6.4
170	6.4
Official Results	
149	5.7

Limit

Limit with CF

Manufacturer Specification

Notes: The limits refer to maximum allowable emissions when measured using a laboratory test with controlled conditions. Official results for CO_2 and fuel consumption are declared by the manufacturer based upon a laboratory test. Real-world driving can result in emissions and fuel consumption that differ significantly from these values.

Real World Emissions Summary Report: VW Golf - Pre Recall

REAL WORLD ECONOMY & EMISSIONS

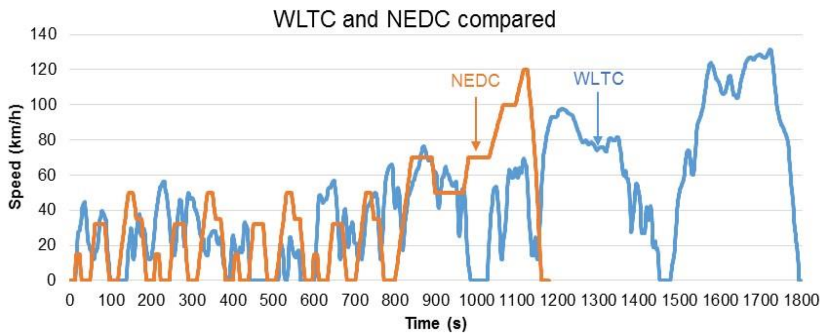
EXPLANATION OF TESTING METHOD AND RESULTS

Light duty vehicles can be classified by the emissions standard to which they conform when they were manufactured. For vehicles sold in Australia, they conform to the European "Euro" emissions standards. From Euro 3 to Euro 6, these standards have become progressively more stringent, with limits regulating the maximum allowable noxious emissions. New vehicles currently sold in Australia must conform to the Euro 5 standard, although many vehicle models are Euro 6 compliant as this is the current standard in Europe.

Up to and including Euro 6b, vehicle noxious emissions, CO_2 and fuel economy are assessed against these limits by performing a laboratory based test, driving a simulated urban, rural and motorway route known as the New European Drive Cycle (NEDC). The NEDC was last updated in 1997 and over time, cars have been optimised to reduce emissions according to the conditions experienced in the NEDC, yet vehicle performance and real-world traffic conditions have changed.

This has led to a growing discrepancy between real-world car emissions and fuel economy and the measurements obtained according to the NEDC.

To assess these differences, this summary report compares the real-world emissions measured when driving according to conditions required by the forthcoming Euro 6d Real Driving Emissions (RDE) legislation with the original limits required by the laboratory based test for the appropriate emissions standard.



In order to address this difference, a reform of the Euro emissions legislation is underway. In Europe, the impending Euro 6d legislation will require vehicles to be tested according to a new laboratory based test; the World-Harmonised Light-Duty Test Cycle (WLTC), whilst additionally verifying the real-world emissions using a Real Driving Emissions (RDE) test. The WHTC has been designed to be much more representative of modern, global driving conditions and the RDE legislation has very detailed requirements of the conditions that must be experienced by a vehicle tested in the real-world in order for it to be compliant. Some of these requirements are not able to be satisfied in Australia due to ambient conditions or road regulations.

As it is accepted that there is a still a difference between a Euro 6 vehicle's real-world emissions and those determined by the laboratory based (improved) WHTC test, the Euro 6d legislation allows a conformity factor (CF) to be applied to the laboratory based limits to translate this into a (higher) limit for the real-world emissions. Currently, this conformity factor is 2.1 and applies only to emissions of NOx as this has the highest discrepancy with laboratory measurements.

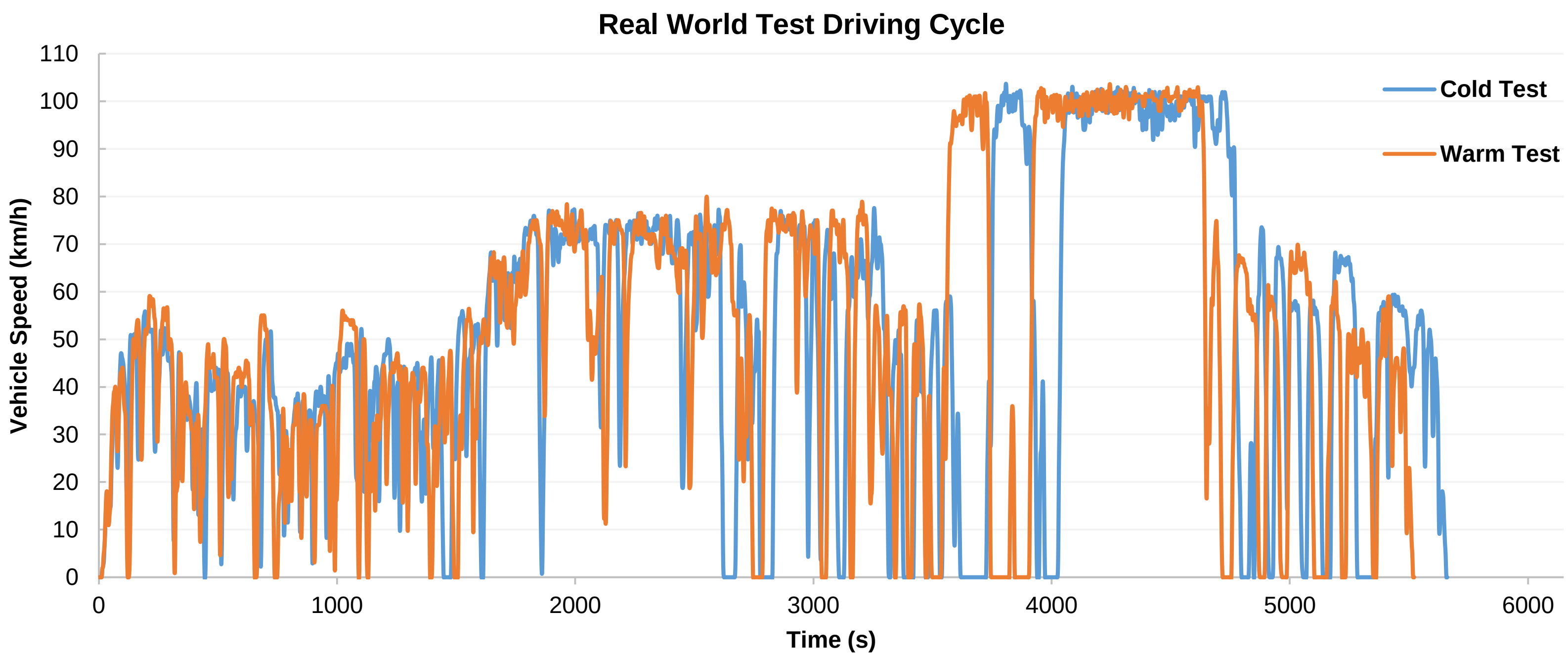
Hypothetically, this conformity factor could be used to compare the real-world emissions of Euro 4 and Euro 5 vehicles to their respective laboratory based limits although it is noted that this was not intended from a historical perspective.

Real World Emissions Summary Report: VW Golf - Pre Recall

REAL WORLD ECONOMY & EMISSIONS

REQUIREMENTS OF RDE LEGISLATION & VARIATIONS TO SUIT AUSTRALIAN CONDITIONS

TEST CONDITION	REQUIRMENT	VARIATIONS	COMMENTS
Maximum vehicle speed	145 km/h	100 km/h speed limit	Maximum vehicle speed limits for Australian motorways and freeways varies from 100 km/h to 110 km/h, whereas motorways in Europe have speed limits ranging from 110km/h to no upper speed limit (autobahns).
Urban average vehicle speed	15 - 30 km/h	Average actual 25 - 50 km/h	European city vehicle speeds typically range from 30 km/h to 50 km/h compared to Australia with 40 km/h to 60 km/h.
Motorway vehicle speed range	90 - 110 km/h; At least 5 minutes above 100 km/h	No test time above 100 km/h	It is not possible to achieve a test toute with freeway speed over 100 km/h whilst satisfying the urban and rural components, as the majority of Victorian freeways close to urban areas are speed limited to 100 km/h. Every effort is made to drive at 100 km/h for at least 5 minutes, however this may not always be met due to traffic conditions.



Real World Emissions Summary Report: VW Golf - Pre Recall

RWE
REAL WORLD ECONOMY & EMISSIONS

TRIP REQUIREMENTS

Velocity Thresholds	Units	COLD TEST Urban 2 - 60	COLD TEST Rural 60 - 80	COLD TEST M'way 80 - 100	COLD TEST Total	WARM TEST Urban 2 - 60	WARM TEST Rural 60 - 80	WARM TEST M'way 80 - 100	WARM TEST Total
Average Velocity (ECU)	km/h	31	70	99	50	32	71	100	52
Share <= 1km/h; Minutes >= 100 km/h		17.20%		6.1 min		15.60%		7.4 min	
Trip Share ECU Distance	%	38	33	29		37	33	30	
Distance (ECU)	km	30	26	23	79	29	26	24	79
Duration	min	58	22	14	94	55	22	15	92
Maximum Velocity	km/h			104				104	

DPF Regeneration	-	-	-	-	n/a	-	-	-	n/a
Number Vehicle Stops > 10 s (min. 1)	-	-	-	-	13	-	-	-	14
Pos. Elev. Gain (max.1200 m/100 km)	m/100km	-	-	-	897	-	-	-	906
Delta Start / End Altitude (max. 100 m)	m	-	-	-	7	-	-	-	14

TOTAL TRIP REQUIREMENTS

Trip Shares	COLD Pass/Fail	WARM Pass/Fail
Urban 34% +10% and ≥ 29%	pass	pass
Rural 33% ±10%	pass	pass
Motorway 33% ±10%	pass	pass
Minimum Distance		
Urban 16 km	pass	pass
Rural 16 km	pass	pass
Motorway 16 km	pass	pass
Total Trip Duration 90 - 120 min	pass	pass

URBAN REQUIREMENTS

	COLD	WARM
Average Velocity 15 - 40 km/h	pass	pass
Stop periods 6 - 30% urban time	pass	pass

MOTORWAY REQUIREMENTS

	COLD	WARM
5 Minutes ≥ 100 km/h	NA*	NA*
Velocity covers 90 - 110 km/h	NA*	NA*

NA* *It is not possible to achieve a speed over 100 km/h and satisfy the Urban and Rural components, as the majority of Victorian Freeways close to urban areas are limited to 100 km/h. Every effort is made to drive at 100 km/h for at least 5 minutes, however this may not always be possible due to traffic conditions.*

Real World Emissions Summary Report: VW Golf - Post Recall

Client	AAA
Project Number	2017_01_AAA_02
Report Number	Post-Recall Fix - VW Golf Wagon

EMISSION STANDARDS & RESULTS SUMMARY

Emission Std	Conformity Factor (CF) Applied	Fuel
Euro 5a	#N/A	Diesel

	NOx	CO	PM	THC	HC + NOx	NMHC	CO_2	Fuel
Lab	440%	7%	2%	N/A	355%	N/A	132%	130%
CF	N/A	*CF: Euro 6 permits higher real-world driving NOx emissions than lab-based limits*						

VEHICLE DETAILS

Make	VW
Model	Golf Wagon 103 TDI
Model Year	2010
Vehicle Kilometers (Start / End)	113346 km / 113426 km
Engine & Fuel Type	2.0L Turbo Diesel
OBD Check? - DiagnosticTrouble Codes (DTC)?	Yes - No DTC Active
Applicable Emissions Standard	Euro 5

TEST INFORMATION	COLD TEST	WARM TEST
Test Date	13-Jul-17	13-Jul-17
Test Trip Meets Requirements?	YES	YES
Average Ambient Temperature (°C)	14	13
Average Ambient Pressure (kPa)	101.0	100.7
Average Ambient Humidity (%)	50	57
Road Condition	Dry	Light Rain
Traffic Condition	Normal Traffic - No route deviation	
Fuel Sample	Sampled from tank. Density tested.	

TEST EQUIPMENT - PART DESCRIPTION	SERIAL #
Gaseous (NO, NO_2, CO, CO_2, THC)	500
Particulate Matter & Soot Sensor	205 and 210
Exhaust Flow Meter	175

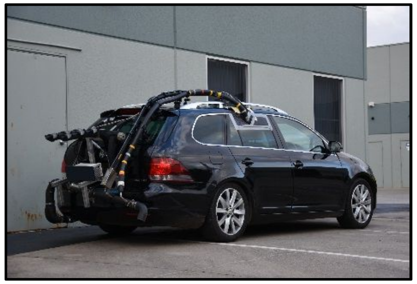
TEST OVERVIEW

These tests has been conducted generally in accordance with EC No 2016_427 & EC Regulation No 2016_646, known as Real Driving Emissions (RDE), modified for Australian roads and ambient conditions. Two tests have been conducted; one with a cold engine start and one with a warm engine start. The drive route was conducted in Victoria, starting an urban segment in the eastern suburbs of Melbourne, followed by a rural segment near Lysterfield Park, and a segment on the Eastlink Freeway.

This report compares real-world emissions and fuel consumption measurements against the noxious emissions limits and manufacturer's declared CO_2 and fuel consumption when tested in a laboratory under controlled conditions.

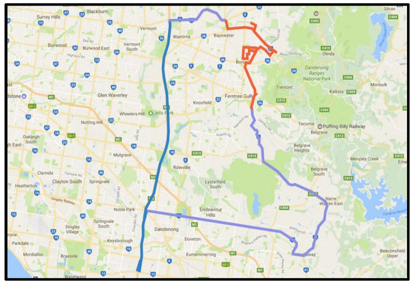
VEHICLE PHOTOS AND ROUTE MAP

Test Vehicle



Exhaust Sampling and Flow Measurement

PEMS Equipment Installed in Vehicle

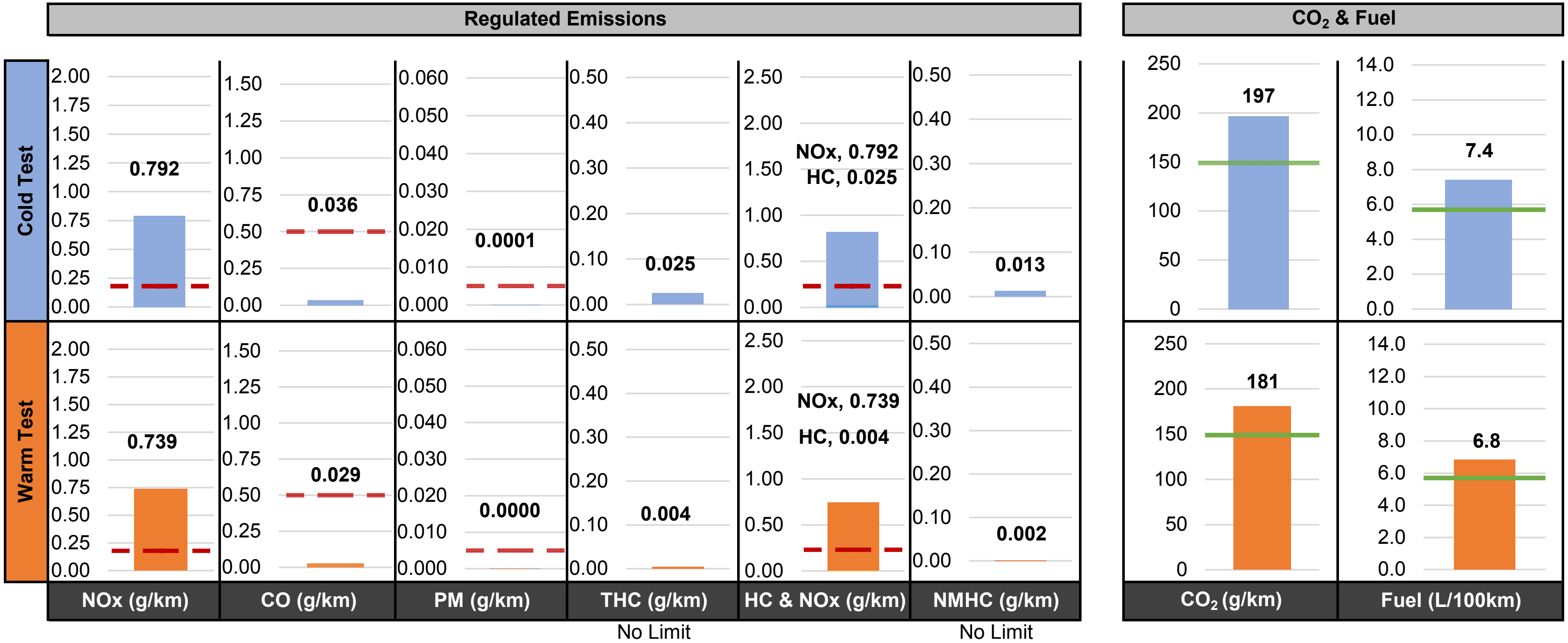


Test Route Map

PH: +61 3 9729 5129
www.abmarc.com.au

Real World Emissions Summary Report: VW Golf - Post Recall

RWE REAL WORLD ECONOMY & EMISSIONS



Euro 5a Diesel Cars - NEDC

Emissions	NOx	CO	PM	THC	HC & NOx	NMHC	CH_4	NO_2	NO
	g/km	g/km	g/km	g/km	g/km	g/km	g/km	g/km	g/km
Cold Test	0.792	0.036	0.0001	0.025	0.817	0.013	0.014	0.160	0.632
Warm Test	0.739	0.029	0.0000	0.004	0.744	0.002	0.003	0.198	0.541
Limit	0.18	0.50	0.0050	#N/A	0.23	#N/A	#N/A	#N/A	#N/A
Limit with CF	#N/A								

CO_2	Fuel
g/km	L/100km
197	7.4
181	6.8
Official Results	
149	5.7

- - Limit
— Limit with CF
— Manufacturer Specification

Notes: The limits refer to maximum allowable emissions when measured using a laboratory test with controlled conditions. Official results for CO_2 and fuel consumption are declared by the manufacturer based upon a laboratory test. Real-world driving can result in emissions and fuel consumption that differ significantly from these values.

Real World Emissions Summary Report: VW Golf - Post Recall

REAL WORLD ECONOMY & EMISSIONS

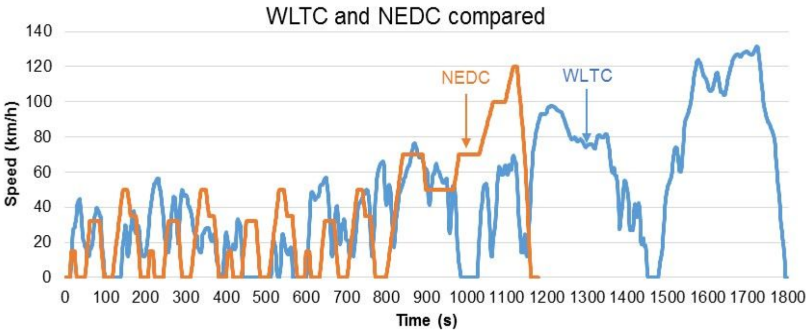
EXPLANATION OF TESTING METHOD AND RESULTS

Light duty vehicles can be classified by the emissions standard to which they conform when they were manufactured. For vehicles sold in Australia, they conform to the European "Euro" emissions standards. From Euro 3 to Euro 6, these standards have become progressively more stringent, with limits regulating the maximum allowable noxious emissions. New vehicles currently sold in Australia must conform to the Euro 5 standard, although many vehicle models are Euro 6 compliant as this is the current standard in Europe.

Up to and including Euro 6b, vehicle noxious emissions, CO_2 and fuel economy are assessed against these limits by performing a laboratory based test, driving a simulated urban, rural and motorway route known as the New European Drive Cycle (NEDC). The NEDC was last updated in 1997 and over time, cars have been optimised to reduce emissions according to the conditions experienced in the NEDC, yet vehicle performance and real-world traffic conditions have changed.

This has led to a growing discrepancy between real-world car emissions and fuel economy and the measurements obtained according to the NEDC.

To assess these differences, this summary report compares the real-world emissions measured when driving according to conditions required by the forthcoming Euro 6d Real Driving Emissions (RDE) legislation with the original limits required by the laboratory based test for the appropriate emissions standard.



In order to address this difference, a reform of the Euro emissions legislation is underway. In Europe, the impending Euro 6d legislation will require vehicles to be tested according to a new laboratory based test; the World-Harmonised Light-Duty Test Cycle (WLTC), whilst additionally verifying the real-world emissions using a Real Driving Emissions (RDE) test. The WHTC has been designed to be much more representative of modern, global driving conditions and the RDE legislation has very detailed requirements of the conditions that must be experienced by a vehicle tested in the real-world in order for it to be compliant. Some of these requirements are not able to be satisfied in Australia due to ambient conditions or road regulations.

As it is accepted that there is a still a difference between a Euro 6 vehicle's real-world emissions and those determined by the laboratory based (improved) WHTC test, the Euro 6d legislation allows a conformity factor (CF) to be applied to the laboratory based limits to translate this into a (higher) limit for the real-world emissions. Currently, this conformity factor is 2.1 and applies only to emissions of NOx as this has the highest discrepancy with laboratory measurements.

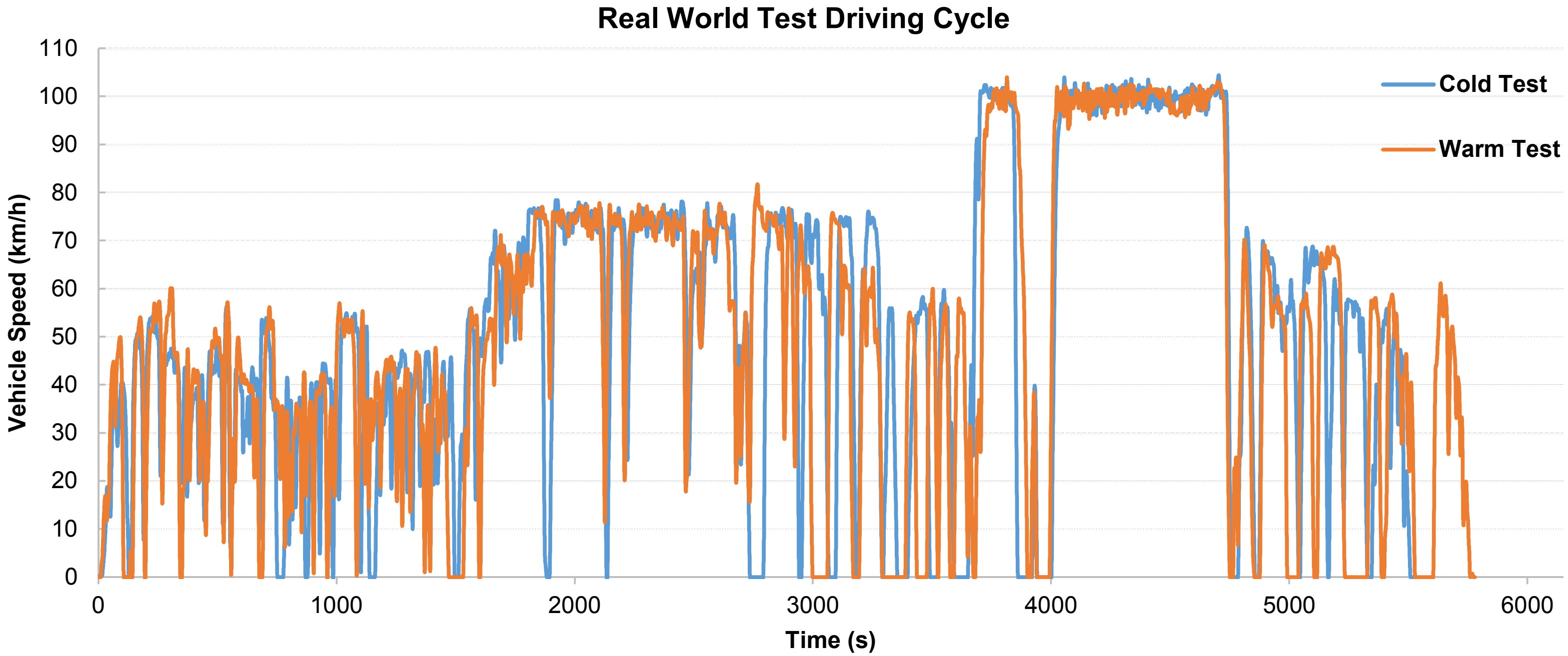
Hypothetically, this conformity factor could be used to compare the real-world emissions of Euro 4 and Euro 5 vehicles to their respective laboratory based limits although it is noted that this was not intended from a historical perspective.

Real World Emissions Summary Report: VW Golf - Post Recall

REAL WORLD ECONOMY & EMISSIONS

REQUIREMENTS OF RDE LEGISLATION & VARIATIONS TO SUIT AUSTRALIAN CONDITIONS

TEST CONDITION	REQUIRMENT	VARIATIONS	COMMENTS
Maximum vehicle speed	145 km/h	100 km/h speed limit	Maximum vehicle speed limits for Australian motorways and freeways varies from 100 km/h to 110 km/h, whereas motorways in Europe have speed limits ranging from 110km/h to no upper speed limit (autobahns).
Urban average vehicle speed	15 - 30 km/h	Average actual 25 - 50 km/h	European city vehicle speeds typically range from 30 km/h to 50 km/h compared to Australia with 40 km/h to 60 km/h.
Motorway vehicle speed range	90 - 110 km/h; At least 5 minutes above 100 km/h	No test time above 100 km/h	It is not possible to achieve a test toute with freeway speed over 100 km/h whilst satisfying the urban and rural components, as the majority of Victorian freeways close to urban areas are speed limited to 100 km/h. Every effort is made to drive at 100 km/h for at least 5 minutes, however this may not always be met due to traffic conditions.



Real World Emissions Summary Report: VW Golf - Post Recall

RWE REAL WORLD ECONOMY & EMISSIONS

TRIP REQUIREMENTS

Velocity Thresholds	Units	COLD TEST Urban 2 - 60	COLD TEST Rural 60 - 80	COLD TEST M'way 80 - 100	COLD TEST Total	WARM TEST Urban 2 - 60	WARM TEST Rural 60 - 80	WARM TEST M'way 80 - 100	WARM TEST Total
Average Velocity (ECU)	km/h	31	71	99	52	30	71	99	49
Share <= 1km/h; Minutes >= 100 km/h		18.00%		6.6 min		21.20%		5.5 min	
Trip Share ECU Distance	%	35	34	31		37	32	31	
Distance (ECU)	km	28	27	24	79	30	25	24	79
Duration	min	54	23	15	92	60	22	15	97
Maximum Velocity	km/h			104				103	

DPF Regeneration	-	-	-	-	n/a	-	-	-	n/a
Number Vehicle Stops > 10 s (min. 1)	-	-	-	-	19	-	-	-	18
Pos. Elev. Gain (max.1200 m/100 km)	m/100km	-	-	-	923	-	-	-	895
Delta Start / End Altitude (max. 100 m)	m	-	-	-	1	-	-	-	13

TOTAL TRIP REQUIREMENTS

Trip Shares	COLD Pass/Fail	WARM Pass/Fail
Urban 34% +10% and ≥ 29%	pass	pass
Rural 33% ±10%	pass	pass
Motorway 33% ±10%	pass	pass
Minimum Distance		
Urban 16 km	pass	pass
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Motorway 16 km	pass	pass
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URBAN REQUIREMENTS

	COLD	WARM
Average Velocity 15 - 40 km/h	pass	pass
Stop periods 6 - 30% urban time	pass	pass

MOTORWAY REQUIREMENTS

	COLD	WARM
5 Minutes ≥ 100 km/h	NA*	NA*
Velocity covers 90 - 110 km/h	NA*	NA*

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