



On-road testing of CO₂ and exhaust emissions from Euro 6 passenger cars in the EU: Technical Report

29 September 2016

Summary

Emissions Analytics conducted a test programme on Euro 6 diesel passenger cars for the International Council on Clean Transportation (ICCT). This document sets out the objectives, test programme and headline results.

Background

Emissions Analytics is an independent commercial test house that uses PEMS equipment exclusively and intensively to analyse true in-use performance. Operating since 2011, it has carried out PEMS tests on more than 1,200 model variants of passenger car in addition to testing passenger cars, heavy goods vehicles, tractors, taxis, vans and buses. It is the unrivalled expert in the field of on-road emissions monitoring.

Objectives

The primary objective for ICCT was to evidence the CO₂, CO, NO and NO₂ and NO_x emissions from a range of diesel and gasoline Euro 6 passenger cars.

The secondary objective was to measure particulate number (PN).

Timetable

The testing was conducted between 2 December 2015 and 9 February 2016.

Section 1 – Equipment and measurements

Test equipment

The emissions tests were conducted using a Sensors SEMTECH-DS for gaseous emissions. Details can be found on our website, www.emissionsanalytics.com, and technical details can be provided if required. No permanent modification to the vehicles was required to install the equipment.



To measure the total mass flow of gas a Sensors flow tube was used, mounted on the exterior of the vehicle.



Particulates were measured by a Pegasor Mi2, which is a real-time sampler of the raw exhaust. It uses a corona diffusion charger for estimating both particle number and mass. It can be configured to measure either particle mass concentration or number concentration. It is an alternative method to the filter-paper-based regulatory approach, but has the advantages that:

- It can measure sub-23nm particles
- The results are real-time
- It reports both particle number by size class and mass
- There are no consumables such as filter papers
- It does not require a dilution tunnel.



Measurements

The following emissions were monitored, with their associated effects:

Pollutant		Description
Carbon monoxide	CO	Toxic to humans. Air pollutant contributing to photochemical smog. Indirect greenhouse gas contribution.
Carbon dioxide	CO ₂	Greenhouse gas with lifetime of >100 years.
Nitric oxide	NO	Air pollutant. Converted to nitrogen dioxide in the atmosphere.
Nitrogen dioxide	NO ₂	Causes inflammation of airways in humans. Combines with moisture in atmosphere to produce acid rain.
Particulates	PM	Associated with asthma, lung cancer and heart disease. Ultra-fine particles are particularly damaging to cardiovascular system.

Fuel economy was derived using the carbon balance method.

Section 2 – Test methodology and cycle

Methodology

For each vehicle the following procedure was followed:

1. Receive and check vehicle
2. Pre-condition and check vehicle
3. Run first test
4. Re-check vehicle
5. Run second test
6. Re-check vehicle
7. Run third test
8. Analyse emissions results
9. Check and return vehicle.

The protocol incorporated the following:

- Use of a small repertoire of trained Emissions Analytics' drivers
- Vehicles fully warmed up before commencing each test
- Standard market fuel.

Duty cycle

Emissions Analytics designed a cycle for the public highway in the UK, located around South West London. The test protocol had three elements:

1. Route 1: standard driving with no air conditioning or cold start, and with no ECU (vehicle interface) connection
2. Route 2: higher acceleration rates, steeper hills, air conditioning use
3. Route 1, but with ECU connection.

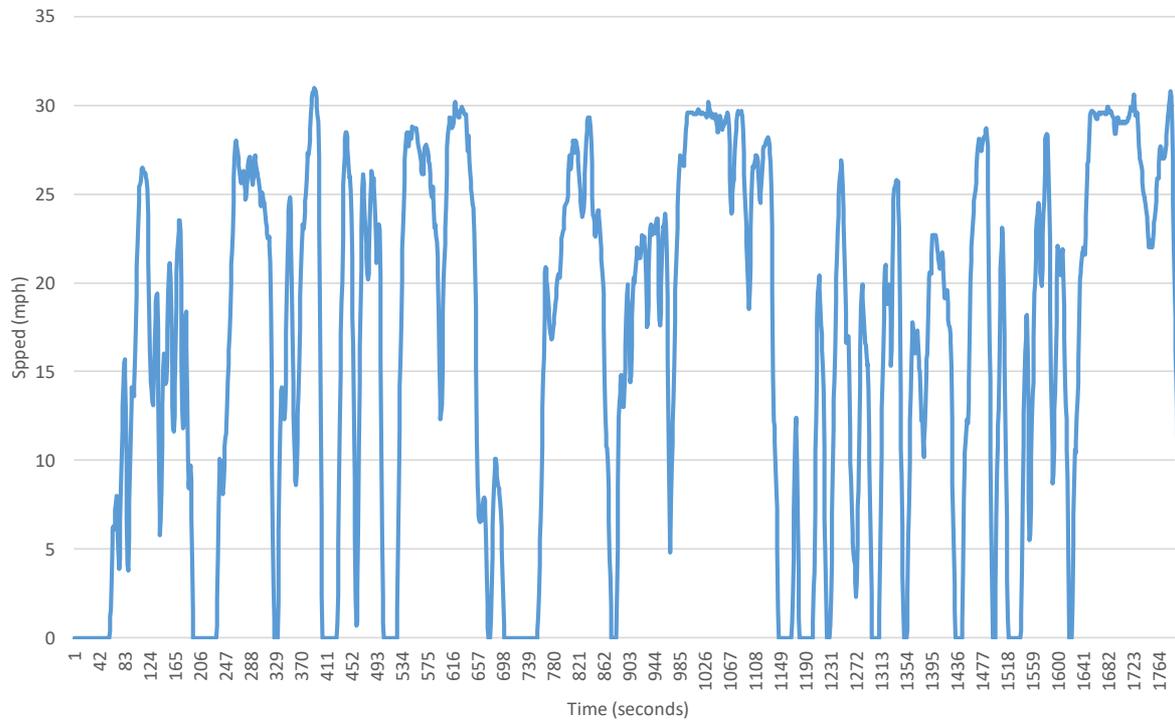
In total Route 1 was around 53 minutes long, over 24 miles at an average speed of 27 mph. Route 2 was longer at 70 minutes, 31 miles at an average speed of 27 mph.

Details of the lengths, average speeds, acceleration rates, gradients and idling of each part of each cycles are show in the table:

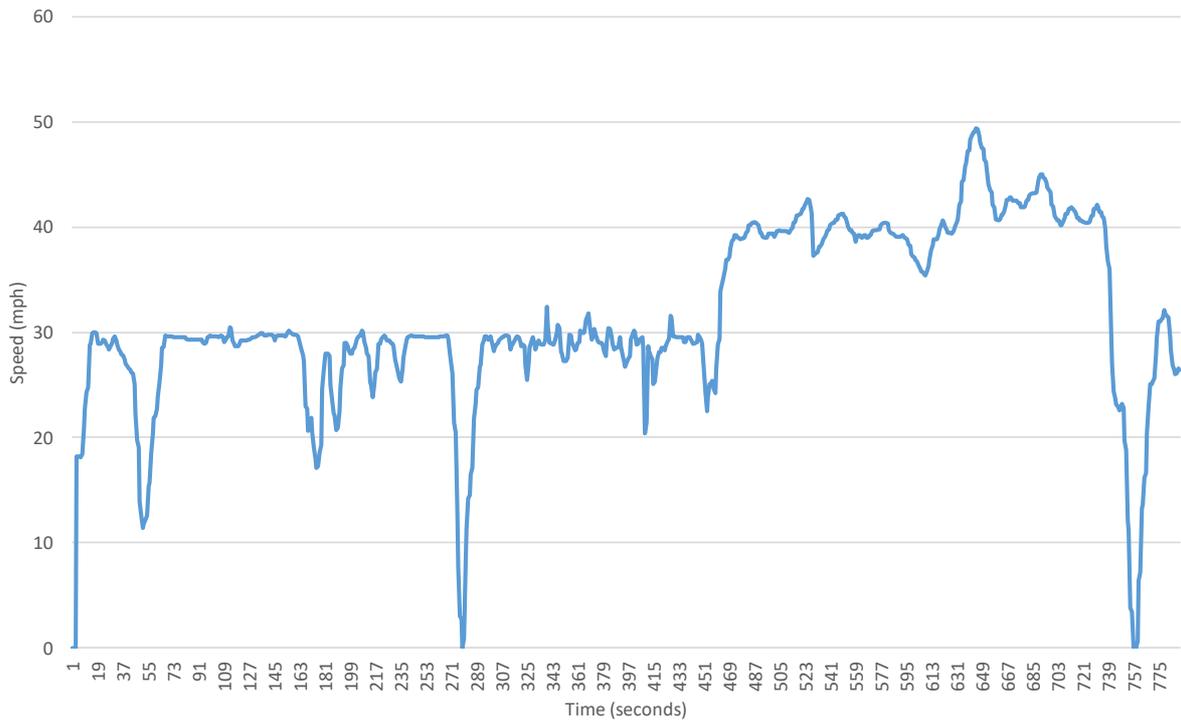
Cycle	Route	Time (s)	Length (miles)	Average speed	Average positive acceleration	Average negative acceleration	Average positive gradient	Average negative gradient	Percentage idling time
Route 1	Urban	1800	8.2	16.3	0.27	-0.23	1.02	-1.12	18%
	Rural	787	6.9	31.6	0.36	-0.42	0.74	-0.77	1%
	Motorway	604	9.1	54.4	0.32	-0.25	0.81	-1.09	6%
Route 2	Urban	2659	15.0	20.3	0.31	-0.32	1.20	-1.31	8%
	Rural	1019	6.9	24.4	0.47	-0.49	1.16	-1.33	1%
	Motorway	526	9.1	62.5	0.39	-0.33	0.87	-0.93	0%

The speed-time traces of each part of the cycle were as follows.

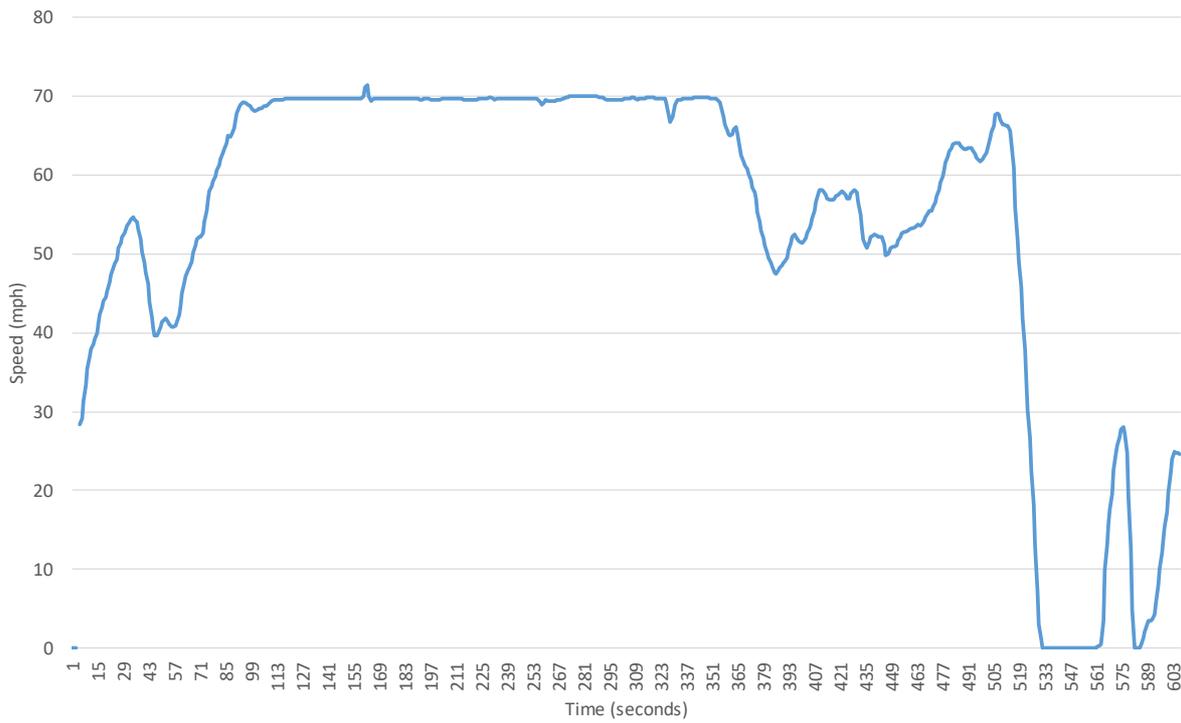
Route 1 – urban



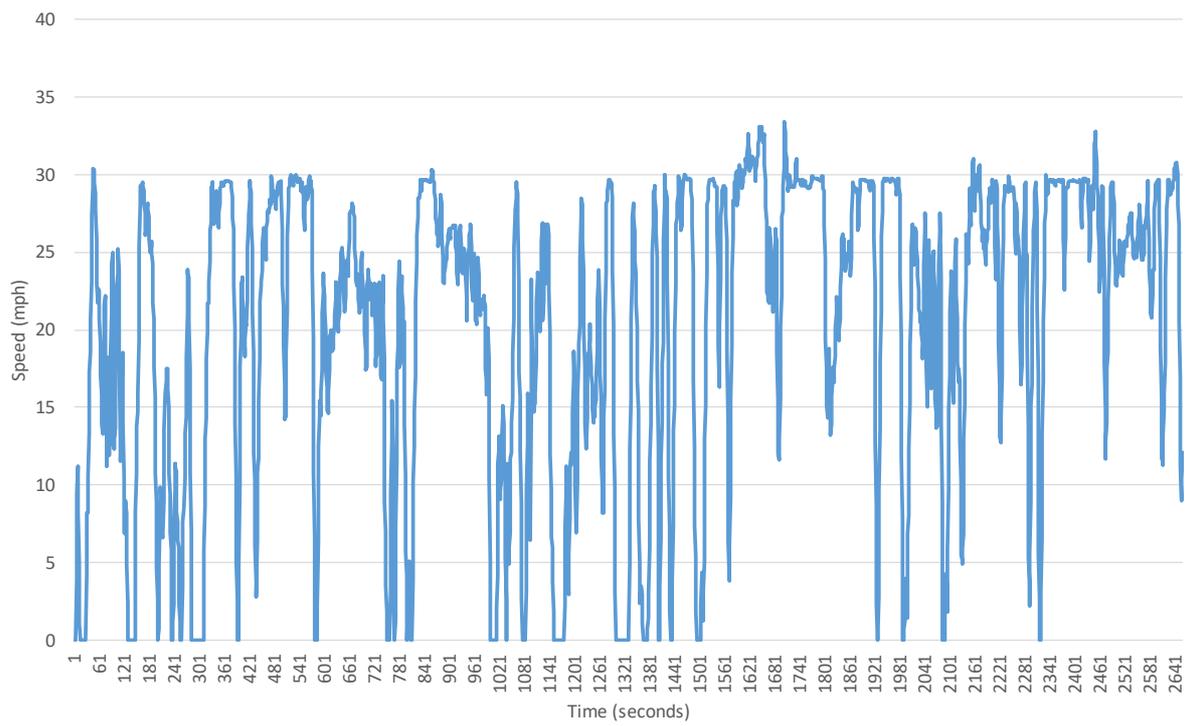
Route 1 – rural



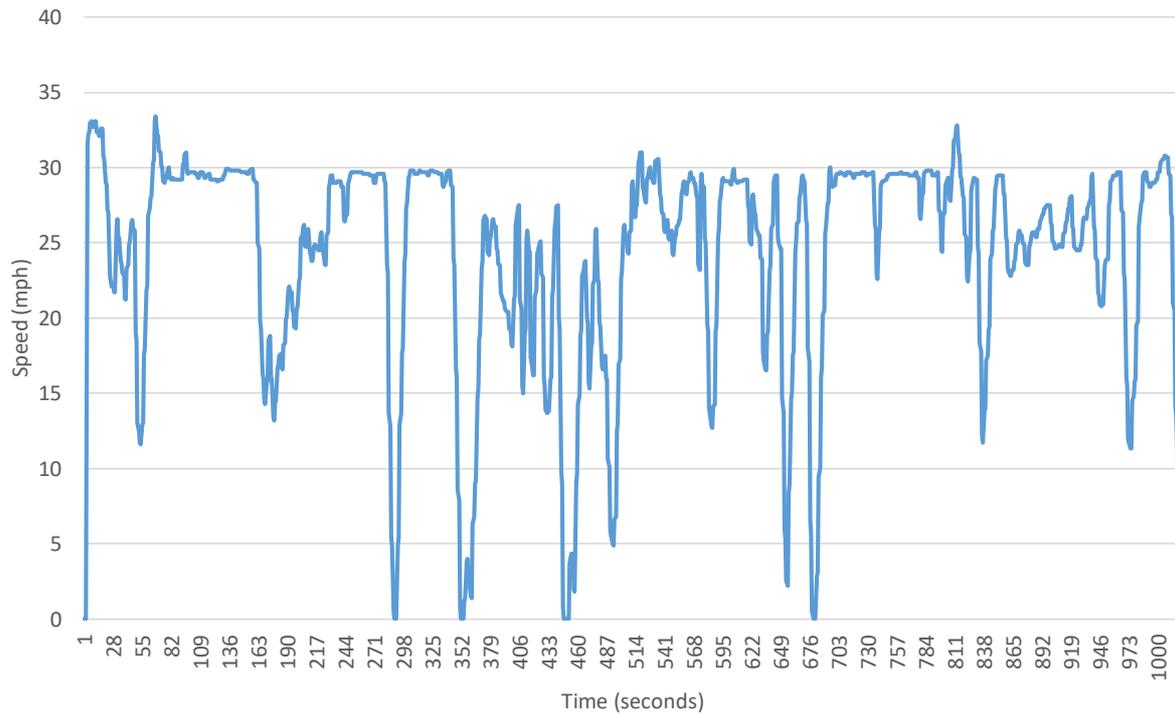
Route 1 – motorway



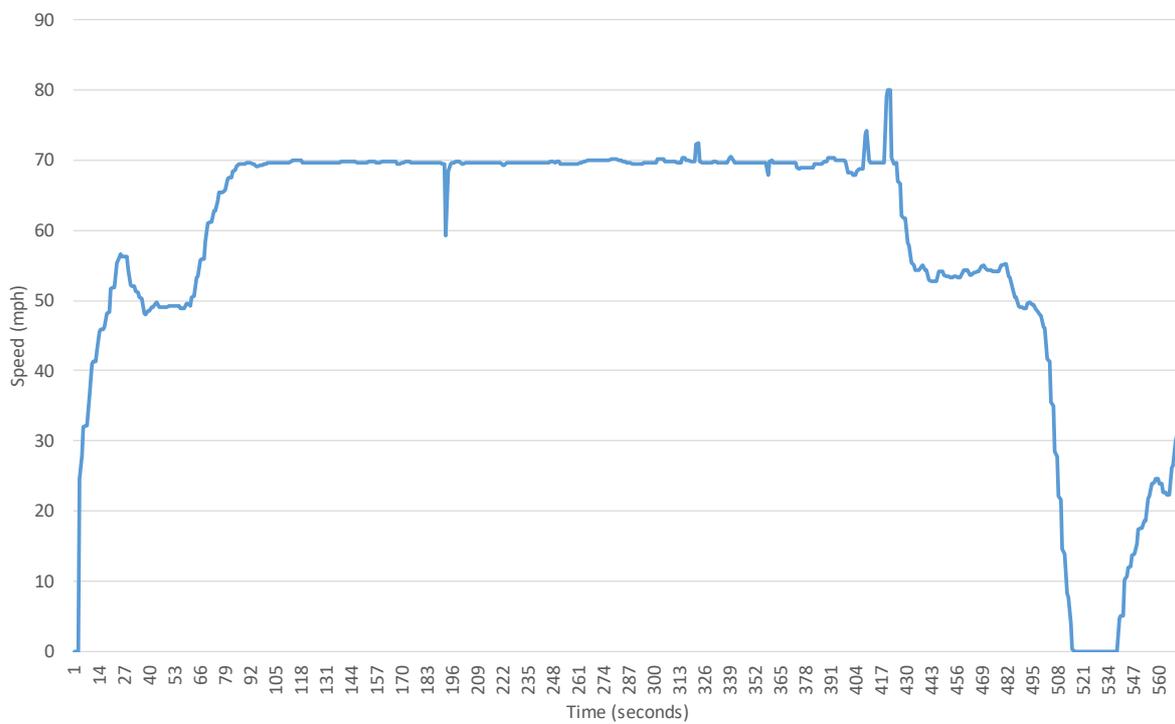
Route 2 – urban



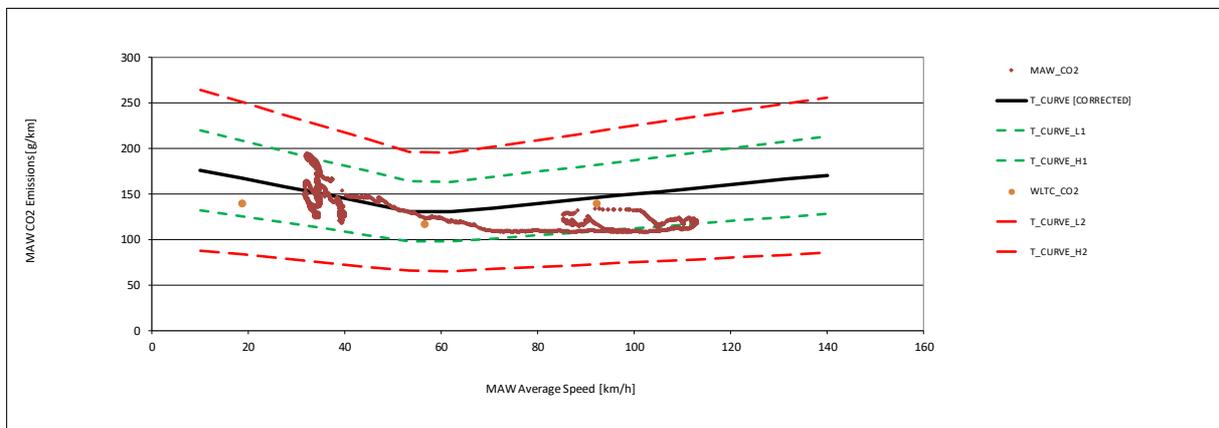
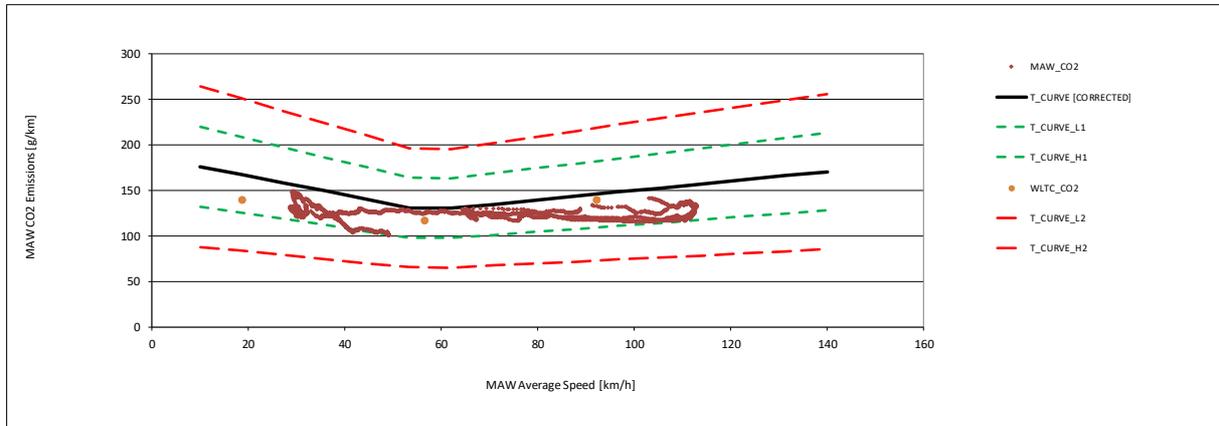
Route 2 – rural



Route 2 – motorway



The results presented in this report represent the raw emissions from each test, and have not been normalised through either EMROAD and CLEAR. Nevertheless, both Route 1 and Route 2 would conform to valid RDE cycles in all material respects, as demonstrated with the moving average window plots from EMROAD for Route 1 and Route 2 respectively:



Quality control

The following quality control was performed immediately after each test and before delivery of the data, including:

- Post-processing of data using software from Sensors Inc, which performs multiple processes including wet-correction of NO_x data
- Checking of engine coolant temperature to verify vehicle was operating fully warmed up (if relevant)
- Checking of exhaust temperature to identify any evidence for diesel particulate filter (DPF) regeneration, where applicable
- Plotting the time-series graphs of each of the emissions, against speed – by a process of inspection any anomalies such as time alignment or drop-outs can be identified
- Checking the CO₂ concentration over time to check consistency with stoichiometric combustion for gasoline vehicles.

If the data was deemed unsatisfactory, then the affected part(s) of the test was re-run.

Section 3 – Vehicles

Vehicles

The project scope was to test two gasoline direct injection passenger cars, three diesel passenger cars and one light commercial vehicle, all Euro 6. As the first van was affected regeneration of the diesel particulate filter, a second van with the same engine was tested in addition.

The seven vehicles tested are listed in the table.

Manufacturer	Model	Engine size (litres)	Derivative	Power (PS)	Fuel	Bodystyle	Transmission
Ford	Focus	1.0	EcoBoost	125	Petrol	Hatchback	6-Spd Manual
Volkswagen	Golf	1.2	BlueMotion Technology TSI	85	Petrol	Hatchback	5-Spd Manual
Citroen	C4	1.6	VTR+ BlueHDI	120	Diesel	MPV	6-Spd Manual
Mercedes-Benz	C220	2.2	BlueTec Sport Premium	172	Diesel	Saloon	7-Spd Auto
Vauxhall	Astra	1.6	CDTi	136	Diesel	Hatchback	6-Spd Manual
Volkswagen	Transporter	2.0	T28 Trendline TDI BMT	102	Diesel	Van	5-Spd Manual
Volkswagen	Caddy C20	2.0	TDI BlueMotion	102	Diesel	Panel Van	5-Spd Manual

Manufacturer	Model	Engine size (litres)	NO _x control technology	Official combined CO ₂ (g/km)
Ford	Focus	1.0	Three-way catalyst	108
Volkswagen	Golf	1.2	Three-way catalyst	113
Citroen	C4	1.6	Selective Catalytic Reduction	100
Mercedes-Benz	C220	2.2	Selective Catalytic Reduction	110
Vauxhall	Astra	1.6	Lean NO _x trap	103
Volkswagen	Transporter	2.0	Selective Catalytic Reduction	153
Volkswagen	Caddy C20	2.0	Selective Catalytic Reduction	114

Vehicles were not sourced directly from manufacturers to ensure that genuine, standard production vehicles were tested. A range of rental sources in the UK were used, so there was no awareness from the supplier that the vehicle would be tested, to avoid any non-standard set-up being provided.

A selection of images from the testing are shown below.



Section 4 – Headline results

In the following tables “VI” refers to the vehicle interface, where data from the vehicle’s ECU is being captured via the OBD. The results shaded in orange below were affected by regeneration of diesel particulate filter.

Nitrogen oxides (NO_x)

The regulated level is 0.08 g/km for diesels and 0.06 g/km for petrol/gasoline.

Cycle g/km	Route	Ford Focus	VW Golf	Citroen C4	Mercedes C220	Vauxhal I Astra	VW Transporter Diesel	VW Caddy Diesel
		Petrol	Petrol	Diesel	Diesel	Diesel	Diesel	Diesel
Route 1 – no VI	Motorway	0.039	0.003	0.268	0.314	0.566	0.278	0.028
	Urban	0.054	0.014	0.389	0.262	0.453	0.026	0.060
	Rural	0.027	0.019	0.371	0.146	0.250	0.039	0.082
	Combined	0.049	0.010	0.365	0.233	0.383	0.217	0.057
Route 2	Motorway	0.020	0.006	0.366	0.206	0.756	0.097	0.059
	Urban	0.029	0.012	0.343	0.123	0.404	0.137	0.089
	Rural	0.200	0.040	0.184	0.101	0.204	0.116	0.096
	Combined	0.056	0.014	0.324	0.139	0.411	0.128	0.077
Route 1 – with VI	Motorway	0.026	0.004	0.286	0.264	0.624	0.043	0.050
	Urban	0.096	0.009	0.171	0.376	0.298	0.077	0.159
	Rural	0.122	0.011	0.148	0.318	0.471	0.086	0.140
	Combined	0.063	0.006	0.241	0.261	0.395	0.064	0.116

Expressing these results in terms of Conformity Factor, comparing emissions in g/km to the regulated level, the results were as follows.

Cycle CF#	Route	Ford Focus	VW Golf	Citroen C4	Mercedes C220	Vauxhal I Astra	VW Transporter Diesel	VW Caddy Diesel
		Petrol	Petrol	Diesel	Diesel	Diesel	Diesel	Diesel
Route 1 – no VI	Motorway	0.6	0.0	3.4	3.9	7.1	3.5	0.3
	Urban	0.9	0.2	4.9	3.3	5.7	0.3	0.8
	Rural	0.4	0.3	4.6	1.8	3.1	0.5	1.0
	Combined	0.8	0.2	4.6	2.9	4.8	2.7	0.7
Route 2	Motorway	0.3	0.1	4.6	2.6	9.5	1.2	0.7
	Urban	0.5	0.2	4.3	1.5	5.0	1.7	1.1
	Rural	3.3	0.7	2.3	1.3	2.5	1.4	1.2
	Combined	0.9	0.2	4.0	1.7	5.1	1.6	1.0
Route 1 – with VI	Motorway	0.4	0.1	3.6	3.3	7.8	0.5	0.6
	Urban	1.6	0.2	2.1	4.7	3.7	1.0	2.0
	Rural	2.0	0.2	1.9	4.0	5.9	1.1	1.8
	Combined	1.1	0.1	3.0	3.3	4.9	0.8	1.5

Carbon dioxide (CO₂)

Cycle g/km	Route	Ford Focus	VW Golf	Citroen C4	Mercedes C220	Vauxhal Astra	VW Transporter	VW Caddy
		Petrol	Petrol	Diesel	Diesel	Diesel	Diesel	Diesel
Route 1 – no VI	Motorway	142.5	132.6	160.4	160.8	177.8	214.8	152.5
	Urban	150.0	155.7	137.3	183.8	140.8	160.1	143.9
	Rural	101.9	128.5	134.0	141.9	117.2	196.1	121.0
	Combined	135.7	133.0	156.2	163.4	144.5	208.1	141.4
Route 2	Motorway	131.0	134.6	166.7	147.4	184.5	176.1	156.2
	Urban	159.4	154.8	157.9	174.0	174.4	197.9	130.0
	Rural	128.0	160.2	163.6	165.2	167.3	211.1	133.5
	Combined	152.5	139.0	167.5	154.1	170.4	194.4	138.2
Route 1 – with VI	Motorway	134.0	124.7	172.9	144.9	181.3	163.8	163.2
	Urban	141.7	123.5	168.8	183.9	171.1	203.8	148.8
	Rural	110.7	105.0	146.1	165.4	141.5	282.3	130.8
	Combined	139.8	117.5	166.1	173.9	165.1	187.9	169.6

Carbon monoxide (CO)

The regulated level is 0.5 g/km for diesels and 1.0 g/km for petrol/gasoline.

Cycle g/km	Route	Ford Focus	VW Golf	Citroen C4	Mercedes C220	Vauxhal Astra	VW Transporter	VW Caddy
		Petrol	Petrol	Diesel	Diesel	Diesel	Diesel	Diesel
Route 1 – no VI	Motorway	0.649	0.119	0.118	0.087	0.123	0.103	0.097
	Urban	0.095	0.137	0.166	0.141	0.183	0.113	0.093
	Rural	0.079	0.039	0.143	0.094	0.123	0.164	0.060
	Combined	0.270	0.128	0.143	0.107	0.139	0.121	0.115
Route 2	Motorway	0.398	0.147	0.090	0.068	0.114	0.069	0.106
	Urban	0.162	0.088	0.159	0.220	0.184	0.129	0.145
	Rural	0.114	0.038	0.131	0.169	0.175	0.146	0.137
	Combined	0.348	0.077	0.123	0.125	0.144	0.102	0.124
Route 1 – with VI	Motorway	0.348	0.178	0.079	0.083	0.111	0.222	0.111
	Urban	0.130	0.056	0.211	0.166	0.177	0.373	0.144
	Rural	0.051	0.093	0.084	0.131	0.149	0.594	0.099
	Combined	0.236	0.111	0.116	0.131	0.141	0.301	0.144

Particulate number (PN)

The regulated level is $6.0 \times 10^{11}/\text{km}$ for diesels and $6.0 \times 10^{11}/\text{km}$ for direct injection petrol/gasoline, but $6.0 \times 10^{12}/\text{km}$ for first three years of Euro 6.

Cycle #x10 ¹¹	Route	Ford Focus Petrol	VW Golf Petrol
Route 1 – no VI	Motorway	45.2	9.7
	Urban	33.0	8.3
	Rural	18.8	7.2
	Combined	30.3	9.2
Route 2	Motorway	28.0	9.8
	Urban	22.2	15.0
	Rural	15.3	11.9
	Combined	28.7	10.7
Route 1 – with VI	Motorway	20.6	8.3
	Urban	39.2	7.2
	Rural	18.9	6.7
	Combined	25.7	7.6

Fuel economy (MPG)

Cycle Miles per Imperial gallon	Route	Ford Focus	VW Golf	Citroen C4	Merced es C220	Vauxhal l Astra	VW Trans- porter	VW Caddy
		Petrol	Petrol	Diesel	Diesel	Diesel	Diesel	Diesel
Route 1 – no VI	Motorway	47.7	51.4	47.8	47.6	43.1	35.8	50.3
	Urban	45.6	43.7	55.6	41.6	54.2	48.0	53.2
	Rural	66.8	53.3	56.6	53.8	65.1	39.1	63.1
	Combined	50.3	51.3	48.9	46.7	52.9	36.8	54.1
Route 2	Motorway	52.0	50.8	45.9	51.9	41.6	43.6	49.0
	Urban	42.8	44.1	48.4	43.7	43.9	38.7	58.7
	Rural	53.4	42.6	46.5	46.0	45.7	36.4	57.4
	Combined	44.7	49.1	45.5	49.5	45.0	39.3	55.3
Route 1 – with VI	Motorway	50.9	54.6	44.2	52.7	42.2	46.9	46.9
	Urban	48.1	55.3	45.3	41.6	44.7	37.7	51.4
	Rural	61.6	65.0	52.4	46.2	54.1	27.1	58.6
	Combined	48.8	58.0	46.1	44.0	46.4	40.6	45.1