THE REAL WORLD DRIVING EMISSIONS TEST

Australian Automobile Association

ABMARC

2017 FUEL ECONOMY AND EMISSIONS REPORT

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SUMMARY REPORT

Overview

This report presents the emissions and fuel consumption test results from 30 different passenger and light commercial vehicles ("light duty vehicles"), measured with a Portable Emissions Measurement System (PEMS) on Australian Roads. Testing was conducted by ABMARC for the Australian Automobile Association in general accordance with the Real Driving Emissions (RDE) procedure defined in EC 2016_427, adapted to suit Australia's unique roads and driving conditions. Each vehicle was tested twice, with one cold start and one warm start per test sequence. The testing was conducted on Melbourne roads between May 2016 and June 2017.

Project background

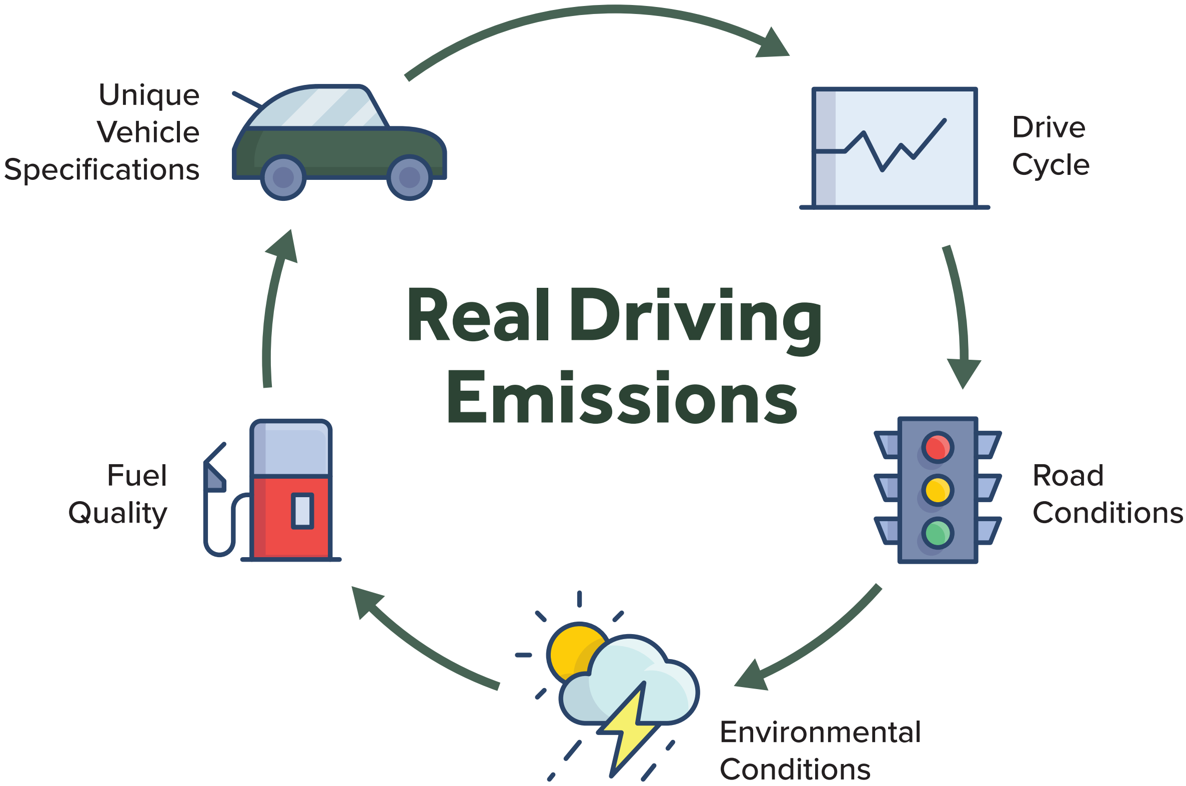
Real world vehicle testing by various agencies overseas has confirmed that the emissions from some light duty vehicles are substantially higher when measured on the road than when measured in a controlled laboratory environment. Pollutants, such as NOx (oxides of nitrogen) from diesel cars, have regularly been found to exceed the permitted test-cycle emission limits by 4 to 8 times. The disconnect between on-road and laboratory emissions performance was first identified as an air quality issue in Europe; reductions in permissible NOx emissions from road transport vehicles were not effective at improving air quality as the regulations had anticipated. Similarly, official fuel consumption figures determined during laboratory testing were often not reflective of what motorists were able to achieve on road.

The discrepancy between official fuel consumption figures and real-world fuel consumption figures has been increasing over time, most likely as a result of manufacturers optimising technologies to comply with global laboratory test CO2 regulations, which are unable to replicate a large portion of normal real-world driving.

To improve compliance with emissions requirements the European Commission has enacted legislation and the European Commission's Joint Research Centre (JRC) has developed a test procedure with Portable Emissions Measurement System (PEMS) for mandatory Real Driving Emissions testing for type approval of new vehicles and on-going in-service conformity of emissions.

Real world measurement of emissions and fuel consumption enables a vehicle to be tested in the same road type and environmental conditions it will be subjected to during normal operation. This testing reduces the ability of manufacturers to implement "defeat devices", and limits the use of emissions reduction technologies that are more effective on the laboratory test drive cycle than in real-world use. Figure 1 below provides an illustration of the factors impacting a vehicle's Real Driving Emissions and why regional considerations should also be taken into account.

Figure 1.
Factors Impacting Real Driving Emissions



In Australia, the current new vehicle emissions standard for both petrol and diesel is Euro 5. The Australian government is currently considering adopting Euro 6 emissions standards, CO2 standards, in addition to changing the Australian fuel quality standards.

Presently, the RDE regulation requires testing of vehicles on European roads under European conditions. The Australian market has a number of vehicles or vehicle configurations not sold in Europe. This may result in a situation where vehicles are sold in Australia that have not been subjected to the regulatory requirements of RDE testing. In any case, none of these vehicles will have undergone RDE testing under Australian conditions.

Introduction of a CO2 policy is likely to result in consumers incurring additional costs (higher vehicle purchase price), and it is considered necessary to ensure that additional costs incurred by consumers provide benefit via real CO2 emissions reductions matching those achieved in the laboratory test.

Real-world driving emissions testing objectives

The objective of the AAA program of real world emissions and fuel consumption measurement is to:

- Compare the on-road vehicle performance of a range of cars to the regulated emissions limits and
- Compare the on-road vehicle performance of a range of cars to the laboratory fuel consumption results.

This testing will enable the AAA to better understand how Australian vehicles perform in Australian real-world conditions.

The key outcomes of the AAA's real-world driving emissions testing program are:

- An evidence based approach to policy development.
- Real-world fuel economy over the designated route incorporating urban, rural and freeway driving conditions, and comparison to the official fuel economy.
- Evaluation of vehicle emissions in real-world driving conditions compared to their certified laboratory limits.
- Evaluation of the emissions performance and fuel consumption across a range of fuel types and technologies available in the Australian market.

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 the requirements outlined in EC 2016_427.

- **Gaseous:** Total Hydrocarbons, Carbon Monoxide (CO), Carbon Dioxide (CO2), Nitric Oxide (NO) and Nitrogen Dioxide (NO2).
- **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. Gross calorific value was tested according to ASTM D240 on select samples for comparison.

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/100 km)

The emissions data processing and calculations were performed in accordance with prescribed methodologies conforming to EC2016_427 Annex IIIA Appendix 4, for the analysis of RDE measurement data.

The allowable emissions on the RDE test are determined by using a Conformity Factor (CF). The CF is applied to the laboratory limits. Presently, there is only a CF specified for NOx (at 2.1), with a CF for Particle Number currently under consideration.

There is no regulated CF available for pre-Euro 6c vehicles. The purpose of this study is to compare the real-world pollutants emitted from vehicles to their respective laboratory limits and not to any conformity factor.

Emissions test procedure

Tests were conducted by driving each vehicle on a compliant route in Melbourne, Victoria. Test route variation is allowed under the RDE procedure. ABMARC developed two test routes. The Joint Research Council (JRC) was consulted in the development of the test for Australian conditions. Each route consisted of urban, rural 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 routes were devised to satisfy the Real Driving Emissions test procedure. In order to be a viable test route using public roads in Australian conditions, some minor modifications were made (as allowed under RDE regulation), specifically:

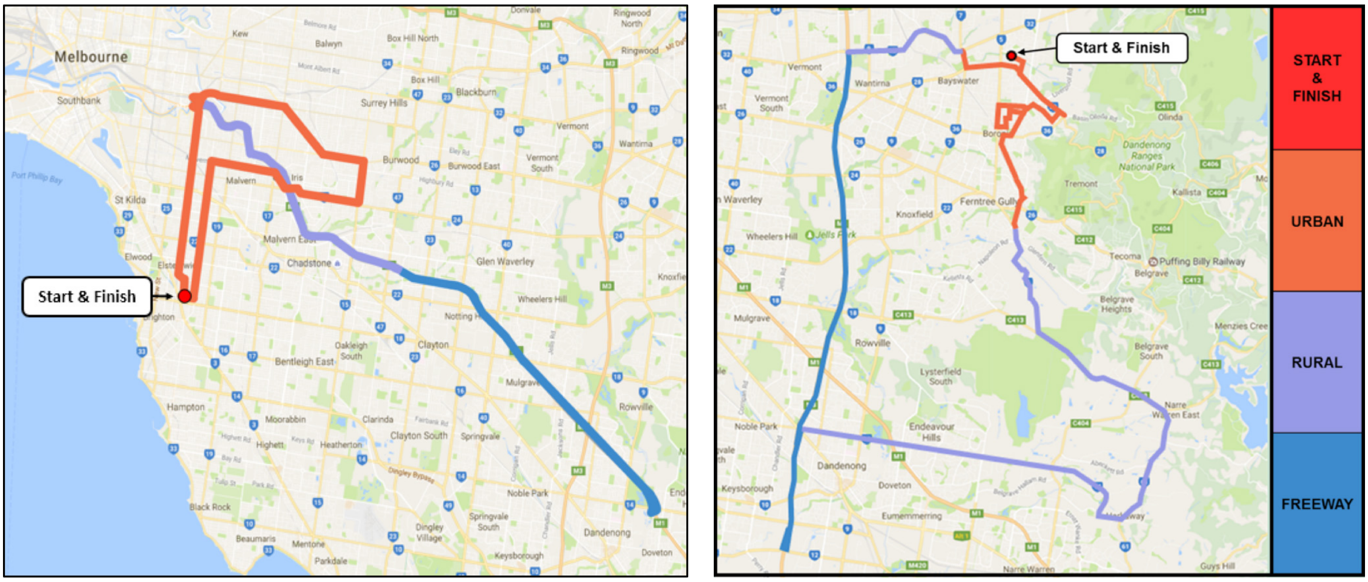
- Maximum speed was limited to 100 km/h which inhibits the ability to achieve at least 5 minutes' driving in excess of 100 km/h for RDE.
- Urban average vehicle speed in Australia is around 25 – 50 km/h, compared to 15 – 30 km/h in Europe, due to different city speed limits.

In line with the RDE procedure, no less than 16 kilometres must be travelled in each of the urban, rural and freeway test segments, with an overall test duration between 90 and 120 minutes. The actual trip distance was approximately 80 km, and duration was between 95 and 115 minutes (depending on traffic and weather conditions) for both ABMARC test routes. ABMARC Test Route 1 was used for the first 11 tests, however around 20% of tests did not meet the time specification due to traffic and required repeat testing to obtain a valid result. Test Route 2 has proved to be highly repeatable in terms of duration.

An overview of ABMARC's Drive Routes are shown in Figure 2.

Figure 2.

Test Route Overview: Route 1 (left), Route 2 (right)



Repeatability

An evaluation of the test to test fuel consumption repeatability has been conducted over both drive routes. It has been found that the variation on Route 2 is excellent, and on average within 3%. This test to test variation includes the variation between warm start and cold start tests. It is anticipated that if each test sequence was repeated with the same start temperature that the repeatability would be improved further.

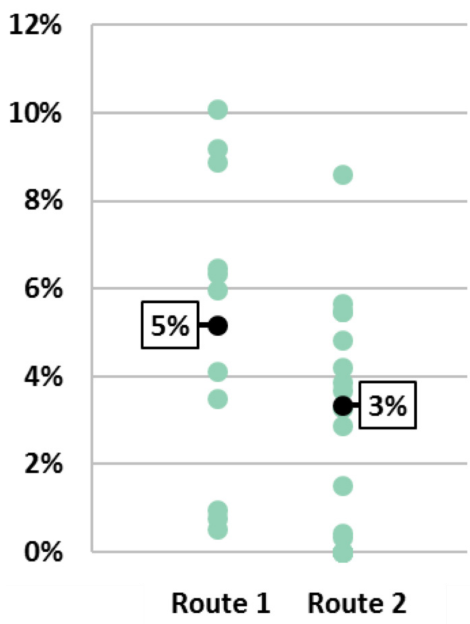
The average test to test variation experienced on Route 1 was 5% and this was largely due to highly variable traffic volumes and the impact of school zones on this route.

Two vehicles were excluded from the repeatability evaluation due to outlier results:

- The results for the plug-in hybrid vehicle were excluded due to the cold start test using a full battery and warm start test an empty battery.
- The result for one diesel vehicle was excluded due to a DPF re-generation event occurring during the cold start test, causing a significant fuel consumption variation of 19% between tests.

Chart 1.

Variation of Fuel Consumption Results between 30 Tests



Test vehicles

Thirty vehicles were tested. One vehicle was tested in two configurations (Petrol and LPG), meaning that a total of 31 test sequences were conducted.

The 30 vehicles have been selected to:

- Maximise the representation of Australia's new vehicle fleet
- Cover a representative range of:
  - Manufacturers
  - Vehicle segments
  - Fuel types
- Include vehicles of interest by:
  - Technology
  - Fuel type
- Include some low volume, new market entries and models not sold into Europe or the USA

Vehicles tested were taken from the general service fleet. All vehicles tested were chosen based on the following criteria:

- The current model available in Australia
- Targeted mileage between 2,000 km not more than 50,000 km. The actual maximum mileage was higher on some vehicles due to vehicle availability. Four vehicles had between 50,000 km and 85,000 km. Two vehicles, a 2004 and 2011 model, had mileage greater than 100,000 km.
- 2014 model or newer, with two exceptions:
  - One 2004 model was tested to compare the emissions with a 2014 model, (to measure the change in emissions compared to newer vehicles), and
  - One 2011 model was selected as a vehicle of interest, being from an emerging market.

Table 1 provides summary information on the vehicles tested.

Fuel consumption results

On average, the real-world fuel consumption of all tested vehicles compared to official results were:

- 23% higher than the official fuel results for all vehicles tested.
- 21% higher for diesel vehicles. The lowest diesel fuel consumption recorded was 4% below the official results. The highest diesel fuel consumption recorded was 59% above the official results.
- 24% higher for petrol vehicles. The lowest petrol fuel consumption recorded was 3% below the official results. The highest petrol fuel consumption recorded was 55% above the official results.
- The LPG vehicle was 27% higher than a calculated official number.
- The fuel consumption of the plug-in hybrid vehicle was 166% higher than the official figures with a full state of charge, and 337% higher when tested from a low state of charge.
- The 2004 model vehicle was 7% higher than the official figures on average.

Note: The 2004 model vehicle and the plug-in hybrid were excluded from the total test vehicle averages.

Details of the fuel results are available on Chart 2.

Table 1.

Test Vehicles

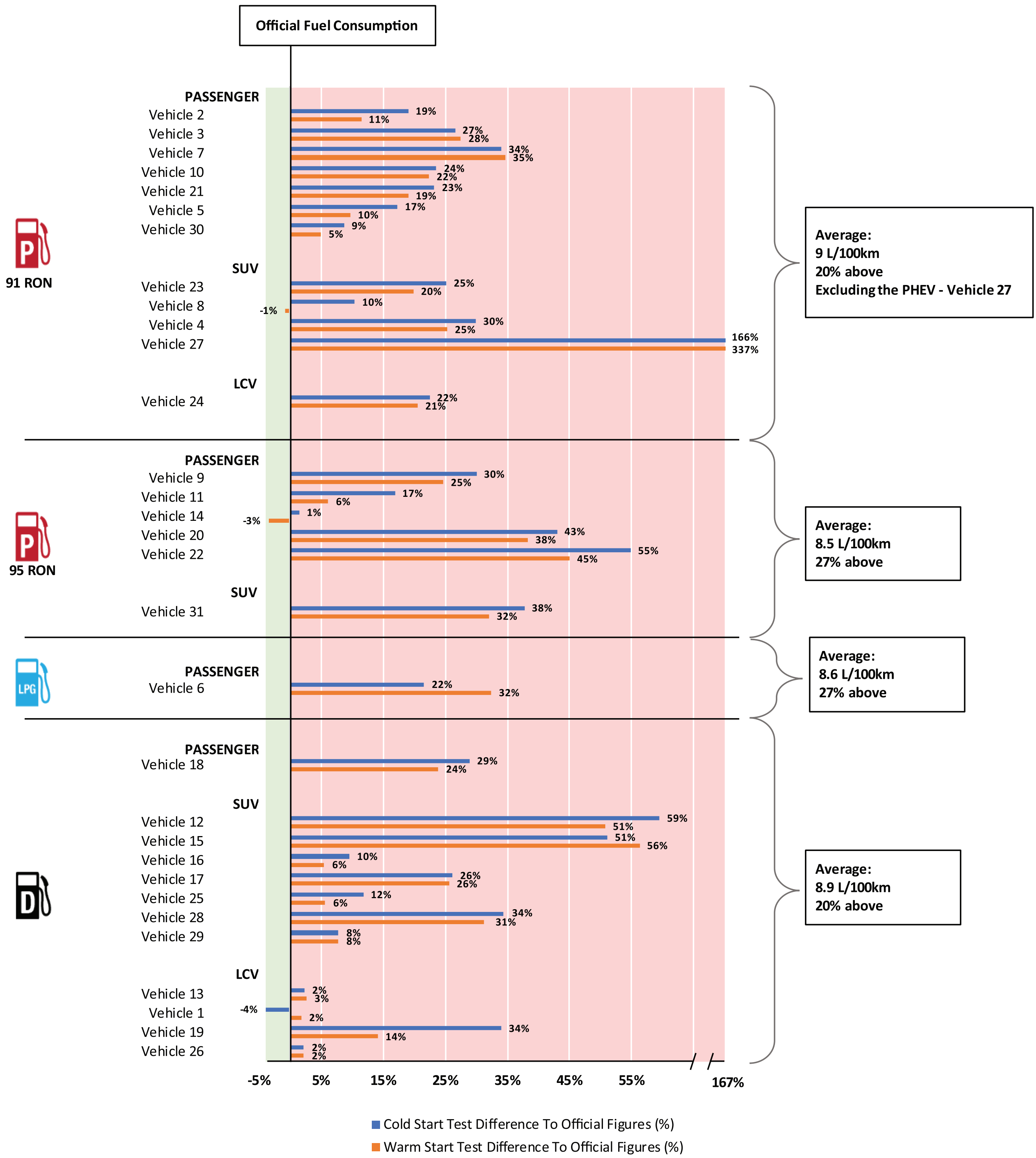
		Powertrain					Segment			Region		
	Total	Petrol	Diesel	Hybrid - Petrol	Hybrid - LPG	Plug In Hybrid	Passenger	SUV	LCV	Asia	North America	Europe
Euro 2	1	1					1			1		
Euro 4	10	3	7				3	3	4	6	3	1
Euro 5	15	10	2	1	1	1	7	7	1	10	2	3
Euro 6	5	2	3				2	3				5
TOTAL	31	16	12	1	1	1	13	13	5	17	5	9

Official fuel consumption figures for vehicles with diesel particulate filters (DPF) include the application of a K_i factor to account for higher fuel consumption during filter regeneration. Significantly higher fuel consumption can be observed during DPF regeneration and they occur at regular intervals, which increases overall average fuel consumption in the real world. To account for this, a K_i factor of 1.05 has been applied to the test results from the vehicles that have a DPF installed, and where the DPF did not actively regenerate on the test, to capture the likely average increase in fuel consumption due to DPF regeneration events.

Two vehicles underwent a DPF regeneration during testing. A K_i factor was not applied to these tests due to the occurrence of DPF regeneration over the drive route.

Chart 2.

Fuel Consumption Compared to Official Numbers



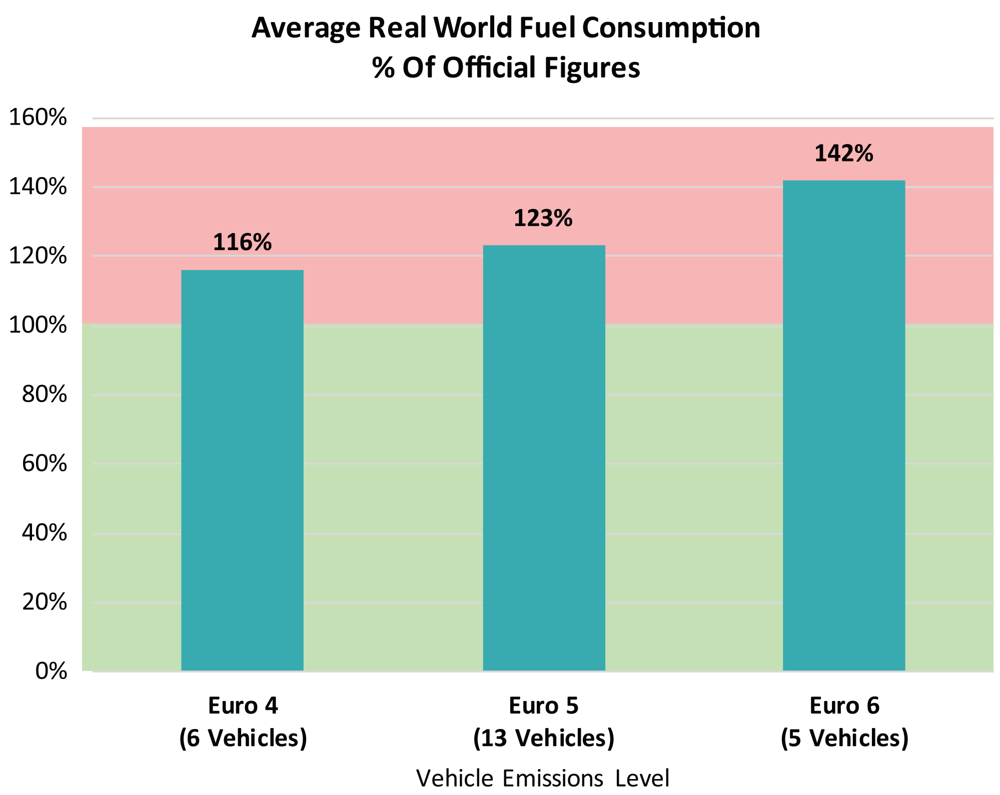
Passenger vehicle and SUV average real world fuel consumption by Euro level

As European vehicles are required to meet more and more stringent CO2 fleet average targets, the average discrepancy in fuel consumption results between the laboratory and the real world has been increasing. This is demonstrated by tracking the average fuel consumption discrepancy as the vehicle emission standards become more stringent.

The Euro 6 compliant vehicles tested had the highest discrepancy between real world and official fuel consumption with the average real-world results being 142% of the official figures. Euro 5 vehicles tested had the next highest discrepancy at 123% and Euro 4 vehicles had a real-world fuel consumption discrepancy of 116% compared to the official figures. This is clear evidence that the average real-world fuel consumption of passenger vehicles and SUV's compared to the official figures has been increasing over time, and in line with Europe's increasingly stringent CO2 standards.

Chart 3.

Average Real-World Fuel Consumption Compared to Official Figures – Passenger & SUV



The plug-in hybrid vehicle and 2004 vehicle model have been excluded from the analysis in the chart above

Emissions results

The number of vehicles that exceeded laboratory limits during real-world testing for each regulated pollutant is shown below in Chart 4.

13 vehicles exceeded the laboratory limit for NOx emissions when tested in the real world. 11 of these were diesel vehicles and of note, only 12 diesel vehicles were tested. The same 11 diesel vehicles exceeded their respective HC and NOx limits. 5 petrol vehicles exceeded the CO laboratory limit in the real world. One diesel vehicle exceeded the laboratory PM limit when tested in the real world.

Chart 4.

Number of Vehicles Exceeding the Laboratory Limit During Real World Testing for Cold Start and Warm Start Tests

Average emissions of petrol and diesel vehicles are shown below in Table 2. On average, the real-world diesel NOx and PM emissions were 24 and 26 times higher respectively than the tested petrol vehicles. However, diesel vehicles emitted an average of 10 times lower CO emissions than the petrol vehicles.

Table 2.

Average Emissions Of All Tested Vehicles

	NOx (g/km)	CO (g/km)	PM (g/km)	THC (g/km)	HC & NOx (g/km)	NMHC (g/km)
Petrol	0.04	1.02	0.66	0.02	0.07	0.02
Diesel	1.00	0.11	17.19	0.02	1.02	0.02
Comparison	24x higher	10x lower	26x higher	Equal	15x higher	Equal

The average real-world emissions as a percentage of the applicable laboratory limit are shown for all tested petrol and diesel vehicles below in Chart 5.

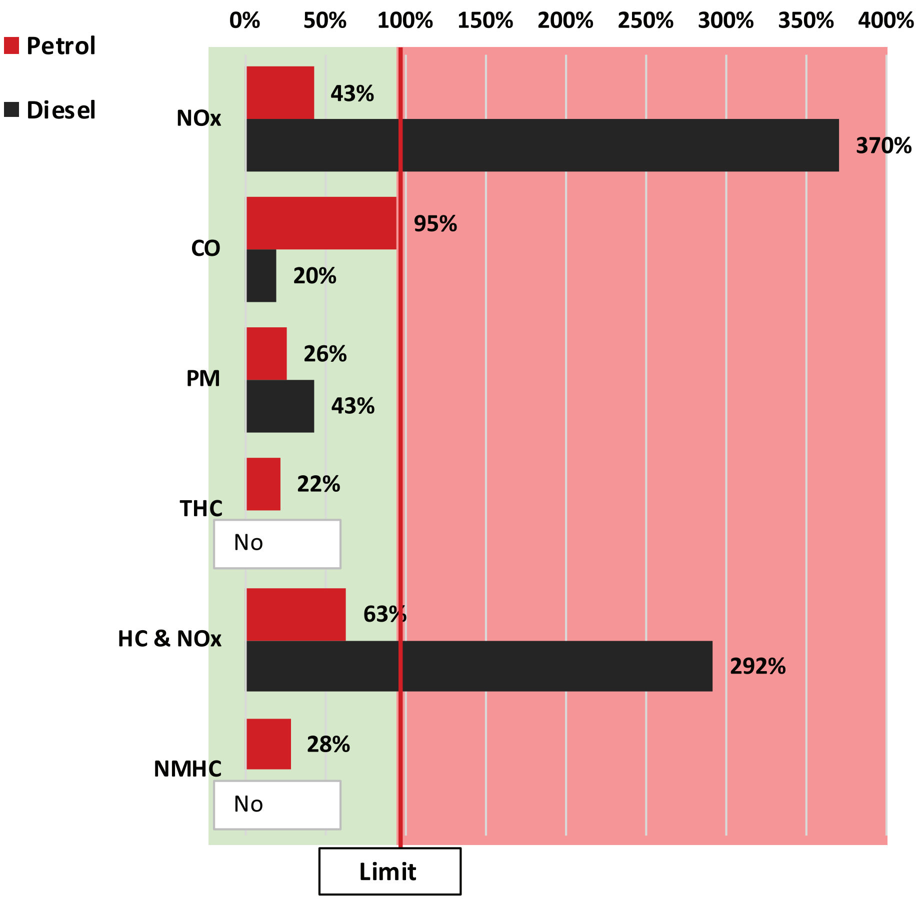
On average, the tested diesel vehicles exceeded their laboratory NOx limit by 370% (3.7 times the limit). They also exceeded their HC and NOx limit by an average of 292%. The tested petrol vehicles emitted 43% of their NOx laboratory limit in the real-world.

The average real-world CO emissions of petrol vehicles was below the laboratory limits, at 95%. The tested diesel vehicles emitted an average of 20% of the laboratory limit in the real world.

In the real world, petrol (Euro 5 and 6 GDI) and diesel vehicles emitted an average of 26% and 43% of their PM laboratory limit respectively.

Chart 5.

Average Real-World Emissions Compared to Laboratory Limits



The HC and NOx for petrol vehicles above relates only to the 2004 model vehicle – limits do not apply to other petrol vehicles.

Summary of real-world noxious emissions and fuel consumption

Table 3 and 4 provide a summary of the real-world noxious emissions and fuel consumption for all vehicles tested compared to each vehicle's regulated laboratory emission limit or official fuel consumption results. In these tables, the applicable regulated limit for each Euro standard is represented by 100%. 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. The text "No Limit" in the white cells represents there being no limit relevant to that particular vehicle for that pollutant.

Whilst a large number of vehicles exceeded various emissions limits by significant amounts, including at levels above the OBD diagnostic threshold, no vehicles displayed any OBD fault code or had the Malfunction Indicator Lamp illuminated.

Table 3.

Cold Start Test - Summary Results All Vehicles

	Fuel Type	Vehicle	NOx	CO	PM	THC	HC & NOx	Fuel
Euro 2	P 91 RON	Vehicle 30	No Limit	57%	No Limit	No Limit	61%	109%
Euro 4	P 91 RON	Vehicle 2	46%	32%	No Limit	15%	No Limit	119%
Euro 4	P 91 RON	Vehicle 5	9%	25%	No Limit	25%	No Limit	117%
Euro 4	P 91 RON	Vehicle 24	135%	99%	No Limit	51%	No Limit	122%
Euro 4	D	Vehicle 18	296%	6%	0%	No Limit	249%	129%
Euro 4	D	Vehicle 25	581%	15%	94%	No Limit	493%	112%
Euro 4	D	Vehicle 17	625%	2%	30%	No Limit	533%	126%
Euro 4	D	Vehicle 29	464%	8%	22%	No Limit	395%	108%
Euro 4	D	Vehicle 26	396%	10%	32%	No Limit	340%	102%
Euro 4	D	Vehicle 1	185%	4%	59%	No Limit	161%	96%
Euro 4	D	Vehicle 13	182%	10%	140%	No Limit	156%	102%
Euro 5	P 91 RON	Vehicle 27	4%	278%	No Limit	84%	No Limit	266%
Euro 5	P 91 RON	Vehicle 8	17%	35%	No Limit	16%	No Limit	110%
Euro 5	P 91 RON	Vehicle 23	18%	66%	No Limit	11%	No Limit	125%
Euro 5	P 91 RON	Vehicle 4	63%	334%	No Limit	46%	No Limit	130%
Euro 5	P 91 RON	Vehicle 7	10%	18%	No Limit	12%	No Limit	134%
Euro 5	P 91 RON	Vehicle 10	15%	21%	6%	16%	No Limit	124%
Euro 5	P 91 RON	Vehicle 21	22%	256%	No Limit	20%	No Limit	123%
Euro 5	P 91 RON	Vehicle 3	2%	4%	No Limit	7%	No Limit	127%
Euro 5	LPG	Vehicle 6	20%	8%	No Limit	8%	No Limit	122%
Euro 5	P 95 RON	Vehicle 11	55%	56%	7%	21%	No Limit	117%
Euro 5	P 95 RON	Vehicle 14	77%	430%	64%	71%	No Limit	101%
Euro 5	P 95 RON	Vehicle 22	166%	35%	61%	32%	No Limit	155%
Euro 5	P 95 RON	Vehicle 31	34%	123%	32%	42%	No Limit	138%
Euro 5	D	Vehicle 16	562%	17%	2%	No Limit	443%	121%
Euro 5	D	Vehicle 19	408%	10%	98%	No Limit	381%	134%
Euro 6	P 95 RON	Vehicle 9	10%	16%	12%	17%	No Limit	130%
Euro 6	P 95 RON	Vehicle 20	20%	10%	35%	22%	No Limit	143%
Euro 6	D	Vehicle 12	422%	6%	53%	No Limit	201%	159%
Euro 6	D	Vehicle 15	75%	92%	1%	No Limit	38%	151%
Euro 6	D	Vehicle 28	289%	14%	51%	No Limit	149%	134%

Table 4.

Warm Start Test - Summary Results All Vehicles

	Fuel Type	Vehicle	NOx	CO	PM	THC	HC & NOx	Fuel
Euro 2	P 91 RON	Vehicle 30	No Limit	37%	No Limit	No Limit	66%	105%
Euro 4	P 91 RON	Vehicle 2	33%	25%	No Limit	7%	No Limit	111%
Euro 4	P 91 RON	Vehicle 5	4%	26%	No Limit	7%	No Limit	110%
Euro 4	P 91 RON	Vehicle 24	106%	74%	No Limit	38%	No Limit	121%
Euro 4	D	Vehicle 18	295%	0%	0%	No Limit	248%	124%
Euro 4	D	Vehicle 25	496%	15%	92%	No Limit	421%	106%
Euro 4	D	Vehicle 17	703%	1%	30%	No Limit	599%	126%
Euro 4	D	Vehicle 29	428%	9%	23%	No Limit	365%	108%
Euro 4	D	Vehicle 26	335%	11%	41%	No Limit	286%	102%
Euro 4	D	Vehicle 1	196%	4%	96%	No Limit	168%	102%
Euro 4	D	Vehicle 13	443%	56%	89%	No Limit	378%	103%
Euro 5	P 91 RON	Vehicle 27	8%	288%	No Limit	23%	No Limit	437%
Euro 5	P 91 RON	Vehicle 8	22%	7%	No Limit	5%	No Limit	99%
Euro 5	P 91 RON	Vehicle 23	24%	12%	No Limit	4%	No Limit	120%
Euro 5	P 91 RON	Vehicle 4	60%	434%	No Limit	50%	No Limit	125%
Euro 5	P 91 RON	Vehicle 7	10%	10%	No Limit	5%	No Limit	135%
Euro 5	P 91 RON	Vehicle 10	18%	12%	2%	10%	No Limit	122%
Euro 5	P 91 RON	Vehicle 21	20%	290%	No Limit	10%	No Limit	119%
Euro 5	P 91 RON	Vehicle 3	2%	2%	No Limit	3%	No Limit	128%
Euro 5	LPG	Vehicle 6	103%	0%	No Limit	6%	No Limit	132%
Euro 5	P 95 RON	Vehicle 11	33%	30%	13%	5%	No Limit	106%
Euro 5	P 95 RON	Vehicle 14	57%	318%	39%	36%	No Limit	97%
Euro 5	P 95 RON	Vehicle 22	200%	19%	41%	10%	No Limit	145%
Euro 5	P 95 RON	Vehicle 31	54%	97%	21%	27%	No Limit	132%
Euro 5	D	Vehicle 16	513%	22%	1%	No Limit	404%	117%
Euro 5	D	Vehicle 19	299%	3%	1%	No Limit	248%	114%
Euro 6	P 95 RON	Vehicle 9	33%	14%	12%	14%	No Limit	125%
Euro 6	P 95 RON	Vehicle 20	40%	9%	20%	17%	No Limit	138%
Euro 6	D	Vehicle 12	310%	8%	2%	No Limit	147%	151%
Euro 6	D	Vehicle 15	106%	142%	42%	No Limit	64%	156%
Euro 6	D	Vehicle 28	283%	8%	NA	No Limit	137%	131%

Conclusion

To date, this program has determined that:

- The discrepancy between the real-world and laboratory test values for emissions and fuel consumption is not due to any single vehicle attribute, and cannot be determined or inferred by a simple equation; discrepancies occur across a range of fuel types, technology levels, and vehicle emissions standards, however;
- There is a clear link to an increasing fuel consumption discrepancy with increasing vehicle emission standard levels. This is related to the CO_2 standards in Europe becoming more and more stringent and manufacturers deploying technologies that are optimised for the laboratory drive cycle.
- Due to the highly complex nature of vehicles, emission systems and fuel consumption performance, regulators need to be cautious when changing or implementing new regulations or standards to ensure that the policy intent can be delivered in the real world. Of the tested vehicles, Euro 6 vehicles had the highest discrepancy in the real world compared to official fuel consumption results, with the average real-world results being 142% of the official figures. This has increased from the average measured for Euro 4 vehicles of 116%.
- Technology implemented to achieve a specific air quality or fuel efficiency standard will result in the consumer paying more for their vehicle, and may also have the unintended consequence of worsening another attribute. For example, the dieselisation of the European fleet to meet CO_2 standards has resulted in a net increase in NO_x and PM emissions.
- Unless a real-world testing component is incorporated alongside any fuel efficiency or vehicle CO_2 regulation, it is very likely that consumers will be paying for fuel efficiency technologies that do not always provide the same level of benefits in the real world as they do in the laboratory where they have been optimised.
- It is not possible to meet the requirements of the European Real Driving Emissions test schedule on Australian roads due to differing traffic and speed conditions. In addition, Australia experiences significantly higher maximum temperatures. Over the course of the test program, there were a number of days that exceeded the maximum temperature requirement of $30^{o}C$. Of the vehicles tested under high temperature conditions, three demonstrated significant increases across some or all pollutant emissions.
- It may not be possible to rely on real-world driving tests conducted in Europe to ensure the compliance of Australia's light duty fleet, as many vehicles sold in Australia are not available in Europe and roads and the environmental conditions are different.
- On average, the real-world fuel consumption of vehicles tested was 23% higher than the NEDC results.
- During the cold start test, 18 vehicles (or nearly 60% of vehicles tested) did not achieve the regulated emissions pollutant limit for one or more pollutant.
- Of the 12 diesel vehicles tested, 11 did not achieve the regulated NO_x limit and were on average three times higher than their respective limits.
- 27% of petrol vehicles exceeded the CO limit.

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