THE INTERNATIONAL COUNCIL ON CLEAN TRANSPORTATION

BRIEFING

MARCH 2015

Comparison of real-world off-cycle NO_X emissions control in Euro IV, V, and VI

Heavy-duty vehicles built and certified in conformity to Euro IV and V emissions standards frequently do not achieve the real-world NO_x emissions expected under those standards. Now data is becoming available to show whether new certification protocols in the Euro VI regulation resolve this problem. The evidence thus far indicates that under Euro VI, NO_x emissions are indeed meeting expectations, even in the most difficult operating conditions. As a result, Euro VI standards may achieve a much greater reduction in NO_x emissions from Euro IV/V levels than the emissions limits alone would indicate.

It has been known for some time that Euro IV and V heavy-duty vehicles produce higher NO_x emissions off of the regulatory test cycles than had been expected.[1] (These are generally termed "off-cycle emissions," i.e., emissions that occur at engine speed/load points not covered by the relevant certification test.) This is mostly attributable to the fact that the certification protocol for Euro IV and V vehicles is not sufficient to ensure that manufacturers control NO_x in the most difficult, low-temperature exhaust regimes. The consequence is that Euro IV and V vehicles may produce NO_x at elevated levels under real-world operation, especially in traffic conditions typical of urban areas, resulting in greater exposure of the population to NO_2 and ground-level ozone.

The adoption of Euro VI, which went into effect in the EU starting with new vehicle types in 2014, not only tightened the NO_x certification level but also made significant changes to the certification test protocol to ensure proper operation of the NO_x control device at low exhaust temperatures. Table 1 compares the key features of Euro IV, Euro V, and Euro

1 Dana Lowell and Fanta Kamakaté, "Urban off-cycle NO_x emissions from Euro IV/V trucks and buses: Problems and solutions for Europe and developing countries," 2012. Retrieved from http://theicct.org/urban-cycle-nox-emissions-euro-ivv-trucks-and-buses. Qiang Zhang, et al., "Investigation of Diesel Emissions in China," 2013. Retrieved from http://www.theicct.org/sites/default/files/publications/Investigation_of_Diesel_Emissions_in_China_Oct_2013_final.pdf

Prepared by Rachel Muncrief

VI certification. Euro V also includes a special category called Enhanced Environmentally Friendly Vehicle (EEV), which has the same certified NO_x level and test protocol but requires lower PM emissions than Euro V.

It can be seen that Euro IV/V certification protocol does not utilize a cold-start test and, in addition, utilizes duty cycles with a higher average engine load/power and less idling time than the Euro VI duty cycle. The Euro IV/V protocol does not "test" the NO_x aftertreatment catalyst under the low temperature conditions where maintaining catalytic activity can be challenging. It is therefore not surprising that these vehicles display NO_x emissions far exceeding certified levels, especially in urban driving conditions. The new Euro VI protocols are meant to mitigate this trend.

Table 1. Comparison of Euro IV, V, and VI Heavy-Duty Engine Emissions Standards and Test Protocols

		Euro IV	Euro V/EEV	Euro VI
NO_x certification level (g/kwh)		3.5	2	0.4/0.46
Adoption (year)		2005	2008	2014
Steady State Duty Cycle	**Cycle Name**	ESC	ESC	WHSC
	Average Engine Load	55%	55%	25%
Transient Duty Cycle	**Cycle Name**	ETC	ETC	WHTC
	Average Engine Power	31%	31%	17%
	Idling %	6%	6%	17%
	Cold Start Tests	0	0	1

Data from tests of Euro IV, V, and VI certified heavy-duty vehicles performed in the 2013-2014 timeframe in a chassis dynamometer test cell at VTT Technical Research Centre of Finland show that the new certification protocols are effective at mitigating off-cycle NO_x emissions.[2] A summary of the vehicle types tested for the data presented here can be found in Table 2. The vehicle makes and models are kept anonymous. All vehicles were fueled with ultra-low sulfur diesel fuel (nominally, 10ppm sulfur). A total of 38 vehicles are reported here, made up of buses, rigid trucks, and tractor trucks. In addition, a range of duty cycles was utilized. The duty cycles utilized in this testing are shown in Table 3. Not all vehicles were tested with all duty cycles. Results from a total of 210 tests are reported here.

Table 2. Vehicle Types Tested

Emissions Level	Number of Tests	Bus	Rigid Truck	Tractor Truck
Euro IV	22		1	1
Euro V/EEV	133	20	5	
Euro VI	55	6	1	4

Table 3. Duty Cycles Utilized for Vehicle Testing

Duty Cycle Name	Short Description	Average Speed (km/h)	Idling (%)
Braunschweig	City Driving Cycle	22.5	25.4
Jakelu	Truck Delivery Cycle	36.6	12.7
WHVC	World Harmonized Vehicle Cycle	40.1	13.7
FIGE	European Transient Cycle	58.9	4.3
Maantie	Truck Motorway Cycle	80.0	0
Moottoritie	Truck Highway Cycle	82.4	0

2 Data presented with permission from VTT.

The NO_x emissions for all tests are shown in Figure 1, plotted as NO_x emissions (in g/kWh) vs. average vehicle speed (in km/h). The Euro IV, V, and VI certification levels are indicated for reference. It can be seen that for both the Euro IV and V vehicles, many tests resulted in overall NO_x emissions significantly higher than the certification level (mostly in lower-speed tests, but sometimes in higher-speed tests as well), while the Euro VI vehicles stayed at very low levels, nearly always at or below the certification level, for all tests (even those at low speed).

Figure 2 shows the Euro VI test results in more detail. It can be seen that there are two data points (of 55) that lie slightly higher than the certification level for the transient test, but all remaining points lie below that level. These results indicate that the Euro VI certification protocols ensure that the NO_x control technology employed by manufacturers of those engines will be much more effective at controlling NO_x over a wide range of real-world operating conditions. Improvements in NO_x control technology include such things as more efficient catalyst formulations, better thermal management of the catalyst, improved urea dosing strategies, and other aftertreatment optimizations. Relatedly, the average urea consumption for the set of vehicles tested increased about 25% from Euro V to VI, which clearly assisted in achieving the respective NO_x reduction.

Euro IV and V vehicles tend to produce a wide range of real world emissions, as shown in Figure 3. For the vehicles tested here, the Euro IV emissions ranged from just under 2.8 to 11.3 gNO_x/kWh, with an average of 6.5 g/kWh, and the Euro V emissions ranged from 0.9 to 9.7 gNO_x/kWh, with an average of 4.4 g/kWh. The Euro VI vehicles showed a much smaller range, 0.01 to 0.50 gNO_x/kWh, with an average of 0.13 g/kWh. As another way of looking at the data, Figure 4 shows the conformity factors for all tests. A conformity factor of one or below indicates that the emissions were within the certification values for that test. It can be seen that the Euro IV and V vehicles show conformity factors well above one for the majority of the tests, while the same is not the case for the Euro VI vehicles.

What are the implications of these results? Most important, that countries considering tightening their HDV emissions standards from Euro IV equivalent would be well advised to leapfrog Euro V and adopt Euro VI standards for maximum real-world benefit. The results strongly indicate that going directly from Euro IV to Euro VI will achieve a larger NO_x reduction than the 88% reduction in certification level would indicate. In practice, this number is likely closer to 98%, and could be even higher due to the fact that real world Euro IV/V emissions are much higher than the emissions limits would indicate. Euro VI standards not only ensure lower NO_x emissions but can also give regulators confidence that off-cycle NO_x emissions should no longer be an issue even for low-speed urban vehicles.

Although it is possible to adopt supplemental or improved test procedures for Euro IV/V vehicles (as is being done in China[3]), the best solution is to implement Euro VI. In addition to lowered real-world NO_x emissions, the stricter standard brings additional benefits as well — e.g., a significant reduction in particulate matter emissions. Fixing Euro IV/V should be considered only as a short-term measure. Lastly, although these results indicate that Euro VI standards are working effectively, these standards must still be complemented with strong in-use compliance and enforcement programs to ensure a successful and well-rounded approach to HDV emissions control.

3 Vance Wagner, Supplemental WHTC testing for Euro IV/V heavy-duty vehicles in China, 2014. Retrieved from http://www.theicct.org/supplemental-whtc-testing-hdvs-china.

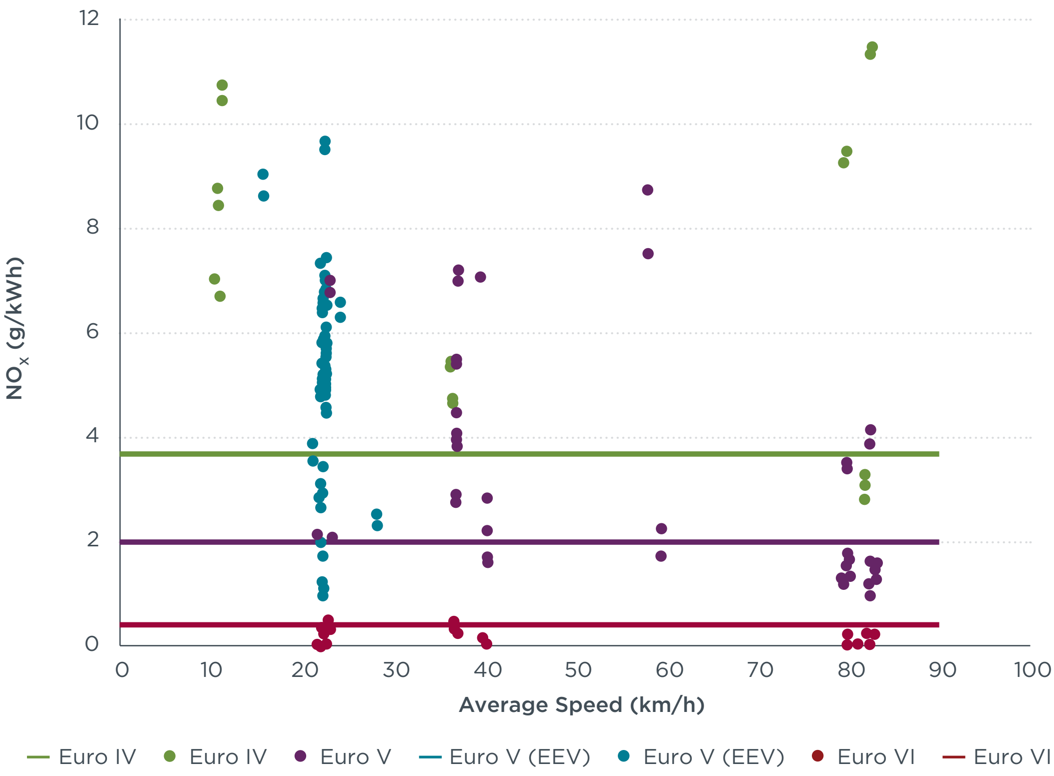

Figure 1. Euro IV, V, VI NO_x Emissions vs Average Vehicle Speed for all Tests

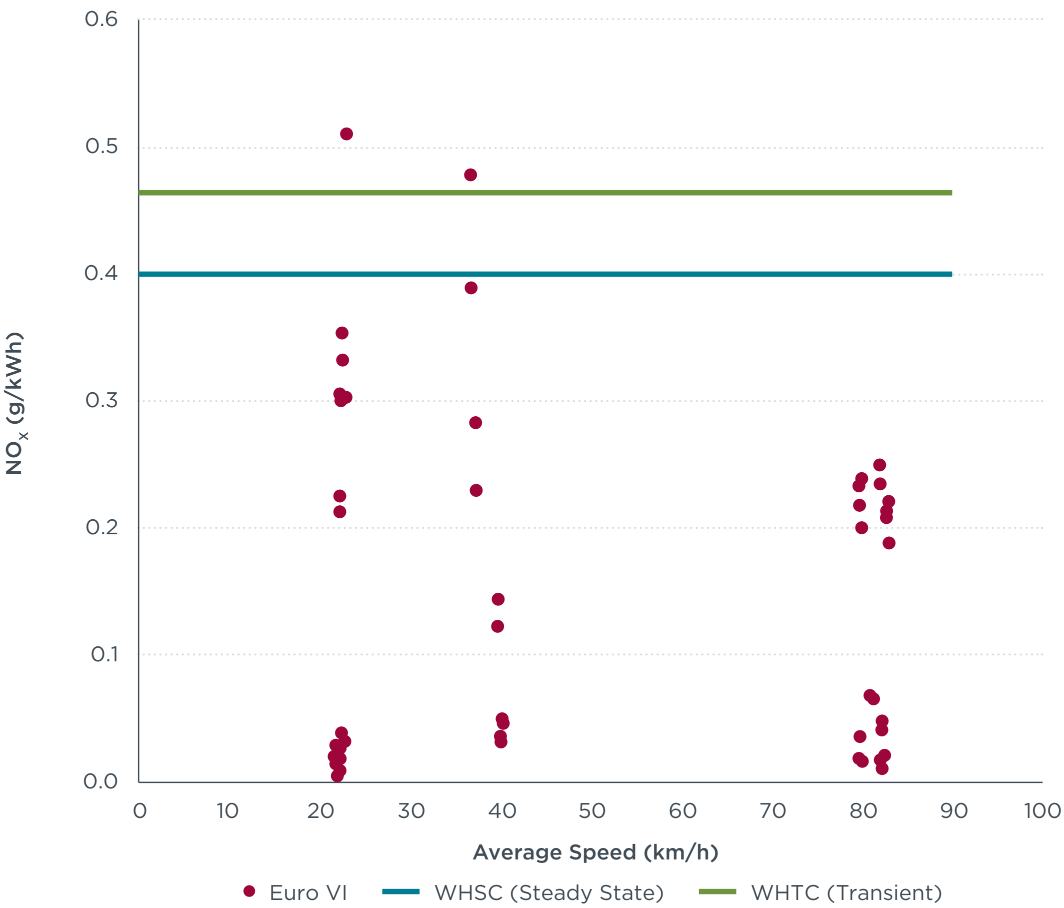

Figure 2. Euro VI NO_x Emissions vs Average Speed for all Tests

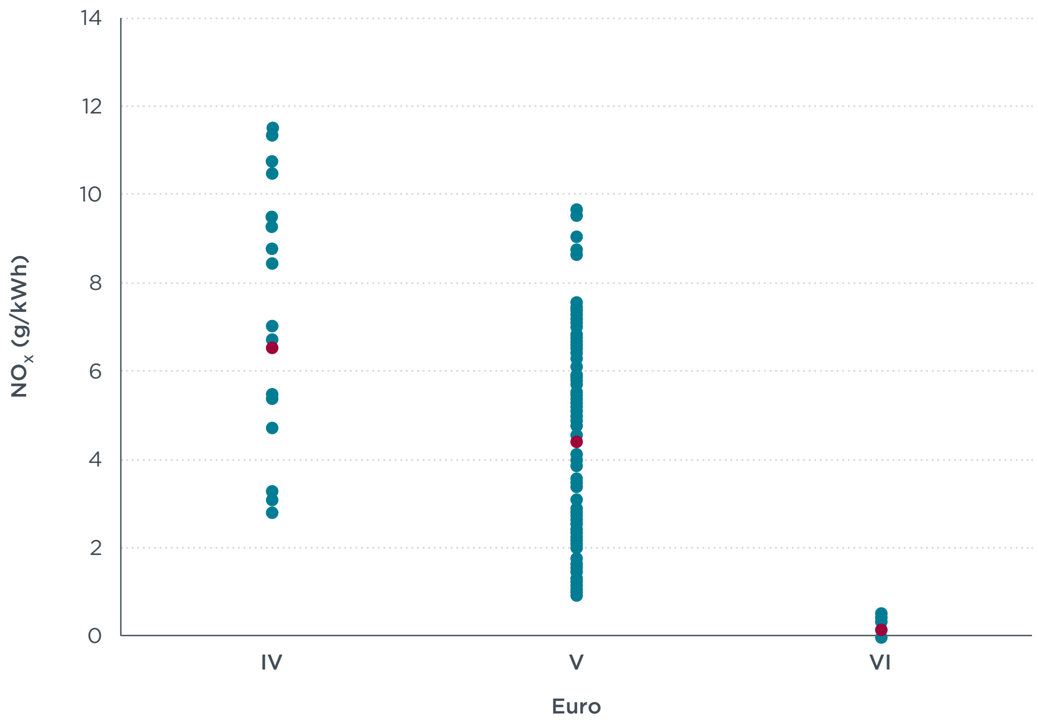

Figure 3. NO_x emissions for all tests plotted vs Euro level. Red point to indicate average of all data

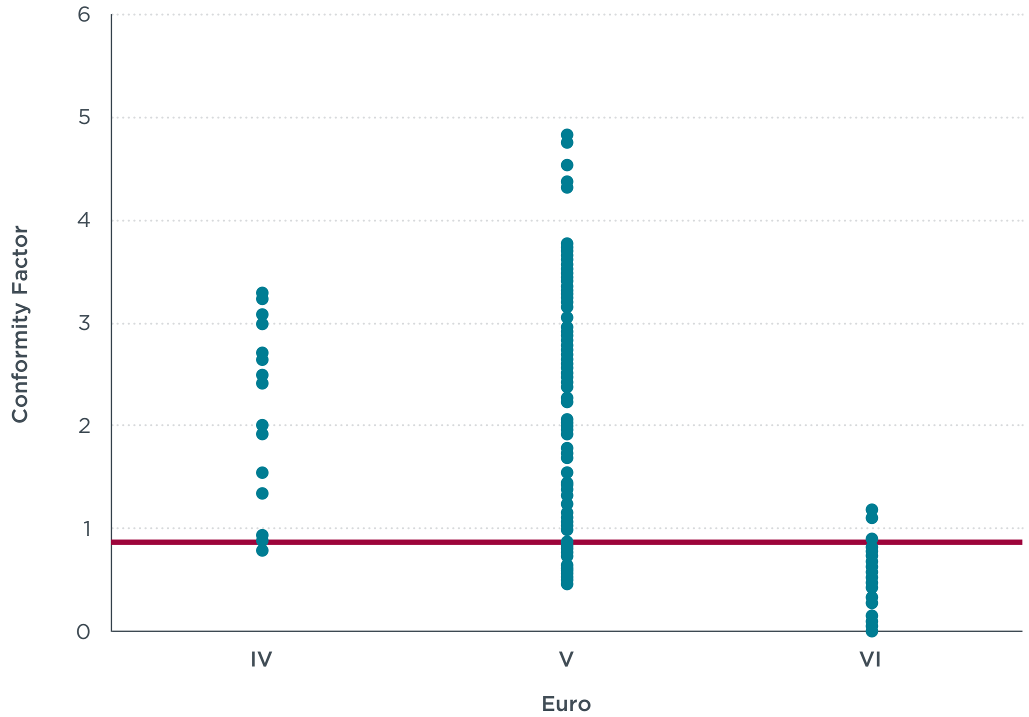

Figure 4. NO_x emissions conformity factors for all tests plotted vs Euro level. Red line to indicate conformity factor of one.