WORKING PAPER 2014-2

FEBRUARY 2014

SERIES: HEAVY-DUTY VEHICLE POLICIES FOR MEXICO

THE INTERNATIONAL COUNCIL ON CLEAN TRANSPORTATION

On-board diagnostics for heavy-duty vehicles: Considerations for Mexico

AUTHOR: Francisco Posada
DATE: February 2014
KEYWORDS: On-board diagnostics (OBD), heavy-duty vehicles (HDV), selective catalytic reduction (SCR)

On-board diagnostic (OBD) systems monitor the performance of engine and aftertreatment components including those responsible for controlling emissions.[1] Historically, OBD systems were first deployed in light duty vehicles (LDVs), in 1991 the United States and 10 years later in Europe. Those first OBD systems were very basic and had very little standardization, meaning that each manufacturer adopted a different system to derive and provide data to drivers and mechanics. By 1996 the OBD system was standardized and the monitoring and emission limits for malfunction were unified across US manufacturers. OBD was introduced to heavy-duty vehicles (HDV) in 2005 in Europe. The phase-in schedule of U.S. Environmental Protection Agency (EPA) OBD requirements started with medium-duty vehicles, as an extension of technologies adopted for LDVs, and now covers the heavier categories. Intended to support the regulatory process around revision of heavy-duty emissions standards in Mexico (NOM 044), this memo focuses on the deployment schedule for OBD on HDVs for Europe and the U.S. and presents the main technical features of these two advanced OBD programs.

Importance of OBD Requirements

There would be significant long-term emissions benefits of adoption of OBD systems in Mexico, as well as important benefits for vehicle owners. OBD is designed to help ensure proper operation of the emission control equipment to ensure that vehicles meet emissions limits during everyday use. OBD systems are a valuable tool for vehicle owners and technicians as they provide important feedback about the need for engine maintenance and potential urgent repairs. OBD assists in the service and repair of vehicles by providing a simple, quick, and cost-effective way to identify problems by retrieving diagnostics data. OBD systems are also a vital component of inspection and maintenance programs for reducing in-use emissions and controlling high emitters.

Adoption of OBD in Mexico would also bring fuel economy benefits, which can be explained from both a technical and a market perspective. From a technical perspective, OBD systems provide a significant amount of information to help optimize engine performance for fuel economy, while ensuring compliance with emissions limits. OBD systems provide manufacturers with more information and a higher number of control variables to improve engine operation. As an example, the best engine performance, in terms of fuel consumption, is found at the same conditions as high NO_x operation. Selective Catalytic Reduction (SCR) systems are designed to allow the engine to be calibrated for high NO_x operation. Thus, SCR aftertreatment systems are designed for engines that emit the highest engine-out NO_x while providing great fuel efficiency. These FE benefits are expected not only under dynamometer testing conditions, but also during in-use operation. SCR use for NO_x aftertreatment requires knowledge of the NO_x levels in the vehicle exhaust in order to inject the right amount of urea for catalytic reduction. NO_x levels in the exhaust can be measured using a NO_x

1 Definition according to the United States Environmental Protection Agency.

AUTHORS Francisco Posada is a researcher with the ICCT passenger vehicle and heavy-duty vehicle programs.

ABOUT THIS SERIES This series is intended to provide technical inputs in support of Mexico's development of transportation and environmental policies to reduce pollutant emissions, fuel consumption, and health and environmental impacts of heavy-duty vehicles. Contributions to the series include global comparative reviews, technical studies, and cost-benefit analyses.

sensor or can be estimated using statistical data gathered during engine testing. A NO_x sensor allows for real-time calibration of the system for the highest engine-out NO_x possible, and best FE possible. A NO_x sensor also ensures proper rates of urea injection and sufficient engine temperatures for proper SCR operation. Without a NO_x sensor manufacturers have to rely on engine-out NO_x maps from calibration curves, which would lead to sub-optimal operation under some operating conditions.

From a market perspective, under both U.S. and European Union (EU) regulations, manufacturers are working towards full OBD deployment by model year (MY) 2016. In the U.S., OBD requirements run parallel with greenhouse gases/fuel economy (GHG/FE) standards for heavy-duty engines, standards that require a 6 percent reduction in fuel consumption and CO_2 emissions by MY2017 from a 2010 baseline. Manufacturers, who already have a strong incentive to improve fuel economy of their engines, are likely to invest in the development of a single engine that meets both OBD and GHG/FE requirements. Without a requirement in Mexico for OBD requirements in place, there is a risk that manufacturers would supply the market with older model year designs that do not have bring the same fuel efficiency benefits.

U.S. OBD

For vehicles with gross vehicle weight rating (GVWR) of 14,000 lbs or less, engines have been fully OBD compliant since MY2007; full vehicles (both diesel and Otto cycle) have been fully OBD compliant since MY2008. The OBD phase-in schedule for heavier vehicles, GVWR > 14,000 lbs, is presented in Table 1. OBD requirements for this weight class are phased in beginning MY2013 until MY2016. The evolution of OBD requirements and migration among vehicle categories can be summarized as:

- MY2007 and later HD engines for vehicles with GVW > 14,000 lbs, require Engine Manufacturer Diagnostics (EMD) systems.[2] This is a preliminary stage, non-standardized OBD for deployment in 2010. The EMD system uses a Malfunction Indication Light (MIL) for engine system problems but the regulation does not specify fault codes, or thresholds for MIL activation.
- For model years 2010 to 2012 only the engine family with highest projected weighted sales are required to have certified OBD systems, liable to monitoring and detection. During this phase-in period the engine with the highest weighted sales (the “parent” of the engine family) has full liability to thresholds, while the other members of the engine family (the “children”) only require certification documentation and no threshold liabilities.
- Starting with MY2013, monitoring thresholds become stricter, and standardization is required across engines. In MY 2013 manufactures are required to fully certify one to three parent ratings, where each one represents similar aftertreatment and OBD system architectures; the HD engine family that is fully certified corresponds to that one selected for MY 2010 OBD certification. These certified parents would be liable to certification procedures and threshold monitoring values. All other engines will have to have OBD systems, but no certification by testing would be required; only documentation proving the existence of the system would be required, along with monitoring and detection not liable to threshold values. The extension of certification procedures and monitoring/detection limits is known as “Extrapolated OBD”.
- Starting MY 2016 manufacturers are required to certify all ratings for all vehicle families, and are liable to thresholds according to certification demonstration procedures.

Table 1. OBD Phase in for the U.S. for vehicle over 14,000 lbs GVWR. Based on work by DieselNet (2014)[3]

Model Year	OBD
2010-2012	Engine family with highest projected weighted sales[1]: • Full OBD[2] for engine rating with highest weighted sales; and • Extrapolated OBD for all other ratings.
2013-2015	Full OBD for all engine ratings subject to 2010-2012 OBD requirements. All other engine families: • Full OBD for engine rating within each OBD group with highest projected weighted sales; • Extrapolated OBD for other ratings and engines; and • More strict monitoring threshold values
2016 and later	Full OBD on all engines

Notes:
(1) A manufacturer’s projected U.S. sales number for engines to be used in on-road heavy-duty vehicles multiplied by their useful life.
(2) 2010-2012 engines with OBD are exempt from standardization requirements.

U.S. OBD TECHNICAL REQUIREMENTS

There are three main categories of U.S. OBD requirements: threshold monitoring, non-threshold monitoring, and OBD testing and validation.

Threshold monitoring requirements apply to the main emission control systems. MIL light would go on when the sensors detect emission levels above certain limit value.

2 http://transportpolicy.net/index.php?title=US:_OBD

3 Dieselnet, http://www.dieselnet.com/standards/us/obd_fed.php. Accessed Jan 2014.

Each limit value is set as a multiplier, or added value in the case of NO_x, of the emission standard or family emission limit. In some cases, the multiplier/added value is reduced with time, following phase-in requirements. Table 2 presents monitors and the emission thresholds for diesel and gasoline engines under the U.S. OBD regulation. NO_x and PM threshold additive levels are tightened starting MY 2013. Annex 1 presents a detailed list of technologies that are monitored under the U.S. regulation.

Non-threshold monitoring involves functional, rational and electrical monitoring of 75-100 signals per engine. The monitoring conditions, for both threshold and non-threshold monitoring, should: detect malfunctions and avoid false passes and false malfunction indications; occur under normal driving conditions; and be reproducible under the U.S. federal test procedure (FTP) protocol. Some signals require that manufacturers define the conditions needed for the monitoring test to occur.

OBD Testing and Validation covers the design of tests that prove the correct OBD functionality under the established threshold values. This includes engine FTP tests and other component specific tests. In order to determine the proper operation of emission control systems, manufacturers must correlate component and system performance with exhaust emissions to determine when deterioration will cause emissions to exceed a certain threshold. This may require extensive testing and calibration for each engine model.

Table 2. Emission Thresholds for Diesel and Gasoline fueled CI engines over 14,000 lbs GVWR

Monitor	Model Year	Thresholds			
		NMHC	CO	NO_x	PM
DIESEL					
NO_x catalyst system	2010-2012	-	-	+0.6	-
	2013+	-	-	+0.3	-
Diesel Particulate Filter (DPF) System	2010-2012	2.5x	-	-	0.05/+0.04
	2013+	2.0x	-	-	0.05/+0.04
Air-fuel ratio sensors upstream	2010-2012	2.5x	2.5x	+0.3	0.03/+0.02
	2013+	2.0x	2.0x	+0.3	0.03/+0.02
Air-fuel ratio sensors downstream	2010-2012	2.5x	-	+0.3	0.05/+0.04
	2013+	2.0x	-	+0.3	0.05/+0.04
NO_x Sensors	2010-2012	-	-	+0.6	0.05/+0.04
	2013+	-	-	+0.3	0.05/+0.04
Other monitors with emission thresholds	2010-2012	2.5x	2.5x	+0.3	0.03/+0.02
	2013+	2.0x	2.0x	+0.3	0.03/+0.02
GASOLINE					
Catalytic converter system	2010+	1.75x	-	1.75x	-
Other monitors with emission thresholds	2010+	1.5x	1.5x	1.5x	-
Evaporative emissions	2010+	0.150" leak	-		-

Notes: 2.5x means a multiple of 2.5 times the applicable emissions standard or family emissions limit (FEL); +0.3 means the standard or FEL plus 0.3; 0.05/+0.04 means an absolute level of 0.05 or an additive level of the standard or FEL plus 0.04, whichever level is higher. Not all monitors have emissions thresholds; some instead rely on functionality and rationality checks.

EU OBD PHASE-IN

European requirements for OBD were introduced in 2005 for Euro IV and have been improved for Euro V (2008) and Euro VI. Euro VI OBD requirements will be phased in between 2013 and 2016. The European HDV OBD program evolution can be summarized as:

- Euro IV OBD (Stage 1)requirements for 2005 may include the following monitoring areas:
    - Reduction in the efficiency of the catalyst;
    - Complete removal of a catalyst;
- Reduction in the efficiency of the NO_x reduction system;
- Reduction in the efficiency of the NO_x reduction system and DPF and other emissions control equipment;
- And as an alternative, the OBD system may monitor for major failure of the catalyst (as a separate unit of the NO_x reduction system and DPF), NO_x reduction system, DPF, and combined DPF and NO_x reduction system.

- Correct operation of NO_x control measures, active since 2006, include:
  - NO_x emission control in terms of MIL activation limits and threshold values for torque limiter activation;
  - Urea monitoring, including level, consumption and quality, including threshold levels for torque limiter activation;
  - The definition of torque limiter value for N (commercial) and M (passenger) class vehicles; and
  - Operating conditions in terms of environmental temperature, altitude and engine coolant temperatures.
- Euro V OBD (Stage 2) requirements starting in 2008 added:
  - Monitoring of electronic interface between Engine Control Unit (ECU) and other powertrain and other vehicle electrical or electronic system for continuity;
  - Monitoring of fuel injection systems, other emission related components, such as Exhaust Gas Recirculation (EGR) and boost, check on circuit continuity for emission related sensors and components, and proper levels of urea; and
  - Adoption of standardized OBD systems across manufacturers, and also access to repair information.
- Euro VI regulations introduced many improvements, including (details in Annex A):
  - More stringent OBD threshold values and type approval based upon on the World Harmonized Test Cycle (WHTC);
  - Adoption of In-Use Performance Ratios (IUPR) to identify how often the conditions for monitoring occurred and how often the monitoring occurred, with minimum values set at IUPR = 0.1 (or 1 in 10); and
  - Additional monitoring requirements for EGR flow, EGR cooling system, boost (turbo and superchargers) and fuel injection systems.

EU OBD THRESHOLD MONITORING

Euro VI regulations introduced many improvements, including more stringent OBD threshold values and type approval based upon on the WHTC. The threshold limits for new vehicles are reduced for NO_x and PM from January 2013 to January 2016 as shown in Table 3. This phase in applies to new model vehicles, while all other vehicles have one more year to comply. The European OBD threshold limits applicable to the OBD system apply to engines fitted to vehicles belonging to M3, N2 vehicles (maximum permissible mass > 7.5 tons), and N3 vehicles.

Table 3. EU Threshold values for CI and SI engines and different phase in periods

ENGINE Type	Periods	NO_x limit, mg/kWh	PM mass limit, mg/kWh	NO_x limit, mg/kWh
Compression Ignition (CI)	Phase in	1500	25	NA
	General	1200	25	NA
Spark Ignition (SI)	Phase in	1500	NA	TBD
	General	1200	NA	TBD

During the phase-in period manufacturers have these flexibilities:

- They are allowed to define a reagent concentration for threshold monitoring different from that of the final date;
- They are allowed to activate driver warning systems based on more relaxed deviation from typical urea consumption rates, 50% instead of 20% for final date;
- There are not in-use requirements for the OBD system;
- They are not required to comply with minimum IUPR; and
- The use of performance monitoring of the DPF, via delta pressure for example, in place of monitoring against PM OBD threshold.

The schedule of implementation for both the EU and the U.S. tends to converge around 2018, as seen in Table 4. GHG/FE standards in the U.S. will also be fully phased in for HDVs in this timeframe.

Table 4. HDV OBD schedule of deployment in the U.S. and the EU

Year	EU	US
Previous	Euro V OBD & NO_x control monitoring	US2010
2013	Euro VI OBD Phase In: 01.01.2013 (New vehicle types)	OBD Phase in for Diesel HDV (GVWR > 14,000 lbs) Full OBD for 1 to 3 engine families per year, Extrapolated OBD for the rest OBD is standardized across manufacturers
2014	Euro VI OBD Phase In: 01.01.2014 (All vehicle types) OBD PM sensors evaluated in September 2014	Full OBD for 1 to 3 engine families per year, Extrapolated OBD for the rest **GHG/FE Phase-In**
2015		Full OBD for 1 to 3 engine families per year, Extrapolated OBD for the rest PM sensor phase-in Urea quality sensor
2016	Euro VI Final OBD: 01.01.2016 (New vehicle types)	Full OBD for HDVs, all engines, all vehicles Full PM sensor
2017	Euro VI Final OBD: 01.01.2016 (All vehicle types)	**GHG/FE Full Stringency**

Special considerations for SCR systems

All manufacturers are now using selective catalytic reduction (SCR) technology to attain the Euro VI and EPA 2010 NO_x standards. Vehicles equipped with SCR use a liquid urea solution as the NO_x reductant, known commonly as diesel exhaust fluid (DEF). Proper operation of the SCR depends on availability of DEF at all times during engine operation, as well as proper DEF quality. Operating a vehicle equipped with SCR without DEF or with poor quality DEF, or water, would invariably result in high NO_x emissions during the period of improper operation. Thus, regulators and manufacturers have incorporated safeguards into the OBD and vehicle control system that alert the driver to malfunction of the SCR system and induce the correction of these conditions, preventing the operation of the vehicle under high NO_x emissions.

"Inducement" is a term aimed at keeping engines that utilize SCR aftertreatment from operating without urea. There are three primary events that could initiate an inducement: (1) low DEF level, (2) incorrect fluid in DEF tank, and (3) SCR faults due to incorrect dosage or tampering. The inducement is structured also in three levels of progressive severity. In the first stage, the warning system will alert the driver that there is low level of urea or urea of incorrect quality. If the issue persists, the second level inducement action will be a reduction in truck performance, aiming at encouraging the driver to refill the DEF tank. The driver will recognize a performance penalty initiated by the Electronic Control Module (ECM), resulting in a loss of vehicle speed or engine power (torque). Ultimately, if the detected issue persists and is not corrected, the third and most severe inducement level action will follow: the ECM will immobilize the vehicle. It is important to note that before the vehicle experiences low level and severe inducement actions, performance reductions there are ample driver / operator reminders and warnings for corrective action. For example, drivers will see dash lamps to remind them to add DEF and are alerted if there is incorrect fluid in the DEF tank.

The implementation of OBD measures covering special considerations for SCR systems is presented for Europe and the United States in Table 5. Common features include monitoring of urea quality and quantity, driver warnings, and means to limit vehicle performance given insufficient or poor quality urea. Note that the language on the European regulation requires the adoption of warnings and inducement systems; on the other hand, U.S. EPA and the California Air Resources Board (ARB), regulations provide some general guidelines and exercise significant discretion over the approval of specific designs.

It is stated in the regulations that manufacturers should provide vehicle operators with a detailed set of instructions, or operational manual, describing proper care and maintenance of the SCR systems. This includes whether the reagent is required, its quality, and rate of consumption and expected refilling frequency. The operational manual should explain also the set of warning systems and actions, as well as the driver inducements and operational degradation steps.

Table 5. Selected SCR OBD Requirements by Region for Heavy-Duty Vehicles

Requirement	EU[1]	US[4]
UREA MONITORING		
Level	Dashboard indicator	Dashboard indicator
Quality	Required (direct or indirect)	Required (direct or indirect)
Dosing	Required	Required
Driver Warnings	1. Warning for low urea (10% volume) 2. Warning for incorrect quality (measured or indirectly determined)[2] 3. Warning for deviation of 20% between expected and demanded urea consumption[3]	1. Warning for low urea (10% volume) 2. Warning for incorrect quality (measured or indirectly determined) 3. Warnings for system tampering –DEF injection interruption 4. Record non-compliance time
Vehicle performance degradation—Low level Inducement	Actions: Vehicle torque output is reduced by 25% in case corrective actions are not taken in cases of: 1. Urea level: at least 2.5% of urea left in urea tank. 2. Poor reagent quality detected within 10 hours of engine operation 3. Improper dosing detected within 10 hours of engine operation 4. NO_x > 7 g/kWh within 10 hours of engine operation	Actions: Typically, vehicle torque output is reduced by 25% in case corrective actions are not taken in cases of: 1. Urea level close to 2.5% of maximum storage. 2. Poor reagent quality, upon detection 3. SCR tampering or improper dosage, upon detection
Vehicle performance degradation—Severe Inducement	Actions: the vehicle speed is limited to 20 km/h max in cases of: 1. Urea level: below 2.5% of urea left in urea tank. 2. Poor reagent quality detected within 20 hours of engine operation 3. Improper dosing detected within 20 hours of engine operation 4. NO_x > 7 g/kWh detected within 20 hours of engine operation The severe inducement is triggered once: 1. the engine is shut down (key-off) 2. the fuel tank level has risen to 10% 3. the vehicle has been parked for more than 1.0 hour	Actions: Typically, vehicle speed is limited to 5 mph, no power or idle-only options in cases of: 1. Urea level empty, low level not corrected and reported by OBD 2. Poor reagent quality and system tampering detected within 4 hours of operation The severe inducement is triggered once two of the following occurs: 1. After refueling 2. After parking 3. After restart
Vehicle performance restored	At idle, when conditions for torque limiting activation has ceased.	> 2.5% urea level in urea tank, or when conditions for torque limiting activation has ceased

Notes:
(1) In EU regulation these requirements apply to vehicles with maximum permissible mass exceeding 7.5 tons.
(2) Manufacturers determine a minimum acceptable reagent concentration that results emissions below type-approval emission rates.
(3) During the phase-in of the European OBD program, ending by 2017, the deviation accepted is 50%.
(4) Specific engine torque/speed reductions are proposed by manufacturers and approved by EPA.

Conclusions

Adoption of OBD in Mexico could dramatically improve the ability to do inspection and maintenance for heavy-duty vehicles, greatly reduce the incidence of high emitters, and provide valuable information about maintenance issues and repair needs to vehicle owners. As a result,

OBD systems will bring long-term emissions benefits and help to reduce fuel consumption.

The incorporation of advanced aftertreatment devices into the emissions control systems of advanced heavy-duty vehicles makes OBD even more critical. Failure of a DPF, for example, could cause engine failure. Failure of the SCR system, on the other hand, could easily go unnoticed by the driver and would not harm the vehicle at all but would result in extremely high NO_x emissions. In either case, OBD systems will help to ensure that high emissions or costly repairs are avoided through ensuring proper operation of the emissions control system.

OBD systems could be required or incentivized in Mexico starting with MY 2016, in order to promote the adoption of the cleanest engine technologies and the most efficient ones. Full harmonization of emissions standards and OBD requirements starting in 2018 will unify the U.S., European and Mexican markets into a common set of heavy-duty emission requirements, promoting competitiveness and reducing regulatory burden in Mexico, while also dramatically reducing emissions of new vehicles. Because of the improvements in efficiency associated with improvements in heavy-duty vehicle engines, these standards would also reduce fuel consumption and would be expected to come at a net negative cost for consumers.

Annex 1. US Monitoring Requirements

Since MY 2007 a manufacturer can opt to certify heavy-duty vehicles at or below 14,000 lbs GVWR on chassis tests. This extends also to OBD requirements. Thus, US OBD regulations for HDVs are separated in the CFR according to GVWR:

Vehicles at or below 14,000 lbs GVWR

According to Section 86.1863-07 of the U.S. Code of Federal Regulations (Chassis certification for diesel vehicles), a manufacturer may optionally certify heavy-duty diesel vehicles 14,000 pounds GVWR or less to the standards specified. Such vehicles must meet all the requirements applicable to Otto-cycle vehicles, except for evaporative, refueling, and OBD requirements where the diesel-specific OBD requirements would apply. For OBD, diesel vehicles optionally certified under this section are subject to the OBD requirements of Section 86.1806.

Engines destined for vehicles above 14,000 lbs GVWR

OBD requirements for these engines are covered under Section 86.010-18 of the code.

Table A1. Monitoring Requirements for Diesel-Fueled/Compression-Ignition Engines

System and §86.010-18 reference	General	Thresholds after 2013	Details	Continuous monitoring
Fuel System Monitoring (g)1	The OBD system must monitor the fuel delivery system to verify that it is functioning properly. The individual electronic components (e.g., actuators, valves, sensors, pumps) that are used in the fuel system have special monitoring provisions.	NO_x: +0.3 PM: 0.03/+0.02 NMHC: 2.0X CO: 2X	Fuel system pressure control Fuel injection quantity Fuel injection timing Unit injector systems may be combined into one malfunction (pressure, quantity, and timing) Feedback signals	Fuel system pressure control (continuously monitored unless new hardware needed) Feedback signals (continuously monitored) * Continuous monitoring would be defined by manufacturer according to in-use performance requirements
Engine Misfire Monitoring (g)2	The OBD system must monitor the engine for misfire causing excess emissions.	NO_x: +0.3 PM: 0.03/+0.02 NMHC: 2.0X CO: 2X	Misfire monitored at idle (MY 2010-12) and continuously (MY 2013+)	For MY 2013+, OBD monitors continuously for engine misfire under all positive torque engine speed and load conditions
EGR System Monitoring (g)3	OBD monitors the EGR system for low flow rate, high flow rate, and slow response malfunctions. For engines equipped with EGR coolers (e.g., heat exchangers), the OBD system must monitor the cooler for insufficient cooling malfunctions. The individual electronic components (e.g., actuators, valves, sensors) have special monitoring provisions	NO_x: +0.3 PM: 0.03/+0.02 NMHC: 2.0X CO: 2X	EGR flow rate, high and low, including leaks EGR response rate EGR feedback signals EGR Cooling System Performance	EGR flow rate (high and low, continuously monitored) EGR feedback signals (continuously monitored) EGR response rate and cooling monitoring would be defined by manufacturer according to in-use performance requirements
Turbo Boost Control System Monitoring (g)4	The OBD system must monitor the boost pressure control system for under and over boost malfunctions. For engines equipped with variable geometry turbochargers (VGT), the OBD system must monitor the VGT system for slow response malfunctions. The OBD system must monitor the charge air cooler system for cooling system performance malfunctions, if available. The individual electronic components (e.g., actuators, valves, sensors) that are used in the boost pressure control system must be monitored in accordance with the comprehensive component.	NO_x: +0.3 PM: 0.03/+0.02 NMHC: 2.0X CO: 2X	Under and over boost malfunctions Slow response (VGT systems only) Charge air undercooling Feedback signals	Under and over boost malfunctions (continuously monitored) Feedback signals (continuously monitored) VGT response rate and charge air cooling monitoring would be defined by manufacturer according to in-use performance requirements.
Non-Methane Hydrocarbon (NMHC) Converting Catalyst Monitoring g(5)	The OBD system must monitor the NMHC converting catalyst(s) for proper NMHC conversion capability. Conversion on the DPF is not included	NA	NMHC Conversion Temperature for proper PM filter regeneration Exothermal monitor strategy	Monitoring would be defined by manufacturer according to in-use performance requirements
SCR and Lean NO_x Catalyst Monitoring (g)6	The OBD system must monitor the SCR and/or the lean NO_x converting catalyst(s) for proper conversion capability. The individual electronic components (e.g., actuators, valves, sensors, heaters, pumps) in the active/intrusive reductant injection system must be monitored	NO_x: +0.3	Conversion efficiency Reductant delivery performance(e.g., urea injection, separate injector fuel injection, post injection of fuel, air assisted injection/mixing) Reductant quality Reductant quantity Feedback control	Conversion efficiency and reductant quality monitoring defined by manufacturer according to in-use performance requirements Reductant delivery performance and quantity, an Feedback signals are continuously monitored

continued

System and §86.010-18 reference	General	Thresholds after 2013	Details	Continuous monitoring
NO_x Adsorber / Lean NO_x Trap (LNT) System Monitoring (g)7	The OBD system must monitor for proper performance. The OBD system must monitor the active/intrusive injection system for proper performance. The individual electronic components (e.g., injectors, valves, sensors) that are used in the active/intrusive injection system must be monitored.	NO_x: +0.3	Adsorption and conversion efficiency Reductant delivery for NO_x adsorber systems that use active/intrusive injection (e.g., in-cylinder post fuel injection, in-exhaust air-assisted fuel injection) Feedback control	Reductant delivery and feedback signals are continuously monitored. Adsorption and Conversion efficiency monitoring defined by manufacturer according to in-use performance requirements.
DPF System Monitoring (g)8	The OBD system must monitor the DPF for proper performance. For engines equipped with active regeneration systems that use an active/intrusive injection (e.g., in-exhaust fuel injection, in-exhaust fuel/air burner), the OBD system must monitor the active/intrusive injection system for proper performance. The individual electronic components (e.g., injectors, valves, sensors) that are used in the active/intrusive injection system must be monitored.	PM: 0.05/+0.04 NMHC: 2X	Filtering performance: this includes PM threshold reading capabilities and a temporary option for pressure differential reading methods before 2013. Regeneration frequency Regeneration completion Missing, removed DPF Insufficient action for regeneration Feedback control (continuously monitored)	OBD monitoring is defined by manufacturer according to in-use performance requirements. PM filter monitoring based on differential pressure requires continuous monitoring
Exhaust Gas Sensor Monitoring (g)9	The OBD system must monitor for proper output signal, activity, response rate, and any other parameter that can affect emissions, all exhaust gas sensors, including: oxygen sensors, air-fuel ratio sensors, NO_x sensors, and other sensors used for emission control system feedback (e.g., EGR control/feedback, SCR control/feedback, NO_x adsorber control/feedback) and/or as a monitoring device. The OBD system must monitor the heater for proper performance of heated oxygen sensors.	Air-Fuel ratio sensor upstream of device: NO_x: +0.3 PM: 0.03/+0.02 NMHC: 2X CO: 2X Air-fuel ratio sensors downstream of aftertreatment devices NO_x: +0.3 PM: 0.05/+0.04 NMHC: 2X CO: -- NO_x sensors: NO_x: +0.3 PM: 0.05/+0.04 NMHC: -- CO: --	Sensor performance (sensor voltage, resistance, impedance, current, response rate, amplitude, offset) Circuit continuity or out of range signals Feedback faults that cause an emission control system to default out of closed loop Insufficient performance of the sensor for use for other OBD monitors Heater performance Circuit faults (continuously monitored) Feedback control (continuously monitored)	Sensor performance monitoring based on differential pressure requires continuous monitoring Circuit integrity and feedback function is monitored continuously.
Variable Valve Timing (VVT) system monitoring (g)10	The OBD system must monitor the VVT system on engines so equipped for target error and slow response malfunctions. The individual electronic components (e.g., actuators, valves, sensors) that are used in the VVT system must be monitored.	NO_x: +0.3 PM: 0.03/+0.02 NMHC: 2.0X CO: 2X	Target error: checks for deviations from target Slow response	VVT target and response rate monitoring is defined by the manufacturer according to in-use performance requirements.

Table A2. US Monitoring Requirements for all engines

System	Monitoring details	Continuous monitoring
Engine Cooling System Monitoring	• Thermostat function • Engine coolant temperature (ECT) sensor readings • Circuit malfunction (Continuous)	
Crankcase Ventilation System (CVS) Monitoring	**Gasoline requirement**: Detect disconnection of the system between: • the crankcase and CV valve, or • the CV valve and the intake manifold, or • design the systems to avoid disconnection **Diesel requirement**: Manufacturer submits plan for review: combination of detection and, more likely, design of the system to avoid disconnection	CVS monitoring is defined by the manufacturer according to in-use performance requirements.
Comprehensive Component Monitors	Required to monitor electronic components that are used/inputs to the engine controller and that: • can cause a measurable emission increase during and reasonable driving condition; or • affect any other OBD monitors. Requirement: Detect following faults: • circuit and rationality faults for input components; and • functional faults for output components. Monitors not tied to emission thresholds	
Other Emissions Control System Monitoring	Other emission control systems not addressed here and that should be reported by manufacturer	
Exceptions to Monitoring Requirements	Certain monitors can be disabled under certain conditions, generally ambient conditions. Such disablements should be approved by the administrator	

MONITORING REQUIREMENTS FOR GASOLINE/SPARK-IGNITION ENGINES

- Same as light-duty OBD II monitoring requirements.
- Alternate fueled engines: Subject to requirements for gasoline engines (even if they are derived from a diesel engine). Must meet HD OBD requirements in 2020+.

Appendix 2. Euro VI Monitoring Requirements

The set of systems monitored by the OBD system under the European regulation are presented in Table A3 [From Appendix 3 to Annex 9B to UN/ECE Regulation No 49, and EC 582/2011]

Table A3. EU Monitoring Requirements for Heavy Duty Engines

System	Monitoring Requirement	Description
Electric / electronic components monitoring	Electric/electronic components used to control or monitor the emission control systems	Includes: pressure sensors, temperature sensors, exhaust gas sensors and oxygen sensors when present, knock sensors, in-exhaust fuel or reagent injector(s), in-exhaust burners or heating elements, glow plugs, intake air heaters. Closed loop sensors involved with emission control systems
DPF System	DPF substrate	Presence of substrate and total failure DPF performance: clogging DPF filtering performance: the filtering and continuous regeneration process of the DPF. **PM emission threshold monitoring**
SCR System	SCR injection	System's ability to regulate reagent delivery properly
	SCR reagent	Availability Quality Proper consumption rates
	Conversion Efficiency	**NO_x emission threshold monitoring**
LNT or NO_x adsorber system	LNT capability	Monitors the LNT system's ability to adsorb/store and convert NO_x
	LNT reagent	System's ability to regulate reagent delivery properly (in case fuel or other reagent is added)
Oxidation Catalyst (OC)[1]	HC conversion efficiency	OC's ability to convert HC upstream and downstream of other aftertreatment devices
EGR system	Low/high EGR flow	Ability to maintain commanded EGR rate **NO_x emission threshold monitoring for CI, performance monitoring for SI** In case OBD threshold limits are not exceeded: for closed and open loop systems, report malfunction when the EGR system cannot increase the EGR flow to achieve the demanded flow rate
	Response rate	Monitors rate of response of EGR actuator Performance monitoring
	EGR cooler underperformance	EGR cooler system's ability to achieve the manufacturer's specified cooling performance Performance monitoring In case OBD threshold limits are not exceeded: the OBD system shall detect a malfunction when the system has no detectable amount of EGR cooling
Fuel Injection	Fuel injection pressure control	Ability to achieve the commanded fuel pressure Performance monitoring
	Fuel injection timing	Ability to achieve the commanded fuel timing Performance monitoring
	Fuel injection system	Ability to achieve the commanded air-fuel ratio (for SI engine only) Performance monitoring.
	Fuel injectors malfunction	Manufacturer should submit analysis and plan for controlling effects of malfunctioning fuel injectors.
Turbocharging or Supercharging systems	Low Boost Pressure	Ability to maintain the commanded boost pressure. **Emission threshold monitoring** In case OBD threshold limits are not exceeded: the OBD system shall detect a malfunction when the boost system cannot increase the boost pressure to achieve the demanded boost pressure, for open and closed boos control systems.
	VGT response rate	VGT system's ability to achieve the commanded geometry within desired time.
VVT system	VVT target error	Ability to achieve the commanded valve timing Performance monitoring.
	VVT response rate	VVT system's ability to achieve the commanded valve timing within desired time. Performance monitoring.
Misfire	Misfire monitoring	Diesels: No prescriptions SI: Misfire that may cause catalyst damage – performance monitoring
Crankcase Ventilation System	-	-
Engine Cooling System	Engine coolant temperature (thermostat)	Stuck open thermostat. Manufacturers need not monitor the thermostat if its failure will not disable any other OBD monitors. Total functional failure
Exhaust gas and oxygen sensors monitoring	Electrical elements of the exhaust gas sensors	Proper operation Component monitoring
	Primary and secondary oxygen sensors	Proper operation Component monitoring
Idle speed control	Electrical elements	Proper operation Component monitoring
Three way catalyst	Conversion efficiency	SI only: the catalyst ability to convert NO_x and CO – performance monitoring

(1) Applies to oxidation catalysts that are separate from other after treatment systems (not if part of the DPF or SCR system)