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GLOBAL OVERVIEW OF ON-BOARD DIAGNOSTIC (OBD) SYSTEMS FOR HEAVY-DUTY VEHICLES

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INTRODUCTION

On-board diagnostic (OBD) systems monitor the performance of engine and after-treatment components, including those responsible for controlling emissions.[1] The OBD system is designed to help ensure proper operation of the emission control equipment, alerting the driver in case of malfunctions, so that vehicles meet emissions limits during everyday use. OBD systems are a valuable tool for vehicle owners and technicians, as they supply important feedback about engine maintenance needs and point toward potentially 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 vital automobile diagnostics data. OBD systems are also a vital component of inspection and maintenance programs for reducing in-use emissions and cutting down on high-emitting vehicles.

OBD systems were first deployed in gasoline light duty vehicles (LDVs). General Motors began introducing OBD systems in its vehicles in 1980. California, which was allowed by the Federal Government to set its own emission rules because of its poor air quality, issued the first requirements for OBD systems starting with the 1991 model year, and Europe followed 10 years later (DieselNet, 2007). Those first OBD systems were basic and had very little standardization, meaning that each manufacturer adopted a different system to read and communicate data to drivers and mechanics. By 1996 the OBD system was standardized in the United States, and the monitoring and emission limits for malfunctions were unified across the range of U.S. manufacturers.

OBD was first introduced for heavy-duty vehicles (HDVs) in 2005 in Europe. The phase-in schedule of the U.S. Environmental Protection Agency (EPA) OBD requirements started with HDVs with a gross vehicle weight rating (GVWR) below 14,000 lbs between 2005 and 2008, as an extension of technologies adopted for LDVs, and were later extended to the heavier categories starting in 2010. California matched the phase-in schedule of EPA's HDV OBD program.

Other countries have adopted HDV OBD requirements following the European program model. India adopted OBD requirements for its Bharat IV emission standards starting in 2013; Brazil has adopted OBD requirements similar to Euro IV/V since 2012 for its PROCONVE P-7 HD standards; China requires European OBD as part of the China IV HDV standards since July 2013.

This white paper focuses on the OBD deployment schedule and monitoring requirements for HDVs in Brazil, China, Europe, India, and the United States (EPA and California's Air Resources Board). Given that Brazil, China, and India follow the European model, this analysis focuses on the European OBD regulations and then checks for differences in the implementation in Brazil, China, and India. The implementation schedules are presented first, then the thresholds and monitoring requirements are tabulated; the final section focuses on the measures for proper nitrogen oxide (NO_x) control measures on selective catalytic reduction (SCR)–equipped vehicles.

1 Defintion according to the United States Environmental Protection Agency.

1. HDV OBD IMPLEMENTATION SCHEDULES

U.S. EPA HDV OBD PHASE-IN

The OBD implementation schedule in the United States has been tied to gross vehicle weight (GVW), moving from light vehicles in the 1990s to medium-duty vehicles in the late 2000s and to HDVs starting in 2010. The evolution of HDV OBD requirements and migration across vehicle categories can be summarized as follows:

» Medium-duty vehicles with gross vehicle weight rating (GVWR) of 14,000 lbs or less have been fully OBD compliant since model year (MY) 2007.

» MY2007 and later heavy-duty (HD) engines for vehicles with GVW greater than 14,000 lbs, require Engine Manufacturer Diagnostics (EMD) systems (TransportPolicy.Net, 2013). This is a preliminary, nonstandardized step to prepare for OBD deployment in 2010. EMD systems use a malfunction indicator 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 by useful life[2] is required to have ”full” OBD, which entails certified OBD systems, liable for proper monitoring and detection. Full OBD requires that the manufacturer design testing protocols to correlate the systems performance with the emission levels, aiming to determine when deterioration will cause the OBD threshold limits (OTLs) to be exceeded. During this phase-in period, the engine with the highest sales (the “parent” of the engine family) has full liability for emission thresholds, while the other members of the engine family (the “children”) only require certification documentation and no emission threshold requirements.

» Starting with MY2013, monitoring thresholds become stricter, and standardization is required across manufacturers. Manufacturers are required to certify fully one to three parent engines, where each one represents similar after-treatment and OBD system designs; the fully certified engine family corresponds to the one selected for MY2010 OBD certification. These certified parents are liable for certification procedures and emission threshold monitoring values. All other engines must have OBD systems, but no certification by testing would be required—only documentation proving existence, monitoring, and detection—and they are not subject to threshold values. The extension of certification procedures and monitoring/detection limits is known as “extrapolated OBD.”

» Starting with MY 2016, manufacturers are required to certify all engines and are subject to emission thresholds according to certification demonstration procedures.

The OBD phase-in schedule for HDVs is presented in Table 1.

2 The manufacturer projected sales times the useful life of each engine. This translates to emphasis on the engines that are going to accumulate the most miles on the road.

Table 1. OBD Phase-in for HDVs (GVWR > 8,500 lbs) in the United States

Model Year	OBD
2008	• HDVs with gross vehicle weight rating (GVWR) < 14,000 lbs are fully OBD compliant.

2010–12	• Engine family with highest projected weighted sales:
	  • Full OBD for engine rating with highest weighted sales;
	  • Extrapolated OBD for all other ratings.

2013–15	• Full OBD for all engine ratings subject to 2010–12 OBD requirements.
	• All other engine families:
	  • Full OBD for the engine rating within each OBD group with the highest projected weighted sales;
	  • Extrapolated OBD for other ratings and engines.
	• Stricter monitoring of OBD threshold values.

2016 and later	Full OBD on all engines.

Source: DieselNet, 2009.

CALIFORNIA ARB OBD PHASE-IN

California's HDV OBD requirements span seven years, starting in 2010 and ending in 2016. Similar to the EPA HDV OBD program, the California Air Resources Board (ARB) program provides a series of phase-in stages that facilitate the design and implementation of OBD technology across a vehicle manufacturer's portfolio of engines and vehicles. The main difference throughout the years is the timeline for adoption of full OBD and extrapolated OBD and the percentage of new vehicles that are covered by each level. Table 2 shows the primary ARB program timeline features.

Table 2. ARB OBD Phase-in for HDVs

Model Year	OBD
2010–12	• Full OBD: Only one engine rating (i.e., OBD parent rating) within one of the engine families. The OBD parent rating is selected from the engine family with highest weighted sales figure for 2010 and should be the engine rating with highest weighted sales within that engine family. • Extrapolated OBD: For all other ratings within the single engine family (i.e., children ratings) where the full OBD system is deployed for the parent. • For these engines, for both full and extrapolated OBD systems, the OBD is partially standardized with respect to data communication. • EMD systems for all other engine families not covered with full or extrapolated OBD.

2013–15	• Full OBD for all engine ratings of the same family subject to 2010–12 OBD requirements (the engine ratings with extrapolated OBD).
	• All other engine families:
	  • Full OBD for the engine rating within each OBD group with the highest projected weighted sales;
	  • Extrapolated OBD for other ratings and engines.
	• Stricter monitoring of OBD threshold values.

2016 and later	Full OBD on all engines.

Source: DieselNet, 2010.
Note: Within the ARB regulatory framework, "weighted sales" means a manufacturer's projected sales figure for engines to be used in California heavy-duty vehicles multiplied by a weight class factor. Sales numbers for diesel engines for heavy-duty vehicles with GVWR less than 19,499 lbs are multiplied by 1.0. Sales numbers for diesel engines for heavy-duty vehicles with GVWR between 19,500 and 33,000 lbs are multiplied by 1.68. Sales numbers for diesel engines for heavy-duty vehicles with GVWR greater than 33,000 lbs and for urban buses are multiplied by 3.95. Sales numbers for all gasoline engines for heavy-duty vehicles are multiplied by 1.0.

EUROPEAN UNION HDV OBD PHASE-IN

European requirements for OBD were introduced in 2005/2006 (TA/FR)[3] for Euro IV and have been improved for Euro V (2008/09) and Euro VI. Euro VI OBD requirements will be phased in between 2013 and 2016. The European HDV OBD program's evolution is summarized in Table 3.

Table 3. OBD Phase-in for HDVs in Europe

Year	OBD
2005	**Euro IV OBD** (Stage I) requirements include after-treatment systems monitoring (nonstandardized OBD).
2006	Correct operation of NO_x control measures: • NO_x emission control in terms of MIL activation limits and threshold values for torque limiter activation. • Urea monitoring, including level, consumption, and quality. The regulation also includes NO_x threshold levels for torque limiter activation.
2008	**Euro V OBD** (Stage II) Additional monitoring requirement plus standardization of OBD communication protocols across manufacturers.
2013–16	**Euro VI OBD** phase-in. • More stringent OBD threshold values and type approval based upon the World Harmonized Test Cycle (WHTC), replacing the European Transient Cycle (ETC). • Adoption of in-use performance ratios (IUPR). IUPRs give an idea of how often the conditions subject to monitoring occurred and how frequent the monitoring intervals occurred. • During the phase-in, the OBD emissions thresholds are tightened in two steps (phase-in and general) as explained in the next section. • The phase-in period offers flexibility for MIL and warning triggers for urea concentration and consumption rates, soot measurement, and IUPR reporting, among others.

INDIA HDV OBD PHASE-IN

India follows the European program with regard to OBD requirements for HDVs (Ministry of Road Transport and Highways, n.d.). Bharat IV standards were implemented in April 2013 and are equivalent to Euro IV OBD requirements, including monitoring of emission-related system components, threshold limits, and special measures for proper operation of SCR systems.

From April 2013, the OBD system for all diesel engines and vehicles must indicate the failure of an emission-related component of the engine system when that failure results in an increase in emissions above the OBD thresholds. It should be noted that the thresholds are equal to the Euro IV requirements and developed over the same test cycle, the European Transient Cycle (ETC).

CHINA HDV OBD PHASE-IN

China also follows the European OBD program. The OBD standard is applicable to compression ignition and gasoline-fueled positive ignition engines and vehicles in M2, M3, N1, N2, N3, and M1 (these vehicle designations follow those of the United Nations

3 TA and FR are type approval and first registration; these concepts define the dates that manufacturers can sell their vehicles to the market. TA covers new engines or vehicles, FR covers the engines and vehicles that are currently being sold. Note that the FR date is usually a year later than the TA dates.

Economic Commission for Europe, or UNECE, for four-wheeled passenger [M] or freight [N] vehicles in various weight classes) with GVW above 3,500 kg and with speed above 25 km/h (Ministry of Environmental Protection, 2008).

The OBD standard was designed to apply nationally from July 1, 2008, although this has been delayed to harmonize with the adoption of China IV and V regulations. The regulatory text does not provide a set of dates per OBD level; therefore, it is assumed here that OBD1 and OBD2 apply according to the respective emission standards (China IV and China V) and to local implementation schedules.

BRAZIL HDV OBD PHASE-IN

In Brazil, the PROCONVE P7 standard, equivalent to Euro V standards, was instituted in January 2012. This standard required the adoption of OBD systems for certification, but its requirements are closer to Euro IV OBD requirements. Technical details defining the OBD main elements, such as monitoring, emission thresholds, and proper operation of urea-based NO_x control systems, are detailed in the Instruction Norm No. 04 of May 12, 2010 (Ministry of the Environment, 2010).

OBD GLOBAL SCHEDULE SUMMARY

Table 4 presents an overview of the OBD implementation schedules for the five countries/regions presented. The schedule of implementation in the European Union (EU) and the United States tends to converge around 2017. This implies that the most advanced OBD control systems, with the most stringent threshold limits and complete monitoring requirements, will be available by that time.

Table 4. HDV OBD schedule of deployment in selcted countries

Year	US EPA & ARB	EU	Brazil	India	China
2005	OBD phase-in for diesel HDV, **GVWR <14,000** lbs	Euro IV HDV OBD	—	—	—
2008	OBD (100 percent) for diesel HDV, **GVWR <14,000** lbs	Euro V HDV OBD	—	—	—
2010	OBD phase-in for diesel HDV, **GVWR >14,000** lbs		—	—	—
2012	Top sales family: Full OBD for top sales rating and extrapolated OBD for other ratings		—	—	—
2013	Top sales family: Full OBD for all ratings Other families: Full OBD for top sales rating and extrapolated OBD for all other ratings	Euro V OBD & NO_x control monitoring 01.01.2013 (New vehicle types) phase-in Euro VI OBD	**PROCONVE P7** (Similar to Euro IV OBD)	**Bharat IV OBD**	**China IV** Nationwide **China V** Beijing
2014		Euro VI – 01.01.2014 (all vehicle types)			China V Shanghai
2015	**PM sensor phase-in** **Urea quality sensor**	OBD: Until 01.09.2015 for alternative diesel particulate filter (DPF) monitoring. Pressure drop instead of PM sensor			
2016	Full OBD for HDVs, all engines, all vehicles **Full PM sensor**	01.01.2016 Final OBD Euro VI (new vehicle types)			
2017		01.01.2017 Final OBD Euro VI (all vehicle types)			

2. HDV OBD MONITORING REQUIREMENTS

There are three main categories of on-board diagnostic system requirements: threshold monitoring, nonthreshold monitoring, and OBD testing and validation.

Threshold monitoring requirements apply to the main emission control systems. The malfunction indicator light goes on when sensors detect emission levels above certain limit values or under certain conditions pointing to system malfunction. Each limit value is set as a multiplier or an added value, of the emission standard or engine family emission limit. It should be noted that European OBD regulations require only thresholds for particulate matter (PM) and NO_X, while the US OBD requirements cover nonmethane hydrocarbons (NMHC) and carbon monoxide (CO) in addition.

Nonthreshold monitoring involves functional, rational, and electrical monitoring of 75–100 signals per engine. This includes monitoring of engine and certain after-treatment components for total failure, ability to achieve a designated commanded target, response rate to reach the specified target, circuit continuity, voltage, current, and many more characteristics of each separate system involved in reducing emissions.

The monitoring setup for both threshold and nonthreshold monitoring, should detect problems and avoid giving either false passes or false malfunction indications. Monitoring is expected to occur under normal driving conditions; it also has to be reproducible under specific testing conditions (engine testing). Some signals can be monitored continuously (e.g., electrical connections), but others require that manufacturers define the conditions needed for the monitoring test to occur (for instance, the monitoring of urea injection necessitates that the selective catalytic reduction (SCR) system be operating, which happens only after the system reaches a specific temperature). The U.S. and the European programs have adopted in-use performance ratio (IUPR) monitoring values that provide a minimum frequency of monitoring events per drive. For example, in the United States, the minimum IUPR is 0.1, meaning that there should be at least one monitoring event during 10 trips.

OBD testing and validation covers the design of tests that prove the correct OBD functionality under the established threshold values. This includes engine 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.

This section presents the heavy-duty vehicle OBD thresholds and monitoring requirements. It starts with the European program (all stages) and then moves on to India, China, Brazil, and the U.S. regime. It should be noted that India, China, and Brazil follow the European OBD requirements (Euro IV and Euro V), with very small variations. At the end a summary of monitoring requirements for these programs is presented.

EU HDV OBD REQUIREMENTS

The OBD threshold limits are presented in Table 5, starting with OBD Stage 1 and Stage 2 requirements, followed by Euro VI. The Euro VI OBD thresholds for new vehicles are being phased in from January 2013 to January 2016. 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 pertain to engines fitted to vehicles belonging to the following UNECE classes:

» M3,

» N2, with maximum permissible mass greater than 7.5 metric tons, and

» N3.

Table 5. Euro VI threshold values for CI and SI engines and different phase-in periods

Standard		Periods	NO_x limit, mg/kWh	PM mass limit, mg/kWh
Stage 1 Euro IV	CI only	2005/06	7,000	100
Stage 2 Euro V	CI and SI	2008/09	7,000	100
Euro VI	CI	Phase-in	1,500	25
		General	1,200	25
	SI	Phase-in	1,500	NA
		General	1,200	NA

Note: CI: compression ignition (diesel); SI: Spark ignition (gasoline).

Monitoring requirements evolved in two main areas: requirements for the efficiency of conversion (applies to after-treatment systems) became mandatory; also, the conditions for monitoring became clearly defined, indicating the frequency of monitoring and some specific operation parameters. Regarding access to OBD data communication, European-based OBD systems should conform to either ISO 15765 or SAE J1939. Details on monitoring requirements are presented in the appendix.

Stage 1 Euro IV OBD requirements of 2005

The Stage 1 OBD system must monitor thresholds as follows:

» Complete removal of a catalyst when fitted in a separate housing from diesel particulate filter (DPF) and deNO_x systems (includes SCR, lean NO_x traps and NO_x catalysts);

» Reduction in the efficiency of the deNO_x system, with respect to NO_x;

» Reduction in the efficiency of the DPF, with respect to PM;

» Reduction in the efficiency of the combined deNO_x + DPF, with respect to both NO_x and PM.

As an alternative to OBD threshold monitoring, the OBD system may monitor for major failure of the following components:

» A catalyst (as a unit separate from the deNO_x system and DPF);

» A deNO_x system. Examples of monitoring for major functional failure are complete removal of the system or replacement of the system by a bogus system (both representing instances of intentional failure), lack of required reagent for a deNO_x system, failure of any SCR electrical component, or any electrical failure of a component (e.g., sensors and actuators, dosing control unit) of a deNO_x system, including, when applicable, the reagent heating system or the reagent dosing system (e.g., missing air supply, clogged nozzle, dosing pump failure);

» A DPF system. Examples of monitoring for major functional failure are major melting of the trap substrate or a clogged trap resulting in a differential pressure beyond the range declared by the manufacturer, any electrical failure of a component (e.g., sensors and actuators, dosing control unit) of a particulate filter, or any failure, when applicable, of a reagent dosing system (e.g., clogged nozzle, dosing pump failure);

- Monitoring of the electronic components of fuel injection systems and fuel quantity and timing actuators for circuit integrity;
- Monitoring of all other engine or exhaust after-treatment emission-related components or systems that are connected to a computer, the failure of which would result in tailpipe emissions exceeding the OBD threshold limits. At a minimum, examples include the exhaust gas recirculation (EGR) system, systems or components for monitoring and control of air mass flow, air volumetric flow (and temperature), boost pressure and inlet manifold pressure (and relevant sensors to enable these functions to be carried out), sensors and actuators of a $deNO_x$ system, and sensors and actuators of an electronically activated particulate filter;
- Monitoring for electrical disconnection (circuit integrity);
- For engines equipped with an SCR system, the OBD should monitor for availability, quality, and consumption and dosing of reagent (e.g., urea).

Stage 2 Euro V OBD requirements (2008)

Stage 2 OBD added the following requirements:

- Monitoring of the electronic interface between the engine control unit (ECU) and other powertrain and vehicle electrical or electronic systems for continuity;
- Adoption of standardized OBD systems across manufacturers and also access to repair information.

Euro VI OBD requirements (2013/16)

This regulation introduced many more improvements, including (see the appendix for further details)

- More stringent OBD threshold values and type approval based on the World Harmonized Test Cycle (WHTC);
- Adoption of in-use performance ratios. IUPRs give an idea of how often the conditions subject to monitoring occurred and how frequently the monitoring was conducted. The regulation established a minimum of IUPR = 0.1 (or 1 in 10 times);
- Additional monitoring requirements for EGR flow, EGR cooling system, boost (turbo and superchargers) and fuel injection systems.

During the Euro VI OBD phase-in period manufacturers have these areas of flexibility:

- Manufacturers are allowed to define a reagent concentration for threshold monitoring different from that ultimately specified;
- Manufacturers are allowed to activate driver warning systems based on more relaxed deviation from typical urea consumption rates, 50 percent instead of 20 percent at the final date;
- During the phase-in period there are no in-use requirements for the OBD system;
- During the phase-in period manufacturers are not required to comply with minimum in-use performance ratios (European Commission, 2011);
- The regulation allows the use of performance monitoring of the DPF, via delta pressure, for example, in place of monitoring against the PM OBD threshold.

INDIA HDV OBD REQUIREMENTS

Bharat IV monitoring requirements are the same as those of the Euro IV Stage 1 OBD regulation, with threshold limits (see Table 6).

Table 6. India HDV OBD thresholds—Bharat IV

Standard	Vehicle	NO_x limit, g/kWh	PM mass limit, G/KWH
Bharat IV	CI	7.0	0.10

A list of monitored systems is detailed in the Appendix section.

CHINA HDV OBD REQUIREMENTS

There are three levels of OBD systems in China, as shown in Table 7, following the EU model. OBD1 is applied to China IV emission standards, and OBD2 is applied to China V emission standards. OBD1 + NO_x monitoring requirements are similar to those of the Euro IV regulation.

Table 7. China OBD threshold values in different emissions stages

Emissions Stage	OBD System	Thresholds	
		NO_x g/kWh	PM[4] g/kWh
IV	OBD1+NO_x Control[1]	5.0[2] / 7.0[3]	0.1
V	OBD2+NO_x Control[1]	3.5[2] / 7.0[3]	0.1
EEV	OBD2+NO_x Control[1]	3.5[2] / 7.0[3]	0.1

Notes:
[1] Proper operation of NO_x control measures.
[2] NO_x control limits under European Transient Cycle testing.
[3] OBD1 limits under European Stationary Cycle testing and OBD2 and NO_x control limits under ETC. If NO_x control is above the limits, torque limiter will be activated.
[4] Not applicable to gas-fueled engines.

A summary list of monitored systems is provided below and the detailed list in the Appendix section:

- Reduction in the efficiency of the particulate filter;
- Complete removal of a catalyst;
- Reduction in the efficiency of the deNO_x system;
- Reduction in the efficiency of the combined deNO_x system and filter;
- As an alternative for the above monitoring items, the OBD system of diesel engines may monitor for major failure of the catalyst (as a unit separate from the deNO_x system and DPF), deNO_x system, DPF, and combined DPF + deNO_x.
- DeNO_x major functional failures include complete removal of the deNO_x system or bogus system installation as a replacement, reagent depletion, electronic component malfunctions of the SCR system, electronic component malfunctions of the deNO_x system (e.g., sensors, actuators, control equipment for reagent dosage), including malfunctions of the reagent heating and injection systems (e.g., no air supply, injection port blockage, injection pump malfunction);
- Major functional failures of the particulate filter system, such as melting of the trap substrate or a clogged trap resulting in a differential pressure beyond the range

declared by the manufacturer, electronic component malfunction (e.g., sensors, actuators, quantity control equipment), reagent injection system (e.g., injection port blockage, injection pump malfunction);

- Urea-based SCR systems require monitoring of urea usage, loss, and dosage;
- Monitoring of the electronic components of fuel injection systems and fuel quantity and timing actuators;
- Monitoring of all other engine or exhaust after-treatment emission-related components or systems that are connected to a computer, the failure of which would result in tailpipe emissions exceeding the OBD threshold limits.

OBD2 + NO_x adds the following monitoring requirements:

- Reduction in the efficiency of the catalyst (if applicable);
- Monitoring of the electronic interface between the engine control unit and other powertrain and vehicle electrical or electronic systems for continuity.

BRAZIL EU HDV OBD REQUIREMENTS

The OBD requirement only applies to compression ignition engines, except those used in vehicles with a gross vehicle weight (GVW) less than 3,856 kg and alternative fuel vehicles (ethanol, compressed natural gas, liquefied petroleum gas). The regulation establishes NO_x emission limits for certification, activation of the malfunction indicator light (MIL), and torque limiter activation. One significant deviation from European HDV OBD requirements is the lack of PM thresholds. Table 8 presents NO_x thresholds under Proconve P7.

Table 8. Brazil HDV OBD NO_x threshold values in different emissions stages

OBD actions and Certification values	NO_x EMISSION LIMIT (G/KWH)
Torque limiter activation	7.0
Malfunction indicator light activation	3.5

Note: The type approval limit for NO_x is 2.0 g/kWh.

Brazil's monitoring requirements are similar to Euro V, which covers OBD Euro IV requirements plus the addition of electric components monitoring, but lack the urea quality and dosage monitoring requirements. In addition, Brazilian OBD requirements do not include the additional Stage 2 requirements in accordance with Euro V OBD, keeping only those from Stage 1, Euro IV. A detailed list of monitored systems is provided in the Appendix section.

US HDV OBD REQUIREMENTS—EPA AND ARB

The U.S. Environmental Protection Agency OBD threshold limits are established in the Code of Federal Regulations, CFR 86.010-18, while the California Air Resources Board values are covered by the California Code of Regulations (CCR), Title 13, section 1971.1**.** Threshold monitoring covers all the emission-related systems for diesel engines, as shown in Tables 9 and 10. The OBD emission threshold limits (OTL) differ slightly between the two programs, with ARB's being the stricter. Also, the phase-in requirements are somewhat similar, but ARB will require more stringent OTLs starting in 2016, making its program the most demanding one.

In 2008, ARB and EPA requirements for heavy-duty OBD were reasonably similar. ARB has amended its HD OBD requirements twice since then (2009 and 2012), whereas

EPA has not made any amendments. Most of the changes can be best classified as fine tuning, resulting in marginal divergences between the two programs. According to OBD expert staff at ARB,[4] virtually every new HD engine that is certified in the United States meets ARB requirements because EPA accepts the ARB OBD system as compliant with EPA requirements. Table 11 presents a summary of the main differences between the EPA's and ARB's HDV OBD requirements. The summary includes not only the thresholds by pollutant and monitored system but also other important differences between OBD testing procedures and requirements.

See the appendix to this paper for a detailed list of emission control technologies that are monitored under the U.S. regulations.

Table 9. EPA Emission Thresholds for Diesel- and Gasoline-Fueled CI engines over 14,000 lbs

Monitor	Model Year	Thresholds			
		NMHC	CO	NO_x	PM
Diesel					
NO_x after-treatment systems (includes SCR and lean NO_x trap systems)	2010–12	—	—	+0.6	—
	2013+	—	—	+0.3	—
DPF system	2010–12	2.5x	—	—	0.05/+0.04
	2013+	2.0x	—	—	0.05/+0.04
Air-fuel ratio sensors upstream	2010–12	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	2010–12	2.5x	—	+0.3	0.05/+0.04
	2013+	2.0x	—	+0.3	0.05/+0.04
NO_x sensors	2010–12	—	—	+0.6	0.05/+0.04
	2013+	—	—	+0.3	0.05/+0.04
Other monitors with emission thresholds (fuel injection system, engine misfire monitoring, EGR system, turbocharging system, variable valve timing system)	2010–12	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 but instead rely on functionality and rationality checks.

4 Personal communications with Allen Lyons, Staff Air Pollution Specialist, OBD Development Section, California Air Resources Board, 2014.

Table 10. ARB Emission Thresholds for Diesel- and Gasoline-Fueled CI engines over 14,000 lbs

Monitor	Model Year	Thresholds			
		NMHC	CO	NO_x	PM
Diesel					
NMHC converting catalysts (e.g., diesel oxidation catalyst and PM filter)	2010–12	2.0x	—	—	—
	2013–15	2.0x	—	+0.2	—
	2016+	2.0x	—	+0.2	—
NO_x conversion catalyst (e.g., SCR or active lean NO_x catalysts)	2010–12	—	—	+0.4	—
	2013–15	2.0x	—	+0.3-0.2[1]	—
	2016+	2.0x	—	+0.2[1]	—
NO_x adsorber catalyst (e.g., lean NO_x trap)	2010–12	—	—	+0.3	—
	2013–15	2.0x	—	+0.2	—
	2016+	2.0x	—	+0.2	—
DPF system	2010–12	2.0x[3]	—	-	+0.06
	2013–15[2]	2.0x[3]	—	+0.2[3]	+0.04
	2016+	2.0x[3]	—	+0.2[3]	+0.02
Air-fuel ratio sensors upstream	2010–12	2.0x	2.0x	2.0x	+0.02
	2013+	2.0x	2.0x	2.0x	+0.02
Air-fuel ratio sensors downstream	2010–12	2.5x	—	+0.3	+0.04
	2013+	2.0x	—	+0.2	+0.02
NO_x and PM sensors	2010–12	—	—	+0.4	+0.04
	2013–15[4]	—	—	+0.3	+0.02
	2016+	2.0x	—	+0.2	+0.02
Variable valve timing and/or control (VVT) system	2010+	2.0x	2.0x	2.0x	+0.02
Cold start emission reduction strategy	2013+	2.0x	2.0x	2.0x	+0.02
Gasoline					
Catalyst (TWC)		1.75x	-	1.75x	—
Fuel system	2010+	1.5x	1.5x	1.5x	—
Misfire	2010+	1.5x	1.5x	1.5x	—
EGR system	2010+	1.5x	1.5x	1.5x	—
Cold start emission reduction strategy	2010+	1.5x	1.5x	1.5x	—
Secondary air system	2010+	1.5x	1.5x	1.5x	—
Oxygen sensors, primary and secondary	2010+	1.5x	1.5x	1.5x	—
VVT system	2010+	1.5x	1.5x	1.5x	—
Evaporative emissions	2010+	0.150" leak	—		—

Notes:
[1] The more lax OTL applies for at least 20 percent of 2014 model year diesel engines and at least 50 percent of 2015 model year diesel engines.
[2] Two options: at least 20 percent of 2014 model year diesel engines and at least 20 percent of 2015 model year diesel engines or at least 50 percent of MY 2015 diesel engines meet the 2016+ OTLs.
[3] NMHC and NO_x OTL values apply only during DPF regeneration events that occur at frequencies considered as higher than expected for normal DPF regeneration events.
[4] For at least 20 percent of 2014 model year diesel engines and at least 50 percent of 2015 model year diesel engines, the OTL values are those of MY 2016+.

Table 11. EPA and ARB Monitoring and Threshold Values Comparison

Item	Years	EPA	ARB
DPF filtering thresholds	2010–12	PM family emissions limit (FEL)+0.04 Optional physics monitor	PM FEL+0.06
	2013–15	PM FEL+0.04	PM FEL+0.04
	2016+	PM FEL+0.04	PM FEL+0.02 (all engine families)
DPF regeneration frequency thresholds	2010–12	NMHC x 2.5	NMHC x 2.0
	2013+	NMHC x 2.0	NMHC x 2.0 NO_x FEL+0.2
DPF NMHC conversion thresholds	2010–12	No thresholds	No thresholds
	2013+	No thresholds	NMHC x 2.0
SCR conversion and reductant delivery thresholds	2010–12	NO_x FEL+0.6	NO_x FEL+0.4
	2013+	NO_x FEL+0.3	NO_x FEL+0.2
NOx adsorber threshold	2010–12	NO_x FEL+0.6	NO_x FEL+0.3
	2013+	NO_x FEL+0.3	NO_x FEL+0.2
NMHC catalyst conversion threshold	2010–12	No thresholds	NMHC x 2.0
	2013+	No thresholds	NMHC x 2.0 NO_x FEL+0.2
NMHC catalyst feedgas generation	2010+	No monitoring required	Detect inability to generate NO_x feedgas for SCR systems
NMHC exothermal for DPF regeneration	2010+	Detect inability to increase temperature by 100C within 60 seconds Abort regeneration if regeneration temperature is not reached within five minutes Abort regeneration if regeneration temperature cannot be sustained Optional NMHC threshold of 2.5x and must include OBD-specific infrequent regeneration adjustment factor (IRAF)	Detect inability to generate exothermal (and see OBD-specific IRAFs, below)
OBD-specific infrequent regeneration adjustment factors included in thresholds	2010–12	Not required (but see NMHC exothermal for DPF regeneration, above)	Must be included for any thresholds affected by infrequent regenerations
Test cycle over which monitors should be demonstrated	2010+	Cycle that results in the most robust monitor	Cycle that results in the most stringent monitor
Engine and catalyst aging for certification demonstration	2010–12	Engine aged to 125 hours Catalysts aged to useful life (rapid aging allowed)	Engine aged to 125 hours Catalysts aged to useful life (rapid aging allowed)
	2013–15	Same as 2010–12	Entire system aged to full useful life (rapid) Manufacturer must collect in-use data on engine + after-treatment system having at least 185K miles; meaningful findings must be incorporated into rapid aging process
	2016+	Same as 2013–15	Same as 2013–15 except systems must have full useful life miles

Source: ARB staff.

SUMMARY OF GLOBAL OBD MONITORING REQUIREMENTS

The summary presents a comparison of the OBD threshold limit (OTL) values with respect to their respective emission level standard as well as monitoring requirements for all the programs described in this report (Table 12).

The OTL comparison shown in Figure 1 covers the EU program (which can be used as a proxy for China, India, and, to some extent, Brazil) and the U.S. programs, EPA's and ARB's. The ratio between OTL and emission level standard for NO_x and PM from the previous tables takes into account the primary emission control system used to treat those pollutants. For NO_x, the SCR system was selected and, for PM, the DPF.

Figure 1 shows that OBD systems are being designed for MIL activation progressively closer to the emission limits, as shown by the reduction in OTL/standard ratios for both NO_x and PM. Also the figure shows that, in the United States, the ARB program is stricter than the EPA program on this aspect of HDV regulation. This implies that under the ARB regime particularly the OBD system would be activated earlier with respect to potential deterioration of emission control systems, reducing the probability of a vehicle being driven on the road with troublesome emissions issues. Also, the figure suggests that the OBD Euro VI program is much stricter with respect to PM (DPF failures) than either the EPA and ARB programs and is similar to EPA regarding NO_x (SCR failures).

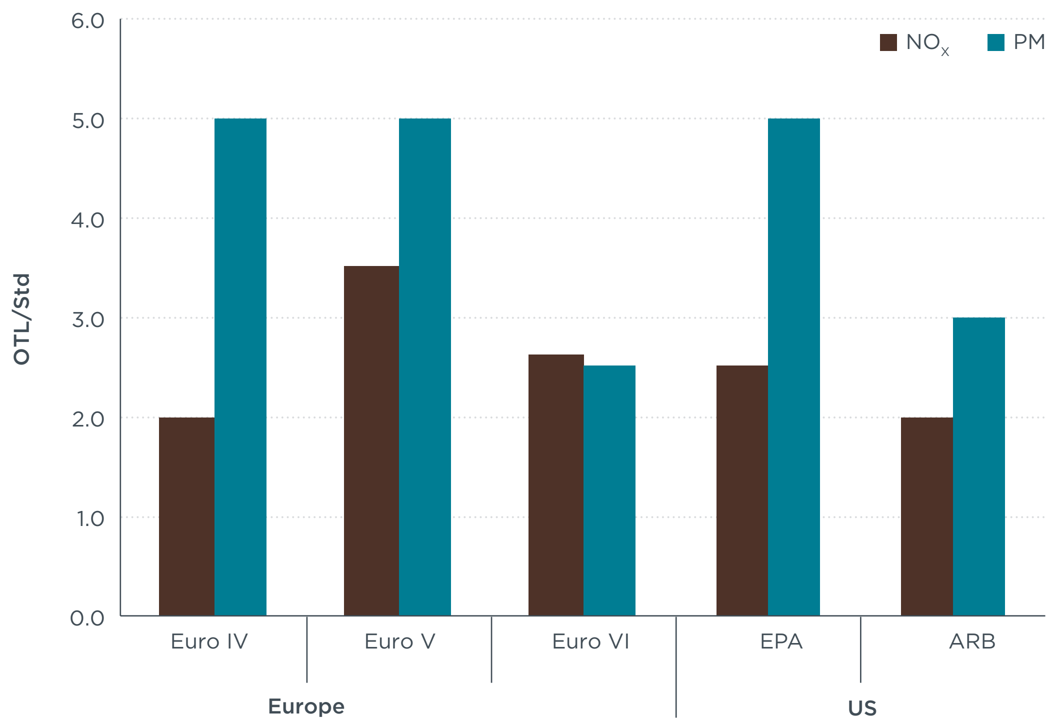

Figure 1. Ratios between OTL and the emission standard for NO_x and PM under the European and U.S. HDV OBD programs

Table 12. Summary of Global OBD Monitoring Requirements

OBD Requirement	Euro IV/V Stage 1 and 2	India	China	Brazil	Euro VI	US EPA/ARB
Implementation year	2005 and 2008[1]	2013	2013–14[2]	2012	2013–16[1]	2010–16
Diesel threshold monitoring and OTL ratios[3]	NO_x and PM				NO_x (3.2x–2.6x) and PM (2.5x)	NO_x (3.0x–2.5x), PM (5.0x), NMHC (2.0x), CO (2.0x)
Catalyst—diesel oxidation catalyst	Removal and major failure				Conversion efficiency for hydrocarbons	NMHC catalyst conversion, DPF heating
Lean NO_x trap (LNT) or NO_x absorber	Not explicit				Conversion efficiency and reductant delivery if used	Conversion efficiency, NO_x OBD threshold limits (OTL) monitoring and reductant delivery if used
SCR system	Conversion efficiency; OBD threshold limits (OTL) for NO_x; major failure (removal; electrical failure of sensors and actuators)				Conversion efficiency—OTL for NO_x; reductant delivery (quantity, quality, consumption rate)	Conversion efficiency; NO_x OTL monitoring; reductant delivery (quantity, quality, consumption rate), response of control system
SCR urea system	Monitoring of urea quantity, quality, and consumption			Brazil: Monitoring of urea quantity only	Monitoring of urea quantity, quality, and consumption	Monitoring of urea quantity, quality, and consumption
DPF system	Conversion efficiency; OBD threshold limits (OTL) for PM; major failure (removal; electrical failure of sensors; clogged filter)				Conversion efficiency—OTL for PM; major failure (removal; electrical failure of sensors; clogged filter); regeneration	Filtering performance—PM and NMHC OTL monitoring; pressure differential; regeneration (frequency, completion), missing substrate; active regeneration (fuel delivery); response of control system
Combined deNO_x + DPF	Conversion efficiency and thresholds for NO_x and PM; major failure				No available information	Not available
Fuel systems	Monitoring quantity, timing, and circuit integrity				Pressure, quantity, timing, control	OTL monitoring, pressure, quantity, timing, response of control system
Air boost systems	Mass air flow; boost pressure and inlet manifold pressure				OTL monitoring, flow rate, response, cooler operation, control; VGT-commanded geometry	OTL monitoring, flow rate, response, cooler operation, response of control system; VGT-commanded geometry
EGR systems	Monitor for malfunctions conducing to exceeding emission thresholds. No explicit mention of EGR cooling systems				OTL for NO_x; flow rate, response; EGR cooler performance	OTL monitoring, flow rate, response, cooler operation, response of control system
Valve timing systems—VVT	Not explicit				VVT target and response	PM, NMHC, and CO OTL monitoring ; VVT target and response of control system
Engine cooling systems	Not explicit				Thermostat and total failure	Thermostat, engine coolant temperature, circuit malfunction
Sensors and actuators	Monitor for electrical disconnection—circuit integrity				Proper operation; voltage, circuit integrity, monitoring capacity	OTL monitoring for exhaust gas sensors; performance (voltage, current); circuit continuity, feedback control, monitoring capacity

Notes:
[1] For Europe, type approval dates; first registration dates start one year later.
[2] National dates' standards are Euro IV; Euro V applies to local standards in advance of national regulations.
[3] OBD monitors for malfunctions that lead to emissions above OBD thresholds for NO_x, PM, hydrocarbons, and CO. The ratios are presented as factor of the corresponding standard (e.g., NO_x 2.0x means 2.0 times the NO_x standard).

3. SPECIAL REQUIREMENTS TO ENSURE THE CORRECT OPERATION OF SCR SYSTEMS

The majority of engine manufacturers chose selective catalytic reduction (SCR) technology to attain the Euro IV, V, VI, and EPA 2010 NO_x standards. All 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 urea quality. Driving a vehicle equipped with SCR in the absence of urea or using urea of poor quality, 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 on-board diagnostics and vehicle control system that alert the driver and prompt correction of malfunctions of the SCR system, even preventing the operation of the vehicle under conditions of high NO_x emissions.

The system of warnings and inducements that are part of the special measures for proper operation of NO_x control measures is designed to keep engines that utilize SCR after-treatment from operating without urea. There are three primary events that could initiate a prompt: (1) Low DEF level, (2) Incorrect fluid in DEF tank, and (3) SCR faults attributable to incorrect dosage rates or tampering. The warning and inducement system is structured according to three levels of progressive severity. First, the warning system will alert the driver that there is low level of urea or urea of incorrect quality; second, if the urea deficiency or quality issue persists, warnings will be followed by a low-level action, in the form of a reduction in truck performance, aimed at encouraging the driver to refill the DEF tank. The driver will suffer 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 ECM will immobilize the vehicle. It is important to note that before the vehicle experiences low-level penalties or immobilization, there are ample driver/operator reminders and warnings for corrective action. For example, drivers will see dashboard lights to remind them to add DEF and will be alerted if there is incorrect fluid in the DEF tank.

It should be noted that this set of special requirements that ensure the proper operation of SCR systems is independent of the OBD regulation, as defined within the U.S. and the EU regulatory programs, as well as the OBD regulatory programs adopted by Brazil, China, and India. The objective of the OBD system is to detect system failures, while the objective of the SCR warnings and inducements is to prevent the occurrence of SCR system failures owing to human interaction or lack thereof. Because the OBD system also monitors urea quantity and quality, the SCR and OBD requirements tend to be confused; the SCR requirements utilize a subset of signals from the OBD system to take actions that go well beyond what the OBD is designed for, such as reducing the torque or immobilizing the vehicle.

The implementation of OBD measures covering special considerations for SCR systems is presented for Europe, India, China, Brazil, and the United States in Table 13. 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 in the European program (adopted as Euro IV and V by India, China, and partially by Brazil) requires the adoption of warnings and inducement systems; on the other hand, the U.S. Environmental Protection Agency and the California Air Resources Board (ARB) regulations provide some general guidelines and exercise significant discretion over the approval of specific manufacturer's designs.

Table 13. Selected SCR OBD Requirements by Region for Heavy-Duty Vehicles

Requirement	Europe	India	China	Brazil	Europe	US[2]
Standard	Euro IV—2005/06 Euro V 2008/09	Bharat IV	China IV/V	PROCONVE P7	Euro VI	EPA 2010
Application dates	Nov. 2006/ Oct. 2007	April 2010	July 2008 [1]	April 2012	2013	2010
Urea level	Required on dashboard			Required on dashboard	Required on dashboard	Required on dashboard
Urea quality	Required			No	Required	Required
Urea consumption	Required			No	Required	Required
Driver warnings	1. Warning for low urea below 10 percent of urea tank volume or a higher percentage at the choice of the manufacturer, **or** 2. Warning for urea level below the level corresponding to the driving distance possible with the fuel reserve level specified by the manufacturer			1. Warning for low urea below 10 percent of urea tank volume	1. Warning for low urea below 10 percent of urea tank volume 2. Warning for incorrect quality (measured or indirectly determined) 3. Warning for deviation of 20 percent between expected and demanded urea consumption	1. Warning for low urea below 10 percent of urea tank volume 2. Warning for incorrect quality (measured or indirectly determined) 3. Warnings for system tampering—DEF injection interruption
Driver inducements or vehicle performance degradation	Actions: torque is limited to 1. 60 percent of engine maximum torque for vehicles of category N3 > 16 metric tons, M > 7.5 tons 2. 75 percent of engine maximum torque for vehicles of category N ≤ 16 tons, 3.5 < M1 ≤ 7.5 tons, M2 and M3 <7.5 tons Torque limiter activated when: 1. urea tank is empty 2. NO_x level exceeds OBD threshold 3. poor urea quality detected 4. there is a deviation of 50 percent between expected and demanded urea consumption 5. there is an interruption in reagent dosing Operational Condition for torque activation: after vehicle becomes stationary			Actions: torque is limited to 1. 60 percent of engine maximum torque for vehicles with maximum total indicated mass > 16 tons 2. 75 percent of engine maximum torque for vehicles with maximum total indicated mass ≤ 16 tons The inducement is triggered: 1. immediately after urea tank reaches empty 2. upon detection of NO_x >7 g/kWh	**General inducement** Actions: the vehicle torque output is reduced by 25 percent Torque limiter activated when: 1. urea level is at 2.5 percent of urea tank volume 2. there is poor reagent quality within 10 hours of engine operation 3. there is improper dosing within 10 hours of engine operation 4. NO_x >7 g/kWh within 10 hours of engine operation **Severe Inducement** Actions: the vehicle speed is limited to 20 km/h max in cases of: 1. urea level: below 2.5 percent 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 percent 3. the vehicle has been parked for more than one hour	Actions: typically, vehicle torque output is reduced by 25 percent if corrective actions are not taken in cases of: 1. urea level hovering close to 2.5 percent of maximum storage 2. poor reagent quality upon detection 3. SCR tampering or improper dosage upon detection Actions: Typically, vehicle speed is limited to 5 mph, no power, or idle-only options in cases of: 1. urea level registering as empty, low level not corrected and reported by OBD 2. poor reagent quality and system tampering detected within four hours of operation The severe inducement is triggered once two of the following occurs: 1. refueling 2. parking 3. restart
Vehicle performance restored	At idle, when conditions for torque-limiting activation have ceased			At idle, when conditions for torque-limiting activation have ceased	At idle, when conditions for torque-limiting activation have ceased	Once there is a 2.5 percent urea level in urea tank, or when conditions for torque-limiting activation have ceased

Notes:
[1] The OBD standard was designed to apply nationally from July 1, 2008, although this date has been delayed to accord with the adoption of the China IV and V emission standards.
[2] Specific engine torque/speed reductions are proposed by manufacturers and approved by the EPA.

It is stated in the US and European regulations that manufacturers should provide vehicle operators with a detailed set of instructions or operations manual, describing proper care and maintenance of the SCR systems. This includes whether the reagent is required, its quality, and its rate of consumption and expected refilling frequency. The operations manual should explain also the set of warning systems, prompts for the driver, and steps toward operational degradation if such prompts are neglected.

CONCLUSIONS

New on-board diagnostics requirements for Euro VI 2013–16 and U.S. EPA and ARB 2013–16 will bring stricter monitoring, including more stringent OBD threshold limit (OTL) monitoring and performance and functionality monitoring. This potentially will result in better in-use performance for the heavy-duty vehicles affected.

India and China have adopted OBD requirements identical to those of Euro IV/V. Brazil, which uses Euro V tailpipe emission standards, has adopted very similar requirements, except the monitoring of urea quality and dosage.

Measures to ensure the proper operation of SCR systems (warnings and inducements) have been clearly defined by the European regulation and have been imported into the Chinese and Indian standards—and into the Brazilian program as well by removing the urea quality monitoring and dosage sections. In the United States, manufacturers are allowed to design their own SCR warnings and inducement measures, but these are subject to EPA approval before commercialization.

From a market perspective, under both U.S. and European regulations, manufacturers are working toward full OBD deployment by model year 2016. In the United States, OBD requirements are set to function in tandem with greenhouse gas or fuel economy standards for heavy-duty engines that require a 6 percent reduction in fuel consumption and CO_2 emissions by model year 2017, from a 2010 baseline.

RELEVANT OBD REGULATIONS

EPA 2010

Since model year 2007, and depending on vehicle gross weight, a manufacturer can certify a heavy-duty engine on an engine dynamometer. Alternatively, it can certify the whole HD vehicle on a chassis test. This extends also to on-board diagnostics requirements. Thus, U.S. OBD regulations for HD vehicles are separated in the Code of Federal Regulations according to gross vehicle weight rating (GVWR):

Vehicles at or below 14,000 lbs GVWR

According to **§86.1863-07** (chassis certification for diesel vehicles), a manufacturer may optionally certify heavy-duty diesel vehicles of 14,000 lbs GVWR or less according to the standards specified in **§86.1816**. Such vehicles must meet all the requisites applicable to Otto-cycle vehicles, except for evaporative, refueling, and OBD requirements where the diesel-specific OBD rules would apply. For OBD, **diesel vehicles** optionally certified under this section are subject to the OBD requirements of **§86.1806**.

Engines destined for vehicles above 14,000 lbs GVWR

OBD requirements for these engines are covered under **§86.010-18**.

CALIFORNIA ARB OBD

California Code of Regulations (CCR), Title 13, section 1971.1

§1971.1. On-Board Diagnostic System Requirements—2010 and Subsequent Model-Year Heavy-Duty Engines

EURO VI

Under the European regulatory framework, performance requirements are those set out in section 5 of Annex 9B to UN/ECE Regulation No. 49 of the United Nations Economic Commission for Europe and Regulation **EC 582/2011**.

APPENDIX. DETAILED OBD MONITORING REQUIREMENTS

US EPA AND ARB MONITORING REQUIREMENTS

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

System and §86.010-18 reference	Monitoring requirements	General
Fuel System Monitoring **(g)1**	Fuel system pressure control (OBD threshold limit, or OTL) Fuel injection quantity (OTL) Fuel injection timing (OTL) Unit injector systems may be combined into one malfunction monitor (pressure, quantity, and timing) Feedback signals	The on-board diagnostics (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.
Engine Misfire Monitoring **(g)2**	Misfire monitored at idle (model years 2010–12) and continuously (MY2013+) (OTL)	The OBD system must monitor the engine for misfire causing excess emissions.
Exhaust Gas Recirculation (EGR) System Monitoring **(g)3**	EGR flow rate, high and low, including leaks (OTL) EGR response rate (OTL) EGR feedback signals EGR cooling system performance (OTL)	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.
Turbo Boost Control System Monitoring **(g)4**	Under- and over-boost malfunctions (OTL) Slow response (VGT systems only) (OTL) Charge air undercooling (OTL) Feedback signals	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.
Nonmethane Hydrocarbon (NMHC) Converting Catalyst Monitoring **(g)5**	NMHC conversion Temperature for proper PM filter regeneration Exothermal monitor strategy	The OBD system must monitor the NMHC converting catalyst(s) for proper NMHC conversion capability. Conversion on the diesel particulate filter (DPF) is not included.
Selective Catalytic Reduction (SCR) and Lean NO_x Catalyst Monitoring **(g)6**	Conversion efficiency (OTL) Reductant delivery performance (e.g., urea injection, separate injector fuel injection, post-injection of fuel, air-assisted injection/mixing) (OTL) Reductant quality Reductant quantity Feedback control	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 Adsorber (Lean NO_x Trap) System Monitoring **(g)7**	Adsorption and conversion efficiency (OTL) 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	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.
Diesel Particulate Filter (DPF) System Monitoring **(g)8**	Filtering performance: this includes PM threshold reading capabilities (OTL) and a temporary option for pressure differential reading methods before 2013 (OTL). Regeneration frequency Regeneration completion Missing, removed DPF Insufficient action for regeneration Feedback control (continuously monitored)	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.

System and §86.010-18 reference	Monitoring requirements	General
Exhaust Gas Sensor Monitoring **(g)9**	Air-Fuel ratio sensor upstream and downstream of device and NO_x sensors: sensor performance (sensor voltage, resistance, impedance, current, response rate, amplitude, offset)—OTL 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)	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.
Variable Valve Timing (VVT) System Monitoring **(g)10**	Target error: checks for deviations from target (OTL) Slow response (OTL)	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.

Table A2. U.S. Monitoring Requirements for All Engines

System	Monitoring details
Engine Cooling System Monitoring	· Thermostat function · Engine coolant temperature (ECT) sensor readings · Circuit malfunction (continuous)
Crankcase Ventilation (CV) System 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
Comprehensive Component Monitors	Required to monitor electronic components or inputs to the engine controller that are used and that · can cause a measurable emission increase during any reasonable driving condition or · affect any other OBD monitors Requirement—detect the following faults: · circuit and rationality faults for input components · 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 for light –duty vehicles (post MY1996) monitoring requirements.

» Alternatively fueled engines: subject to requirements for gasoline engines (even if they are derived from a diesel engine). Must meet HD OBD requirements in 2020 and beyond.

EURO IV AND V, BHARAT IV, CHINA IV AND PROCONVE P7 MONITORING REQUIREMENTS

Euro IV and V monitoring requirements are laid out in European Commission (2005). For India's Bharat OBD Standards, see Ministry of Road Transport and Highways (n.d.). For China IV OBD requirements, see Ministry of Environmental Protection (2008). The Brazilian OBD requirements are found in Ministry of the Environment (2010).

Table A2. Euro IV and V Program Monitoring Requirements for Heavy-Duty Engines

System	Monitoring Requirement	Description
Catalyst System	Presence	Complete removal of a catalyst, where fitted in a separate housing, that may or may not be part of a deNO$_x$ system or particulate filter.
DeNO$_x$ System	Efficiency or functional failure	Monitor for NO$_x$ reduction efficiency, monitoring against the **OBD threshold limits**, or as an alternative the system may monitor for major functional failure. Examples of functional failure: · complete removal of the system or replacement of the system by a bogus system (both representing intentional failure) · lack of required reagent for a deNO$_x$ system · failure of any SCR electrical component · any electrical failure of a component (e.g., sensors and actuators, dosing control unit) · failure of the reagent dosing system (e.g., missing air supply, clogged nozzle, dosing pump failure)
Urea-based SCR System	Functional	· lack of any required reagent · the quality of the required reagent being within the specifications · reagent consumption and dosing activity
DPF System	Efficiency or functional failure	Monitor for PM reduction efficiency, monitoring against the **OBD threshold limits**, or as an alternative the system may monitor for major functional failure. Examples of functional failure: · major melting of the trap substrate or a clogged trap resulting in a differential pressure beyond the range declared by the manufacturer · any electrical failure of a component (e.g., sensors and actuators, dosing control unit) of a particulate filter
Combined DPF-deNO$_x$	Efficiency or functional failure	Monitor for PM and NO$_x$ reduction efficiency, monitoring against the **OBD threshold limits**, or as an alternative the system may monitor for major functional failure.
Fuel-Injection System	Circuit continuity and functional failure	Monitor the electronic system, fuel quantity, and timing actuator(s)
Other Emission-related Systems	Failure resulting in breach of the emissions threshold	All other engine or exhaust after-treatment, emission-related components or systems that are connected to a computer, the failure of which would result in tailpipe emissions exceeding the OBD threshold limits. Example: · exhaust gas recirculation (EGR) system, · systems or components for monitoring and control of air mass flow, air volumetric flow (and temperature), · boost pressure and inlet manifold pressure, · sensors and actuators of a deNO$_x$ system, · sensors and actuators of an electronically activated particulate filter

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 of the United Nations Commission for Europe and EC 582/2011].

Table A3. Euro VI 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 (OTL)**
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 (OTL)**
Lean NO_x Trap (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]	hydrocarbon conversion efficiency	OC's ability to convert hydrocarbons upstream and downstream of other after-treatment devices
EGR System	Low/high EGR flow	Ability to maintain designated EGR rate **NO_x emission threshold monitoring for diesel, performance monitoring for spark ignition (OTL)** 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 discernable 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 spark ignition engines 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 (OTL)** In case OBD threshold limits are not exceeded, the OBD system shall detect a malfunction when the system cannot sufficiently increase the boost pressure, for open and closed boost control systems.
	VGT response rate	VGT system's ability to achieve the specified geometry within desired time

System	Monitoring Requirement	Description
Variable Valve Timing System (VVT)	VVT target error	Ability to achieve the designated valve timing Performance monitoring
	VVT response rate	VVT system's ability to achieve the designated valve timing within desired time Performance monitoring
Misfire	Misfire monitoring	Diesels: no prescriptions Spark ignition engines: 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	Spark ignition engines 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).

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