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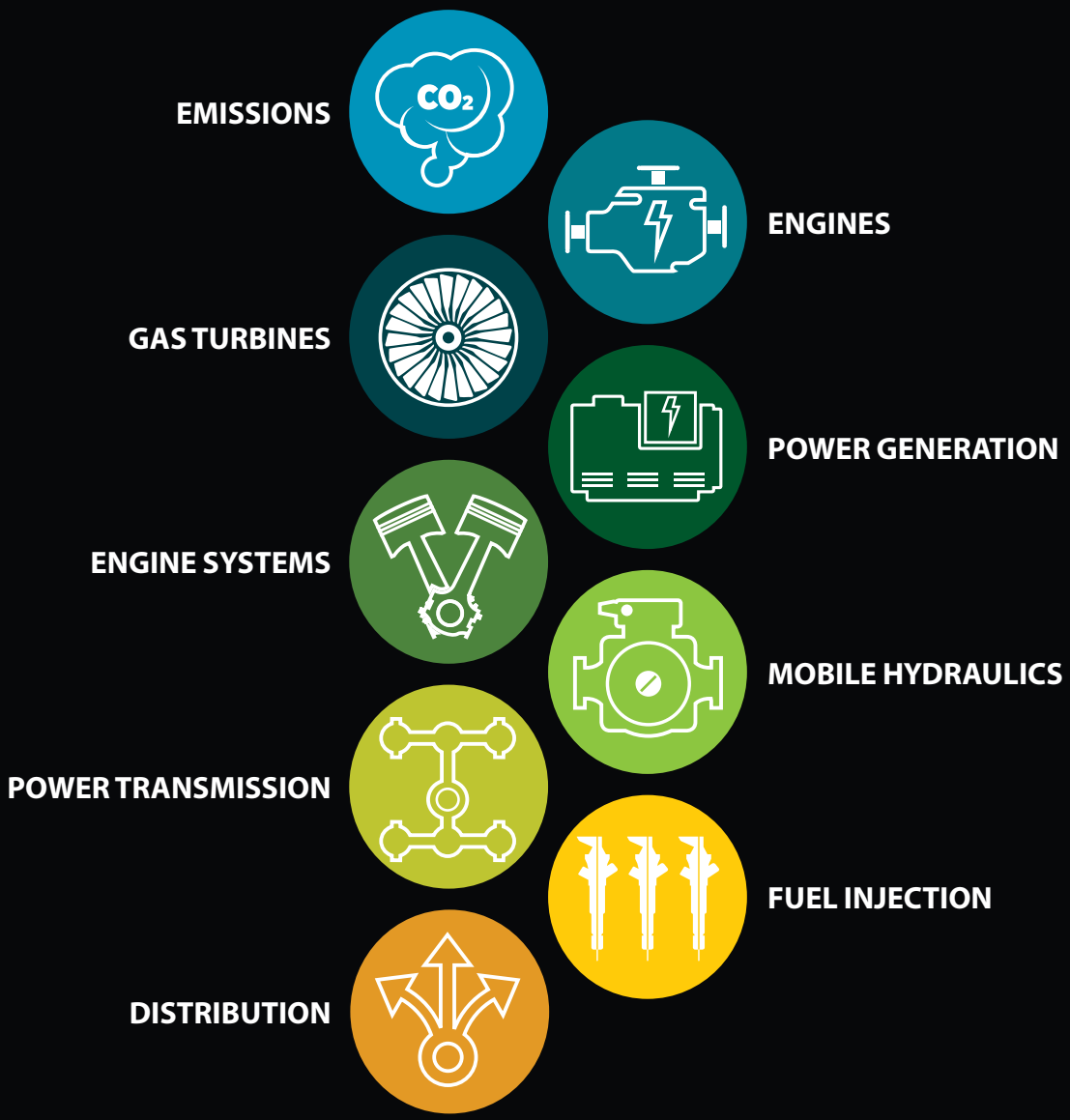

THE GUIDE FOR DESIGN ENGINEERS

DIESEL PROGRESS | DIESEL PROGRESS INTERNATIONAL | Diesel & Gas Turbine WORLDWIDE

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Emissions Reference Guide & Standards:
Table Of Contents

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Emissions Standards: U.S.A.

On-Highway Diesel Truck And Bus Engines

Applicability and Test Cycles

The emission standards discussed here apply to new engines used in heavy-duty on-road (highway) vehicles, such as trucks and buses. These standards apply to diesel fueled engines, as well as to compression-ignition (CI) engines fueled by natural gas and other alternative fuels.

Heavy-duty vehicles are defined as vehicles of GVWR (gross vehicle weight rating) of above 8,500 lbs in the federal jurisdiction and above 14,000 lbs in California (model year 1995 and later). Diesel engines used in heavy-duty vehicles are further divided into service classes by GVWR, as follows.

- Light heavy-duty diesel engines: 8,500 < LHDDE < 19,500 (14,000 < LHDDE < 19,500 in California, 1995+).
- Medium heavy-duty diesel engines: 19,500 ≤ MHDDE ≤ 33,000.
- Heavy heavy-duty diesel engines (including urban bus): HHDDE > 33,000.

Under the federal light-duty Tier 2 regulation vehicles of GVWR up to 10,000 lbs used for personal transportation have been re-classified as "medium-duty passenger vehicles" (MDPV - primarily larger SUVs and passenger vans) and are subject to the light-duty vehicle legislation. Therefore, the same diesel engine model used for the 8,500-10,000 lbs vehicle category may be classified as either light- or heavy-duty and certified to different standards, depending on the application.

U.S. and California regulations do not require that complete heavy-duty diesel vehicles be chassis certified, instead requiring certification of their engines (as an option, complete heavy-duty diesel vehicles under 14,000 lbs can be chassis certified). Consequently, the basic standards are expressed in g/bhp-hr and require emissions testing over the Transient FTP engine dynamometer cycle (however, chassis certification may be required for complete heavy-duty gasoline vehicles with pertinent emissions standards expressed in g/mile).

Additional emissions testing requirements, phased in from 1998 to 2007, include:

- Supplemental Emissions Test (SET): A steady-state test to ensure that heavy-duty engine emissions are controlled during steady-state type driving. SET emissions limits are numerically equal to the FTP limits.
- Not-to-Exceed (NTE) testing: Driving of any type that could occur within the bounds of a pre-defined NTE control area, including operation under steady-state or transient conditions and under varying ambient conditions.

Emission Standards

The emission limits for heavy-duty engines were tightened in a number of steps, as shown in Table 1. The current mandatory emission standards for heavy-duty engines were phased-in over the period of 2007-2010. The table also covers the 2015 California Optional Low NOx Standards.

In addition to the limits shown, the following emission standards apply:

- Smoke Opacity—Smoke opacity limits of 20% / 15% / 50% at acceleration/lug/peak modes, respectively.
- Idle CO Standard—An idle CO emission standard of 0.5% applies to compression-ignition engines fueled by diesel fuel since 1988, by methanol since 1990, and by natural gas and LPG since 1994.

ABT Program. Since 1991, the emission regulations include

Table 1. US EPA & California Emission Standards for Heavy-Duty CI Engines g/bhp-hr)

Year	CO	HC[a]	HC[a]+NO_x	NO_x	PM	
					General	Urban Bus
1974	40	-	16	-	-	
1979	25	1.5	10	-	-	
1985	15.5	1.3	-	10.7	-	
1987	15.5	1.3	-	10.7[d]	0.60[f]	
1988	15.5	1.3[b]	-	10.7[d]	0.60	
1990	15.5	1.3[b]	-	6.0	0.60	
1991	15.5	1.3[c]	-	5.0	0.25	0.25[g]
1993	15.5	1.3[c]	-	5.0	0.25	0.10
1994	15.5	1.3[c]	-	5.0	0.10	0.07
1996	15.5	1.3[c]	-	5.0[e]	0.10	0.05[h]
1998	15.5	1.3	-	4.0	0.10	0.05[h]
2004[j]	15.5	-	2.4[i]	-	0.10	0.05[h]
1985	15.5	0.14[k]	-	0.20[k]	0.01	
1985	15.5	0.14	-	0.02[l]	0.01	

[a] - NMHC for 2004 and later standards
[b] - For methanol-fueled engines, the standard is for total hydrocarbon equivalent (THCE)
[c] - California: NMHC = 1.2 g/bhp-hr, in addition the THC limit
[d] - California: NOx = 6.0 g/bhp-hr
[e] - California: Urban bus NOx = 4.0 g/bhp-hr
[f] - California only, no federal PM limit
[g] - California standard 0.10 g/bhp-hr
[h] - In-use PM standard 0.07 g/bhp-hr
[i] - Alternative standard: NMHC+NOx = 2.5 g/bhp-hr and NHMC = 0.5 g/bhp-hr
[j] - Under the 1998 Consent Decrees, several manufacturers supplied 2004 compliant engines from October 2002
[k] - NOx and NHMC standards were phased-in on a percent-of-sales basis: 50% in 2007-2009 and 100% in 2010. Most manufacturers certified their 2007-2009 engines to a NOx limit of about 1.2 g/bhp-hr, based on a fleet average calculation
[l] - Optional. Manufacturers may choose to certify engines to the California Optional Low NOx Standards of 0.10, 0.05 or 0.02 g/bhp-hr

an emission averaging, banking, and trading (ABT) program for NOx and PM emissions, similar to those that have been a part of most US EPA emission control programs.

Model Year 1974-2003

Historically, the first sets of emission standards were adopted at the federal level beginning from 1974. Since 1987, California standards required on several occasions that PM and NOx emission limits be introduced in California. Some of the regulatory emission challenges of that period that required the development of new emission technologies were:

- **1991 PM emission standard of 0.25 g/bhp·hr.**
- **1994 PM emission standard of 0.10 g/bhp·hr.**
- **Gradual tightening of the NOx limit to 4 g/bhp·hr (1998).**

These challenges were generally met through in-cylinder emission control. However, the 1994 PM limit did trigger some usage of diesel oxidation catalysts, mostly on mechanically controlled heavy-duty engines. A sulfur limit of 500 ppm in diesel fuel became effective in October 1993 to enable the 1994 PM emission standard of 0.10 g/bhp·hr.

Optional Standards. Manufacturers could voluntarily certify engines to the Clean Fuel Fleet (CFF) emission standards shown in Table 2. It was a federal program that applied to 1998-2003 model year engines, both CI and SI, over 8,500 lbs GVWR.

Table 2. Clean Fuel Fleet Program for Heavy-Duty SI and CI Engines, g/bhp-hr

Category*	CO	NMHC+NO_x	PM	HCHO
LEV (Federal Fuel)		3.8		
LEV (California Fuel)		3.5		
ILEV	14.4	2.5		0.050
ULEV	7.2	2.5	0.05	0.025
ZLEV	0	0	0	0

* LEV - low emissions vehicle; ILEV - inherently low emissions vehicle; ULEV - ultra low emissions vehicle; ZEV - zero emissions vehicle

Model Year 2004-2006

The 2004 standards for heavy-duty engines—as adopted by the EPA in 1997 [EPA 1997]—were harmonized with California standards, with the intent that manufacturers could use a single engine or machine design for both markets. On-board diagnostic (OBD) requirements applicable to heavy-duty diesel engines and vehicles ≤ 14,000 lbs GVWR were phased-in from the 2005 through 2007 model years. Discharge of crankcase emissions was not allowed for any new 2004 or later model year engines, with the exception of turbocharged or supercharged diesel fueled engines. To achieve the 2004 emissions, most manufacturers introduced exhaust gas recirculation (EGR)—in many cases in conjunction with diesel oxidation catalysts—on heavy-duty diesel engines.

Consent Decrees. In October 1998, a court settlement was reached between the EPA, Department of Justice, California ARB and engine manufacturers (Caterpillar, Cummins, Detroit Diesel, Volvo, Mack Trucks/Renault and Navistar) over the issue of high NO_x emissions from heavy-duty diesel engines during certain driving modes. Since the early 1990's, the manufacturers used engine control software that caused engines to switch to a more fuel efficient (but higher NO_x) driving mode during steady highway cruising. The EPA considered this engine control strategy an illegal "emissions defeat device."

Provisions of the Consent Decree included civil penalties for engine manufacturers and requirements to allocate funds for pollution research; upgrading existing engines to lower NO_x emissions; supplemental emissions tests (steady-state) with a limit equal to the FTP standard and NTE limits of 1.25 x FTP (with the exception of Navistar); and meeting the 2004 emissions standards by October 2002, 15 months ahead of time.

In the aftermath of the Consent Decrees, California certifications for all model year 2005-2007 engines required SET testing and NTE limits of 1.25 Ч FTP standards. California also adopted more stringent standards for MY 2004-2006 engines for public urban bus fleets.

Model Year 2007 and Later

The EPA rule of December 21, 2000 [EPA 2001] included two components: (1) 2007 and later heavy-duty engine emission standards, and (2) diesel fuel regulations. The California ARB adopted virtually identical 2007 heavy-duty engine standards in October 2001. The emission standards included new, very stringent limits for PM (0.01 g/bhp·hr) and NOx (0.20 g/bhp·hr). The PM emission standard took full effect in 2007. The NOx standard was phased-in for diesel engines between 2007 and 2010. In the 2007-2009 period, most manufacturers opted to meet a NOx family emission limit (FEL) of around 1.2 g/bhp·hr for most of their engines. Because of this compliance path during the NOx limit phase-in period, engines produced during 2007-2009 were technologically very different from those required to comply in 2010 and later when all engines needed to comply with the 0.2 g/bhp-hr NOx limit. While it is common to refer to "2010 standards" in a way that implies they are different from "2007 standards", legally, there was not a standard for 2010 that differed from 2007.

Starting in 2007, manufacturers could choose to chassis certify complete heavy-duty diesel vehicles (HDV) with GVWR of 14,000 lb or less as an option to engine certification. Diesel engines thus certified were considered to be legally equivalent to a 0.20 g/bhp-hr NOx engine provided they met the 2008 Otto-cycle HDV limits (0.2 g/mile NOx and 0.02 g/mile PM for 8500 lb < GVWR ≤ 10000 lb and 0.4 g/mile NOx and 0.02 g/mile PM for 10000 lb < GVWR ≤ 14000 lb). After 2011, all manufacturers of complete HDVs with GVWR ≤ 14000 lb (primarily heavy pick-ups and utility vans) adopted this optional chassis certification approach because of the heavy-duty vehicle GHG regulations that came into effect for MY 2014.

In addition to the FTP testing, emission certification requirements include:

- SET test, with limits equal to the FTP standards.
- NTE limits of 1.5 Ч FTP standards (or 1.25 Ч FTP for engines with NOx FEL > 1.5 g/bhp·hr).

The diesel fuel regulation limited the sulfur content in on-highway diesel fuel to 15 ppm (wt.), down from the previous

500 ppm. The ULSD fuel has been introduced as a "technology enabler" to pave the way for sulfur-intolerant exhaust emission control technologies, such as catalytic diesel particulate filters and NOx catalysts.

Other Provisions. The 2007 emission standards and later amendments introduced a number of additional provisions:

- Crankcase Ventilation—Effective from 2007, the regulation maintains the earlier crankcase emission control exception for turbocharged heavy-duty diesel fueled engines but requires that if the emissions are discharged into the atmosphere, they be added to the exhaust emissions during all testing. The deterioration of crankcase emissions must also be accounted for in exhaust deterioration factors.
- DEF Refill Interval—For SCR-equipped heavy-duty diesel engines, a minimum DEF (urea solution) refill interval is defined as at least as far (in miles or hours) as the vehicle's fuel capacity [EPA 2014].
- Ammonia Emissions—While ammonia emissions are unregulated, the EPA recommends that ammonia slip should be below 10 ppm average over the applicable test cycles [EPA 2011].
- Emergency Vehicles—Heavy-duty engines in fire trucks, ambulances and other types of emergency vehicles can be equipped with an AECD to override performance inducements related to the emission control system.

California Optional Low NOx Standards. On October 21, 2014, California ARB adopted Optional Low NOx Standards for heavy-duty engines [CARB 2013]. Under the program, manufacturers may choose to certify their engines to three optional NOx emission standards: 0.10, 0.05 or 0.02 g/bhp·hr. Other pollutants must meet the conventional emission standards. Engine families certified to the optional NOx standards cannot be included in the ABT program for NOx. Instead, credits may be generated by an alternative mechanism proposed by the engine manufacturer and approved by the ARB.

Useful Life and Warranty Periods. Compliance with emissions standards has to be demonstrated over the useful life of the engine, which was adopted as follows (federal & California):

- LHDDE — 8 years/110,000 miles (whichever occurs first).
- MHDDE — 8 years/185,000 miles.
- HHDDE — 8 years/290,000 miles.

Federal useful life requirements were later increased to 10 years, with no change to the above mileage numbers, for the urban bus PM standard (1994+) and for the NO_x standard (1998+).

Useful Life: 2004+. The EPA established revised useful engine lives, with significantly extended requirements for the heavy heavy-duty diesel engine class, as follows:

- LHDDE—10 years/110,000 miles.
- MHDDE—10 years/185,000 miles.
- HHDDE—10 years/435,000 miles/22,000 hours.

Warranty. The mandatory emission warranty period is 5 years/100,000 miles (5 years/100,000 miles/3,000 hours in California), but no less than the basic mechanical warranty for the engine family. Since 2004, the federal warranty period for the LHDDE class has been reduced to 5 years/50,000 miles.

Emissions Standards: U.S.A.
Off-Highway Engines

Background

Tier 1-3 Standards. The first federal standards (Tier 1) for new nonroad (or off-road) diesel engines were adopted in 1994 for engines over 37 kW (50 hp), to be phased-in from 1996 to 2000. The 1998 regulation introduced Tier 1 standards for equipment under 37 kW (50 hp) and increasingly more stringent Tier 2 and Tier 3 standards for all equipment with phase-in schedules from 2000 to 2008. The Tier 1-3 standards are met through advanced engine design, with no or only limited use of exhaust gas aftertreatment (oxidation catalysts).

Tier 4 Standards. In 2004, the EPA signed the final rule introducing Tier 4 emissions standards, which were to be phased-in over the period of 2008-2015. The Tier 4 standards require that emissions of PM and NO_x be further reduced by about 90%.

Nonroad Diesel Fuel. At the Tier 1-3 stage, the sulfur content in nonroad diesel fuels was not limited. The oil industry specification was 0.5% (wt., max), with the average in-use sulfur level of about 0.3% = 3,000 ppm. To enable sulfur-sensitive control technologies in Tier 4 engines — such as catalytic particulate filters and NO_x adsorbers — the EPA mandated reductions in sulfur content in nonroad diesel fuels, as follows:

- 500 ppm effective June 2007 for nonroad, locomotive and marine (NRLM) diesel fuels;
- 15 ppm (ultra-low sulfur diesel) effective June 2010 for nonroad fuel, and June 2012 for locomotive and marine fuels.

California. In most cases, federal nonroad regulations also apply in California, whose authority to set emissions standards for new nonroad engines is limited. The federal Clean Air Act Amendments of 1990 (CAA) preempt California's authority to control emissions from new farm and construction equipment under 175 hp and require California to receive authorization from the federal EPA for controls over other off-road sources.

The U.S. nonroad emissions standards are harmonized to a certain degree with European nonroad emissions standards.

Applicability

The nonroad standards cover mobile *nonroad diesel engines* of all sizes used in a wide range of construction, agricultural and industrial equipment. The EPA definition of the *nonroad engine* is based on the principle of mobility/portability, and includes engines installed on (1) self-propelled equipment, (2) on equipment that is propelled while performing its function, or (3) on equipment that is portable or transportable, as indicated by the presence of wheels, skids, carrying handles, dolly, trailer, or platform. Nonroad engines are all internal combustion engines except motor vehicle (highway) engines, stationary engines (or engines that remain at one location for more than 12 months), engines used solely for competition, or engines used in aircraft. Effective May 14, 2003, the definition of nonroad engines was changed to also include all

diesel powered engines — including stationary ones — used in agricultural operations in California.

The nonroad diesel emissions regulations are not applicable to all nonroad diesel engines. Exempted are engines used in railway locomotives and marine vessels, both of which have their own regulations: engines used in underground mining equipment, which are regulated by the Mine Safety and Health Administration (MSHA); and hobby engines (below 50 cm^3 per cylinder).

A new definition of a compression-ignition (diesel) engine is used in the regulatory language since the 1998 rule. The definition focuses on the engine cycle, rather than the ignition mechanism, with the presence of a throttle as an indicator to distinguish between diesel-cycle and otto-cycle operation. Regulating power by controlling the fuel supply in lieu of a throttle corresponds with lean combustion and diesel-cycle operation. This language allows the possibility that a natural gas-fueled engine equipped with a sparkplug is considered a compression-ignition engine.

Tier 1-3 Emissions Standards

The 1998 nonroad engine regulations are structured as a 3-tiered progression. Each tier involves a phase in (by horsepower rating) over several years. Tier 1 standards were phased-in from 1996 to 2000. The more stringent Tier 2 standards take effect from 2001 to 2006, and yet more stringent Tier 3 standards phase-in from 2006 to 2008 (Tier 3 standards apply only for engines from 37-560 kW).

Tier 1-3 emissions standards are listed in Table 1. Nonroad regulations are in the metric system of units, with all standards expressed in grams of pollutant per kWh. Manufacturers who signed the 1998 Consent Decrees with the EPA may be required to meet the Tier 3 standards one year ahead of schedule (i.e. beginning in 2005).

Voluntary, more stringent emissions standards that manufacturers could use to earn a designation of "Blue Sky Series" engines (applicable to Tier 1-3 certifications) are listed in Table 2.

Engines of all sizes must also meet smoke standards of 20/15/50% opacity at acceleration/lug/peak modes, respectively.

The regulations include several other provisions, such as averaging, banking and trading of emissions credits and maximum "family emissions limits" (FEL) for emissions averaging.

Tier 4 Emissions Standards

The Tier 4 emissions standards — to be phased-in from 2008-2015 — introduce substantial reductions of NO_x (for engines above 56 kW) and PM (above 19 kW), as well as more stringent HC limits. CO emissions limits remain unchanged from the Tier 2-3 stage.

Engines up to 560 kW. Tier 4 emissions standards for engines up to 560 kW are listed in Table 3. In engines of 56-560 kW rated power, the NO_x and HC standards were phased-in over a few year period, as indicated in the notes to Table 3. The initial standards (PM compliance) are sometimes referred to as the 'interim Tier 4' (or 'Tier 4i'), 'transitional Tier 4' or 'Tier 4 A', while the final standards (NO_x/HC compliance) are sometimes referred to as 'Tier 4 B'.

As an alternative to introducing the required percentage of

Table 1. EPA Tier 1-3 Nonroad Diesel Engine Emissions Standards, g/kWh (g/bhp-hr)

Engine Power	Tier	Year	CO	HC	NMHC+NO_x	NO_x	PM
kW < 8 (hp < 11)	Tier 1	2000	8.0 (6.0)	-	10.5 (7.8)	-	1.0 (0.75)
	Tier 2	2005	8.0 (6.0)	-	7.5 (5.6)	-	0.8 (0.6)
8 ≤ kW < 19 (11 ≤ hp < 25)	Tier 1	2000	6.6 (4.9)	-	9.5 (7.1)	-	0.8 (0.6)
	Tier 2	2005	6.6 (4.9)	-	7.5 (5.6)	-	0.8 (0.6)
19 ≤ kW < 37 (25 ≤ hp < 50)	Tier 1	1999	5.5 (4.1)	-	9.5 (7.1)	-	0.8 (0.6)
	Tier 2	2004	5.5 (4.1)	-	7.5 (5.6)	-	0.6 (0.45)
37 ≤ kW < 75 (50 ≤ hp < 100)	Tier 1	1998	-	-	-	9.2 (6.9)	-
	Tier 2	2004	5.0 (3.7)	-	7.5 (5.6)	-	0.4 (0.3)
	Tier 3	2008	5.0 (3.7)	-	4.7 (3.5)	-	-†
75 ≤ kW < 130 (100 ≤ hp < 175)	Tier 1	1997	-	-	-	9.2 (6.9)	-
	Tier 2	2003	5.0 (3.7)	-	6.6 (4.9)	-	0.3 (0.22)
	Tier 3	2007	5.0 (3.7)	-	4.0 (3.0)	-	-†
130 ≤ kW < 225 (175 ≤ hp < 300)	Tier 1	1996	11.4 (8.5)	1.3 (1.0)	-	9.2 (6.9)	0.54 (0.4)
	Tier 2	2003	3.5 (2.6)	-	6.6 (4.9)	-	0.2 (0.15)
	Tier 3	2006	3.5 (2.6)	-	4.0 (3.0)	-	-†
225 ≤ kW < 450 (300 ≤ hp < 600)	Tier 1	1996	11.4 (8.5)	1.3 (1.0)	-	9.2 (6.9)	0.54 (0.4)
	Tier 2	2001	3.5 (2.6)	-	6.4 (4.8)	-	0.2 (0.15)
	Tier 3	2006	3.5 (2.6)	-	4.0 (3.0)	-	-†
450 ≤ kW < 560 (600 ≤ hp < 750)	Tier 1	1996	11.4 (8.5)	1.3 (1.0)	-	9.2 (6.9)	0.54 (0.4)
	Tier 2	2002	3.5 (2.6)	-	6.4 (4.8)	-	0.2 (0.15)
	Tier 3	2006	3.5 (2.6)	-	4.0 (3.0)	-	-†
kW ≥ 560 (hp ≥ 750)	Tier 1	2000	11.4 (8.5)	1.3 (1.0)	-	9.2 (6.9)	0.54 (0.4)
	Tier 2	2006	3.5 (2.6)	-	6.4 (4.8)	-	0.2 (0.15)

† Not adopted, engines must meet Tier 2 PM standard.

Table 2. EPA Voluntary Emissions Standards for Nonroad Diesel Engines, g/kWh (g/bhp-hr)

Rated Power (kW)	NMHC+NO_x	PM
kW < 8	4.6 (3.4)	0.48 (0.36)
8 ≤ kW <19	4.5 (3.4)	0.48 (0.36)
19 ≤ kW <37	4.5 (3.4)	0.36 (0.27)
37 ≤ kW < 75	4.7 (3.5)	0.24 (0.18)
75 ≤ kW <130	4.0 (3.0)	0.18 (0.13)
130 ≤ kW < 560	4.0 (3.0)	0.12 (0.09)
kW ≥ 560	3.8 (2.8)	0.12 (0.09)

Tier 4 compliant engines, manufacturers may certify all their engines to an *alternative NO_x limit* in each model year during the phase-in period. These alternative NO_x standards are:

- Engines 56-130 kW:
  - Option 1: NO_x = 2.3 g/kWh = 1.7 g/bhp-hr (Tier 2 credits used to comply, MY 2012-2013).
  - Option 2: NO_x = 3.4 g/kWh = 2.5 g/bhp-hr (no Tier 2 credits claimed, MY 2012-2014).
- Engines 130-560 kW: NO_x = 2.0 g/kWh = 1.5 g/bhp-hr (MY 2011-2013).

Engines Above 560 kW. Tier 4 emissions standards for engines above 560 kW are listed in Table 4. The 2011 standards are sometimes referred to as 'transitional Tier 4', while the 2015 limits represent final Tier 4 standards.

Other Provisions. The Tier 4 regulation and later amendments include a number of additional provisions.

- Smoke Opacity—Existing Tier 2-3 smoke opacity standards and procedures continue to apply in some engines. Exempted from smoke emission standards are engines certified to PM emission standards at or below 0.07 g/kWh.
- Crankcase Ventilation—The Tier 4 regulation does not require closed crankcase ventilation in nonroad engines. However, in engines with open crankcases, crankcase emissions must be measured and added to exhaust emissions in assessing compliance.
- DEF Refill Interval—For SCR-equipped nonroad diesel engines, a minimum DEF (urea solution) refill interval is defined as at least as long (in engine-hours) as the vehicle's fuel capacity.
- Ammonia Emissions—While ammonia emissions are unregulated, the EPA recommends that ammonia slip should be below 10 ppm average over the applicable test cycles.
- Emergency Operation—To facilitate the use of certain nonroad engines in temporary emergency situations, the engines can be equipped with an AECD to override performance inducements related to the emission control system. This flexibility is intended primarily for engines used in construction equipment and portable equipment used for temporary power generation and flood control.
- ABT Program—Similarly to earlier standards, the Tier 4 regulation includes such provisions as averaging, banking and trading of emission credits and FEL limits for emission averaging.

Table 3. Tier 4 Emissions Standards — Engines up to 560 kW, g/kWh (g/bhp-hr)

Engine Power	Year	CO	NMHC	NMHC+NO_x	NO_x	PM
kW < 8 (hp < 11)	2008	8.0 (6.0)	-	7.5 (5.6)	-	0.4[a] (0.3)
8 ≤ kW < 19 (11 ≤ hp < 25)	2008	6.6 (4.9)	-	7.5 (5.6)	-	0.4 (0.3)
19 ≤ kW < 37 (25 ≤ hp < 50)	2008	5.5 (4.1)	-	7.5 (5.6)	-	0.3 (0.22)
	2013	5.5 (4.1)	-	4.7 (3.5)	-	0.03 (0.022)
37 ≤ kW < 56 (50 ≤ hp < 75)	2008	5.0 (3.7)	-	4.7 (3.5)	-	0.3[b] (0.22)
	2013	5.0 (3.7)	-	4.7 (3.5)	-	0.03 (0.022)
56 ≤ kW < 130 (75 ≤ hp < 175)	2012-2014[c]	5.0 (3.7)	0.19 (0.14)	-	0.40 (0.30)	0.02 (0.015)
130 ≤ kW ≤ 560 (175 ≤ hp ≤ 750)	2011-2014[d]	3.5 (2.6)	0.19 (0.14)	-	0.40 (0.30)	0.02 (0.015)

[a] - hand-startable, air-cooled, DI engines may be certified to Tier 2 standards through 2009 and to an optional PM standard of 0.6 g/kWh starting in 2010
[b] - 0.4 g/kWh (Tier 2) if manufacturer complies with the 0.03 g/kWh standard from 2012
[c] - PM/CO: full compliance from 2012; NO_x/HC: Option 1 (if banked Tier 2 credits used)—50% engines must comply in 2012-2013; Option 2 (if no Tier 2 credits claimed)—25% engines must comply in 2012-2014, with full compliance from 2014.12.31
[d] - PM/CO: full compliance from 2011; NO_x/HC: 50% engines must comply in 2011-2013

Table 4. Tier 4 Emissions Standards — Engines Above 560 kW, g/kWh (g/bhp-hr)

Year	Category	CO	NMHC	NO_x	PM
2011	Generator sets > 900 kW	3.5 (2.6)	0.40 (0.30)	0.67 (0.50)	0.10 (0.075)
	All engines except gensets > 900 kW	3.5 (2.6)	0.40 (0.30)	3.5 (2.6)	0.10 (0.075)
2015	Generator sets	3.5 (2.6)	0.19 (0.14)	0.67 (0.50)	0.03 (0.022)
	All engines except gensets	3.5 (2.6)	0.19 (0.14)	3.5 (2.6)	0.04 (0.03)

Transitional Period Flexibility

Nonroad emission regulations include flexibilities that allow equipment manufacturers to install exempted engines (i.e., those not required to meet applicable standards) during the transitional period to a more stringent tier of standards. Similar to the on-road regulations, manufacturers of nonroad equipment are allowed to use their engine inventory. While the exact engine quantities are not specified, it has been the EPA practice to allow the use of exempted engines for a three-month production period and—in some cases—beyond. Under the regulations, this provision may not be used to stockpile engines that were built before new standards take effect.

The Equipment Manufacturer Flexibility, also referred to as the Transition Program for Equipment Manufacturers (TPEM), allows equipment manufacturers to install a limited number of exempted engines during a seven-year period after the Tier 4 effective dates. During the seven-year period of the general availability of allowances, manufacturers are allowed to continue using Tier 3 engines after the Tier 4i standards become effective. If a manufacturer chooses not to use this flexibility (does not use any Tier 3 engines during the specified period), he is allowed the delayed availability of allowances. During the delayed allowances period, the manufacturer can use Tier 4i engines after the effective dates of the Tier 4 final standards. The general and delayed allowances periods cannot be combined. The maximum number of exempted engines allowed for an equipment manufacturer within the seven-year period is determined by one of two options:

- Percentage-of-Production Allowance—The number of units with exempted engines is calculated using a percentage of

the total sales within each power category relative to the total US-directed production volume. The sum of these percentages within a power category during the seven-year period may not exceed 80%.

- Small-Volume Allowance—Alternatively, a specific number of exempted engines may be determined using one of the following approaches:
  - Up to 700 units with exempted engines within a power category during the seven-year period, with no more than 200 units in any single year within a power category. Exempted engines within a power category must be from a single engine family within a given year.
  - For engines below 130 kW, up to 525 units within a power category during the seven-year period, with no more than 150 units in any single year within a power category. For engines ≥ 130 kW, up to 350 units within a power category during the seven-year period, with no more than 100 units in any single year within a power category. Exemptions may apply to engines from multiple engine families in a given year.

Test Cycles and Fuels

Nonroad engine emissions are measured on a steady-state test cycle that is nominally the same as the ISO 8178 C1, 8-mode steady-state test cycle. Other ISO 8178 test cycles are allowed for selected applications, such as constant-speed engines (D2 5-mode cycle), variable-speed engines rated under 19 kW (G2 cycle), and marine engines (E3 cycle).

Transient Testing. Tier 4 standards have to be met over both the steady-state test and the nonroad transient cycle, NRTC. The transient testing requirements begin with MY 2013 for engines below 56 kW, in 2012 for 56-130 kW, and in 2011 for 130-560 kW engines. Engines above 560 kW are not tested on the transient test. Also constant-speed, variable-load engines of any power category are not subject to transient testing. The NRTC protocol includes a cold start test. The cold start emissions are weighted at 5% and hot start emissions are weighted at 95% in calculating the final result.

Tier 4 nonroad engines will also have to meet not-to-exceed standards (NTE), which are measured without reference to any specific test schedule. The NTE standards became effective in 2011 for engines above 130 kW; in 2012 for 56-130 kW; and in 2013 for engines below 56 kW. In most engines, the NTE limits are set at 1.25 times the regular standard for each pollutant (in engines certified to NO_x standards below 2.5 g/kWh or PM standards below 0.07 g/kWh, the NTE multiplier is 1.5). The NTE standards apply to engines at the time of certification, as well as in use throughout the useful life of the engine. The purpose of the added testing requirements is to prevent the possibility of "defeating" the test cycle by electronic engine controls and producing off-cycle emissions.

Certification Fuels. Fuels with sulfur levels no greater than 0.2 wt% (2,000 ppm) are used for certification testing of Tier 1-3 engines. From 2011, all Tier 4 engines will be tested using fuels of 7-15 ppm sulfur content.

A change from measuring total hydrocarbons to nonmethane hydrocarbons (NMHC) has been introduced in the 1998 rule. Since there is no standardized EPA method for measuring methane in diesel engine exhaust, manufacturers can either use their own procedures to analyze nonmethane hydrocarbons or measure total hydrocarbons and subtract 2% from the measured hydrocarbon mass to correct for methane.

Engine Useful Life

Emissions standards listed in the tables must be met over the entire useful life of the engine. EPA requires the application of deterioration factors (DFs) to all engines covered by the rule. The DF is a factor applied to the certification emissions test data to represent emissions at the end of the useful life of the engine. The engine useful life and the in-use testing liability period, as defined by the EPA for emissions testing purposes, are listed in Table 5 for different engine categories. The Tier 4 rule maintains the same engine useful life periods.

Table 5. Useful Life and Recall Testing Periods

Power Rating	Rated Engine Speed	Useful Life		Recall Testing Period	
		hours	years	hours	years
< 19 kW	all	3000	5	2250	4
19-37 kW	constant speed engines ≥ 3000 rpm	3000	5	2250	4
	all others	5000	7	3750	5
>37 kW	all	8000	10	6000	7

Environmental Benefit and Cost

1998 Regulation: At the time of signing the 1998 rule, the EPA estimated that by 2010 NOx emissions would be reduced by about a million tons per year, the equivalent of taking 35 million passenger cars off the road.

The costs of meeting the emission standards were expected to add under 1% to the purchase price of typical new nonroad diesel equipment, although for some equipment the standards may cause price increases on the order of 2-3%. The program was expected to cost about $600 per ton of NOx reduced.

Tier 4 Regulation: When the full inventory of older nonroad engines are replaced by Tier 4 engines, annual emission reductions are estimated at 738,000 tons of NOx and 129,000 tons of PM. By 2030, 12,000 premature deaths would be prevented annually due to the implementation of the proposed standards.

The estimated costs for added emission controls for the vast majority of equipment was estimated at 1-3% as a fraction of total equipment price. For example, for a 175 hp bulldozer that costs approximately $230,000 it would cost up to $6900 to add the advanced emission controls and to design the bulldozer to accommodate the modified engine.

EPA estimated that the average cost increase for 15 ppm S fuel would be 7 cents per gallon. This figure would be reduced to 4 cents by anticipated savings in maintenance costs due to low sulfur diesel.

Emissions Standards: U.S.A.
Stationary Diesel Engines (NSPS)

Background

The new source performance standards (NSPS) for reciprocating internal combustion engines (RICE) establish US federal emission requirements for compression ignition (CI) stationary engines. The Compression Ignition NSPS rule was adopted in 2006 [EPA 2006] and amended on several occasions [EPA 2011][EPA 2016]. NSPS emission regulations for stationary CI engines are published in the Code of Federal Regulations (CFR), Title 40, Part 60, Subpart IIII.

The emission standards apply to engines whose construction, modification or reconstruction commenced after July 11, 2005—the date the proposed rule was published in the Federal Register.

Fuel Program. The NSPS rule introduced low sulfur fuel requirements for CI stationary engines, as follows:

- Engines below 30 liters per cylinder:
  - No more than 500 ppm sulfur by October 2007.
  - Ultra-low sulfur diesel (15 ppm sulfur) by October 2010.
- Engines ≥ 30 liters per cylinder: 1,000 ppm sulfur fuel from 2014.

These fuel requirements are consistent with those for mobile nonroad engines and marine engines. Some of the fuel quality requirements are delayed in areas of Alaska.

Economic Impact. The EPA estimated that the 2006 rule would affect 81,500 new stationary diesel engines. Emission reductions would occur gradually from 2005 to 2015, with the total nationwide annual costs for the rule to be $57 million in 2015.

The following are EPA estimates of the price increase for the compliant equipment due to the added cost of emission controls (year 2015):

- Irrigation systems: 2.3%.
- Pumps and compressors: 4.3%.
- Generator sets and welding equipment: 10.0%.

Emission Standards

The standards apply to emissions of NOx, PM, CO, and NMHC. They are expressed in units of g/kWh and smoke standards as a percentage. No new emission limits were developed for stationary engines. Rather, the engines are required to meet emission standards for various types of mobile engines, depending on the engine size and application:

- Engines of displacement below 10 liters per cylinder must meet Tier 1 through Tier 4 emission standards for mobile nonroad diesel engines (almost all stationary engines in the USA belong to this size category). Engines used only for emergencies, for example stand-by generator sets, are exempted from the most stringent Tier 4 emission requirements.
- Engines of displacement above 10 liters per cylinder must meet emission standards for marine engines.

Table 1. Emissions Requirements for Non-Emergency Stationary Engines

Displacement (D)	Power	Year	Emissions Certification
D < 10 L per cylinder	≤ 3000 hp	2007+	Nonroad Tier 2/3/4
	> 3000 hp	2007-2010	Nonroad Tier 1
		2011+	Nonroad Tier 2/4
10 ≤ D < 30 L per cylinder	All	2007+	Marine Cat. 2 Tier 2/3/4 (Tier 3/4 proposed)
D ≥ 30 L per cylinder	All	2010-2011	Marine Cat. 3 Tier 1 (proposed)
		2012+	Marine Cat. 3 Tier 2/3 (proposed)

Two groups of standards have been adopted: (1) for engine manufacturers, and (2) for engine owners/operators. Beginning with model year (MY) 2007, engine manufactures are required to emission certify stationary engines, and so they are responsible for compliance. During the transitional period before the MY 2007, engines can be sold that are not emission certified. In that case, the engine owner/operator is responsible for emission compliance.

Standards for Engine Manufacturers. Emission certification requirements for stationary non-emergency diesel engines are summarized in Table 1. All stationary engines must be certified to the respective standards, as applicable for the model year and maximum engine power (and displacement per cylinder in marine standards).

Engines in "remote areas" of Alaska are allowed to use Tier 3 engines in lieu of Tier 4 engines. The requirements to use Tier 4 engines with "add-on" emission controls were removed in two steps: in 2011 for NOx [EPA 2011] and in 2019 for PM [EPA 2019].

Stationary CI engines can be designed to allow operators to temporarily override performance inducements related to the emission control system—for instance, to allow engine operation without urea in the SCR system—in case of emergency that presents a risk to human life [EPA 2016]. This facilitates the use of stationary CI engines to perform life-saving work during fires, floods, hurricanes, and other emergency situations. During the emergency situation, the engine must meet the Tier 1 emission standards.

Emission certification requirements also apply to emergency engines from 2007, but the certification levels are less stringent:

- Emergency engines that are not fire pump engines must be certified to the standards shown in Table 1, with the exception of standards (including nonroad Tier 4 and marine Category 3 Tier 3) that require "add-on" controls such as diesel particulate filters or NOx reduction catalysts.

- Emergency fire pump engines must be certified to standards that are generally based on nonroad Tier 1 and Tier 2, with Tier 2 becoming effective around 2008-2011, depending on the engine power category.

The time allowed for maintenance and testing of emergency engines is 100 hours per year.

Standards for Engine Owners/Operators. Depending on the engine category, owners and operators are responsible for emission compliance as follows:

- Engines < 30 liters per cylinder
  - Pre-2007:
    - Engines < 10 liters per cylinder must meet nonroad Tier 1 emission standards.
    - Engines ≥ 10 liters per cylinder must meet MARPOL Annex 6 NOx limits (Tier 1 marine standards)
  - 2007 and later: owners/operators must buy emission certified engines
- Engines ≥ 30 liters per cylinder:
  - Under the 2006 rule, owners/operators are required to reduce NOx emissions by 90%, or alternatively they must limit NOx to 1.6 g/kWh (1.2 g/hp-hr).
  - Owners/operators are also required to reduce PM emissions by 60%, or alternatively they must limit PM to 0.15 g/kWh (0.11 g/hp-hr).
  - Under the 2011 rule, engines must be certified to the standards shown in Table 1.

Owners/operators of pre-2007 engines < 30 liters per cylinder can demonstrate compliance by purchasing a certified engine. If a non-certified engine is purchased, compliance may be demonstrated using emission test results from a test conducted on a similar engine; data from the engine manufacturer; data from the control device vendor; or conducting a performance test. If in-use performance test is conducted, the owner would be required to meet not-to-exceed (NTE) emission standards instead of the respective certification emission standards. Pre-2007 engines must meet NTE standards of 1.25 Ч the applicable certification emission standard. The information which demonstrates engine compliance and the appropriate maintenance records must be kept on site.

Owners/operators of engines ≥ 30 liters per cylinder must conduct an initial performance test to demonstrate emissions compliance (NOx is measured using EPA Method 7E, PM using EPA Method 5 [40 CFR part 60 appendix A]). The NTE standards do not apply to engines ≥ 30 liters per cylinder. Spark-Ignition (SI) Engines (NSPS)

The new source performance standards (NSPS) for reciprocating internal combustion engines (RICE) establish US federal emission requirements for a number of categories of spark ignition (SI) engines. The Spark Ignition NSPS rule was adopted in 2008 [EPA 2008] and amended in 2011 [EPA 2011]. NSPS emission regulations for stationary SI engines are published in the Code of Federal Regulations (CFR), Title 40, Part 60, Subpart JJJJ.

The NSPS regulations for SI engines define a number of emission standards, depending on the engine maximum power, fuel, application, and other factors. Depending on the engine category, the onus for compliance is either on the engine manufacturer or the engine owners/operators. Engines rated at 19 kW or less and non-emergency gasoline and rich burn LPG engines rated above 19 kW require the engine manufacturer to certify the engine. For non-emergency natural gas and lean burn LPG engines as well as all emergency engines rated above 19 kW, engine operators are allowed two alternative compliance methods—by either purchasing a manufacturer certified engine or else by demonstrating compliance through emission testing in the field.

Many of the SI NSPS standards are based on nonroad emission standards for the corresponding non-stationary (i.e., mobile or portable) SI engine categories. These standards are expressed in g/kWh or g/bhp-hr. Some of the in-use standards are also expressed in terms of volumetric concentrations (such as volume ppm, dry, corrected to 15% O2).

The SI NSPS standards for stationary engines are structured as follows:

- Engines ≤ 19 kW (25 hp)
- Engines > 19 kW (25 hp)

- Non-emergency engines:
  - Gasoline and rich burn liquefied petroleum gas (LPG) engines.
  - Natural gas (NG) and lean burn LPG engines.
  - Landfill/digester gas engines.
  - Emergency engines.

Fuel Requirements. In addition to emission standards, the 2008 rule introduced a requirement that owners and operators who use gasoline in their stationary SI engine must use gasoline that meets the requirements of 40 CFR 80.195, which include a gasoline sulfur per gallon cap of 80 ppm.

Test Cycles. For engines that must be certified by the manufacturer or which are voluntarily certified by the manufacturer, discreet or ramped mode cycles with 2-6 modes are used. Engines certified by the engine operator are certified within 10% of 100% peak load or the highest achievable load.

Volatile Organic Compounds (VOC). NSPS standards for some engine types limit VOC emissions. A number of different test procedures are allowed to determine VOCs. Formaldehyde should not be included when determining VOC emissions. Engine manufacturers are allowed to exclude methane and ethane from the determinations of VOCs. Some of the methods allowed for field testing for certification by operators can be operated to exclude methane and ethane.

Emissions Standards: U.S.A.
Existing Stationary Engines (NESHAP)

Background

The U.S. Environmental Protection Agency (EPA) issued a number of rules to control emissions of toxic air pollutants from existing stationary reciprocating internal combustion engines (RICE):

Over 2011-2013, the EPA introduced several amendments and clarifications to the 2010 regulations [EPA 2011][EPA 2013]. These amendments relaxed some of the emission requirements—such as by extending the allowable annual use periods for emergency engines and withdrawing emission standards for SI engines in remote are-as.

The rules, entitled National Emission Standards for Hazardous Air Pollutants (NESHAP) for Reciprocating Internal Combustion Engines, are intended to reduce emissions of toxic air pollutants—such as formaldehyde (HCHO), acetaldehyde, acro-lein, methanol and other air toxics—from several categories of previously unregulated stationary engines. The EPA has determined that carbon monoxide (CO) can be often used as an appropriate surrogate for formaldehyde. Since testing for CO emissions has many advantages over testing for emissions of hazardous air pollutants (HAP), many of the emission standards have been finalized in terms of CO as the only regulated pollutant.

The NESHAP regulations for stationary engines are published in Title 40, Part 63, Subpart ZZZZ (63.6580) of the Code of Federal Regulations (CFR). Regulatory docu-ments as well as fact sheets and related information can be also found in the US EPA stationary engine pages.

Applicability

The applicability of the emissions standards depends on the classification of the source of air toxics emissions. "Major sources" of air toxics are defined as those that emit 10 short tons per year of a single air toxic or 25 short tons per year of a mixture of air toxics. "Area sources" are those sources that are not "major sources".

The NESHAP rules are applicable to "existing" diesel and SI engines, as determined by their date of construction or reconstruction:

- "Area sources" of air toxics emissions: Engines constructed or reconstructed before June 12, 2006.
- "Major sources" of air toxics emissions:
  - Engines ≤ 500 hp constructed or reconstructed before June 12, 2006.
  - Engines > 500 hp constructed or reconstructed before December 19, 2002.

"New" engines or "reconstructed" engines are those constructed or reconstructed, respectively, after the above dates.

Emergency Engines. The NESHAP requirements apply to engines used for non-emergency purposes. The following operational requirements must be met by emergency engines:

- There is no time limit on the use in emergency situations (e.g., power outage, fire, flood).
- The engine may be used for up to 100 hours per calendar year for maintenance checks, testing, and for emergency demand response (i.e., blackout and brownout prevention).
- The engine may be used for up to 50 hours per year for certain non-emergency uses such as local reliability (the operation counts toward the above 100-hour limit).

Emissions Standards

The NESHAP regulations include three types of emission standards:

- Emission Limits—Limits for lean-burn engines are expressed as volumetric, dry CO concentrations (ppm) at 15% O2. Limits for rich-burn SI engines are expressed as volumetric, dry concentrations of HCHO (ppm or ppb) at 15% O2. The standards must be met during any operating conditions, except during periods of start-up (of maximum 30 minutes). Emissions are tested at 100% load.
- Percentage CO/HCHO Reductions—Alternative compliance options are available in certain engine categories, expressed as percentage CO or HCHO/THC emission reductions. These reductions can be achieved by retrofitting engines with emission controls.
- Equipment Standards—Engines must be retrofitted with

Table 1. NESHAP Emissions Requirements for Stationary Diesel (CI) Engines

Engine Category	Emissions Standard	Alternative CO Reduction
Area Sources		
Non-Emergency 300 < hp ≤ 500	49 ppmvd CO	70%
Non-Emergency > 500 hp	23 ppmvd CO	70%
Major Sources		
Non-Emergency 100 ≤ hp ≤ 300	230 ppmvd CO	-
Non-Emergency 300 < hp ≤ 500	49 ppmvd CO	70%
Non-Emergency > 500 hp	23 ppmvd CO	70%

Table 2. NESHAP Emissions Requirements for Stationary Gas (SI) Engines

Engine Category	Emissions Standard	Alternative CO/ HCHO Reduction
Area Sources		
4SLB, Non-Emergency > 500 hp	47 ppmvd CO	93% CO
4SRB, Non-Emergency > 500 hp	2.7 ppmvd HCHO	76% HCHO
Major Sources		
2SLB, Non-Emergency 100 ≤ hp ≤ 500	225 ppmvd CO	-
4SLB, Non-Emergency 100 ≤ hp ≤ 500	47 ppmvd CO	-
4SRB, Non-Emergency 100 ≤ hp ≤ 500	10.3 ppmvd HCHO	-
Landfill/Digester Gas, Non-Emergency 100 ≤ hp ≤ 500	177 ppmvd CO	-
4SRB, Non-Emergency > 500 hp	350 ppmvd HCHO	76% HCHO

Table 3. NESHAP Emissions Requirements for new CI and SI Engines at Major Sources		
Engine Category	**Emissions Standard**	**Alternative CO/ HCHO Reduction**
CI Engines		
Non-Emergency > 500 hp	580 ppb CH_2O	70% CO
SI Engines		
2SLB, Non-Emergency > 500 hp	12 ppm CH_2O	58% CO
4SLB, Non-Emergency > 250 hp	14 ppm CH_2O	93% CO
4SRB, Non-Emergency > 500 hp	350 ppb CH_2O	76% CH_2O
Note: New limited use engines >500 hp at major sources do not meet any emission standards under the NESHAP		

emission controls: oxidation catalysts on lean-burn engines and NSCR catalysts on rich-burn engines.

Engine Standards. The standards for existing stationary diesel engines are listed in Table 1. Standards for spark ignition, gas-fired stationary engines are summarized in Table 2. NESHAP standards for new engines are also applicable to certain categories of new CI and SI engines located at major sources, shown in Table 3.

Emissions Standards: U.S.A.
Locomotives

Background

U.S. emissions standards for railway locomotives apply to newly manufactured, as well as remanufactured railroad locomotives and locomotive engines. The standards have been adopted by the EPA in two regulatory actions:

- *Tier 0-2 standards:* The first emissions regulation for railroad locomotives was adopted on December 17, 1997 [63 FR 18997-19084, April 16, 1998]. The rulemaking, which became effective from 2000, applies to locomotives originally manufactured from 1973, any time they are manufactured or remanufactured. Tier 0-2 standards are met though engine design methods, without the use of exhaust gas aftertreatment.
- *Tier 3-4 standards:* A regulation signed on March 14, 2008 introduced more stringent emissions requirements [73 FR 88 25098-25352, May 6, 2008]. Tier 3 standards, to be met by engine design methods, become effective from 2011/12. Tier 4 standards, which are expected to require exhaust gas aftertreatment technologies, become effective from 2015. The 2008 regulation also includes more stringent emissions standards for remanufactured Tier 0-2 locomotives.

Table 1. Tier 0-2 Locomotive Emissions Standards, g/bhp-hr				
Duty Cycle	**HC***	**CO**	**NO_x**	**PM**
Tier 0 (1973-2001)				
Line-haul	1.0	5.0	9.5	0.60
Switch	2.1	8.0	14.0	0.72
Tier 1 (2002-2004)				
Line-haul	0.55	2.2	7.4	0.45
Switch	1.2	2.5	11.0	0.54
Tier 2 (2005 and later)				
Line-haul	0.3	1.5	5.5	0.20
Switch	0.6	2.4	8.1	0.24
Non-Regulated Locomotives (1997 estimates)				
Line-haul	0.5	1.5	13.5	0.34
Switch	1.1	2.4	19.8	0.41
* HC standard is in the form of THC for diesel engines				

Test Cycles. Locomotive emissions are measured over two steady-state test cycles which represent two different types of service including (1) *line-haul* and (2) *switch* locomotives. The duty cycles include different weighting factors for each of the 8 throttle notch modes, which are used to operate locomotive engines at different power levels, as well as for idle and dynamic brake modes. The switch operation involves much time in idle and low power notches, whereas the line-haul operation is characterized by a much higher percentage of time in the high power notches, especially notch 8.

Locomotive certification and compliance programs include several provisions, including production line testing (PLT) program, in-use compliance emissions testing, as well as averaging, banking and trading (ABT) of emissions.

Fuels. To enable catalytic aftertreatment methods at the Tier 4 stage, the EPA regulated (as part of the nonroad Tier 4 rule) the availability of low sulfur diesel fuel for locomotive engines. Sulfur limit of 500 ppm is effective as of June 2007, sulfur limit of 15 ppm from June 2012.

Emissions regulations for locomotives and locomotive engines can be found in the U.S. Code of Federal Regulations, 40 CFR Parts 85, 89 and 92.

Tier 0-2 Standards

Three separate sets of emissions standards have been adopted, termed Tier 0, Tier 1, and Tier 2. The applicability of the standards depends on the date a locomotive is first manufactured, as follows:

- Tier 0 — The first set of standards applies (effective 2000) to locomotives and locomotive engines originally manufactured from 1973 through 2001, any time they are manufactured or remanufactured.
- Tier 1 — These standards apply to locomotives and locomotive engines originally manufactured from 2002 through 2004. These locomotives and locomotive engines are required to meet the Tier 1 standards at the time of the manufacture and each subsequent remanufacture.
- Tier 2 — This set of standards applies to locomotives and locomotive engines originally manufactured in 2005

Table 2. Locomotive Smoke Standards, % opacity (normalized)			
	Steady-state	**30-sec peak**	**3-sec peak**
Tier 0	30	40	50
Tier 1	25	40	50
Tier 2 and later	20	40	50

and later. Tier 2 locomotives and locomotive engines are required to meet the applicable standards at the time of original manufacture and each subsequent remanufacture.

Exempted from the emissions standards are electric locomotives, historic steam-powered locomotives, and locomotives originally manufactured before 1973.

The Tier 0-2 emissions standards, as well as typical emissions rates from non-regulated locomotives, are listed in Table 1. A dual cycle approach has been adopted in the regulation, i.e., all locomotives are required to comply with both the line-haul and switch duty cycle standards, regardless of intended usage. Locomotive engines must also meet smoke opacity standards, Table 2.

Tier 3-4 Standards

The 2008 regulation strengthens the Tier 0-2 standards for existing locomotives, and introduces new Tier 3 and Tier 4 emissions standards:

- Tier 0-2 standards — More stringent emissions standards for existing locomotives when they are remanufactured.
- Tier 3 standards — Near-term engine-out emissions standards for newly-built and remanufactured locomotives. Tier 3 standards are to be met using engine technology.
- Tier 4 standards — Longer-term standards for newly built and remanufactured locomotives. Tier 4 standards are expected to require the use of exhaust gas aftertreatment technologies, such as particulate filters for PM control, and urea-SCR for NO_x emissions control.

Table 3. Line-Haul Locomotive Emissions Standards, g/bhp-hr

Tier	MY	Date	HC	CO	NO_x	PM
Tier 0[a]	1973-1992[c]	2010[d]	1.00	5.0	8.0	0.22
Tier 1[a]	1993[c]-2004	2010[d]	0.55	2.2	7.4	0.22
Tier 2[a]	2005-2011	2010[d]	0.30	1.5	5.5	0.10[e]
Tier 3[b]	2012-2014	2012	0.30	1.5	5.5	0.10
Tier 4	2015 or later	2015	0.14[f]	1.5	1.3[f]	0.03

[a] - Tier 0-2 line-haul locomotives must also meet switch standards of the same tier.
[b] - Tier 3 line-haul locomotives must also meet Tier 2 switch standards.
[c] - 1993-2001 locomotive that were not equipped with an intake air coolant system are subject to Tier 0 rather than Tier 1 standards.
[d] - As early as 2008 if approved engine upgrade kits become available.
[e] - 0.20 g/bhp-hr until January 1, 2013 (with some exceptions).
[f] - Manufacturers may elect to meet a combined NOx+HC standard of 1.4 g/bhp-hr.

Table 4. Switch Locomotive Emissions Standards, g/bhp-hr

Tier	MY	Date	HC	CO	NO_x	PM
Tier 0	1973-2001	2010[b]	2.10	8.0	11.8	0.26
Tier 1[a]	2002-2004	2010[b]	1.20	2.5	11.0	0.26
Tier 2[a]	2005-2010	2010[b]	0.60	2.4	8.1	0.13[c]
Tier 3	2011-2014	2011	0.60	2.4	5.0	0.10
Tier 4	2015 or later	2015	0.14[d]	2.4	1.3[d]	0.03

[a] - Tier 1-2 switch locomotives must also meet line-haul standards of the same tier.
[b] - As early as 2008 if approved engine upgrade kits become available.
[c] - 0.24 g/bhp-hr until January 1, 2013 (with some exceptions).
[d] - Manufacturers may elect to meet a combined NO_x+HC standard of 1.3 g/bhp-hr.

The locomotive regulations apply for locomotives originally built in or after 1973 that operate extensively within the United States. Exceptions include (1) historic steam-powered locomotives, (2) electric locomotives, and (3) some existing locomotives owned by small businesses. Furthermore, engines used in locomotive-type vehicles with less than 750 kW total power (used primarily for railway maintenance), engines used only for hotel power (for passenger railcar equipment), and engines that are used in self-propelled passenger-carrying railcars, are excluded from the regulations. The engines used in these smaller locomotive-type vehicles are generally subject to the nonroad engine requirements.

The emissions standards are summarized in Table 3 and Table 4. The Tier 0-2 standards apply to existing locomotives of the indicated manufacture years (MY) at the time they are remanufactured, beginning from the effective date. The Tier 3-4 standards apply to locomotives of the indicated manufacture years at the time they are newly built or remanufactured.

Tier 3-4 locomotives must also meet smoke opacity standards as specified in Table 2.

Manufacturers may certify Tier 0-2 locomotives to an alternate CO emissions standard of 10.0 g/bhp-hr if they also certify those locomotives to alternate PM standards less than or equal to one-half of the otherwise applicable PM standard.

Locomotives may discharge crankcase emissions to the ambient atmosphere if the emissions are added to the exhaust emissions (either physically or mathematically) during all emissions testing.

Useful Life. The emissions standards apply to new and/or remanufactured locomotives for their useful life. The useful life, generally specified as MW-hrs and years, ends when either of the values (MW-hrs or years) is exceeded or the locomotive is remanufactured.

The minimum useful life in terms of MW-hrs is equal to the product of the rated horsepower multiplied by 7.50. The minimum useful life in terms of years is 10 years. For locomotives originally manufactured before January 1, 2000 and not equipped with MW-hr meters, the minimum useful life is equal to 750,000 miles or 10 years, whichever is reached first. The minimum emissions warranty period is one-third of the useful life (with some exceptions).

Emissions Standards: U.S.A.
Marine Diesels

Background

Engine Categories. For the purpose of emissions regulations, marine engines are divided into three categories based on displacement (swept volume) per cylinder, as shown in Table 1. Each of the categories represents a different engine technology. Categories 1 and 2 are further divided into subcategories, depending on displacement and net power output.

Table 1. Marine Engine Categories

Category	Displacement per Cylinder (D)		Basic Engine Technology
	Tier 1-2	Tier 3-4	
1	D < 5 dm^3†	D < 7 dm^3	Land-based nonroad diesel
2	5 dm^3 ≤ D < 30 dm^3	7 dm^3 ≤ D < 30 dm^3	Locomotive engine
3	D ≥ 30 dm^3		Unique marine engine design

† And power ≥ 37 kW

Category 3 marine diesel engines typically range in size from 2,500 to 70,000 kW (3,000 to 100,000 hp). These are very large marine diesel engines used for propulsion power on ocean-going vessels such as container ships, oil tankers, bulk carriers, and cruise ships. Emissions control technologies which can be used on these engines are limited. An important limitation is the residual fuel on which they are operated. This fuel is the by-product of distilling crude oil to produce lighter petroleum products. It possesses high viscosity and density, which affects ignition quality, and it typically has high ash, sulfur and nitrogen content in comparison to marine distillate fuels. Furthermore, residual fuel parameters are highly variable because its content is not regulated. The EPA estimated that residual fuel can increase engine NO_x emissions from 20-50% and PM from 750% to 1250% (sulfate particulates) when compared to distillate fuel.

Category 1 and Category 2 marine diesel engines typically range in size from about 500 to 8,000 kW (700 to 11,000 hp). These engines are used to provide propulsion power on many kinds of vessels including tugboats, pushboats, supply vessels, fishing vessels, and other commercial vessels in and around ports. They are also used as stand-alone generators for auxiliary electrical power on many types of vessels.

Regulatory Acts. Emissions from marine diesel engines (compression ignition engines) have been regulated through a number of rules — the first one issued in 1999 — applicable to different engine categories. Certain overlap also exists with the regulations for mobile, land-based nonroad engines, which may be applicable to some types of engines used on marine vessels. The following are the major regulatory acts which establish emissions standards for marine engines:

- 1999 Marine Engine Rule — On November 23, 1999, the EPA signed the final rule "Control of Emissions of Air Pollution from New CI Marine Engines at or above 37 kW" *[40 CFR Parts 89, 92][64 FR 64 73300-73373, December 29, 1999]*. The adopted Tier 2 standards for Category 1 and 2 engines are based on the land-based standard for nonroad engines, while the largest Category 3 engines are expected — but not required by the rule — to comply with IMO MARPOL Annex 6 limits.
- 2002 Recreational Engine Rule — Diesel engines used in recreational vessels are covered in the "Emissions Standards for New Nonroad Engines — Large Industrial Spark-ignition Engines, Recreational Marine Diesel Engines, and Recreational Vehicles" regulation, signed on September 13, 2002 *[40 CFR Part 89 et al.] [67 FR 68241-68447, November 8, 2002]*.
- 2003 Category 3 Engine Rule — The decision to leave the largest Category 3 engines unregulated triggered a law suit against the EPA by environmental organizations. A court settlement was reached that required the EPA to develop NO_x emissions limits for Category 3 engines. The final rule "Control of Emissions From New Marine Compression-Ignition Engines at or Above 30 Liters Per Cylinder" *[40 CFR Part 9 and 94][68 FR 9745-9789, February 28, 2003]* — signed by the EPA in January 2003 — establishes Tier 1 emissions standards for marine engines virtually equivalent to the IMO MARPOL Annex 6 limits.
- 2008 Category 1/2 Engine Rule — A regulation signed on March 14, 2008 introduced Tier 3 and Tier 4 emissions standards for marine diesel engines *[73 FR 88 25098-25352, May 6, 2008]*. The Tier 4 emissions standards are modeled after the 2007/2010 highway engine program and the Tier 4 nonroad rule, with an emphasis on the use of emissions aftertreatment technology. To enable catalytic aftertreatment methods, the EPA established a sulfur cap in marine fuels (as part of the nonroad Tier 4 rule). Sulfur limit of 500 ppm becomes effective in June 2007, sulfur limit of 15 ppm in June 2012 (the sulfur limits are not applicable to residual fuels).
- 2009 Category 3 Engine Rule — On December 18, 2009, the EPA signed a new emissions rule for Category 3 engines (published April 30, 2010), which introduced Tier 2 and Tier 3 standards in harmonization with the 2008 Amendments to IMO MARPOL Annex 6.

Applicability

1999 Marine Engine Rule. The scope of application of the marine engine rule covers all new marine diesel engines at or above 37 kW (50 hp) (engines below 37 kW must comply with the nonroad standards). Regulated engines include both propulsion and auxiliary marine diesel engines. A propulsion engine is one that moves a vessel through the water or assists in guiding the direction of the vessel (for example, bow thrusters). Auxiliary engines are all other marine engines.

Classification of drilling rigs depends on their propulsion capability. Drilling ships are considered marine vessels, so their engines are subject to the marine rule. Semi-submersible drilling rigs which are moored to the ocean bottom, but have some propulsion capability, are also considered marine vessels. In contrast, permanently anchored drilling platforms are

not considered marine vessels, so none of the engines associated with one of these facilities are marine engine.

Consistently with the land-based nonroad regulation, a portable auxiliary engine that is used onboard a marine vessel is not considered to be a marine engine. Instead, a portable auxiliary engine is considered to be a land-based auxiliary engine and is subject to the land-based nonroad requirements. To distinguish a marine auxiliary engine installed on a marine vessel from a land-based portable auxiliary engine used on a marine vessel, EPA specified in that rulemaking that an auxiliary engine is installed on a marine vessel if its fuel, cooling, or exhaust system are an integral part of the vessel or require special mounting hardware. All other auxiliary engines are considered to be portable and therefore land-based.

The following engine categories are exempted from the 1999 marine regulation:

- Engines used in recreational vessels (standards for recreational diesel engines were established by the 2002 rule).
- Emissions certified new land-based engines modified for marine applications (provided certain conditions are met).
- Competition (racing) engines.
- Engines used in military vessels (National Security Exemption).
- Other exemptions (testing, display, export, ...) may also apply to marine engines.

The 1999 rule also included so called Foreign-Trade Exemption which was available (for engines Category 1 and 2 used on ocean vessels with Category 3 propulsion) for U.S. vessels that spend less than 25% of total operating time within 320 kilometers of U.S. territory. The Foreign-Trade Exemption was eliminated for all engine categories by the 2003 (Category 3) regulation.

Under the 1999 rule, the same emissions standards apply to engines fueled by diesel fuel and by other fuels.

2002 Recreational Vessel Rule. This rule applies to new recreational marine diesel engines over 37 kW (50 hp) that are used in yachts, cruisers, and other types of pleasure craft. The 2002 rule does not apply to outboard and personal watercraft spark ignited engines, which are regulated separately.

The same emissions standards apply to recreational engines fueled by diesel fuel and by alternative fuels.

Category 3 Engines, 2003 & 2009 Rules. These standards apply to new marine engines and to new vessels that include marine engines. The rules apply only to vessels flagged or registered in the U.S.A. However, equivalent emissions standards are applicable to foreign ships in U.S. waters under the IMO Annex 6 regulation.

Category 1/2 Engines, 2008 Rule. The regulations introduce two tiers of standards — Tier 3 and Tier 4 — which apply to both newly manufactured and remanufactured marine diesel engines, as follows:

1. *Newly built engines:* Tier 3 standards apply to engines used in commercial, recreational, and auxiliary power applications (including those below 37 kW that were previously covered by nonroad engine standards). Tier 4 standards, based on aftertreatment, apply to engines above 600 kW (800 hp) on commercial vessels.
2. *Remanufactured engines:* The standards apply to commercial marine diesel engines above 600 kW when these engines are remanufactured.

Table 2. Tier 2* Marine Emissions Standards

Cat.	Displacement (D) dm³ per cylinder	CO g/kWh	NO_x+THC g/kWh	PM g/kWh	Date
1	Power ≥ 37 kW D < 0.9	5.0	7.5	0.40	2005
	0.9 ≤ D < 1.2	5.0	7.2	0.30	2004
	1.2 ≤ D < 2.5	5.0	7.2	0.20	2004
	2.5 ≤ D < 5.0	5.0	7.2	0.20	2007[a]
2	5.0 ≤ D < 15	5.0	7.8	0.27	2007[a]
	15 ≤ D < 20 Power < 3300 kW	5.0	8.7	0.50	2007[a]
	15 ≤ D < 20 Power ≥ 3300 kW	5.0	9.8	0.50	2007[a]
	20 ≤ D < 25	5.0	9.8	0.50	2007[a]
	25 ≤ D < 30	5.0	11.0	0.50	2007[a]

* - Tier 1 standards are equivalent to the MARPOL Annex 6 Tier 1 NO_x limits
[a] - Tier 1 certification requirement starts in 2004

Table 3. "Blue Sky Series" Voluntary Emissions Standards

Displacement (D) dm³ per cylinder	NO_x+THC g/kWh	PM g/kWh
Power ≥ 37 kW & D < 0.9	4.0	0.24
0.9 ≤ D < 1.2	4.0	0.18
1.2 ≤ D < 2.5	4.0	0.12
2.5 ≤ D < 5.0	5.0	0.12
5.0 ≤ D < 15	5.0	0.16
15 ≤ D < 20 & Power < 3300 kW	5.2	0.30
15 ≤ D < 20 & Power ≥ 3300 kW	5.9	0.30
20 ≤ D < 25	5.9	0.30
25 ≤ D < 30	6.6	0.30

Table 4. Recreational Marine Diesel Engines Standards

Displacement (D) dm³ per cylinder	CO g/kWh	NO_x+HC g/kWh	PM g/kWh	Date
0.5 ≤ D < 0.9	5.0	7.5	0.40	2007
0.9 ≤ D < 1.2	5.0	7.2	0.30	2006
1.2 ≤ D < 2.5	5.0	7.2	0.20	2006
D ≥ 2.5	5.0	7.2	0.20	2009

The 2008 rule includes exemptions for the following engine categories:

- Test engines, manufacturer-owned engines, display engines.
- Marine diesel engines that are produced by marinizing a certified highway, nonroad, or locomotive engine ("dresser exemption").
- Competition engines.
- Export engines.
- Certain military engines.
- Engines installed on a vessel manufactured by a person for his/her own use (intended to allow hobbyists and fishermen to install a used/rebuilt engine or a reconditioned

vintage engine — not to order a new uncontrolled engine from an engine manufacturer).

Not all exemptions are automatic. Engine or vessel manufacturers, or vessel owners, may need to apply for a specific exemption to the EPA.

Emissions Standards — Category 3

Tier 1 Standards. In the 2003 rule, EPA adopted Tier 1 NO_x emissions standards for Category 3 engines, which are equivalent to the international IMO MARPOL Annex 6 limits. These limits range from 17 to 9.8 g/kWh depending on the engine speed, with higher limits for slower engines.

The EPA Tier 1 limits are in effect for new engines built in 2004 and later. These limits are to be achieved by engine-based controls, without the need for exhaust gas aftertreatment. Emissions other than NO_x are not regulated.

Tier 2-3 Standards. In the 2009 rule, EPA has adopted Tier 2 and Tier 3 emissions standards for newly built Category 3 engines.

- Tier 2 standards apply beginning in 2011. They require the use of engine-based controls, such as engine timing, engine cooling, and advanced electronic controls. The Tier 2 standards result in a 15 to 25% NO_x reduction below the Tier 1 levels.
- Tier 3 standards apply beginning in 2016. They can be met with the use of high efficiency emissions control technology such as selective catalytic reduction (SCR) to achieve NO_x reductions 80% below the Tier 1 levels.

The EPA Tier 2-3 NO_x limits are equivalent to the respective IMO Tier 2-3 standards. Depending on the engine speed, Tier 2 limits range from 14.4 to 7.7 g/kWh, while Tier 3 limits range from 3.4 to 1.96 g/kWh. In addition to the NO_x limits, EPA adopted a HC emissions standard of 2.0 g/kWh and a CO standard of 5.0 g/kWh from new Category 3 engines. No emissions standard was adopted for PM, but manufacturers are required to measure and report PM emissions.

IMO Emissions Control Areas (ECA). The IMO has designated waters along the U.S. and Canadian shorelines as the North American ECA for the emissions of NO_x and SO_x

Table 5. Tier 3 Standards for Marine Diesel Category 1 Commercial Standard Power Density (≤ 35 kW/dm³) Engines

Power (P) kW	Displacement (D) dm³ per cylinder	NO_x+HC† g/kWh	PM g/kWh	Date
P < 19	D < 0.9	7.5	0.40	2009
19 ≤ P < 75	D < 0.9[a]	7.5	0.30	2009
		4.7[b]	0.30[b]	2014
75 ≤ P < 3700	D < 0.9	5.4	0.14	2012
	0.9 ≤ D < 1.2	5.4	0.12	2013
	1.2 ≤ D < 2.5	5.6	0.11[c]	2014
	2.5 ≤ D < 3.5	5.6	0.11[c]	2013
	3.5 ≤ D < 7	5.8	0.11[c]	2012

† Tier 3 NO_x+HC standards do not apply to 2000-3700 kW engines.
[a] - < 75 kW engines ≥ 0.9 dm³/cylinder are subject to the corresponding 75-3700 kW standards.
[b] - Option: 0.20 g/kWh PM & 5.8 g/kWh NO_x+HC in 2014.
[c] - This standard level drops to 0.10 g/kWh in 2018 for < 600 kW engines.

Table 6. Tier 3 Standards for Marine Diesel Category 1 Commercial High Power Density (> 35 kW/dm³) Engines And All Diesel Recreational Engines

Power (P) kW	Displacement (D) dm³ per cylinder	NO_x+HC g/kWh	PM g/kWh	Date
P < 19	D < 0.9	7.5	0.40	2009
19 ≤ P < 75	D < 0.9[a]	7.5	0.30	2009
		4.7[b]	0.30[b]	2014
75 ≤ P < 3700	D < 0.9	5.8	0.15	2012
	0.9 ≤ D < 1.2	5.8	0.14	2013
	1.2 ≤ D < 2.5	5.8	0.12	2014
	2.5 ≤ D < 3.5	5.8	0.12	2013
	3.5 ≤ D < 7	5.8	0.11	2012

[a] - < 75 kW engines ≥ 0.9 dm³/cylinder are subject to the corresponding 75-3700 kW standards.
[b] - Option: 0.20 g/kWh PM & 5.8 g/kWh NO_x+HC in 2014.

Table 7. Tier 3 Standards for Marine Diesel Category 2 Engines‡

Power (P) kW	Displacement (D) dm³ per cylinder	NO_x+HC† g/kWh	PM g/kWh	Date
P < 3700	7 ≤ D < 15	6.2	0.14	2013
	15 ≤ D < 20	7.0	0.27[a]	2014
	20 ≤ D < 25	9.8	0.27	2014
	25 ≤ D < 30	11.0	0.27	2014

‡ Option: Tier 3 PM/NO_x+HC at 0.14/7.8 g/kWh in 2012, and Tier 4 in 2015.
† Tier 3 NO_x+HC standards do not apply to 2000-3700 kW engines.
[a] - 0.34 g/kWh for engines below 3300 kW.

Table 8. Tier 4 Standards for Marine Diesel Category 1/2 Engines

Power (P) kW	NO_x g/kWh	HC g/kWh	PM g/kWh	Date
P ≥ 3700	1.8	0.19	0.12[a]	2014[c]
	1.8	0.19	0.06	2016[b,c]
2000 ≤ P < 3700	1.8	0.19	0.04	2014[c,d]
1400 ≤ P < 2000	1.8	0.19	0.04	2016[c]
600 ≤ P < 1400	1.8	0.19	0.04	2017[d]

[a] - 0.25 g/kWh for engines with 15-30 dm³/cylinder displacement.
[b] - Optional compliance start dates can be used within these model years.
[c] - Option for Cat. 2: Tier 3 PM/NO_x+HC at 0.14/7.8 g/kWh in 2012, and Tier 4 in 2015.
[d] - The Tier 3 PM standards continue to apply for these engines in model years 2014 and 2015 only.

(enforceable from August 2012) and waters surrounding Puerto Rico and the U.S. Virgin Islands as the U.S. Caribbean ECA for NO_x & SO_x (enforceable from 2014).

The ECAs ensure that foreign flagged vessels comply with IMO Tier 3 NO_x limits while in U.S. waters (the IMO Tier 3 standards are only applicable within ECAs). The ECA also triggers low sulfur fuel requirements — by IMO and U.S. EPA — for vessels in U.S. waters.

Emissions Standards — Category 1 and 2

Tier 1-2 Standards. Emissions standards for engines Category 1 and 2 are based on the land-based standard for nonroad and locomotive engines. The emissions standards, referred to as Tier 2 Standards by the EPA, and their implementation dates are listed in table 2. The Tier 1 NO_x standard, equivalent to MARPOL Annex 6, was voluntary under the 1999 rule, but was made mandatory by the 2003 (Category 3) rule for Category 2 and Category 1 engines of above 2.5 liter displacement per cylinder, effective 2004.

The regulated emissions include NO_x+THC, PM, and CO. There are no smoke requirements for marine diesel engines. The regulators believed that the new PM standards will have a sufficient effect on limiting smoke emissions.

In the earlier proposal, the EPA also listed a more stringent Tier 3 standard to be introduced between 2008 and 2010. The Tier 3 standard was not adopted in the final 1999 rule.

Blue Sky Series Program. The 1999 regulation sets a voluntary "Blue Sky Series" program which permits manufacturers to certify their engines to more stringent emissions standards. The qualifying emissions limits are listed in Table 3. The Blue Sky program begins upon the publication of the rule and extends through the year 2010.

Recreational Vessels (2002 Rule). Recreational vessels standards are phased-in beginning in 2006, depending on the size of the engine as listed in Table 4. These standards are similar to the Tier 2 standards for Category 1 commercial vessels.

Recreational engines are also subject to NTE limits. There are no smoke requirements for recreational marine diesel engines. Similarly to commercial vessels, a voluntary "Blue Sky Series" limits exist for recreational vessels, which are based on a 45% emissions reduction beyond the mandatory standards.

Tier 3-4 Standards. The standards and implementation schedules are shown in Table 5 through Table 8. The engine-based Tier 3 standards are phasing in over 2009-2014. The aftertreatment-based Tier 4 standards for commercial marine engines at or above 600 kW are phasing in over 2014-2017. For engines of power levels not included in the Tier 3 and Tier 4 tables, the previous tier of standards — Tier 2 or Tier 3, respectively — continues to apply.

A differentiation is made between *high power density engines* typically used in planing vessels and *standard power density engines,* with a cut point between them at 35 kW/dm^3 (47 hp/dm^3).

In addition to the above NO_x+HC and PM standards, the following CO emissions standards apply for all Category 1/2 engines starting with the applicable Tier 3 model year:

1. 8.0 g/kWh for engines < 8 kW.
2. 6.6 g/kWh for engines ≥ 8 kW and < 19 kW.
3. 5.5 g/kWh for engines ≥ 19 kW and < 37 kW.
4. 5.0 g/kWh for engines ≥ 37 kW.

Emissions Testing

Category 1/2 Engines. Emissions from Category 1 engines are tested using the nonroad (Tier 1-3) test procedures (40 CFR 89), while Category 2 engines are tested using the locomotive test procedures (40 CFR 92), with certain exceptions including different test cycles, certification fuels and NTE testing. Category 1/2 engines are tested on various ISO 8178 test cycles as summarized in Table 9.

Table 9. Test Cycles for Certifying Category 1/2 Marine Diesel Engines

Application	Test Cycle
General Marine Duty Cycle	ISO 8178 E3
Constant-Speed Propulsion Engines	ISO 8178 E2
Variable-Speed Propulsion Engines Used on Nonpropeller Law Vessels and Variable-Speed Auxiliary Engines	ISO 8178 C1
Constant-Speed Auxiliary Engines	ISO 8178 D2
Recreational Marine	ISO 8178 E5

In addition to the test cycle measurement, which is an average from several test modes, the regulations set "not-to-exceed" (NTE) emissions limits, which provide assurance that emissions at any engine operating conditions within an NTE zone are reasonably close to the average level of control. NTE zones are defined as areas on the engine speed-power map. The emissions caps within the NTE zones represent a multiplier (Tier 1/2: between 1.2 and 1.5; Tier 3/4: 1.2-1.9) times the weighted test result used for certification for all of the regulated pollutants (NO_x+THC, CO, and PM).

The test fuel for marine diesel engine testing has a sulfur specification range of 0.03 to 0.80 %wt, which covers the range of sulfur levels observed for most in-use fuels.

Category 3 Engines. Category 3 engines are tested using methods similar to those stipulated by IMO MARPOL Annex 6 (E2 and E3 cycles of the ISO 8178 test). The major differences between the EPA and MARPOL compliance requirements are: (1) EPA liability for in-use compliance rests with the engine manufacturer (it is the vessel operator in MARPOL), (2) EPA requires a durability demonstration (under MARPOL, compliance must be demonstrated only when the engine is installed in the vessel), (3) there are differences in certain test conditions and parameters in EPA and MARPOL testing (air and water temperatures, engine setting, etc.).

Category 3 engines have no NTE emissions limits or test requirements.

Category 3 engines can be tested using distillate fuels, even though vessels with Category 3 marine engines use primar-

Table 10. Useful Life and Emissions Warranty Periods				
Category	Useful Life		Warranty Period	
	hours	years	hours	years
Category 3	10,000	3	10,000	3
Category 2	20,000	10	10,000	5
Category 1	10,000	10	5,000	5
Recreational	1,000	10	500	3

ily residual fuels (this allowance is consistent with MARPOL Annex 6).

Other Provisions

Useful life and *warranty* periods for marine engines are listed in Table 10. The periods are specified in operating hours and in years, whichever occurs first. The relatively short useful life period for Category 3 engines is based on the time that engines operate before being rebuilt for the first time.

The periods in the table are the minimum periods specified by the regulations. In certain cases, longer useful life/warranty periods may be required (e.g., in most cases the emissions warranty must not be shorter than the warranty for the engine or its components).

The regulations contain several other provisions, such as emissions Averaging, Banking, and Trading (ABT) program, deterioration factor requirements, production line testing, in-use testing, and requirements for rebuilding of emissions certified engines.

Emissions Standards: U.S.A.
On-Board Diagnostics

Introduction

On-board diagnostic (OBD) systems provide self-diagnostic functionality incorporated into the engine control system, in order to alert the vehicle driver/operator about potential problems that can affect the emissions performance of the vehicle. OBD requirements were first introduced for light-duty vehicles in California in 1991. Today, OBD requirements apply to light-duty vehicles and heavy-duty engines, both in California and under the federal EPA requirements.

The most detailed requirements for OBD systems are provided by the California regulations. Because systems developed for use in California can generally be used for compliance with EPA requirements with only minor differences, it is expected that OBD systems for vehicles and engines sold outside of California will be similar.

California light-duty and heavy-duty regulations define a number of general requirements for the malfunction indicator light (MIL), trouble codes, monitoring, thresholds and standardized communications common to all OBD systems. These requirements — outlined in the following sections — also apply to systems intended to comply with U.S. federal requirements.

MIL and Fault Code Requirements

The Malfunction Indicator Light (MIL) is located on the instrument panel. Except for a functionality check where it illuminates for 15-20 seconds when in the key-on position before engine cranking, it is normally illuminated only when the OBD system has detected and confirmed a malfunction that could increase emissions.

A number of things must happen before the MIL illuminates. When the OBD determines that a malfunction has occurred, it generates and stores a "pending fault code" and a "freeze frame" of engine data. At this point, the MIL does not illuminate. If the malfunction is detected again before the next driving cycle in which the suspected system or component is monitored, the MIL illuminates continuously and a "MIL-on" or "confirmed" fault code is generated and stored as well as a "freeze frame" of engine data. If the malfunction is not detected by the end of the driving cycle, the "pending fault code" is erased.

Except for misfires and fuel system faults, if the malfunction is not detected in the next 3 driving cycles, the MIL can be extinguished but the trouble code is still stored for at least 40 engine warm-up cycles. The MIL can also be extinguished and fault codes erased with a scan tool that technicians use to diagnose malfunctions. Alternate MIL illumination strategies are also possible but subject to approval.

Monitoring

The systems and parameters that require monitoring are outlined in Table 1. While some components can be monitored continuously, this is not always possible. Therefore, manufacturers must define conditions under which important emissions control components and subsystems can be monitored for proper function. The monitoring conditions should meet the following requirements:

- Ensure robust detection of malfunctions by avoiding false passes and false indications of malfunctions.
- Ensure monitoring will occur under conditions that may reasonably be expected to be encountered in normal vehicle operation and use.
- Ensure monitoring will occur during the FTP cycle.

In order to quantify the frequency of monitoring, an in-use monitor performance ratio is defined as:

In-use monitoring performance ratio = Number of monitoring events/Number of driving events.

Each component and subsystem requiring monitoring requires its own ratio. For example, for 2013 and later heavy-duty engines, the minimum acceptable value of this ratio is 0.100 (i.e. monitoring should occur at least during 1 vehicle trip in 10).

Comprehensive Component Monitoring requires the monitoring of any electronic engine component/system not specifically covered by the regulation that provides input to or receives commands from on-board computers and that can affect emissions during any reasonable in-use driving condition or is used as part of the diagnostic strategy for any other

Table 1. Monitoring Requirements of California OBD Systems

System/Component	Parameter Requiring Monitoring
Fuel system	Fuel system pressure control
	Injection quantity
	Injection timing
	Feedback control
Misfire	Detect continuous misfire
	Determine % of misfiring cycles per 1000 engine cycles (2013 and later engines)
EGR	Low flow
	High flow
	Slow response
	EGR cooler operation
	EGR catalyst performance
	Feedback control
Boost pressure	Underboost
	Overboost
	Slow response
	Charge air under cooling
	Feedback control
NMHC catalyst	Conversion efficiency
	Provide DPF heating
	Provide SCR feedgas (e.g., NO_2)
	Provide post DPF NMHC clean-up
	Provide ammonia clean-up
	Catalyst aging
SCR NO_x catalyst	Conversion efficiency
	SCR reductant: • delivery performance, • tank level, • quality, and • injection feedback control
	Catalyst aging
NO_x adsorber	NO_x adsorber capability
	Desorption function fuel delivery
	Feedback control
DPF	Filtering performance
	Frequent regeneration
	NMHC conversion
	Incomplete regeneration
	Missing substrate
	Active regeneration fuel delivery
	Feedback control
Exhaust gas sensors	For air-fuel ratio and NO_x sensors: • performance, • circuit faults, • feedback, and • monitoring capability
	Other exhaust gas sensors
	Sensor heater function
	Sensor heater circuit faults
VVT	Target error
	Slow response
Cooling system	Thermostat
	ECT sensor circuit faults
	ECT sensor circuit out-of-range
	ECT sensor circuit rationality faults
CCV	System integrity
Comprehensive component monitoring	
Cold-start emissions-reduction strategy	
Other emissions control system monitoring	

monitored system or component.

Monitoring is also required for all other emissions control systems that are not specifically identified. Examples include: hydrocarbon traps, HCCI control systems or swirl control valves.

Malfunction Criteria

Malfunction criteria for the various malfunctions listed in Table 1 vary depending on the system or component and individual parameter being monitored. In some cases, such as feedback control systems, sensor rationality checks and checks for circuit faults, a go/no-go criteria is used. In other cases such as the fuel system, EGR, turbocharger physical parameters and aftertreatment system performance, the OBD system must be able to determine when deterioration or other changes cause emissions to exceed a specified threshold.

In order to determine malfunction criteria for many of these faults, 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.

In determining the malfunction criteria for diesel engine monitors that are required to indicate a malfunction before emissions exceed an emissions threshold (e.g., 2.0 times any of the applicable standards), the emissions test cycle and standard that would result in higher emissions with the same level malfunction is to be used. Some adjustment is possible for those components experiencing infrequent regeneration.

Manufacturers have the option of simplifying monitoring requirements if failure or deterioration of a parameter will not cause emissions to exceed the threshold limits. For parameters that are controlled, such as temperature, pressure and flow, a malfunction in such a case would only need to be indicated when the commanded setting cannot be achieved. For aftertreatment devices, a malfunction would be indicated when the aftertreatment device has no conversion/filtering capability.

To account for the fact that current technology may not be adequate to detect all malfunctions at the required threshold, some flexibility has been built into the regulations. A manufacturer may request a higher emis-

sions threshold for any monitor if the most reliable monitoring method developed requires a higher threshold. Additionally, the PM filter malfunction criteria may be revised to exclude detection of specific failure modes (e.g., partially melted substrates or small cracks) if the most reliable monitoring method developed is unable to detect such failures.

A number of other exceptions are available including the possibility to disable OBD monitoring at ambient engine start temperatures below 20°F or at elevations above 8000 feet above sea level.

Standardization Requirements

OBD systems have a standardization requirement that makes diagnostics possible with a universal scan tool that is available to anyone — not just manufacturer's repair facilities. The standardization requirements include:

- A standard data link connector.
- A standard protocol for communications with a scan tool. In-use performance ratio tracking and engine run time tracking requirements.
- Engine manufacturers must provide the aftermarket service and repair industry emissions-related service information.
- Standardized functions to allow information to be accessed by a universal scan tool. These functions include:
    - Readiness status: The OBD system indicates "complete" or "not complete" for each of the monitored components and systems.
    - Data stream: A number of specific signals are made available through the standardized data link connector. Some of these include: torque and speed related data, temperatures, pressures, fuel system control parameters, fault codes and associated details, air flow, EGR system data, turbocharger data and aftertreatment data.
    - Freeze frame: The values of many of the important parameters available in the Data Stream are stored when a fault is detected.
    - Fault codes.
    - Test results: Results of the most recent monitoring of the components and systems and the test limits established for monitoring the respective components and systems are stored and made available through the data link.
    - Software calibration identification: Software Calibration Verification Number.
    - Vehicle Identification Number (VIN).
    - Erasing emissions-related diagnostic information: The emissions-related diagnostic information can be erased if commanded by a scan tool (generic or enhanced) or if the power to the on-board computer is disconnected.

Emissions Standards: Canada
On-Road Vehicles And Engines

Background

Authority to regulate emissions from internal combustion engines in Canada currently rests with *Environment Canada* and *Transport Canada*. The *Canadian Environmental Protection Act 1999* (CEPA 1999) gave legislative authority to Environment Canada to regulate emissions from engines other than those used in aircraft, railway locomotives and commercial marine vessels. Authority to regulate emissions from aircraft, railway locomotives and commercial marine vessels rests with Transport Canada.

Increasingly, the general approach to setting vehicle emissions standards in Canada is to harmonize them with U.S. EPA federal standards as much as possible. In 1988, on-road vehicle emissions standards were first aligned with the U.S. federal standards. In February 2001, the Minister of the Environment in the *Federal Agenda on Cleaner Vehicles, Engines and Fuels* set out a number of policy measures that would continue the harmonization of on-road emissions standards as well as to expand this harmonization by developing emissions standards for off-road engines and standards for fuels that are aligned with those of the federal U.S. EPA requirements.

On-Road Engines and Vehicles

Canadian federal regulations establishing exhaust emissions limits for on-road vehicles were first promulgated in 1971 under the *Motor Vehicle Safety Act* which is administered by Transport Canada. On March 13, 2000, legislative authority for controlling on-road vehicle emissions was transferred to Environment Canada under the Canadian Environmental Protection Act 1999 (CEPA 1999). Under CEPA 1999, the *On-Road Vehicle and Engine Emissions Regulations* where promulgated on January 1, 2003, and came into effect on January 1, 2004. These regulations replaced the previous regulations adopted under the Motor Vehicle Safety Act. The new regulations adopted under CEPA 1999 continued the past approach of aligning with the federal emissions standards of the U.S. EPA.

MOU. In the interim period between the phase-out of the emissions regulations under the Motor Vehicle Safety Act and the effective date of the On-Road Vehicle and Engine Emissions Regulations, Environment Canada signed a *Memorandum of Understanding* (MOU) with the Canadian Vehicle Manufacturers Association, the Association of International Automobile Manufacturers of Canada, and the member companies of those associations in June 2001. The MOU formalized an industry commitment to market the same low emissions light-duty vehicles and light-duty trucks in Canada as in the U.S. for model years 2001-2003.

On-Road Emissions Regulations. The Regulations align vehicle and engine certification requirements with those of the U.S.

federal EPA requirements beginning January 1, 2004 and including the U.S. Tier 2 program for new light-duty vehicles, light-duty trucks and medium-duty passenger vehicles, and Phase 1 and Phase 2 programs for new heavy-duty vehicles and engines.

The Regulations set out technical standards for vehicles and engines for exhaust, evaporative and crankcase emissions, on-board diagnostic systems and other specifications related to emissions control systems. The intention of the Regulations is to ensure that vehicles and engines meeting more stringent exhaust emissions standards will begin entering the Canadian market in the 2004 model year and will be phased-in over the 2004 to 2010 model year period. The phase-in schedules vary by standard and by vehicle class and can be summarized as follows:

- Tier 2 standards for light-duty vehicles and light light-duty trucks (2004-2007).
- Tier 2 standards for heavy light-duty trucks and medium-duty passenger vehicles (2004-2009).
- Phase 1 (2005) and Phase 2 (2008-2009) standards for complete heavy-duty vehicles.
- Phase 1 (2004-2006) and Phase 2 (2007-2010) standards for heavy-duty engines.

During any phase-in period, every model of vehicle or engine that is certified by the U.S. EPA, and that is sold concurrently in Canada and the United States, is required to meet the same emissions standards in Canada as in the United States. Canadian vehicles will therefore have progressively improved emissions performance without specifying interim phase-in percentages in the Regulations. The final phased-in standards apply to all vehicles and engines sold in Canada, in the model year that they apply, to 100% of a class of vehicles or engines in the United States.

Vehicle Weight Classes. The regulations define the weight classes for vehicles and engines as outlined in Table 1.

Light-Duty Vehicles

The exhaust emissions standards for Light-Duty Vehicles, Light-Duty Trucks and Medium-Duty Passenger Vehicles align with the U.S. Tier 2 emissions standards. Manufacturers certify every vehicle to one of eleven "bins", each of which contains standards for NO_x, non-methane organic gases (NMOG), CO, formaldehyde and PM (see table in U.S. section). The manufacturers' choices of bin within which to certify each vehicle is limited by the obligation to comply with fleet average NO_x emissions standards.

Based on vehicle sales from each "bin", a company calculates a sales-weighted "fleet average NO_x value" for each model year. The emissions bins, fleet average NO_x emissions standards, timing of phase-ins and methods of calculating fleet average NO_x values are consistent with the U.S. Tier 2 emissions program. As in the U.S. program, the Canadian standards have separate fleet average requirements for LDV/LLDTs and HLDT/MDPVs until the end of the 2008 model year. However, there are no separate distinctions between Tier 2 vehicles and interim non-Tier 2 vehicles as in the U.S. program. All Canadian Tier 2 LDV/LLDTs must meet one fleet average requirement and all HLDT/MDPVs another, as outlined in Table 2.

While this results in an upper fleet average LDV/LLDT NO_x limit that is equal to that obtained for the U.S. Tier 2 program, there is a small difference for 2004-2006 HLDT/MDPVs fleet average NO_x limit for Canada. For the U.S. 2004-2006 model year HLDT/MDPVs, a significant proportion of sales do not have to meet Tier 2 or interim non-Tier 2 fleet average NO_x requirements. The only stipulation is that they meet bin 10 requirements if they are HLDTs or bin 11 requirements if they are MDPVs. The Canadian regulations require that all HLDT/MDPVs meet a fleet average NO_x requirement during this period.

As in the U.S. Tier 2 program, by 2009 when the standards are fully phased in, a company's combined fleet of light-duty vehicles, light-duty trucks and medium-duty passenger vehicles will be subject to a single fleet average NO_x emissions standard of 0.07 g/mile, corresponding to the NO_x standard in bin 5. A company can, in any model year, generate NO_x emissions credits by achieving a fleet average NO_x value that is lower than the standard. These credits can be used in a subsequent model year to offset a NO_x emissions deficit (the fleet average NO_x value exceeds the standard). A deficit must be offset no later than the third model year following the year in which it is incurred. NO_x emissions credits may also be transferred to another company.

In order to allow some flexibility in the regulations to account for market differences between Canada and the U.S., the Canadian regulations allow a company to exclude from the fleet average compliance requirement U.S. certified

Table 1. Vehicle Categories

Class	GVWR, kg (lb)
Motorcycle	≤793 (1,749)
Light-Duty Vehicle	≤3,856 (8,500)
Light-Duty Truck	≤3,856 (8,500)
Light Light-Duty Truck	≤2,722 (6,000)
Heavy Light-Duty Truck	>2,722 to 3,856 (6,000 to 8,500)
Medium-Duty Passenger Vehicle	3,856 to <4,536 (8,500 to 10,000)
Complete Heavy-Duty Vehicle (Otto Cycle Only)	3,856 to 6,350 (8,500 to 14,000)
Heavy-Duty Vehicle/Heavy-Duty Engine	>3,856 (8,500)
Light Heavy-Duty Engine	<8,847 (19,500)
Medium Heavy-Duty Engine	8,847 to 14,971 (19,500 to 33,000)
Heavy Heavy-Duty Engine	>14,971 (33,000)

Table 2. Canadian Fleet average NO_x requirements, g/mile

Model Year	LDV/LLDTs	HLDT/MDPV
2004	0.25	0.53
2005	0.19	0.43
2006	0.13	0.33
2007	0.07	0.20
2008	0.07	0.14
2009 & later	0.07	

vehicles that are sold concurrently in Canada and the U.S.A. For vehicle models certified to emissions bins having a NO_x standard higher than the fleet average, this is not allowed if the total number of vehicles of the particular model sold in Canada exceeds the number sold in the U.S.A. If a company chooses this option, they must include all eligible vehicles in that group, they cannot generate emissions credits or transfer credits to another company in that model year and they forfeit any emissions credits obtained in previous model years. In all cases, fleet average emissions must be reported at the end of the year.

Heavy-Duty Engines

Diesel Engines. Phase 1 standards for heavy-duty diesel truck and bus engines apply starting with the 2004 model year. As with the U.S. EPA, there are two options for NO_x+NMHC limits and tighter standards for urban busses (see U.S. table). Phase 2 standards apply starting with the 2007 model year.

In the U.S.A., the Phase 2 NMHC, CO and PM standards apply in 2007 and the NO_x standard is phased in from 2007-2010. In the case of a standard that is set out in the U.S. Code of Federal Regulations (CFR) to be phased in over a period of time, the standard comes into effect in Canada in the model year for which the CFR specifies that the standard applies to 100% of that class, and continues to apply until another standard comes into effect that applies to 100% of that class. This creates a difference in Canadian and U.S. standards during this phase in period. However, because every engine that is covered by an EPA certificate and that is sold concurrently in Canada and the U.S. must conform to the EPA certification and in-use standards, the differences in emissions profiles of engines sold during this period are expected to be small.

There are no emissions averaging, banking and trading options for heavy-duty engines in Canada.

Otto Engines. The standards for heavy-duty Otto cycle engines are outlined in Table 3. Phase 2 standards are the same as those for heavy-duty diesel engines and apply in 2008. As with the heavy-duty diesel engine standards, the NO_x standards in the U.S.A. are phased in and apply to 100% of engines in 2010. Similar comments apply here as those noted above for heavy-duty diesel engines during this phase-in period.

Table 3. Heavy-Duty Otto Engine Emissions Standards, g/bhp-hr

	GVWR kg (lb)	NO_x	NMHC	NO_x + NMHC	CO	PM
Pre-2005	≤ 6,350 (14,000)	4.0	1.1	-	14.4	-
	> 6,350 (14,000)	4.0	1.9	-	37.1	-
Phase 1 (2005)	≤ 6,350 (14,000)	-	-	1.0	14.4	-
	> 6,350 (14,000)	-	-	1.0	37.1	-
Phase 2 (2008 - 2010)	≥ 3,856 (8,500)	0.2	0.14	-	14.4	0.01

Table 4. Complete Heavy-Duty Vehicle Exhaust Emissions Standards, g/mi

	GVWR kg (lb)	NO_x	NMHC	HCHO	CO	PM
Phase 1 (2005)	3,856 - 4,536 (8,500 - 10,000)	0.9	0.28	-	7.3	-
	4,536 - 6,350 (10,000 - 14,000)	1	0.33	-	8.1	-
Phase 2 (2008 - 2009)	3,856 - 4,536 (8,500 - 10,000)	0.2	0.195	0.032	7.3	0.02
	4,536 - 6,350 (10,000 - 14,000)	0.4	0.23	0.04	8.1	0.02

Heavy-Duty Vehicles

Complete Heavy-Duty Vehicles. A complete heavy-duty vehicle is one with a gross vehicle weight rating of 6,350 kg (14,000 lb) or less and that is powered by an Otto-cycle engine and with the load carrying device or container attached after it leaves the control of the manufacturer. As with the U.S. EPA requirements, Phase 1 standards apply starting in the 2005 model year. Because the Phase 2 standards are phased in during 2008 in the U.S.A. and apply to 100% of U.S. vehicles only in 2009, similar comments to those made previously for heavy-duty diesel engines apply. The standards for these vehicles are outlined in Table 4:

Heavy-Duty Vehicles. On-road heavy-duty vehicles other than complete heavy-duty vehicles must meet the heavy-duty engine requirements for the particular engine installed in that vehicle. Alternatively, heavy-duty diesel vehicles of 6,350 kg (14,000 lb) GVWR or less can conform to the standards for complete heavy-duty vehicles.

There are no emissions averaging, banking and trading options for heavy-duty vehicles or complete heavy-duty vehicles in Canada.

Emissions Standards: Canada
Off-Road Vehicles And Engines

Emissions regulations have been adopted for the following categories of off-road engines:

- Off-Road Compression-Ignition Engines, such as those used in construction and agricultural machinery.
- Off-Road Small Spark-Ignition Engines.
- Marine Engines.

The authority for regulating railway locomotive emissions lies with Transport Canada under the Railway Safety Act. Environment Canada monitored locomotive emissions through information provided under a MOU signed by Environment Canada, the Canadian Council of Ministers of the Environment and the Railway Association of Canada in 1995. The MOU set a cap on annual NO_x emissions from railway locomotives operating in Canada of 115,000 tonnes per annum. Since this agreement expired in 2005, locomotive emissions remain unregulated.

Off-Road Compression-Ignition Engines

Prior to the *Canadian Environmental Protection Act 1999* (CEPA 1999), there was no federal authority for regulating emissions from off-road engines such as those typically found in construction, mining, farming and forestry machines. Under the December 2000 Ozone Annex to the 1991 Canada-United States Air Quality Agreement, Canada committed to establishing emissions regulations under CEPA 1999 for new off-road engines that aligned with the U.S. federal EPA requirements. In the period before the regulations were promulgated, Environment Canada signed MOUs with 13 engine manufacturers in 2000. Under the terms of these MOUs, manufacturers agreed to supply off-road diesel engines designed to meet U.S. EPA Tier 1 standards.

The Off-Road Compression-Ignition Engine Emissions Regulations were promulgated on February 23, 2005. These regulations introduced emissions standards for model year 2006 and later diesel engines used in off-road applications such as those typically found in construction, mining, farming and forestry machines. These regulations encompassed the U.S. EPA Tier 2 and Tier 3 standards. In November 2011, the regulations were amended to align with the U.S. EPA Tier 4 standards.

The Off-Road Compression-Ignition Engine Emissions Regulations apply to "reciprocating, internal combustion engines, other than those that operate under characteristics significantly similar to the theoretical Otto combustion cycle and that use a spark plug or other sparking device". This definition is not exactly the same as the definition of a diesel engine used in the On-Road Vehicle and Engine Emissions Regulations where a diesel engine is defined as one "that has operating characteristics significantly similar to those of the theoretical Diesel combustion cycle. The non-use of a throttle during normal operation is indicative of a diesel engine". The off-road regulations focus on the ignition mechanism while the on-road regulations focus on the load control mechanism in distinguishing the engine type.

The regulations specifically exempt engines:

- Designed exclusively for competition.
- Regulated by the On-Road Vehicle and Engine Emissions Regulations.
- Designed to be used exclusively in underground mines.
- With a per-cylinder displacement of less than 50 cm^3.
- For military machines used in combat or combat support.
- Being exported and not sold or used in Canada.
- Designed to be used in a vessel and for which the fuel, cooling and exhaust systems are integral parts of the vessel.

While not specifically exempted by the regulation, Environment Canada does not have legislative authority to regulate emissions from railway locomotive engines.

The Canadian Off-Road Compression-Ignition Engine Emissions Regulations do not include an optional averaging, banking and trading program as do the U.S. EPA regulations.

Tier 2/3 Standards. The Canadian Off-Road Compression-Ignition Engine Emissions Regulations align the engine certification values with those of the U.S. EPA Tier 2 and Tier 3 values, Table 1. The implementations dates, however, were later. In the U.S., compliance with Tier 2 requirements was mandatory as early as model year 2001 and with Tier 3 starting with model year 2006. Compliance in Canada with U.S. EPA Tier 2 requirements was not mandatory until the 2006 model year.

Table 1. Canadian Tier 2/3 Off-Road Compression-Ignition Engine Emissions Standards, g/kWh

Power (P), kW	Tier	Year	NMHC + NO_x	CO	PM
P < 8	Tier 2	2006	7.5	8.0	0.80
8 ≤ P < 19	Tier 2	2006	7.5	6.6	0.80
19 ≤ P < 37	Tier 2	2006	7.5	5.5	0.60
37 ≤ P < 75	Tier 2	2006	7.5	5.0	0.40
	Tier 3	2008	4.7	5.0	0.40
75 ≤ P < 130	Tier 2	2006	6.6	5.0	0.30
	Tier 3	2007	4.0	5.0	0.30
130 ≤ P < 225	Tier 3	2006	4.0	3.5	0.20
225 ≤ P < 450	Tier 3	2006	4.0	3.5	0.20
450 ≤ P < 560	Tier 3	2006	4.0	3.5	0.20
P > 560	Tier 2	2006	6.4	3.5	0.20

Tier 4 Standards. On November 17, 2011, Environment Canada adopted amendments to the Off-Road Compression-Ignition Engine Emissions Regulations which align Canadian emissions standards with the U.S. EPA Tier 4 standards for non-road engines. The Tier 4 standards come into force on January 16, 2012 and apply to engines of the 2012 and later model years manufactured on and after January 16, 2012.

Table 2. Small Spark-Ignition Engine Emissions Standards, g/kWh

Class	Engine Type	Displacement (D), cm³	Date	HC + NO_x[b]	NMHC + NO_x	CO
1-A	Non-handheld	D < 66	2005	50	-	610
1-B		66 ≤ D < 100	2005	40	37	610
1		100 ≤ D < 225	2005[1]	16.1[a]	-	519[a]
			2005[2]	16.1	14.8	610
			2007	16.1	14.8	610
2		D ≥ 225	2005	12.1	11.3	610
3	Handheld	D < 20	2005	50	-	805
4		20 ≤ D < 50	2005	50	-	805
5		D ≥ 50	2005	119	-	603
			2006	96	-	603
			2007	72	-	603

a - Standards apply only when the engine is new
b - Some engine classes include a combined NMHC+NO_x standard that applies only when the engine is fueled by natural gas
1 - For models already in production at coming into force of the Regulations
2 - For models initially produced after coming into force of the Regulations

Alternative less stringent emissions standards, consistent with those available under the CFR, are available:

- For HC+NO_x levels for engines in machines used exclusively in wintertime, such as ice augers and snow-blowers; These engines are subject to the applicable CO standard.
- For replacement engines which are engines manufactured exclusively to replace an existing engine in a machine for which no current model year engine with physical or performance characteristics necessary for the operation of the machine exists.
- For class 3, 4 and 5 when less than 2000 engines of a particular model are sold in total in Canada to accommodate Canada-only niche products.

Mining Engines. Emissions from engines used exclusively in underground mining equipment fall under provincial jurisdiction. While emissions from these engines are not directly regulated, provincial regulations exist for ventilation rates in mines were these engines are used. Canadian Standards Association (CSA) standards have been established that describe the technical requirements and procedures necessary for the design, performance, and testing of new or unused non-rail-bound, diesel-powered, self-propelled machines in underground mines (MMSL02-043). Testing carried out according to these CSA standards establish the minimum ventilation rate required for any engine to keep air quality at an acceptable level. Some provinces base their ventilation requirements on the results of testing according to the CSA standards.

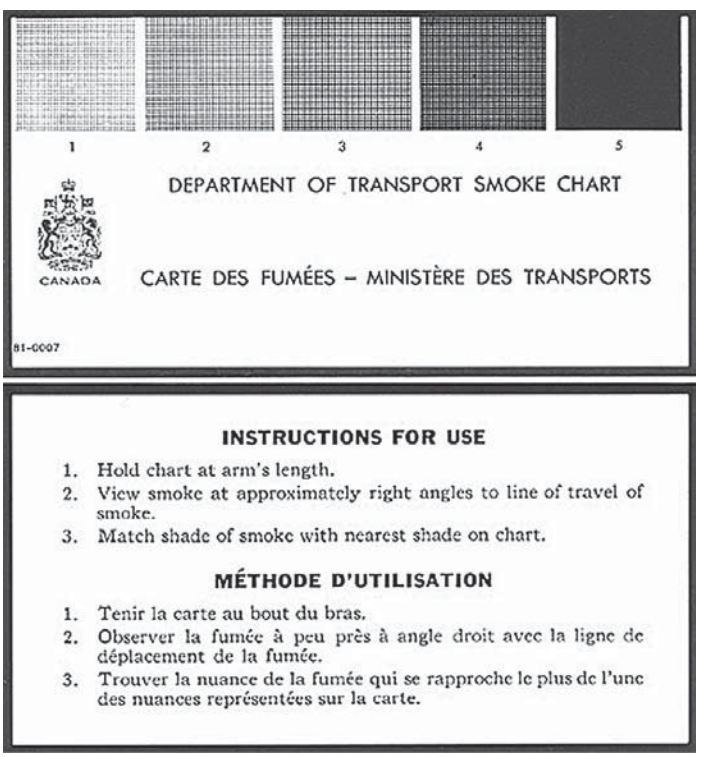
Off-Road Small Spark-Ignition Engines

The Off-Road Small Spark-Ignition Engine Emissions Regulations were promulgated on November 19, 2003. The Regulations apply to off-road engines of model year 2005 and later that use sparkplugs and develop no more than 19 kW (25 hp) of power. The emissions standards are divided into seven classes based on engine displacement and usage in either a handheld or non-handheld application as shown in Table 2.

Engines must meet the emissions standards throughout their useful life (with the exception of pre-2005 Class 1 engines, as indicated in the table). At the time of engine certification, a manufacturer can select one of three specified useful life periods, which range from 50 to 1000 hours depending on the engine class. For example, for a class 1 engine, the useful life can be 125, 250 or 500 hours. The selection of useful life duration must be supported by technical information. Longer useful lives, which entail a higher manufacturing cost, are typically found in commercial equipment while home consumer products are often designed for shorter useful lives.

On February 4, 2011, Environment Canada adopted Marine Spark-Ignition Engine, Vessel and Off-Road Recreational Vehicle Emissions Regulations. These emissions regulations apply to outboard engines, personal watercraft, snowmobiles, off-highway motorcycles and all-terrain vehicles. Most of the regulatory provisions came into force from April 5, 2011. The standards align with corresponding U.S. EPA rules for marine spark-ignition engines and off-road recreational engines

Figure 1. Smoke Density Chart



and vehicles. An earlier MOU with the Canadian Marine Manufacturers Association covered only marine spark ignition engines and under its terms, engine manufacturers voluntarily committed to supply engines designed to meet United States federal emissions standards into Canada starting with the 2001 model year.

Environment Canada plans to propose regulations to address emissions from large spark-ignition engines used in industrial applications such as forklifts and ice re-surfacing machines in the future.

Marine Engines

Authority to regulate emissions from marine propulsion engines smaller than 37 kW falls to Environment Canada. The Off-Road Compression-Ignition Engine Emissions Regulations cover compression ignition marine engines less than 37 kW. Regulations are planned for marine spark-ignition engines.

Transport Canada has authority to regulate emissions from marine propulsion engines larger than 37 kW. Current emissions standards from ships are under the authority of Transport Canada. The Air Pollution Regulations of the Canada Shipping Act regulates the density of black smoke from ships in Canadian waters and within 1 mile of land. Smoke density rating is determined by the Department of Transport Smoke Chart set out in the schedule of the regulations and reproduced below. For vessels with diesel engines a smoke density less than No. 1 is normally required with the exception that a smoke density of No. 2 for an aggregate of not more than 4 minutes in any 30-minute period is allowed (Figure 1).

Pollution Prevention Regulations under the Canada Shipping Act are under development to align with IMO MARPOL 73/78 Annex 6. This agreement sets limits for NO_x emissions from marine engines with power outputs more than 130 kW that have either been installed on a ship constructed on or after January 1, 2000 or have had major conversions on or after January 1, 2000.

Emissions Standards: Mexico
On-Road Vehicles And Engines

Background

Mexican emissions requirements for new vehicles and engines are adopted by the *Secretaria de Medio Ambiente y Recursos Naturales (SEMARNAT)*. Emissions compliance is generally required with either the U.S. or European emissions standards.

First emissions standards for both light- and heavy-duty vehicles were established on June 6, 1988 and became effective in model year 1993 [NOM-044-ECOL-1993]. The light-duty standards were later strengthened to be equivalent to the U.S. Tier 1, effective 2001 [NOM-042-ECOL-1999]. A mix of U.S. Tier 1/2 and Euro 3/4 standards is required since 2004 [NOM-042-SEMARNAT-2003].

New emissions requirements for heavy-duty truck and bus engines were adopted on October 12, 2006, which require compliance with U.S. 2004 or Euro 4 equivalent standards effective July 2008 [NOM-044-SEMARNAT-2006].

Light-Duty Vehicle Classification

Light-duty vehicles are defined as vehicles of GVW ≤ 3857 kg. Passenger cars (PC) are defined as vehicles with up to 10 seats, including the driver. Light trucks are classified in four groups — corresponding to the U.S. Light-Duty Truck 1 to 4 — based on the GVW and the test weight (weight of the vehicle with full fuel tank) as follows:

- CL1: GVW ≤ 2722 kg, test weight ≤ 1701 kg.
- CL2: GVW ≤ 2722 kg, test weight 1701 - 2608 kg.
- CL3: GVW 2722 - 3857 kg, test weight ≤ 2608 kg.
- CL4: GVW 2722 - 3857 kg, test weight 2608 - 3857 kg.

Weight ratings based on the European grouping for passenger cars and light commercial vehicles using a vehicle's reference mass (weight of vehicle with full tank of fuel + 100 kg) are also used:

- CL Class 1: reference mass ≤ 1305 kg.
- CL Class 2: reference mass > 1305 kg but ≤ 1760 kg.
- CL Class 3: reference mass > 1760 kg.

Model Year 1993-2003

Emissions standards for light-duty vehicles are summarized in Table 1. The standards were based on the U.S. regulations

Table 1. Emissions Standards for Cars and Light-Duty Trucks, g/km

Year	CO	NMHC*	NO_x		PM†
			Gasoline	Diesel	
Passenger Cars					
1993	2.11	0.25	0.62	0.62	0.07
2001	2.11	0.156	0.25	0.62	0.07
Light Trucks CL1					
1994	8.75	0.63	1.44	1.44	0.07
2001	2.11	0.156	0.25	0.62	0.07
Light Trucks CL2					
1994	8.75	0.63	1.44	1.44	0.07
2001	2.74	0.20	0.44	0.62	0.07
Light Trucks CL3					
1994	8.75	0.63	1.44	1.44	0.07
2001	2.74	0.20	0.44	0.62	0.07
Light Trucks CL4					
1994	8.75	0.63	1.44	1.44	0.10
2001	3.11	0.24	0.68	0.62	0.10

* total hydrocarbons (THC) prior to model-year 2001
† diesel vehicles only

and test methods (FTP-75). The 1993 requirements were based on the U.S. 1981 emissions standards. The 2001 requirements represent the U.S. Tier 1 standards *without OBD 2 provisions*.

The standards apply both to gasoline and diesel vehicles, with the exception of NO_x standards, as specified, and the PM standard that applies only to diesels. Natural gas and LPG vehicles have the same standards as gasoline vehicles.

Gasoline, natural gas, and LPG vehicles of all classes and all model years must also meet an evaporative (SHED) limit of 2 g/test.

Model Year 2004 and Later

The model year 2004 and later standards are based on U.S. Tier 1 and Tier 2 standards and Euro 3 and Euro 4 limits. New vehicles must meet the standards set out in either Table 2 (based on U.S. Tier 1/2 limits) or Table 3 (based on Euro 3/4 limits). Vehicles meeting these standards are also required to be equipped with OBD.

Notes to Table 2 and Table 3:

1. Emissions durability requirements:
   - 80,000 km / 50,000 miles for U.S. EPA option (Table 2), or
   - 100,000 km for European option (Table 3)
2. Gasoline vehicle standards also apply to natural gas and LPG vehicles.
3. Gasoline, natural gas, and LPG vehicles of all classes and all model years must also meet an evaporative (SHED) limit of 2 g/test.

An important factor in the phase-in of these vehicles is the introduction of gasoline with 30 ppm average and 80 ppm maximum sulfur, and diesel fuel with 15 ppm sulfur. The calendar year that these fuels become available nationally is referred to as "Year 1" (Aco 1). It is expected to be 2009, according to Mexican fuel quality regulations [NOM-086-SEMARNAT-SENER-SCFI-2005]. Vehicles meeting the "A" standard in Table 2 are those produced between 2004 to 2009. Vehicles meeting "B" standard in Table 2 and Table 3 are those produced from 2007 to "Year 3"— 2 calendar years after "Year 1". Vehicles meeting "C" standard

Table 2. Light-Duty Vehicle Emissions Limit Option Based on U.S. EPA Standards, g/km

Standard	Class	CO		NMHC		NO_x		PM	
		Gasoline	Diesel	Gasoline	Diesel	Gasoline	Diesel	Gasoline	Diesel
A	PC	2.11		0.156		0.25	0.62	n/a	0.050
	CL1								
	CL2	2.74		0.200		0.44	0.62		0.062
	CL3								
	CL4	3.11		0.240		0.68	0.95		0.075
B	PC	2.11		0.099		0.249 0.062 0.075		n/a	0.050
	CL1								
	CL2								
	CL3	2.74		0.121					
	CL4								
C	PC	2.11		0.047		0.068 0.062		n/a	0.050
	CL1								
	CL2								
	CL3		0.087		0.124 0.075				
	CL4								

Table 3. Light-Duty Vehicle Emissions Limit Option Based on European Standards, g/km

Standard	Class	CO		NMHC		NO_x		PM	
		Gasoline	Diesel	Gasoline	Diesel	Gasoline	Diesel	Gasoline	Diesel
B	PC	1.25	0.64	0.125	0.56	0.100	0.50	n/a	0.050
	CL Class 1								
	CL Class 2	2.26	0.80	0.162	0.72	0.125	0.65		0.070
	CL Class 3	2.83	0.95	0.200	0.86	0.137	0.78		0.100
C	PC	1.00	0.50	0.10	0.30	0.08	0.25	n/a	0.050
	CL Class 1								
	CL Class 2	1.81	0.63	0.13	0.39	0.10	0.33		0.040
	CL Class 3	2.27	0.74	0.16	0.46	0.11	0.39		0.060

Table 4. Phase-In Schedule of Light-Duty Vehicles Meeting B Standards

Standard	2007	2008	2009	2010
A	75%	50%	30%	0%
B	25%	50%	70%	100%

Table 5. Phase-In Schedule of Light-Duty Vehicles Meeting C Standards

Standard	Year 1	Year 2	Year 3	Year 4
A+B	75%	50%	30%	0%
C	25%	50%	70%	100%

in Table 2 and Table 3 are those produced starting in "Year 1". The phase-in schedules for vehicles meeting B and C standards are laid out in Table 4 and Table 5, respectively.

While the standards in Table 2 and Table 3 are based on U.S. EPA limits and European limits, they are not necessarily structured the same way. For example, the NO_x and PM limits defined by the "A" standard in Table 2 are a combination of 50,000 mile and full useful life U.S. EPA Tier 1 limits. For the "B" and "C" standards, the PM limits do not change, (i.e., they stay at the Tier 1 limits) while the NO_x standards decrease to limits based on 50,000 mile U.S. EPA Tier 2 values. The NO_x limit for the "B" standard is U.S. Tier 2 Bin 10 and for the "C" standard is Bin 7 (for lighter vehicles) and Bin 9 (for heavier vehicles). With the exception of "B" standard for gasoline, LPG and natural gas, the standards in Table 3 are equivalent to Euro 3 and 4 limits. Note the different durability requirements for the standards in Table 2 (80,000 km) and Table 3 (100,000 km).

Heavy-Duty Trucks and Buses

Emissions standards for new heavy-duty diesel engines — applicable to vehicles of GVW > 3,857 kg — became first effective in model year 1993. These standards were based on U.S. 1991 and later requirements, including the U.S. EPA test methods (FTP transient test).

Table 6. Emissions Requirements for Diesel Truck and Bus Engines

Date	Requirements	
	US EPA	European
1993	US 1991	
1994	US 1994	
1998	US 1998	
2003.02	US 1998	Euro 3
2008.07†	US 2004	Euro 4

† Through 2011.06; later requirements are not specified.

Since February 2003, engines in Mexico can also meet European standards, as an alternative to the U.S. EPA requirements. The U.S. EPA or European reference standard requirements are summarized in Table 6.

No emissions standards were adopted for gasoline fueled trucks and buses.

Emissions Standards: European Union
Heavy-Duty Truck And Bus Engines

Regulatory Framework

European emissions regulations for new heavy-duty diesel engines are commonly referred to as Euro 1 ... 6. Sometimes Arabic numerals are also used (Euro 1 ... 6).

The emissions standards apply to all motor vehicles with a "technically permissible maximum laden mass" over 3,500 kg, equipped with compression ignition engines or positive ignition natural gas (NG) or LPG engines.

The regulations were originally introduced by the *Directive 88/77/EEC*, followed by a number of amendments. In 2005, the regulations were re-cast and consolidated by the *Directive 05/55/EC*. Beginning with the Euro 6 stage, the legislation became simplified, as "directives"— which need to be transposed into all of the national legislations — were replaced by "regulations" which are directly applicable. The following are some of the most important rulemaking steps in the heavy-duty engine regulations:

- Euro 1 standards were introduced in 1992, followed by the introduction of Euro 2 regulations in 1996. These standards applied to both truck engines and urban buses, the urban bus standards, however, were voluntary.
- In 1999, the EU adopted *Directive 1999/96/EC*, which introduced Euro 3 standards (2000), as well as Euro 4/5 standards (2005/2008). This rule also set voluntary, stricter emissions limits for extra low emissions vehicles, known as "enhanced environmentally friendly vehicles" or EEVs.
- In 2001, the European Commission adopted *Directive 2001/27/EC* which prohibits the use of emissions "defeat devices" and "irrational" emissions control strategies, which would be reducing the efficiency of emissions control systems when vehicles operate under normal driving conditions to levels below those determined during the emissions testing procedure.
- *Directive 2005/55/EC* adopted by the EU Parliament in 2005 introduced durability and OBD requirements, as well as re-stated the emissions limits for Euro 4 and Euro 5 which were originally published in 1999/96/EC. In a "split-level" regulatory approach, the technical requirements pertaining to durability and OBD — including provisions for

Table 1. EU Emissions Standards for HD Diesel Engines, g/kWh (smoke in m^{-1})

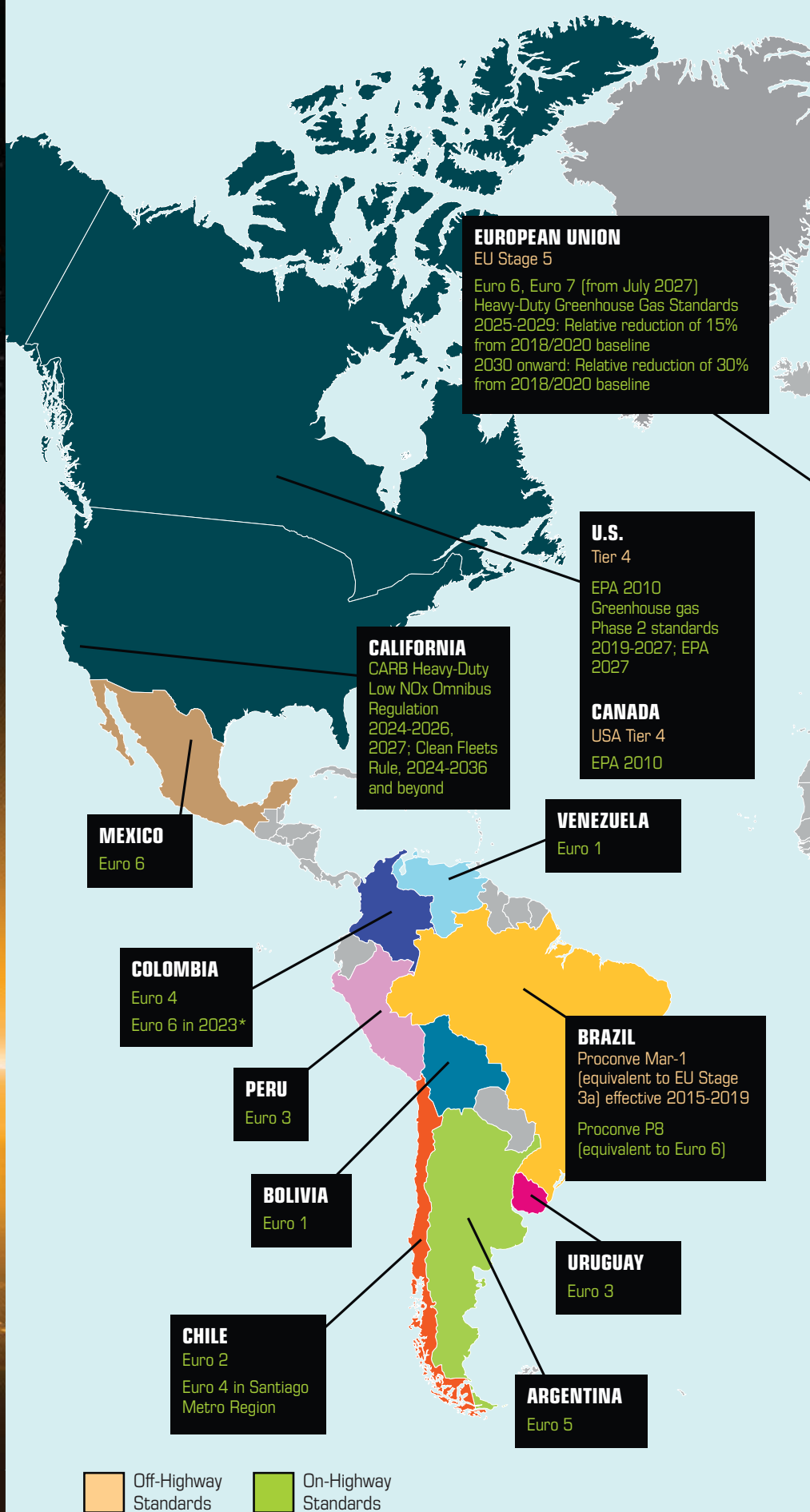
Tier	Date	Test	CO	HC	NO_x	PM	Smoke
Euro 1	1992, < 85 kW	ECE R-49	4.5	1.1	8.0	0.612	
	1992, > 85 kW		4.5	1.1	8.0	0.36	
Euro 2	1996.10		4.0	1.1	7.0	0.25	
	1998.10		4.0	1.1	7.0	0.15	
Euro 3	*1999.10, EEVs only*	*ESC & ELR*	*1.5*	*0.25*	*2.0*	*0.02*	*0.15*
	2000.10	ESC & ELR	2.1	0.66	5.0	0.10 0.13[a]	0.8
Euro 4	2005.10		1.5	0.46	3.5	0.02	0.5
Euro 5	2008.10		1.5	0.46	2.0	0.02	0.5
Euro 6	2013.01		1.5	0.13	0.4	0.01	

[a] - for engines of less than 0.75 dm^3 swept volume per cylinder and a rated power speed of more than 3000 min^{-1}

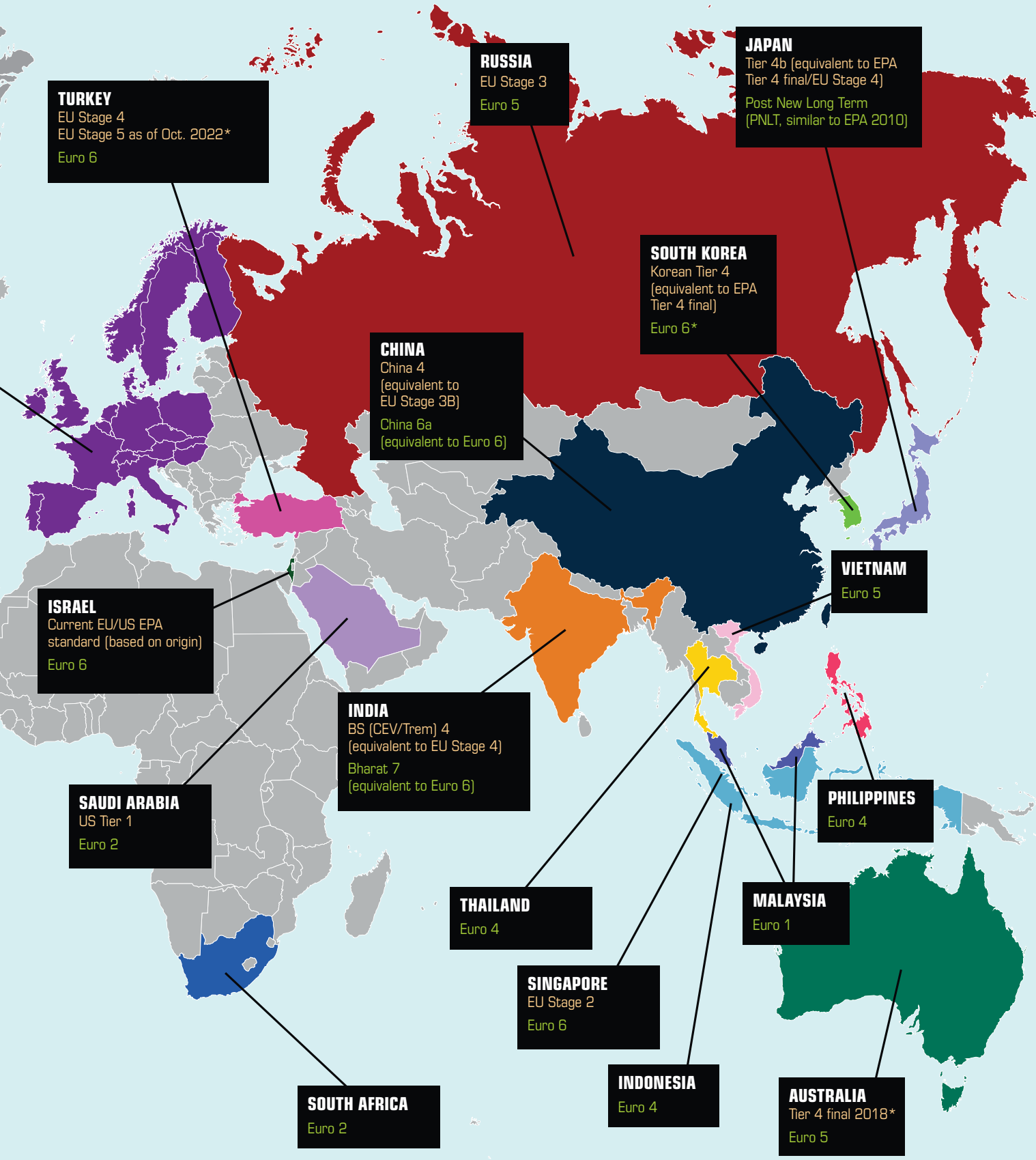
2023-24 GLOBAL DIESEL EMISSIONS REGULATIONS-AT-A-GLANCE

For more information on specific emissions levels and the various standards, visit the Emissionsguide.net at Dieselandgasturbineguide.net. For the most current global emissions information, visit DieselNet.com. Emissions information drawn from government and industry sources. Diesel Progress *is not responsible for the accuracy of the data as presented.*

** proposed or under consideration*



DIESEL PROGRESS


TURKEY
EU Stage 4
EU Stage 5 as of Oct. 2022*
Euro 6
RUSSIA
EU Stage 3
Euro 5
JAPAN
Tier 4b (equivalent to EPA Tier 4 final/EU Stage 4)
Post New Long Term (PNLT, similar to EPA 2010)
SOUTH KOREA
Korean Tier 4 (equivalent to EPA Tier 4 final)
Euro 6*
CHINA
China 4 (equivalent to EU Stage 3B)
China 6a (equivalent to Euro 6)
VIETNAM
Euro 5
ISRAEL
Current EU/US EPA standard (based on origin)
Euro 6
INDIA
BS (CEV/Trem) 4 (equivalent to EU Stage 4)
Bharat 7 (equivalent to Euro 6)
SAUDI ARABIA
US Tier 1
Euro 2
PHILIPPINES
Euro 4
THAILAND
Euro 4
MALAYSIA
Euro 1
SINGAPORE
EU Stage 2
Euro 6
INDONESIA
Euro 4
AUSTRALIA
Tier 4 final 2018*
Euro 5
SOUTH AFRICA
Euro 2

emissions systems that use consumable reagents — have been described by the Commission in *Directive 2005/78/EC*.

- Euro 6 emissions standards were introduced by *Regulation 595/2009* published on July 18, 2009 (with a Corrigenda of July 31, 2009). The new emissions limits, comparable in stringency to the U.S. 2010 standards, become effective from 2013 (new type approvals) and 2014 (all registrations). In the "split-level" approach, a number of technical details will be specified in the implementing regulation ('comitology') which should be adopted by the end of 2010.

Emissions Standards

Table 2 contains a summary of the emissions standards and their implementation dates. Dates in the tables refer to new type approvals; the dates for all type approvals are in most cases one year later (EU type approvals are valid longer than one year).

Since the Euro 3 stage (2000), the earlier steady-state engine test ECE R-49 has been replaced by two cycles: the European Stationary Cycle (ESC) and the European Transient Cycle (ETC). Smoke opacity is measured on the European Load Response (ELR) test. The following testing requirements apply:

1. Compression ignition (diesel) engines:
   - Euro 3:
     1. Conventional diesel engines: ESC/ELR test.
     2. Diesel engines with "advanced aftertreatment" (NO_x aftertreatment or DPFs) and EEVs: ESC/ELR + ETC.
   - Euro 4 and later: ESC/ELR + ETC.
2. Positive ignition gas (natural gas, LPG) engines, Euro 3 and later: ETC cycle.

Emissions standards for diesel engines that are tested on the ETC test cycle, as well as for heavy-duty gas engines, are summarized in Table 2.

Euro 6 Regulation. Additional provisions of the Euro 6 regulation include:

- An ammonia (NH_3) concentration limit of 10 ppm applies to diesel (ESC + ETC) and gas (ETC) engines.
- A particle number limit, in addition to the mass limit, is to be introduced in the implementing regulation. The number limit would prevent the possibility that the Euro 6 PM mass limit is met using technologies (such as "open filters") that would enable a high number of ultra fine particles to pass.
- The world-harmonized test cycles — WHSC and WHTC — will be used for Euro 6 testing. WHSC/WHTC based limit values will be introduced by the implementing regulation based on correlation factors with the current ESC/ETC tests.
- A maximum limit for the NO_2 component of NO_x emissions may be defined in the implementing regulation.

Emissions Durability. Effective October 2005 for new type approvals and October 2006 for all type approvals, manufacturers should demonstrate that engines comply with the emissions limit values for useful life periods which depend on the vehicle category, as shown in Table 3.

Effective October 2005 for new type approvals and October 2006 for all type approvals, type approvals also require confirmation of the correct operation of the emissions control devices during the normal life of the vehicle under normal conditions of use ("conformity of in-service vehicles properly maintained and used").

Early Introduction of Clean Engines. EU Member States are allowed to use tax incentives in order to speed up the marketing of vehicles meeting new standards ahead of the regulatory deadlines. Such incentives have to comply with the following conditions:

- They apply to all new vehicles offered for sale on the market of a Member State which comply in advance with the mandatory limit values set out by the Directive.
- They cease when the new limit values come into effect.
- For each type of vehicle they do not exceed the additional cost of the technical solutions introduced to ensure compliance with the limit values.

Euro 6 type approvals, if requested, must be granted from August 7, 2009, and incentives can be given from the same date. Euro 6 incentives can also be given for scrapping existing vehicles or retrofitting them with emissions controls in order to meet Euro 6 limits.

Early introduction of cleaner engines can be also stimulated by such financial instruments as preferential road toll rates. In Germany, road toll discounts were introduced in 2005 which stimulated early launch of Euro 5 trucks.

Table 2. Emissions Standards for Diesel and Gas Engines, ETC Test, g/kWh

Tier	Date	Test	CO	NMHC	CH_4[a]	NO_x	PM[b]
Euro 3	*1999.10, EEVs only*	*ETC*	*3.0*	*0.40*	*0.65*	*2.0*	*0.02*
	2000.10	ETC	5.45	0.78	1.6	5.0	0.16 0.21[c]
Euro 4	2005.10		4.0	0.55	1.1	3.5	0.03
Euro 5	2008.10		4.0	0.55	1.1	2.0	0.03
Euro 6	2013.01		4.0	0.16[d]	0.5	0.4	0.01

[a] - for gas engines only (Euro 3-5: NG only; Euro 6: NG + LPG)
[b] - not applicable for gas fueled engines at the Euro 3-4 stages
[c] - for engines with swept volume per cylinder < 0.75 dm^3 and rated power speed > 3000 min^{-1}
[d] - THC for diesel engines

Table 3. Emissions Durability Periods

Vehicle Category†	Period*	
	Euro 4-5	Euro 6
N1 and M2	100 000 km / 5 years	160 000 km / 5 years
N2 N3 ≤ 16 ton M3 Class 1, Class 2, Class A, and Class B ≤ 7.5 ton	200 000 km / 6 years	300 000 km / 6 years
N3 > 16 ton M3 Class 3, and Class B > 7.5 ton	500 000 km / 7 years	700 000 km / 7 years

† Mass designations (in metric tons) are "maximum technically permissible mass"
* km or year period, whichever is the sooner

Emissions Standards: European Union
Non-Road Diesel Engines

Background

The European emissions standards for new nonroad diesel engines have been structured as gradually more stringent tiers known as Stage 1-4 standards. Additionally, emissions standards have been adopted for small, gasoline fueled nonroad engines. The main regulatory steps were:

- Stage 1/2. The first European legislation to regulate emissions from nonroad (off-road) mobile equipment was promulgated on December 16, 1997 *[Directive 97/68/EC]*. The regulations for nonroad diesels were introduced in two stages: Stage 1 implemented in 1999 and Stage 2 implemented from 2001 to 2004, depending on the engine power output.

  The equipment covered by the standard included industrial drilling rigs, compressors, construction wheel loaders, bulldozers, nonroad trucks, highway excavators, forklift trucks, road maintenance equipment, snow plows, ground support equipment in airports, aerial lifts and mobile cranes. Agricultural and forestry tractors had the same emissions standards but different implementation dates *[Directive 2000/25/EC]*. Engines used in ships, railway locomotives, aircraft, and generating sets were not covered by the Stage 1/2 standards.
- On December 9, 2002, the European Parliament adopted Directive 2002/88/EC, amending the nonroad *Directive 97/68/EC* by adding emissions standards for small, gasoline fueled utility engines below 19 kW. The Directive also extended the applicability of Stage 2 standards on constant speed engines. The utility engine emissions standards are to a large degree aligned with the U.S. emissions standards for small utility engines.
- Stage 3/4. Stage 3/4 emissions standards for nonroad engines were adopted by the European Parliament on April 21, 2004 *[Directive 2004/26/EC]*, and for agricultural and forestry tractors on February 21, 2005 *[Directive 2005/13/EC]*.

  Two additional Directives were adopted in 2010: *Directive 2010/26/EU* provides further technical details on the testing and approvals of Stage 3b and Stage 4 engines, and *Directive 2010/22/EU* amends the earlier legislation applicable to agricultural and forestry tractors.

  Stage 3 standards — which are further divided into Stages 3a and 3b — are phased-in from 2006 to 2013, Stage 4 enter into force in 2014. The Stage 3/4 standards, in addition to the engine categories regulated at Stage 1/2, also cover railroad locomotive engines and marine engines used for inland waterway vessels. Stage 3/4 legislation applies only to new vehicles and equipment; replacement engines to be used in machinery already in use (except for railcar, locomotive and inland waterway vessel propulsion engines) should comply with the limit values that the engine to be replaced had to meet when originally placed on the market.

EU nonroad emissions standards usually specify two sets of implementation dates:

- *Type approval* dates, after which all newly type approved models must meet the standard, and
- *Market placement* (or first registration) dates, after which all new engines placed on the market must meet the standard.

The dates listed in the following tables are the market placement dates. In most cases, new type approval dates are one year before the respective market placement dates.

Regulatory authorities in the EU, U.S.A., and Japan have been under pressure from engine and equipment manufacturers to harmonize worldwide emissions standards, in order to streamline engine development and emissions type approval/certification for different markets. Stage 1/2 limits were in part harmonized with U.S. regulations. Stage 3/4 limits are harmonized with the U.S. Tier 3/4 standards.

Stage 1/2 Standards

Stage 1 and Stage 2 emissions shall not exceed the amount shown in Table 1. The Stage 1 emissions are engine-out limits and shall be achieved before any exhaust aftertreatment device.

A sell-off period of up to two years is allowed for engines produced prior to the respective market placement date. Since the sell-off period — between zero and two years — is

Table 1. EU Stage 1/2 Emissions Standards for Nonroad Diesel Engines

Cat.	Net Power	Date*	CO	HC	NO_x	PM
	kW		g/kWh			
Stage 1						
A	130 ≤ P ≤ 560	1999.01	5.0	1.3	9.2	0.54
B	75 ≤ P < 130	1999.01	5.0	1.3	9.2	0.70
C	37 ≤ P < 75	1999.04	6.5	1.3	9.2	0.85
Stage 2						
E	130 ≤ P ≤ 560	2002.01	3.5	1.0	6.0	0.2
F	75 ≤ P < 130	2003.01	5.0	1.0	6.0	0.3
G	37 ≤ P < 75	2004.01	5.0	1.3	7.0	0.4
D	18 ≤ P < 37	2001.01	5.5	1.5	8.0	0.8

* Stage 2 also applies to constant speed engines effective 2007.01

Table 2. Stage 3a Standards for Nonroad Engines

Cat.	Net Power	Date†	CO	NO_x+HC	PM
	kW		g/kWh		
H	130 ≤ P ≤ 560	2006.01	3.5	4.0	0.2
I	75 ≤ P < 130	2007.01	5.0	4.0	0.3
J	37 ≤ P < 75	2008.01	5.0	4.7	0.4
K	19 ≤ P < 37	2007.01	5.5	7.5	0.6

† dates for constant speed engines are: 2011.01 for categories H, I and K; 2012.01 for category J.

determined by each Member State, the exact timeframe of the regulations may be different in different countries.

Emissions are measured on the ISO 8178 C1 8-mode cycle and expressed in g/kWh. Stage 1/2 engines are tested using fuel of 0.1-0.2% (wt.) sulfur content.

Stage 3/4 Standards

Stage 3 standards — which are further divided into two sub-stages: Stage 3a and Stage 3b — and Stage 4 standards for nonroad diesel engines are listed in Table 2, Table 3, and Table 4, respectively. These limit values apply to all nonroad diesel engines of indicated power range for use in applications other than propulsion of locomotives, railcars and inland waterway vessels.

The implementation dates in the following tables (Table 2 through Table 7) refer to the market placement dates. For all engine categories, a sell-off period of two years is allowed for engines produced prior to the respective *market placement* date. The dates for *new type approvals* are, with some exceptions, one year ahead of the respective market placement date.

Stage 3/4 standards also include a limit for ammonia emissions, which must not exceed a mean of 25 ppm over the test cycle.

Stage 3b standards introduce PM limit of 0.025 g/kWh, representing about 90% emissions reduction relative to Stage 2. To meet this limit value, it is anticipated that engines will have to be equipped with particulate filters. Stage 4 also introduces a very stringent NO_x limit of 0.4 g/kWh, which is expected to require NO_x aftertreatment.

To represent emissions during real conditions, a new transient test procedure — the Non-Road Transient Cycle (NRTC) — was developed in cooperation with the U.S. EPA. The NRTC is run twice — with a cold and a hot start. The final emissions results are weighted averages of 10% for the cold start and 90% for the hot start run. The new test will be used in parallel with the prior steady-state schedule, ISO 8178 C1, referred to as the Nonroad Steady Cycle (NRSC).

- The NRSC (steady-state) shall be used for stages 1, 2 and 3a, as well as for constant speed engines at all stages. The NRTC (transient) can be used for Stage 3a testing by the choice of the manufacturer.
- Both NRSC and NRTC cycles shall be used for Stage 3b and 4 testing (gaseous and particulate pollutants).

Inland Water Vessels

Unlike the Stage 1/2 legislation, the Stage 3a standards also cover engines used in inland waterway vessels, Table 5. Engines are divided into categories based on the displacement (swept volume) per cylinder and net power output. The engine categories and the standards are harmonized with the U.S. standards for marine engines. There are no Stage 3b or Stage 4 standards for waterway vessels.

Table 3. Stage 3b Standards for Nonroad Engines

Cat.	Net Power	Date	CO	HC	NO_x	PM
	kW		g/kWh			
L	130 ≤ P ≤ 560	2011.01	3.5	0.19	2.0	0.025
M	75 ≤ P < 130	2012.01	5.0	0.19	3.3	0.025
N	56 ≤ P < 75	2012.01	5.0	0.19	3.3	0.025
P	37 ≤ P < 56	2013.01	5.0	4.7†		0.025

† NO_x+HC

Table 4. Stage 4 Standards for Nonroad Engines

Cat.	Net Power	Date	CO	HC	NO_x	PM
	kW		g/kWh			
Q	130 ≤ P ≤ 560	2014.01	3.5	0.19	0.4	0.025
R	56 ≤ P < 130	2014.10	5.0	0.19	0.4	0.025

Table 5. Stage 3a Standards for Inland Waterway Vessels

Cat.	Displacement (D)	Date	CO	NO_x+HC	PM
	dm^3 per cylinder		g/kWh		
V1:1	D ≤ 0.9, P > 37 kW	2007.01	5.0	7.5	0.40
V1:2	0.9 < D ≤ 1.2		5.0	7.2	0.30
V1:3	1.2 < D ≤ 2.5		5.0	7.2	0.20
V1:4	2.5 < D ≤ 5	2009.01	5.0	7.2	0.20
V2:1	5 < D ≤ 15		5.0	7.8	0.27
V2:2	15 < D ≤ 20, P ≤ 3300 kW		5.0	8.7	0.50
V2:3	15 < D ≤ 20, P > 3300 kW		5.0	9.8	0.50
V2:4	20 < D ≤ 25		5.0	9.8	0.50
V2:5	25 < D ≤ 30		5.0	11.0	0.50

Table 6. Stage 3a Standards for Rail Traction Engines

Cat.	Net Power	Date	CO	HC	HC+NO_x	NO_x	PM
	kW		g/kWh				
RC A	130 < P	2006.01	3.5	-	4.0	-	0.2
RL A	130 ≤ P ≤ 560	2007.01	3.5	-	4.0	-	0.2
RH A	P > 560	2009.01	3.5	0.5*	-	6.0*	0.2

* HC = 0.4 g/kWh and NO_x = 7.4 g/kWh for engines of P > 2000 kW and D > 5 liters/cylinder

Table 7. Stage 3b Standards for Rail Traction Engines

Cat.	Net Power	Date	CO	HC	HC+NO_x	NO_x	PM
	kW		g/kWh				
RC B	130 < P	2012.01	3.5	0.19	-	2.0	0.025
R B	130 < P	2012.01	3.5	-	4.0	-	0.025

Rail Traction Engines

Stage 3a and 3b standards have been adopted for engines above 130 kW used for the propulsion of railroad locomotives (categories R, RL, RH) and railcars (RC), Table 6 and Table 7.

Stage 5 Standards

Stage 5 emissions limits for engines in nonroad mobile machinery (category NRE) are shown in Table 8. These standards are applicable to diesel (CI) engines from 0 to 56 kW and to all types of engines above 56 kW. Engines above 560 kW used in generator sets (category NRG) must meet standards shown in Table 9.

Stage 5 regulations introduce a new limit for particle number emissions. The PN limit is designed to ensure that a highly efficient particle control technology — such as wall-flow particulate filters — be used on all affected engine categories. The Stage 5 regulation would also tighten the mass-based PM limit for several engine categories, from 0.025 g/kWh to 0.015 g/kWh.

HC Limits for Gas Engines. For engine categories where an A factor is defined, the HC limit for fully and partially gaseous fueled engines indicated in the table is replaced by the one calculated from the formula:

HC = 0.19 + (1.5 Ч A Ч GER)

where GER is the average gas energy ratio over the appropriate cycle. Where both a steady-state and transient test cycle applies, the GER shall be determined from the hot-start transient test cycle. If the calculated limit for HC exceeds the value of 0.19 + A, the limit for HC should be set to 0.19 + A.

In 2020, due to the COVID-19 pandemic, The European Parliament agreed to delay some Stage V transition deadlines by one year.

Table 8. Stage 5 Emissions Standards for Nonroad Engines

Ca.	Ign.	Net Power	Date	CO	HC	NO_x	PM	PN
		kW		g/kWh				1/kWh
NRE-v/c-1	CI	P < 8	2019	8.00	7.50[a,c]		0.40[b]	-
NRE-v/c-2	CI	8 ≤ P < 19	2019	6.60	7.50[a,c]		0.4	-
NRE-v/c-3	CI	19 ≤ P < 37	2019	5.00	4.70[a,c]		0.015	1×10^{12}
NRE-v/c-4	CI	37 ≤ P < 56	2019	5.00	4.70[a,c]		0.015	1×10^{12}
NRE-v/c-5	All	56 ≤ P < 130	2020	5.00	0.19[c]	0.4	0.015	1×10^{12}
NRE-v/c-6	All	130 ≤ P ≤ 560	2019	3.50	0.19[c]	0.4	0.015	1×10^{12}
NRE-v/c-7	All	P > 560	2019	3.50	0.19[d]	3.5	0.045	-

[a] $HC+NO_x$

[b] 0.60 for hand-startable, air-cooled direct injection engines

[c] A = 1.10 for gas engines

[d] A = 6.00 for gas engines

Table 9. Stage 5 Emissions Standards for Generator Set Engines Above 560 kW

Cat.	Ign.	Net Power	Date	CO	HC	NO_x	PM	PN
		kW		g/kWh				1/kWh
NRG-v/c-1	All	P > 560	2019	3.50	0.19[a]	0.67	0.035	-

[a] A = 6.00 for gas engines

Emissions Standards: Germany
Stationary Engines — TA Luft

Background

Emissions from stationary engines in Germany are controlled by the TA Luft regulation introduced in 1986 and later by the 44th BImSchV introduced in 2019.

The *Technische Anleitung zur Reinhaltung der Luft*, in short referred to as *TA Luft*, is a regulation covering air quality requirements—including emissions, ambient exposures and their control methods—applicable to a number of pollutants from a range of stationary sources. The TA Luft regulation, based on the "Federal Air Pollution Control Act" ("*Bundes-Immissionsschutzgesetz*"), was introduced and enforced by the German Environment Ministry BMU (*Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit*).

Among other sources, the TA Luft regulation covers emissions of pollutants from stationary internal combustion engines. The TA Luft requirements have been widely applied to stationary gas and diesel engines not only in Germany, but also in several other European markets.

The most recent revision of the TA Luft regulation, known as *TA Luft 2002*, was adopted on July 24, 2002. Compared to the previous requirements, TA Luft 2002 introduced more stringent emission limits for particulate matter, sulfur oxides, and nitrogen oxides from internal combustion engines.

On June 20, 2019, updated emissions standards previously covered by TA Luft 2002 entered into force with the publication of 44. Verordnung zur Durchfьhrung des Bundes-Immissionsschutzgesetzes (Verordnung ьber mittelgroЯe Feuerungs-, Gasturbinen- und Verbrennungsmotoranlagen)—

44th BImSchV. While this incorporated EU Directive 2015/2193 (Medium Combustion Plant Directive, MCPD) into German law, 44th BImSchV included more stringent emission limits as well as limits on pollutants such as CO, NH3 and formaldehyde not included in the EU MCPD. Due to delays in finalization of the legislation, some of the 44th BImSchV requirements apply retroactively. The 44th BImSchV requirements apply to new plants while TA Luft 2002 requirements continue to apply to existing sources until the end of 2024.

Engine Emission Standards

TA Luft 2002 and 44th BImSchV emission limits are given in the following tables [4701][4700]. Different limits exist for compression ignition (CI) and for spark ignited (SI) engines. Gas fueled CI engines (dual fuel with diesel pilot ignition) often enjoy more relaxed limits, especially if fueled by biogas (such as sewage or landfill gas). It should be noted that the concentration values in the tables are at 5% O2 while those for the EU's MCPD are at 15% O2.

Under the 44th BImSCHv, existing installations are those that: (1) were put into service before December 20, 2018 or (2) were approved under the Federal Emission Control Act (Bundes-Immissionsschutzgesetz) and put into service by December 20, 2018. Installations to which the above definition does not apply are regarded as new installations. The 44th BImSchV limits apply to new installations according to the above dates and to exiting installations starting January 2025 unless otherwise noted.

The following apply to engines subject to the 44th BImSchV and used exclusively for emergency operation or operated no more than 300 h/year (peak shaving operation) [4700]:

- For new liquid fueled engines, a DPF is mandatory with particulate emissions limited to 5 mg/m3 unless particulate emissions are less than 50 mg/m3.
- For existing liquid fueled engines, a DPF is not required but particulate emissions must be less than 80 mg/m3.
- CO emissions are not controlled but state of the art measures must be used to limit emissions.
- Only for engines used exclusively only for emergency operation (not engines used < 300 h/y), the formaldehyde limit is 60 mg/m3.
- NOx emissions are not controlled for engines using liquid fuels, biogas, natural gas and LPG but state of the art measures must be used to limit emissions.
- NOx emissions from biogas engines operated < 300 h/y (not those used exclusively for emergency operation), are limited to 0.50 g/m3.
- SOx and total carbon emissions are not limited.

Consistent with the EU's MCPD, the 44th BImSchV has an

Table 1 TA Luft 2002 and 44th BImSchV emission limits for new and existing gaseous fueled engines
TAL = TA Luft 2002; BIm = 44th BImSchV; Values expressed as concentration at 5% O_2

Gaseous Fuel	Engine Type		Power		CO[e]		NOx[e]		SOx[a,e]		HCHO		TD[a]		TC[e]		NH_3[d]	
			MW_{th}		g/Nm³		g/Nm³		mg/Nm³		mg/Nm³		mg/Nm³		mg/Nm³		mg/Nm³	
	TAL	BIm	TAL	BIm	TAL	BIm	TAL	BIm	TAL	BIm	TAL	BIm[f]	TAL	BIm	TAL	BIm	TAL	BIm
Natural gas	Lean burn	-		-	0.3	0.25	0.5	New: 0.25 0.1 from 2029 Existing: 0.1 from 2029	9	9	60	New: 30[b] 20 from 2020 Existing: 30[b,c]				New & existing: 1.3 from 2025		30
	Other						0.25									New & existing, λ=1: 0.3 from 2025		
Mine gas	Lean burn				0.65	0.5	0.5	0.5	31	31	60			9		New & existing: 1.3 from 2025		30
	Other						0.25											
Biogas	Pilot injection	-	<3	-	2	0.5	1	New: 0.50[g] 0.1 from 2023 Existing: 0.1 from 2029	310	89	40					New: 1.3 from 2023 Existing: 0.3 from 2029		30
			≥3		0.65		0.5				40							
	Spark ignition		<3		1		0.5				60							
			≥3		0.65		0.5				60							
Sewage gas	Pilot injection	-	<3	-	2	0.5	1	0.5	310	89	60					New & existing: 1.3 from 2025		30
			≥3		0.65		0.5				60							
	Spark ignition		<3		1		0.5				60							
			≥3		0.65		0.25				60							
Landfill gas	Lean burn	-		-	0.65	0.65	0.5		310	New: 31 Existing: 31; 310 for P<1 MW_{th}	60	New: 60[b] 40 from 2025 Existing: 40		9				30
	Other						0.25				60							

[a] - these limit values are specified in the 44th BImSchV with 3% reference oxygen and are converted to 5% in this table
[b] - applies to spark-ignition or lean-burn engines; a limit value of 5 mg/m³ applies to other engines
[c] - if formaldehyde emissions of up to 40 mg/m³ were measured during the last emission measurement before 05.12.2016, the limit values must be complied with from 05.02.2019
[d] - for engines using selective catalytic or selective non-catalytic reduction
[e] - limits do not apply to emergency engines or engines used for peak shaving for less than 300 h/y
[f] - for emergency only engines, a limit of 60 mg/m³ applies
[g] - limit applies to biogas engines operating < 300 h/y

emission monitoring requirement. In most cases, this requires measurements once a year or once every 3 years depending on the fuel used and the particular emission component. However, NOx and NH3 emissions must be continuously monitored. Monitoring of NH3 is not required if an ammonia slip catalyst (ASC) is used.

All of the above engine emission limits are expressed as dry gas concentrations at STP conditions, that have been corrected to a 5% oxygen content using the following formula:

EB = EM Ч (21 - OB)/(21 - OM)

where:

EB - mass concentration of pollutant corrected for the reference O2 concentration,

EM - measured mass concentration of pollutant,

OB - reference O2 concentration, vol. %,

OM - measured O2 concentration, vol. %.

Table 2 TA Luft 2002 and 44th BImSchV emission limits for new and existing liquid fueled engines
TAL = TA Luft 2002; BIm = 44th BImSchV; Values expressed as concentration at 5% O_2

Liquid Fuel	Power		CO[b]		NOx[b]		HCHO		TD		NH_3[d]	
	MW_{th}		g/Nm^3		g/Nm^3		mg/Nm^3		mg/Nm^3		mg/Nm^3	
	TAL	BIm	TAL	BIm	TAL	BIm	TAL	BIm	TAL	BIm	TAL	BIm
Diesel, light fuel oil, ethanol, methanol, etc.	<3	-	0.3	0.3	1	0.1	60	20/60[c]	20/80[a]	20/50[a]	-	30
	≥3	-			0.5							

[a] - higher value applies to engines used for emergency operation only or peak shaving operation for less than 300 h/y
[b] - limits do not apply to emergency engines or engines used for peak shaving for less than 300 h/y
[c] - higher value applies to engines used for emergency operation only
[d] - for engines using selective catalytic or selective non-catalytic reduction

The TA Luft 2002 limits for diesel engines are rather strict. The NOx limit of 0.5 g/Nm3 typically requires the use of SCR catalysts on large diesel engines.

Sulfur Regulations

According to TA Luft 2002, a liquid fired stationary engine is to burn a light fuel oil according to DIN 51603 Part 1 (March 1998) containing max. 0.2% (wt.) sulfur and with a lower heating value > 42.6 MJ/kg, or to reach an equivalent SO2 limit by installing a flue gas desulfurization unit. The equivalent SO2 limit resulting from the above fuel requirement is about 110 mg/Nm3 @ 15% O2 = approx. 300 mg/Nm3 @ 5% O2. The

TA Luft 2002 sulfur limits no longer apply to either new or existing installations.

Only the following liquid petroleum fuels may be used in stationary diesel engines: heating oils according to DIN 51603 Part 1 (petroleum fuels) or Part 6 (petroleum fuels/renewable fuel blends), March 2017 edition, with a maximum sulfur content of 0.1% mass or diesel fuels according to EN 590 with a maximum sulfur content of 10 mg/kg. Requirements for gaseous fuels are also covered by the regulations [4701][4702].

Emissions Standards: Russia
All Vehicles Categories

Light-Duty Vehicles

Russia adopts European emissions standards, which apply to both manufactured and imported vehicles. Implementation dates are listed in Table 1.

Heavy-Duty Engines

Heavy-duty highway engines are required to meet European emissions standards. The implementation schedule is outlined in Table 2.

Nonroad Engines

Russia adopts European emissions standards for mobile nonroad engines. Current requirements are shown in Table 3.

Fuel Quality

According to the "Technical rules on the Requirements for Automobile and Aviation Fuel, Diesel and Ship Fuel, Fuel for Reactive Engines and Heating Oil" (with amendments delaying the requirements), low sulfur diesel fuels are phased-in based on the following schedule:

- Euro 2 fuel is required from December 31, 2012.
- Euro 3 fuel (equivalent to EN 590:1999 with max 350 ppm sulfur) is required from December 31, 2014.
- Euro 4 fuel (equivalent to EN 590:2004 with max 50 ppm sulfur) is required from December 31, 2015.
- The state may order lower standard fuel for defense purposes. Fuels from the state reserve can be sold for five more years.

Table 1. Emissions Requirements for Light-Duty Vehicles

Date	Requirement
1999.01	Euro 1 (ECE R83.02)
2006.04	Euro 2 (ECE R83.03)
2008.01	Euro 3 (ECE R83.05 Stage 3)
2010.01	Euro 4 (ECE R83.05 Stage 4)
2014.01	Euro 5

Table 2. Emissions Requirements for Heavy-Duty Engines

Date	Requirement
1999.01	Euro 1 / Ecological Class 1 (ECE R49.02)
2006.01	Euro 2 / Ecological Class 2 (ECE R49.02 Stage 2)
2008.01	Euro 3 / Ecological Class 3 (ECE R49.04-A)
2010.01	Euro 4 / Ecological Class 4 (ECE R49.04-B1)
2014.01	Euro 5 / Ecological Class 5 (ECE R49.04-B2 C)

Table 3. Emissions Requirements for Mobile Nonroad Engines

Standard	EU Equivalent
GOST R41 96-99	Stage 1 (Dir 77/537/EC and Dir 97/68/EC, ECE R24 test)

Emissions Standards: Turkey
Non-Road Diesel Engines

Emissions standards for non-road engines are adopted by the Turkish Ministry of Industry and Trade. The standards are fully harmonized with the EU regulations, but implementation dates are different, as outlined in the following table. All the implementation dates are market placement dates.

Table 1. Turkish Emissions Standards for Nonroad Diesel Engines

Stage	Power (P), kW	Date
Mobile Nonroad Engines		
Stage 1 (Phase 1)	37 ≤ P ≤ 560	2003.04
Stage 2 (Phase 2)	18 ≤ P ≤ 560	2007
Stage 3a (Phase 3a)	19 ≤ P ≤ 560	2010
Stage 3b (Phase 3b)	130 ≤ P ≤ 560	2011
	56 ≤ P < 130	2012
	37 ≤ P < 56	2013
Stage 4 (Phase 4)	130 ≤ P ≤ 560	2014
	56 ≤ P < 130	2014.10
Inland Waterway Vessels		
Stage 3a (Phase 3a)	37 ≤ P	2010
Rail Engines		
Stage 3a (Phase 3a)	130 ≤ P	2010
Stage 3b (Phase 3b)	130 ≤ P	2012

Emissions Standards: Japan
New Engines And Vehicles

Regulatory Authorities

Japanese emissions standards for engines and vehicles and fuel efficiency targets are jointly developed by a number of government agencies, including:

- Ministry of the Environment (MOE).
- Ministry of Land, Infrastructure and Transport (MLIT).
- Ministry of Economy, Trade and Industry (METI).

In developing engine emissions standards and policies, the Ministry of the Environment relies on recommendations of its advisory body known as the Central Environment Council (CEC).

Engine and vehicle emissions standards are developed under the authority of the "Air Pollution Control Law", while fuel efficiency targets are adopted under the "Law Concerning the Rational Use of Energy" (Energy Conservation Law).

On-Road Engines and Vehicles

Japan introduced fist new engine emissions standards for on-road vehicles in the late 1980's. The Japanese standards, however, remained relaxed through the 1990's. In 2003 the MOE finalized very stringent 2005 emissions standards for both light and heavy vehicles. At the time they came to power, the 2005 heavy-duty emissions standards (NO_x = 2 g/kWh, PM = 0.027 g/kWh) were the most stringent diesel emissions regulation in the world. Effective 2009, these limits are further tightened (NO_x = 0.7 g/kWh, PM = 0.01 g/kWh) to a level in-between the U.S. 2010 and Euro 5 requirements.

Most categories of onroad vehicles, including passenger cars and heavy-duty trucks and buses, are also subject to mandatory fuel efficiency targets. The Japanese fuel efficiency requirements for heavy trucks and buses were the world's first fuel economy regulation for heavy vehicles.

Off-Road Engines

First emissions regulations for new off-road engines and vehicles, known as MOT/MOC standards, were adopted by the former Ministry of Transport (MOT) and Ministry of Construction (MOC).

After the reorganization of Japanese government in 2001, off-road engine emissions fell under the jurisdiction of MOE and MLIT, the same ministries that are responsible for regulating emissions from highway engines. First MOE/MLIT standards for off-road engines were promulgated in 2005.

Marine Engines

In 2003, the MLIT proposed emissions regulations for new and existing ocean-going ships. The regulations, aligned with the 1997 MARPOL 73/78 Annex 6 limits (by International Maritime Organization), require cutting NO_x emissions by about 10% from previous non-regulated levels.

Emissions Standards: Japan
In-Use Vehicle Regulations

Automotive NO_x and PM Law

In 1992, to cope with NO_x pollution from existing vehicle fleets the MOE adopted the Motor Vehicle NO_x Law, which aimed at the elimination of the oldest, most polluting vehicles from in-use fleets in certain geographical areas. In 2001, the regulation has been amended to also include PM emissions requirements, and renamed as Automotive NO_x and PM Law.

Tokyo Retrofit Program

The Tokyo government and several neighboring prefectures adopted diesel emissions regulations, which require retrofitting of older in-use diesel vehicles with PM control devices (catalytic converters or particulate filters), or else replacing them with newer, cleaner models. The Tokyo retrofit requirements became effective in October 2003.

Emissions Standards: Japan
On-Road Vehicles And Engines

Emissions standards for new diesel fueled commercial vehicles are summarized in Table 1 for light vehicles (chassis dynamometer test) and in Table 2 for heavy vehicles (engine dynamometer test).

Light-duty trucks and buses are tested on the 10-15 mode cycle, which will be fully replaced by the JC08 mode test by 2011. The test procedure for heavy-duty engines is the JE05 mode cycle (hot start version). Before 2005, heavy-duty engines were tested over the 13-mode cycle and the 6-mode cycle. Vehicles and engines are tested using 50 ppm S fuel for the 2005 standards.

Table 1. Diesel Emissions Standards for Light Commercial Vehicles GVW ≤ 3500 kg (≤ 2500 kg before 2005)

Vehicle Weight*	Date	Test	Unit	CO	HC	NO_x	PM
				mean (max)	mean (max)	mean (max)	mean (max)
≤ 1700 kg	1988	10-15 mode	g/km	2.1 (2.7)	0.40 (0.62)	0.90 (1.26)	
	1993			2.1 (2.7)	0.40 (0.62)	0.60 (0.84)	0.20 (0.34)
	1997			2.1 (2.7)	0.40 (0.62)	0.40 (0.55)	0.08 (0.14)
	2002			0.63	0.12	0.28	0.052
	2005[b]	JC08[c]		0.63	0.024[d]	0.14	0.013
	2009			0.63	0.024[d]	0.08	0.005
> 1700 kg	1988	6 mode	ppm	790 (980)	510 (670)	DI: 380 (500) IDI: 260 (350)	
	1993	10-15 mode	g/km	2.1 (2.7)	0.40 (0.62)	1.30 (1.82)	0.25 (0.43)
	1997[a]			2.1 (2.7)	0.40 (0.62)	0.70 (0.97)	0.09 (0.18)
	2003			0.63	0.12	0.49	0.06
	2005[b]	JC08[c]		0.63	0.024[d]	0.25	0.015
	2009[e]			0.63	0.024[d]	0.15	0.007

* - gross vehicle weight (GVW)
[a] - 1997: manual transmission vehicles; 1998: automatic transmission vehicles
[b] - full implementation by the end of 2005
[c] - full phase-in by 2011
[d] - non-methane hydrocarbons
[e] - 2009.10 for new domestic models; 2010.09 for existing models & imports

Table 2. Diesel Emissions Standards for Heavy Commercial VehiclesGVW > 3500 kg (> 2500 kg before 2005)

Date	Test	Unit	CO	HC	NO_x	PM
			mean (max)	mean (max)	mean (max)	mean (max)
1988/89	6 mode	ppm	790 (980)	510 (670)	DI: 400 (520) IDI: 260 (350)	
1994	13 mode	g/kWh	7.40 (9.20)	2.90 (3.80)	DI: 6.00 (7.80) IDI: 5.00 (6.80)	0.70 (0.96)
1997[a]			7.40 (9.20)	2.90 (3.80)	4.50 (5.80)	0.25 (0.49)
2003[b]			2.22	0.87	3.38	0.18
2005[c]	JE05		2.22	0.17[d]	2.0	0.027
2009			2.22	0.17[d]	0.7	0.01

[a] - 1997: GVW ≤ 3500 kg; 1998: 3500 < GVW ≤ 12000 kg; 1999: GVW > 12000 kg
[b] - 2003: GVW ≤ 12000 kg; 2004: GVW > 12000 kg
[c] - full implementation by the end of 2005
[d] - non-methane hydrocarbons

Emissions Standards: Japan
Off-Road Engines

Regulatory Background

After the reorganization of Japanese government in 2001, off-road engine emissions standards became the responsibility of MOE and MLIT. The former MOT/MOC emissions regulations were replaced by three groups of emissions standards, applicable to the following categories of equipment:

1. *Special Motor Vehicles* — self-propelled nonroad vehicles and machinery that are registered for operation on public roads (fitted with license plates).
2. *Nonroad Motor Vehicles* — self-propelled and non-registered nonroad vehicles and machinery.
3. *Portable And Transportable Equipment: Recognition System* — recognition of low emissions engines for designation of low emissions construction machinery.

Special/Nonroad Motor Vehicles

These standards apply to nonroad vehicles rated between 19-560 kW with *(Special Motor Vehicles)* or without *(Nonroad Motor Vehicles)* licence plates. The emissions limits for the two vehicle categories are the same, but they are introduced by separate regulatory acts. On June 28, 2005, the MOE promulgated a new set of standards for Special Vehicles, superseding former MOT standards. On March 28, 2006, the same standards were promulgated for Nonroad Vehicles, superseding former MOC standards.

The standards are summarized in Table 1 for compression ignition engines, and in Table 2 for spark ignited engines. Emissions are measured according to JIS B 8001-1 (Japanese version of ISO 8178) 8-mode test for diesel, 7-mode test for SI. Smoke is measured according to JCMAS T-004.

These standards, although similar in stringency to the U.S. Tier 3 (2006-2008) and the EU Stage 3a (2005-2007), are not harmonized with U.S. and EU regulations. The standards do not require the use of exhaust aftertreatment devices, such as diesel particulate filters. The MOE's Central Environmental Council indicated it will consider adopting "aftertreatment-forcing" standards with implementation dates around 2010.

Table 1. Emissions Standards for Diesel Special/Nonroad Vehicles, g/kWh

Power (P)	CO	HC	NO_x	PM	Smoke	Date	
						New Models	All Models†
kW	g/kWh				%		
19 ≤ P < 37	5.0	1.0	6.0	0.4	40	2007.10	2008.09
37 ≤ P < 56	5.0	0.7	4.0	0.3	35	2008.10	2009.09
56 ≤ P < 75	5.0	0.7	4.0	0.25	30	2008.10	2010.09
75 ≤ P < 130	5.0	0.4	3.6	0.2	25	2007.10	2008.09
130 ≤ P < 560	3.5	0.4	3.6	0.17	25	2006.10	2008.09

† Applies to continuously produced nonroad vehicles (but not special vehicles) and imported special/nonroad vehicles.

Table 2. Emissions Standards for Spark Ignited Special/Nonroad Vehicles, g/kWh

Power (P)	7-mode			Idle		Date	
	CO	HC	NO_x	CO	HC	New Models	All Models†
kW	g/kWh			%	ppm		
19 ≤ P < 560	20.0	0.60	0.60	1	500	2007.10	2008.09

† Applies to continuously produced nonroad vehicles (but not special vehicles) and imported special/nonroad vehicles.

Portable/Transportable Equipment (Recognition System)

Under the recognition system regulations that became effective on March 17, 2006, manufacturers may apply for their engines to be recognized as a *low emissions engine* for use in designated *low emissions construction machinery*. The recognition system applies to portable and transportable (i.e., non-self-propelled) equipment, which is not emissions regulated under the Special/Nonroad Motor Vehicle regulations.

The emissions standards are listed in Table 3. Emissions are measured over the JIS B 8001-1 (ISO 8178) 8-mode test. For generator application, the rated speed is for 60 Hz and the intermediate speed is for 50 Hz.

Table 3. Emissions Limits — Recognition System, g/kWh

Power (P)	CO	HC	NO_x	PM	Smoke
kW	g/kWh				%
8 ≤ P < 19	5.0	7.5*		0.4	40
19 ≤ P < 37	5.0	1.0	6.0	0.4	40
37 ≤ P < 56	5.0	0.7	4.0	0.3	35
56 ≤ P < 75	5.0	0.7	4.0	0.25	30
75 ≤ P < 130	5.0	0.4	3.6	0.2	25
130 ≤ P < 560	3.5	0.4	3.6	0.17	25

* NO_x + HC

Emissions Standards: Japan
Fuel Economy

Heavy-Duty Vehicles: 2015 Targets

The fuel economy standards for heavy vehicles — effective from 2015 — apply to diesel fueled, type-approved commercial vehicles with GVW > 3.5 t, including trucks and buses designed to carry 11 or more passengers. The standards are also applicable to non-type-approved diesel vehicles that are equipped

with CO or other emissions control devices. Fuel economy from heavy vehicles fueled by gasoline, LPG or other alternative fuels is not regulated.

When the targets are fully met, the fleet average fuel economy is estimated at:

- For trucks: 7.09 km/L (369.6 g CO_2/km), a 12.2% increase over 2002 performance of 6.32 km/L (414.6 g CO_2/km).
- For buses: 6.30 km/L (416.0 g CO_2/km), a 12.1% increase over 2002 performance of 5.62 km/L (466.3 g CO_2/km).

Table 1. 2015 Fuel Efficiency Targets for Heavy-Duty Transit Buses

Category	GVW, t	FE Target, km/L
1	6 < GVW ≤ 8	6.97
2	8 < GVW ≤ 10	6.30
3	10 < GVW ≤ 12	5.77
4	12 < GVW ≤ 14	5.14
5	14 < GVW	4.23

Table 2. 2015 Fuel Efficiency Targets for Heavy-Duty General (Non-Transit) Buses

Category	GVW, t	FE Target, km/L
1	3.5 < GVW ≤ 6	9.04
2	6 < GVW ≤ 8	6.52
3	8 < GVW ≤ 10	6.37
4	10 < GVW ≤ 12	5.70
5	12 < GVW ≤ 14	5.21
6	14 < GVW ≤ 16	4.06
7	16 < GVW	3.57

The standards for heavy vehicles are summarized in the following tables.

Testing. A computer simulation procedure has been developed that allows to calculate fuel efficiency (in km/L) of heavy-duty trucks and buses based on engine dynamometer testing. The engine testing is performed over the urban JE05 test and over an interurban transient test (speed: 80 km/h, load factor: 50%). A number of vehicle factors, such as vehicle mass, payload, tire size, gear ratios and efficiency, and others are accounted for in the calculation.

Table 3. 2015 Fuel Efficiency Targets for Heavy-Duty Trucks (Excluding Tractors)

Category	GVW, t	Max Load (L), t	FE Target, km/L
1	3.5 < GVW ≤ 7.5	L ≤ 1.5	10.83
2		1.5 < L ≤ 2	10.35
3		2 < L ≤ 3	9.51
4		3 < L	8.12
5	7.5 < GVW ≤ 8		7.24
6	8 < GVW ≤ 10		6.52
7	10 < GVW ≤ 12		6.00
8	12 < GVW ≤ 14		5.69
9	14 < GVW ≤ 16		4.97
10	16 < GVW ≤ 20		4.15
11	20 < GVW		4.04

Table 4. 2015 Fuel Efficiency Targets for Heavy-Duty Tractors

Category	GVW, t	FE Target, km/L
1	GVW ≤ 20	3.09
2	GVW > 20	2.01

Emissions Standards: China
Heavy-Duty On-Road Engines

Implementation Schedule

With a few exceptions, emission standards for new on-road heavy-duty vehicles (HGV) and engines are based on the European standards. Implementation dates for the emission standards are listed in Table 1. China 6a and China 6b standards include the same emission limits, but China 6b includes some more stringent in-use (PEMS) testing and monitoring requirements.

China 3-7 Emission Standards

Emission Limits

The legislation for China 3-5 stages — which were based on Euro 3-5, respectively — was adopted in 2005 *[2881]*. The emission limits are shown in Table 2.

At the China 1/2 stage (not shown in the table), the test was ECE R-49 or the Chinese 9-mode.

Supplemental China 4-5 Requirements

Supplemental requirements were adopted to prevent excess NOx emissions during low-speed, urban driving conditions from some HDVs type approved to China 4 and China 5 standards. These requirements included:

- World Harmonized Transient Cycle (WHTC) limits — applicable in Beijing and nationally, and
- PEMS testing requirements — first applicable in Beijing, then nationally.

The Beijing Municipal Environmental Protection Bureau (EPB) released two local standards in February 2013 and the Ministry of Environmental Protection adopted a national standard in January 2014. These standards are supplemental to China 4 and 5 standards and apply to China 4 and 5 vehicles with GVW > 3,500 kg, registered in Beijing and nationally, respectively.

Table 1. Emission standards implementation dates

Stage		Beijing	Shanghai	Guangzhou Type Approval	Nationwide		Initially Scheduled
					All Vehicles		
China 1					2000.09	2001.09	
China 2					2003.09	2004.01	
China 3	PI	2010.07	2010.08	2009.07	2009.07	2010.07	2007.07
	CI	2006.01	2007.01	2007.07	2007.01	2008.01	2007.01
China 4	PI	2011.01			2012.07	2013.07	2010.01
	CI	2011.01	2009.11	2010.08	2010.01	2015.01	2010.01
China 5		2013.02[a,c] 2015.06[b]	2014.01[a]	2016.01[a]		2016.04[d,e] 2017.01[e] 2017.07[b]	2012.01
China 6a	Gas					2019.07	
	All					2021.07[f]	
China 6b	Gas					2021.07	
	All					2023.07	

[a] Public buses and municipal service vehicles
[b] All vehicles
[c] Starting 2016.01, DPFs are also required on new public HDDVs (buses and municipal service vehicles)
[d] Beijing, Shanghai, Tianjin, Hebei, Liaoning, Jiangsu, Zhejiang, Fujian, Shandong and Guangzhou
[e] Public transportation buses, sanitary and postal vehicles
[f] 2020.07 for urban HDVs

Table 2. China 3-5 emission standards for heavy-duty engines

Stage	Test Cycle	CO	HC	NMHC	NOx	PM	NH_3	Smoke
		g/kWh					ppm	1/m
China 3	ESC + ELR	2.1	0.66	-	5.0	0.10[a]		0.8
	ETC	5.45	-	0.78	5.0	0.16[a]		-
China 4	ESC + ELR	1.5	0.46	-	3.5	0.02		0.5
	ETC	4.0	-	0.55	3.5	0.03		-
China 5	ESC + ELR	1.5	0.46	-	2.0	0.02	10[b]	0.5
	ETC	4.0	-	0.55	2.0	0.03	10[b]	-

[a] 0.13/0.21 (ESC/ETC) for engines < 0.75 L per cylinder and rated speed > 3000 rpm
[b] Cycle average; 25 ppm maximum

Table 3. Beijing WHTC emission limits for diesel and gas China IV and V engines, g/kWh

Stage	Date	CO	NMHC	CH_4[a]	NOx	PM[b]
China 4	2013.03	4.0	0.55	1.1	3.7	0.03
China 5	2013.07[c]	4.0	0.55	1.1	2.8	0.03

[a] Only gas engines
[b] Not applicable to gas engines
[c] Buses and sanitary vehicles; other vehicles upon availability of suitable fuel

Table 4. National WHTC emission limits for diesel China IV and V engines, g/kWh

Stage	Date	CO	NMHC	NOx	PM
China 4	2015.01	4.0	0.55	3.7	0.03
China 5	in line with China 5	4.0	0.55	2.8	0.03

WHTC Limits. One of the Beijing standards *[2895]* implemented March 1, 2013 and the national standard *[2897] [3400]* implemented January 1, 2015, required China 4 and 5 engines to be tested over the WHTC in addition to the ETC (in Europe, testing over the WHTC was not required until the Euro 6 stage). The Beijing standards applied to diesel and gas fueled engines while the national standards applied to only diesel fueled engines. Both cold-start and hot-start tests were required, with results weighted 14% and 86%, respectively. Table 3 and Table 4 provide the WHTC cycle limits for the China 4 and 5 stages. Most of the limit values are equal to the Euro 4/5 ETC values except those for NOx emissions.

PEMS Testing. The second Beijing standard [2896], implemented July 1, 2013, established in-use, complete vehicle Portable Emission Measurement System (PEMS) testing requirements for manufacturers to prove that real-world emissions do not overly exceed the type approval limit values. From October 1, 2017, PEMS testing requirements became effective nationally, applicable to new type approvals of China V heavy-duty diesel- and gas-powered models.

China 6 Emission Standards

The first proposal for Euro 6-based emission standards was published in 2015 by the City of Beijing. These Beijing 6 emission standards were never finalized and have been replaced with the national China 6 program. The final China 6 emission standards were published in 2018, with a phase-in schedule from 2019.07 through 2023.07 (Table 1). The emission limits are shown in Table 5.

Table 5. China 6 emission standards for heavy-duty engines

Stage	Test Cycle	CO	HC	NMHC	CH_4	NOx	PM	PN	NH_3
		mg/kWh						kWh^{-1}	ppm
China 6 CI	WHSC	1500	130	-	-	400	10	8.0×10^{11}	10
	WHTC	4000	160	-	-	460	10	6.0×10^{11}	10
	WNTE	2000	220	-	-	600	16	-	-
China 6 PI	WHTC	4000	-	160	500	460	10	6.0×10^{11}	10
	WNTE	2000	220	-	-	600	16	-	-

Table 6. Emission durability requirements

Category	Useful Life		Aftertreatment Testing	
	China 1-5	China 6	GB 20890-2007	HJ 438-2008
M1 (GVW > 3.5 t) M2	100,000 km/5 yrs	200,000 km/5 yrs	50,000 km	100,000 km
M3 (GVW ≤ 7.5 t) N2 and N3 (GVW ≤ 16 t)	200,000 km/6 yrs	300,000 km/6 yrs	60,000 km	125,000 km
M3 (GVW > 7.5 t) N3 (GVW > 16 t)	500,000 km/7 yrs	700,000 km/7 yrs	80,000 km	167,000 km

The China 6 regulation includes a multi-component compliance program involving agency- and manufacturer-run emission tests during pre-production, production, and in-use stages. It also includes full vehicle PEMS testing requirements based on the European PEMS regulations.

The China 6 standards include two phases, China 6a and China 6b. China 6a is largely equivalent to the Euro 6 standard. China 6b introduces more stringent testing requirements (including a PN limit of 1.2Ч1012 kWh-1 for full-vehicle PEMS tests) and a remote emission monitoring system.

Emission Durability

Emission durability requirements, including the engine useful life and the minimum aftertreatment testing periods, are shown in Table 6. The aftertreatment periods according to HJ 438-2008 are mandatory for type approval and production conformity, while GB 20890-2007 provides a guideline to conduct aftertreatment durability testing during product development.

The GB 20890-2007 standard recommends that aftertreatment testing be conducted on-vehicle, over the China Heavy-Duty Durability Cycle — Vehicle (C-HDD-V). Alternatively, an engine-based durability test can be conducted over the China Heavy-Duty Durability Cycle — Engine (C-HDD-E).

Emission Warranty. China 6 regulations introduced the first mandatory emission warranty program for HDVs. The China 6 minimum emission warranty periods are 80,000 km/5 years for vehicle categories M1, M2 and N1; and 160,000 km/5 years for categories M3, N2, and N3.

OBD Requirements

China 6 regulations include OBD requirements that are based on the Euro 6 OBD program. An OBD system must be installed on all China 6 engines and vehicles to identify, record and communicate types of malfunctions. The OBD threshold limits are listed in Table 7. If emissions exceed an OBD threshold over a certain amount of time, a permanent code must be stored in the computer. An operator inducement system is also required that, when activated, reduces the vehicle torque and/or limits the maximum speed.

Remote OBD. China 6b standards require HDVs to be equipped with an on-board remote emissions monitoring system. Real-time engine data from the ECU, NOx sensor, DPF and other emission-related data are required to be reported remotely to the monitoring center of the regulatory agency.

Table 7. OBD threshold limits, mg/kWh

Engine type	NOx	PM	CO
Compression ignition	1200	25	-
Gas-fueled positive ignition	1200	-	7500

Emissions Standards: China
Non-Road Engines

Regulatory Background

The implementation of China's emission standards for diesel and small spark ignition (SI) mobile nonroad engines is summarized in Table 1. Some of the important regulatory steps include:

Diesel Stage 2/3 standards: The first emission standards

for mobile nonroad diesel engines (GB 20891-2007) were adopted in 2007 [2880]. The requirements were based on the European Stage 1/2 nonroad emission standards. However, the Chinese regulation also covered small diesel engines, which were not subject to the European standards. Emission limits for the smallest engines were consistent with US Tier 1/2 nonroad standards.

A Stage 4 implementation date of 2020.01 was proposed and later changed to 2020.12.

Smoke emissions: In September 2018, a test procedure and limits for measuring smoke emissions from non-road equipment and vehicles, GB 36886-2018, was published. The procedure became effective in December 2018.

Table 1. Implementation of National Non-Road Engine Emission Standards

Year	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21+
Diesel	1		1/2	2				2/3	3						4
Small SI; HH					1				2						
Small SI; nHH					1		2								

Table 2. Stage 1/2 Standards for Non-Road Diesel engines, g/kWh

Max Power (P), kW	CO	HC	NOx	HC+NOx	PM
Stage1†					
130 ≤ P ≤ 560	5.0	1.3	9.2	-	0.54
75 ≤ P < 130	5.0	1.3	9.2	-	0.7
37 ≤ P < 75	6.5	1.3	9.2	-	0.85
18 ≤ P < 37	8.4	2.1	10.8	-	1.0
8 ≤ P < 18	8.4	-	-	12.9	-
0 < P < 8	12.3	-	-	18.4	-
Stage 2					
130 ≤ P ≤ 560	3.5	1.0	6.0	-	0.2
75 ≤ P < 130	5.0	1.0	6.0	-	0.3
37 ≤ P < 75	5.0	1.3	7.0	-	0.4
18 ≤ P < 37	5.5	1.5	8.0	-	0.8
8 ≤ P < 18	6.6	-	-	9.5	0.8
0 < P < 8	8.0	-	-	10.5	1.0

† Stage 1 limits shall be achieved before any exhaust aftertreatment device.

Table 3. Stage 3 and Proposed Stage 4 Limits

Stage	Power	CO	HC	NOx	HC+NOx	PM
	kW	g/kWh				
Stage 3	P>560	3.5			6.4	0.20
	130≤P≤560	3.5			4.0	0.20
	75≤P<130	5.0			4.0	0.30
	37≤P<75	5.0			4.7	0.40
	P<37	5.5			7.5	0.60
Proposed Stage 4	P>560	3.5	0.40	3.5, 0.67*		0.10
	130≤P≤560	3.5	0.19	2.0		0.025
	75≤P<130	5.0	0.19	3.3		0.025
	56≤P<75	5.0	0.19	3.3		0.025
	37≤P<56	5.0			4.7	0.025
	P<37	5.5			7.5	0.60

* Applicable to mobile generator sets with Pmax > 900 kW diesel engines

Small SI Stage 1/2 standards: In December 2010, emissions standards for mobile nonroad spark ignition engines < 19 kW were published (GB26133-2010), with limits based on EU and US standards. Stage 1 requirements became effective 2010.03. Stage 2 implementation was different for non-handheld/handheld engines with requirements for new engine types starting 2013.01/2015.01 respectively and all new engines 2014.01/2016.01 respectively.

Diesel Engines

Stage 1/2 Emission Standards

The standards, Table 2, were based on European regulations. The compliance dates were:

- Stage 1 standards: 2007.10
- Stage 2 standards: 2009.10

Emissions were measured over a steady-state test cycle equivalent to the ISO 8178 C1, 8-mode test. Other ISO 8178 test cycles could be used for selected applications.

Stage 3/4 Emission Standards

GB20891-2014 included the Stage 3 limits as well as Stage 4 limits, Table 3. The Stage 3 limits are based on EU Stage 3a standards and the proposed Stage 4 limits on EU Stage 3b standards but with the addition of engines with net power >560 kW and < 37 kW. Limits for engines above 560 kW and under 37 kW are based on US Tier 2 requirements. Stage 3 engines and constant speed Stage 4 engines are measured over the ISO 8178. Variable speed Stage 4 engines were to be tested over the NRTC. Durability requirements are shown in Table 4 .

Stage 4 Emission Standards—2018/19 Revisions

The Stage 4 requirements proposed in GB 20891-2014, Table 3, were further clarified and supplemented with additional requirements through a proposal issued 2018.02. This proposal supplemented the Stage 4 requirements in Table 3 with a DPF-forcing standard — a maximum PN limit of 5Ч1012 #/kWh. Engine manufacturers were also encouraged to instead meet limits based on EU Stage 5 limits, Table 5.

Initially, an implementation date of 2020.01 was proposed; all nonroad engines produced on or after this date would be required to meet the updated Stage 4 requirements. A revision to the proposal published 2019.02 changed the implementation date to 2020.12, pointed to a supplemental document "Technical Requirements for Non-road Diesel Mobile Machinery Pollutant Emission Control" (HJ 1014) for additional compliance guidance and stated that proposed China Stage 5 limits will also be included in the final regulation.

Additional details for Stage 4 include:

- Constant speed diesel engines would be tested over the NRSC and variable speed engines over the NRTC;
- Wider applicable ambient boundary conditions;
- PN limit to apply to 37-560 kW engines (engines to be equipped with a wall-flow DPF);
- There should be no visible smoke during DPF regeneration;
- Average ammonia emissions are not to exceed 25 ppm;
- If the engine is equipped with a vanadium containing SCR catalyst, data demonstrating that vanadium emissions will not occur during the useful life is required and SCR inlet temperatures above 550°C are not allowed;
- PEMS to be used as the primary in-use compliance tool;
- An OBD requirement for NOx and PM controls, covering EGR, DOC, DPF, SCR;
- Global positioning system will be required for all NRMMs equipped with engines of 37-560 kW.

Table 4. Stage 3/4 Durability Requirements

Power, kW	Rated speed, rpm	Effective life, h	Minimum durability test duration, h
P≥37	All	8000	2000
19≤P<37	Variable speed	5000	1250
	Constant speed < 3000		
	Constant speed ≥ 3000	3000	750
P<19	All		

Table 5. Voluntary Emission Limits Proposed in 2018

Power	CO	HC	NOx	HC+NOx	PM	PN
kW	g/kWh					#/kWh
P>560	3.5	0.19	3.5, 0.67*		0.045	
130≤P≤560	3.5	0.19	0.40		0.015	1×1012
56≤P<130	5.0	0.19	0.40		0.015	1×1012
37≤P<56	5.0			4.7	0.015	1×1012
19≤P<37	5.0			4.7	0.015	1×1012
P<19	5.5			7.5	0.40	

* Applicable to mobile generator sets with Pmax > 900 kW diesel engines

Table 6. Exhaust Smoke Limits

Category	Rated net power, P_{max}	Light absorption coefficient[a]	Ringelmann Blackness
	kW	1/m	
Class 1	Pmax < 19	3.00	1
	19 ≤ Pmax < 37	2.00	
	37 ≤ Pmax ≤ 560	1.61	
Class 2	Pmax < 19	2.00	1
	19 ≤ Pmax < 37	1.00	1 (no visible smoke)
	Pmax ≥ 37	0.80	
Class 3	Pmax < 37	0.80	1 (no visible smoke)
	Pmax ≥ 37	0.50	

[a] for engines operating above 1700 m, the limit can be increased by 0.25 1/m
Class 1 limits apply to machinery with Stage 1 and 2 diesel engines (GB 20891-2007) and Class 2 limits to machinery with Stage 3 and subsequent diesel engines (GB 20891-2014). Class 3 limits can be used to limit emissions in low emission zones defined by the government.

In-Use Smoke Emissions

In the September 2018, Limits and measurement methods for exhaust smoke from non-road mobile machinery equipped with diesel engine, GB 36886-2018, was published. This standard specifies the exhaust smoke limit and measurement method for on-site measurements of non-road diesel mobile machinery and vehicles as well as new and imported equipment. Smoke measurements can be carried out with an opacity meter according to GB 3847 or using the Ringelmann method as described in an appendix to GB 36886-2018. The corresponding limits are summarized in Table 6.

On-site smoke measurements are carried out during the normal usage cycle of the equipment. If this is not possible, the free acceleration method (GB 3847) can be used. Opacity meter measurements are carried out with a sampling frequency

no less than 1 Hz and the maximum reading is taken as the test result. Ringelmann readings can be taken by video or other similar method with the maximum Ringelmann rating taken as the test result.

Small SI Engines: Stage 1/2 Emission Standards

Stage 1 and 2 emissions requirements for small nonroad spark ignition engines are found in GB26133-2010. This standard applies to spark ignition engines with a net power of no more than 19 kW for use in nonroad mobile machinery such as: lawn mowers, chain saws, generators, water pumps and brush cutters. Engines with a net power greater than 19 kW but a working volume of no more than 1 L may be certified as well. It does not apply to engines for the following purposes: for driving boats; for underground mining or underground mining equipment; for emergency rescue equipment; for recreational vehicles such as sleds, motocross and all-terrain vehicles; engines built for export.

The application dates are as follows:

- Stage 1: New types/all new non-handheld and hand-held engines 2011.03/2012.03, respectively.
- Stage 2:
  - New types/all new non-handheld engines 2013.01/2014.01
  - New types/all new hand-held engines 2015.01/2016.01, respectively.

Testing is in accordance with ISO 8178 (GB/T 8190.4). Emission requirements are based on EU Directive 97/68/EC and its amendments found in 2002/88/EC as well as US EPA Phase 1 and 2 regulations (40 CFR Part 90).

Engines are classified according to displacement volume as shown in Table 7.

Stage 1 limits are shown in Table 8 and Stage 2 limits in Table 9. The durability requirements are shown in Table 10. Two-stroke engines for snowblowers, whether or not they are hand-held, only need to meet the SH1, SH2 or SH3 of the corresponding working volume. For natural gas-fueled engines, NMHC may be used instead of HC.

Table 7. Small SI Engine Classification

	Engine classification	Displacement Volume, cm^3
Handheld	SH1	V<20
	SH2	20≤V<50
	SH3	V≥50
Non-handheld	FSH1	V<66
	FSH2	66≤V<100
	FSH3	100≤V<225
	FSH4	V≥225

Table 8. Small SI Engine Stage 1 Emission Limits, g/kWh

Engine classification	CO	HC	NOx	HC+NOx
SH1	805	295	5.36	
SH2	805	241	5.36	
SH3	603	161	5.36	
FSH1	519			50
FSH2	519			40
FSH3	519			16.1
FSH4	519			13.4

Table 9. Small SI Engine Stage 2 Emission Limits, g/kWh

Engine classification	CO	NOx	HC+NOx
SH1	805	10	50
SH2	805	10	50
SH3	603	10	72
FSH1	610	10	50
FSH2	610	10	40
FSH3	610	10	16.1
FSH4	610	10	13.4

Table 10. Durability Requirements For Small SI Engines, Hrs

Engine classification	Durability class		
	1	2	3
SH1	50	125	300
SH2	50	125	300
SH3	50	125	300
FSH1	50	125	300
FSH2	125	250	500
FSH3	125	250	500
FSH4	250	500	1000

Locomotives

Emission standards for locomotives and other rail traction engines are published by the State Railway Administration. TB/T 2783-2017 specifies the limits for emissions from diesel engines for railway traction. The standard applies to diesel engines for railway traction, new traction equipment for railways or diesel engines reinstalled with existing traction equipment. It does not apply to special-purpose locomotive diesel engines (such as for refinery or mining locomotives) and diesel engines with output power less than 100 kW. Emission standards have been based on UIC and EU NRMM standards. Table 11 lists the emission standards that apply. EPA Tier 2 locomotives are also claimed to be acceptable and development of locomotives capable of meeting EPA Tier 3 and 4 and EU NRMM Stage 3B is being encouraged [4395].

Emissions Standards: India
On-Road Vehicles And Engines

Table 1. Indian Emissions Standards (4-Wheel Vehicles)

Standard	Reference	Date	Region
India 2000	Euro 1	2000	Nationwide
Bharat Stage 2	Euro 2	2001	NCR*, Mumbai, Kolkata, Chennai
		2003.04	NCR*, 11 Cities†
		2005.04	Nationwide
Bharat Stage 3	Euro 3	2005.04	NCR*, 11 Cities†
		2010.04	Nationwide
Bharat Stage 4	Euro 4	2010.04	NCR*, 11 Cities†

* National Capital Region (Delhi)
† Mumbai, Kolkata, Chennai, Bangalore, Hyderabad, Secunderabad, Ahmedabad, Pune, Surat, Kanpur and Agra

Table 2. Emissions Standards for Light-Duty Vehicles, g/km

Year	Reference	CO	HC	HC+NO_x	NO_x	PM
Diesel						
1992	-	17.3-32.6	2.7-3.7	-	-	-
1996	-	5.0-9.0	-	2.0-4.0	-	-
2000	Euro 1	2.72-6.90	-	0.97-1.70	-	0.14-0.25
2005†	Euro 2	1.0-1.5	-	0.7-1.2	-	0.08-0.17
2010†	Euro 3	0.64 0.80 0.95	-	0.56 0.72 0.86	0.50 0.65 0.78	0.05 0.07 0.10
2010‡	Euro 4	0.50 0.63 0.74	-	0.30 0.39 0.46	0.25 0.33 0.39	0.025 0.04 0.06
Gasoline						
1991	-	14.3-27.1	2.0-2.9	-	-	-
1996	-	8.68-12.4	-	3.00-4.36	-	-
1998*	-	4.34-6.20	-	1.50-2.18	-	-
2000	Euro 1	2.72-6.90	-	0.97-1.70	-	-
2005†	Euro 2	2.2-5.0	-	0.5-0.7	-	-
2010†	Euro 3	2.3 4.17 5.22	0.20 0.25 0.29	-	0.15 0.18 0.21	-
2010‡	Euro 4	1.0 1.81 2.27	0.1 0.13 0.16	-	0.08 0.10 0.11	-

* for catalytic converter fitted vehicles
† earlier introduction in selected regions, see Table 1
‡ only in selected regions, see Table 1

Table 3. Alternative Emissions Standards for Light-Duty Diesel Engines, g/kWh

Year	Reference	CO	HC	NO_x	PM
1992	-	14.0	3.5	18.0	-
1996	-	11.20	2.40	14.4	-
2000	Euro 1	4.5	1.1	8.0	0.36*
2005†	Euro 2	4.0	1.1	7.0	0.15

* 0.612 for engines below 85 kW
† earlier introduction in selected regions, see Table 1

Background

The first Indian emissions regulations were idle emissions limits which became effective in 1989. These idle emissions regulations were soon replaced by mass emissions limits for both gasoline (1991) and diesel (1992) vehicles, which were gradually tightened during the 1990's. Since the year 2000, India started adopting European emissions and fuel regulations for four-wheeled light-duty and for heavy-duty vehicles. Indian own emissions regulations still apply to two- and three-wheeled vehicles.

On October 6, 2003, the National Auto Fuel Policy has been announced, which envisages a phased program for introducing Euro 2 — 4 emissions and fuel regulations by 2010. The implementation schedule of EU emissions standards in India is summarized in Table 1.

The above standards apply to all new 4-wheel vehicles sold and registered in the respective regions. In addition, the National Auto Fuel Policy introduces certain emissions requirements for interstate buses with routes originating or terminating in Delhi or the other 10 cities.

Light-Duty Vehicles

Emissions standards for light-duty vehicles (GVW ≤ 3,500 kg) are summarized in Table 2. Ranges of emissions limits refer to different categories and classes of vehicles; compare the EU light-duty vehicle emissions standards page for details on the Euro 1 and later standards. The lowest limit in each range applies to passenger cars (GVW ≤ 2,500 kg; up to 6 seats). When three limits are listed, they refer to vehicles category M & N1 Class 1, N1 Class 2, and N1 Class 3, respectively.

The test cycle has been the NEDC for low-powered vehicles (max. speed limited to 90 km/h). Before 2000, emissions were measured over an Indian test cycle.

Gasoline vehicles must also meet an evaporative (SHED) limit of 2 g/test (effective 2000).

Through the BS 2 (Euro 2) stage, engines

for use in light-duty vehicles could be alternatively emissions tested using an engine dynamometer. The respective emissions standards are listed in Table 3.

OBD Requirements. OBD 1 is required from April 1, 2010 (except LPG or CNG-fuelled vehicles and those >3500 kg GVW). OBD 2 is required from 1 April 2013 for all categories.

Truck and Bus Engines

Emissions standards for new heavy-duty engines — applicable to vehicles of GVW > 3,500 kg — are listed in Table 4.

Table 4. Emissions Standards for Diesel Truck and Bus Engines, g/kWh

Year	Reference	Test	CO	HC	NO_x	PM
1992	-	ECE R49	17.3-32.6	2.7-3.7	-	-
1996	-	ECE R49	11.20	2.40	14.4	-
2000	Euro 1	ECE R49	4.5	1.1	8.0	0.36*
2005†	Euro 2	ECE R49	4.0	1.1	7.0	0.15
2010†	Euro 3	ESC	2.1	0.66	5.0	0.10
		ETC	5.45	0.78	5.0	0.16
2010‡	Euro 4	ESC	1.5	0.46	3.5	0.02
		ETC	4.0	0.55	3.5	0.03

* 0.612 for engines below 85 kW
† earlier introduction in selected regions, see Table 1
‡ only in selected regions, see Table 1

Emissions Standards: India
Non-Road Diesel Engines

Regulatory Background

Bharat (CEV) Stage 2 - 3 emission standards for diesel construction machinery were adopted on 21 September 2006. The standards were structured into two tiers:

- BS (CEV) 2 - These standards are based on the EU Stage 1 requirements, but also cover smaller engines that were not regulated under the EU Stage 1.
- BS (CEV) 3 - These standards are based on US Tier 2/3 requirements.

First standards for agricultural tractors, Bharat (Trem) Stage 1, became effective in 1999. From the Bharat (Trem) Stage 3a, emission requirements for agricultural tractors became harmonized with those for construction machinery for most engine categories.

On 5 March 2018, India adopted Bharat Stage (CEV/Trem) 4 - 5 emission standards for diesel nonroad engines used in construction and agricultural equipment. The BS (CEV/Trem) 4 emission standards are aligned with EU Stage 4 standards, while the BS (CEV/Trem) 5 standards are aligned with EU Stage 5.

Table 1. Bharat (CEV) Stage 2 - 3 Emission Standards for Diesel Construction Machinery

Engine Power	Date	CO	HC	HC+NO_x	NO_x	PM
kW		g/kWh				
Bharat (CEV) Stage 2						
P < 8	2008.10	8.0	1.3	-	9.2	1.00
8 ≤ P < 19	2008.10	6.6	1.3	-	9.2	0.85
19 ≤ P < 37	2007.10	6.5	1.3	-	9.2	0.85
37 ≤ P < 75	2007.10	6.5	1.3	-	9.2	0.85
75 ≤ P < 130	2007.10	5.0	1.3	-	9.2	0.70
130 ≤ P < 560	2007.10	5.0	1.3	-	9.2	0.54
Bharat (CEV) Stage 3						
P < 8	2011.04	8.0	-	7.5	-	0.80
8 ≤ P < 19	2011.04	6.6	-	7.5	-	0.80
19 ≤ P < 37	2011.04	5.5	-	7.5	-	0.60
37 ≤ P < 75	2011.04	5.0	-	4.7	-	0.40
75 ≤ P < 130	2011.04	5.0	-	4.0	-	0.30
130 ≤ P < 560	2011.04	3.5	-	4.0	-	0.20

Table 2. Bharat (CEV) Stage 3 Useful Life Periods

Power Rating		Useful Life Period
		hours
< 19 kW		3000
19-37 kW	constant speed	3000
	variable speed	5000
> 37 kW		8000

Bharat Stage (CEV/Trem) 1 - 3 Construction Machinery

The standards are summarized in the following table. The limit values apply for both type approval (TA) and conformity of production (COP) testing. Testing is performed on an engine dynamometer over the ISO 8178 C1 (8-mode) and D2 (5-mode) test cycles.

The Bharat Stage 3 standards must be met over the useful life periods shown in Table 2. Alternatively, manufacturers may use fixed emission deterioration factors of 1.1 for CO, 1.05 for HC, 1.05 for NOx, and 1.1 for PM.

Table 3. Bharat (Trem) Stage 1 – 3a Emission Standards for Diesel Agricultural Tractors

Engine Power	Date	CO	HC	$HC+NO_x$	NO_x	PM
kW		g/kWh				
Bharat (Trem) Stage 1						
All	1999.10	14.0	3.5	-	18.0	-
Bharat (Trem) Stage 2						
All	2003.06	9.0	-	15.0	-	1.00
Bharat (Trem) Stage 3						
All	2005.10	5.5	-	9.5	-	0.80
Bharat (Trem) Stage 3a						
P < 8	2010.04	5.5	-	8.5	-	0.80
8 ≤ P < 19	2010.04	5.5	-	8.5	-	0.80
19 ≤ P < 37	2010.04	5.5	-	7.5	-	0.60
37 ≤ P < 75	2011.04	5.0	-	4.7	-	0.40
75 ≤ P < 130	2011.04	5.0	-	4.0	-	0.30
130 ≤ P < 560	2011.04	3.5	-	4.0	-	0.20

Table 4. Bharat (CEV/Trem) Stage 4 - 5 Emission Standards

Engine Power	Date	CO	HC	NOx	PM	PN	Test Cycle
kW		g/kWh				1/kWh	
Bharat (CEV/Trem) Stage 4							
37 ≤ P < 56	2020.10	5.0	4.7*		0.025	-	NRSC and NRTC
56 ≤ P < 130		5.0	0.19	0.4	0.025	-	
130 ≤ P < 560		3.5	0.19	0.4	0.025	-	
Bharat (CEV/Trem) Stage 5							
P < 8	2024.04	8.0	7.5*		0.4	-	NRSC
8 ≤ P < 19		6.6	7.5*		0.4	-	
19 ≤ P < 37		5.0	4.7*		0.015	1×10^{12}	NRSC and NRTC
37 ≤ P < 56		5.0	4.7*		0.015	1×10^{12}	
56 ≤ P < 130		5.0	0.19	0.4	0.015	1×10^{12}	
130 ≤ P < 560		3.5	0.19	0.4	0.015	1×10^{12}	
P ≥ 560		3.5	0.19	3.5	0.045	-	NRSC

* NOx + HC

Agricultural Tractors1

Emission standards for diesel agricultural tractors are summarized in Table 3. Emissions are tested over the ISO 8178 C1 (8-mode) cycle.

For Bharat (Trem) Stage 3a, the useful life periods and deterioration factors are the same as for Bharat (CEV) Stage 2, Table 2.

Bharat Stage (CEV/Trem) 4 - 5

Bharat Stage (CEV/Trem) 4 – 5 emission standards for nonroad diesel engines used in construction and agricultural equipment are summarized in Table 4. The BS 4/5 nonroad regulations include no BS 4 emission standards for diesel engines with rated power below 37 kW (a category that includes some 90% of ag tractors in India) or for engines above 560 kW, but the BS 5 standards cover all power ratings. The regulation includes a six-month grace period when registrations of equipment complying with the previous set of emission standards is allowed. From April 2026, an in-service conformity check is required for all BS 5 approved engines manufactured.

Engines equipped with SCR must meet an ammonia emission limit of 25 ppm for engines ≤ 56 kW and 10 ppm for engines above 56 kW. The limits are defined as a mean value over the NRTC and NRSC cycles.

The standards must be met over the useful life periods shown in Table 5. Alternatively, manufacturers may use fixed emission deterioration factors of 1.3 for CO, 1.3 for HC, 1.15 for NOx, and 1.05 for PM (NRSC and NRTC).

Table 5. Bharat (CEV/Trem) Stage 4 - 5 Useful Life Periods

Power Rating		Useful Life Period
		hours
≤ 37 kW	constant speed	3000
	variable speed	5000
> 37 kW		8000

Table 6. Proposed locomotive emission standards, g/bhp-hr

Locomotive Type	CO	HC	NOx	PM
Alco type	3.0	1.00	17.0	0.45
EMD (HHP locomotives)	1.4	1.00	9.0	0.35

Locomotives

In March 2017, India's Central Pollution Control Board (CPCB) submitted proposed emission standards for diesel locomotives to the Ministry of Environment and Forests (MoEF).

The proposed limits, outlined in a CPCB Interim Report, are based on emission measurements conducted by CPCB on Indian railways.

There are two sets of limits: for ALCO type locomotives and for high horsepower EMD locomotives. The standards would be applicable through the useful life of the locomotive. The report proposes to define a compliance protocol — including certification, production line testing, and in-use testing — based on the practice followed by US railroads.

Emissions Standards: India
Generator Sets

Emissions from new diesel engines used in generator sets have been regulated by the Ministry of Environment and Forests, Government of India *[GSR 371(E), 17.05.2002]*. The regulations impose type approval certification, production conformity testing and labeling requirements. Certification agencies include: (1) Automotive Research Association of India, (2) Vehicle Research and Development Establishment, and (3) International Centre for Automotive Technology *[GSR 280(E), 11.04.2008]*. The emissions standards are listed below.

Engines are tested over the 5-mode ISO 8178 D2 test cycle. Smoke opacity is measured at full load.

Concentrations are corrected to dry exhaust conditions with 15% residual O_2.

Table 1. Emissions Standards for Diesel Engines ≤ 800 kW for Generator Sets

Engine Power (P)	Date	CO	HC	NO_x	PM	Smoke
		g/kWh				1/m
P ≤ 19 kW	2004.01	5.0	1.3	9.2	0.6	0.7
	2005.07	3.5	1.3	9.2	0.3	0.7
19 kW < P ≤ 50 kW	2004.01	5.0	1.3	9.2	0.5	0.7
	2004.07	3.5	1.3	9.2	0.3	0.7
50 kW < P ≤ 176 kW	2004.01	3.5	1.3	9.2	0.3	0.7
176 kW < P ≤ 800 kW	2004.11	3.5	1.3	9.2	0.3	0.7

Table 2. Emissions Limits for Diesel Engines > 800 kW for Generator Sets

Date	CO	NMHC	NO_x	PM
	mg/Nm^3	mg/Nm^3	ppm(v)	mg/Nm^3
Until 2003.06	150	150	1100	75
2003.07 - 2005.06	150	100	970	75
2005.07	150	100	710	75

Emissions Standards: South Korea
On-Road Vehicles And Engines

Light-Duty Vehicles

South Korean diesel emissions standards for passenger cars (<8 seats, GVW<2,500 kg) are listed in Table 1. Emissions standards for light-duty diesel trucks (GVW<3,000 kg) are listed in Table 2.

Emissions are tested over the U.S. FTP-75 cycle and expressed in g/km.

The South Korean government has proposed that Euro 4 emissions standards will apply to light-duty diesel vehicles effective January 2006 (and California ULEV standards for gasoline vehicles).

Heavy-Duty Vehicles

South Korean emissions standards for heavy-duty diesel trucks (GVW>3,000 kg) are listed in Table 3. Some of the truck engine categories have additional smoke opacity requirements which are not listed in the table.

Since 1996, emissions are tested over the Japanese diesel 13-mode cycle and expressed in g/kWh. The 2003 emissions limits are aligned with Euro 3 requirements.

Table 1. Emissions Standards for Diesel Passenger Cars

Date	CO	HC	NMHC	NO_x	PM	Smoke
-	g/km					%
1993.1.1	2.11	0.25	-	0.62	0.12	
1996.1.1	2.11	0.25	-	0.62	0.08	
1998.1.1	1.50	0.25	-	0.62	0.08	
2000.1.1	1.20	0.25	-	0.62	0.05	20%
2001.1.1	0.5	-	0.01	0.02	0.01	20%
2002.7.1	0.5	-	0.01	0.02	0.01	15%

Table 2. Emissions Standards for Light-Duty Diesel Trucks

Date	CO	HC	NO_x	PM
-	g/km			
1993-1997				
1993.1.1	980†	670†	350† IDI 750† DI	-
1996.1.1	6.21	0.50	1.43	0.31
1998 and later, LW<1,700 kg				
1998.1.1	2.11	0.25	1.40	0.14
2000.1.1	2.11	0.25	1.02	0.11
2004.1.1	1.27	0.21	0.64	0.06
1998 and later, LW>1,700 kg				
1998.1.1	2.11	0.50	1.40	0.25
2000.1.1	2.11	0.50	1.06	0.14
2004.1.1	1.52	0.33	0.71	0.08

LW (loaded weight) = curb weight + 130 kg
† JP 6-mode test, limits expressed in ppm

Table 3. Emissions Standards for Heavy-Duty Diesel Engines

Date	CO	HC	NO_x	PM
-	g/kWh			
1993.1.1	980†	670†	350† IDI 750† DI	-
1996.1.1	4.90	1.20	11.0	0.90
1998.1.1	4.90	1.20	6.0 (9.0)*	0.25 (0.50)*
2000.1.1	4.90	1.20	6.0	0.25 (0.10)*
2002.1.1	4.90	1.20	6.0	0.15 (0.10)*
2003.1.1	2.1	0.66	5.0	0.10

* applies to buses
† JP 6-mode test, limits expressed in ppm

Emissions Standards: South Korea
Non-Road Engines

South Korea has proposed emissions standards for mobile nonroad diesel engines used in construction and industrial equipment. The standards would apply to engines between 18 - 560 kW rated power, in such applications as excavators (>1 t), bulldozers, loaders (>2 t), cranes, graders, rollers, and forklift trucks.

The standards would be implemented in two Tier schedules, as shown in Table 1. The South Korean Tier 2 standards are equivalent to the U.S. Tier 2. Emissions are measured over the ISO 8178 C1 test and expressed in g/kWh. There are no smoke opacity requirements.

Diesel fuel specifications are: density 815 - 855 kg/m^3, sulfur < 430 ppm.

Engines (engine families) are to be certified by the South Korean Ministry of Environment or the National Institute of Environmental Research.

Table 1. Proposed Emissions Standards for Nonroad Engines

Power	CO	HC	NO_x+HC	NO_x	PM
kW	g/kWh				
Tier 1: 2004.1.1					
18 - 37	5.5	-	9.5	-	0.8
37 - 75	5.5	1.3	-	9.2	0.6
75 - 130	5.0	1.3	-	9.2	0.6
130 - 225	5.0	1.3	-	9.2	0.54
225 - 560	5.0	1.3	-	9.2	0.54
Tier 2: 2005.1.1					
18 - 37	5.5	-	7.5	-	0.6
37 - 75	5.0	-	7.5	-	0.4
75 - 130	5.0	-	6.6	-	0.3
130 - 225	3.5	-	6.6	-	0.2
225 - 560	3.5	-	6.4	-	0.2

Emissions Standards: Australia
On-Road Vehicles And Engines

Background

Australian emissions standards are based on European regulations for light-duty and heavy-duty (heavy goods) vehicles, with acceptance of selected U.S. and Japanese standards. The long term policy is to fully harmonize Australian regulations with UN ECE standards. The development of emissions standards for highway vehicles and engines is coordinated by the National Transport Commission (NTC) and the regulations — Australian Design Rules (ADR) — are administered by the Department of Infrastructure and Transport.

The emissions standards apply to new vehicles including petrol (gasoline) and diesel cars, light omnibuses, heavy omnibuses, light goods vehicles, medium goods vehicles and heavy goods vehicles, as well as to forward control passenger vehicles and larger motor tricycles. They also cover off-road passenger vehicles (but not off-road engines, such as those used in construction or agricultural machinery).

The evolution of vehicle emissions standards in Australia occurred through a number of regulatory actions. Some of the important steps can be summarized as follows:

- Emissions standards for petrol engined light vehicles commenced in the early 1970s.
- A smoke emissions requirement (ADR30/00) was introduced in 1976 for vehicles with 4 or more wheels powered by a diesel engine. The alternative smoke standards were U.S. EPA '74 or later or British standards "Performance of Diesel Engines for Road Vehicles" BS AU 141a:1971 or ECE R 24/00, 24/01, 24/02 or 24/03 "Diesel and Pollutants" or, in the case of an engine alone, ECE R 24/03.
- The first emissions standards (apart from smoke standards) for heavy diesel fueled vehicles became effective in 1995 for all new models and in 1996 for all existing models. These emissions standards were introduced via ADR70/00 (adopting ECE R49, U.S. & Japanese HDV standards). The requirements of the 1995/96 standards were:
  - Required: Euro 1 for both light-duty and heavy-duty vehicles. Euro 2 and 3 were also accepted though not included in the regulation.
  - Acceptable alternatives: U.S. EPA '91 or '94 (EPA '98 was also accepted though not included in the regulation); 1993 Japanese exhaust emissions standards for "light duty and medium duty vehicles" and 1994 Japanese exhaust emissions standards for "passenger cars and heavy duty vehicles."
- A second round of more stringent emissions standards applied from 2002/2003 model year (for new/existing models). The standards — initially equivalent to Euro 2/3 — have been gradually tightened to adopt Euro 4 for light-duty cars and trucks (diesel and petrol), and Euro 5 for heavy-duty diesel engines.
- A third round of emissions regulations, adopted in 2011, mandates Euro 5/6 emissions standards for light-duty vehicles with an implementation schedule from 2013 to 2018.

Emissions Standards: 2002/03 and Later

The emissions standards were introduced via a series of new ADRs, which apply to vehicles depending on their gross vehicle mass (GVM):

- For light-duty vehicles at or below 3.5 t GVM:
  - Euro 2/4 stage: ADR79/00, ADR79/01, and ADR79/02 (replacing ADR37/01).
  - Euro 5/6 stage: ADR79/03, ADR79/04, and ADR79/05.
- For heavy-duty vehicles above 3.5 t GVM: ADR80/00, ADR80/01, ADR80/02, and ADR80/03 (replacing ADR70/00).

The above ADRs apply to new vehicles fueled with petrol, diesel, as well as with LPG or natural gas. The requirements and the implementation schedules are summarized in Table 1 (the requirements and dates for heavy LPG and NG vehicles are the same as for diesel).

The two year date combinations shown in the table refer to the dates applicable to new model vehicles and all model vehicles, respectively. For example, in the case of 02/03, this means that from January 1, 2002 any new model first produced with a date of manufacture after January 1, 2002 must comply with the ADR, and from January 1, 2003 all new vehicles (regardless of the first production date for that particular model) must comply.

Notes to Table 1

1. The introduction of Euro 2 standards for light-duty petrol and light-duty diesel vehicles is via ADR79/00, which adopts the technical requirements of ECE R83/04.

Table 1. Vehicle Emissions Standards: 2002/03 and Later

ADR Categories			ECE Cat	ADR	02/03 Diesel	03/04 Petrol	05/06 Petrol	06/07 Diesel	07/08 Diesel	08/10[a] Petrol	10/11 Petrol	10/11 Diesel	13/16[b] All	17/18[c] All
Descr	GVM†	Cat‡												
Passenger Vehicles														
	≤ 3.5t	MA, MB, MC	M1	ADR 79/..	Euro 2	Euro 2	Euro 3	Euro 4		Euro 4			Euro 5[d]	Euro 6
	> 3.5t			ADR 80/..	Euro 3	US96	US98		Euro 4		Euro 4			
Buses														
Light	≤ 3.5t	MD	M2	ADR 79/..	Euro 2	Euro 2	Euro 3	Euro 4		Euro 4			Euro 5[d]	Euro 6
	3.5 ≤ 5t			ADR 80/..	Euro 3	US96	US98		Euro 4 or US04, JE05		Euro 4 or US08	Euro 5 or US07, JE05		
Heavy	> 5t	ME	M3	ADR 80/..	Euro 3 or US98[e]	US96	US98		Euro 4 or US04, JE05		Euro 4 or US08	Euro 5 or US07, JE05		
Goods Vehicles (Trucks)														
Light	≤ 3.5t	NA	N1	ADR 79/..	Euro 2	Euro 2	Euro 3	Euro 4		Euro 4			Euro 5[d]	Euro 6
Medium	3.5 ≤ 12t	NB	N2	ADR 80/..	Euro 3 or US98[e]	US96	US98		Euro 4 or US04, JE05		Euro 4 or US08	Euro 5 or US07, JE05		
Heavy	> 12t	NC	N3	ADR 80/..	Euro 3 or US98[e]	US96	US98		Euro 4 or US04, JE05		Euro 4 or US08	Euro 5 or US07, JE05		

† Gross vehicle mass

‡ Vehicle categories: MA - passenger cars; MB - forward control vehicles, MC - passenger off-road vehicles

[a] - 1 July 2008/1 July 2010 for new/existing models

[b] - 1 November 2013/1 November 2016 for new/existing models

[c] - 1 July 2017/1 July 2018 for new/existing models

[d] - 'Core' Euro 5 applicable to new models from 1 November 2013, full Euro 5 applicable from 1 November 2016 (see notes below)

[e] - US EPA model year 2000 or later certificate or equivalent testing required (to ensure that no emissions "defeat devices" are used)

2. The introduction of Euro 3 standards for light-duty petrol vehicles, and Euro 4 standards for light-duty diesel vehicles, is via ADR79/01, which adopts the technical requirements of ECE Regulation 83/05. R83/05 embodies the Euro 3 and Euro 4 requirements for light-duty petrol and diesel vehicles, however the ADR only mandates the Euro 3 (pre 2005) provisions of R83/05 for petrol vehicles, but allows petrol vehicles optional compliance with Euro 4 standards.

3. The introduction of Euro 4 standards for light-duty petrol vehicles is via ADR79/02, which adopts the technical requirements of ECE R83/05.

4. The introduction of Euro 3 and Euro 4 standards for medium- and heavy-duty diesel vehicles is via ADR80/00 and ADR80/01, respectively, which adopt the technical requirements of European Directive 99/96/EC amending Directive 88/77/EEC. ADR80/01 has been replaced by ADR80/02 effective 2007/8.

5. The introduction of Euro 4 and Euro 5 standards for medium- and heavy-duty diesel vehicles is via ADR80/02 and ADR80/03, respectively, which adopt the technical requirements of Directive 2005/55/EC as amended by 2005/78/EC and 2006/51/EC.

6. The 'core' Euro 5 (ADR79/03) adopts the technical requirements of ECE R83/06, except that it does not require the new, PMP-based testing methods for PM mass (allowing the old test method with the 0.005 g/km PM limit to be used as an alternative) and has no PN limit. Some other requirements are also relaxed, including the OBD threshold. ADR79/04 applies the full requirements of ECE R83/06 from November 1, 2016.

Other Provisions

Smoke Limits. A smoke emissions ADR30/01 also applies to all categories of diesel vehicles. The smoke standard, which applies from 2002/3, adopts UN ECE R24/03 and allows the U.S. 94 smoke standards as an alternative. This new ADR replaces ADR30/00.

OBD. ADR79/03-05 introduces European OBD requirements for light-duty vehicles. At the 'core' Euro 5 stage (ADR79/03) a relaxed OBD threshold limit for PM mass of 80 mg/km is accepted for M and N category vehicles of reference mass above 1760 kg.

ADR80/02 requires heavy-duty vehicles to have OBD systems meeting the Euro 4 (or Japanese) requirements to warn against "functional failures" (such as an empty urea tank in engines with SCR). ADR80/03 requires vehicles to have OBD systems meeting the Euro 5 requirements to directly monitor emissions levels against set OBD thresholds.

Diesel Fuel. The new emissions requirements were synchronized with new diesel fuel specifications of reduced sulfur content, as follows:

500 ppm sulfur effective December 31, 2002.
50 ppm sulfur effective January 1, 2006.
10 ppm sulfur effective January 1, 2009.

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Emissions Standards: Argentina
Heavy-Duty On-Road Engines

Model Year 1994-2005

Emission standards for new, model year 1994-2005 diesel fueled trucks and buses in Argentina are summarized in Table 1 [Decree 779/95].

The standards were based on European heavy-duty engine emission regulations. The standards were also applicable to engines used in light commercial vehicles (LCV), as indicated.

Table 1. Emissions Standards for Diesel Trucks and Buses

Year	Reference Standard	CO	HC	NO_x	PM	Comments
		g/kWh				
1994	Euro 0	11.2	2.45	14.4	-	Urban buses
1995	Euro 1*	4.9	1.23	9.0	-	Urban buses
1996	Euro 1*	4.9	1.23	9.0	0.4[a]	LCV & Trucks
1998	Euro 2	4.0	1.1	7.0	0.4[a]	Urban buses
2000	Euro 2	4.0	1.1	7.0	0.15[a]	LCV & Trucks

* production conformity limit
[a] - multiply by a factor of 1.7 for engines below 85 kW

Table 2. Emissions Standards for Diesel Trucks and Buses: MY 2006 and later			
Reference Standard	Year		Comments
	New models	All models	
Euro III	2006	2007	Resolution 731/2005 [2766]
Euro VI[a]	2009	2011	Resolution 731/2005 [2766]
Euro V	2016	2018	Resolution 35/2009 [2770], 1434/2011 [2769], 1800/2011 [2768], 1448/2012 [2767], 1464/2014 [3201], Directive 2005/55/EC [1569]
[a] - Euro III ceifications are allowed for engines in hevy vehicles (>3500 kg) until 31 December 2015.			

Since 2006, Argentina has been adopting EU heavy-duty emission standards by reference. The implementation schedule is summarized in Table 2.

Emissions Standards: Brazil
Heavy-Duty Engines

Regulatory Background

Brazilian emission regulations for heavy-duty engines have been adopted as a series of increasingly more stringent tiers, designated PROCONVE P-1, P-2, P-3, etc. The emission standards are applicable to motor vehicles for the transportation of passengers and/or goods, with maximum gross vehicle weight higher than 3,856 kg or the vehicle curb weight higher than 2,720 kg.

The smoke control or, indirectly, particulate matter control began in 1987 with the adoption of opacity limit (k > 2.5) throughout the maximum torque curve of diesel engines. Noise control began in 1994. Emission standards were adopted in a series of steps:

PROCONVE P-1 voluntary standards were implemented in 1990, followed by P-2 mandatory standards in 1993, P-3 standards in 1994 and P-4 standards in 1998. These standards were also applicable to engines used in light trucks.

PROCONVE P-5, based on Euro III and including transient testing, was phased-in over 2004-2006.

PROCONVE P-6, based on Euro IV, was scheduled to become effective from 2009. However, because low sulfur diesel fuel was not available, the P-5 stage remained in effect until the end of 2011.

PROCONVE P-7, Resolution Conama 403/2008, was adopted in 2008 with implementation from 2012. The standards are based on Euro V.

PROCONVE P-8, based on Euro VI, was adopted in 2018 with implementation from 2022.

1993-2005: P1 Through P4

Emission standards for new MY 1993-2005 diesel fueled trucks and buses are summarized in Table 1. The same standards also applied to light-duty truck engines. All truck and bus engines, including those used in light trucks, were certified on an engine dynamometer (test cycle ECE R-49).

In addition to the P1 to P4 srtandards, new engines have to meet the following free acceleration smoke limits (effective March 94):

0.83/m (30 HSU) for naturally aspirated engines.

1.19/m (40 HSU) for turbocharged engines.

2006-2021: P-5 through P-7

Emission standards applicable to heavy-duty diesel and gas engines since 2006 are summarized in Table 2. Diesel engines are tested over both the ESC and ETC tests, while gas engines are tested over the ETC test only.

Table 1. Emissions Standards for Diesel-fueled Trucks and Buses							
Tier	Year		CO	HC	NO_x	PM	Reference Standard
	City Bus	All	g/kWh				
P-1	1990†		11.2	2.45	14.4	-	Urban buses
P-2	1993		4.9	1.23	9.0	-	Urban buses
P-3	1994	1996	4.9	1.23	9.0	0.4[a]	LCV & Trucks
P-4	1998	2000	4.0	1.1	7.0	0.4[a]	Urban buses
† - voluntary standards [a] - production conformity limit [b] - multiply by a factor of 1.7 for engines below 85 kW [c] - 0.25 g/kWh for engines up to 0.7 liter, rated speed above 3000 rpm							

Table 2. Emissions Standards for Heavy-duty Diesel and Gas Engines (Durability: 160,000 km/5 years)

Tier	Year	Test	CO	THC	NMHC	NO_x	PM†	Smoke
			g/kWh					m-1
P-5	2006[1,2,3]	ESC/ELR	2.1	0.66	-	5.0	0.10 or 0.13[5]	0.8
		ETC[4]	5.45	-	0.78	5.0	0.16 or 0.21[5]	-
P-6	2009[6]	ESC/ELR	1.5	0.46	-	3.5	0.02	0.5
		ETC	4.0	-	0.55	3.5	0.03	-
P-7	2012	ESC/ELR	1.5	0.46	-	2.0	0.02	0.5
		ETC	4.0	-	0.55	2.0	0.03	-

† - applicable to diesel engines only
[1] - 2004 for urban buses or 60% of annual production of urban buses (100% by 01/01/2005); in that case, manufacturers must produce at least 60% observing PROCONVE P-5 for the non-urban bus HD annual production
[2] - 2005 for micro-buses
[3] - 2005 40% of production/year of HD (except urban bus and micro-bus) per manufacturer
[4] - diesel vehicles without catalysts or particulate filters can be tested over ESC cycle only
[5] - for engines of less than 0.75 dm^3 swept volume per cylinder and a rated power speed of more than 3000 rpm
[6] - PROCONVE P-6 standards were never enforced (because low sulphur fuel was not available), P-5 standards remained in effect through the end of 2011

2022 and Later: P-8 Standards

The P-8 standards apply to all new on-road passenger and freight vehicles with compression-ignition or spark-ignition engines and weighing at least 3,856 kg. The standards go into effect on 1 January 2022 for new type approvals, and on 1 January 2023 for all new sales and registrations [4257] [4258].

Table 3. PROCONVE P-8 emissions standards for heavy-duty engines

Test	CO	THC[a]	NMHC[b]	CH_4[b]	NOx	NH_3	PM	PN
	mg/kWh					ppm	mg/kWh	kWh^{-1}
WHSC[a]	1500	130	-	-	400	10	10	$8.0x10^{11}$
WHTC[a]	4000	160	-	-	460	10	10	$6.0x10^{11}$
WHTC[b]	4000	-	160	500	460	10	10	-
OCE (WNTE)	2000	220	-	-	600	-	16	-
ISC (PEMS)	6000	240	240	750	690	-	-	-

[a] Applicable to compression-ignition (diesel) engines only
[b] Applicable to spark-ignition (gasoline and natural gas) engines only
[c] Applicable to engines with SCR aftertreatment and to natural gas engines

The P-8 standards are based on Euro VI regulations—they introduce the Euro VI test cycles and testing requirements, off-cycle emission (OCE) and in-service conformity (ISC) testing, as well as particle number (PN) emission limits for diesel engines. The latter are expected to force the use of diesel particulate filters on all heavy-duty diesel engines. P-8 emission limits are summarized in Table 3.

Emissions Standards: Brazil
Non-Road Diesel Engines

In July 2011, CONAMA adopted Resolution 433/2011 [Conama 2011] limiting exhaust emissions and noise from new construction and farm machinery. Referred to as PROCONVE MAR-I, it is the first legislation to regulate emissions from nonroad mobile machinery in Brazil. It sets limits equivalent to USA Tier 3 and EU Stage III A for nonroad diesel engine emissions.

MAR-I emission limits are phased in from 2015 to 2019. The implementation dates depend on the power category and type of machinery (construction or farm), as shown in Table 1. Noise emission limits apply from 2015 for certain types of construction machinery with engines rated below 500 kW.

Table 1. MAR-I Emissions Standards for Nonroad Engines

Rated Power	Date		CO	NO_x+HC	PM
kW	Construction	Farming	g/kWh		
130 ≤ P ≤ 560	2015.01	2017.01	3.5	4.0	0.2
75 ≤ P < 130	2015.01	2017.01	5.0	4.0	0.3
37 ≤ P < 75	2015.01	2019.01	5.0	4.7	0.4
19 ≤ P < 37	2017.01	2019.01	5.5	7.5	0.6

Emissions are measured in accordance with ISO 8178-1.

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