

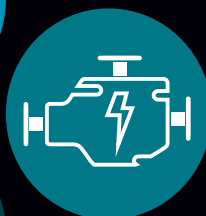
POWER SOURCING GUIDE 2024-2025

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THE GUIDE FOR DESIGN ENGINEERS

Emissions standards

United States: Heavy-duty On-road Engines

U.S. federal emission standards for heavy-duty engines are set by the Environmental Protection Agency (EPA) and California standards by California Air Resources Board (CARB). In the heavy-duty engine sector, the federal and California emission standards have historically been well aligned; the differences were relatively minor and, in most cases, temporary. However, the California Advanced Clean Truck (ACT) and Advanced Clean Fleets (ACF) regulations set zero-emission vehicle (ZEV) requirements for Class 2b-8 trucks beginning from 2024 that have no equivalent at the federal level.

The emission standards discussed in Table 1 apply to new compression ignition engines – including diesel engines and compression ignition engines fueled by natural gas and other fuels – used in heavy-duty on-road vehicles such as trucks and buses. A different set of standards (not discussed here) is applicable to heavy-duty spark ignition engines.

Table 1 summarizes the evolution of emission standards over the Federal Testing Procedure (FTP) since the 1990s.

Additional emission testing requirements have been introduced in two major steps:

1. **SET and NTE** testing was introduced in 1998 for some manufacturers and extended to all engine families from 2007.

TABLE 1. U.S. EPA Emission Standards for Heavy-duty CI Engines, FTP, g/bhp-hr						
Year	CO	HC ^a	HC ^a +NO _x	NO _x	PM	
					General	Urban Bus
1990	15.5	1.3	–	6.0	0.60	
1991	15.5	1.3	–	5.0	0.25	0.25
1993	15.5	1.3	–	5.0	0.25	0.10
1994	15.5	1.3	–	5.0	0.10	0.07
1996	15.5	1.3	–	5.0	0.10	0.05 ^b
1998	15.5	1.3	–	4.0	0.10	0.05 ^b
2004 ^c	15.5	–	2.4 ^d	–	0.10	0.05 ^b
2007	15.5	0.14 ^e	–	0.20 ^e	0.01	
2027	6.0	0.06	–	0.035 ^f	0.005	

^a - NMHC for 2004 and later standards

^b - In-use PM standard 0.07 g/bhp-hr

^c - Under the 1998 Consent Decrees, several manufacturers supplied 2004-compliant engines from October 2002.

^d - Alternative standard: NMHC+NO_x = 2.5 g/bhp-hr and NMHC = 0.5 g/bhp-hr

^e - NO_x and NMHC 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 NO_x limit of about 1.2 g/bhp-hr, based on a fleet average calculation.

^f - A NO_x compliance allowance of 0.015 g/bhp-hr is added to the standard for any in-use testing of Medium HDE and Heavy HDE

In addition, under the EPA in-use compliance testing program launched in 2005, the EPA, CARB and engine manufacturers measure in-use emissions of heavy-duty vehicles using PEMS, with compliance determined against NTE standards.

- **SET (Supplemental Emission Test):** A steady-state test to ensure that heavy-duty engine emissions are controlled during steady-state type driving and high load operation. SET emission limits are numerically equal to the FTP limits.
- **NTE (Not-to-Exceed) testing:** Driving of any type that could occur within the bounds of a predefined NTE control area, including operation under steady-state or transient conditions. NTE emission limits are higher than the corresponding FTP limits.

2. **LLC and off-cycle MAW testing** and the corresponding emission limits are applicable from 2027. The off-cycle MAW testing methodology and emission limits replace the NTE testing requirements and emission standards.

- **LLC (Low Load Cycle):** A transient dynamometer test cycle representing low speed and load driving conditions, such as in slow urban traffic. LLC emission limits are higher than FTP limits (e.g., the EPA 2027 LLC limit for NO_x is 0.050 g/bhp-hr).
- **Off-Cycle MAW Testing:** A binned moving average windows (MAW) methodology for in-use vehicle emission testing using PEMS instruments. In the EPA procedure, emissions are separated into two bins: bin 1 representing idle and very low load operation, and bin 2 representing higher power operation (including much of the operation covered by the prior NTE test). Bin 1 and bin 2 have two sets of respective emission standards.

Another important aspect of the EPA 2027 emission standards is the extension of engine *useful life periods* (i.e., the periods over which engines must meet emission standards) and mandatory warranty periods for emission-related components. For heavy heavy-duty engines (GVWR > 33,000 lb.), the useful life period is extended from 435,000 miles to 650,000 miles and the emission warranty period from 100,000 to 450,000 miles.

California: Heavy-duty On-road Engines

In August 2020, CARB adopted the heavy-duty “Omnibus” regulation. It was the first “Low NO_x” emission regulation, which preceded the EPA 2027 emission standards.

The main provisions of the Omnibus rule include lower NO_x emission standards (FTP) – 0.050 g/bhp-hr from 2024 and 0.020

g/bhp-hr from 2027 – a new low load certification cycle (LLC) and corresponding NO_x emission limits, and extended engine useful life periods. The future impact of the Omnibus regulation has been limited by the Clean Truck Partnership agreement reached in July 2023 between CARB and the leading U.S. truck manufacturers. Under the agreement, CARB committed itself to align its 2027 NO_x requirements with EPA’s 2027 standards and to modify elements of the 2024 NO_x emission regulations.

TABLE 2. California ZEV sales percentage schedule for medium- and heavy-duty vehicles (ACT/ACF regulations)

Model Year	Class 2b-3	Class 4-8	Class 7-8 Tractors
2024	5%	9%	5%
2025	7%	11%	7%
2026	10%	13%	10%
2027	15%	20%	15%
2028	20%	30%	20%
2029	25%	40%	25%
2030	30%	50%	30%
2031	35%	55%	35%
2032	40%	60%	40%
2033	45%	65%	40%
2034	50%	70%	40%
2035	55%	75%	40%
2036	100%	100%	100%

In return, manufacturers who signed the Clean Truck Partnership committed to meet California zero-emission vehicle (ZEV) and criteria pollutant regulations regardless of any attempts by other entities to challenge California’s authority. These regulations, including the CARB Advanced Clean Trucks (ACT) and Advanced Clean Fleets (ACF) rules, put in place a phased-in transition toward 100% sale and use of zero-emission technology for medium- and heavy-duty vehicles (Table 2). Until the end of 2035, manufacturers may generate partial credits by selling near-zero-emission vehicles (NZEV), defined as plug-in hybrid electric vehicles with a minimum all-electric range.

The ACT/ACF regulations have no federal equivalent; however, the U.S. EPA Phase 3 GHG emission regulations (not yet finalized at the time of writing) – to be phased-in from 2027 through 2032 – will require a certain adoption rate of heavy-duty ZEV trucks.

United States: Non-road Engines

In 2004, the EPA signed a final rule introducing the Tier 4 emission standards for non-road engines, which were phased in over the period of 2008-2015. The non-road standards cover mobile non-road diesel engines of all sizes used in a wide range of construction, agricultural and industrial equipment.

Tier 4 emission standards for engines up to 560 kW are shown in Table 3.

In engines of 56- to 560-kW rated power, the NO_x and HC standards were phased in over a few years 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”.

TABLE 3. U.S. Tier 4 emission standards – Engines up to 560 kW, g/kWh (g/bhp-hr)

Engine Power	Year	CO	NMHC	NMHC ^a +NO _x	NO _x	PM
kW < 8 (hp < 11)	2008	8.0 (6.0)	–	7.5 (5.6)	–	0.4 (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 2014.12.3

^d – PM/CO: full compliance from 2011; NO_x/HC: 50% engines must comply in 2011-2013

TABLE 4. U.S. Tier 4 emission 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)

Tier 4 emission 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.

California Tier 5 Standards. In November 2021, CARB commenced the development of Tier 5 emission standards for off-road engines. The Tier 5 standards will seek to further reduce NO_x and PM emissions from off-road engines by 50% to 90% – depending on the engine power category – in the 2030-2034 timeframe. The Tier 5 regulation would be applicable to manufacturers of new off-road diesel engines. The emission standards would be based on diesel engine technology, with no ZEV requirements.

The Tier 5 standards development is currently limited to California; there is no corresponding development at the federal level. Without a Tier 5 regulation by the U.S. EPA, California-only Tier 5 standards would have a limited scope. First, federal Clean Air Act Amendments of 1990 preempt California’s authority to control emissions from new farm and construction equipment under 175 hp – a category

representing some 50% of California off-road engine emissions. Second, current regulations do not prevent bringing off-road engines and equipment from other states to California. If California Tier 5 engines are more expensive than out-of-state Tier 4

engines, California customers can be expected to purchase their off-road equipment out of state.

The Tier 5 standards considered by CARB as of November 2023 are summarized in Table 5.

In addition, Tier 5 final emission limits for NO_x, PM and NMHC over the non-road LLC test cycle would be applicable for engines in the 56- to 560-kW power category. A GHG emission reduction of 6% would be required for engines of 56 to 560 kW.

TABLE 5. Proposed California Tier 5 criteria emission standards, g/kWh (NRTC/RMC)

Power Category	Implementation Period	NO _x	PM	NMHC	CO
< 8 kW (< 11 hp)	2031-2033	6.0*	0.3	–	8.0
	2034+	5.0*	0.2		
8 ≤ kW < 19 (11 ≤ hp < 25)	2031-2033	5.5*	0.2	–	6.6
	2034+	4.0*	0.1		
19 ≤ kW < 56 (25 ≤ hp < 75)	2031-2033	3.7	0.015	0.19	5.0
	2034+	2.5	0.008		
56 ≤ kW < 130 (75 ≤ hp < 175)	2031-2033	0.22	0.005	0.19	5.0
	2034+	0.040		0.080 ^a	
130 ≤ kW ≤ 560 (175 ≤ hp ≤ 750)	2029-2032	0.22	0.005	0.19	3.5
	2033+	0.040		0.080 ^a	
> 560 kW (Gensets) (> 750 hp)	2030-2033	0.50	0.015	0.19	3.5
	2034+	0.35	0.008	0.080 ^a	
> 560 kW (Mobile) (> 750 hp)	2030-2033	3.5	0.040	0.19	3.5
	2034+	3.0			

* - NMHC + NO_x

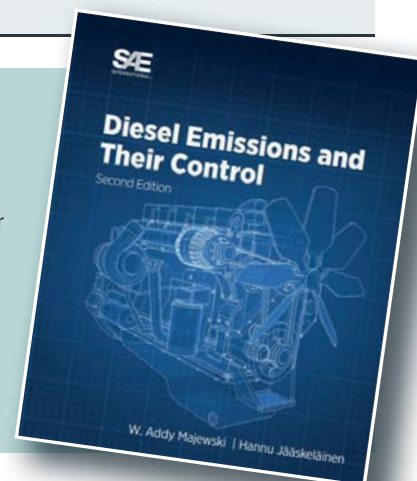
^a - The NMHC standard for lean-burn NG engine families remains at 0.19 g/kWh

REFERENCE GUIDE

The second edition of “Diesel Emissions and Their Control” by W. Addy Majewski and Hannu Jaaskelainen is available for order. It offers a substantial update to the original classic, with the authors expanding coverage of the latest emission technologies to nearly twice the information and overall pages.

The reference guide is rooted in the wealth of information available on DieselNet.com, where the “Technology Guide” papers offer in-depth insights. Each chapter includes links to relevant online materials, granting readers access to even more expertise and knowledge.

Learn more at www.sae.org/publications/books/content/r-533/



European Union: Heavy-duty On-road Engines

European emissions regulations for new heavy-duty engines are commonly referred to as Euro I ... VII. Sometimes Arabic numerals are also used (Euro 1 ... 7).

The following tables contain a summary of the emission standards since the Euro III stage and their implementation dates. Dates in the tables refer to new type approvals – the dates for all vehicles are in most cases one year later.

TABLE 6. EU emission standards for heavy-duty CI (diesel) engines: Steady-state testing								
Stage	Date	Test	CO	HC	NOx	PM	PN	Smoke
			g/kWh				1/kWh	1/m
Euro III	1999.10 <i>EEV only</i>	ESC & ELR	1.5	0.25	2.0	0.02		0.15
	2000.10		2.1	0.66	5.0	0.10 ^a		0.8
Euro IV	2005.10		1.5	0.46	3.5	0.02		0.5
Euro V	2008.10		1.5	0.46	2.0	0.02		0.5
Euro VI	2013.01	WHSC	1.5	0.13	0.40	0.01	8.0×10 ¹¹	
Euro VII ^b	2028 ^c		1.5	0.080 ^d	0.20	0.008	6.0×10 ¹¹	
^a 0.13 g/kWh for engines < 0.75 dm ³ swept volume per cylinder and a rated power speed > 3,000 rpm								
^b Not yet finalized								
^c Four years after the regulation is entered into force								
^d Non-methane organic gases, NMOG								

There are two sets of emission standards, with different types of testing requirements:

- Steady-state Testing: Table 6 lists emission standards applicable to diesel (compression ignition, CI) engines only, with steady-state emission testing requirements.
- Transient Testing: Table 7 lists standards applicable to both diesel and positive ignition (PI) engines, with transient testing requirements.

Additional provisions of the Euro VI regulation include:

- Emission limits and requirements for off-cycle emission and in-service conformity testing.
- An ammonia (NH₃) concentration limit of 10 ppm applies to CI (WHSC + WHTC) and PI (WHTC) engines.

Additional provisions of the Euro VII regulation include:

- New emission limits for NH₃ (60 mg/kWh) and N₂O (200 mg/kWh) over WHSC and WHTC tests.
- On-road testing (PEMS) limits for NOx, PN, CO, NMOG, NH₃, CH₄ and N₂O.
- Non-tailpipe emission limits for particle emissions from tires and brakes wear.

CO₂ Emission Regulations. In addition to criteria emission regulations, manufacturers of heavy trucks over 7.5 tonnes and coaches must meet fleet-average CO₂ emission reduction targets. The target for 2025 is defined in existing regulations, while the later targets – designed to force the adoption of zero-emission trucks – are a proposed regulation. The targets, compared to 2019 emission levels, are:

TABLE 7. EU emission standards for heavy-duty CI (diesel) and PI engines: Transient testing								
Stage	Date	Test	CO	NMHC	CH ₄ ^a	NOx	PM ^b	PN
			g/kWh					1/kWh
Euro III	1999.10 <i>EEV only</i>	ETC	3.0	0.40	0.65	2.0	0.02	
	2000.10		5.45	0.78	1.6	5.0	0.16 ^c	
Euro IV	2005.10		4.0	0.55	1.1	3.5	0.03	
Euro V	2008.10		4.0	0.55	1.1	2.0	0.03	
Euro VI	2013.01	WHTC	4.0	0.16 ^d	0.5	0.46	0.01	6.0×10 ^{11e}
Euro VII ^f	2028 ^g		1.5	0.08 ^h	0.5	0.20	0.008	6.0×10 ¹¹

^a Euro III-V: NG only; Euro VI: NG + LPG; Euro VII: all engines

^b Not applicable for gas-fueled engines at the Euro III-IV stages

^c 0.21 g/kWh for engines < 0.75 dm³ swept volume per cylinder and a rated power speed > 3,000 rpm

^d THC for diesel (CI) engines

^e PN limit for PI engines applies for Euro VI-B (2014.09) and later

^f Not yet finalized

^g Four years after the regulation is entered into force

^h Non-methane organic gases, NMOG

- 15% emission reduction from 2025;
- 45% emission reduction from 2030;
- 65% emission reduction from 2035;
- 90% emission reduction from 2040.

European Union: Non-road Mobile Machinery

European emission standards for engines used in new non-road mobile machinery (NRMM) have been structured as gradually more stringent tiers known as Stage I ... V standards. Stage I - IV regulations applied to diesel engines. From Stage V, the NRMM emission requirements apply to all categories of compression ignition (diesel) and positive ignition mobile non-road engines.

Stage V emission limits for engines in non-road 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. The emission limits must be met over the non-road stationary cycle (NRSC) and non-road transient cycle (NRTC).

HC Limits for Gas Engines. For engine categories where an A factor is defined, the HC limit for fully and partially gaseous-

TABLE 8. Stage V emission standards for non-road engines (NRE)								
Category	Ign.	Net Power	Date	CO	HC	NOx	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}		0.40	–
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	0.40	0.015	1×10 ¹²
NRE-v/c-6	All	130 ≤ P ≤ 560	2019	3.50	0.19 ^c	0.40	0.015	1×10 ¹²
NRE-v/c-7	All	P > 560	2019	3.50	0.19 ^d	3.50	0.045	–
^a HC+NOx								
^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								

fuelled engines indicated in the table is replaced by the one calculated from the formula:

HC = 0.19 + (1.5 x A x 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.

The Stage V regulation includes additional sets of emission limits applicable to inland waterway vessel engines and to rail traction engines.

TABLE 9. Stage V emission standards for generator set engines above 560 kW (NRG)								
Category	Ign.	Net Power kW	Date	CO	HC	NOx	PM	PN
				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								

ABOUT THE SOURCE

DieselNet is the central internet resource for technical and business information related to all types of internal combustion engines, their fuels, emissions and the technologies required by the clean and efficient engines of the future.

Find a complete listing of global emission standards by region on the DieselNet site at:
<https://dieselnet.com/standards/>

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