

CLEAN AIR TASK FORCE

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Diesel Engines: Emissions Sources and Regulations



Photo: Ed Jackson

Diesel Engines: Efficient but Dirty.

Rudolph Diesel (1858-1913) filed the first patent for the ‘economical heat motor’ in 1892. Diesel engines are the power source of choice when it comes to heavy-duty trucks, buses, trains, large ships, electricity generators, engines for non-road equipment such as excavators, cranes and agricultural equipment. Today there are over 13 million diesel engines in use in the U.S. Diesels require less maintenance and generate energy more efficiently—with less carbon dioxide emissions—than equivalent ignition-based gasoline engines but when uncontrolled, emit harmful particulate matter, nitrogen oxides and a variety of carcinogenic substances. The federal government sets standards for new diesel engines. However, the responsibility currently rests with states for cleaning up existing diesels. This summary describes major source categories of diesels and the state of current regulatory requirements controlling emissions from these sources. Companion Clean Air Task Force fact sheets are: 1) Health and Environmental Impacts, and 2) Emissions and Exposure, and 3) Emissions Controls and Retrofits. Also see Clean Air Task Force’s report [Diesel and Health in America](#) and interactive companion web at <http://www.catf.us/dieselhealth/>.

- In the U.S. diesels comprise about 5 percent of the on-road vehicles but diesels power the majority of non-road heavy equipment. In Europe, by contrast, one of every three cars sold is a diesel;

- Diesels utilize about two thirds of the fuel of a similar ignition-based gasoline engine for the equivalent power output. As a result, annual fuel costs for diesels are approximately one-third less than equivalent gasoline power engines;
- Despite the fuel economy of the diesel and lower carbon dioxide emissions, today's diesels are more harmful to human health on a per-vehicle basis than emissions from similar gasoline-powered engines;
- Heavy-duty diesel engines (engines powering vehicles with gross vehicle weight ratings of over 8,500 lbs, as classified by EPA) are durable and may be in service for two or three decades and may be typically rebuilt one or more times.

Diesel Powered Highway Vehicles, Construction Equipment, Trains and Ships Contribute to Hazardous Air Pollution.

Heavy-duty diesels can be broken down into four major categories: **1) on-road diesels, 2) non-road diesels, 3) locomotives and 4) marine vessels.** The following provides a brief description of each source category, their contributions to national emissions inventories and highlights some of the major actions to regulate their emissions:

ON-ROAD DIESELS

On-road (or highway) diesels include many types of trucks and buses such as construction, farm and transport trucks and transit, school and commercial buses. A large proportion of on-road diesel emissions come from heavy-duty diesel engines. On-road diesels released 3.4 million tons of nitrogen oxides (NO_x) in 2002, 13 percent of all U.S. NO_x emissions.¹ Emissions of other criteria pollutants are listed in Table 1.



New Heavy-Duty Diesel Emissions Standards for On-Road Engines will Reduce Emissions Significantly.

- EPA established the first standards for new heavy-duty diesel engines (HDDEs) for NO_x + hydrocarbons (HC)² for the 1974 model year.
- PM emissions standards were first promulgated for model year 1988.³
- More recently, in 2000 EPA finalized rules that require an approximate 50% reduction in emissions of NO_x from newly manufactured on-highway HDDEs, effective for model year 2004 (the "2004 HDE Rule");⁴ this rule was based on a 1995 statement of principles among EPA, the California Air Resources Board (CARB) and most heavy-duty engine manufacturers.
- In 1998 EPA, CARB and the U.S. Department of Justice settled an enforcement action against 7 HDDE manufacturers that illegally installed emissions control

“defeat devices” in 1.3 million trucks over a 10-year period. These defeat devices enhanced engine performance during actual highway operation but illegally increased NO_x emissions over those experienced during federal emissions testing. As a part of a one billion dollar settlement/consent decree, these manufacturers agreed to meet 2004 HDE rule emissions standards by October 1, 2002 (the “pull ahead rule”).

- California and a number of states assisted by STAAPA-ALAPCO have required that model year 2005 and 2006 HDDEs meet the same testing procedures as prescribed in the consent decree, filling the regulatory gap between the 2004 and 2007 rules.
- In 2001, EPA finalized regulations requiring substantially more stringent emissions limits for on-road HDDEs (the “2007 HDE Rule”) for NO_x and hydrocarbons that are phased in beginning in 2007 through 2010 and for PM effective in 2007.⁵ These standards cut 2004 model year emissions by an additional 90 percent.⁶ The 2007 HDE Rule also requires testing/certification procedures to more accurately measure emissions during real-world driving conditions.
- The 2007 standards for NO_x and HCs were set approximately 50 times lower than those for 1974⁷ and PM limits were set 60 times lower than 1988.⁸
- The 2007 HDE Rule also requires a reduction in the sulfur content of highway diesel fuel from about 500 ppm to 15 ppm by 2006 (ultra low sulfur diesel fuel or “ULSD”).
- In 2002 EPA and an independent panel found that technology development was on track to meet the requirements of the 2007 HDE Rule; and in 2004, EPA concluded in a second report that “engine manufacturers are on track for 2007.”⁹

Year	NO _x	PM2.5
1984	10.7	0.60
1991	5.0	0.25
1998	4.0	0.10
2004	2.0	0.10
2007	0.2	0.01

Table of emissions requirements for new heavy duty diesel vehicles (in grams per brake-horsepower hour).¹⁰ Diesels on the road today are not required to meet the stringent 2007 standards requiring tenfold reductions in particulate matter and NO_x emissions.

Few Federal or State In-Use Retrofit Programs Exist for On-Road Heavy Duty Diesels.

- Apart from regulations that apply to certain urban buses when they are rebuilt, EPA has not proposed diesel emission regulations for existing in-use vehicles.
- EPA operates a poorly funded voluntary diesel retrofit program supporting fleet-based diesel emission reduction programs in over 30 U.S. cities to date and with commitments for emission reductions on about 130,000 diesels.¹¹

- The California Diesel Risk Reduction Plan recommends that the state adopt retrofit requirements for most types of existing on- and off-road mobile diesels and stationary diesel engines, in conjunction with ultra-low sulfur diesel fuel.¹²
 - Thus far, CARB has enacted regulations requiring many in-use urban buses and waste collection trucks, as well as stationary and portable diesel engines (used as generators, etc.) and transport refrigeration units, to substantially reduce NO_x and PM emissions.¹³
 - Regulations reducing emissions from other California in-use highway, non-road, marine and locomotive diesels are planned.

NON-ROAD DIESELS

Non-road sources are those diesels that do not typically travel on roads or highways. Examples of non-road sources include farm and construction equipment, recreational vehicles and airport service equipment.¹⁴ Non-road diesels represent an important share of NO_x emissions in the U.S. In 2002 non-road diesels released 1.6 million tons of NO_x, 6 percent of all U.S. NO_x emissions. Emissions of other criteria pollutants are listed in Table 1.

Regulation of New Non-road Diesel Emissions.

EPA recently finalized regulations for *non-road* diesel engines that are similar to but for some engines slightly less stringent than the 2007 *on-road* engine standards. There are many kinds of non-road engines and, in general, emissions requirements have been promulgated in stages (“tiers”) relative to engine size/ power output (*e.g.* less than or greater than 50 hp).



- In 1994, EPA set emissions standards for large (> 50 hp) non-road engines (for example bulldozers) for NO_x, HC, CO and PM phased in 2 tiers—1996-2000 and 2001-2006.¹⁵
- In 1998, EPA finalized Tier 1 and 2 NO_x, HC, PM and CO standards for small (under 50 hp) non-road diesel engines (for example lawn tractors), phased in from 1999-2000 and from 2001-06 respectively.¹⁶
- The 1998 non-road rule also set stricter “Tier 3” limits for NO_x + HC emissions from large non-road engines, phased in from 2006-08 and similar in stringency to the on-road 2004 HDE Rule. Tier 3 PM standards were deferred for a later rulemaking.
- EPA’s 2001 Draft *Nonroad Diesel Emissions Standards Technical Staff Paper*¹⁷ found good technical progress toward implementation of the Tier 3 NO_x emissions standards for large non-road diesels.

- In 2004, EPA finalized regulations requiring much tighter NOx and PM emission limits for non-road diesels (the “Tier 4 Nonroad Rule”) that are phased in between 2008 and 2015 for different sized engine classes.¹⁸ Overall, EPA estimates that these standards will eventually (~2030) reduce new engine non-road emissions of PM by 95% and of NOx by 90%.
- The Tier 4 Nonroad Rule also requires a reduction of sulfur in nonroad (and marine and locomotive) diesel fuel in several phases: to 500 ppm in 2007 and to 15 ppm in 2010 for nonroad diesel engines (2012 for marine and locomotive diesel fuels).

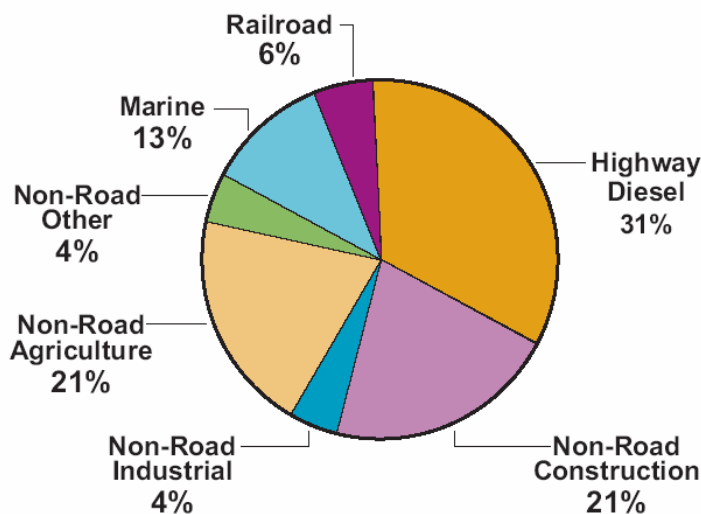
Non-Road Retrofit Programs

- The D.C. Circuit Federal Court of Appeals has ruled that EPA does not have adequate general statutory authority to implement emissions standards (e.g., federally mandated retrofit programs) from existing non-road diesel engines.¹⁹
- California’s Diesel Risk Reduction Plan contemplates controls of in-use non-road diesels.²⁰
- Non-road equipment retrofit programs have been piloted in a few cities such as Boston’s “Big Dig” (<http://www.bigdig.com/thtml/envair01.htm>) demonstrating the cost-effectiveness of retrofit controls.

Source/Pollutant (tons x 1000)	CO	NO _x	SO ₂	VOC	PM ₁₀	PM _{2.5}
On-road diesel	1,016	3,395	105	208	113	99
Non-road diesel	872	1,600	198	789	169	155
Marine diesel ¹	133	1,011	160	32	44	40
Railroad	88	889	47	35	22	20

¹Includes residual oil fueled engines.

Table 1: Major criteria pollutants from the four most important diesel source categories in 2002 (EPA).²¹ (Does not include important air toxics in diesel exhaust.)



Breakdown of the approximate 13 million diesel engines in the U.S. (Data: EPA 2002.)

MARINE DIESELS.

The marine diesel emissions of greatest concern are released from large commercial ships because they represent the largest source of marine emissions. Efforts to control marine diesels have until recently focused on NO_x, although these engines also emit substantial quantities of PM and SO₂.



- Marine diesel engines burning distillate and residual fuel in the U.S. produced over one million tons of NO_x in 2002.²²
- EPA classifies marine diesel engines in three categories according to size from category 1 (smallest) to category 3 (large international ocean-going vessels).
- In 1999, EPA promulgated regulations limiting emissions of NO_x, HC, PM and CO from category 1 and 2 diesel marine engines; the standards are effective between 2004 and 2007 and vary depending on engine size.
- At present, category 3 marine diesel engines (the largest) are not effectively regulated. Annex VI of the International Convention on the Prevention of Pollution from Ships (“Annex VI”)²³ regulates NO_x from new vessels built or modified beginning in 2000, but at roughly current new engine levels. Annex VI also limits the sulfur content of marine fuels to 4.5 % as a global cap beginning in 2005 (the present global average is less than 3%). The US has not yet ratified Annex VI, although it is expected to do so.
- In 2003, EPA finalized regulations to require new diesel marine engines (including category 3 engines) to meet Annex VI NO_x requirements by 2004.²⁴
- EPA’s Tier 4 Nonroad Rule requires a reduction of sulfur content of marine distillate fuel (used by most category 1 and 2 marine engines) to 500 ppm in 2007 and 15 ppm in 2012.²⁵
- EPA has indicated that it is considering proposing tight after-treatment based emission standards for category 1 and 2 marine engines, in order to take advantage of highly-effective after-treatment technologies that use of ULSD will facilitate.²⁶

LOCOMOTIVE DIESELS.

Locomotive diesels account for a significant portion of mobile source emissions in the U.S. today. In many areas, diesel trains travel through core urban and industrial areas, and the so-called “Amtrak” corridor in the Northeast that runs from Washington D.C. to Boston.



- Diesel locomotives released nearly 900,000 tons of NO_x in 2002, about 8% of mobile source NO_x emissions.²⁷
- Diesel locomotives contributed about 5 percent of the PM_{2.5} mobile source emissions in 2002.
- Diesel locomotives typically have a useful life of 40 years²⁸ and are commonly rebuilt 5-10 times during their long service lives. For this reason, cleaning up in-use locomotives is an important priority.
- In 1998, EPA promulgated initial standards for emissions of NO_x, PM, HC, CO and smoke from new and remanufactured locomotives, to be implemented beginning in 2000 in three tiers.²⁹ EPA estimates that the rule will eventually (~2040) produce a 60% reduction of NO_x emissions and a 46% reduction in PM emissions from these engines.
- EPA’s Tier 4 Nonroad Rule requires a reduction of sulfur content of locomotive diesel fuel to 500 ppm in 2007 and 15 ppm in 2012.³⁰
- EPA has indicated that it is considering proposing after-treatment based emission standard for locomotives, in order to take advantage of highly-effective after-treatment technologies that use of ULSD will facilitate.³¹

References:

¹ EPA, “1970 - 2002 Average annual emissions, all criteria pollutants.” See

<http://www.epa.gov/ttn/chief/trends/> and

<http://www.epa.gov/ttn/chief/trends/trends02/trendsreportallpollutants010505.xls>.

² 1974 standard for NO_x + HC = 16 grams per brake hp-hr

³ 1988 standard from PM = 0.60 grams per brake hp-hr

⁴ EPA (2000). 40 CFR Parts 85 and 86. *Control of Emissions of Air Pollution from 2004 and later Model Year Heavy Duty Highway Engines and Vehicles*; Federal Register October 6, 2000, v. 65 no. 195 page 59896.

⁵ EPA (2001). 40 CFR parts 69, 80 and 86. *Control of Air Pollution from New Motor Vehicles: Heavy Duty Engine and Vehicle Standards and Highway Diesel Fuel Sulfur Control Requirements*; Final Rule; Federal Register January 18, 2001, v.66 no 12 page 5001.

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- ⁶ The NOx limit was lowered from 2.5 to 0.2 g/bhp-hr, and the PM was lowered from limit from 0.1 to 0.01 g/bhp-hr.
- ⁷ For 2007 NOX + HC total 0.34 grams per brake hp-hr (NOx: 0.20 grams per brake hp-hr, HC: 0.14 grams per brake hp-hr) in comparison to the combined 16 grams per brake hp-hr in 1974.
- ⁸ 2007 PM requirements: 0.01 grams per brake hp-hr
- ⁹ Highway Diesel Progress Review Report 2, at p. 5, EPA420-R-04-004
<http://www.epa.gov/otaq/regs/hd2007/420r04004.pdf>, March 2004.
- ¹⁰ Environmental Protection Agency fact sheet: Diesel Exhaust in the United States. EPA 420-F-02-048, September, 2002. Available at: <http://www.epa.gov/otaq/retrofit/documents/420f03022.pdf>. The unit of measure used by EPA for diesel emissions, g/bhp-hr = grams of pollutant released per brake horsepower hour.
- ¹¹ For a map of projects, see <http://www.epa.gov/otaq/retrofit/projectmap.htm>. For a table listing EPA projects, see <http://www.epa.gov/otaq/retrofit/gaugewriteup.htm>.
- ¹² California Environmental Protection Agency Air Resources Board (2000). Risk Reduction Plan to Reduce Particulate Matter Emissions from Diesel-fueled Engines and Vehicles. See <http://www.arb.ca.gov/diesel/documents/rrpapp.htm>.
- ¹³ For a description of various CARB mobile diesel programs, see generally, <http://www.arb.ca.gov/diesel/mobile.htm>.
- ¹⁴ <http://www.epa.gov/air/off-road/>
- ¹⁵ 59 Federal Register, p. 31306, June 17, 1994.
- ¹⁶ 63 Federal Register, p. 56968 October 23, 1998
- ¹⁷ Nonroad Diesel Emissions Standards Technical Staff Paper, EPA-420-R01-053
<http://www.epa.gov/otaq/regs/nonroad/equip-hd/r01052.pdf>, October, 2001.
- ¹⁸ EPA (2004); 40 CFR Parts 9, 69, et al.; *Control of Emissions of Air Pollution from Nonroad Diesel Engines and Fuel*; Final Rule; Federal Register June 29, 2004, v.69 no. 124 page 38957 (hereafter Tier 4 Nonroad Rule).
- ¹⁹ *Engine Manufacturers Association v. EPA*, 88 F.3d 1075 (DC Cir. 1996). EPA does have authority under Section 202(a)(3)(D) of the Act (42 USC §7521(a)(3)(D)) to regulate rebuild practices and emissions for heavy-duty on-road engines, and under Section 219(d) of the Act (42 USC §7554(d)) to regulate emissions from certain rebuilt urban buses.
- ²⁰ California Environmental Protection Agency Air Resources Board (2000). Risk Reduction Plan to Reduce Particulate Matter Emissions from Diesel-fueled Engines and Vehicles. See <http://www.arb.ca.gov/diesel/documents/rrpapp.htm>.
- ²¹ EPA, “1970 - 2002 Average annual emissions, all criteria pollutants.” See <http://www.epa.gov/ttn/chief/trends/> and <http://www.epa.gov/ttn/chief/trends/trends02/trendsreportallpollutants010505.xls>.
- ²² EPA, “1970 - 2002 Average annual emissions, all criteria pollutants.” See <http://www.epa.gov/ttn/chief/trends/> and <http://www.epa.gov/ttn/chief/trends/trends02/trendsreportallpollutants010505.xls>
- ²³ International Marine Organization. See http://www.imo.org/Conventions/contents.asp?doc_id=678&topic_id=258.
- ²⁴ EPA (2003), *Control of Emissions from New Marine Compression-Ignition Engines at or Above 30 Liters per Cylinder*; Final Rule; Federal Register February 28, 2003, v. 68 no. 40, page 9746.
- ²⁵ EPA, Tier 4 Nonroad Rule.
- ²⁶ EPA (2004). *Control of Emissions of Air Pollution from New Locomotive Engines and New Marine Compression-Ignition Engines Less than 30 Liters per Cylinder*; Advanced Notice of Proposed Rulemaking; Federal Register, June 29, 2004, v. 69 no. 124 page 39276 (hereafter Marine/Locomotive ANPR).
- ²⁷ EPA, “1970 - 2002 Average annual emissions, all criteria pollutants.” See <http://www.epa.gov/ttn/chief/trends/> and <http://www.epa.gov/ttn/chief/trends/trends02/trendsreportallpollutants010505.xls>.
- ²⁸ <http://www.epa.gov/otaq/locomotv.htm>.
- ²⁹ EPA (1998). 40 CFR Part 85, 89 and 92. *Emission Standards for Locomotives and Locomotive Engines*; Final Rule; Federal Register, April 16, 1998, v.63 no 73 page 18978.
- ³⁰ See note 24.
- ³¹ See note 25.

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