Technical Highlights

Emission Factors for Locomotives

The Environmental Protection Agency (EPA) has established emission standards for oxides of nitrogen (NOx), hydrocarbons (HC), carbon monoxide (CO), particulate matter (PM) and smoke for newly manufactured and remanufactured locomotives. These standards, which are codified at 40 CFR part 1033, include several sets of emission standards with applicability dependent on the date a locomotive is first manufactured. The first set of standards (Tier 0) applies to most locomotives originally manufactured before 2001. The most stringent set of standards (Tier 4) applies to locomotives originally manufactured in 2015 and later. This fact sheet describes EPA's estimates of the typical in-use emission rates for locomotives subject to these standards, as well as the previous standards.

It is important to emphasize that this fact sheet relies on many simplifying assumptions. Thus emission rates calculated as described in this fact sheet should be considered as approximations.

Estimated Locomotive Emission Rates by Tier

EPA has estimated average emission rates, given in grams per brake horsepower-hour (g/bhp-hr), for uncontrolled locomotives and those required to meet the various emission standards. Emissions were estimated for two different types of operation: a low power cycle representing operation in a switch yard, and a higher power cycle representative of general line-haul operation. These estimates are shown in Tables 1 and 2. Note that plus signs in the table indicate that a given tier of standards was revised in a 2008 rulemaking (73 FR 37096, June 30, 2008). For example, locomotives originally manufactured in years 2002-2004 were initially subject to the original Tier 1 standards, but will be required to meet revised Tier 1 standards (also known as Tier 1+ standards) when remanufactured. See the regulatory text for a more precise explanation of which standards apply to which locomotives.

EPA United States Environmental Protection Agency

Office of Transportation and Air Quality
EPA-420-F-09-025
April 2009

It is important to note that there can be significant variability in in-use emission rates, especially for uncontrolled locomotives. Also, a single locomotive's emission rate can vary throughout its life as the engine ages and as ambient conditions change. Thus the values presented here are intended to reflect the average emission rates. It is also worth noting that these emission estimates were developed in the context of adopting new emission standards. This is especially important for the CO emission factors. Because EPA's CO emission standards were intended to cap CO emissions at pre-control levels (which were relatively low), we have not projected any reductions in CO emission factors. However, recent testing indicates that emission controls designed to reduce PM and HC emissions are also reducing CO emissions. Thus the CO emission rates presented here may be too high and should be used with some caution. A similar effect may also apply for HC emissions from Tier 0 and Tier 1 locomotives (but not the Tier 0+ and Tier 1+ locomotives).

Table 1 - Line-Haul Emission Factors (g/bhp-hr)

	PM_{10}	HC	NO_x	CO
UNCONTROLLED	0.32	0.48	13.00	1.28
TIER 0	0.32	0.48	8.60	1.28
TIER 0+	0.20	0.30	7.20	1.28
TIER 1	0.32	0.47	6.70	1.28
TIER 1+	0.20	0.29	6.70	1.28
TIER2	0.18	0.26	4.95	1.28
TIER 2+ & TIER 3	0.08	0.13	4.95	1.28
TIER 4	0.015	0.04	1.00	1.28
+ INDICATES THAT THESE ARE THE REVISED STANDARDS IN 40 CFR PART 1033				

Table 2 - Switch Emission Factors (g/bhp-hr)

	PM_{10}	HC	NO_x	CO
UNCONTROLLED	0.44	1.01	17.40	1.83
TIER 0	0.44	1.01	12.60	1.83
TIER 0+	0.23	0.57	10.60	1.83
TIER 1	0.43	1.01	9.90	1.83
TIER 1+	0.23	0.57	9.90	1.83
TIER2	0.19	0.51	7.30	1.83
TIER 2+	0.11	0.26	7.30	1.83
TIER 3	0.08	0.26	4.50	1.83
TIER 4	0.015	0.08	1.00	1.83
+ INDICATES THAT THESE ARE THE REVISED STANDARDS IN 40 CFR PART 1033				

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Conversion to Gram per Gallon Emission Factors

It is often useful to express emission rates as grams of pollutant emitted per gallon of fuel consumed (g/gal). This can be done by multiplying the emission rates in Table 1 or 2 by a conversion factor relating the fuel consumption (gal/hr) and the usable power (bhp) of the engine. EPA has estimated different conversion factors for different types of locomotive service as shown in Table 3. The two primary reasons for the differences are variations in locomotive age and duty cycle. Fuel efficiency tends to be worse for older locomotive designs and for locomotives used in low power applications such as switching. Note that the g/gal emission factors presented at the end of this fact sheet can be converted back to g/bhp-hr by dividing them by the conversion factors shown here.

Table 3
Conversion Factors (bhp-hr/gal)

Locomotive Application	Conversion Factor (bhp-hr/gal)
Large Line-Haul and Passenger	20.8
Small Line-Haul	18.2
Switching	15.2

Conversion to Gram per Ton-Mile Emission Factors

In some cases, it can be helpful to express emission factors as grams emitted per ton-mile of freight hauled. However, this can also be very problematic because the amount of engine work required for each ton-mile varies significantly with a variety of factors. For example, it takes more work to haul freight through mountainous terrain than across flat areas. Since EPA does not have detailed information about these variations, we cannot provide accurate g/ton-mile emission rates. However, very approximate national average values can be calculated based on data collected by the Association of American Railroads for revenue ton-miles and fuel consumption, which show that about one gallon of fuel is consumed by the railroads to haul 400 tons-miles of freight. Thus dividing g/gal emission rates by 400 ton-miles/gal gives approximate g/ton-mile emission rates.

Emission Inventory Estimation

Total emissions can be calculated by multiplying the emission factors (in g/gal) by the fuel consumption rates (in million-gal/yr) to give annual emission rates (in metric tons per year). Multiplying this metric estimate by 1.102 gives standard U.S. tons (or short tons) per year.

EPA has estimated that locomotives consume approximately 4 billion gallons of diesel fuel each year. This includes national/regional freight service, switching, local freight service, and passenger service. The relative amounts of fuel used in the United States for these four different types of operation are shown in Table 4. The great majority of fuel consumed by locomotives each year is used in line-haul freight service by the largest railroads. Smaller amounts are also used in switching and passenger service, and by very small railroads. For the purpose of this fact sheet, we are aggregating the largest railroads with smaller railroads that are fully subject to EPA's emission requirements. This includes regional railroads as well as other railroads such as those that are owned by large businesses. The local freight category includes only those railroads that meet our regulatory definition of "small railroad" (40 CFR 1033.901) to qualify for small business allowances under our regulations. These railroads are included in this fact sheet as local whether or not they are truly local in nature. The passenger category includes local commuter railroads and AMTRAK.

Table 4 - Locomotive Fuel Consumption by Service Category	
National and Regional Freight Line-haul	88%
National Freight Switching	7%
Local Freight	<2%
Passenger	3%

Other Pollutants

The preceding emission factors include those pollutants for which EPA has set emission standards. However, other pollutants may also be of interest.

The broad category of volatile organic compounds (VOC) is a slightly different way of aggregating the organic pollutants controlled by our HC emission standards. In our rulemaking analysis (http://www.epa.gov/otaq/regs/nonroad/420r08001a.pdf), we estimated that VOC emissions can be assumed to be equal to 1.053 times the HC emissions. Similarly, PM emissions can be expressed as PM_{10} (which includes all particles up to 10 microns in diameter) or $PM_{2.5}$ (which includes only those particles up to 2.5 microns in diameter). $PM_{2.5}$ emissions can be estimated as 0.97 times the PM_{10} emissions, meaning that nearly all of the PM is less than 2.5 microns in diameter.

Gram per gallon emissions of sulfur dioxide (SO_2) and carbon dioxide (CO_2) are largely independent of engine parameters and are primarily dependent on fuel properties. Locomotive-specific emission rates are not presented here. Instead, SO_2 and CO_2 emission rates should be calculated based on the properties of the specific fuel being used by the locomotives. These emission rates can also be assumed to be the same as for other diesel engines operating on similar fuel. Note that special caution should be used when estimating SO_2 emission rates since the sulfur content of diesel fuel varies much more than the carbon content. Also, while the vast majority of sulfur in the fuel is typically converted to SO_2, up to 5 percent of the sulfur is oxidized further to sulfate (and forms particulate matter), so that the fraction of fuel sulfur emitted as SO_2 may be as low as 95 percent. Examples of these calculations are shown below based on inputs described in the NONROAD technical document NR-009c (http://www.epa.gov/otaq/models/nonrdmdl/nonrdmdl2004/420p04009.pdf).

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SO_2 (g/gal) = (fuel density) × (conversion factor) × (64 g SO_2/32 g S) × (S content of fuel)

Consider the example where the density of diesel fuel is 3200 g/gal, the fraction of fuel sulfur converted to SO_2 is 97.8 percent, and the sulfur content of the fuel is 300 ppm.

SO_2 (g/gal) = (3200) × (0.978) × (2.00) × (300×10^{-6}) = 1.88 g/gal

CO_2 (g/gal) = (fuel density) × (44 g CO_2/12 g C) × (C content of fuel)

Consider the example where the density of diesel fuel is 3200 g/gal and the carbon content of the fuel is 87 percent by mass.

CO_2 (g/gal) = (3200) × (3.67) × (0.87) = 10,217 g/gal

Other trace pollutants such as N_2O, methane, and many air toxics are more dependent on engine parameters. At this time, however, EPA does not have detailed emission rates for these pollutants from locomotives. Where estimates are needed for N_2O or methane, you may assume that emissions of these pollutants from locomotives are similar to those of other diesel engines with similar technology. For N_2O, you may assume the emissions are proportional to total NOx. For methane, you may assume the emissions are proportional to total hydrocarbons. Note however, that the presence of catalyzed components in the exhaust can significantly affect these ratios. So it is best to compare emissions from uncatalyzed locomotives to emissions from other uncatalyzed diesel engines. While this same approach could be used for air toxics (assuming that air toxic emissions are proportional to total hydrocarbons), EPA has estimated air toxic emissions from locomotives. These estimates are described in the National Emission Inventory documentation (see ftp://ftp.epa.gov/EmisInventory/2002finalnei/documentation/mobile/2002nei_mobile_nonroad_methods.pdf - appendix C).

Projected Future Emission Factors

Tables 5-7 give the expected fleet average NOx, PM_{10}, and HC emission factors by calendar year for the four categories of locomotives (the same four categories as are shown in Table 4). The steady decline in these emission factors reflects the penetration of the various tiers of locomotives into the fleet over time. More detail regarding the assumptions on which these projections were based can be found in the Regulatory Impact Analysis for the 2008 rulemaking (http://www.epa.gov/otaq/regs/nonroad/420r08001a.pdf)

For More Information

You can access the rule and related documents on EPA's Office of Transportation and Air Quality (OTAQ) Web site at: www.epa.gov/otaq/locomotives.htm.

For more information on this rule, please contact the Assessment and Standards Division information line at:

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Table 5 – NOx Emission Factors (g/gal)

Calendar Year	Large Line-haul	Large Switch	Small Railroads	Passenger/Commuter	Overall Average
2006	180	250	242	244	188
2007	175	249	242	229	183
2008	169	243	242	214	177
2009	165	241	242	200	172
2010	157	236	242	183	165
2011	149	235	242	167	157
2012	144	227	242	157	152
2013	139	225	242	147	147
2014	135	217	242	138	143
2015	129	215	240	131	137
2016	121	208	239	119	129
2017	114	206	237	112	122
2018	108	202	236	105	117
2019	103	200	233	98	112
2020	99	187	231	93	107
2021	94	185	228	88	102
2022	89	177	225	83	97
2023	84	172	223	78	92
2024	79	162	220	73	87
2025	74	150	217	68	81
2026	69	144	215	64	77
2027	65	138	212	60	72
2028	61	132	209	56	68
2029	57	126	206	52	64
2030	53	119	203	49	60
2031	49	112	200	46	56
2032	46	105	197	42	52
2033	43	98	193	39	49
2034	40	91	190	36	46
2035	37	84	187	33	43
2036	35	77	184	30	40
2037	33	71	180	28	38
2038	31	67	177	26	36
2039	29	63	174	24	34
2040	28	60	171	23	32

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Table 6 – PM_{10} Emission Factors (g/gal)

Calendar Year	Large Line-haul	Large Switch	Small Railroads	Passenger/Commuter	Overall Average
2006	6.4	6.5	6.5	6.5	6.4
2007	6.3	6.5	6.5	6.4	6.3
2008	5.1	5.5	5.7	5.1	5.1
2009	4.9	5.5	5.7	5.0	4.9
2010	4.7	5.4	5.7	4.8	4.7
2011	4.4	5.3	5.7	4.5	4.5
2012	4.1	5.1	5.7	4.2	4.2
2013	3.8	5.0	5.6	3.9	3.9
2014	3.6	4.8	5.6	3.6	3.7
2015	3.4	4.8	5.5	3.4	3.5
2016	3.1	4.6	5.5	3.1	3.3
2017	2.9	4.5	5.4	2.8	3.0
2018	2.7	4.4	5.4	2.6	2.8
2019	2.5	4.4	5.4	2.3	2.6
2020	2.3	4.1	5.3	2.1	2.5
2021	2.2	4.0	5.3	2.0	2.4
2022	2.0	3.9	5.3	1.8	2.2
2023	1.9	3.7	5.2	1.7	2.1
2024	1.7	3.5	5.2	1.5	1.9
2025	1.6	3.2	5.1	1.4	1.8
2026	1.5	3.1	5.1	1.2	1.6
2027	1.4	3.0	5.1	1.1	1.5
2028	1.3	2.8	5.0	1.0	1.4
2029	1.1	2.7	5.0	0.9	1.3
2030	1.0	2.5	4.9	0.8	1.2
2031	1.0	2.4	4.8	0.7	1.1
2032	0.9	2.2	4.8	0.7	1.0
2033	0.8	2.1	4.7	0.6	0.9
2034	0.7	1.9	4.6	0.6	0.9
2035	0.7	1.7	4.6	0.5	0.8
2036	0.6	1.6	4.5	0.5	0.7
2037	0.6	1.5	4.4	0.4	0.7
2038	0.5	1.4	4.4	0.4	0.6
2039	0.5	1.3	4.3	0.4	0.6
2040	0.4	1.2	4.2	0.3	0.5

Table 7 - HC Emission Factors (g/gal)

Calendar Year	Large Line-haul	Large Switch	Small Railroads	Passenger/Commuter	Overall Average
2006	9.5	15.0	11.7	9.7	10.0
2007	9.3	15.0	11.7	9.5	9.8
2008	9.0	14.5	11.7	9.3	9.5
2009	8.7	14.5	11.7	9.1	9.1
2010	8.3	14.1	11.7	8.6	8.8
2011	7.7	14.0	11.7	8.1	8.2
2012	7.1	13.3	11.7	7.5	7.6
2013	6.5	13.3	11.7	6.9	7.1
2014	6.1	12.7	11.7	6.3	6.7
2015	5.7	12.6	11.7	5.8	6.3
2016	5.1	12.0	11.7	5.2	5.7
2017	4.6	11.8	11.7	4.6	5.2
2018	4.2	11.5	11.7	4.1	4.8
2019	3.9	11.4	11.7	3.5	4.5
2020	3.6	10.5	11.7	3.1	4.2
2021	3.4	10.4	11.7	2.9	4.0
2022	3.2	9.8	11.7	2.7	3.8
2023	3.0	9.5	11.7	2.4	3.6
2024	2.8	8.9	11.7	2.2	3.4
2025	2.6	8.0	11.7	2.0	3.1
2026	2.5	7.6	11.7	1.8	2.9
2027	2.3	7.3	11.7	1.6	2.8
2028	2.1	6.9	11.7	1.5	2.6
2029	2.0	6.5	11.7	1.3	2.4
2030	1.9	6.2	11.7	1.2	2.3
2031	1.7	5.8	11.7	1.1	2.2
2032	1.6	5.5	11.7	1.0	2.0
2033	1.5	5.1	11.7	0.9	1.9
2034	1.4	4.7	11.7	0.8	1.8
2035	1.3	4.4	11.7	0.7	1.7
2036	1.2	4.0	11.7	0.7	1.6
2037	1.2	3.7	11.7	0.6	1.5
2038	1.1	3.6	11.7	0.6	1.4
2039	1.1	3.4	11.7	0.5	1.4
2040	1.0	3.2	11.7	0.5	1.3