SmartWay®
Transport Partnership
U.S. Environmental Protection Agency

Rail Partner 2.0.11 Tool: Technical Documentation 2011 Data Year - United States Version

EPA United States Environmental Protection Agency

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Transportation and Climate Division
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1.0 Data Sources

The SmartWay Rail Tool was developed to encourage railroad participation in SmartWay by providing methods to calculate emissions, fuel consumption, and comparison metrics based, to the extent possible, on data the participating railroad companies have on hand and provide annually to the Department of Transportation's Surface Transportation Board (STB). For example, while other data may be used, the approach presented uses data elements that Class 1 railway companies submit in their annual R-1 reports (http://stb.dot.gov/stb/industry/econ_reports.html). The relevant data reported annually on the R-1 forms include:

Power Unit Information – Form 710

Locomotive Unit Miles – Form 755, lines 8-14

Railcar Miles by Type – Form 755, lines 15-30

Fuel Consumption by Fuel Type and Unit Type – Form 750, lines 1-3

Ton-Mile Data – Form 755, lines 104, 110, 113

As Class 2 and 3 railroads do not submit R1 reports, in order for them to participate in the SmartWay program they need to develop and submit the required data specific for their operations. Where a Class 2 or 3 railroad company does not have all of the required information, surrogate data are provided in the appendix of this report that may be useful to develop some of the basic data required for the tool. Some information may also be available from the American Shortline and Regional Railroad Association (www.aslrra.org).

2.0 Emission Estimation

Regardless of the locomotive class, the SmartWay Rail Tool was designed to calculate CO2 performance metrics based on fuel consumption estimates, and NOx and PM emissions based on tier-specific engine operation information.

In the SmartWay Rail Tool, the data for line-haul (including short line-haul and passenger rail) and yard operations are handled separately, even though many of the data elements are the same. Line-haul and yard operations are sufficiently different that they require separate emission factors associated with the different duty cycles. If operational surrogates are needed, then these should be compiled specific to either line-haul or yard operations.

The specific Rail Tool calculation outputs include:

a. total mass emissions (CO_2, NOx, PM_{10} and $PM_{2.5}$)
b. g/ton-mile (gross, revenue, non-revenue)
c. g/railcar-mile (just total miles)
d. g/truck-equivalent-mile (just total miles)

The following presents the calculation procedures used to estimate these performance metrics.

1. **Calculating mass emissions (total grams)**
   a. *CO_2* [1]
      i. Diesel fuel: grams of CO_2 = total gallons diesel (freight + passenger + switching) x 10,217 g CO_2/gallon.
      ii. Biodiesel: The tool uses the biodiesel blend percentage to interpolate between regular diesel and 100% biodiesel fuel factors, with 100% biodiesel = 9,460 g/gallon. Therefore 20% biodiesel (B20) has a fuel factor of

          10,217 – (10,217 – 9,460) x (20/100) = 10,066 g CO_2/gallon

      iii. LNG: grams of CO_2 = total gallons LNG (freight + passenger + switching) x 4,394 g CO_2/gallon.
      iv. CNG: If input in cubic feet, grams of CO_2 = total cubic feet (freight + passenger + switching) x 57.8. If CNG input is in equivalent gallons, the tool multiplies total gallons by 7,030 g CO_2/gallon.
      v. Electric: grams of CO_2 = total kWh x 682 g CO_2/kWhr. See Appendix C for details.

[1] With the exception of the electricity factors, the source of the fuel-based CO_2 factors are discussed in the SmartWay Truck Tool Technical Documentation.

b. NOx and PM

i. Diesel - Data Input Methods 2 and 4 (inputs differentiated by line haul and switcher)

1. The tool first calculates the proportion of hrs/units by Tier level.

a. The following provides an example for line haul units –

Tier Level	Hrs	Fraction
Non-Tier -	**3,000 hrs**	**0.15**
0	**0 hrs**	**0.0**
0+	**1,000 hrs**	**0.05**
1	**2,000 hrs**	**0.1**
1+	**5,000 hrs**	**0.25**
2	**0 hrs**	**0.0**
2+	**4,000 hrs**	**0.2**
3	**5,000 hrs**	**0.25**
Total	**20,000 hrs**	**1.00**

b. The tool repeats this calculation for the switcher distribution

c. The tool then calculates weighted average fuel factors for NOx and PM, using the following table (source: http://www.epa.gov/oms/regs/nonroad/locomotv/420f09025.pdf).

Table 1

Engine Tier	Unit Type	g/gal		
		NOx	PM10	PM2.5
Non-tier	Line-Haul/Passenger	270.40	6.66	6.46
	Switcher	264.48	6.69	6.49
Tier 0	Line-Haul/Passenger	178.88	6.66	6.46
	Switcher	191.52	6.69	6.49
Tier 0 +	Line-Haul/Passenger	149.76	4.16	4.04
	Switcher	161.12	3.50	3.40
Tier 1	Line-Haul/Passenger	139.36	6.66	6.46
	Switcher	150.48	6.54	6.34
Tier 1 +	Line-Haul/Passenger	139.36	4.16	4.04
	Switcher	150.48	3.50	3.40
Tier 2	Line-Haul/Passenger	102.96	3.74	3.63
	Switcher	110.96	2.89	2.80
Tier 2+	Line-Haul/Passenger	102.96	1.66	1.61
	Switcher	110.96	1.67	1.62
Tier 3	Line-Haul/Passenger	102.96	1.66	1.61
	Switcher	68.40	1.22	1.18

i. Example calculation for the weighted NOx factor for line-haul case above:
Weighted average = 270.4 x 0.15 + 178.88 x 0.0 + 149.76 x 0.05 + 139.36 x 0.1 + 139.36 x 0.25 + 102.96 x 0.0 + 102.96 x 0.1 + 102.96 x 0.25 = **132.86 g/gal NOx**

ii. The tool repeats these calculations for PM_{10} and $PM_{2.5}$.

iii. All calculations are then repeated for switchers

2. The tool multiplies gallons of (freight + passenger) diesel by weighted average fuel factors for line-haul/passenger category.

3. The tool multiplies gallons of switcher diesel by weighted average fuel factors for switchers.

4. The tool sums grams for line-haul/passenger and switchers to obtain total tons for NOx, PM_{10} and $PM_{2.5}$.

ii. Diesel - Data Input Methods 1 and 3 (inputs NOT differentiated by line haul and switcher)

1. The tool uses Table 2 to calculate the weighted average fuel factors[2]

Table 2

	g/gal		
Engine Tier	NOx	PM10	PM2.5
Non-Tier	**269.96**	**6.66**	**6.46**
Tier 0	**179.83**	**6.66**	**6.46**
Tier 0+	**150.61**	**4.11**	**3.99**
Tier 1	**140.19**	**6.65**	**6.45**
Tier 1+	**140.19**	**4.11**	**3.99**
Tier 2	**103.56**	**3.68**	**3.57**
Tier 2+	**103.56**	**1.66**	**1.61**
Tier 3	**100.37**	**1.63**	**1.58**

[2] The factors in Table 2 are calculated by weighting the line haul/passenger and switcher values from Table 1 by the national average relative fuel consumption levels for these categories (0.925 and 0.075, respectively). National average values were obtained from 2010 R1 reports.

2. The tool follows the same process as for Data Input Methods 2 and 4, but there is no need to sum across unit types (step 4 above).

iii. Biodiesel –

1. Biodiesel NOx and PM10/2.5 emissions are calculated by applying an adjustment factor to diesel emissions. Therefore the first is to multiply the biodiesel gallons by the diesel fuel factors as described above to calculate an unadjusted estimates for grams of NOx, PM_{10} and $PM_{2.5}$.
2. Next the tool calculates adjustment factors based on % biodiesel blend specified – see Truck Tool Technical Documentation for references.
   a. % change in emissions = {exp[a × (vol% biodiesel)] - 1} × 100% Where a = 0.0009794 for NOx, and a = -0.006384 for PM10/2.5
   b. The tool applies the adjustment factor to the unadjusted grams of NOx and $PM_{10/2.5}$ calculated above. In general PM emissions are somewhat lower than diesel emissions, while NOx emissions increase slightly.

iv. LNG – [3]

1. The tool first sums total gallons of LNG across line-haul, passenger, and switchers
2. The tool then multiplies total gallons by 20.3 g/gal to obtain grams NOx; and by 1.35 g/gal to obtain PM_{10}. The tool multiplies the PM_{10} value by 1.31 to obtain $PM_{2.5}$. See Appendix A regarding the source of these fuel-based factors.

v. CNG –

1. The tool converts cubic feet of CNG to gallons if necessary with 1 standard cubic foot of CNT = 0.00823 equivalent gallons.
2. The tool sums total gallons of CNG across line-haul, passenger, and switchers
3. The tool multiplies total gallons by 20.3 g/gal to obtain grams NOx; and by 1.35 g/gal to obtain PM_{10}. The tool multiplies the PM_{10} value by 1.31 to obtain $PM_{2.5}$. See Appendix A regarding the source of these fuel-based factors.

vi. Electricity –

1. The tool sums total kWh of electricity across line-haul, passenger, and switchers
2. The tool then multiplies total kWh by 0.690 to obtain grams NOx; by 0.058 for grams PM_{10}; and by 0.033 for grams $PM_{2.5}$. See Appendix C for details.

[3] LNG, CNG, and Electricity factors do not vary with engine tier. Therefore the tool does not calculate weighted averages based on tier level distributions, but simply uses the gallons and/or kWh amounts from the Operations screen.

2. **Calculate g/ton-mile for each pollutant (three types of "ton-miles")**
    a. Grams per gross ton-mile: the tool divides the grams of each pollutant (fleet total) by gross ton miles entered on Operations screen.
    b. Grams per revenue ton-mile: the tool divides the grams of each pollutant (fleet total) by revenue ton miles entered on Operations screen.
    c. Grams per non-revenue ton-mile: the tool divides the grams of each pollutant (fleet total) by non-revenue ton miles entered on Operations screen.
3. **Calculate g/railcar-mile for each pollutant**
    a. The tool divides the grams of each pollutant by total railcar miles (the **bold** total on the **Cars** screen)
4. **Calculate g/truck-equivalent-mile**
    a. The tool first calculates the weighted average railcar volume for the entire fleet.
        i. The tool uses the final volumes for each car type – these may be the defaults, provided by the user, or a combination thereof. The defaults represent the national average values derived from the 2010 R1 reports, weighted by railcar miles – see **Table 3** below.
        ii. Using the distribution of total railcar miles by type as the weighting factors, the total railcar miles are summed (across Owned and Leased + private / Loaded + Empty – that is, the far right column on the Cars screen) for each type to determine the fractional contribution. Fractions must sum to 1.00.
        iii. The tool applies weighting factors to final volumes by car type and sums across all car types to obtain final weighted average railcar volumes (in cubic feet).
    b. Calculate the "truckload equivalents" factor (TE): divide the weighted average railcar volume by 3,780 cubic feet.[4]
    c. g/truck-equivalent-mile = g/railcar-mile / TE, and is calculated for each pollutant.

[4] Truck industry average freight volume is 2.78 TEU = 3,780 cubic feet (see Shipper Tool Technical Documentation, p. 24).

Table 3. National Average Railcar Volume Data (Tool Defaults)

Type in Tool	Railcar Type	Cubic Feet	Source/Assumption *Key:* Norfolk Southern (NS), Union Pacific (UP), Burlington Northern Santa Fe (BNSF), CSX Transportation (CSX), Guide to Railcars (GTRC), Chicago Rail Car Leasing (CRCL), Union Tank Car Company (UTCC), U.S Department of Agriculture (USDA)
Box-Plain 50' + Box Equipped	Boxcar 50 ft and longer including equipped boxcars	7177	Based on the average of the following boxcar types: 50ft assumed to be 5694 [reflecting the average of 5355 (NS), 5431 (UP), 5238 (CSX), 6175 (BSNF), 6269 (GTRC)]. 60ft assumed to be 6,648 [reflecting the average of 6618 (NS), 6389 (UP), 6085 (CSX), 7500 (BNSF)]. 50ft high cube assumed to be 6,304 [reflecting the average of 6339 (NS) and 6269 (CSX)]. 60 ft high cube assumed to be 6917 [reflecting the average of 7499 (NS) , 6646 (CSX), and 6607 (GTRC)]. 86ft assumed to be 9999 (NS). Autoparts assumed to be 7499 (NS).
Box-Plain 40'	Boxcar 40ft	4555	Based on estimate of 50ft boxcar volume described above. Assumed 40ft length would result in 20% reduction in volume.
Flat TOFC/COFC Flat General Service Flat all other	Flat car – all types except for multi-level	6395	Based on the average of the following flat car types: 60ft assumed to be 6739 (BNSF). 89ft assumed to be 9372(BNSF). Coil assumed to be 3387(NS). Covered coil assumed to be 5294 [reflecting the average of 8328 (NS) and 2260 (BNSF)]. Centerbeam assumed to be 6546 [reflecting the average of 5857 (UP) and 7236 (BNSF)]. Bulkhead assumed to be 7030 (BNSF).
Flat Multi level	Multi-level flat car	13625	Based on the average of the following multi-level flat car types: Unilevel (that carry very large cargo, such as vehicles/tractors) assumed to be 12183 (NS). Bi-level assumed to be 14381(NS). Tri-level assumed to be 14313 (based on average of 15287 (NS) and 13339 (BNSF).
	Flat Car – all types-including multi-level	7428	Based on the average volumes of the flatcar types described above including multi-level as a single flat car type.
Gondola Plain Gondola Equipped	Gondola – all types Including equipped	5190	Based on the average of the following gondola car types: 52-53ft assumed to be 2626 [based on average of 2665 (NS), 2743 (CSX), 2400 (BNSF), and 2697(CRLC)]. 60-66ft assumed to be 3372 [based on average of 3281 (NS), 3242 (CSX), 3350 (BNSF), CRCL-3670,and 3366 (GTRC)]. Municipal Waste assumed to be 7999 (NS). Woodchip assumed to be 7781[based on average of 7862 (NS) and 7700 (CRCL)]. Coal assumed to be 4170 [based on average of 3785 (NS) and 4556 (BNSF)].
Refrigerator Mechanical Refrigerated non-mechanical	Refrigerated - Mechanical /non-Mechanical	6202	Based on the average of the following refrigerated car types: 48-72ft assumed to be 6963 [based on average of 6043 (UP) and 7883 (BNSF)]. 50ft assumed to be 5167(GTRC). 40-90 ft assumed to be 6476 [based on average of 6952 (UP) and 6000 (BNSF)].

Hopper Oper Top-General Service	**Open Top Hopper**	**4220**	**Based on the average of the following open top hopper car types: <u>42ft</u> assumed to be 3000 (UP). <u>54ft</u> assumed to be 3700 (UP). <u>60ft</u> assumed to be 5188 [based on average of 5125 (UP) and 5250 (GTRC)]. <u>45ft+</u> assumed to be 4105 [based on average of 4500 (UP) and 3710 (BNSF). <u>Woodchip</u> assumed to be 7075 [based on average of 7525 (NS), 5999 (UP), and 7700 (CRCL)]. <u>Small Aggregate</u> assumed to be 2252 [based on average of 2150 (NS), 2106 (BNSF), and 2500 (CRCL)].**
Hopper Covered	**Covered Top Hopper**	**4188**	**Based on the average of the following covered top hopper car types: <u>45ft</u> assumed to be 5250 (GTRC). <u>Aggregate</u> assumed to be 2575 [based on average of 2150 (NS) and 3000 (CRCL)]. <u>Small Cube Gravel</u> assumed to be 2939 [based on average of 2655 (NS), 3100 (CSX), and 3063 (BNSF). <u>Med-Large Cube Ores and Sand</u> assumed to be 4169 [based on average of 3750 (NS) and 4589 (BNSF)]. <u>Jumbo</u> assumed to be 5147 [based on average of 4875 (NS), 4462 (CSX), 5175 (BNSF), and 6075 (CRCL)]. <u>Pressure Differential (flour</u>) assumed to be 5050 [based on average of 5124 (NS) and 4975 (CRCL)].**
Tank under 22,000 gallons	**Tank Cars under 22,000 gallons**	**2314**	**Assumes 1 gallon=0.1337 cubic foot (USDA). Based on small tank car average volume of 17304 gallons, which is the average of the following currently manufactured tank car volume design capacities of 13470, 13710, 15100, 15960, 16410,17300,19900,20000,20590, and 20610 gallons (GTRC).**
Tank over 22,000 gallons	**Tank Cars over 22,000 gallons**	**3857**	**Assumes 1 gallon=0.1337 (USDA). Based on large tank car volume of 28851 gallons, which is the average of the following currently manufactured tank car volume design capacities of 23470, 25790, 27200, 28700, 30000, 33000, and 33800 gallons (GTRC).**
All other cars Work Equip & company Freight No payment car-miles	**All Other Cars**	**5014**	**Based on average volume presented above for each of the nine railcar types (all flatcars are represented by the line item that includes multi-level flatcars - 7428).**

References

California Air Resource Board, *Rail Yard Agreement*, Sacramento California 2007.

U.S. Department of Transportation, Bureau of Transportation Statistics, *Freight in America,* January 2006.

U.S. Department of Transportation, Surface Transportation Board, Form R-1 http://stb.dot.gov/stb/industry/econ_reports.html

United States Code of Federal Regulations Title 40 Section Chapter 1, Subchapter Q, Part 600.113,- Fuel Economy Calculations

U.S. Environmental Protection Agency, *Regulatory Support Document: Locomotive Emission Standards Final Rule*, 1997.

U.S. Environmental Protection Agency, *2009 Locomotive Emission Factor Study*, Ann Arbor, MI.2009.

U.S. Environmental Protection Agency, MARKAL Input Data for non-Light Duty Vehicles, Research Triangle Park, NC 2009

Appendix A: Locomotive Emission Factors

A-1. Fuel-based emission Factors

Table A-1.1 – Line Haul Locomotive Emission Factors (grams of pollutant per gallon)

Pollutant	NO_x	PM_{10}	CO_2
Diesel	270.40[2]	6.66[2]	10,217[2]
Biodiesel (B-20)	173[1]	7.88[1]	9,460[4]
CNG			7,030[4]
LNG	20.3[3]	1.35[3]	3,865[4]

1. MARKAL data (2009)
2. EPA Locomotive Emission Factors (2009)
3. ARB Rail Yard Agreement (2007) in terms of diesel equivalents
4. 40 CFR 600.113

Table A-1.2 – Small Line-haul Locomotive Emission Factors (grams of pollutant per gallon)

Small Line-Haul	Emission Factor g/gal
NO_x	236.60
PM_{10}	5.82
CO_2	10,217

Small Line-haul locomotive emission factors were obtained from EPA's Locomotive Emission Factors (2009).

Table A-1.3 – Yard Locomotive Emission Factors (grams of pollutant per gallon)

Yard	Emission Factor g/gal
NO_x	264.48
PM_{10}	6.69
CO_2	10,217

Uncontrolled yard locomotive emission factors were obtained from EPA's Locomotive Emission Factors (2009).

Appendix B: Surrogate Locomotive Data

Surrogate Data for Emission Estimation

Data provided in the R-1 reports have been compiled and evaluated to identify useful surrogates that may help partners gap-fill missing data. Because the data is from Class I operations, it may be biased to larger operations.

B-1 Surrogates for Calculating Fuel Consumption

The basic approach allows for emission calculations that roughly approximate emissions using reported total annual fuel consumption. If annual fuel consumption data are unknown, surrogate data, such as locomotive population, miles traveled, annual ton-miles or TEU-miles, can be used to provide an estimate for line-haul locomotive fuel consumption, as noted in the following table.

Table B-1 Fuel Usage Surrogates

Line-Haul Surrogate Data Options in Absence of Annual Fuel Usage	Number of Locomotives	Total Annual Miles	Total Annual Ton Miles Freight Transported	Total Annual TEU-mile Equivalents
Multiplication Factor for estimating Annual Fuel Usage (gal/yr)	209,165 (gal/yr*locomotive)	0.199 (gal/yr*total miles)	0.002 (gal/yr*ton miles freight transported)	0.026 (gal/yr*TEU-mile Equivalents)

When using the basic approach to estimate yard locomotive emissions, the number of locomotives can be applied to the fuel consumption factors noted in the following equation to estimate annual fuel usage:

Yard Fuel Use (gal/yr) = 195,451 (gal/yr*yard locomotive) x Number of Yard Locomotives

B-2 Surrogates for Metric Comparisons

The railroad model is designed to apply calculated emissions to a variety of operational parameters. This allows the derivation of metrics that can be used as a reference point to evaluate a partner's environmental performance relative to others.

In instances where the necessary information has not been provided, surrogate data presented in Table B-2, may be used to estimate total miles traveled or the total annual ton-miles, based on the number of active line-hail locomotives in the partner's fleet.

Table B-2 Surrogates for Estimating Annual Miles and Ton-Miles

Metric for Which Surrogate Data is Needed	Total Annual Miles Traveled	Total Annual Ton-Miles
Multiplication Factor for Estimating Annual Fuel Usage Based on Number of Locomotives	879,200 (miles/yr*locomotive)	70,276,700 (ton-miles/yr*locomotive)