

# **Locomotive Emission Inventories for the United States from ERTAC Rail**

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## **ABSTRACT**

Three nationwide locomotive emission inventories have been developed in collaboration with twenty-seven state air protection agencies, coordinated through the Eastern Regional Technical Advisory Committee, with support from railroads and industry associations. The inventories are for Class I line-haul locomotives which travel long distances, Class I switcher locomotives which largely operate within railyards, and for Shortline and Regional locomotives which generally serve specific industries and complex railyards and intermodal terminals. This paper presents the data and methodologies used to develop the inventories, the results, and potential improvements.

Locomotives generally utilize very large diesel combustion engines, resulting in emissions of NO<sub>x</sub>, PM, hydrocarbons, and greenhouse gases. Emissions are regionally distributed from long-distance hauling as well as sometimes being highly concentrated in railyards. Along with contributing to secondary pollutants such as ozone and PM<sub>2.5</sub>, which can exceed National Ambient Air Quality Standards, locomotive emissions can directly impact sensitive populations near railroad tracks and railyards (e.g. schools, hospitals, 'Environmental Justice' communities).

Locomotive emission inventory development tools often vary dramatically between states. Except for a few notable exceptions, the resulting inventories generally lack the resolution needed to support air quality modeling or 'hotspot' evaluation and are difficult to combine for cohesive systematic analysis. Freight transportation is projected to increase, dramatically in some areas near the East Coast due to the 2014 Panama Canal expansion, and technologies and techniques for reducing emissions and/or population exposure are available, making these inventories timely and useful to support the safe, efficient advancement of the United States railroad system.

## **INTRODUCTION**

Rail-related emissions can be important components of inventories used to support atmospheric management practices at local, state, regional, and national levels. Previous air quality studies often have not data needed to adequately represent this source sector in air quality modeling and planning<sup>1-6</sup>.

Air protection agencies from twenty-seven states, coordinated through the Eastern Regional Technical Advisory Committee (ERTAC) and headed by the Lake Michigan Air Directors Consortium (LADCO), identified rail as an important, but poorly characterized emission source so established a subcommittee to better quantify and characterize rail-related emissions inventories. The ERTAC Rail Subcommittee (ERTAC Rail) had active representation from twelve member states, three regional planning offices, and the US EPA (Appendix A). The subcommittee’s goals were to (1) standardize agencies’ inventory development methods through a collaborative effort, (2) improve the quality of data received and the resulting emission inventories, and (3) reduce the administrative burden on railroad companies of providing data. Information on ERTAC Rail, Railroad participation, the Rail industry, and effects of rail on air quality are available elsewhere<sup>7</sup>

With support from the Rail industry and assistance from the ERTAC Rail Data Workgroup (Appendix A), ERTAC Rail developed 3 inventories of locomotive emissions as summarized in Table 1. The inventories represent locomotive emisisions from Class I line-haul, Class I railyard switchers, and Shortline (Class III) and Regional Railroads (Class II) and are available at <http://www.georgiaair.org/airpermit/html/planningsupport/regdev/locomotives/inventories2012.htm>

**Table 1.** Summary of ERTAC Rail Inventories: U.S. Locomotive Emissions and Fuel Use for either 2007 or 2008\*.

	Fuel Use** (gal/yr)	Emissions (tons/yr)						
		NO <sub>x</sub>	PM <sub>2.5</sub>	HC	SO <sub>2</sub>	CO	NH <sub>3</sub>	CO <sub>2</sub>
Class I*** line-haul	3,770,914,002	754,443	23,439	37,941	7,836	110,969	347	42,305k
Class I switcher	301,046,290	74,431	2,042	4,867	624	9,230	28	3,367k
Class II and III	157,800,000	47,035	1,065	1,737	327	4,631	14	1,765k

\*See Appendix B for a description of the year and source of data utilized for each inventory.

\*\*Locomotive grade diesel

\*\*\*Excluding Amtrak and including work train fuel use

Because of the difficulty in obtaining data and differences in states’ needs for inventory years, data sources from both 2007 and 2008 were utilized (Appendix B.) Due to the variability and uncertainty in much of the data, the results may be considered applicable for either 2007 or 2008 or scaled to more accurately represent a selected year. This paper presents the data and methodologies used to develop the three categories of locomotive emission inventories. This set of railroad emission inventories should greatly improve our ability to estimate rail-related emissions over large areas and where locally-collected data is not available.

The Surface Transportation Board (STB) defines Class I Railroads as having had minimum carrier operating revenues of \$401.4 million (USD) in 2008. As shown in Table 2, there are 8 Class I Railroads operating in the United States, about 33 Regional Railroads (Class II), and approximately 540 Class III Railroads (Shortlines)<sup>8</sup>. While categorized as a Class I Railroad, Amtrak was excluded from

these inventories because of significant differences in equipment and operation characteristics. Class I railroads are required to report fuel use and number of locomotives for both switchers and line-haul locomotives to the STB, while Class II and III railroads do not submit data. Line-haul locomotives are usually newer, larger locomotives that travel long distances (e.g. between cities) while switcher locomotives are generally older, smaller locomotives that mostly operate within railyards, splitting and joining rail cars with varying destinations. Shortline railroads often utilize smaller, older locomotives than Class I line-haul. While duties are generally segregated, there is not always a hard-line distinction and locomotives are occasionally utilized for both hauling and switching. Passenger and Commuter Rail (including Amtrak), industrial locomotives, and associated non-locomotive equipment are not included in these inventories. The railroad emission inventories are segregated by railroad class and function because of the differences in fleet characteristics, operational patterns ('duties'), and data availability.

Class I line-haul activities are the largest source of rail-related emissions, with estimates of Class I line-haul fuel consumption totals to be from 74 to 84% of all rail sources combined<sup>4, 5</sup>. For this reason, characterizing Class I line-haul emissions were a focal point of the inventory development efforts. However, railyards and local and regional railroads can have important impacts on local scale air quality and elevated direct exposures.

**Table 2.** Class I Railroads, Reported Locomotive Fuel Use, and Railroad Fuel Consumption Index (RFCI)<sup>9</sup>.

Class I Railroads*	R-1 Reported Locomotive Fuel Use (gal/yr)		RFCI (ton-miles/gal)
	Line-Haul (2007)**	Switcher (2008)	
BNSF	1,393,874,954	52,497,057	883.14
Canadian National	93,830,751	12,290,022	1190.79
Canadian Pacific***	50,320,233	4,594,067	1096.28
CSX	514,687,186	53,717,674	963.81
Kansas City Southern	69,787,071	1,816,759	785.89
Norfolk Southern	463,267,278	32,317,375	865.75
Union Pacific	1,185,146,529	143,470,336	974.64
<b>Total</b>	<b>3,770,914,002</b>	<b>300,492,223</b>	<b>929.47</b>

\* Excluding Amtrak

\*\* Includes work trains

\*\*\* CP's line-haul fuel use values include 2008 data (rather than 2007) for their Delaware and Hudson subsidiary.

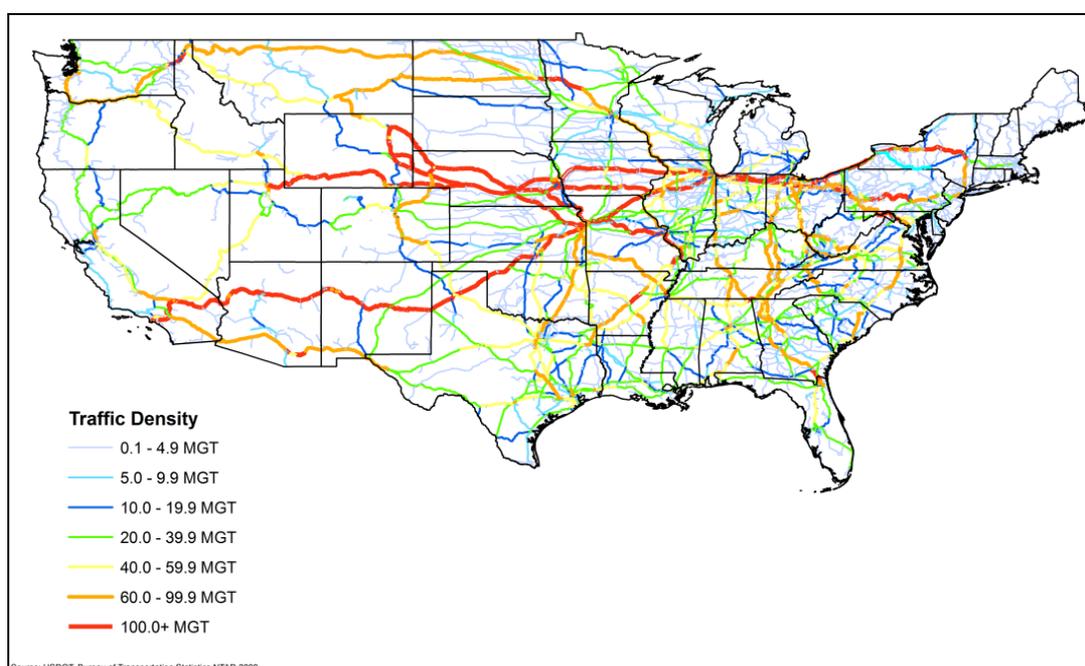
## LOCOMOTIVE EMISSIONS INVENTORY DEVELOPMENT METHODS

### Class I Line-Haul Inventory

Earlier efforts to characterize line-haul railroad emissions relied on highly aggregated activity data and generally apportioned annual system-wide fuel use equally across all route miles of track operated by a Class I railroad. However, the majority of freight tonnage carried by Class I railroads is concentrated on a disproportionately small number of route miles (Figure 1). In addition, emissions calculations were previously based on an estimate of annual nationwide-average locomotive fleet mix to create one set of emissions factors.

For this inventory, the Class I Railroads allowed ERTAC Rail access under a confidentiality agreement to a link-level (single lengths of track) line-haul GIS layer activity dataset managed by the Federal Railroad Administration<sup>10</sup>. Each railroad also provided fleet mix information that allowed ERTAC Rail to calculate weighted emission factors based on the fraction of their line-haul fleet meeting each Tier level category. The use of this data, largely following a line-haul inventory methodology recommended by Sierra Research<sup>2,3</sup>, resulted in a link-level line-haul locomotive emission inventory using railroad-specific emission factors. This segment-level inventory is nationwide, aggregated to state and county level files and can be converted to gridded emissions files for use in photochemical and dispersion modeling. Link-level emissions may be provided to third parties for special study requests pending approval of any Class I railroads operating in the study domain. The calculations are described below as a two-part process, first calculating railroad-specific factors and then total emissions per rail link.

**Figure 1.** US Railroad Traffic Density in 2006.<sup>11</sup> MGT is million gross tons.

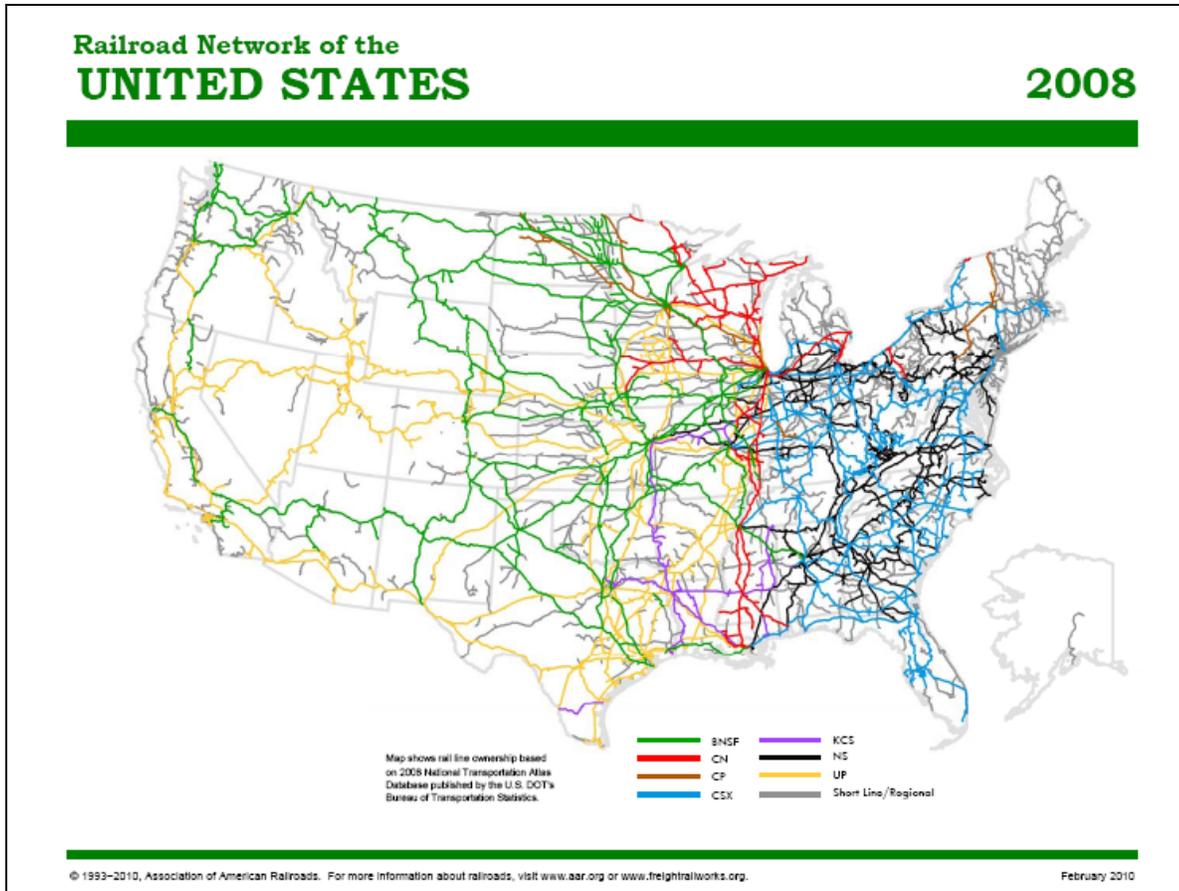


### 1) Calculate Railroad-Specific Factors.

The EPA provides annual default Emission Factors for locomotives based on characteristic operating cycles ('duty cycles') and the estimated nationwide fleet mixes for both switcher and line-haul locomotives. However, fleet mixes vary from railroad to railroad and, as can be seen in Figure 2, Class I railroad activity is highly regionalized in nature and subject to issues of local terrain such as operation on plains vs. mountainous areas, which can have a significant impact on fuel consumption and emissions.

As an alternative approach to using a single nationwide set of emission factors, ERTAC Rail requested each Class I company to provide a description of their line-haul fleet mix based on Tier rating, which each company provided under a confidentiality agreement. An engine's Tier level is based on the year the engine was built and determines allowable emission limits (Table 3).

**Figure 2.** Class I Railroad Territories in the United States<sup>12</sup>.



**Table 3.** EPA line-haul locomotive Emission Factors by Tier, 1997 standards (grams/gal). Note that the new standards released in 2008 did not apply to fleets in the year 2008.<sup>13</sup>

	PM <sub>10</sub>	HC	NO <sub>x</sub>	CO
Uncontrolled (pre-1973)	6.656	9.984	270.4	26.624
Tier 0 (1973-2001)	6.656	9.984	178.88	26.624
Tier 1 (2002-2004)	6.656	9.776	139.36	26.624
Tier 2 (2005 + )	3.744	5.408	102.96	26.624

Based on values in EPA Technical Highlights: Emission Factors for Locomotives, EPA Office of Transportation and Air Quality, EPA-420-F-09-025, April 2009.

Weighted Emission Factors (EF) per pollutant for each gallon of fuel used (gm/gal or lbs/gal) were calculated for each Class I railroad fleet based on its fraction of line-haul locomotives at each regulated Tier level (Equation 1; Table 3).

$$\text{Equation 1} \quad EF_{iRR} = \sum_{T=1}^4 (EF_{iT} * f_{TRR})$$

where

$$EF_{iRR} = \text{Weighted Emission Factor for pollutant } i \text{ for Class I railroad RR (gm/gal).}$$

- $EF_{iT}$  = Emission Factor for pollutant  $i$  for locomotives in Tier  $T$  (gm/gal) (Table 3).  
There were 4 Tiers of locomotives in the 2008 fleets.
- $f_{TRR}$  = Fraction of railroad RR fleet in Tier  $T$ .

While engine emissions are variable within Tier categories, this approach likely provides better regional estimates than uniformly applying the nationwide average emission factors. This approach likely provides conservative emission estimates as locomotive engines are certified to meet or exceed the emissions standard for each Tier, although emission levels may increase after certification and actual operations may vary widely from the line-haul duty-cycle estimation.

Other emission factors are not engine specific. For locomotives,  $PM_{2.5}$  is assumed to be 97% of  $PM_{10}$ <sup>13</sup>, and emission factors applied for  $SO_2$  and  $NH_3$  are 1.88 g/gal<sup>13</sup> and 83.3 mg/gal<sup>14</sup> respectively. Greenhouse gases are estimated using emission factors shown in Table 4. Note that non-road engine and fuel specific information is sparse for these conversions and that locomotive and marine engines are not subject to general non-road fuel or engine standards.

**Table 4.** EPA greenhouse gas emission factors for locomotive diesel fuel (grams/gal).<sup>15</sup>

	<b>CO<sub>2</sub></b>	<b>N<sub>2</sub>O</b>	<b>CH<sub>4</sub></b>
Locomotive diesel	1.015E4	0.26	0.80

A Railroad Fuel Consumption Index (RFCI) was also calculated for each Class I railroad using their system-wide line-haul fuel consumption (FC) and gross ton-mile (GTM) data reported in their annual R-1 reports submitted to the Surface Transportation Board<sup>8</sup> (Equation 2). This value represents the average number of GTM produced per gallon of diesel fuel used over their system in a year and varies between railroad carriers depending on factors such as fleet mix, system terrain, speeds, loading/weight of cargo, train type (e.g., intermodal, unit, and manifest), and operating practices. (Table 2).

$$\text{Equation (2)} \quad RFCI_{RR} = \frac{GTM_{RR}}{FC_{RR}}$$

where

- $RFCI_{RR}$  = Railroad Fuel Consumption Index (gross ton-miles/gal) per Class I railroad (RR).  
 $GTM_{RR}$  = Gross Ton-Miles (GTM), annual system-wide gross ton miles of freight transported per RR. (R-1 Report Schedule 755, Line 104)  
 $FC_{RR}$  = Annual system-wide fuel consumption by line-haul and work trains per RR (gal) (R-1 Report Schedule 750, Lines 1 and 6).

## 2) Calculate Emissions per Link.

Emissions of pollutant  $i$  per link  $L$  ( $E_{iL}$ ) are calculated by multiplying the gallons of diesel fuel consumed by each Class I railroad on the link by that railroad's weighted Emission Factor for the pollutant, and then summing emissions for all Class I railroads operating on that link (Equation 3). This approach splits the activity on each link (represented by MGT) evenly between all railroads operating on the link. Note that the weighted Emission Factors are converted to tons/gal for these calculations, and that variables with units in tons may represent tons of freight hauled (MGT, RFCI) or tons of pollutants (EF, E).

$$\text{Equation (3)} \quad E_{iL} = \sum_{RR=1}^N \left( \frac{MGT_L * 10^6}{N} \right) * l_L * EF_{iRR} / RFCI_{RR}$$

where

- $E_{iL}$  = Emissions of pollutant i per link L (tons/year).
- $N$  = Number of Class I railroads operating on link L.
- $MGT_L$  = Millions of Gross Tons hauled per link per year from the FRA database ( $10^6$  tons/yr)<sup>9</sup>.
- $l_L$  = Link length from the FRA database (miles).
- $EF_{iRR}$  = Weighted Emission Factor for pollutant i per railroad RR (Equation 1; tons/gal).
- $RFCI_{RR}$  = Railroad Fuel Consumption Index per railroad RR (Equation 2; gross ton-miles/gal).

Note that approximately 36% of Class I route miles in the United States are shared by more than one Class I carrier, a fraction that drops to 26% when neglecting track only shared between one Class I freight railroad and Amtrak. Accurately apportioning the specific fractions of tonnage (MGT) per carrier per link was considered, but after comparing likely worst-case areas, the difficulty of merging carrier-specific MGT with the aggregated FRA MGT dataset was considered too great considering the potential gain in accuracy. Where warranted, MGT data may be apportioned more accurately in the future.

### **Class I Railyard Inventory ('Switcher' Locomotives)**

Railyard emissions can be important for air quality management in nonattainment areas and exposure analysis, as well as in regional analysis and for future transportation and freight planning. While there are many unique sources operating in railyards<sup>16</sup>, switcher locomotives are expected to be the largest single source not represented by other emissions accounting techniques. Therefore, as a starting point for a comprehensive railyard inventory, this Class I switcher emission inventory was developed. It is assumed that estimates for yards of interest, associated equipment and activity, and smaller railroads could be refined later. This inventory will be useful for regional and some local modeling, helps identify where railyards need to be better characterized, and provides a strong foundation for future development of a meaningful nationwide Class I switcher emissions inventory.

The inventory provides a comprehensive overview of where Class I railyards are, who owns them, and gives a geographical allocation of switcher emissions based on number of switchers operating and/or tonnage around/through the yards, and is bounded by what is reported as nationwide switcher fuel usage by each Class I railroad. Some results were refined based on yard-specific input by the railroad companies that own the yard or from previous specific studies by states.

While ERTAC Rail represents states east of the Mississippi River, the railroad companies specified they wanted this effort to result in a consistent nationwide inventory. ERTAC Rail agreed to calculate emissions for all states when the data was available and when additional significant effort was not required. Because both the dataset of railyards and switcher fuel use was nationwide in scope, the resulting initial railyard inventory is a nationwide, 'top-down' derivation. However, railroad companies may have different levels and quality of data available, and may have interpreted some data requests

differently. Also, states are requested to update yards they have detailed information on when possible, and a few states (i.e. California) have unique railroad operations and equipment. Therefore, data for some areas will be more accurate than for others, and locally-derived inventories may be more accurate. Yard-specific operations data would greatly improve the representation of emissions<sup>6, 17</sup>.

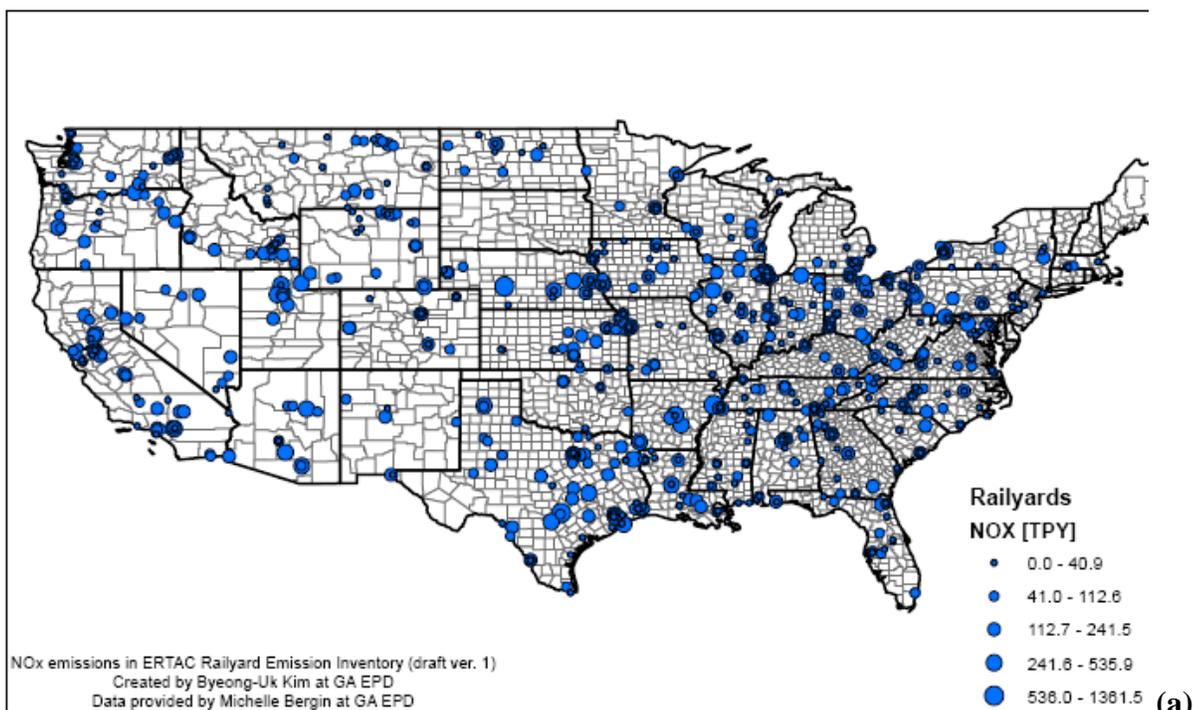
The development of this nationwide top-down railyard switcher inventory consisted of three main activities:

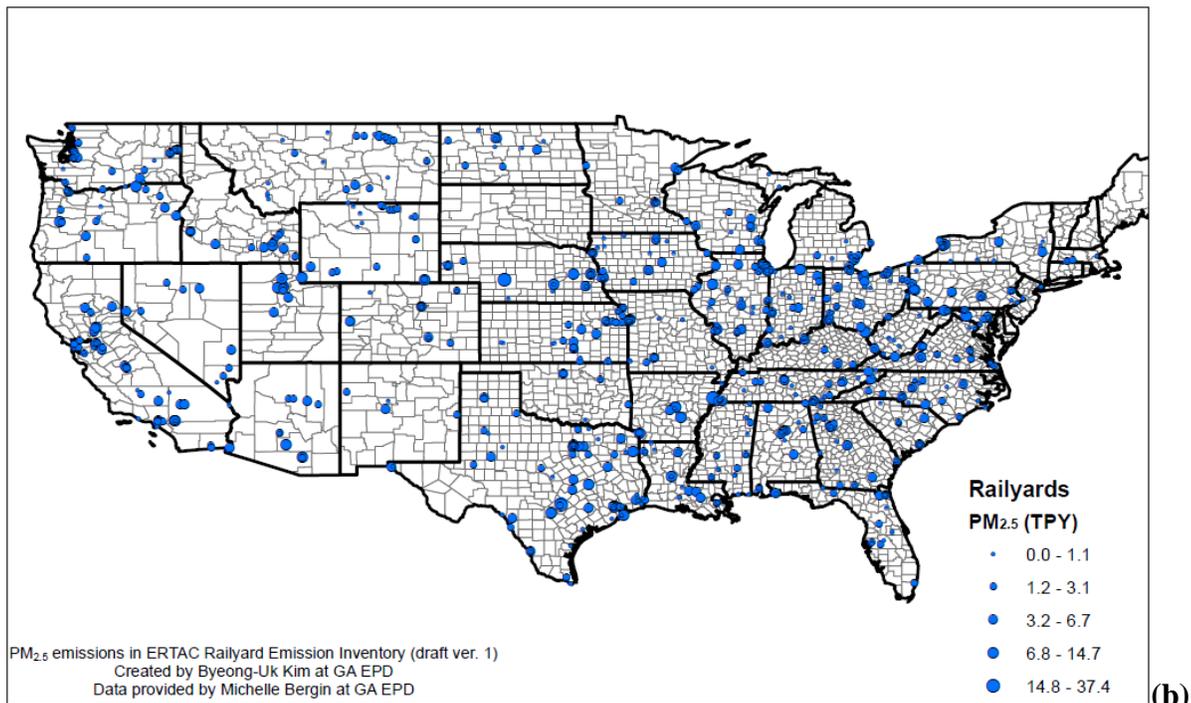
- 1) Locate Class I Railyards
- 2) Select/Calculate Emission Factors
- 3) Estimate Locomotive Activity
- 4) Improve Estimates

### 1) Locate Class I Railyards.

Identification and correct placement of railyards was an important first step, requiring a comprehensive electronic dataset. The confidential FRA database used for the Line-haul inventory<sup>10</sup> was selected because it was the best available database and would provide consistency with the Class I Line-haul inventory. A comparable public database compiled by the Bureau of Transportation Statistics is also available<sup>10</sup>. Data from the public source will not match the confidential data used for this inventory exactly but will be very similar. The FRA database has rail links (track lengths) individually identified as parts of specific railyards. While there may be discrepancies in how each railroad defined railyard links, this dataset appears to identify most Class I railyards in the U.S., and shows a high density of yards in the eastern states (Figure 3a and b). For each railyard link, the database gives length, up to 3 owners and 3 operators, and a Federal Density Code (explained below).

**Figure 3.** Class I Railyards in the United States and estimates of (a) Annual NOx emissions and (b) Annual PM2.5 emissions from switcher locomotives (tons/yr in 2008).





## 2) Select/Calculate Emission Factors.

As described in the Line-haul section, the EPA provides annual default emission factors based on characteristic operating cycles (‘duty cycles’) and an annual estimated nationwide fleet mix for both switcher and line-haul locomotives (i.e. percent of locomotives in each Tier level category). However, switcher fleet mix is not uniform from company to company and, as can be seen in Figure 2, Class I railroad activity is highly regional.

As an alternative approach to using the default factors, ERTAC Rail requested each Class I rail company to provide a description of their switcher fleet mix based on Tier rating, which each company provided under a confidentiality agreement. An engine’s Tier level determines allowable emission limits based on the year the engine was built and/or re-manufactured (Table 5). While engine emissions are variable within Tier categories, this estimate likely provides a better regional estimate than the nationwide average. The company-specific system wide fleet mix was used to calculate weighted average emissions factors for switchers operated by each Class I railroad, resulting in ranges between fleet emission factors such as from 6.10 to 6.69 g/gal PM<sub>10</sub> and 212.98 to 264.48 g/gal NO<sub>x</sub>. Emission factors for PM<sub>2.5</sub>, SO<sub>2</sub>, NH<sub>3</sub>, VOC, and GHGs are the same as for line-haul locomotives.

**Table 5.** EPA switcher locomotive emission factors by Tier, 1997 standards (grams/gal).

	PM <sub>10</sub>	HC	NO <sub>x</sub>	CO
Uncontrolled (pre-1973)	6.688	15.352	264.48	27.816
Tier 0 (1973-2001)	6.688	15.352	191.52	27.816
Tier 1 (2002-2004)	6.536	15.352	150.48	27.816
Tier 2 (2005 +)	2.888	7.752	110.96	27.816

Listed years apply to the year the engine was built. Table based on values from<sup>13</sup>. Note that the new standards released in 2008 did not apply to existing fleets in the year 2008.

Switchers are assumed to operate 24-hour per day 365 days per year. An evaluation of the effects on emissions of variability in operations and in temporal patterns between railyards would be very useful for future emission estimates.

### 3) Estimate Locomotive Activity.

The STB R-1 reports used for the line-haul inventory are also used for the switcher inventory to provide consistency (Table 2). There may be inconsistencies between railroads in how fuel use is estimated to be apportioned between line-haul and switcher locomotive use, and possibly even in the total locomotive fuel use, so these values should be evaluated and may be adjusted in the future. However, the use of these reported values provides a good starting point for segregating and allocating emissions by individual Class I carriers.

The next step for inventory development is to allocate switcher fuel use to each railyard. Two methods were first applied, one that relies on publicly available line-haul activity (the ‘Decode’ method), and the other using confidential line-haul activity (the ‘MGT’ method.) At this time, Norfolk Southern and Kansas City Southern have provided input for use of the MGT method, and the Decode method is applied for the other five railroads.

#### *The Decode Method – based on publicly available data*

Each link in both the publicly available BTS database and the confidential FRA database has a ‘Federal Density Code’ (Decode) ranging from 1 to 7 assigned based on the cumulative annual freight tonnage hauled on the link (track). Total Switcher Fuel Use in each railyard Y (SFU<sub>Y</sub>) is estimated as follows:

First a Switcher Activity Indicator per yard (SAI<sub>Y</sub>) is calculated by multiplying the average decode of the links within a railyard by the sum of the length of the links for that railyard (Equation 4).

$$\text{Equation (4)} \quad \text{SAI}_Y = \sum (l_{nY} * \text{FDC}_{nY})$$

where

$$\begin{aligned} \text{SAI}_Y &= \text{Switcher Activity Indicator in Railyard Y} \\ n_Y &= \text{number of links identified as part of railyard Y} \\ l_{nY} &= \text{length of link n in miles} \\ \text{FDC}_n &= \text{Federal Density Code (1 to 7) of link n} \end{aligned}$$

Next, this value is then weighted (SAI<sub>Y</sub>’) based on an ownership factor (OF) set between 0 and 1. The OF depends on the number of owners listed for each railyard: if there is one owner the OF is set to 1, if there are two owners the primary owner is set to 0.8 and the secondary is 0.2, and if there are 3 owners the primary is 0.7, the secondary is 0.2, and the tertiary is 0.1.

$$\text{Equation (5)} \quad \text{SAI}_Y' = \text{OF}_Y * \text{SAI}_Y$$

Next, the SAI<sub>Y</sub>’ of all railyards belonging to a Class I railroad (RR) were summed, and the fraction of the railroads total SAI associated with each railyard was multiplied by the railroads total annual switcher fuel use reported in the R-1 (TFU<sub>RR</sub>), resulting in the total Switcher Fuel Use for each railyard Y (Equation 6).

$$\text{Equation (6)} \quad SFU_Y = \frac{SAI_Y'}{\sum_{RR} SAI_Y'} * TFU_{RR}$$

where

$SFU_Y$  = Switcher Fuel Use at railyard Y

Finally, the  $SFU_Y$  is multiplied by the emission factors described in the previous section to obtain annual switcher emissions at each railyard.

#### *The MGT Method – based on confidential data*

Two railroads, Norfolk Southern and Kansas City Southern (KCS), allowed the use of confidential link-level tonnage information and weighting factors to correct skewed estimates to improve estimated switcher activity at important yards. Other railroads may also allow the use of this technique for their inventories in the future. In addition, KCS provided yard-specific activity information.

The MGT Method also uses the FRA database for railyard identification and link lengths. However, rather than using the average dencode per link, confidential annual gross tonnage (MGT) hauled per link in the railyard was used to calculate the railyard switcher activity ( $SAI_Y$ ). This is calculated by replacing  $FDC_n$  in Equation 4 with link-specific tonnage  $MGT_n$  (Equation 7).

$$\text{Equation (7)} \quad SAI_Y = \sum (l_{nY} * MGT_{nY})$$

where

$SAI_Y$  = Switcher Activity Indicator in Railyard Y  
 $n_Y$  = number of links identified as part of railyard Y  
 $l_{nY}$  = length of link n in miles  
 $MGT_{nY}$  = million gross tons on link n

This method provides a more refined comparison between railyards than the use of the 7-category dencodes; however, is more susceptible to errors for yards where tonnage is not correlated to switching activity. For example, a yard with large coal trains pulling through used for crews to change over would be assigned an overly high level of emissions for switching activity. To account for this, a discretionary Switching Activity Factor (SAF) was introduced to allow railroads to roughly weight yards with clearly higher or lower levels of switching activity than what results from the mathematical allocation. Therefore,  $SAI_Y$  is weighted based on both the ownership factor (OF) as well as the SAF (Equation 8). For example, a yard used for crew changes and not switching may have an SAF of 0, while a yard at a major interchange between cities may have an SAF of 3.

$$\text{Equation (8)} \quad SAI_Y' = OF_Y * SAF_Y * SAI_Y$$

Again, the  $SAI_Y'$  of all railyards belonging to a Class I railroad (RR) are summed, and the fraction of the railroads total SAI associated with each railyard was multiplied by the railroads total annual switcher fuel use reported in the R-1 ( $TFU_{RR}$ ), resulting in the total Switcher Fuel Use for each railyard Y (Equation 9).

$$\text{Equation (9) } SFU_Y = \frac{SAI_Y'}{\sum_{RR} SAI_Y'} * TFU_{RR}$$

While the SAF allows estimates of yard-specific emissions to be adjusted, the total level of emissions for each railroad, which is based on systemwide fuel use and systemwide emission factors, remains unchanged. The MGT method  $SFU_Y$  is also later multiplied by the emission factors described in the previous section to obtain annual switcher emissions at each railyard.

#### 4) Improve estimates.

In addition to the Switching Activity Factor described above, direct input was also used to improve emission estimates for important railyards. Each Class I railroad provided an estimate of annual average switcher fuel use (generally much lower than the EPA default of 82,490 gal/yr) as well as the name, location, and number of operating switchers for railyards with 8 or more switchers operating in ozone or  $PM_{2.5}$  nonattainment areas. Some railroads, Kansas City Southern in particular, then provided additional railyard specific data. This directly reported data was used to overwrite the dencode or MGT derived emissions estimates for those railyards.

The difference in estimated fuel use for those railyards was re-allocated (added or removed) between the remaining railyards belonging to that Class I railroad. It is important to note that there are some discrepancies in how this data was reported for the large railyards by each railroad. For example, some railroads reported all switchers located at a railyard while others reported ‘full time equivalent’ switchers, meaning the number of switchers normalized to a full working cycle (24-hours per day year-round.) This process should be standardized for future inventory versions. Variability is also introduced because ‘switcher’ locomotives can also be used for ‘road work’, meaning they occasionally haul loads between yards.

States also have the option of updating specific railyard emissions estimates. Because this inventory is derived ‘top-down’, local studies and familiarity with specific railyards is expected to provide better estimates, which can be used to adjust this inventory. Care must be taken to ensure the other railyard estimates are adjusted to account for increases or decreases in estimated fuel use per yard.

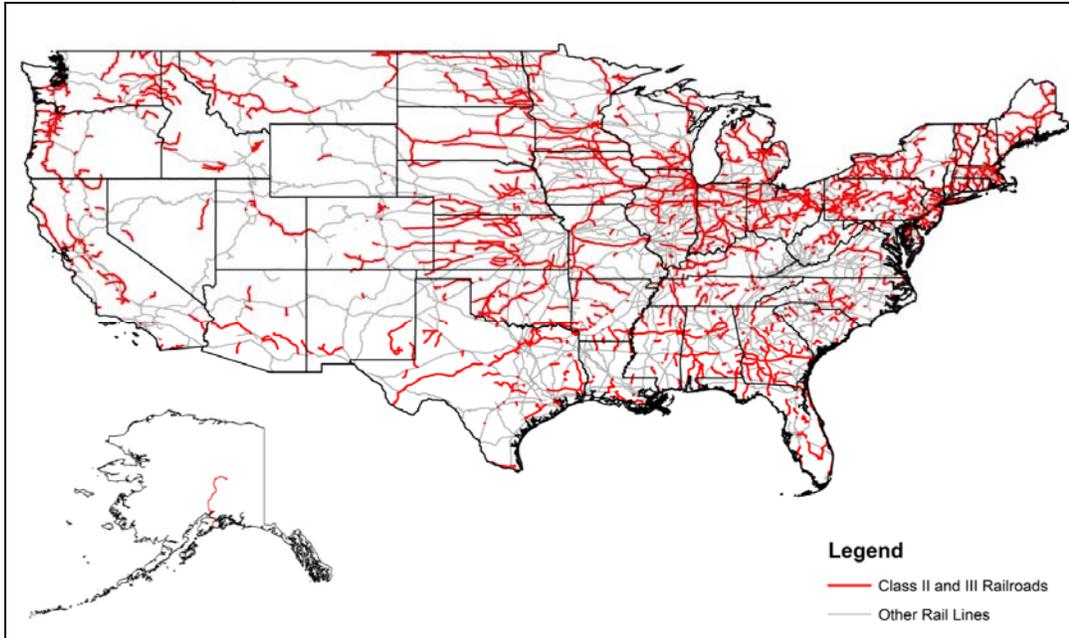
### **Shortline and Regional Railroads (Class II and III)**

There are approximately 570 Class II and III Railroads operating in the United States, around 450 of which are members of the American Shortline and Regional Railroad Association (ASLRRA)<sup>8</sup>. In general, while information on Class II/III link locations and many fleet characteristics are available online, a significant effort would be required to compile this data into a usable format and check the data for reliability. In addition, the Class II and III sectors of the railroad industry have been in considerable flux since partial deregulation from the 1980 Staggers Act. States with relatively large numbers of Class II and III railroads, such as Maine, Pennsylvania, North Carolina, and Massachusetts, have independent surveys and emission inventory estimates available, but no regional or national level cohesive electronic datasets have been previously developed.

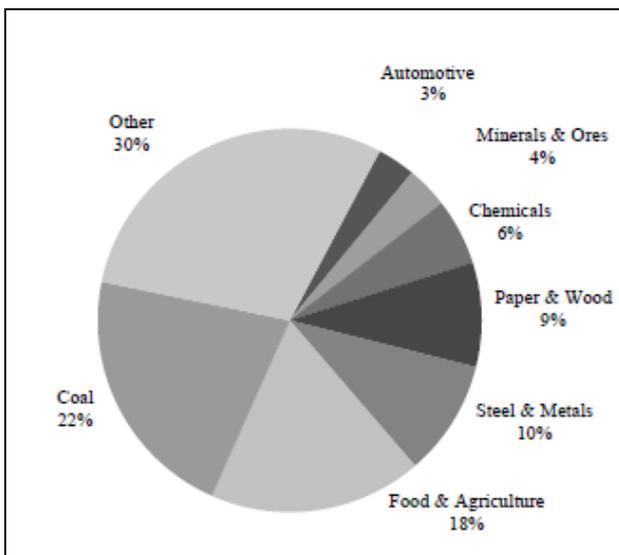
Class II and III activities account for an estimated 4% of the total locomotive fuel use in the combined ERTAC inventories and for approximately 32% of the industry’s national freight rail mileage<sup>18</sup>. These railroads are widely dispersed, though more concentrated in the eastern United States

(Figure 4), and often utilize older, higher emitting locomotives than their Class I counterparts. These railroads provide services to industries requiring consistent transportation of large amounts or very heavy freight, small towns, and/or provide switching and terminal services at complex rail and intermodal intersections (Figure 5).

**Figure 4.** Shortline and Regional Railroads (Class III and II) in the United States (based on GIS data from reference 10).



**Figure 5.** Carloads shipped by Shortline and Regional Railroads by commodity group<sup>8</sup>



To calculate a nationwide Class II/III emissions inventory, ERTAC Rail first surveyed existing data sources, compared states' methods and data used for existing inventories, and contacted members of the Class II and III Railroad communities for guidance, including the ASLRRRA, the FRA, and

Genesee & Wyoming, RailAmerica, and Omnitrac (large holding companies of Class II and III railroads). In particular, Mr. Steve Sullivan from ASLRRA and Mr. David Powell from Genesee & Wyoming were able to provide significant assistance in identification of an appropriate nationwide dataset of Class II and III railroads with links and total locomotive fuel use, the development of a calculation method, and guidance on appropriate assumptions such as fleet average locomotive Tier classification. Data sources, calculations, and assumptions used to develop the resulting inventory are described below.

This ERTAC Rail Class II/III inventory provides a cohesive nationwide inventory with data for where Shortline and Regional Railroads operate and who owns them, and provides a comprehensive geographical allocation of their locomotive emissions bounded by what is reported as total nationwide Class II/III fuel usage by the ASLRRA. This inventory will be useful for regional and some local modeling, helps identify where railroads may need to be better characterized, and provides a strong foundation for future development of a more accurate nationwide Shortline and Regional railroad emissions inventory.

1) Locate Class II and III Railroads.

Identification and correct placement of Class II and III railroads was an important first step, requiring a comprehensive electronic dataset. The FRA database used for the Class I inventories identifies links as owned or operated by specific Shortline or Regional Railroads using “Reporting Marks”, which are brief identification abbreviations. The full list of Reporting Marks is included with the inventory. The locations of these links with associated data including reporting mark, railroad name, class, number of links and route miles owned and/or operated, and total route miles of links were extracted by ERTAC Rail (Matt Harrell, Appendix D.) While this dataset contains confidential data for the Class I railroads, the geographical allocation of Class II and III links (Figure 4) and related information is public<sup>10</sup>, as is the similar Bureau of Transportation Statistics database<sup>10</sup>.

2) Select/Calculate Emission Factors.

While some Class II and III railroads purchase more recent locomotives, locomotives often serve 30 to 40 years in Class I line-haul service before being transferred to switching service or sold to Class II or III railroads. Through guidance from the Class II/III Railroad community, it was agreed that the EPA Non-regulated (pre-1973) emission factors<sup>13</sup> best represent most operating Class II and III locomotives. In addition, although the fuel use and route miles data obtained represent both switching and line-haul activities by the Class II and III railroads, the US EPA line-haul duty cycle was selected as most representative along with the “Small Line-Haul” conversion factor<sup>13</sup> to obtain gm/gal emission factors for hydrocarbons (HC), oxides of nitrogen (NOx), particulate matter (PM), and carbon monoxide (CO) (Table 6). Emission factors for PM<sub>2.5</sub>, SO<sub>2</sub>, NH<sub>3</sub>, VOC, and GHGs are the same as for line-haul locomotives.

**Table 6.** Emission factors over the standard operating line-haul duty cycle using a conversion factor of 18.2 bhp-hr/gal<sup>13</sup>.

	Line-Haul (gm/gal)			
	HC	NOx	PM	CO
Non-regulated (pre 1973)	8.736	236.6	5.824	23.296

### 3) Calculate Emissions.

The ASLRRRA compiles data from the Class II and III railroads every few years<sup>8</sup>, including total industry fuel use for locomotives and total Class II/III Route Miles. The FRA dataset also provides route miles. These values can be used to calculate an average Fuel Use Factor (FUF) for the industry (Equation 10).

$$\text{Equation (10) } FuelUseFactor = \frac{TotalIndustryFuelUse_{ASLRRRA}}{TotalClassII / IIIRouteMiles_{FRA}} = \frac{157,800,000 \text{ gal}}{52,367 \text{ miles}} = 2814.64 \frac{\text{gal}}{\text{mile}}$$

Some data was available from the ASLRRRA to distinguish between the Shortline and Regional Railroad fuel use and miles of track, however the resulting fuel efficiency factors were not intuitively correct so ERTAC Rail chose to keep their emissions inventories combined until the discrepancies can be improved or explained.

ERTAC Rail chose to use the Total Class II/III Route Miles values with non-zero activity from the FRA dataset for this calculation, 52,367 miles, as shown. This way, if a railroad is known to have ceased operations, those route miles are not counted while the total fuel used estimate remains the same. In addition, this dataset was available in GIS format for mapping purposes, the data is also used for the Class I line-haul and switcher inventories, and it is part of a more comprehensive, managed inventory.

For comparison, ERTAC Rail has actual fuel use data and route miles for approximately 50 shortline railroads, which result in an overall average FUF of 2560.10 gal/mile, very close to the nationally calculated FUF. The average of the independently calculated FUFs in the inventory is 3001.09 gal/mile, with the maximum being 15953.78, the minimum being 67.97, and a standard deviation of 3393.08 gal/mile. As can be seen, while the averages are in good agreement, there is a wide range of potential individual FUFs per railroad which can depend on many factors such as frequency of trips, tonnage hauled, terrain, distance, locomotives used, and others. This wide potential range indicates the importance of using specific fuel use data when possible. There are also discrepancies between the FRA route miles assigned to railroads and route miles reported by the railroads. Because of the GIS linkages available with the FRA database, the FRA route miles rather than reported route miles are used in the inventory. These should also be verified when possible and, if necessary, corrected both in the FRA database and the emissions inventory.

The Fuel Use Factor calculated for use in this inventory (2814.64 gal/mile) was multiplied with the route miles listed for each Class II and III railroad in the FRA database, resulting an estimate of gallons of fuel used in 2008 for each railroad. The annual gallons of fuel used were then multiplied with pollutant emission factors for a mass of pollutant emitted for the year.

Further modifications were made to the estimates to reflect actual fuel use collected for specific class II/III railroads, including entries of '0' for railroads known to be out of operation. In particular, specific fuel use data was entered for railroads owned by Genesee & Wyoming and for some Class III railroads operating in Pennsylvania, Massachusetts, and North Carolina. These modifications were accounted for in the Fuel Use Factor calculation applied to the remaining railroads so that the national total fuel use is equal to the total estimate by the ASLRRRA (157,800,800 gal) and the Fuel Use Factor is calculated only using fuel and track data for railroads with no known fuel use information.

## Limitations, Conclusions, and Future Work

It must be noted that freight-related rail activity is not always routine and no annual emissions inventory will ever be able to capture the innate variability of the source. However, as other large emission sources are reduced, and if rail activity increases as expected, it is important to include the best emission estimates possible of these sources for air quality and epidemiological analysis. In the future, on-line data loggers and other tracking technologies, combined with ambient studies and detailed modeling, will hopefully provide more insight to the emissions of locomotives and other railyard sources.

This is a first generation inventory, and many limitations exist. For the Class I inventories, early ERTAC Rail discussions concluded that link-level tonnage was the most important data to obtain, while other variables such as track grade and track speed could not be addressed at this time. ERTAC Rail calculated railroad-specific fleet-averaged emission factors rather than applying the estimated national average; however, it is recognized that emissions from individual engines are highly variable even within Tier categories depending on variables such as the specific locomotive model, operation cycle, and conditions of operation. Future evaluation of emission variability within Tiers and between certain types of operation and locations would be valuable. There is also likely significant variability in actual switching duty-cycles and, potentially, in the number of switchers operating at some railyards at different times of the year. ‘Road-switching’, or the use of what are considered switching locomotives to move between nearby yards, should be addressed in either this or the ERTAC line-haul inventory.

Major areas for future improvement of the Class II and III inventory include distinguishing between switching and hauling operations and updating fleet Tier characteristics where appropriate. More accurate annual fuel use estimates, rather than using the estimated Fuel Use Factor would greatly improve the inventory. For example, 2006 Class II/III fuel use reported to the ASLRRRA was 309 million gallons, almost double what was reported only two years later in 2008. It is unlikely that the industry halved fuel use in two years, but no other activity indicators have been found for comparison. Another area of uncertainty that can be improved is estimates of temporal variability. Emissions inventory preparation guidance from the U.S. EPA describes locomotive activity as constant throughout the year (e.g. no daily, weekly, or seasonal variability), though weekly or seasonal variation is highly likely for the Class II and III lines. States or other areas with local, direct Class II and III data including temporal activity, fleet characteristics, or annual fuel use should use that information in place of this inventory. This inventory was designed to incorporate refinements from industry or state agency representatives, and we request that any data collected be submitted to ERTAC Rail so that the inventory can be continuously improved.

An uncertainty study on the data used for this inventory, including the R-1 reported fuel use for Class I line-hauls and, in particular, switchers, the confidential link-level tonnage data for Class I line-haul operations, and the duty-cycle estimates for line-haul and switcher operations would help in evaluating the quality of this inventory. Additionally, the uncertainty contributed by the use of tonnage hauled as an indicator of the amount of switching activity. Localized studies should examine how shared tracks are apportioned between multiple carriers in their domain.

Emissions inventory preparation guidance from the U.S. EPA describes locomotive activity as relatively constant throughout the year (e.g. no daily, weekly, or seasonal variability); however, actual activity levels do vary seasonally and annual averaging may dilute or exaggerate concentrations during pollution episodes. ERTAC Rail and the Class I railroad community had some discussions addressing if

incorporating more specific fleet mix or monthly or seasonal variation may be worthwhile, and these topics should be looked into further.

Finally, it is important to reiterate that the link-level MGT data maintained by the FRA is proprietary and can only be released to agencies/groups outside the FRA with the express permission of each Class I railroad. It is possible that one or more Class I railroads could withhold permission for access, but data for specialized studies may be provided if requested. This database can also be improved by better distinguishing between haulage and trackage rights, and by apportioning tonnage hauled on links to specific carriers.

## ACKNOWLEDGMENTS

We would like to thank the ERTAC Rail Data Workgroup and the ERTAC Rail Subcommittee for their participation in the development of these inventories (Appendix A), as well as Raquel Wright of the Federal Railroad Administration, Richard Billings of ERG, and David Powell of Genesee & Wyoming, Inc.

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# APPENDICES

## Appendix A

REPRESENTATIVE	ORGANIZATION
<b>ERTAC Rail Data Workgroup</b>	
Matt Harrell	IL EPA
Michelle Bergin (Co-Chair) and Byeong Kim	GA EPD
Mark Janssen (Co-Chair)	LADCO
Julie McDill and Patrick Davis	MARAMA
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Steven Sullivan	ASLRRA
Rick Nath	CSX
David Seep and Lyle Staley	BNSF
Ken Roberge	CPR
Carl Akins and Peter Conlon	KCS
Erika Akkerman	CN
M. John Germer	UP
Brent Mason and Richard Russell	NS
Joanne Maxwell	Amtrak
<b>ERTAC Rail Subcommittee</b>	
1 Allan Ostrander	MI Dept. of Environ. Quality
2 Amanda Carter	AL Dept. of Environ. Manag.
3 Ashley Mixon	SC Dept. of Health and Environ. Control
4 Bob Wooten	NC Dept. of Environ. and Natural Resources
5 Carla Bedenbaugh	SC Dept. of Health and Environ. Control
6 Chad Wilbanks	SC Dept. of Health and Environ. Control
7 Dennis McGeen	MI Dept. of Environ. Quality
8 Douglas Malchenson	PA Dept. of Environ. Protection
9 Eric Zalewsky	NY Dept. of Environ. Conserv.
10 Grant Hetherington	WI Dept. of Natural Resources
11 Jim Boylan	GA Environ. Protection Div.
12 Julie McDill (Co-chair)	Mid-Atlantic Regional Air Management Assoc. (MARAMA)
13 Kelley Matty	PA Dept. of Environ. Protection
14 Kevin McGarry	NY Dept. of Environ. Conserv.
15 Laurel Driver	US EPA OAQPS
16 Lisa Higgins	ME Dept. of Environ. Protection
17 Mark Janssen (Co-chair)	ERTAC/ Lake Michigan Air Directors Consortium (LADCO)
18 Matthew Harrell (GIS lead)	IL Environ. Protection Agency
19 Michelle Bergin (Co-chair)	GA Environ. Protection Division
20 Mike Koerber	LADCO
21 Pat Brewer	Visibility Improvement State and Tribal Association of the Southeast (VISTAS) /ASIP

22 Richard Dalebout	MI Dept. of Environ. Quality
23 Sam Long	IL Environ. Protection Agency
24 Stacy Allen	MO Dept. of Natural Resources
25 Tracy Anderson	AL Dept. of Environ. Manag.
26 William Nichols	OH Environ. Protection Agency

**Appendix B: Source and Year of Data Utilized for Each Inventory**

<b>Data</b>	<b>Year</b>	<b>Source</b>
<b>Class I Line-Haul</b>		
Annual Line-Haul Fuel Use and Gross Ton-Miles	2007	STB R-1 Reports (CP data for D&H is for 2008.)
Line-haul fleet mix for emission factors	2008	Each Class I railroad
Link-level tonnage	2007	FRA confidential database
<b>Class I Railyards (Switcher Locomotives)</b>		
Annual Switcher Fuel Use	2008	R-1 Reports
Switcher fleet mix for emission factors	2008	Each Class I railroad
Link-level tonnage or Density Code (for activity estimate)	2007	FRA confidential database
<b>Class II and III Locomotives</b>		
Annual Total Fuel Use	2008	ASLRRA Annual Report (2008)
Track length and railroad	2007	FRA confidential database
Estimated fleet mix for emission factors		Discussions with ASLRRA and Class II and III representatives.

**Appendix C: Railroad Companies Operating in the United States**

<b><i>Railroad</i></b>
<b>Class I</b>
BNSF
Canadian National
Canadian Pacific***
CSX
Kansas City Southern
Norfolk Southern
Union Pacific
Amtrack
<b>*Regional (Class II)</b>

	Mileage
Alabama and Gulf Coast Railway	435
Alaska Railroad	506
Buffalo and Pittsburgh Railroad	699
Central Oregon and Pacific Railroad	447
Dakota, Missouri Valley and Western Railroad	534
Florida East Coast Railway	386
Great Lakes Central Railroad	396
Indiana Rail Road	602
Indiana and Ohio Railway	692
Iowa Interstate Railroad	608
Kansas and Oklahoma Railroad	869
Kyle Railroad	554
Missouri and Northern Arkansas Railroad	583
Montana Rail Link	905
Montreal, Maine and Atlantic Railway	527
Nebraska Kansas Colorado Railway	559
New York, Susquehanna and Western Railway	357
Northern Plains Railroad	486
Paducah and Louisville Railway	290
Pan Am Railways	1165
Portland and Western Railroad	587
Providence and Worcester Railroad	568
Red River Valley and Western Railroad	575
San Joaquin Valley Railroad	351
South Kansas and Oklahoma Railroad	398
Texas Northeastern Railroad	665
Texas Pacifico Transportation	393
Utah Railway	430
Wheeling and Lake Erie Railway	878
Wisconsin and Southern Railroad	837
<b>Shortline (Class III)</b>	
See <a href="http://www.aslrra.org/our_members/Railroad_Members">www.aslrra.org/our_members/Railroad_Members</a> or <a href="http://www.railsusa.com/links/Shortline_Railroads/">http://www.railsusa.com/links/Shortline_Railroads/</a>	

\* These railroads were classified as regional by the AAR in 2007 as reported in Wikipedia ([http://en.wikipedia.org/wiki/Regional\\_railroad#cite\\_note-2](http://en.wikipedia.org/wiki/Regional_railroad#cite_note-2) , accessed Oct. 7, 2011.) Railroads known to have been purchased by Class I railroads after 2007 have been removed from this list.

## **Appendix D. ERTAC – Class 2/3 Shapefile Documentation (Matt Harrell, 13 Jul 2009)**

### **Introduction**

This document outlines the methods and procedures used to compile a shapefile representing the links in the FRA 1:100,000 railroad dataset that are owned or operated by Class II and III railroad companies. It is important to note that there is a considerable amount of overlap between the Class II's and III's and the Class I and passenger railroads. Class II's and III's can operate on Class I or passenger rail links and vice versa. Although the final shapefile specifically represents Class II and III links, there are many Class I and passenger railroads represented as well.

## Procedure

1. Started with all proprietary FRA links where “NET = ‘M’ and “STCNTYFIPS” <> ‘ ‘ (this definition query selects all active mainline links located within the United States).
2. Ran 12 queries, one for each ownership and trackage rights field, to select all links not associated with a Class I freight railroad or Amtrak and not containing a null value (e.g., "RROWNER1" <> 'AMTK' AND "RROWNER1" <> 'BNSF' AND "RROWNER1" <> 'CN' AND "RROWNER1" <> 'CPRS' AND "RROWNER1" <> 'CSXT' AND "RROWNER1" <> 'KCS' AND "RROWNER1" <> 'NS' AND "RROWNER1" <> 'UP' AND "RROWNER1" <> ' '). The first query was setup as a new selection. Each of the 11 subsequent queries were setup to add records to initial set of records. 26,261 links were selected and exported to a new shapefile.
3. Due to the multitude of railroad codes used to represent commuter rail operations across the country, additional processing was required to remove any links that were not operated by a Class II or III freight railroad. Each commuter railroad was queried out of the new shapefile and the links analyzed to eliminate all links where no Class II or III operations were occurring. The following commuter rail operations were evaluated: NJT (New Jersey Transit), MNCW (Metro-North Commuter Railroad), LI (Long Island Railroad), CDOT (Connecticut DOT), MBTA (Massachusetts Bay Transportation Authority), SEPA (Southeastern Pennsylvania Transportation Authority), MARC (Maryland Area Rail Commuter), VRE (Virginia Railway Express), MTRA (Northeastern Illinois Regional Commuter Railroad), CSS (Northern Indiana Commuter Transportation District), DART (Dallas Area Rapid Transit), SCRA (Southern California Regional Rail Authority – including also SCAX, LACM, LAPT, and LATC), TCRA (South Florida Regional Transportation Authority), PJPB (Caltrain), and ACE (Altamont Commuter Express). Approximately 1581 links were identified with no Class II or III operations and were deleted from the Class 2/3 shapefile.
4. The remaining Class II and III links were then compared to the regional maps contained in the July-August issue of The Official Railway Guide to assess the completeness of the Class 2/3 shapefile. Six specific edits were made to the shapefile to correct the most glaring errors: 1) BMLP links deleted (Black Mesa & Lake Powell, an electric coal hauling railway in Arizona); 2) DSNL links deleted (Durango & Silverton steam tourist railroad in Colorado); 3) CIC haulage rights links on CN from Chicago to Omaha deleted; 4) DMIR links deleted (Duluth, Missabe & Iron Range, now owned and operated by CN in Minnesota); 5) EVWR’s ex-CSXT links coded from Evansville, IN to Okawville, IL (Evansville Western Railroad); 6) INRD ex-CP links coded from Chicago, IL to Louisville, IN (Indiana Rail Road).
5. During the course of reviewing the FRA dataset, 555 “active” links were found to have no ownership or trackage rights codes. 1005 links have no codes listed in the 3 ownership fields. In most cases these links are very short and scattered across the country. Only the links representing the EVWR and INRD spanned large distances and were fixed. The other problem links were deemed to be insignificant. A listing of these links will be provided back to the FRA to assist with their coding in 1:100K railway shapefile.

## **KEY WORDS**

Locomotive emissions

Railroad emissions

Air quality

Nonroad emissions

Emissions inventory

Air quality modeling