DRAFT
ERTAC Rail Emissions Inventory
Part 2: Class I Railyard Switcher Locomotives

Michelle Bergin, GA Environmental Protection Division
Matthew Harrell, IL Environmental Protection Agency
Mark Janssen, Lake Michigan Air Directors Consortium

Acknowledments: Robert Fronczak, Association of American Railroads
Laurel Driver, US EPA, Office of Air Quality Planning and Support
Byeong Kim, GA Environmental Protection Division

Introduction

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 a need to better quantify and characterize rail-related emissions inventories. Traditional locomotives largely utilize diesel engines, resulting in emissions of NO_x, diesel PM, hydrocarbons, greenhouse gases, and other pollutants. These emissions are sometimes concentrated in areas exceeding National Ambient Air Quality Standards. No cohesive nationwide railroad emission estimates are known to have been made previously. Inventory development methods for locomotive emissions estimates vary from state to state and, in general, lack the spatial or temporal resolution needed to support air quality modeling and planning [1-5].

The ERTAC Rail Subcommittee (ERTAC Rail) was established with active representatives from twelve member states, three regional planning offices, and the US EPA. The subcommittee's goals are 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. With support from the Rail industry and assistance from the ERTAC Rail Data Workgroup (Appendix A), ERTAC Rail has developed 3 inventories of locomotive emissions for Class I line-haul, Shortline and Regional Railroads, and Class I railyard switchers (Table 1). Because of the difficulty in obtaining data and differences in states' needs for inventory years, sources from both 2007 and 2008 were utilized (Appendix B.)

The Surface Transportation Board (STB) defines Class I Railroads as having had minimum carrier operating revenues of $401.4 million (USD) in 2008. There are 8 Class I Railroads operating in the United States (Table 2), about 33 Regional Railroads (Class II), and approximately 540 Class III Railroads (Shortlines). While categorized as a Class I Railroad, Amtrak was excluded from these inventories because of significant differences in equipment and operational characteristics. Line-haul locomotives travel long distances (e.g. between cities) while switcher locomotives largely operate in railyards, splitting and joining rail cars with varying destinations. Passenger and Commuter Rail (including Amtrak), industrial locomotives, and associated non-locomotive equipment are not included in these inventories.

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_x	$PM_{2.5}$	HC	SO_2	CO	NH_3	CO_2
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

Table 2. Class I Railroads and Reported Locomotive Fuel Use[6].

Class I Railroads*	R-1 Reported Locomotive Fuel Use (gal/yr)	
	Line-Haul (2007)**	Switcher (2008)
BNSF	1,393,874,954	52,497,057
Canadian National	93,830,751	12,290,022
Canadian Pacific	***50,320,233	4,937,067
CSX	514,687,186	53,717,674
Kansas City Southern	69,787,071	1,816,759
Norfolk Southern	463,267,278	32,317,375
Union Pacific	1,185,146,529	143,470,336
Total	**3,770,914,002**	**301,046,290**

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

This paper documents the data sources and methodologies used for calculating the Class I switcher ("Railyard") inventory. Information on ERTAC Rail, Railroad participation, the Rail industry, and effects of rail on air quality are available elsewhere[7].

Method

Switcher locomotives are expected to be the single largest source of air emissions in railyards. Therefore, as a starting point for a comprehensive railyard inventory, a 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.

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.

This documentation describes development of the initial top-down inventory, which 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. A confidential database was obtained from the Federal Railroad Administration (FRA) with permission from the Class I Railroads (FRA database) [8]. A comparable public database compiled by the Bureau of Transportation Statistics is also available[8]. 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 1). The database gives length, up to 3 owners and 3 operators, and a Federal Density Code (explained below) for each railyard link.

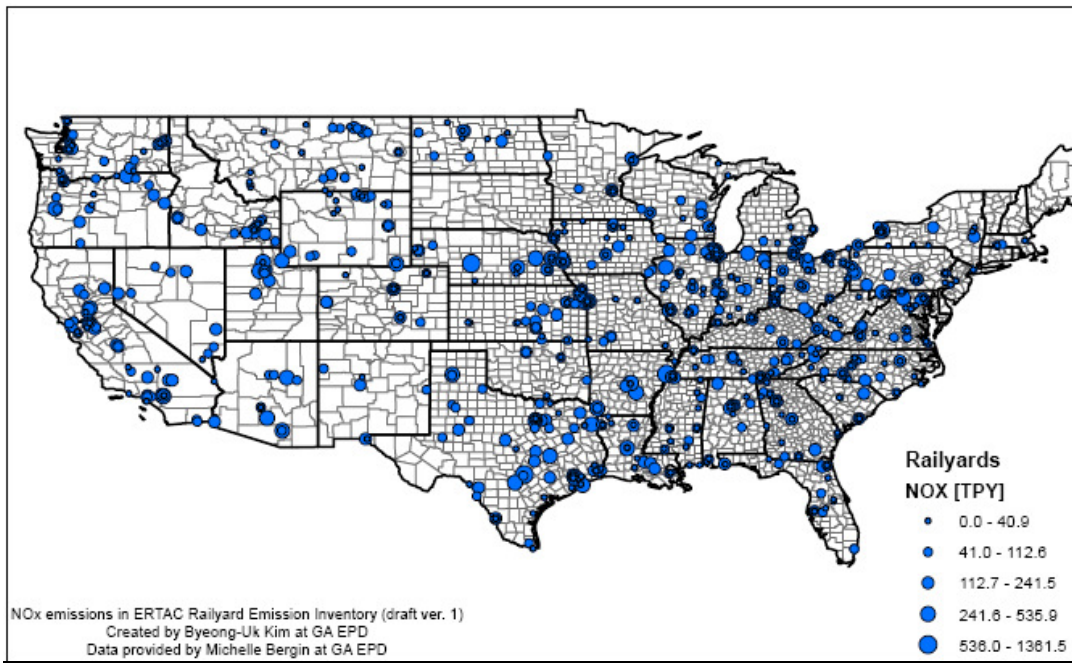

Figure 1. Class I Railyards in the United States and estimates of Annual NOx emissions from switcher locomotives (tons/yr in 2008).

2. Select/Calculate Emission Factors.

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, 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 3). While engine emissions are variable within Tier categories, this estimate likely provides a better regional estimate than the nationwide average. The company-specific systemwide 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_{10} and 212.98 to 264.48 g/gal NO_x.

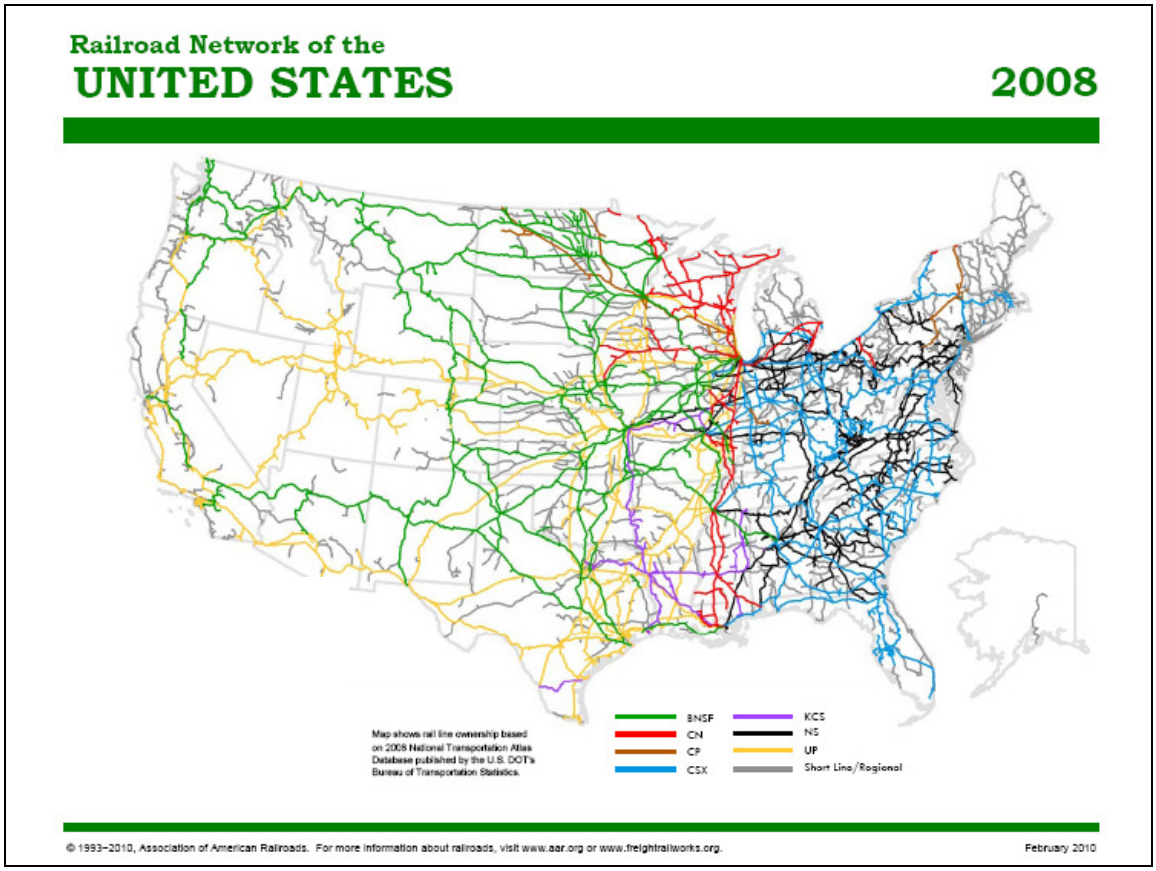

Figure 2. Class I Railroad Territories in the United States[9].

Table 3. EPA switcher locomotive emission factors by Tier, 1997 standards (grams/gal).

	PM_{10}	HC	NO_x	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 [8]. Note that the new standards released in 2008 did not apply to existing fleets in the year 2008.

For locomotives, $PM_{2.5}$ is assumed to be 97% of PM_{10} [10], and emission factors for SO_2 and NH_3 are 1.88 g/gal[10] and 83.3 mg/gal[11] respectively. VOC emissions are calculated as 1.053 times the HC emissions for locomotives[12]. Note that non-road engine and fuel specific information is sparse for these conversions. Greenhouse gases are also estimated using emission factors shown in Table 4.

Table 4. EPA greenhouse gas emission factors for locomotive diesel fuel (grams/gal).[13]

	CO_2	N_2O	CH_4
Locomotive diesel	1.015E4	0.26	0.80

These emission factors are based on a characteristic duty cycle for switchers which assumes operation over 24-hour per day 365 days per year. An evaluation of the effect of variability in railyards and switching duties on emissions would be very useful for future emission estimates.

3. Estimate Locomotive Activity.

Class I railroads report total annual switcher locomotive fuel use to the STB, which is reported in publicly available 'R-1' reports (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 values provides a starting point for estimating total U.S. Class I locomotive-related emissions segregated and spatially allocated by Class I carrier. The R-1 reports were used by ERTAC for both the line-haul and switcher locomotive emissions inventories to provide consistency.

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 'Dencode' 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 Dencode method is applied for the other five railroads.

The Dencode Method – Publicly available data

Each link in both the publicly available BTS database and the confidential FRA database has a 'Federal Density Code' (Dencode) 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_Y) is estimated as follows:

First a Switcher Activity Indicator per yard (SAI_Y) is calculated by multiplying the average dencode of the links within a railyard by the sum of the length of the links for that railyard (Eqn 1).

$$SAI_Y = \sum (l_{nY} * FDC_{nY}) \qquad \text{Equation 1}$$

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
FDC_n = Federal Density Code (1 to 7) of link n

Next, this value is then weighted (SAI_Y') 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.

$$SAI_Y' = OF_Y * SAI_Y \qquad \text{Equation 2}$$

Next, the SAI_Y' 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_{RR}), resulting in the total Switcher Fuel Use for each railyard Y (Eqn 2).

$$SFU_Y = \frac{SAI_Y'}{\sum_{RR} SAI_Y'} * TFU_{RR} \qquad \text{Equation 3}$$

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 – Confidential data

Two railroads, Norfolk Southern and Kansas City Southern (KCS), provided 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 2 with link-specific tonnage MGT_n (Equation 4).

$$SAI_Y = \sum (l_{nY} * MGT_{nY}) \qquad \text{Equation 4}$$

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 5). 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.

$$SAI_Y' = OF_Y * SAF_Y * SAI_Y \qquad \text{Equation 5}$$

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 6).

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

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 work between yards more like a line-haul.

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.

Limitations, Conclusions, and Future Work

What this ERTAC Rail railyard inventory does well is provide a comprehensive overview of where railyards are, who owns them, and gives a geographical allocation of switcher emissions bounded by what is reported as nationwide switcher fuel usage by the Class I railroads. These sources can be important for air quality management in nonattainment areas, as well as in regional analysis and for future transportation and freight planning. 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.

There are important uncertainties associated with estimates from this method, including, but not limited to, the use of tonnage hauled as an indicator of the amount of switching activity, and, for a few of the railroads, how the amount of switcher fuel use was determined to be reported in the R-1. The R-1 reported values are currently under examination.

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.

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 our best estimates of these sources in 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.

References

1. E.H. Pechan & Associates, Inc., "Documentation for Aircraft, Commercial Marine Vessel, Locomotive, and Other Nonroad Components of the National Emissions Inventory, Volume I – Methodology"; EPA Contract No.: 68-D-02-063. Prepared for the US EPA Emissions, Monitoring and Analysis Division, Sept. 30, 2005. ftp://ftp.epa.gov/EmisInventory/2002finalnei/documentation/mobile/2002nei_mobile_nonroad_methods.pdf. Related documents at ftp://ftp.epa.gov/EmisInventory/2002finalnei/documentation/mobile/2002nei_mobile_nonroad_train.pdf
2. Sierra Research, Inc., "Revised Inventory Guidance For Locomotive Emissions"; Report No. SR2004-06-01. Prepared for Southeastern States Air Resource Managers (SESARM), June 2004. http://www.metro4-sesarm.org/pubs/railroad/FinalGuidance.pdf
3. Sierra Research, Inc., "Research Project: Development of Railroad Emission Inventory Methodologies"; Report No. SR2004-06-02. Prepared for Southeastern States Air Resource

Managers (SESARM), June 2004. http://www.metro4-sesarm.org/pubs/railroad/FinalMethodologies.pdf

4. Environ, "Draft LADCO 2005 Locomotive Emissions". Prepared for Lake Michigan Air Director Consortium, Feb 2007. http://www.ladco.org/reports/technical_support_document/references/ladco_2005_locomotive_emissions.021406.pdf

5. Southern Research Institute, "NYSERDA Clean Diesel Technology: Non-Road Field Demonstration Program, Development of the 2002 Locomotive Survey for New York State"; Agreement Number 8958. Prepared for the New York State Energy Research And Development Authority (NYSERDA), Feb. 09, 2007. http://www.nyserda.org/publications/LocomotiveSurveyReportwithAppendices.pdf

6. Surface Transportation Board R-1 Reports, available at: http://www.stb.dot.gov/stb/industry/econ_reports.html.

7. M. Bergin; M. Harrell; J. McDill; M. Janssen; L. Driver; R. Fronczak; R. Nath,; and D. Seep. "ERTAC Rail: A Collaborative Effort in Building a Railroad-Related Emissions Inventory Between Eastern States Air Protection Agencies and Participation with the Railroad Industry," 18th Annual International Emission Inventory Conference. Baltimore, MD. April 14 - 17, 2009. Paper and presentation available at: http://www.epa.gov/ttn/chief/conference/ei18/session6/bergin.pdf

8. Confidential database was provided with assistance from Raquel Wright of the Federal Railroad Administration. Similar public data is available from the Bureau of Transportation Statistics in the NTAD 2009 shapefile data (data is representative for the year 2007): http://www.bts.gov/publications/national_transportation_atlas_database/2009 .

9. Freight Railroads in the United States 2008. Association of American Railroads. Available at: http://www.aar.org/~/media/AAR/InCongress_RailroadsStates/2008unitedstates.ashx .

10. EPA Technical Highlights: Emission Factors for Locomotives, EPA Office of Transportation and Air Quality, EPA-420-F-09-025, April 2009. http://www.epa.gov/otaq/regs/nonroad/locomotv/420f09025.pdf

11. Estimating Ammonia Emissions From Anthropogenic Nonagricultural Sources - Draft Final Report by E.H. Pechan & Assoc. April 2004. Prepared for EPA/STAPPA-ALAPCO Emission Inventory Improvement Program. Supported by personal communication (5/6/2010) with Craig Harvey, US EPA, OTAQ, and Robert Wooten, NC DENR. http://www.epa.gov/ttnchie1/eiip/techreport/volume03/eiip_areasourcesnh3.pdf

12. "Conversion Factors for Hydrocarbon Emission Components," EPA420-R-05-015, December 2005. Docket Document EPA-HQ-OAR-2003-0190-0411. http://epa.gov/otaq/models/nonrdmdl/nonrdmdl2005/420r05015.pdf , http://www.epa.gov/otaq/regs/nonroad/420r08001a.pdf .

13. U.S. Environmental Protection Agency. Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2005, EPA 430-R-07-002, Annex 3.2, (April 2007), web site: http://www.epa.gov/climatechange/emissions/usinventoryreport.html

Appendix A: ERTAC Rail Data Workgroup

REPRESENTATIVE	ORGANIZATION
Matt Harrell	IL EPA
Michelle Bergin (Co-Chair) and Byeong Kim	GA EPD
Mark Janssen (Co-Chair)	LADCO
Julie McDill and Patrick Davis	MARAMA
Laurel Driver	US EPA OAQPS
Robert Fronczak	AAR
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

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

Data	Year	Source
Class I Line-Haul		
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
Class I Railyards (Switcher Locomotives)		
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
Class II and III Locomotives		
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.