January 3, 2012

ERTAC Rail Emissions Inventory
Part 1: Class I Line-Haul Locomotives

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

Acknowledgments:

Robert Fronczak, Association of American Railroads
Raquel Wright, Federal Railroad Administration
Julie McDill, Mid-Atlantic Regional Air Management Association
Patrick Davis, Mid-Atlantic Regional Air Management Association
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 utilize large diesel engines, resulting in emissions of NO_x, diesel PM, hydrocarbons, greenhouse gases, and other air pollutants. These emissions are sometimes concentrated in areas exceeding National Ambient Air Quality Standards. No cohesive nationwide railroad emission estimates based on local operations 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 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 (Table 1) for Class I line-haul, Shortline and Regional Railroads (Class II and III operations), and Class I railyard switchers. 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)[6]. 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 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. Passenger and Commuter Rail (including Amtrak), industrial locomotives, and associated non-locomotive equipment are not included in these inventories.

This paper documents the data sources and methodologies used for calculating the Class I line-haul emissions inventory. 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[4, 5]. For this reason, characterizing Class I line-haul emissions were a focal point of ERTAC Rail's inventory development efforts. This inventory best represents 2007 emissions and can be scaled for a few years back or forward using annual line-haul fuel use reported to the STB. Information on ERTAC Rail, Railroad participation, the Rail industry, and effects of rail on air quality are available elsewhere[7].

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, Reported Locomotive Fuel Use, and Railroad Fuel Consumption Index (RFCI) [8].

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	4,937,067	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
Total	**3,770,914,002**	**301,046,290**	**929.47**

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

Method

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[9]. 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[2, 3], 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.

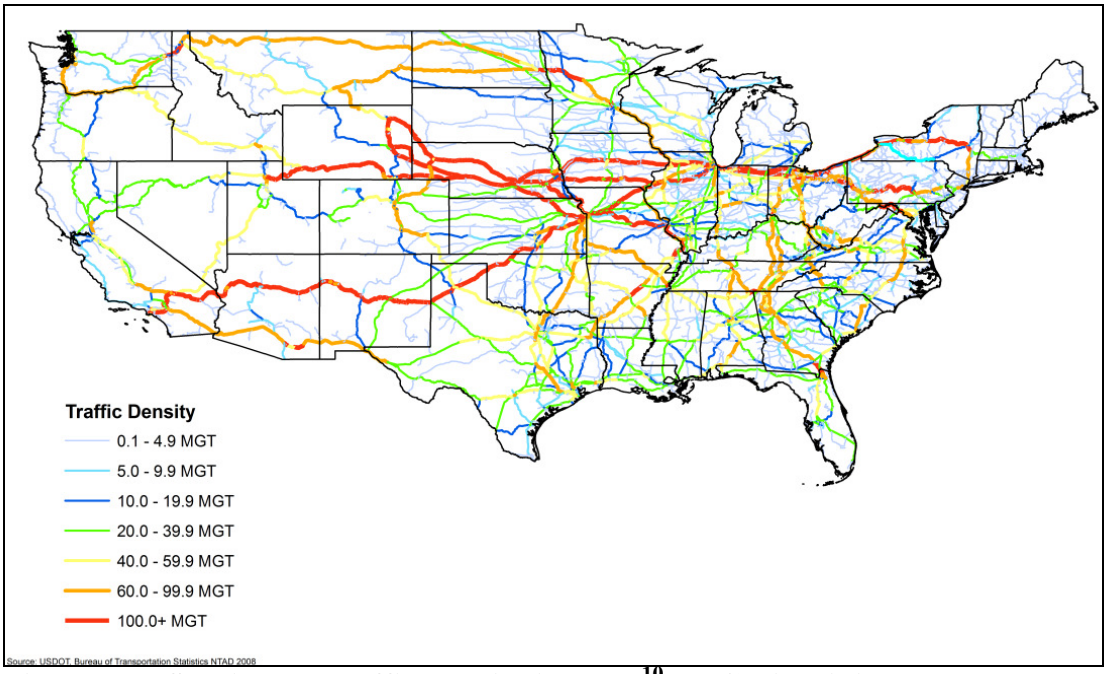

Figure 1. US Railroad Traffic Density in 2006.[10] MGT is million gross tons.

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.

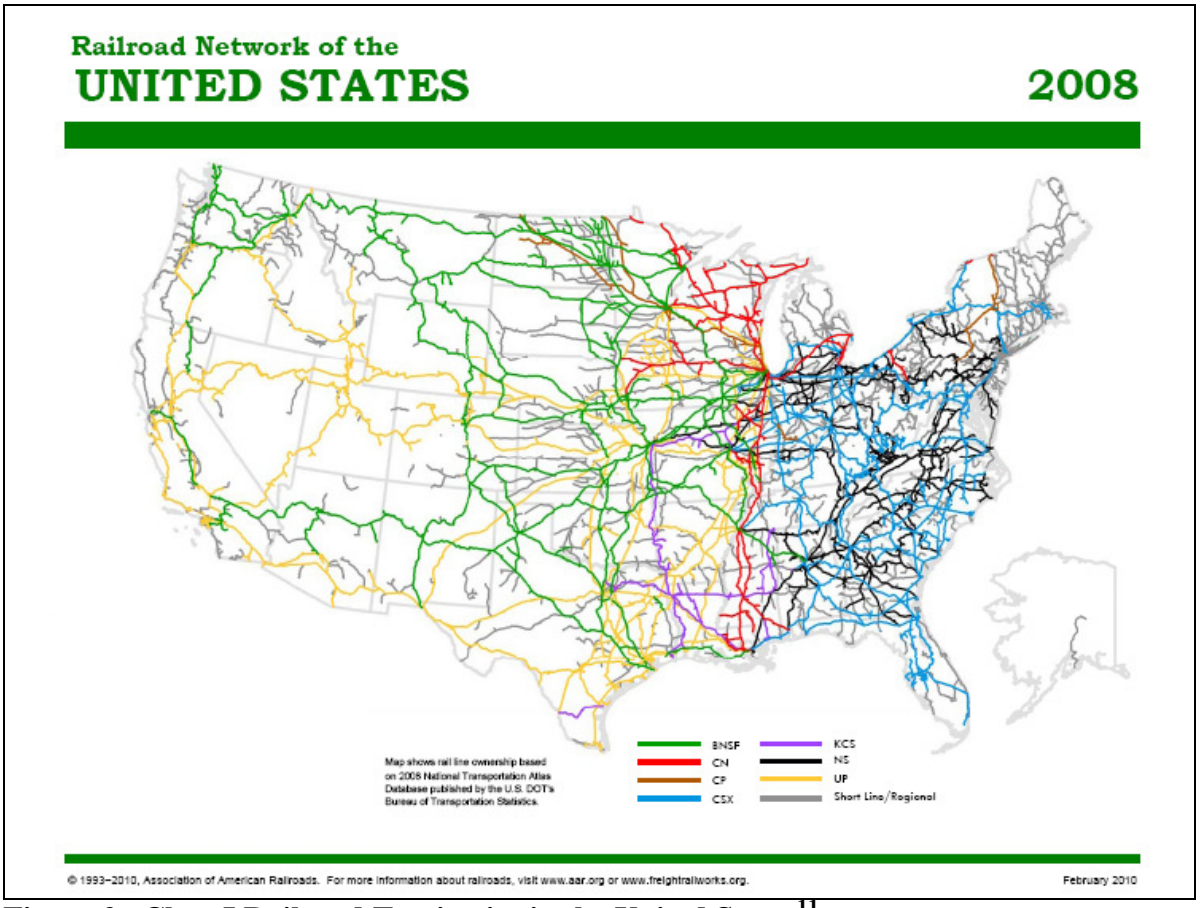

Figure 2. Class I Railroad Territories in the United States[11].

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).

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. [12]

	PM_{10}	HC	NO_x	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 (Eqn 1; Table 3).

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

EF_{iRR} = Weighted Emission Factor for pollutant i 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} [12], and emission factors applied for SO_2 and NH_3 are 1.88 g/gal [12] and 83.3 mg/gal [13] respectively. Greenhouse gases are estimated using emission factors shown in Table 4. Note 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). [14]

	CO_2	**N_2O**	**CH_4**
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[8] (Eqn 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).

$$RFCI_{RR} = \frac{GTM_{RR}}{FC_{RR}} \qquad \text{Equation 2}$$

$RFCI_{RR}$ = 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 (Eqn 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).

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

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)[9].
l_L = Link length from the FRA database (miles).
EF_{iRR} = Weighted Emission Factor for pollutant i per railroad RR (Eqn 1; tons/gal).
$RFCI_{RR}$ = Railroad Fuel Consumption Index per railroad RR (Eqn 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 difficultly 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.

Limitations, Conclusions, and Future Work

Rail-related emissions can be important components of emissions inventories used to support effective air quality management practices at local, state, regional, and national levels. Previous air quality studies often have not had the data needed to adequately represent this source sector. This line-haul inventory, as well as the companion Class I railyard inventory and Class II/III inventory, greatly improve our ability to estimate of rail-related emissions. A systematic study of variability and uncertainty in line-haul locomotive emissions and activity, by fleets, locations, and through time,

would give additional valuable information for identifying how to best improve this inventory as well as provide an indication of how representative the inventory may be. An uncertainty study on the data used for this inventory, including the R-1 reported fuel use, the confidential link-level tonnage data, and the duty-cycle estimate would also help in evaluating the quality of this inventory. Localized studies should examine how shared tracks are apportioned between multiple carriers in their domain.

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.

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.

We would like to thank the Class I Railroads and their representatives for their assistance and support in the development of this inventory.

References

1. Eastern Research Group (ERG) for 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. American Short Line and Regional Association (ASLRRA) 2008 Fact Book. Available at www.alsrra.org.
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. Surface Transportation Board R-1 Reports, available at: http://www.stb.dot.gov/stb/industry/econ_reports.html.
9. Confidential database was provided with assistance from Raquel Wright of the Federal Railroad Administration. Similar public data providing ranges of tonnage hauled rather than link-level tonnage 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 .
10. US DOT Bureau of Transportation Statistics' 2008 National Transportation Atlas Database.
11. Freight Railroads in the United States 2008. Association of American Railroads. Available at: http://www.aar.org/~/media/AAR/InCongress_RailroadsStates/2008unitedstates.ashx .
12. 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
13. 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
14. 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.