Locomotive Emission Inventories for the United States from ERTAC Rail

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U.S. Environmental Protection Agency
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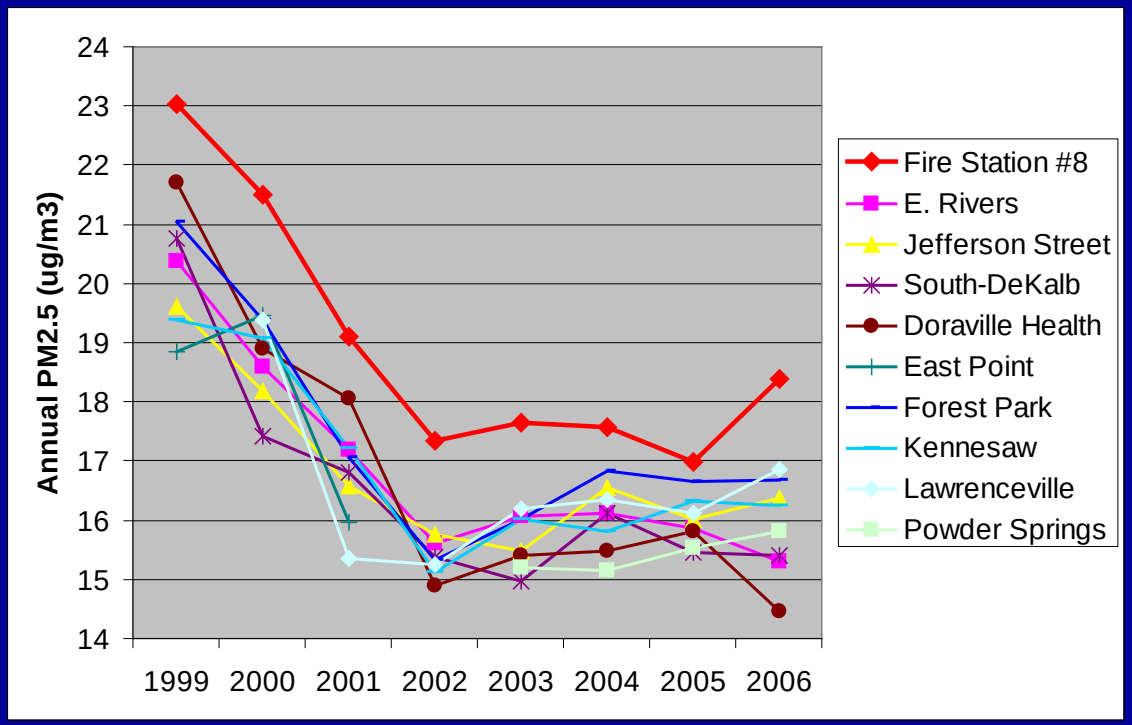
Overview

- Locomotive Emissions and Air Quality Impacts
- ERTAC and ERTAC Rail
- Railroad Characterization and Inventory Definitions
- Locomotive Emissions Inventory Calculations
  - Class I Line-Haul
  - Class I Switcher s
  - Class II and III

Locomotive Emissions

- Very large diesel combustion engines
- Emissions of NO_x, PM, HC, CO, CO_2, NH_3, SO_2.
- Health impacts due to primary emissions and contributions to secondary criteria pollutants
  - Near-source exposures to diesel particulate
  - Contributors to ozone and $PM_{2.5}$
  - Greenhouse gases

Urban Core Monitors and Annual Average PM2.5



FS8 is located near two railyards in Atlanta and is ~ 2 $\mu g/m^3$ $PM_{2.5}$ above other nearby monitors.

ex. Fulton County GA (Atlanta)

- Densely populated Fulton County has been out of attainment for both ozone and $PM_{2.5}$.
- 2002 county level total railroad emissions were estimated at 1375.6 t/yr NO_x and 31.5 t/yr PM .
- Emissions estimates were based on very little data using single nationwide default factors.
- Submitted rail proposal to ERTAC …

What is ERTAC?

Eastern Regional Technical Advisory Committee

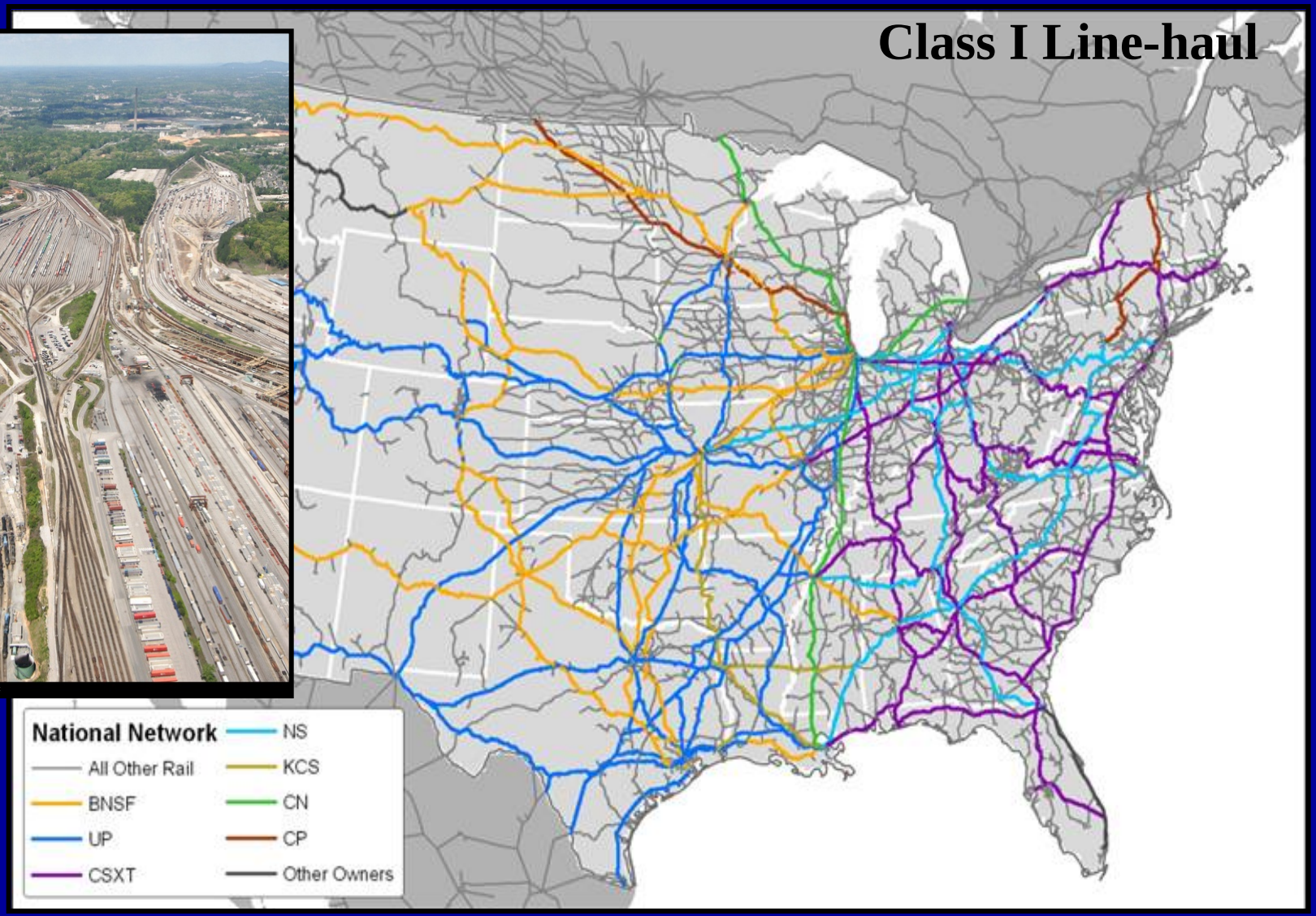
- Voluntary, technical organization comprised of state air quality agencies and planning offices east of the Mississippi.
- Coordinated by LADCO and executed by state staff.

Goals and Principles

- Achieve consensus on data sources and inventory methodologies.
- Promote consistency while respecting state-specific approaches.
- Focus on 5 issues likely to have the biggest impact in air quality modeling

⇒ Coordinate 2008 inventory development …

Extent of Operations and Regional Characteristics



ERTAC Rail

- Collaborative participation
  - 27 Eastern States' air protection agencies
  - Class I and Class II/III associations (AAR and ASLRRA)
  - All Class I railroads
  - Class II/III large shareholders (Genesee & Wyoming)
- Evaluated operations, data sources, and methodologies (selected Sierra Research, 2004) and reached out to Railroad industry. Provided state data and technical support.
- More information on ERTAC Rail is available elsewhere (EPA EI 2009) …

The ERTAC Rail Subcommittee

Name	Organization	Name	Organization
Allan Ostrander	MI Dept. of Environ. Quality	Kevin McGarry	NY Dept. of Environ. Conserv.
Amanda Carter	AL Dept. of Environ. Manag.	Laurel Driver	US EPA OAQPS
Ashley Mixon	SC Dept. of Health and Environ. Control (SC DHEC)	Lisa Higgins	ME Dept. of Environ. Protection
Bob Wooten	NC Dept. of Environ. and Natural Resources	Mark Janssen	ERTAC/ Lake Michigan AirDirectors Consortium (LADCO)
Carla Bedenbaugh	SC DHEC	Matthew Harrell	IL Environ. Protection Agency
Chad Wilbanks	SC DHEC	Michelle Bergin	GA Environ. Protection Division
Dennis McGeen	MI Dept. of Environ. Quality	Mike Koerber	LADCO
Douglas Malchenson	PA Dept. of Environ. Protection	Pat Brewer	Visibility Improvement State and Tribal Association of the Southeast (VISTAS)/ASIP
Eric Zalewsky	NY Dept. of Environ. Conserv.	Richard Dalebout	MI Dept. of Environ. Quality
Grant Hetherington	WI Dept. of Natural Resources	Sam Long	IL Environ. Protection Agency
Jim Boylan	GA Environ. Protection Div.	Stacy Allen	MO Dept. of Natural Resources
Julie McDill	Mid-Atlantic Regional Air Manag. Assoc. (MARAMA)	Tracy Anderson	AL Dept. of Environ. Manag.
Kelley Matty	PA Dept. of Environ. Protection	William Nichols	OH Environ. Protection Agency

ERTAC GIS and Data Workgroup

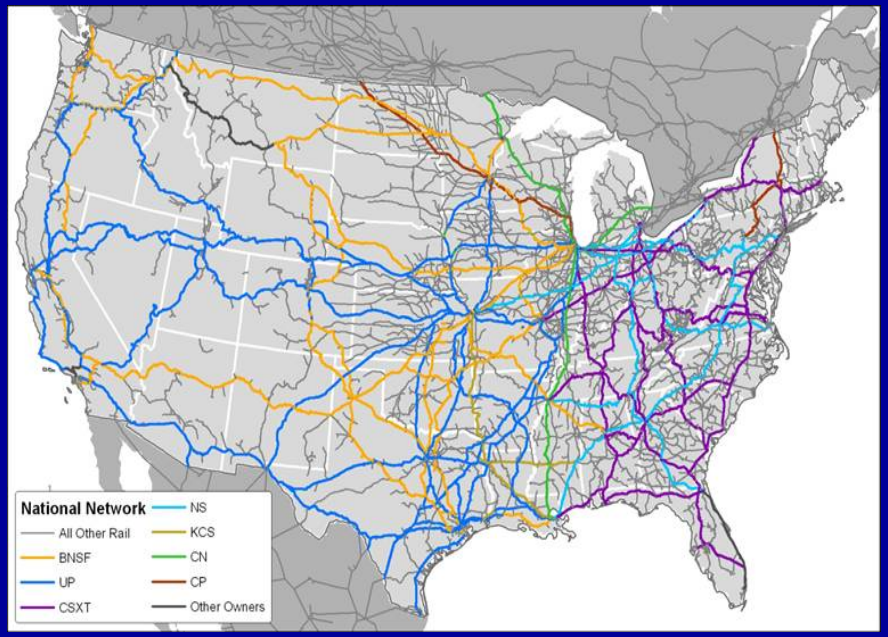
Members	Organization	Members	Organization
Matt Harrell	IL EPA	David Seep and William Watson	BNSF
Michelle Bergin Byeong Kim	GA EPD	Ken Roberge	Canadian Pacific Railway
Mark Janssen	LADCO	Carl Akins	Kansas City Southern
Julie McDill and Patrick Davis	MARAMA	Erika Akkerman	Canadian National Railway
Laurel Driver	US EPA OAQPS	M. John Germer, Lanny Schmid, and Paul Steege,	Union Pacific Railroad
Robert Fronczak	AAR	Brent Mason	Norfolk Southern Corp.
Rick Nath, Abby Clark, and Kelley Slettebo	CSX Transportation	Joanne Maxwell	Amtrak

Duty-Cycles ➔ Emission Factors

- Line-Haul – representing long distance travel. ~ 4500+ hp locomotives, 40+ years.
- Switcher – representing use in and near railyards to break and assemble trains. Locomotive up to ~3000 hp , often retired line-haul locomotives, older and high emitting. Est. about 80% idle.

➢ Each of these operation types are currently represented by one duty-cycle and one set of emission factors averaged over all carriers and locations nationwide.

Locomotive Defining Characteristics: Class and Duty-cycle



Railroad Category	Definition by Revenue
Class I (7 in US + Amtrak)	$346.8M +
Class II (Regional)	$346.8M to $40M
Class III (Shortline)	less than $40M

http://www.aslrra.org/about_aslrra/faqs/

- Class I rail accounts for ~80% of total fuel use and 70% of miles operated.
- Each Class I operates in definable areas.

Current Inventory Methods and Data

Class I Line-haul

- Systemwide annual fuel use and tonnage by carrier.
- Single national industry-averaged set of emission factors.
- Little to no spatial or temporal apportionment of activity.

Class I Switchers

- Single national industry-averaged set of emission factors and annual fuel use per switcher (82k gal/year).
- No consistent data source for location of railyards or number of switchers in general use.

Class II/III, Commuter, and Passenger Rail generally neglected.

Emissions from 3 Class I Switchers based on EPA default factors for 2008

	g/gal	gal/yr	tons/yr	x3 switchers
NOx	243	82490	22.10	**66.29 tons per year NOx**
PM10	5.5	82490	0.50	**1.50 tons per year PM**
				(1.46 tons PM2.5)

EPA Technical Highlights: Emission Factors for Locomotives, EPA OTAQ, EPA-420-F-09-025, April 2009.

Inventory Development

- Class I Line-Haul
- Class I Switcher
- Class II and III combined

Calculations

1. Find best available spatial maps
2. Calculate or select emission factors
3. Calculate an activity indicator (i.e. fuel use)
4. Calculate Emissions per Link, Railyard, or Class II/III System

Emission Factors and Other Data

- Please see companion conference paper for references.
- Non-road engine and fuel specific information is sparse for these factors and conversions.
- Locomotives are not subject to general non-road fuel or engine standards, are not subject to most state regulatory actions, and are not required to submit any data to states.

Best Available Map and Data: FRA

- ERTAC Rail gained access to a business-confidential GIS dataset based on information supplied to the Federal Railroad Administration by the Class I railroads ('FRA')
  - 2007 link level tonnage per Class I line-haul
  - Identification of railyard links and owners
  - Class II and III railroad links and owners.
  - Very similar GIS spatial information is publically available from the Bureau of Transportation Statistics in the 2009 NTAD 2009 (for 2007)

Weighted Emission Factors based on Tier mix of fleet (Class I)

Ex.: EPA line-haul locomotive Emission Factors by Tier, 1997 (grams/gal).

	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

Class I Weighted Emission Factors

$$EF_{iRR} = \sum_{T=1}^{4} (EF_{iT} * f_{TRR})$$ (PM_{10}, HC, NO_x, CO)

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)**

f_{TRR} = **Fraction of railroad RR fleet in Tier T.** (Confidential, supplied by Class Is)

Non-engine specific emission factors

$PM_{2.5}$ = 97% of PM_{10}

SO_2 = 1.88 g/gal

NH_3 = 83.3 mg/gal

EPA greenhouse gas emission factors for locomotive diesel fuel (grams/gal).

	CO_2	N_2O	CH_4
Locomotive diesel	**1.015E4**	**0.26**	**0.80**

Class I Line-Haul Activity: Railroad Fuel Consumption Index

$$RFCI_{RR} = \frac{GTM_{RR}}{FC_{RR}}$$

$RFCI_{RR}$ = 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).

RFCI per railroad …

Railroad Fuel Consumption Index

Class I Railroads, Reported Fuel Use, and Railroad Fuel Consumption Index (RFCI)

Class I Railroads*	R-1 Reported Locomotive Fuel Use (gal/yr)		**Line-Haul** 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
Total	**3,770,914,002**	**300,492,223**	**929.47**

Class I Line-haul link emissions

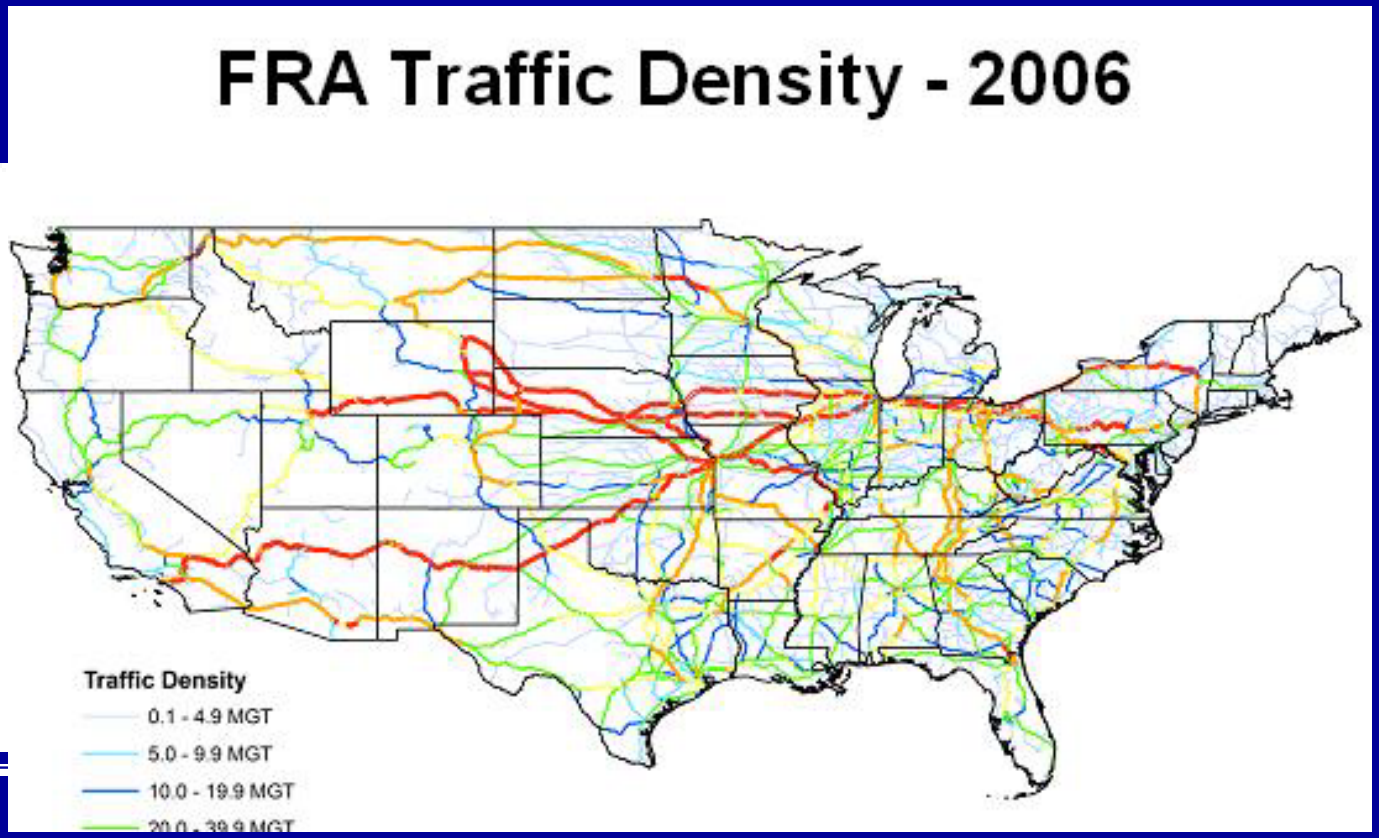
$$E_{iL} = \sum_{RR=1}^{N} \frac{\left(\frac{MGT_L * 10^6}{N} \right) * l_L}{RFCI_{RR}} * EF_{iRR}$$

Aggregated link level to county and state level inventories, more fine resolution may be requested for special studies.

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 (tons/gal).
$RFCI_{RR}$	=	Railroad Fuel Consumption Index per railroad RR (gross ton-miles/gal)

Class I Railyard Switchers

- Location and Operators (Railroads) by FRA
- Fleet weighted and other Emis Factors (gm/gal)
- ➢ Activity by DENCODE or FRA link level MGT



Railyard Switcher Activity Indicator

Scalar calculated based on railyard link activity, either Dencode 1 – 7 or FRA link tonnage

$$SAI_Y' = OF_Y * \sum_{n_Y} (l_{nY} * AF_{nY})$$

SAI_Y'	=	Switcher Activity Indicator in Railyard Y by one Railroad
OF_Y	=	Ownership Factor depending on # of Railroads operating on link 1 for 1 operator, .80/.20 for 2 operators, .70/.20/.10 for 3 operators
n_Y	=	number of links identified as part of railyard Y
l_{nY}	=	length of link n in miles
AF_n	=	Activity Factor for link n, either
	FDC_n =	Federal Density Code (1 to 7) of link n OR
	MGT_{nY} =	million gross tons on link n

Switcher Fuel Use per Yard

$$SFU_{YRR} = \frac{SAI_Y'}{\sum_{Y_{RR}} SAI_{Y_{RR}}'} * TFU_{RR}$$

$SFU_{Y_{RR}}$ = Switcher Fuel Use at railyard Y for RR (gal)

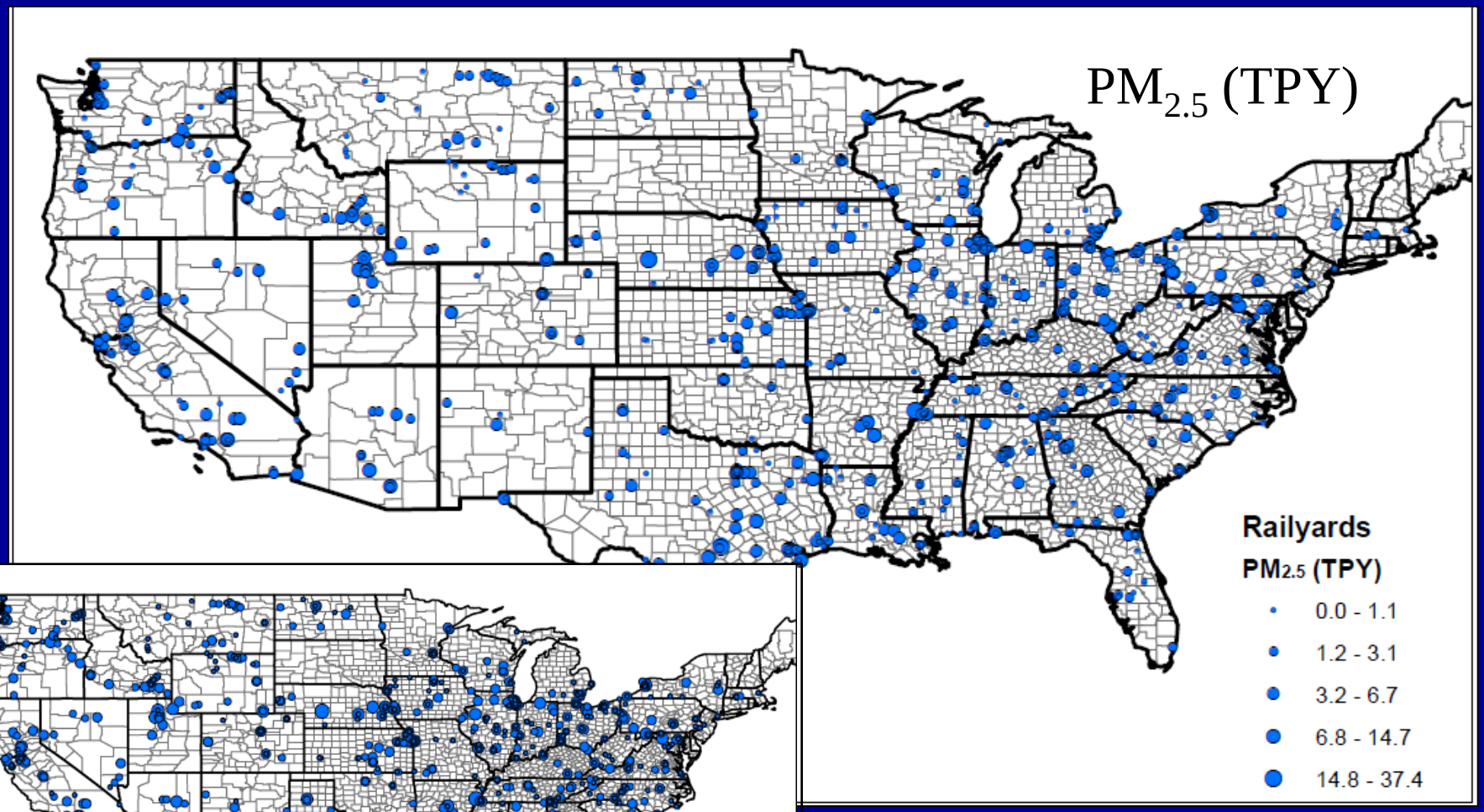
TFU_{RR} = Total Annual Switcher Fuel Use by Railroad RR (gal) (from R-1 report)

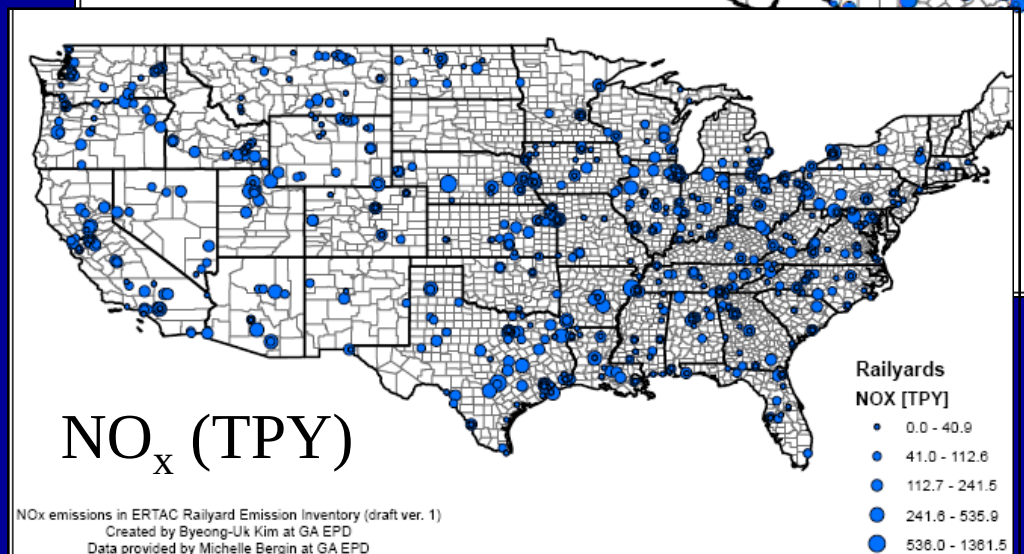
Multiply $SFU_{Y_{RR}}$ by the RR specific or appropriate emission factors and sum emissions for all RRs operating at yard Y.

Yard Switcher Refinement

- Line-haul activity (Dencode and MGT) are not always correlated with switching activity.
- Class I RRs supplied average annual fuel use per switcher and switcher counts for yards in $PM_{2.5}$ nonattainment areas with 8 or more switchers
  - 50,000 gal/yr to 82,490 gal/yr (the EPA default)
- Most Class I Railroads corrected inventory for very large yards using Switching Activity Factor.
- States updated estimates for better known railyards.

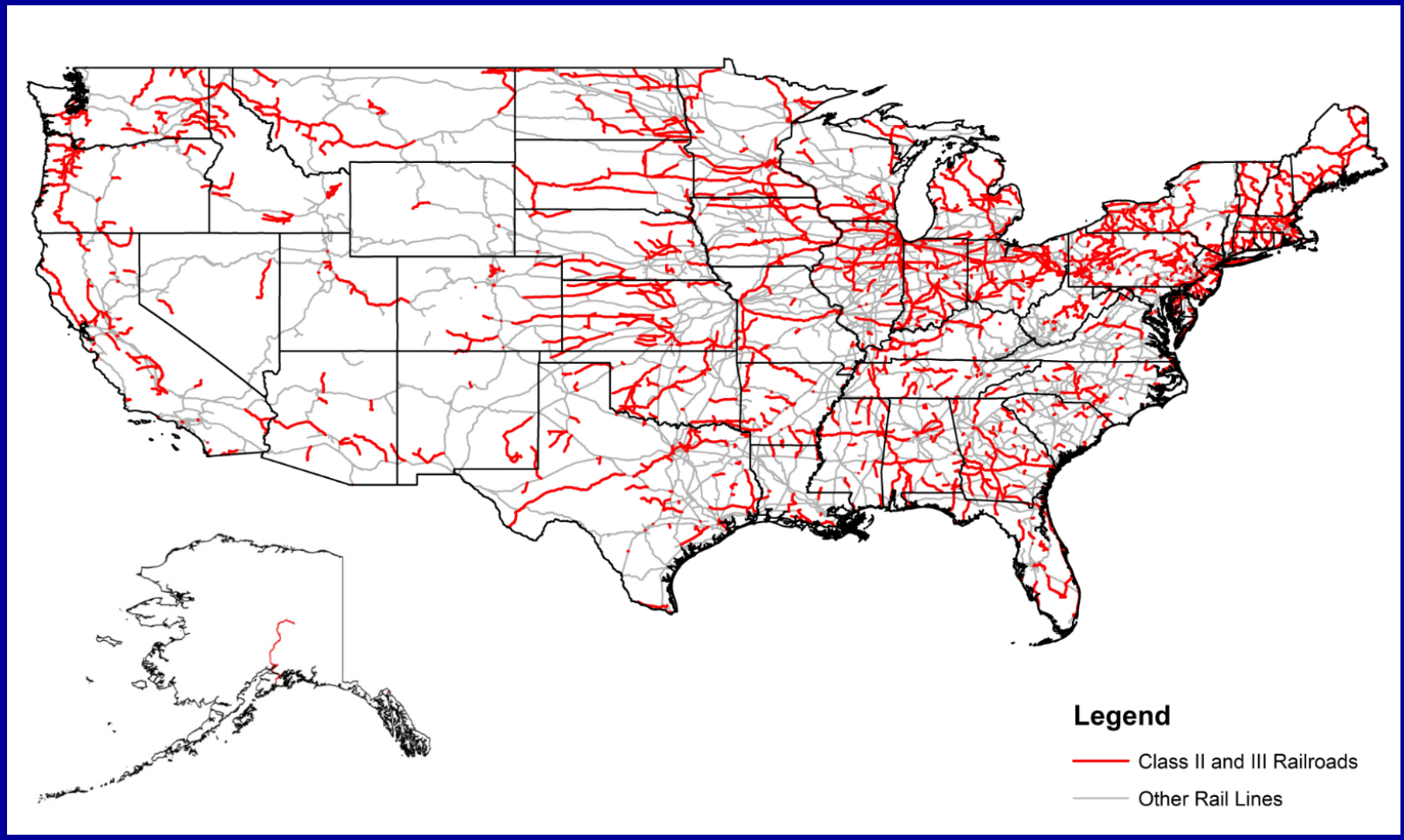
Railyard Switcher Emission Results





Class II and III Inventory

- About 570 Class II and III Railroads.
- Location, owner, and track lengths from FRA database.



Class II and III Inventory

- Industry guidance recommended pre-1973 emission factors as best estimate (EPA 'small line-haul)
- American Shortline and Regional Railroad Assoc. (ASLRRA) compiled 2008 total annual fuel use estimate of 157,800,000 gal.

$$FuelUseFactor = \frac{TotalIndustryFuelUse_{ASLRRA}}{TotalClassII/IIIRouteMiles_{FRA}} = 2814.64 \frac{gal}{mile}$$

Railroad fuel used = FUF * track miles
unless other data was available (refined)
Emissions = fuel used * emission factors
***Many reasons for variability in FUFs, use specific fuel data whenever possible

Summary of ERTAC Rail Inventories

2007 or 2008 U.S. Locomotive Emissions and Fuel Use

	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

Available by county and state, used in a poster here at EI!

http://www.georgiaair.org/airpermit/html/planningsupport/regdev/locomotives/locomotives.html

Limitations/Wish List

- More accurate fuel use information.
- More options for characterization of duty cycles.
- Characterization of temporal variation (emissions constant every hour all year).
- Incorporation of terrain, grade, and speed for line-haul emission calculations.
- Projection methodology and a new year inventory (2011), otherwise scale fuel.

Conclusions

- Railroads are a very important national resource, a valuable component for our freight and energy systems.
- No emissions inventory will ever capture the innate variability of railroad operations.
- Railroads can be (are) an important contributing source to pollutant concentrations.
- Many opportunities exist to improve these inventories (see paper) and to reduce rail emissions.

Any questions, comments, suggestions, corrections, etc. are welcome …

Thank you!

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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.