Locomotive Emission Inventories for the United States from ERTAC Rail

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

U.S. Environmental Protection Agency
2012 International Emission Inventory Conference
Tampa, FL   August 13 – 16, 2012
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 Switchers
  – 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
FS8 is located near two railyards in Atlanta and is \( \sim 2 \mu g/m^3 \) \( PM_{2.5} \) above other nearby monitors.
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

Class I Line-haul

National Network:
- NS
- All Other Rail
- BNSF
- UP
- CSXT
- KCS
- CN
- CP
- Other Owners
ERTAC Rail

• Collaborative participation
  – 27 Eastern States’ air protection agencies
  – Class I and Class II/III associations (AAR and ASLRRRA)
  – 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

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

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

Georgia Environmental Protection Division
Locomotive Defining Characteristics: Class and Duty-cycle

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

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

<table>
<thead>
<tr>
<th>Railroad Category</th>
<th>Definition by Revenue</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class I (7 in US + Amtrak)</td>
<td>$346.8M +</td>
</tr>
<tr>
<td>Class II (Regional)</td>
<td>$346.8M to $40M</td>
</tr>
<tr>
<td>Class III (Shortline)</td>
<td>less than $40M</td>
</tr>
</tbody>
</table>
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

<table>
<thead>
<tr>
<th></th>
<th>g/gal</th>
<th>gal/yr</th>
<th>tons/yr</th>
<th>x3 switchers</th>
</tr>
</thead>
<tbody>
<tr>
<td>NOx</td>
<td>243</td>
<td>82490</td>
<td>22.10</td>
<td>66.29 tons per year NOx</td>
</tr>
<tr>
<td>PM10</td>
<td>5.5</td>
<td>82490</td>
<td>0.50</td>
<td>1.50 tons per year PM</td>
</tr>
</tbody>
</table>

(1.46 tons PM2.5)

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).

<table>
<thead>
<tr>
<th>Tier Type</th>
<th>PM$_{10}$</th>
<th>HC</th>
<th>NO$_x$</th>
<th>CO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uncontrolled (pre-1973)</td>
<td>6.656</td>
<td>9.984</td>
<td>270.4</td>
<td>26.624</td>
</tr>
<tr>
<td>Tier 0 (1973-2001)</td>
<td>6.656</td>
<td>9.984</td>
<td>178.88</td>
<td>26.624</td>
</tr>
<tr>
<td>Tier 2 (2005 + )</td>
<td>3.744</td>
<td>5.408</td>
<td>102.96</td>
<td>26.624</td>
</tr>
</tbody>
</table>
Class I Weighted Emission Factors

\[
EF_{iRR} = \sum_{T=1}^{4} (EF_{iT} \times f_{TRR}) \quad \text{(PM}_{10}, \text{HC}, \text{NO}_x, \text{CO})
\]

- \( EF_{iRR} \) = 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).**

<table>
<thead>
<tr>
<th></th>
<th>CO(_2)</th>
<th>N(_2)O</th>
<th>CH(_4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Locomotive diesel</td>
<td>1.015E4</td>
<td>0.26</td>
<td>0.80</td>
</tr>
</tbody>
</table>
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)

<table>
<thead>
<tr>
<th>Class I Railroads*</th>
<th>R-1 Reported Locomotive Fuel Use (gal/yr)</th>
<th>Line-Haul RFCI (ton-miles/gal)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BNSF</td>
<td>1,393,874,954</td>
<td>52,497,057</td>
</tr>
<tr>
<td>Canadian National</td>
<td>93,830,751</td>
<td>12,290,022</td>
</tr>
<tr>
<td>Canadian Pacific***</td>
<td>50,320,233</td>
<td>4,594,067</td>
</tr>
<tr>
<td>CSX</td>
<td>514,687,186</td>
<td>53,717,674</td>
</tr>
<tr>
<td>Kansas City Southern</td>
<td>69,787,071</td>
<td>1,816,759</td>
</tr>
<tr>
<td>Norfolk Southern</td>
<td>463,267,278</td>
<td>32,317,375</td>
</tr>
<tr>
<td>Union Pacific</td>
<td>1,185,146,529</td>
<td>143,470,336</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>3,770,914,002</strong></td>
<td><strong>300,492,223</strong></td>
</tr>
</tbody>
</table>
Class I Line-haul link emissions

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

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

\[
\text{SAI}_Y' = \text{OF}_Y \times \sum_{n_Y} (l_{n_Y} \times AF_{n_Y})
\]

- \( \text{SAI}_Y' \) = Switcher Activity Indicator in Railyard Y by one Railroad
- \( \text{OF}_Y \) = 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
- \( l_{n_Y} \) = length of link n in miles
- \( AF_{n} \) = Activity Factor for link n, either
  - \( \text{FDC}_n \) = Federal Density Code (1 to 7) of link n OR
  - \( \text{MGT}_{n_Y} \) = million gross tons on link n
Switcher Fuel Use per Yard

\[ SFU_{Y,RR} = \frac{\sum SAI_{Y,RR}'}{\sum SAI_{Y,RR}'} \times TFU_{RR} \]

- \( SFU_{Y,RR} = \) 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

PM$_{2.5}$ (TPY)

NO$_x$ (TPY)
Class II and III Inventory

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

Legend
- Class II and III Railroads
- Other Rail Lines
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. (ASLRRRA) compiled 2008 **total annual fuel use estimate** of 157,800,000 gal.

\[
\text{FuelUseFactor} = \frac{\text{TotalIndustryFuelUse}_{\text{ASLRRRA}}}{\text{TotalClassII/IIIRouteMiles}_{\text{FRA}}} = 2814.64 \frac{\text{gal}}{\text{mile}}
\]

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

<table>
<thead>
<tr>
<th>Class</th>
<th>Fuel Use** (gal/yr)</th>
<th>NOₓ</th>
<th>PM₂.₅</th>
<th>HC</th>
<th>SO₂</th>
<th>CO</th>
<th>NH₃</th>
<th>CO₂</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class I***</td>
<td>3,770,914,002</td>
<td>754,443</td>
<td>23,439</td>
<td>37,941</td>
<td>7,836</td>
<td>110,969</td>
<td>347</td>
<td>42,305k</td>
</tr>
<tr>
<td>line-haul</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Class I</td>
<td>301,046,290</td>
<td>74,431</td>
<td>2,042</td>
<td>4,867</td>
<td>624</td>
<td>9,230</td>
<td>28</td>
<td>3,367k</td>
</tr>
<tr>
<td>switcher</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Class II</td>
<td>157,800,000</td>
<td>47,035</td>
<td>1,065</td>
<td>1,737</td>
<td>327</td>
<td>4,631</td>
<td>14</td>
<td>1,765k</td>
</tr>
<tr>
<td>and III</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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

Michelle Bergin, PhD
Environmental Engineer
GA Environmental Protection Division
Air Protection Branch, Planning and Support
michelle.bergin@dnr.state.ga.us 404-362-4569
<table>
<thead>
<tr>
<th>Data</th>
<th>Year</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class I Line-Haul</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Annual Line-Haul Fuel Use</td>
<td>2007</td>
<td>STB R-1 Reports (CP data for D&amp;H is for 2008.)</td>
</tr>
<tr>
<td>Line-haul fleet mix for emission factors</td>
<td>2008</td>
<td>Each Class I railroad</td>
</tr>
<tr>
<td>Link-level tonnage</td>
<td>2007</td>
<td>FRA confidential database</td>
</tr>
<tr>
<td><strong>Class I Railyards (Switcher Locomotives)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Annual Switcher Fuel Use</td>
<td>2008</td>
<td>R-1 Reports</td>
</tr>
<tr>
<td>Switcher fleet mix for emission factors</td>
<td>2008</td>
<td>Each Class I railroad</td>
</tr>
<tr>
<td>Link-level tonnage or Density Code (for activity estimate)</td>
<td>2007</td>
<td>FRA confidential database</td>
</tr>
<tr>
<td><strong>Class II and III Locomotives</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Track length and railroad</td>
<td>2007</td>
<td>FRA confidential database</td>
</tr>
<tr>
<td>Estimated fleet mix for emission factors</td>
<td></td>
<td>Discussions with ASLRRA and Class II and III representatives.</td>
</tr>
</tbody>
</table>