



# Locomotive Emissions Assessment and Diesel Emission Reduction Options

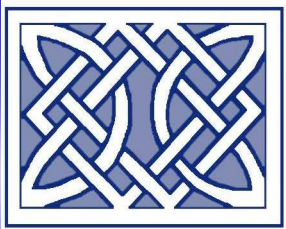
New England Railroad Club Expo 2006

Thomas Balon - MJBA

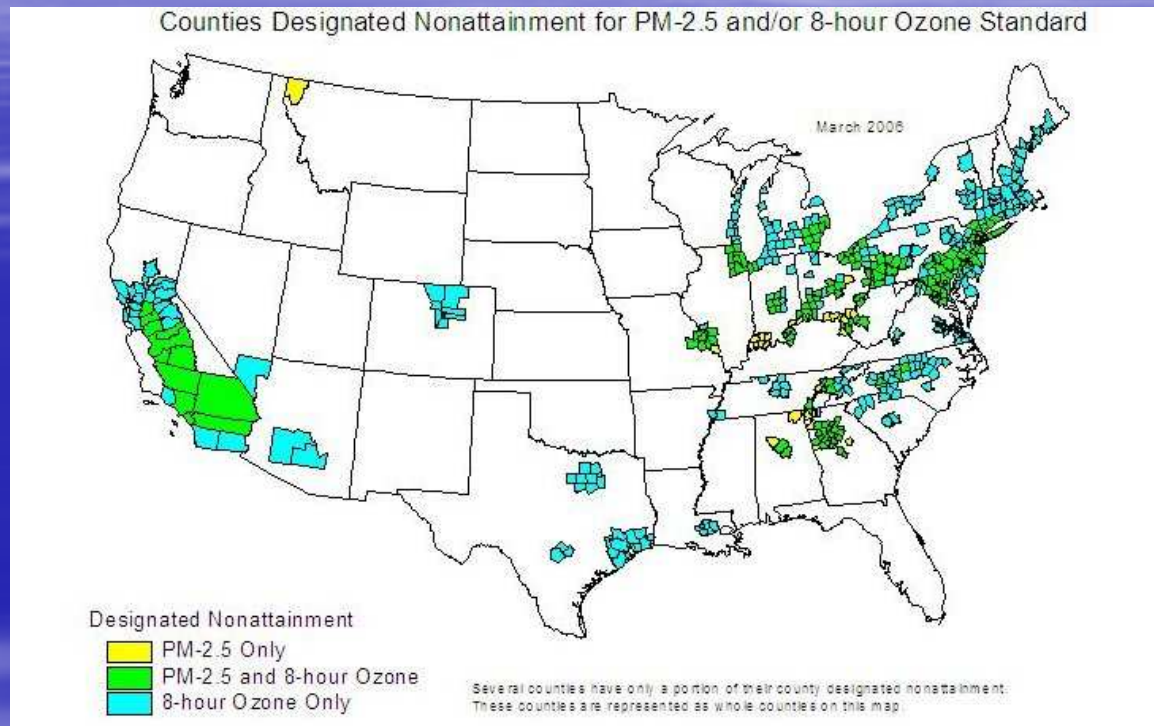


# Criteria Pollutants

- EPA sets ambient emission levels for:
- **Ozone (O<sub>3</sub>)**
  - Ozone precursor, **Oxides of nitrogen (NO<sub>x</sub>)**
  - Ozone precursor, Volatile organic compounds (VOCs)
- **Particulate matter (PM)**
- Other Criteria Pollutants include
  - Lead (Pb), Carbon monoxide (CO), Nitrogen dioxide (NO<sub>2</sub>), Sulfur dioxide (SO<sub>2</sub>)
- Many areas of the US are in **non-attainment**



# PM/Ozone Non-Attainment

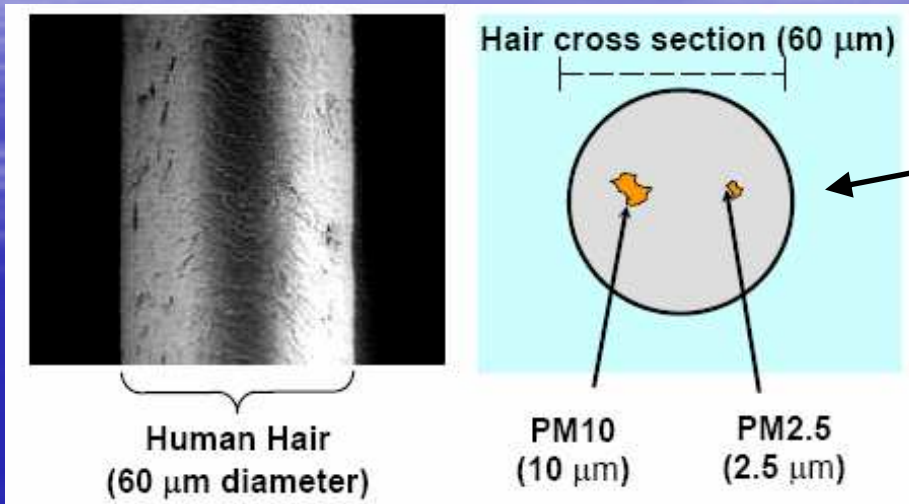


<http://www.epa.gov/air/oaqps/greenbk/mappm25o3.html>

Over 52 percent of the U.S. population lives in counties that have unhealthy levels of either ozone or particle pollution ([http://lungaction.org/reports/sota05exec\\_summ.html](http://lungaction.org/reports/sota05exec_summ.html))



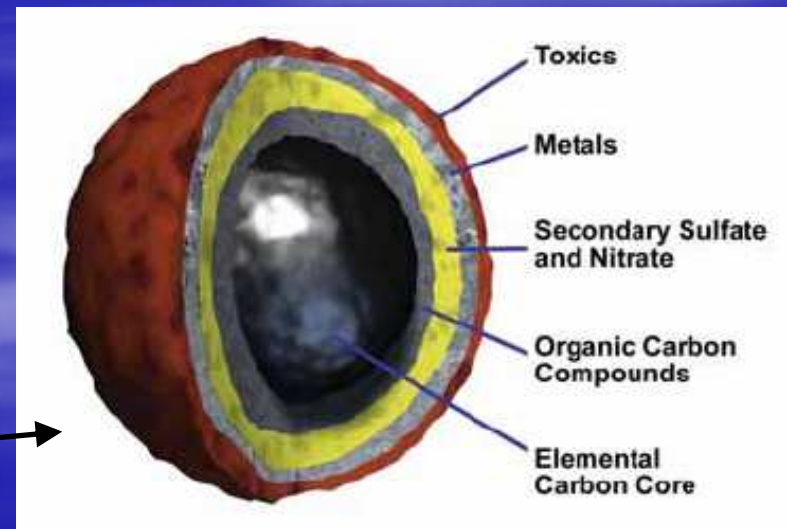
# What is Particulate Matter?



Source: EPA

Diesel PM is primarily composed of a carbon core with organic materials and sulfates adsorbed on the surface (picture is illustrative only)

PM is composed of very small particles that remain airborne and can penetrate deep into the lungs.



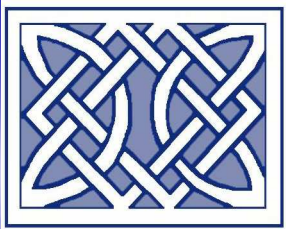
Source: Clean Air Task Force



# Current and Future Fuels (Mandatory)

- Off-Road Diesel/Distillate Oil (~3,000 ppm sulfur), (DO)
- Low Sulfur Diesel (500 ppm sulfur), (LSD)
- Ultra-Low Sulfur Diesel (15 ppm sulfur), (ULSD)

	Current	June 2006	June 2007	June 2010	June 2012
On-Road	500	15	15	15	15
Off-Road	~3,000	~3,000	500	15	15
Marine/Rail	~3,000	~3,000	500	500	15

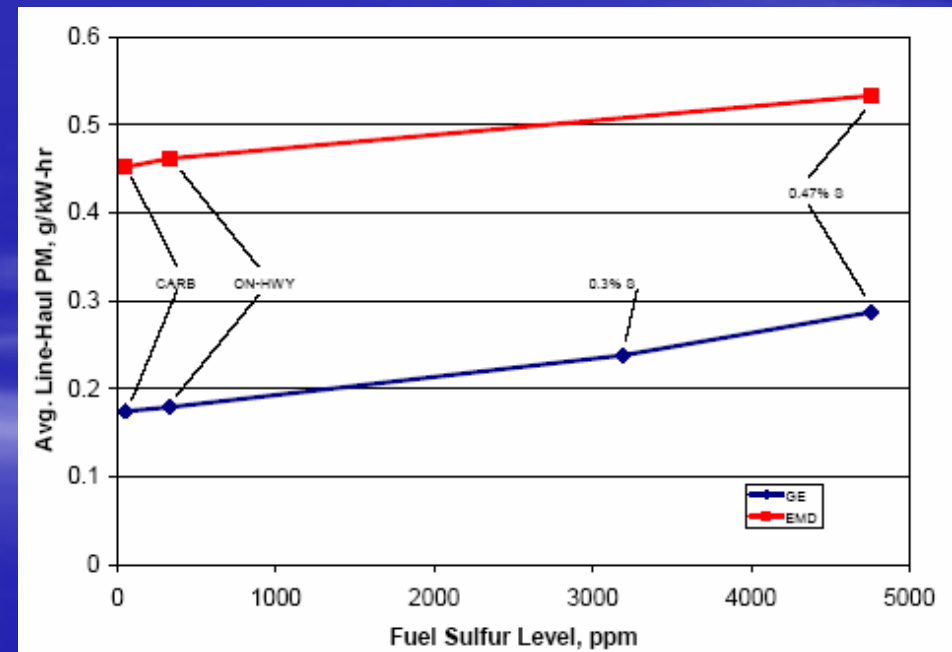


# Reducing Sulfur In Diesel

- **Sulfur IN** (fuel + lube oil) = **Sulfur OUT** (tailpipe)
  - Reducing sulfur reduces emission of Sulfur dioxide (SO<sub>2</sub>), **PM contributing Sulfate (SO<sub>3</sub>)**, and Sulfuric Acid (H<sub>2</sub>SO<sub>4</sub>)

The switch from >3000-ppm sulfur fuel to on-highway <500-ppm fuel in an SWRI study resulted in PM reductions of 16% to 38%

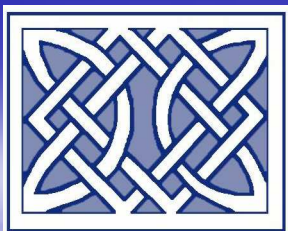
PM emission reductions are essentially linear with sulfur content





## Reducing Sulfur In Diesel (2)

- Sulfur interferes with **CATALYSTS** used in many diesel emissions reduction devices and can also lead to increased Sulfate particulate emissions
- LSD facilitates a Diesel Oxidation Catalyst (DOC)
  - Below 500-ppm sulfur, a DOC can be used to **catalytically oxidize** organics including those adsorbed onto the PM surface
  - LSD will also facilitate the use of an active filter (space concerns)
- ULSD facilitates a Diesel Particulate Filter (DPF)
  - Below 15-ppm sulfur a **highly catalyzed** passive DPF can be used to physically filter PM from the exhaust gas where it is eventually oxidized to CO<sub>2</sub>

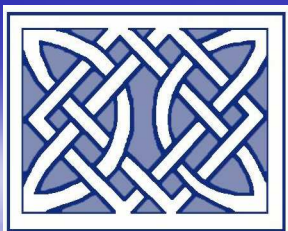


# Locomotive Emission

## Weighted Modal Standards (g/bhp-hr)

- Tier 0, 1 emission standards apply during rebuild (mandatory)
  - 1998 Truck, 4 g/bhp-hr NOx, 0.1 g/bhp-hr PM
  - 2007/10 Truck, 0.2 g/bhp-hr NOx, 0.01 g/bhp-hr PM

Duty Cycle	Tier	Years Covered	THC	CO	NOx	PM
Switchyard	0	1973 – 2001	2.1	8.0	14.0	0.72
	1	2002 – 2004	1.2	2.5	11.0	0.54
	2	2005 –	0.6	2.4	8.1	0.24
Line-Haul	0	1973 – 2001	1.0	5.0	9.5	0.6
	1	2002 – 2004	0.55	2.2	7.4	0.45
	2	2005 –	0.3	1.5	5.5	0.2



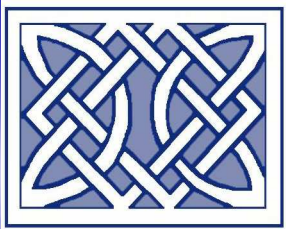
# Inventory Methodology

- Several course methods for estimating emissions and typically all are used for comparison
  - 1) Hp-hr method
    - Engine HP x Hours x Load Factor (modal weighted) = **hp-hr**
    - **Hp-hr** x emission factor (g/bhp-hr) / 454 g/lb / 2000 lb/ton = Annual Tons
  - 2) Fuel Consumption Methods
    - Fuel gallons x hp-hr/gal x engine efficiency = **hp-hr**
    - Pounds of fuel / BSFC (lb/hp-hr) = **hp-hr**



## Inventory Methodology (2)

- Several **course** methods for estimating emissions and typically all are used for comparison
  - 1) Hp-hr method
    - $4100 \text{ hp} \times 5000 \text{ hrs} \times 0.29 \text{ lf} = 5,945,000 \text{ hp-hr}$
    - $5,945,000 \text{ hp-hr} \times 9.5 \text{ g/bhp-hr NOx} / 454 \text{ g/lb} / 2000 \text{ lb/ton} = 62.2 \text{ NOx tons per year (tpy)}$
  - 2) Fuel Consumption Methods (line haul weighted)
    - $325,000 \text{ gallons} \times \sim 18 \text{ hp-hr/gal} = 5,850,000 \text{ hp-hr}$
    - $2,275,000 \text{ lbs} / 0.38 \text{ lb/hp-hr} = 5,986,842 \text{ hp-hr}$

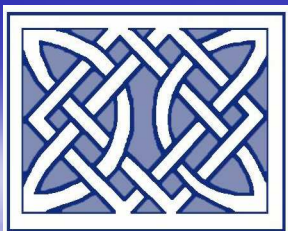


# Locomotive Emissions

## Comparison to 1998 Truck

Duty Cycle	Tier	Assumptions	NOx		PM	
Switchyard	0	2000 hp, 5000 hr/yr	14.0	g/bhp-hr	0.72	g/bhp-hr
		Load Factor = 10%	15.4	tpy	0.8	tpy
Line-Haul	0	4100 hp, 5000 hr/yr	9.5	g/bhp-hr	0.6	g/bhp-hr
		Load Factor = 29%	62.2	tpy	3.9	tpy
Truck	1998	400-hp, 2000 hr/yr	4.0	g/bhp-hr	0.1	g/bhp-hr
		Load Factor = 22%	0.8	tpy	0.02	tpy

Line Haul Locomotive equals ~80 trucks for NOx, ~200 for PM in tpy



# Locomotive Menu of Options

(Voluntary)

- Cleaner Fuel (ULSD vs. LSD)
- Idle Management, Idle Stop/Start (Fuel Savings)
- Auxiliary Power Units, HEP modifications
- Diesel Hot Start, Electric Hot Start
- Hybrid-Electric Locomotives, Gen-Set Locomotives
- Tier 1 kits on Tier 0 locomotives (improved BSFC)
- **Oxidation Catalyst Retrofits (Being Demonstrated)**