Locomotive Emissions Assessment and Diesel Emission Reduction Options

New England Railroad Club Expo 2006

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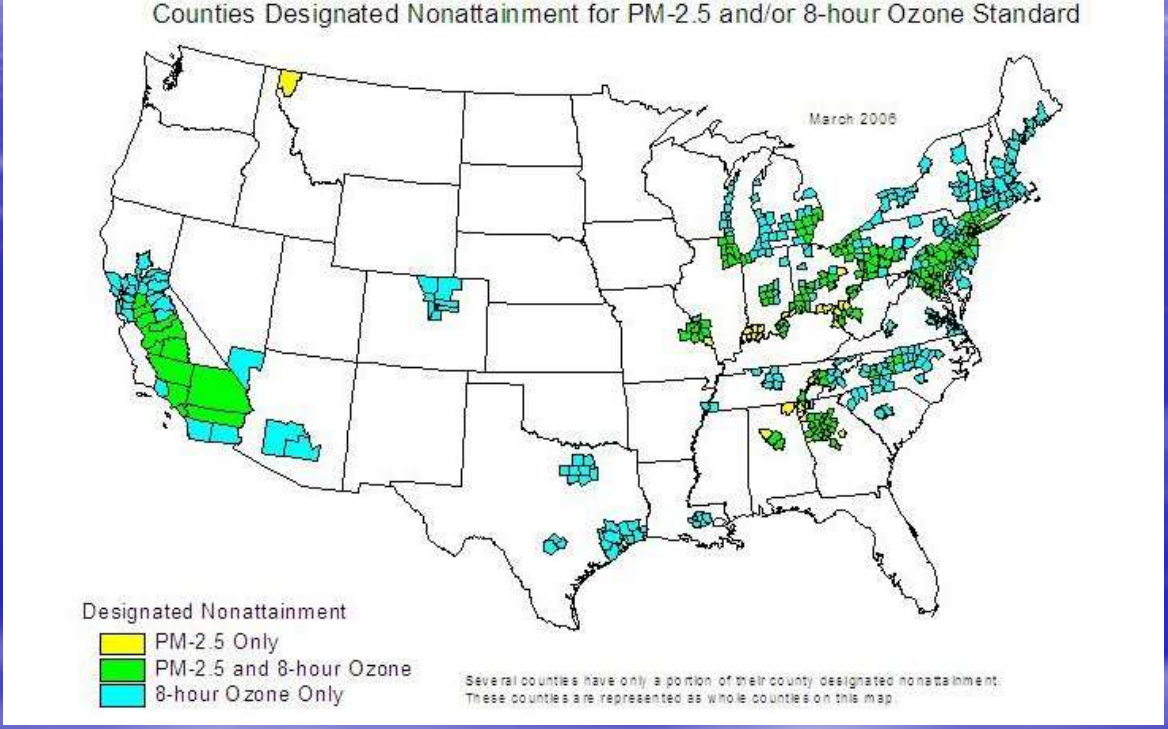
Criteria Pollutants

- EPA sets ambient emission levels for:
- Ozone (O_3)
  - Ozone precursor, Oxides of nitrogen (NOx)
  - Ozone precursor, Volatile organic compounds (VOCs)
- Particulate matter (PM)
- Other Criteria Pollutants include
  - Lead (Pb), Carbon monoxide (CO), Nitrogen dioxide (NO_2), Sulfur dioxide (SO_2)
- Many areas of the US are in non-attainment

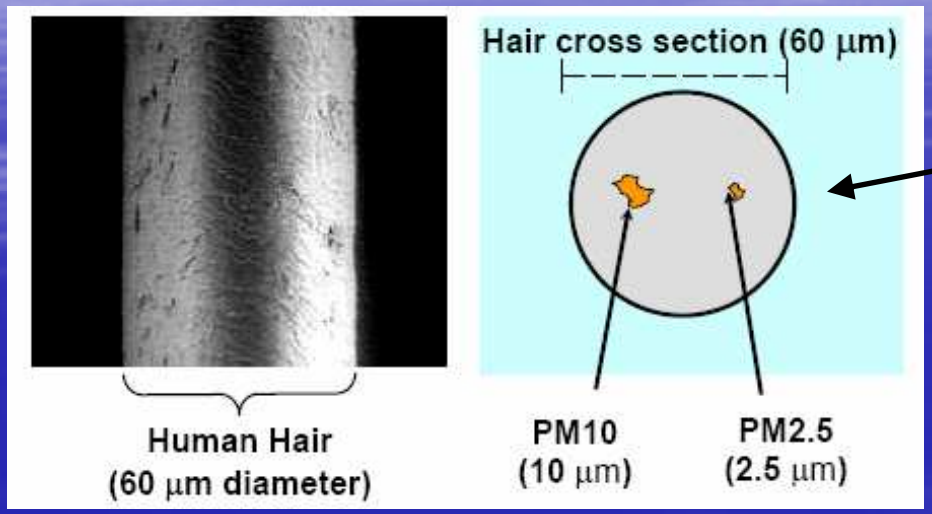
PM/Ozone Non-Attainment



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

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

What is Particulate Matter?

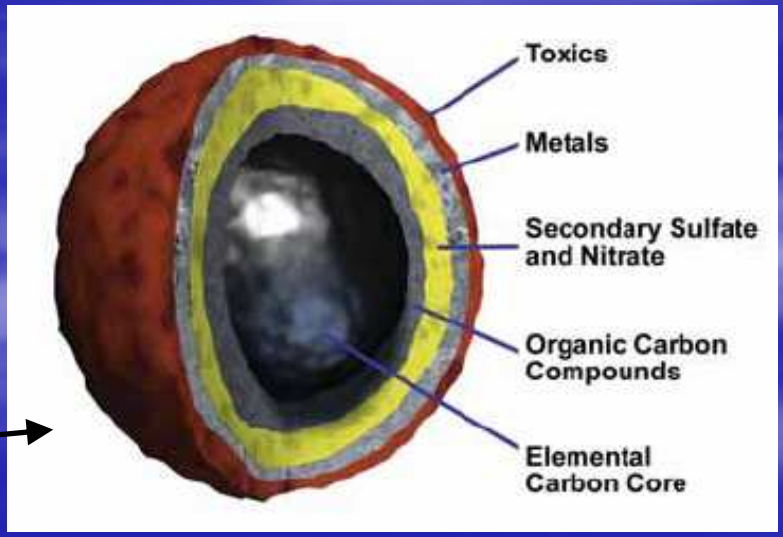


Source: EPA

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

Diesel PM is primarily composed of a carbon core with organic materials and sulfates adsorbed on the surface

(picture is illustrative only)



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)

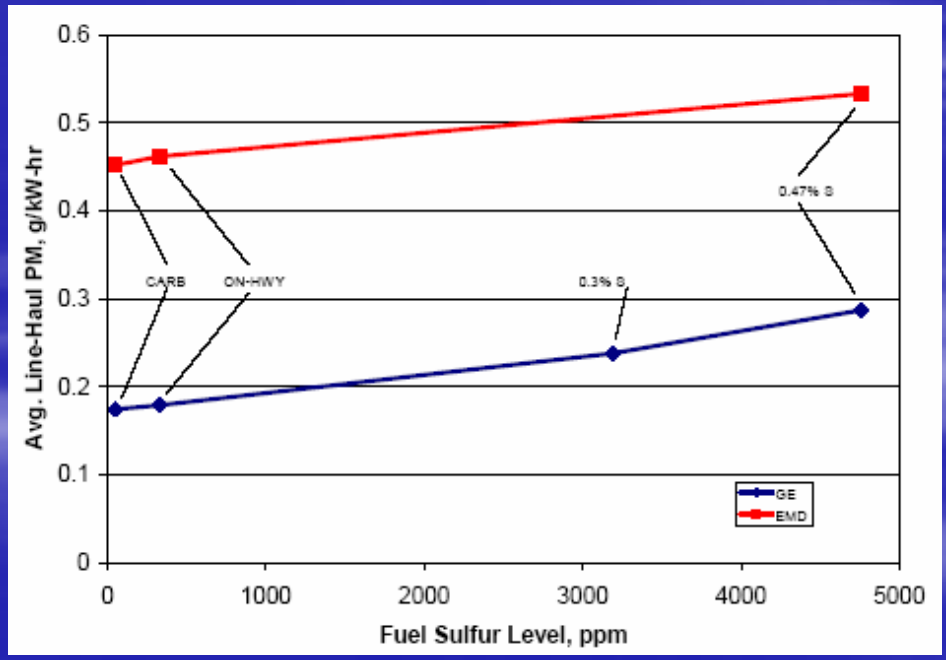
	Current	June 2006	June 2007	June 2010	June 2012
On-Road	500	15	15	15	15
Off-Road	~3,000	~3,000	500	15	15
Marine/Rail	~3,000	~3,000	500	500	15

Reducing Sulfur In Diesel

- Sulfur IN (fuel + lube oil) = Sulfur OUT (tailpipe)
  - Reducing sulfur reduces emission of Sulfur dioxide (SO_2), PM contributing Sulfate (SO_3), and Sulfuric Acid (H_2SO_4)

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



ICEF2005-1228, S. Fritz et al, SWRI, ASME

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_2

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 hp x 5000 hrs x 0.29 lf = 5,945,000 hp-hr
    - 5,945,000 hp-hr x 9.5 g/bhp-hr NOx / 454 g/lb / 2000 lb/ton = 62.2 NOx tons per year (tpy)
  - 2) Fuel Consumption Methods (line haul weighted)
    - 325,000 gallons x ~18 hp-hr/gal = 5,850,000 hp-hr
    - 2,275,000 lbs / 0.38 lb/hp-hr = 5,986,842 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)