Burlington Northern Santa Fe Corporation

Train Resistance and Railroad Emissions and Efficiency

Mark Stehly
October 24, 2008

About BNSF

- Headquartered in Fort Worth, Texas; operates in 28 states and two Canadian provinces
- Employs more than 40,000 people nationwide, with major Southern California operations in Los Angeles, San Bernardino and Barstow
- BNSF is North America's largest grain-hauling railroad and also carries plastics, building and construction materials and consumer goods.
- Moves more intermodal traffic than any other rail system in the world

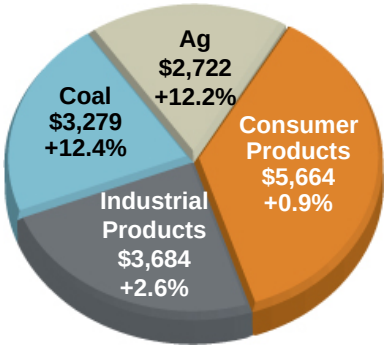
BNSF System & Revenue

One of the largest North American railroads

32,000 route miles, covering 28 states and two Canadian provinces

Freight revenue and % change from 2006

$ Millions



2007 Total BNSF Freight Revenue $15,349 +5.5%

Topics

- Train resistance
  - Wheel/rail interaction and bearing drag
  - Aerodynamic drag

- Criteria air pollutants from locomotives and railyards
  - Non-attainment areas
  - Locomotive contribution to inventories

  - Fuel efficiency
  - System efficiency and locomotive efficiency
  - Greenhouse gas emissions

Train Resistance

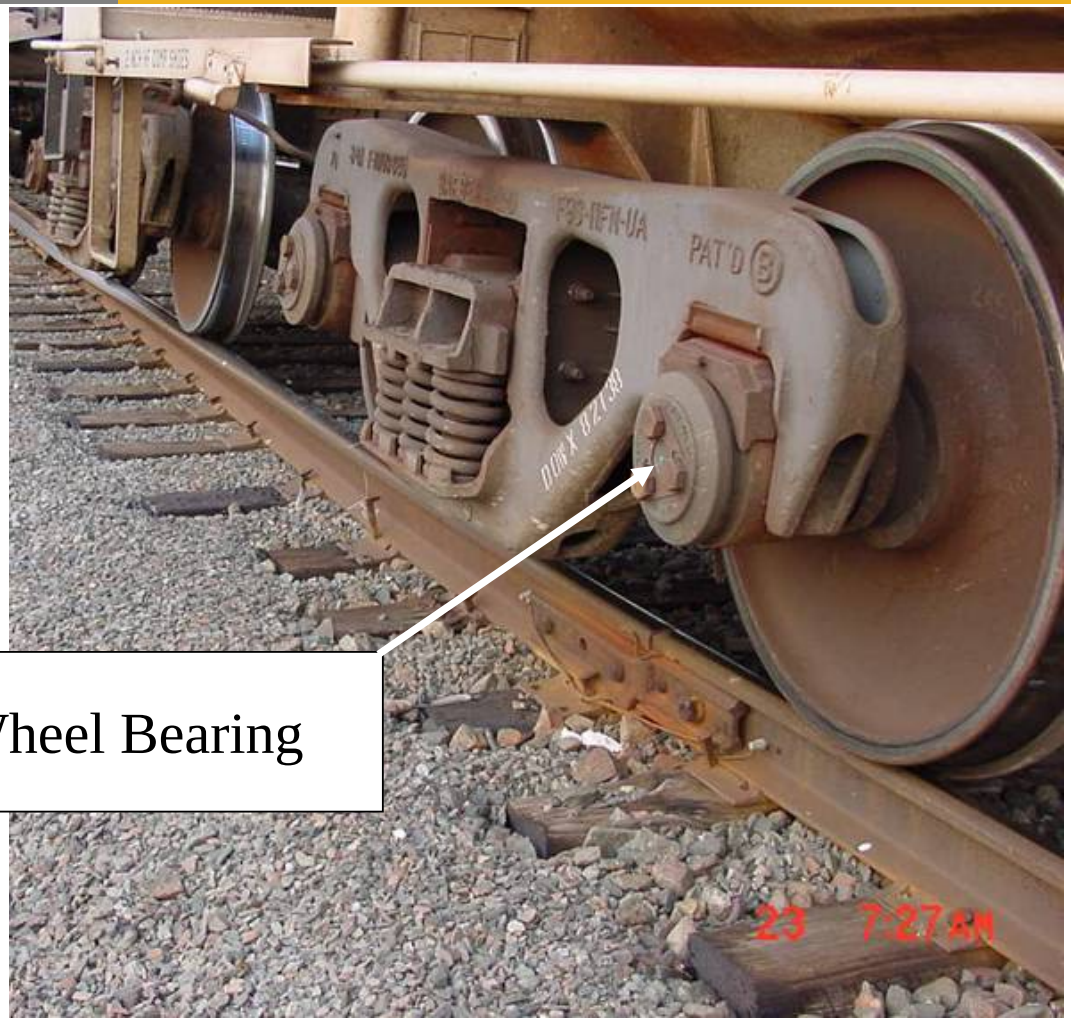
- **Train resistance is a quadratic equation.**
- **R = A + BV + CVsquared + curving + grade + acceleration**
- **A is wheel bearing drag and wheel/rail friction.**
- **B is track bed deformation and is nearly zero.**
- **C is aerodynamic drag having the velocity with respect to the wind.**
- **R is in lbs force or lbs force per ton of train weight.**

A Term

- **Bearings require that a torque be applied for movement. Bearing drag with a rubbing seal typically is 10 lbs force per bearing at a typical wheel size. This is 0.6 lbs force per ton of train weight. Removal of the seal reduces bearing drag by 50%. New labyrinth seals which are non-rubbing can reduce bearing drag by 30% or more.**

- **Wheel/rail friction on tangent track without lubrication typically is 2 lbs force per ton of train weight.**

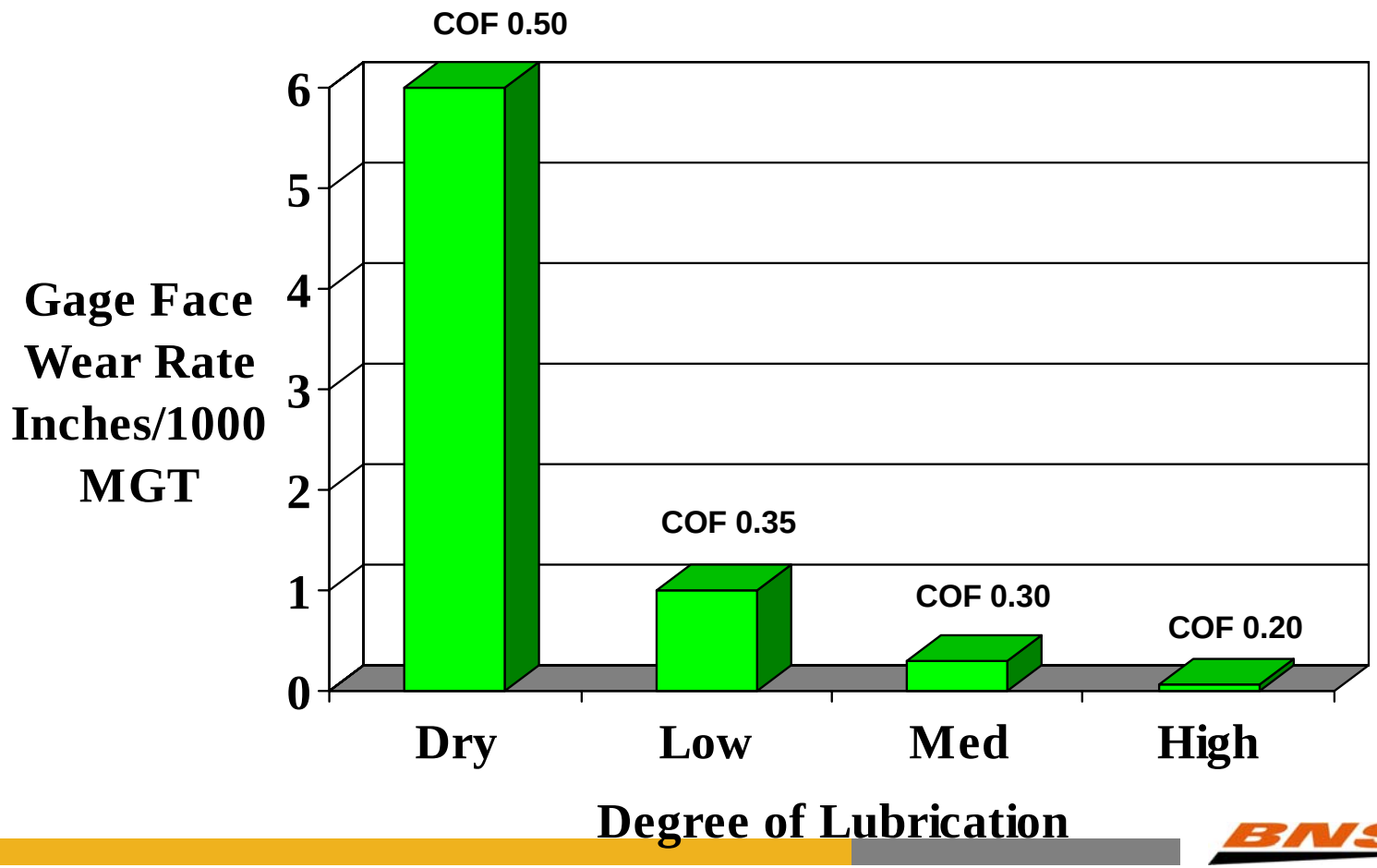
Wheels and Bearings



Wheel Bearing

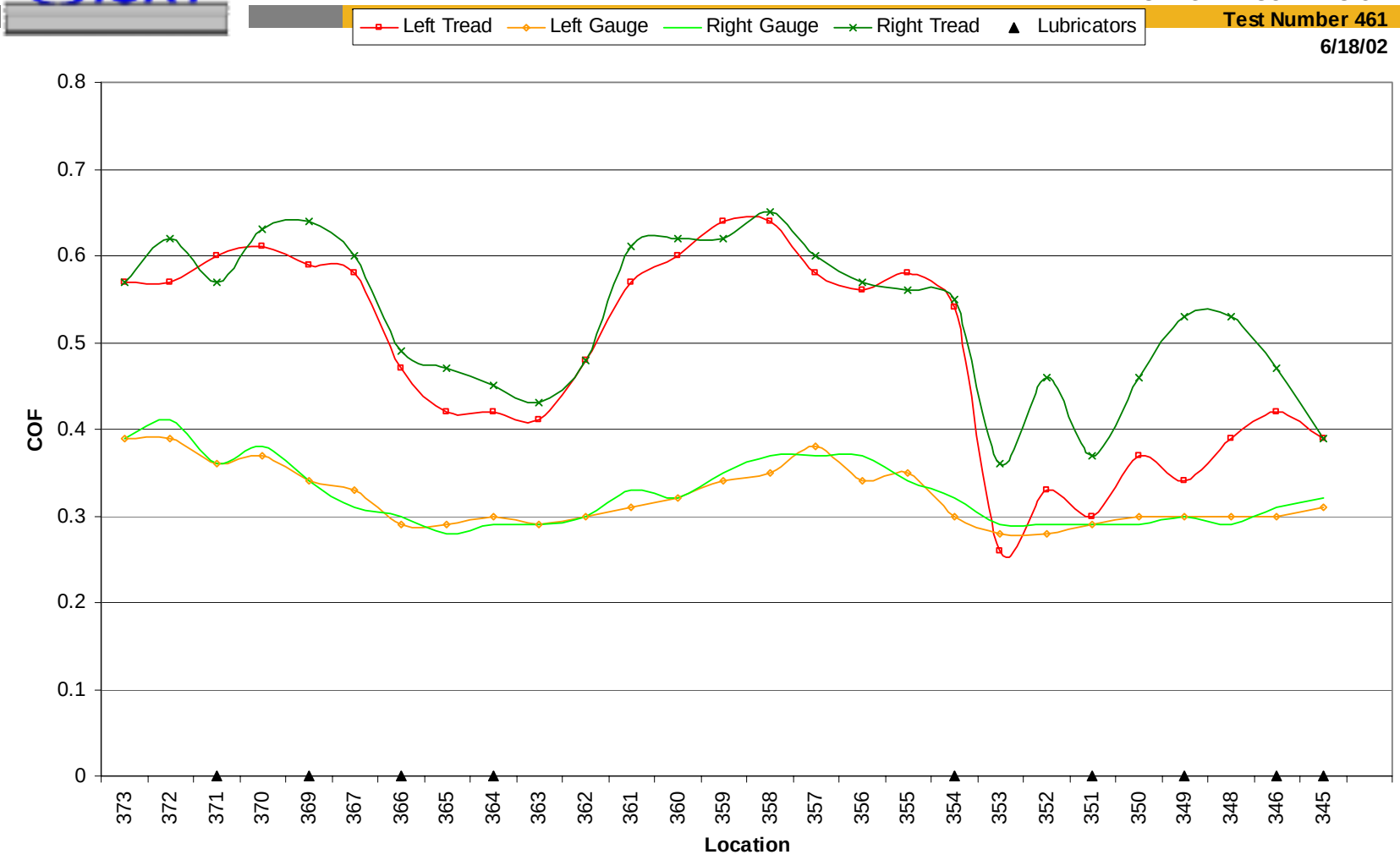
Wayside Gage Face Lubrication

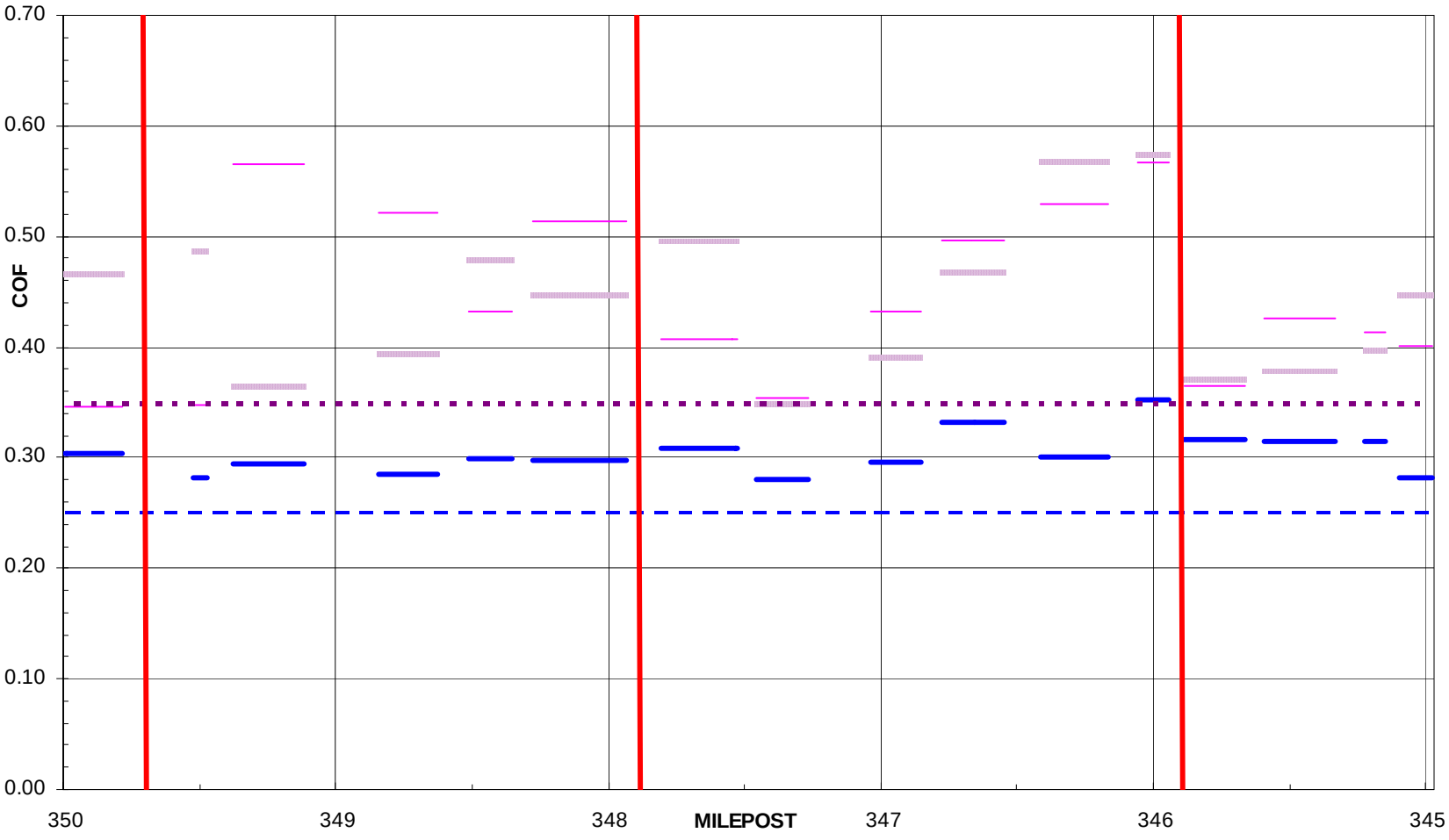
Effect of Gage Face Lubrication Levels on Gage Face Wear Rate in Curves With Std Rail



Portec High Speed Tribometer

BNSF
SELIGMAN SUBDIVISION
Test Number 461
6/18/02





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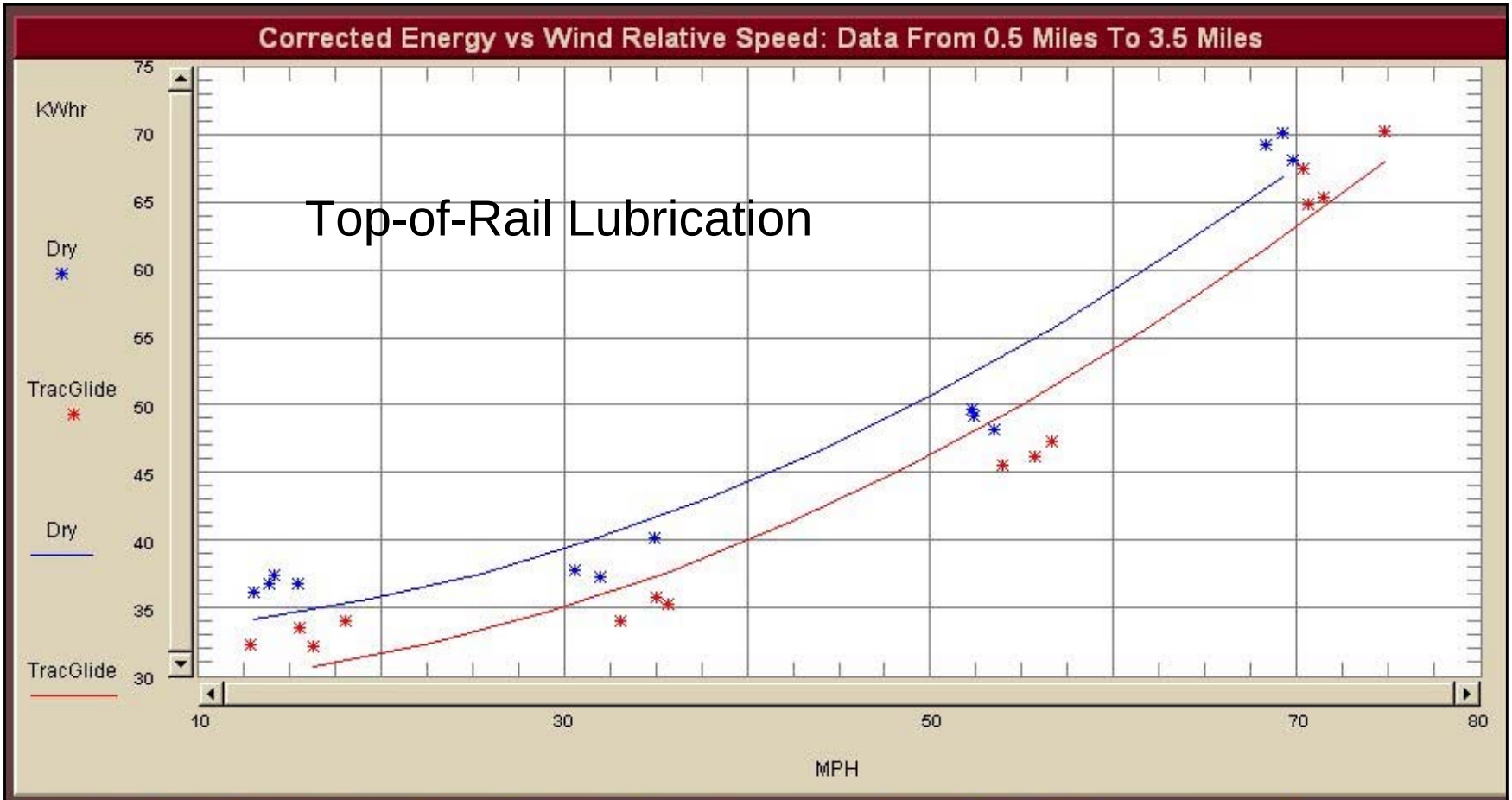
Test Number 461
6/18/02

Full Scale Train Resistance Testing

Five miles of continuous tangent track with 14 feet of rise



Dry Fitted Equation

0.007094 X^2 +32.99

TracGlide Fitted Equation

0.007043 X^2 +28.73

Equation Comparison

	A Term	C Term
Dry	0.0071	32.99
TracGlid	0.0070	28.73
% Diff	0.71	12.90

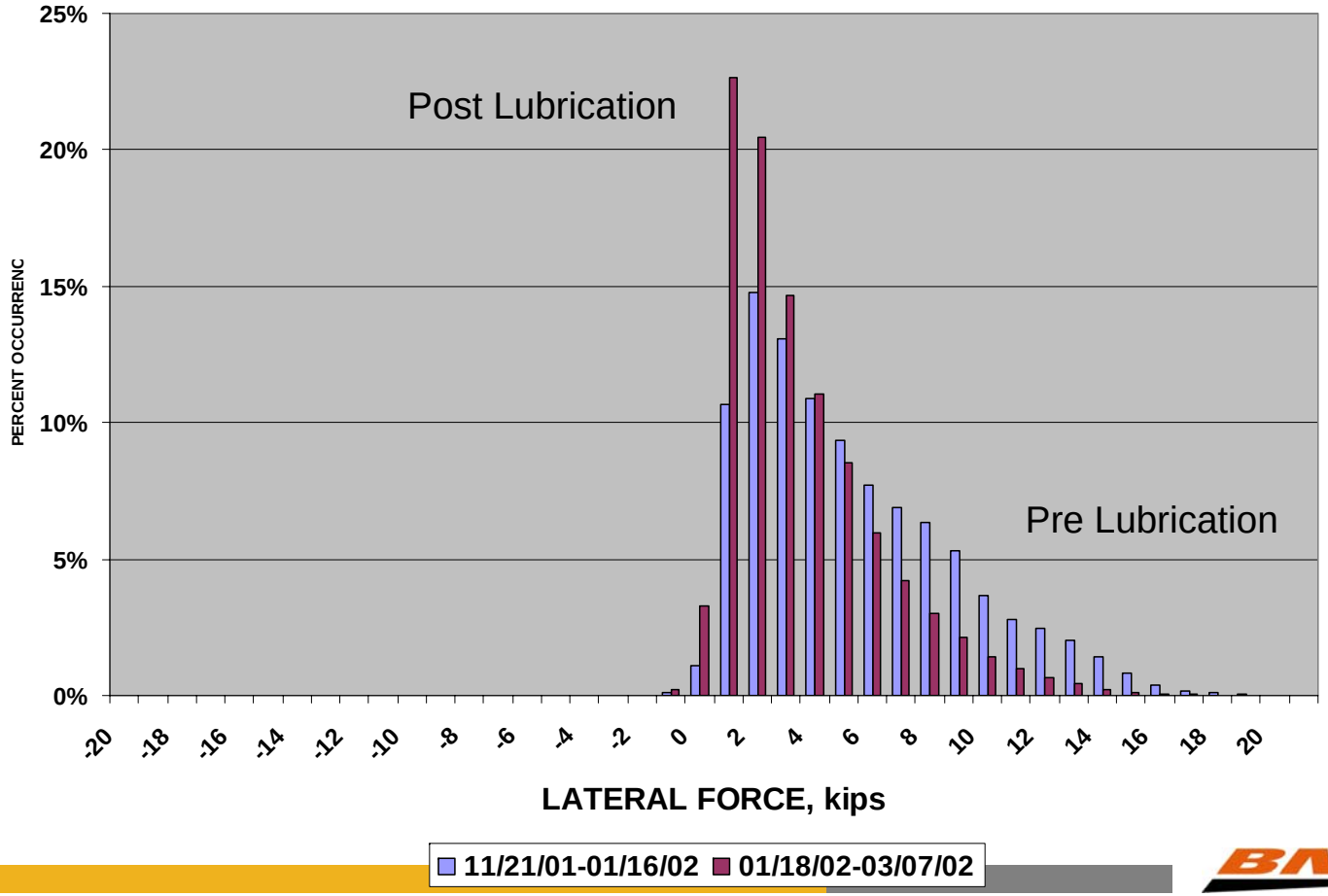
Predicted Energy

MPH	Dry	TracGl	% Diff
10	33.70	29.44	12.64
20	35.83	31.55	11.93
30	39.37	35.07	10.92
40	44.34	40.00	9.78
50	50.72	46.34	8.64
60	58.53	54.09	7.58
70	67.75	63.25	6.65

PrintScreen

Exit

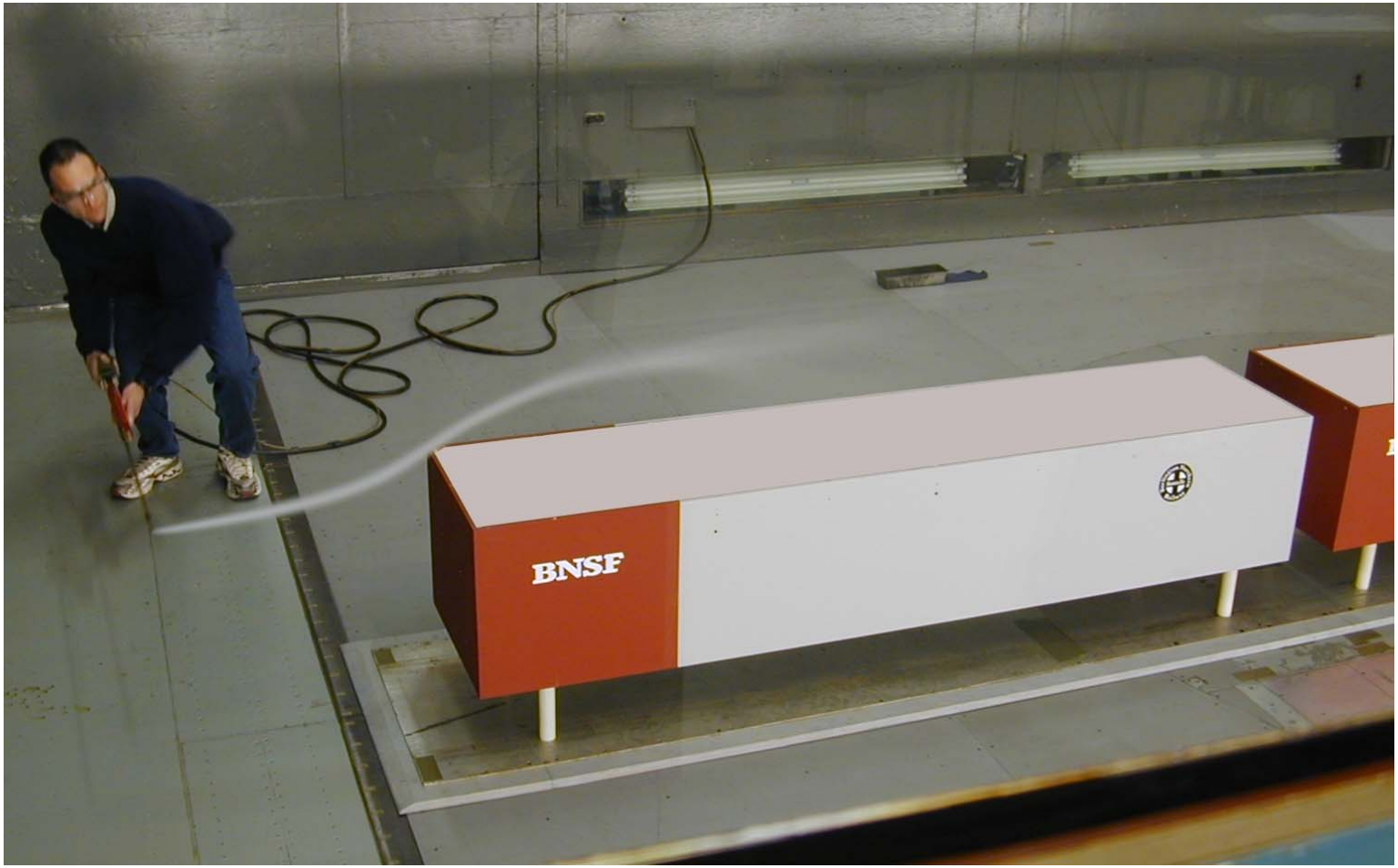
Lateral Force Measurements, Average of Leading Axles Both Rails, All Cars



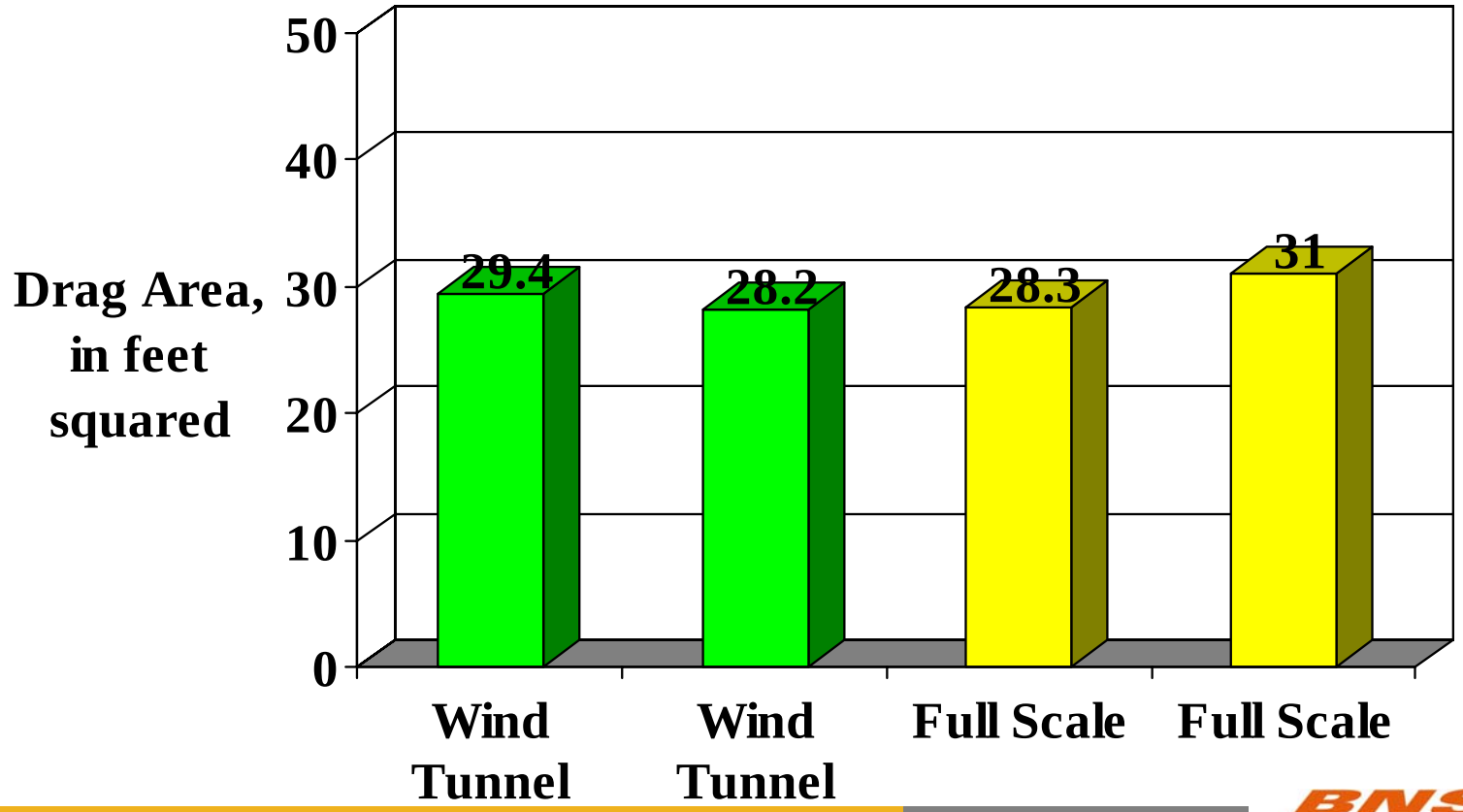
Aerodynamic Drag

- **C is the aerodynamic drag having the velocity with respect to the wind.**
- **$C = \frac{1}{2} \rho \times Cd \times Af$**
- **ρ is the air density**
- **Cd is the drag coefficient.**
- **Af is the frontal area.**
- **Drag is often reported as Drag Area per 100 square feet of frontal area.**

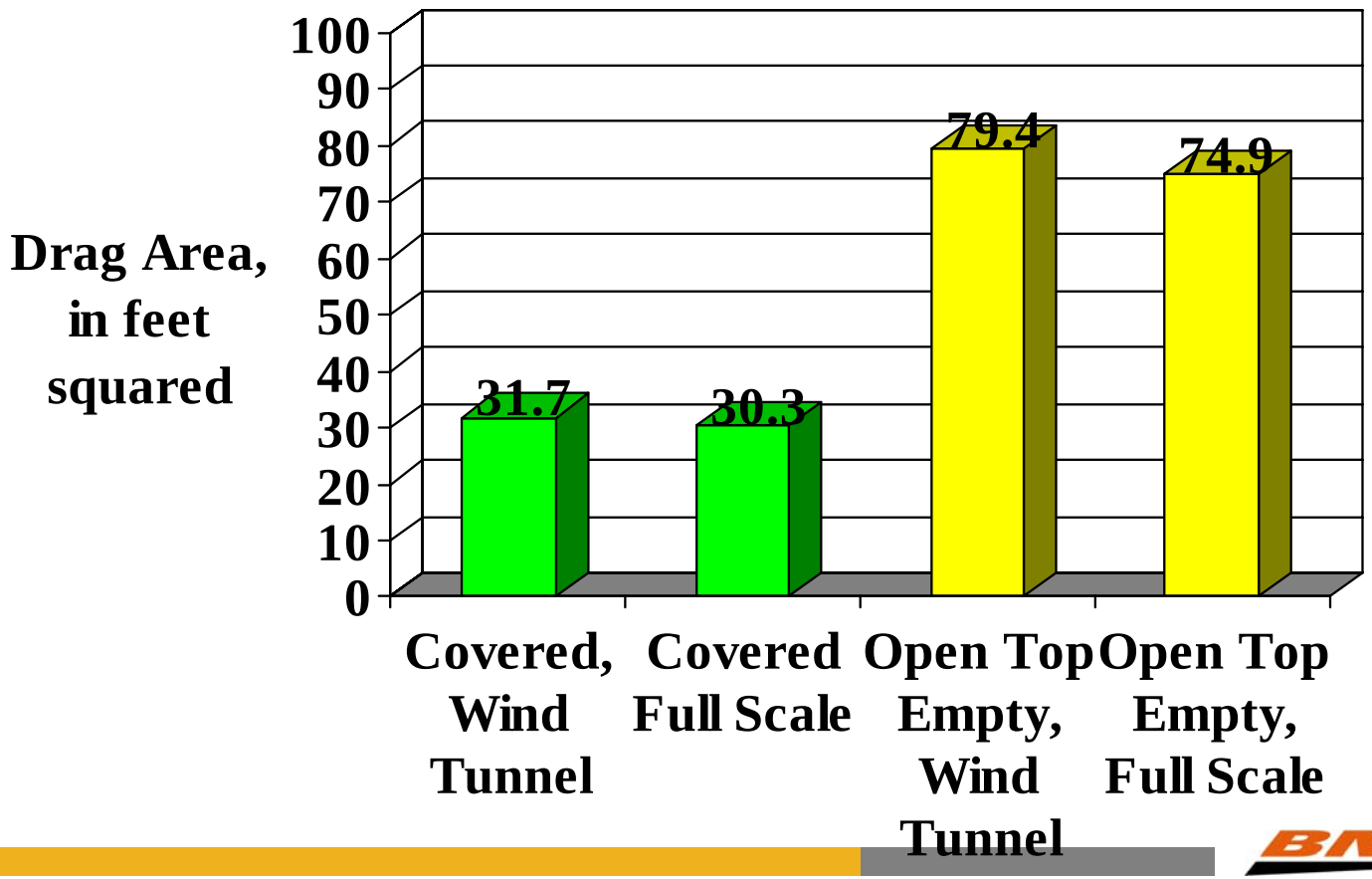
Wind Tunnel Testing of a Covered Coal Car



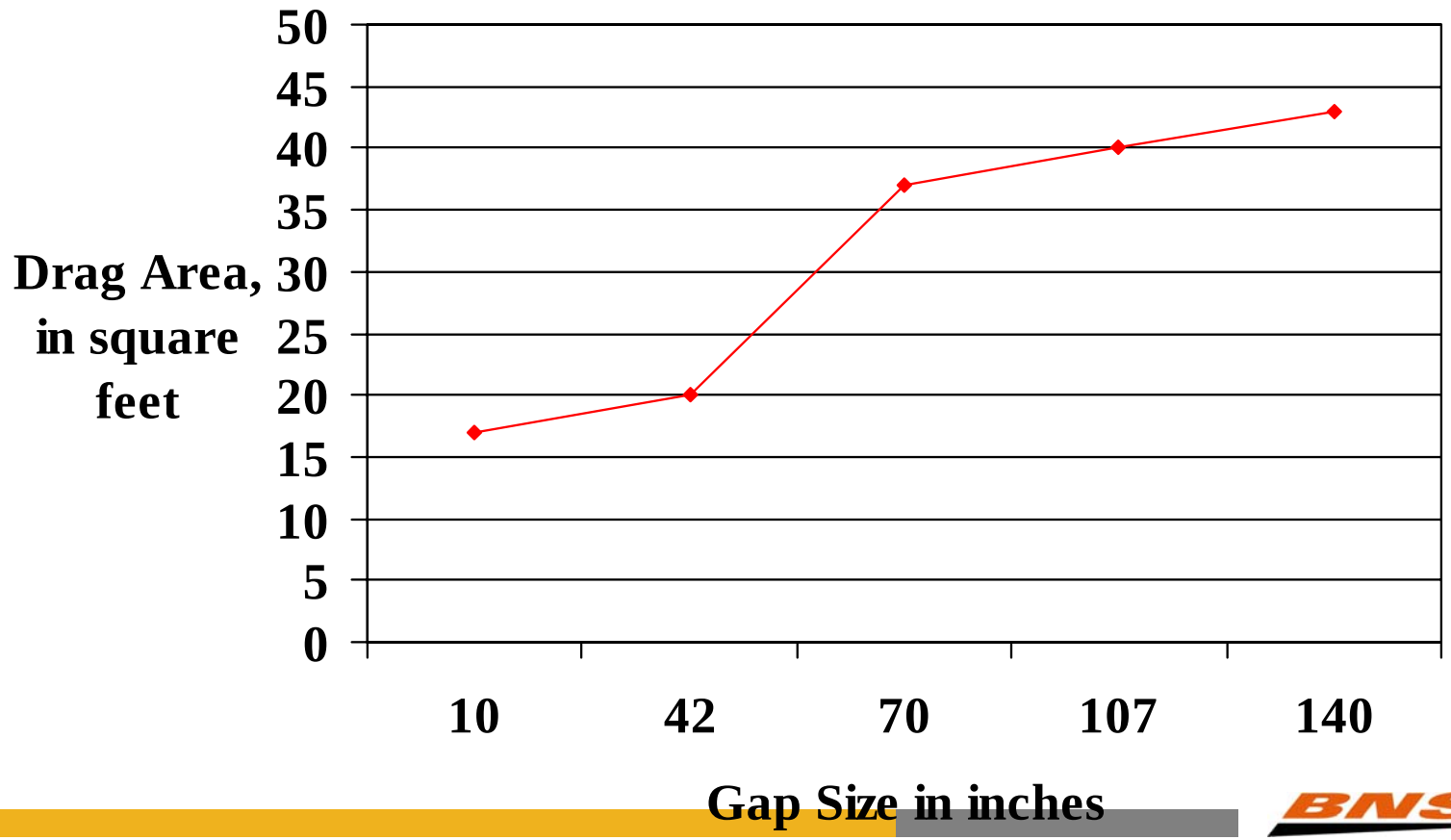
Comparison of Wind Tunnel and Full-Scale, covered hopper cars



Comparison of Wind Tunnel and Full-Scale, open top and covered gons with 5 degree yaw



Effect of Gap Size on Aerodynamic Drag, trailer on a spine car in a wind tunnel



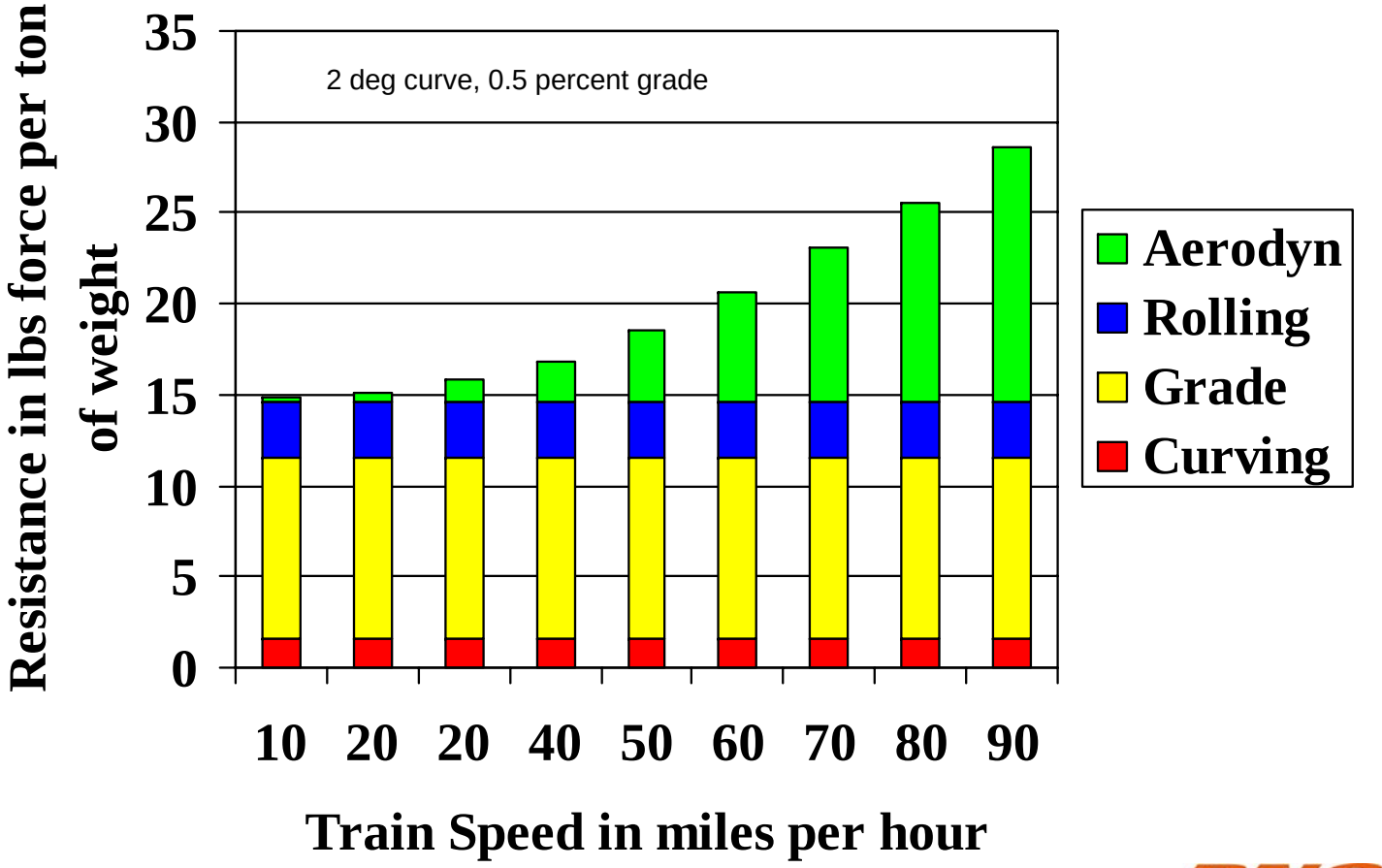
Other Train Resistance Factors

- **Curving typically is 0.8 lbs force per ton per degree of curvature. A 5 degree curve would result in 4 lbs force per ton of train weight.**

- **Grade is the resistance due to gravity acting on the train mass. The resistance is 20 lbs of force per ton of train weight for a 1 percent grade.**

- **Acceleration requires a force of 91 lbs per ton per mile per hour per second. A train accelerating at 10 miles per hour per minute would require a force of 15 lbs per ton. This is equivalent to a 0.75% grade.**

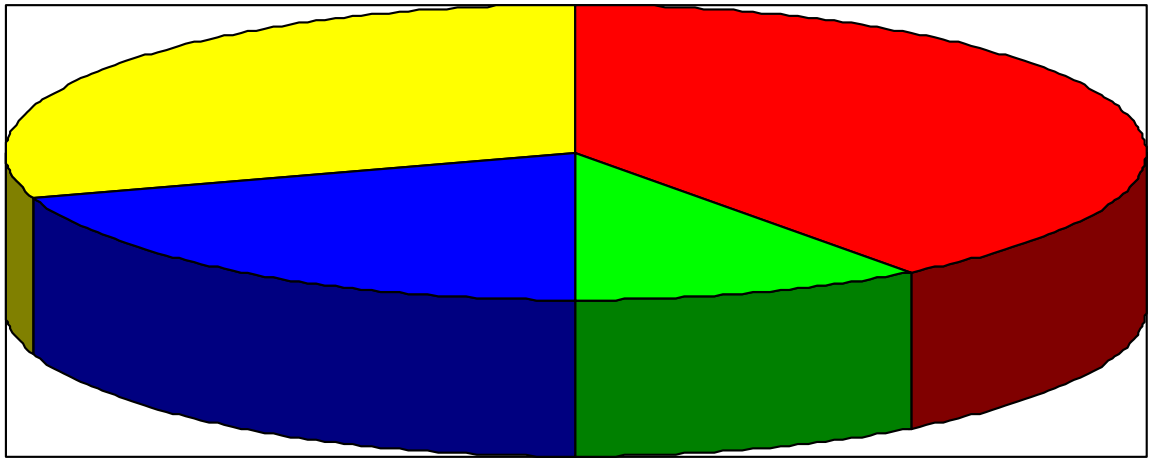
Sources of Train Resistance



Intermodal Train Fuel Consumption By Cause

Aerodynamics 30%

Grade 40%

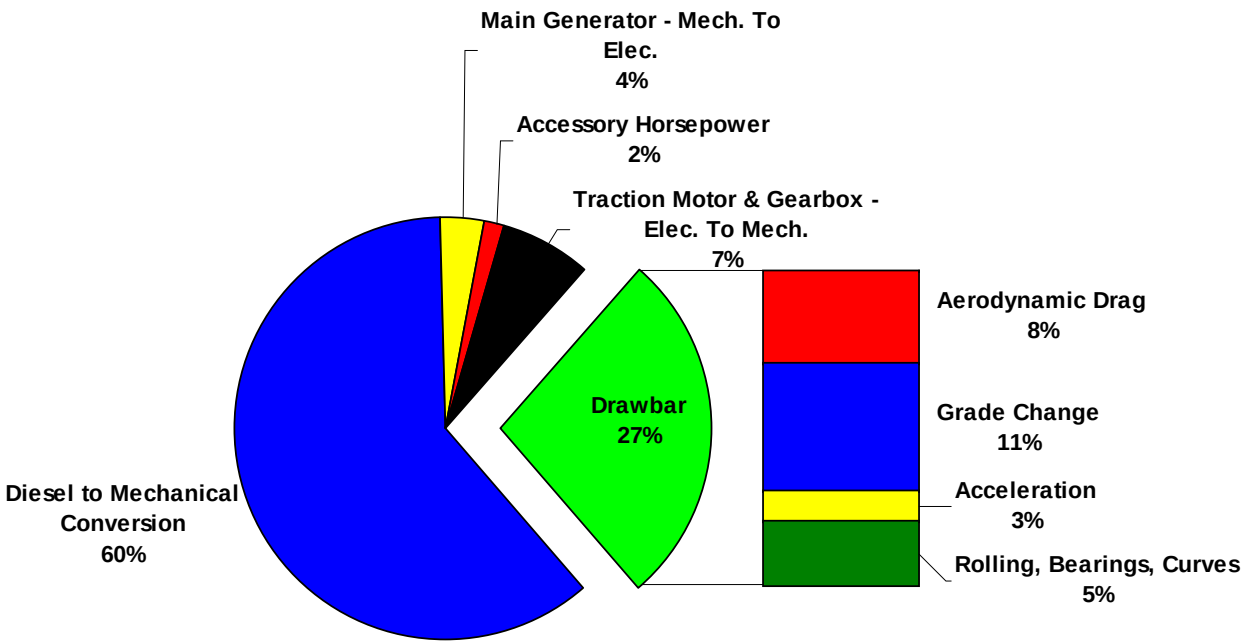


Rolling, Bearing, Curving 20%

Acceleration 10%

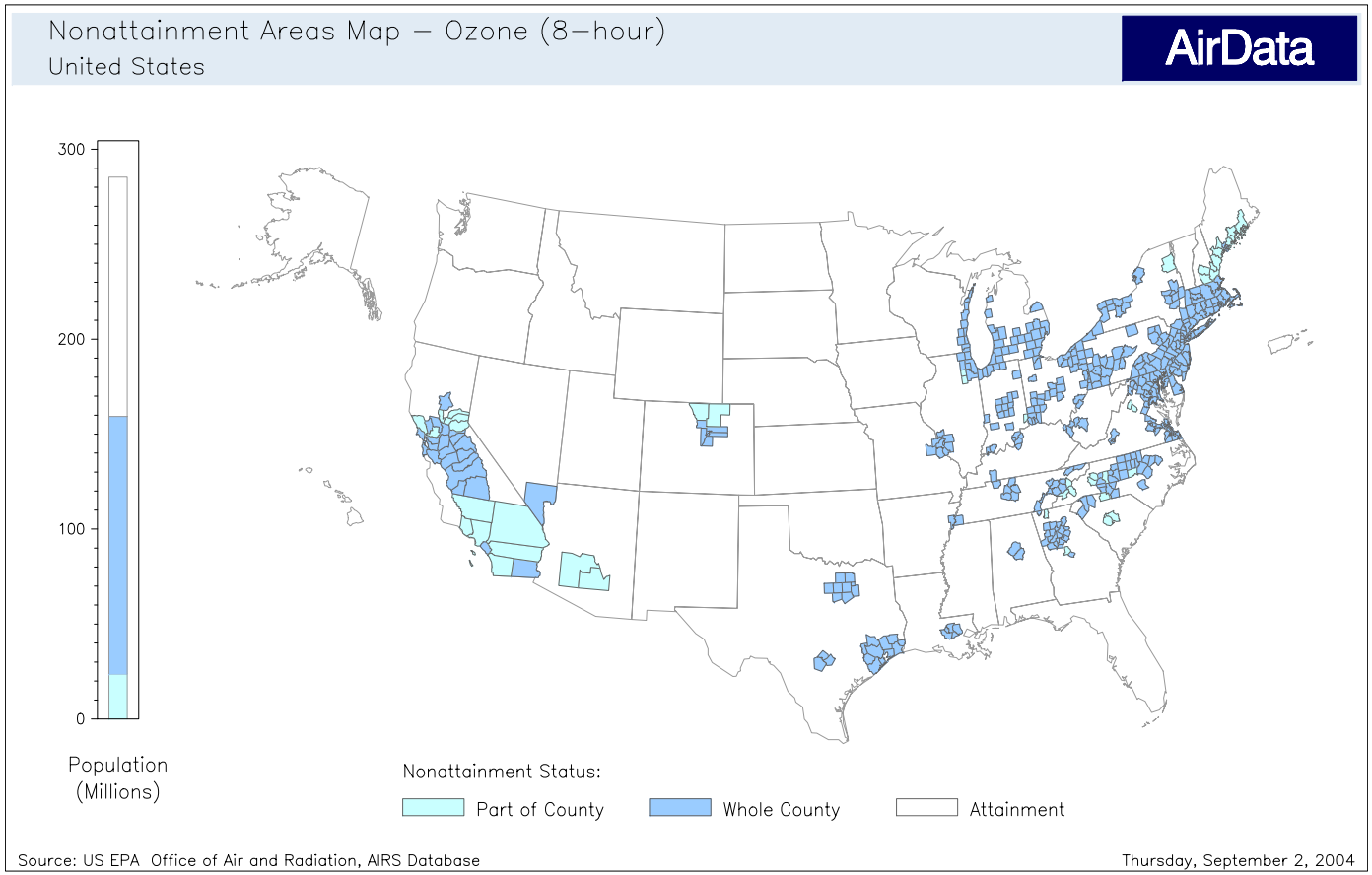

740
BNSF
745
BNSF
BNSF
744

FUEL ENERGY USES AND LOSSES



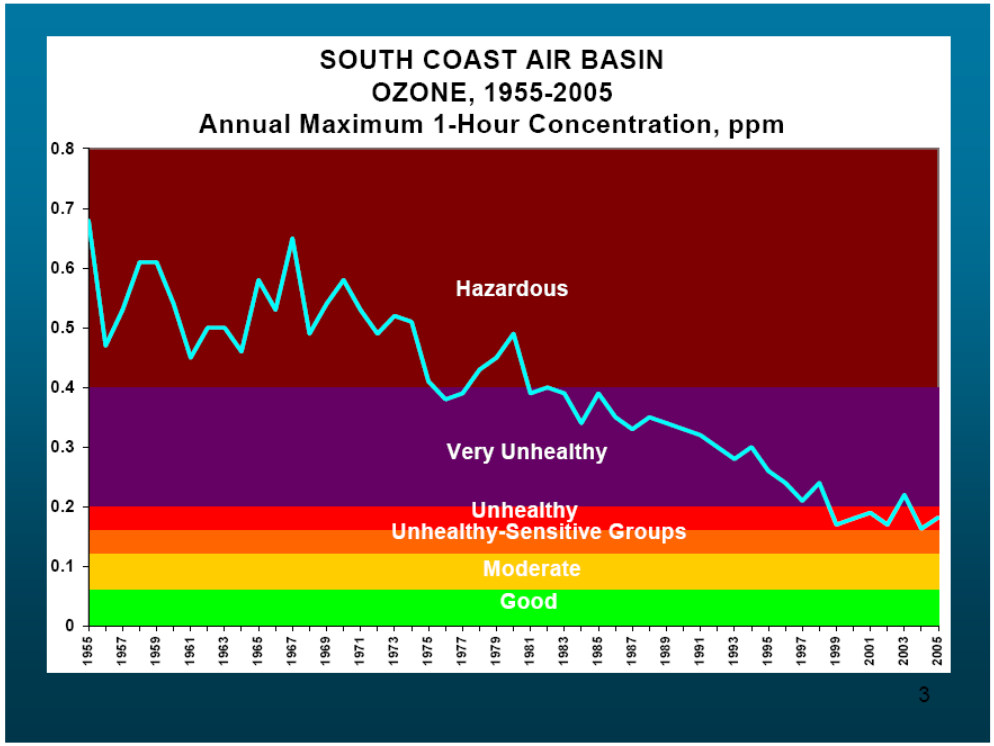
Diesel engine efficiency based on SD70MAC at full load. Division of Drawbar horsepower representative of intermodal service.

Ozone Non-Attainment Areas

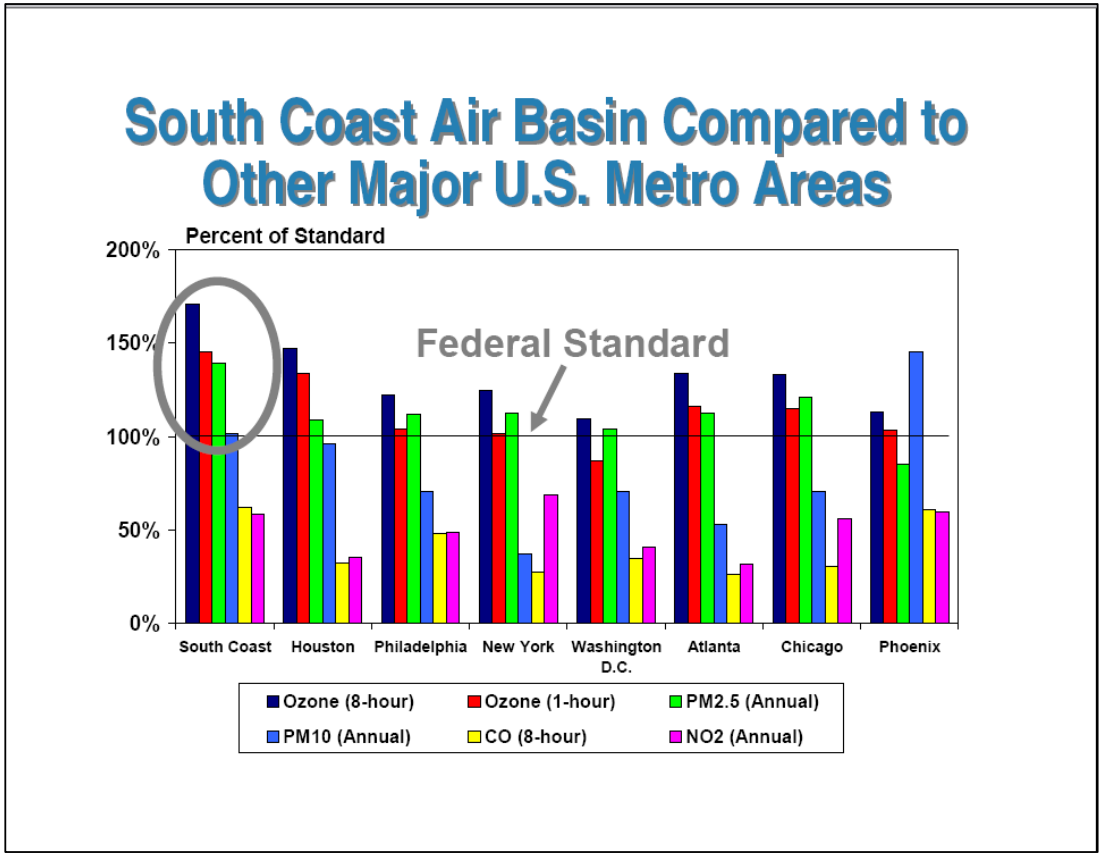


US Railroad Intermodal Flows

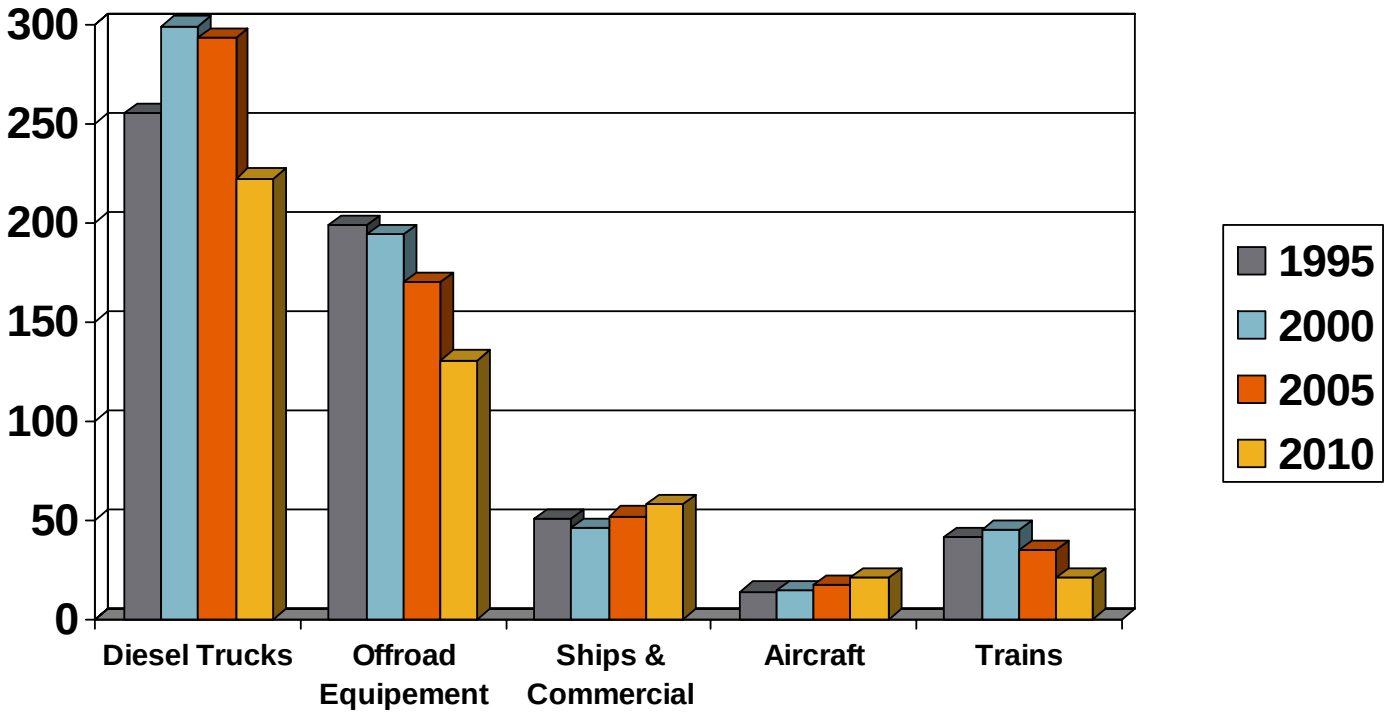
So. California Historical Air Quality



Air Quality in Metropolitan Areas



SCAQMD NOx Inventories

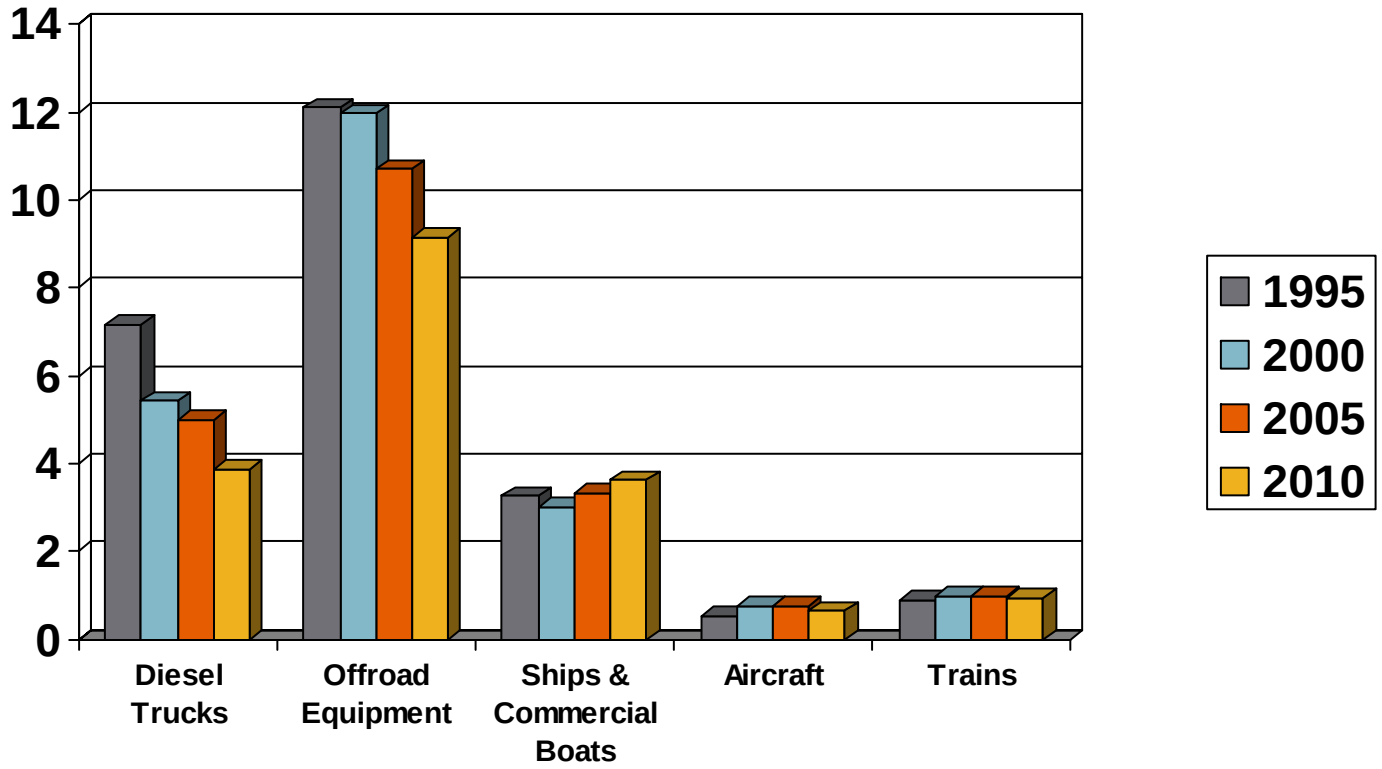


2010	Diesel Trucks	Offroad Equip	Ships	Aircraft	Trains
% SCAQMD NOx Inventory	28.5%	16.7%	12.6%	2.4%	2.7%

Data Source: ARB – Almanac Emission Projection Data (Published in 2005).

Diesel Trucks – LHDD1, LHDD2, MHDD, HHDD

SCAQMD PM2.5 Inventories

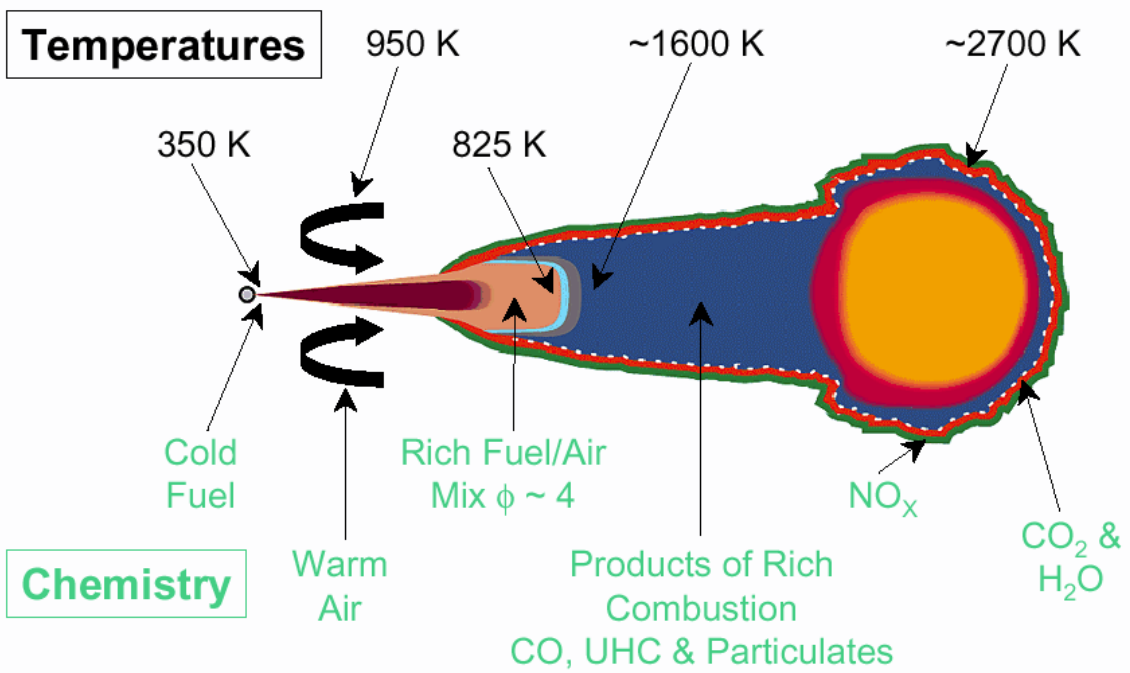


2005	Diesel Trucks	Offroad Equip	Ships	Aircraft	Trains
% SCAQMD NOx Inventory	3.2%	7.5%	5.6%	0.5%	0.8%

Data Source: ARB – Almanac Emission Projection Data (Published in 2005).

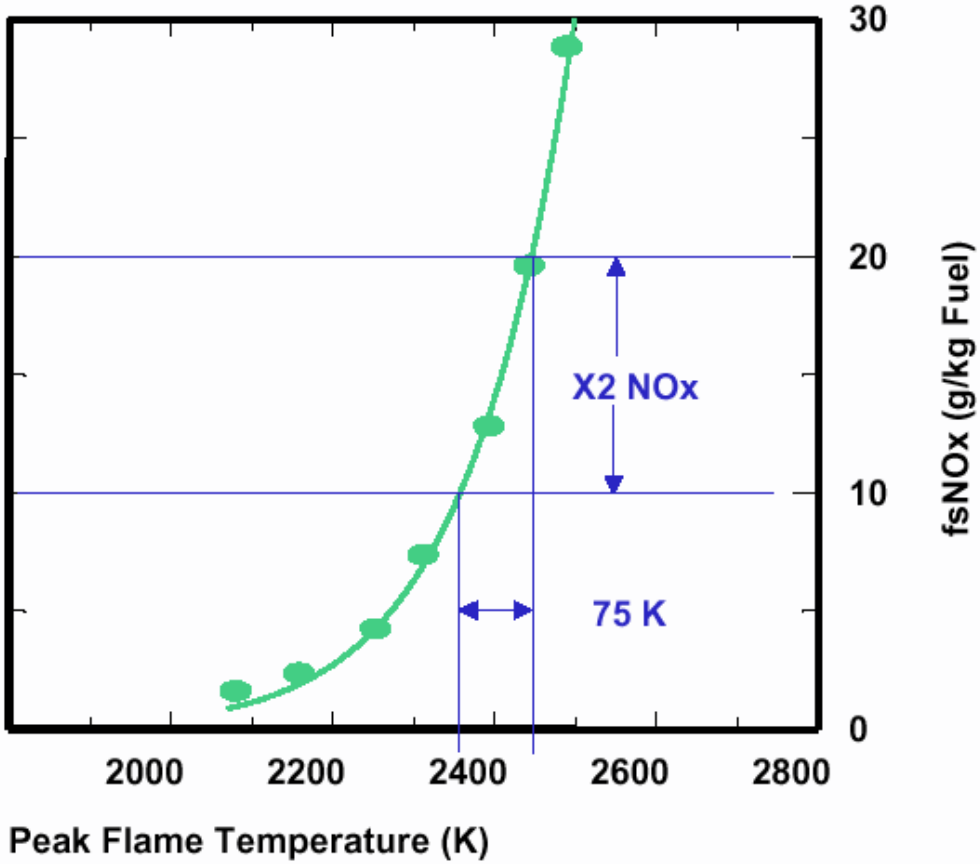
Diesel Trucks – LHDD1, LHDD2, MHDD, HHDD

Overall Picture

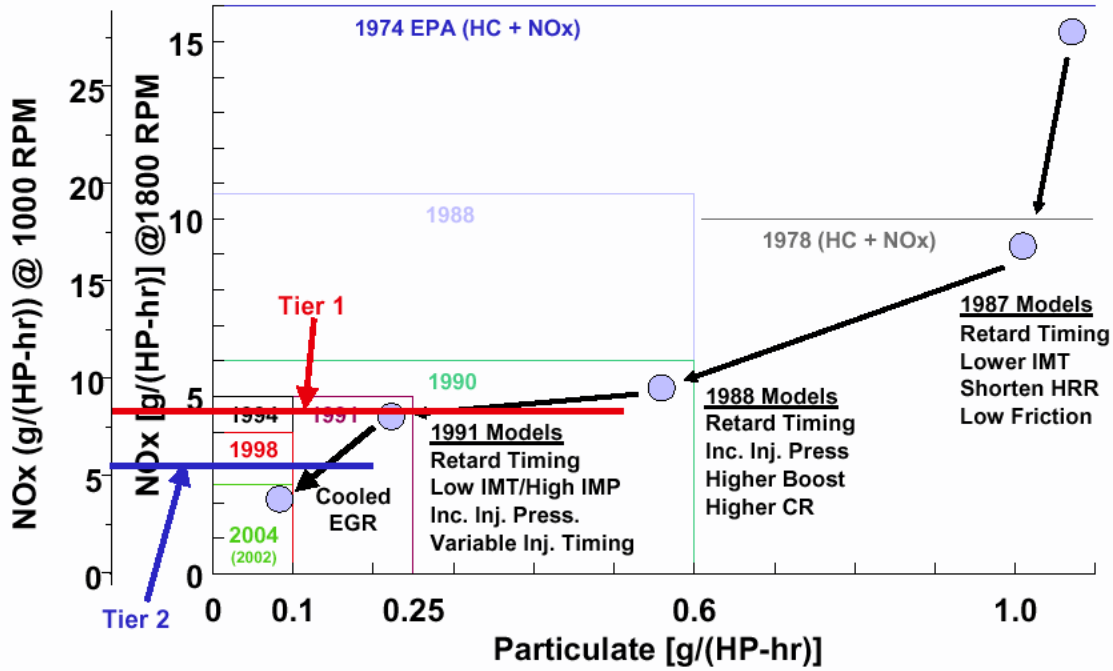


SAE Paper 990509

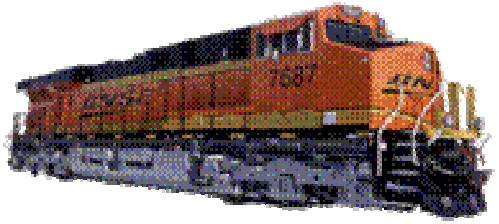
NOx Vs Combustion Temperature



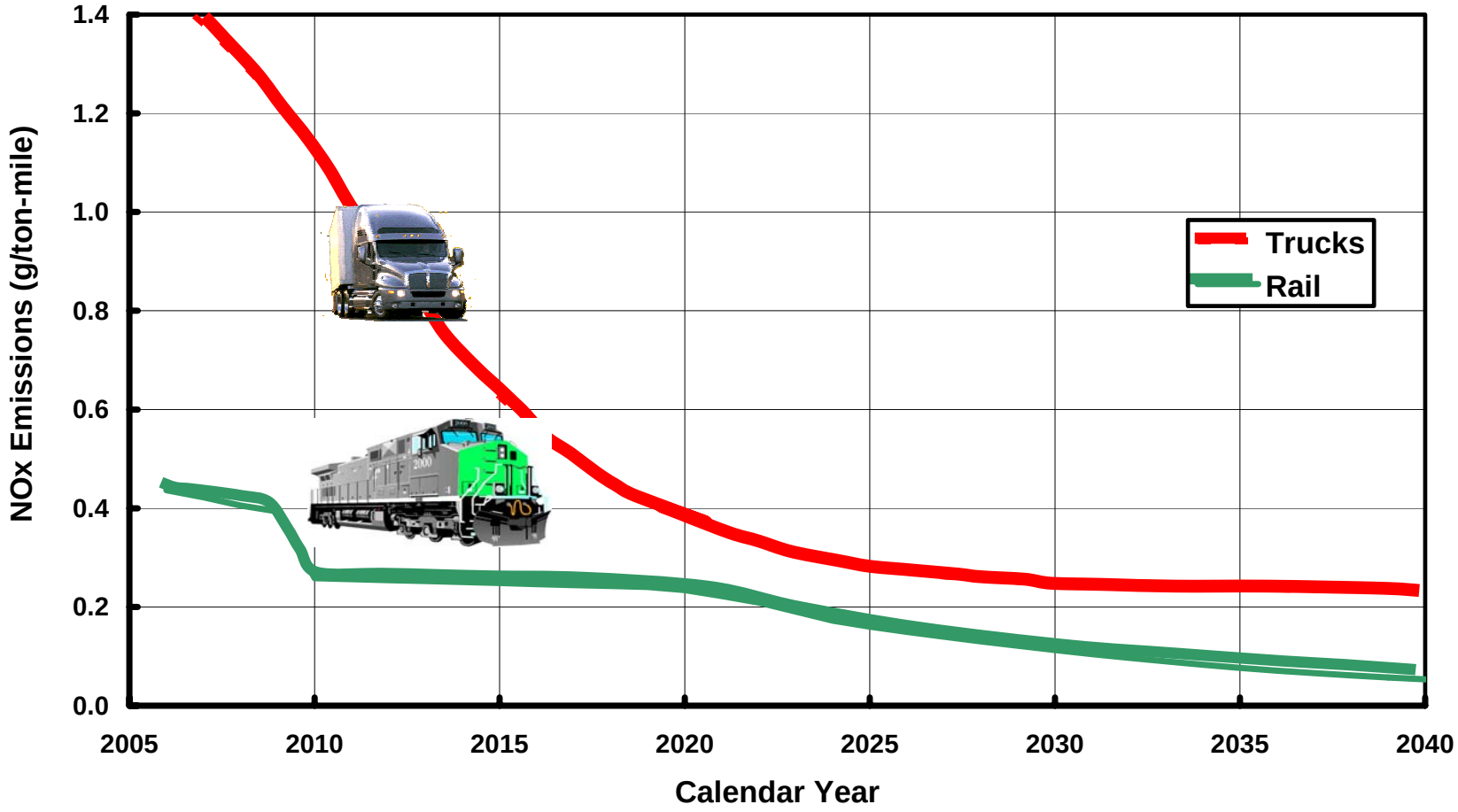
Evolution of Engine Emission Control



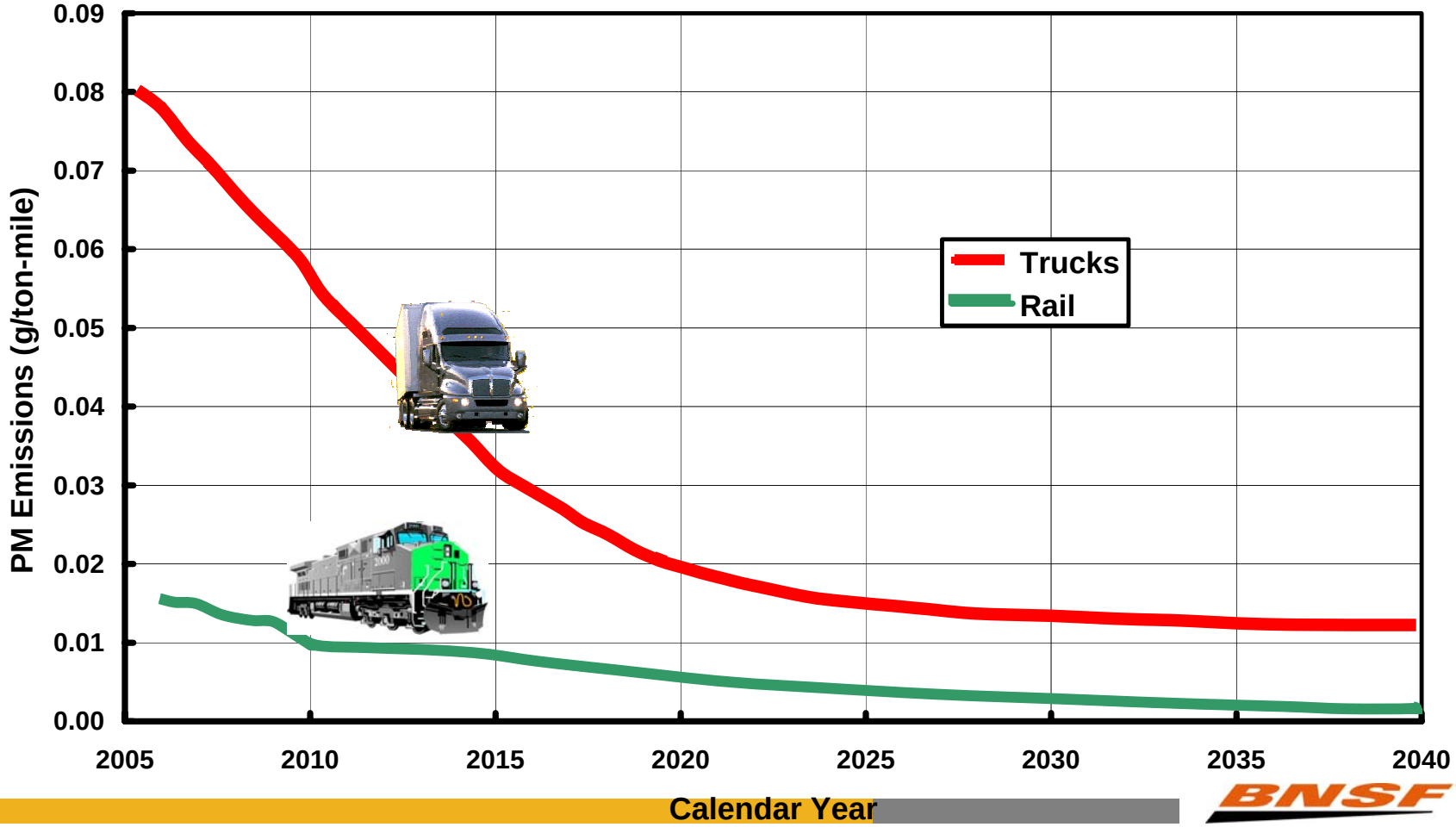
Inherent Efficiencies of Rail

	 vs. 
Capacity	**1 double stack train equals volume of up to 280 trucks**
Fuel Efficiency	**Trains are <u>2-4 times more fuel efficient</u> than trucks on a ton-mile basis**
NOx Emissions	**Trains are <u>2-3 times cleaner</u> than trucks on a ton-mile basis**

NOx Emissions per ton Mile of Freight South Coast Air Basin



PM Emissions per ton Mile of Freight
South Coast Air Basin



Comparison of Mobile Source Requirements (South Coast Inventory 2010)

	Trucks	Off-Road Equipment	Ships	Aircraft	Urban Buses	Loco-motives
Inventory NOx / PM	21% / 2.4%	17% / 7.9%	7% / 3.2%	4% / 4%	2% /	**2%** / **0.8%**
Standards for New Units	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**
Retrofit Existing Units	**No**	**No**	**No**	**No**	**Yes**	**Yes**
Rebuild to New Standards	**No**	**No**	**No**	**No**	**No**	**Yes**
NOx Fleet Avg. in SCAQMD	**No**	**No**	**No**	**No**	**No**	**Yes**
Statewide PM 2005 MOU	**No**	**No**	**No**	**No**	**No**	**Yes**

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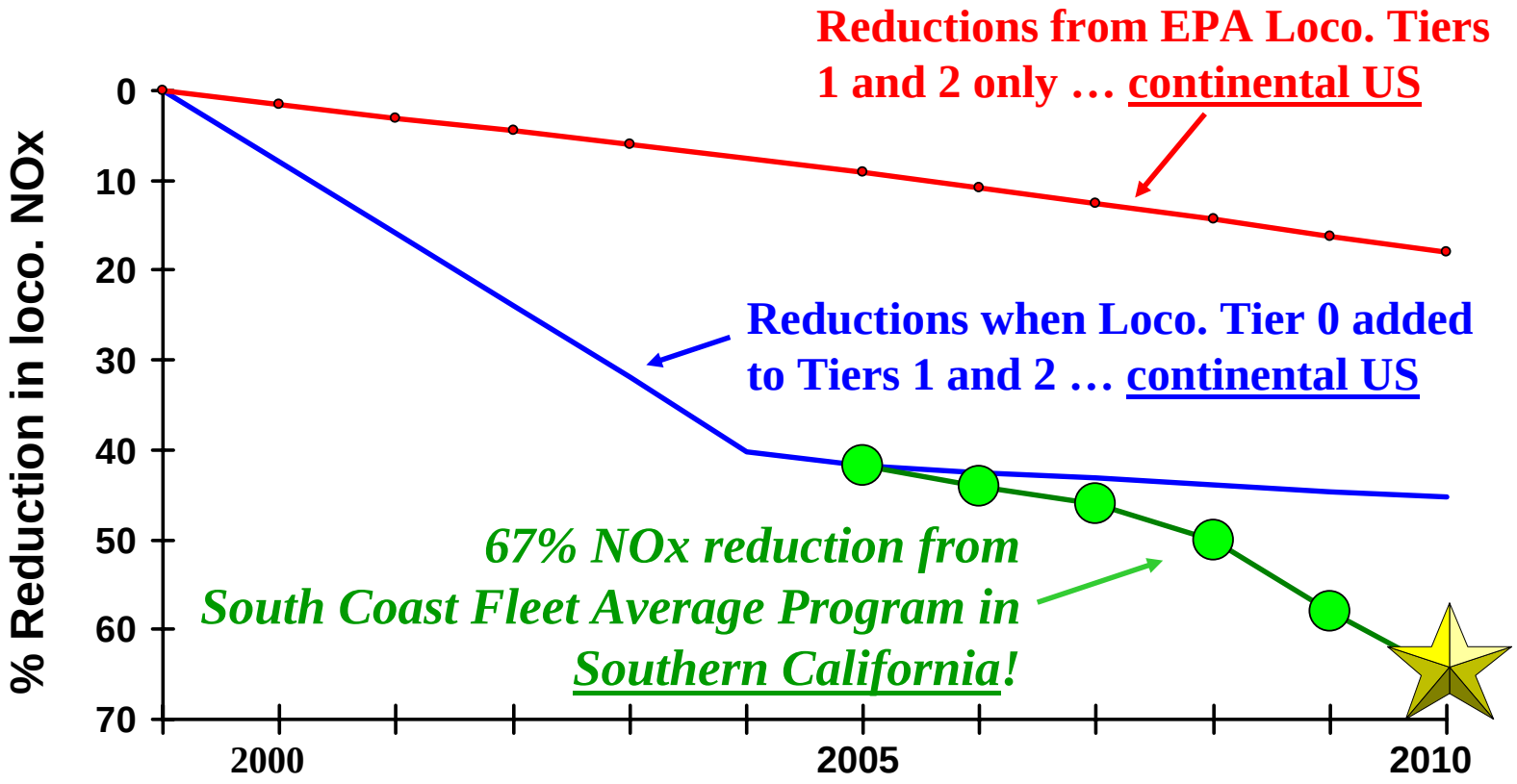
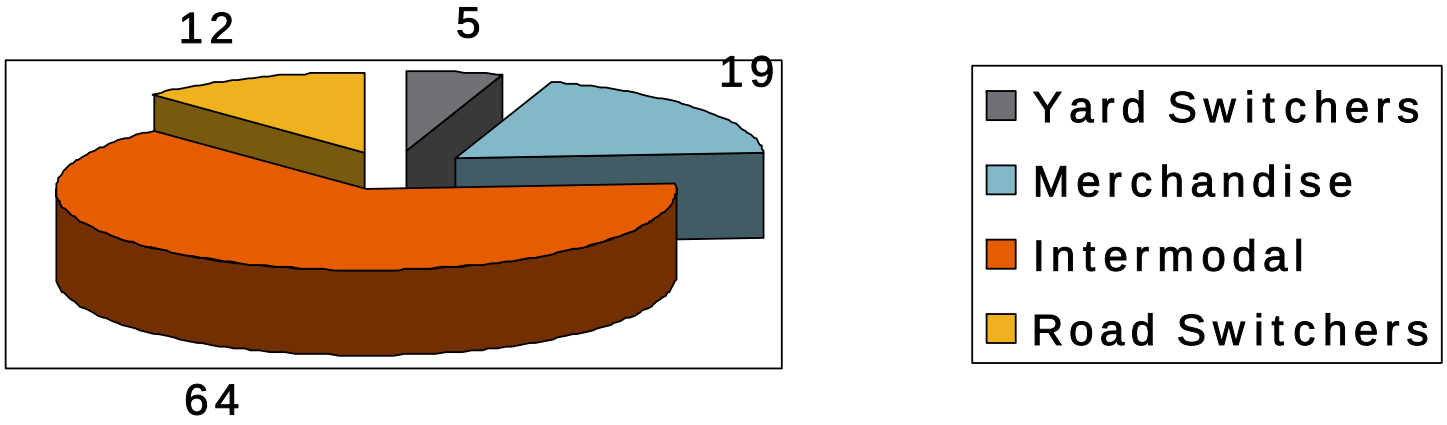
South Coast Fleet Average



Southern California commitment from the Railroads

Work Done By Train Type, in percent



Switcher Locomotives

Green Goat® Locomotives

- **"Hybrid" light-medium duty switcher**
- **Reduces fuel consumption and atmospheric emissions by 60 percent**
- **Emits 80 to 90 percent fewer pollutants than conventional train engines**
- **Batteries recharged by 290 HP EPA *off-road Tier 2* diesel gen set (significantly exceeds EPA locomotive Tier 2 requirements)**

Liquefied Natural Gas Locomotive

- **BNSF operates the only four environmentally friendly liquid natural gas locomotives that reduce emissions and fuel consumption**
- **1200 sustainable horsepower, spark ignited**

Multiple Gen Set Switcher

- **Powered by multiple diesel gen sets with truck-like engines**
- **700 sustainable horsepower from each gen set**
- **Typically 3 engines per locomotive**

Comparison of Existing and New EPA locomotive emission regulations, g/hphr

		Nitrogen Oxides		Particulate Matter		Date required
	Original Build Date	Existing	New Reg	Existing	New Reg	
Uncontrolled	1975	*13.1*		*0.3*		
Remanuf Tier 0	1973-1992	*9.5*	*8.0*	*0.6*	*0.22*	*2008-10*
Remanuf Tier 0	1993-2002	*9.5*	*7.4*	*0.6*	*0.22*	*2008-10*
Remanuf Tier 1	2003-2004	*7.4*	*7.4*	*0.45*	*0.22*	*2008-10*
Remanuf Tier 2	2005-2011	*5.5*	*5.5*	*0.20*	*0.10*	*2008-13*
Tier 3	2012-2014		*5.5*		*0.10*	
Tier 4	2015		*1.3*		*0.03*	

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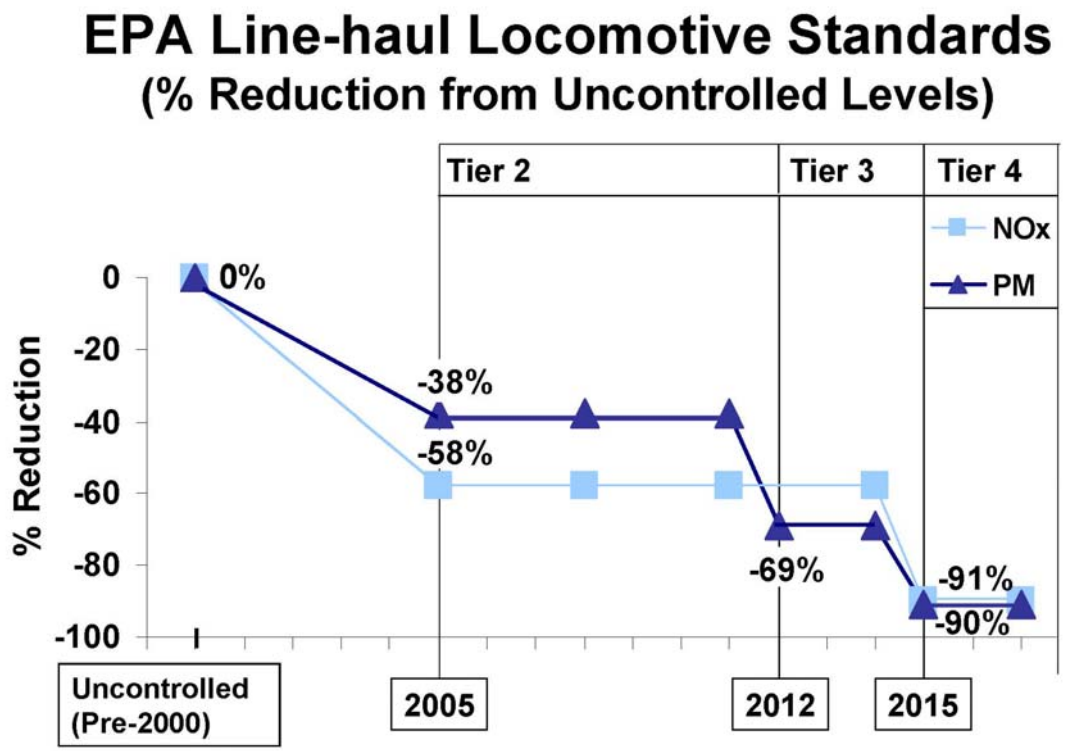
EPA Locomotive Standards

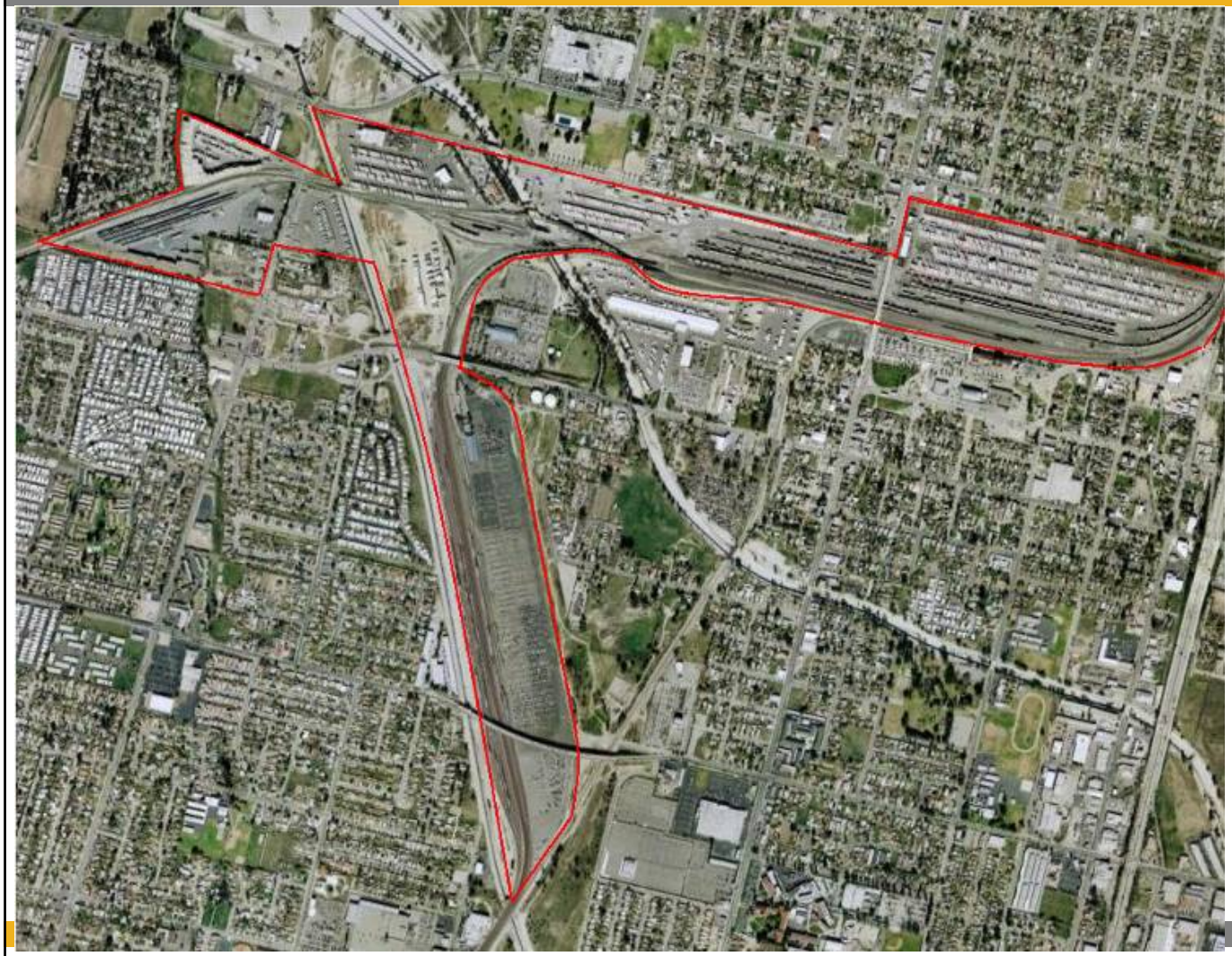


Prepared by California Environmental Associates

Sources of Emissions at a Large Intermodal Yard

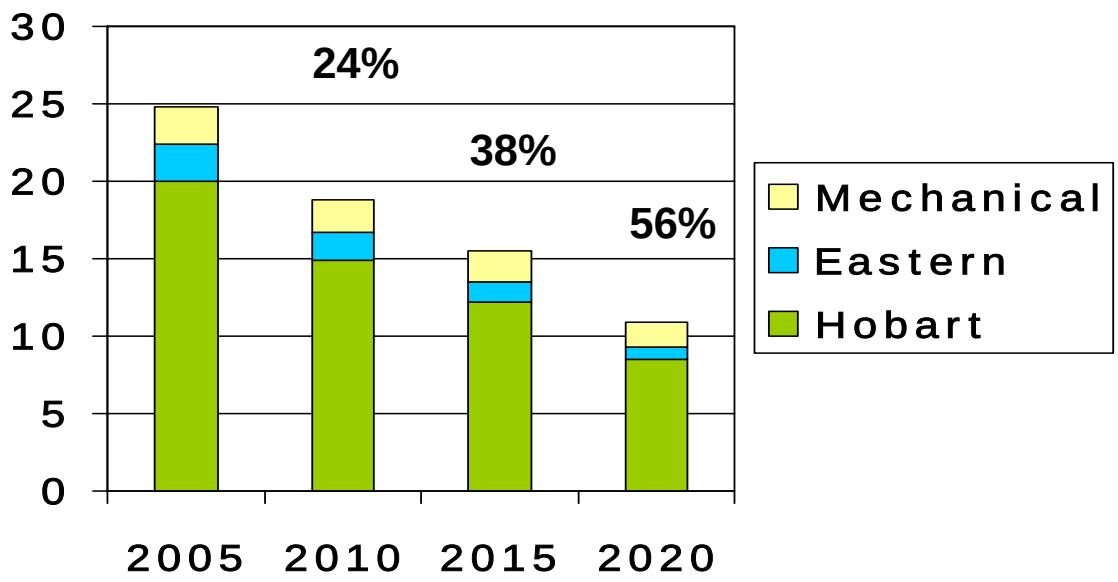
- **Drayage trucks** **40%**
- **Cargo handling equipment** **20%**
  - **Cranes**
  - **Yard Tractors**
- **Linehaul locomotives** (Arriving & Departing trains) **10%**
- **Transportation Refrigeration Units** **10%**
- **Switch Engines** **10%**
- **Adjacent Mainline Freight** **5%**
- **Adjacent Commuter Rail** **3%**
- **Other** **2%**

San Bernardino, California



BNSF Commerce Yards, emission reductions

Diesel Particulate Matter in metric tons per year



Predicted reductions with 4% annual growth in activity
Typical drayage truck fleet turnover assumed (not CAAP)

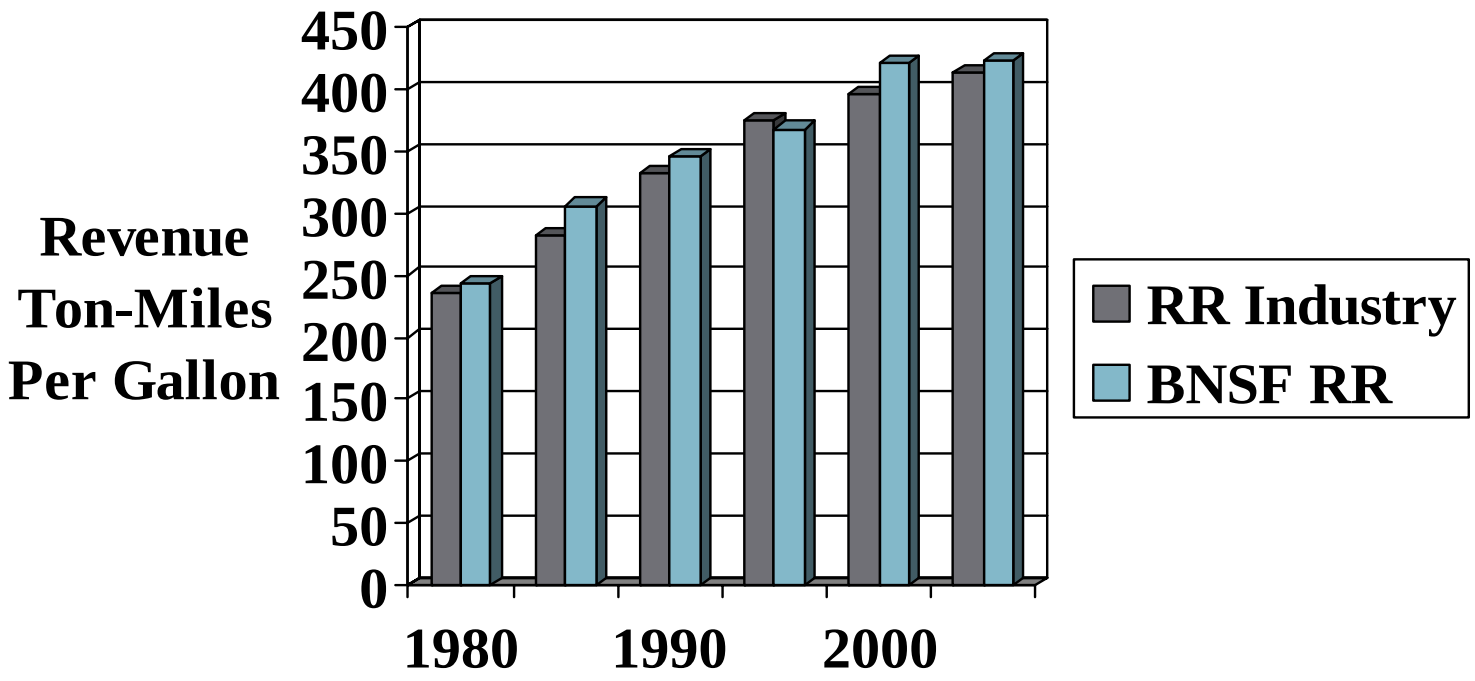
New Intermodal Yard Green Technology

- **Electric Rail-Mounted Gantry (RMG) cranes**
  - Reduced air emissions, noise and light
- **LNG (or equivalent) yard hostler tractors**
- **LNG, multi-engine or “hybrid” switch engines**
- **Low-sulfur fuel and idle shut-down feature for road locomotives**
- **Low emission drayage trucks**

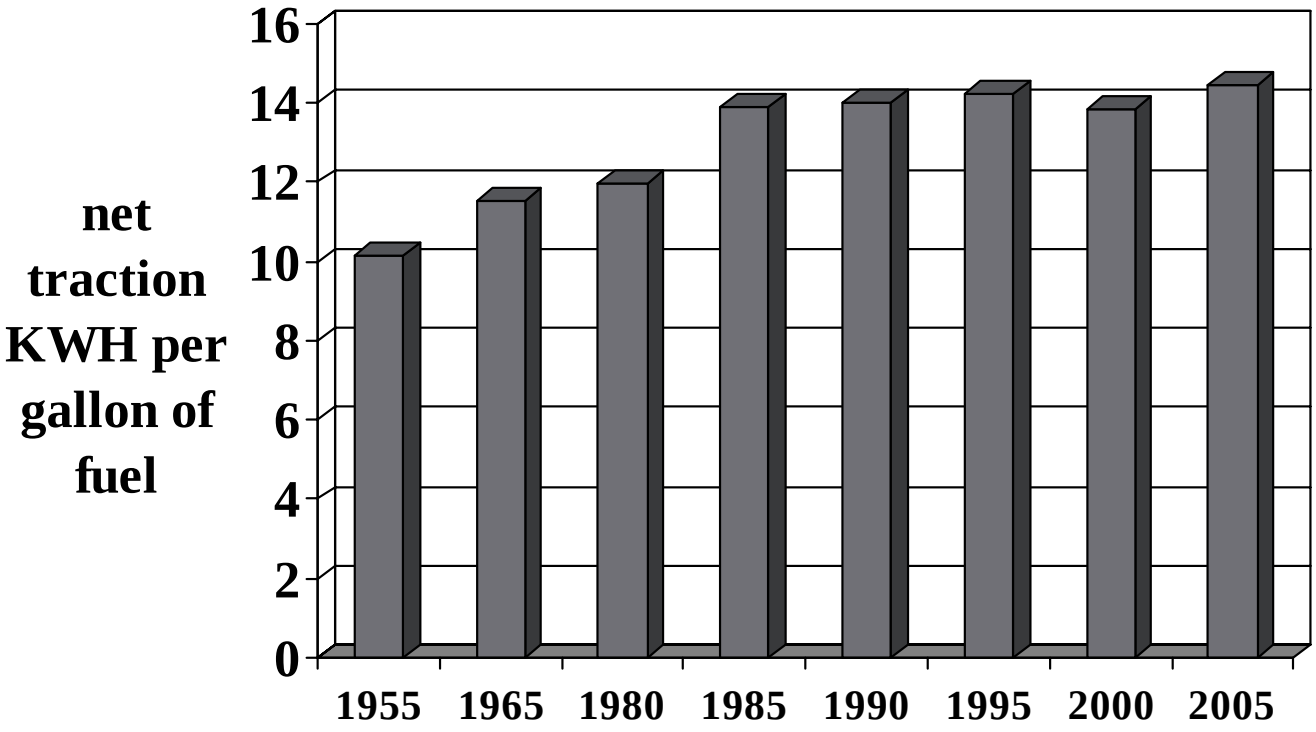
At the end of 2007

- Total fleet is 6800 locomotives
- Installed 3300+ locomotives with AESS
- Retrofit 2200 locomotives to Tier 0
- Purchased 620 Tier 1 locomotives
- Purchased 880 Tier 2 locomotives
- Fleet average nitrogen oxides emissions reduced 30% since 2000
- 2260 more locomotives to retrofit to Tier 0
- 900 locomotives pre 1973 (not subject to retrofit)

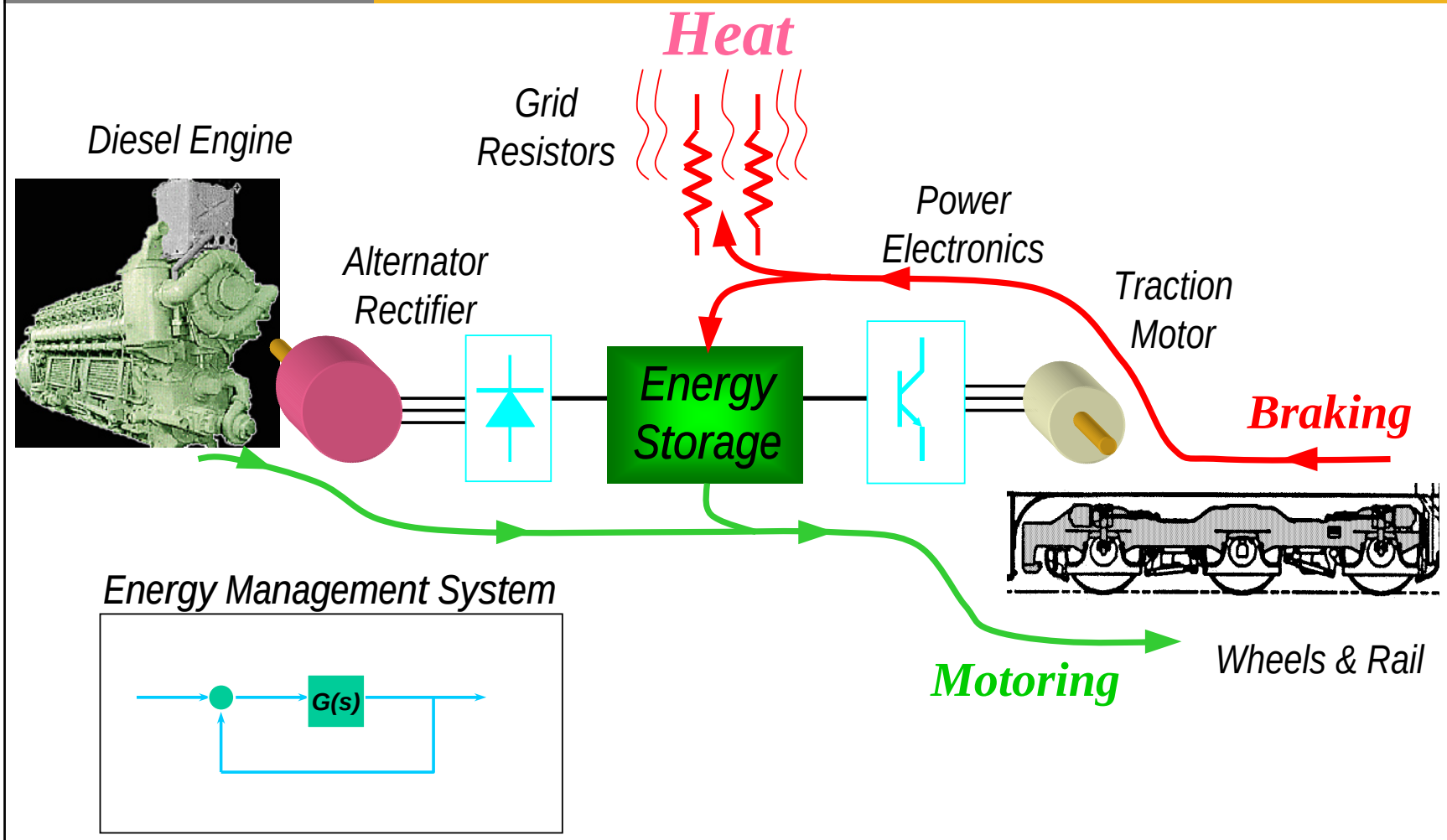
System Fuel Efficiency



Locomotive Fuel Efficiency,
medium duty cycle



Road Locomotive Hybrid Concept



Greenhouse Gas Emissions

Year	GTM/Gal	Fuel Volume Gal	Million Tons of CO2
1995	693.3	1,080,878,000	12.10
1999	734.4	1,187,305,000	13.29
2000	747.2	1,172,949,000	13.13
2001	760.4	1,177,144,000	13.17
2002	760.3	1,148,682,000	12.86
2003	751.2	1,213,409,000	13.58
2004	752.9	1,344,000,000	13.98
2005	756.9	1,402,000,000	14.75
2006	757.6	1,478,000,000	15.02

Reducing Greenhouse Gases

- **Reduce locomotive idling (install Idle Reduction Devices**
- **Acquire new line haul locomotives (better fuel efficiency)**
- **Acquire new switch locomotives (GenSet multi-engine, and hybrid locomotives)**
- **Improve train performance through engineer training and evaluation programs**

Reducing Greenhouse Gases

- **Promote the use of Low Torque Roller Bearings**
- **Continue to improve wheel and rail lubrication**
- **Improve intermodal loading methods to reduce aerodynamic drag**

From 1995 and 2006

11,066,000 tons of CO2 reduction

Summary

- **Railroads are part of the environmental solution**
- **Railroads contribute to the problem and will achieve large reductions in emissions**
- **Railroads do more than other mobile sources**
- **Railroads are addressing needs around our yards**
- **If stationary sources were mobile, they couldn't achieve their current reductions either**

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