What to Expect from Your New Low (and Ultra-Low) Sulfur Fuels

Presented at the
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Research Vessel Operator's Committee (RVOC)

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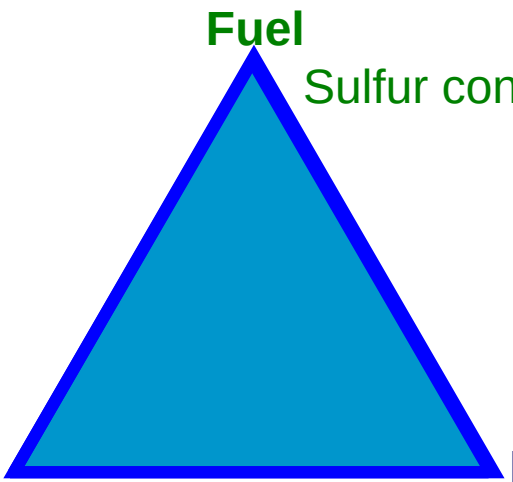
Outline

- What is Diesel Fuel?
  - Specifications and Properties
- Locomotive and Inland Marine Emissions Standards (Tiers)
- Technologies to Meet Emissions Standards
  - “Fine-tuning,” New Engine Designs, After-treatment devices
- Introduction of Lower Sulfur Fuels – Timing and Reasons
  - To enable emissions technologies
- Operational Experiences with Lower Sulfur Fuels
  - Good - Better lubricant base number retention
  - Bad - Higher cost, lower fuel economy
  - Ugly - Deposits, smoke, oil consumption increase
  - Other - No significant difference
- Possible Remedies

Cause for Concern?

- These are Uncertain Times for Railroads/Inland Marine!
- Emissions Standards Continue to Tighten
  - New Engine Designs Anticipated (Tier 3 & 4)
  - Lower Sulfur Fuel is Part of the Solution
- Transition Period(s)
  - How to Minimize Operational Disruptions?



Fuel
Sulfur content (among other things)

Engine
Including emissions devices

Lubricating Oil
Designed in conjunction with above

Number 2 Diesel Fuel Specifications (ASTM D975-08)

"Sulfur Designation"	"High"	"Low"	"Ultra-Low"
Name	S-5000	S-500	S-15
Sulfur Content	**<0.50 m%**	**<0.05 m%**	**<15 ppm**
Viscosity @ 40°C	1.9 – 4.1	1.9 – 4.1	1.9 – 4.1
Flash Point	>52°C	>52°C	>52°C
Cetane Number	≥40	≥40	≥40
Cetane Index		≥40	≥40
Aromatics		≤35	≤35
Lubricity, HFRR	≤520	≤520	≤520
Conductivity	≥25	≥25	≥25
Distillation @90°C	282 – 338	282 – 338	282 – 338
Ash	≤0.01	≤0.01	≤0.01
Water & Sediment	≤0.05%	≤0.05%	≤0.05%
Carbon Residue	≤0.35%	≤0.35%	≤0.35%
Copper Corrosion	≤3	≤3	≤3

US EPA Locomotive Emissions Standards (g/bhp-hr)

Model Year:	Tier 0 1973	Tier 1 2002	Tier 2 2005	Tier 3 2012	Tier 4 2015
Parameter					
Nitrogen Oxides (NO_X)					
Linehaul	8.0	7.4	5.5	5.5	1.3
Switcher	11.8	11.0	8.1	5.0	1.3
Particulates (PM)					
Linehaul	0.22	0.22	0.20	0.10	0.03
Switcher	0.26	0.26	0.24	0.10	0.03
Hydrocarbon (HC)					
Linehaul	1.00	0.55	0.30	0.30	0.14
Switcher	2.10	1.20	0.60	0.60	0.14
Carbon Monoxide (CO)					
Linehaul	5.0	2.2	1.5	1.5	1.5
Switcher	8.0	2.5	2.4	2.4	2.4
Smoke Opacity					
Steady-state	30	25	20	20	20
30-sec peak	40	40	40	40	40
3-sec peak	50	50	50	50	50

40CFR Parts 85, 89, and 92 (2000) & 40CFR 1033.825 (signed 14 March 2008)

Inland Marine Emissions Regulations

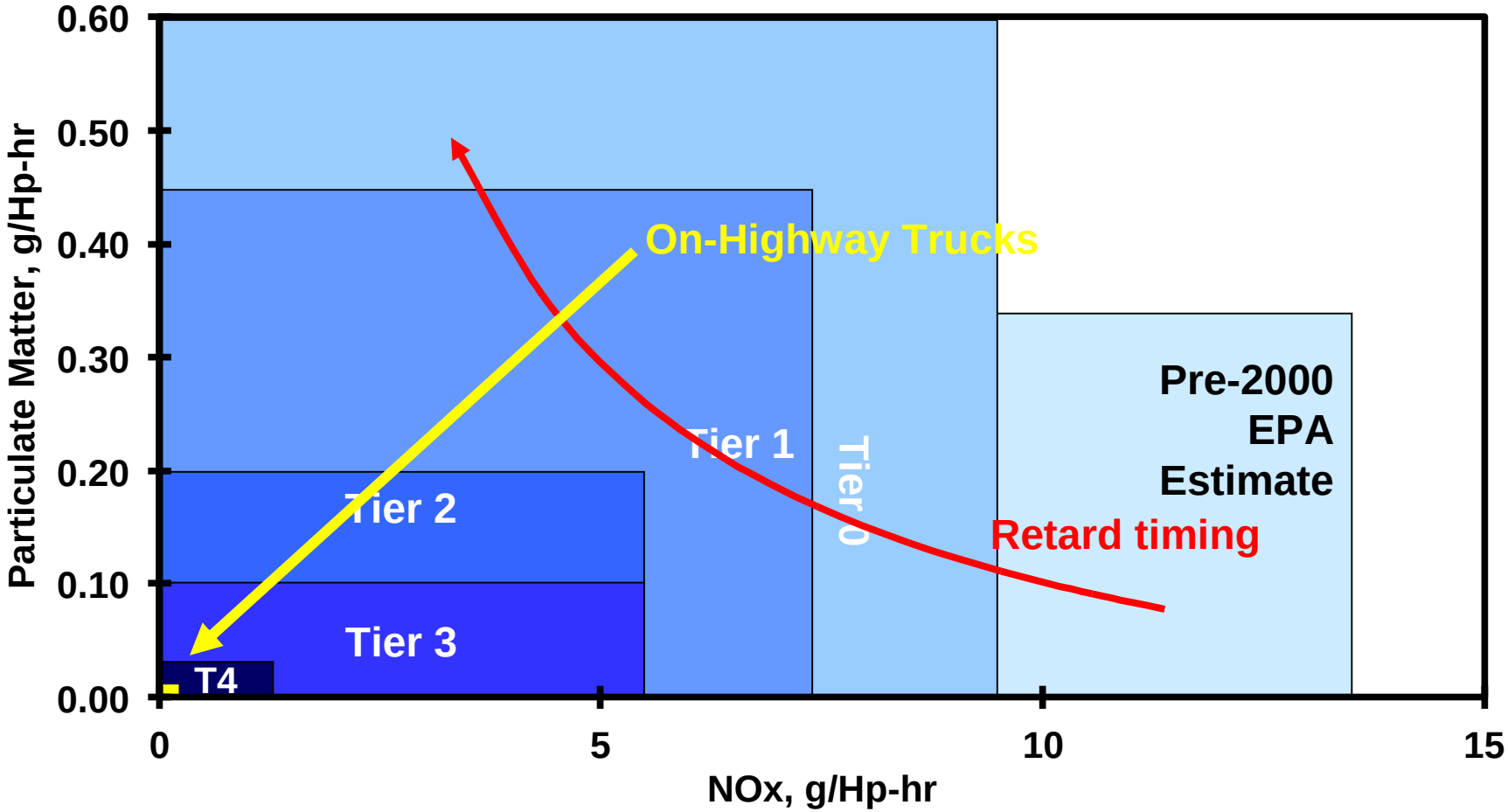
	Displacement		Power		Median Life
Category	L/cyl	cu in	kW	Hp	years
1	< 5	< 305	> 37	> 50	15
2	5 – 30	305 – 1831			23
3	> 30	> 1831			

					g/kW-hr		
Category	L/cyl	cu in	kW	Year	NO_X + HC	PM	CO
1	< 0.9	> 55	≥37	2005	7.5	0.40	5.0
1	≥0.9 – <1.2	55 – 73		2004	7.2	0.30	5.0
1	≥1.2 – <2.5	73 – 153		2004	.2	0.20	5.0
1	≥2.5 – <5.0	153 – 305		2007	7.2	0.20	5.0
2	≥5.0 – <15	305 – 915		2007	7.8	0.27	5.0
2	≥15 – <20	915 – 1221	<3300	2007	8.7	0.50	5.0
2	≥15 – <20	915 – 1221	≥3300	2007	9.8	0.50	5.0
2	≥20 – <25	1221 – 1526		2007	9.8	0.50	5.0
2	≥25 – <30	1526 - 1831		2007	11.0	0.50	5.0

International Maritime Organization (IMO)			
Engine Speed, rpm:	< 130	130 - 2000	> 2000
NO_X (g/Kw-hr):	17.9	$45N^{-0.2}$	9.8

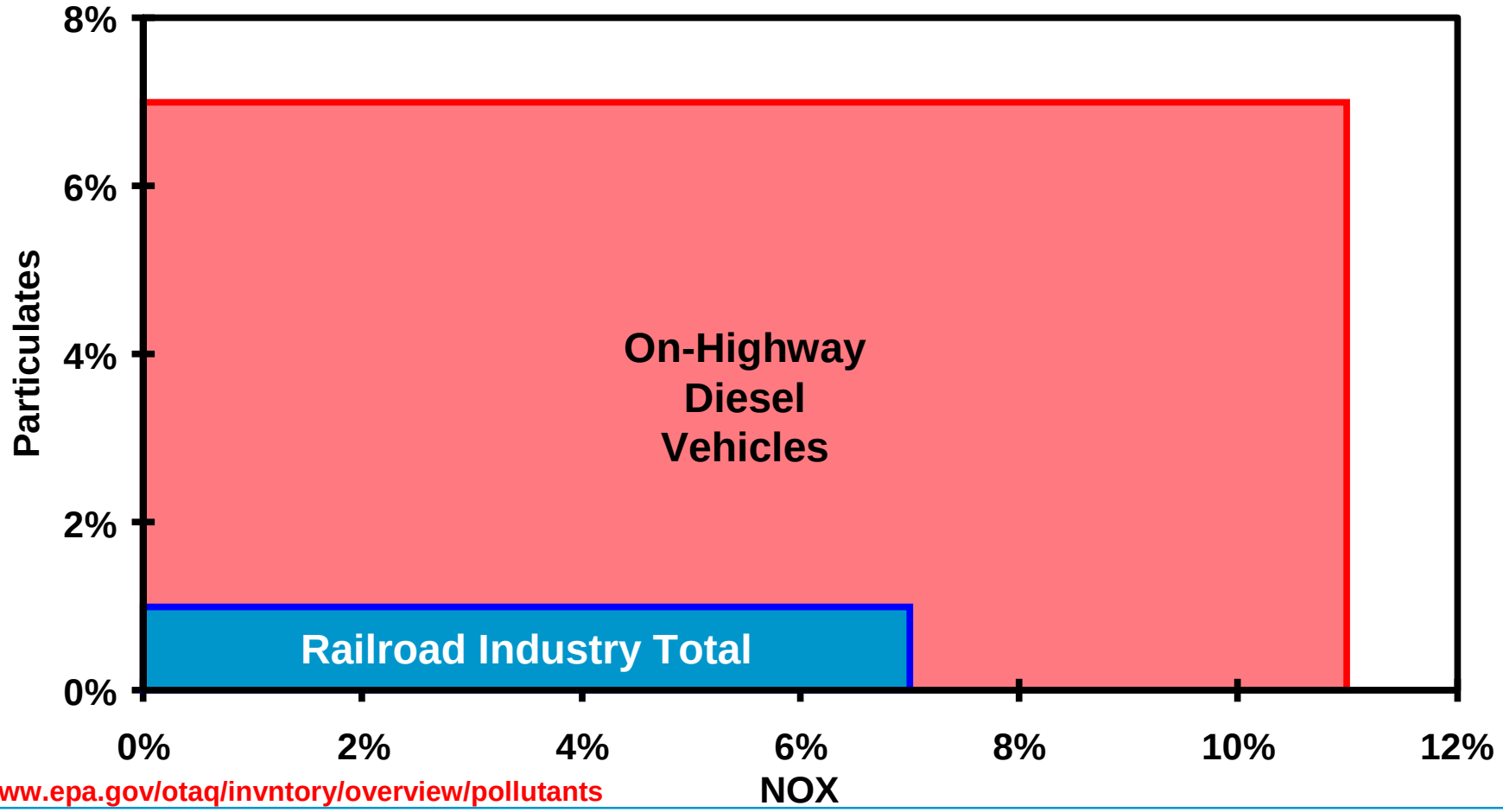
USA EPA Locomotive Emissions Standards (Linehaul)

- NOX and Particulates often trade-off
  - Reducing both simultaneously requires new technologies



Trucks vs. Trains (2007)

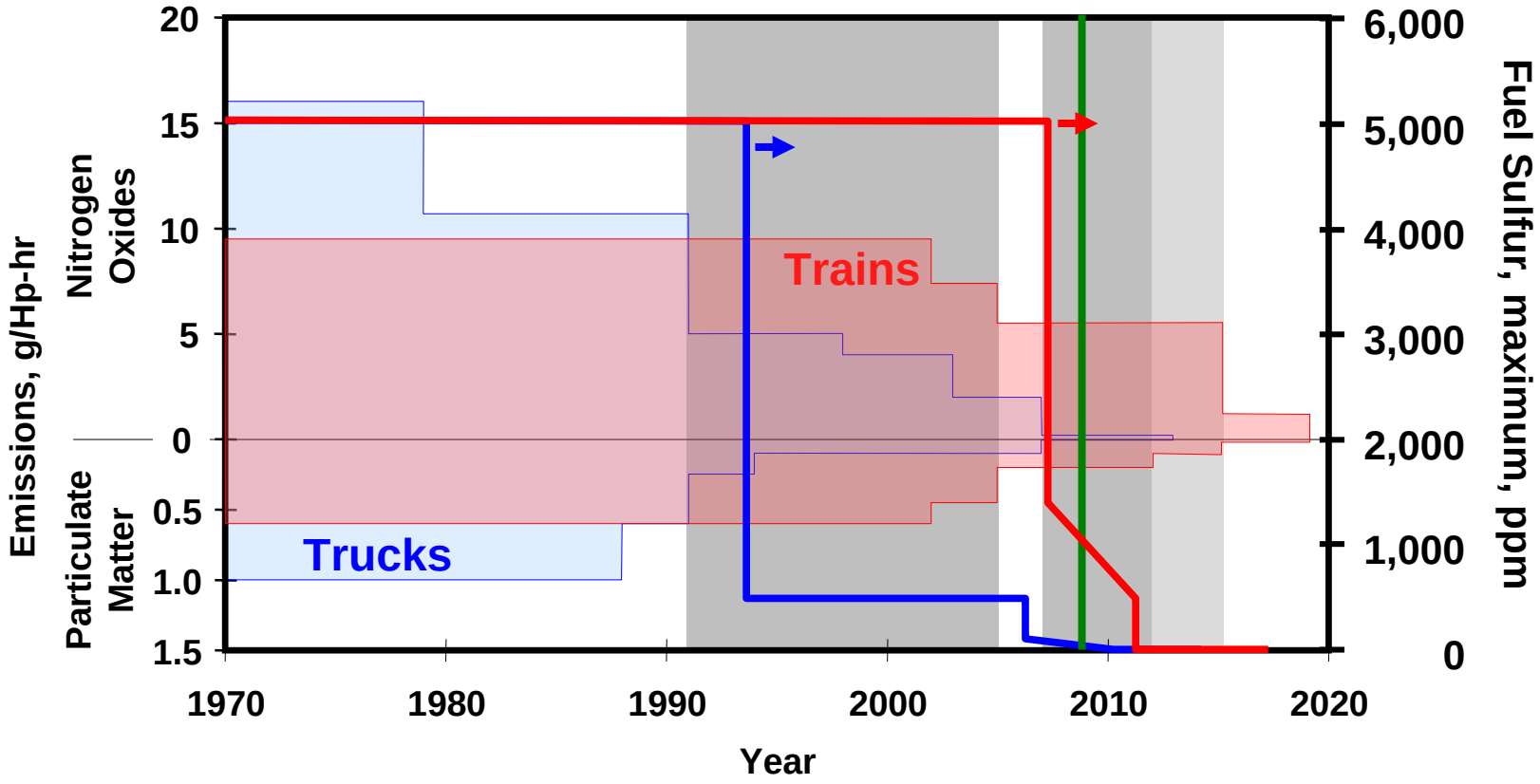
- Railroad has lower overall contribution to emissions than trucking
  - 49% of NO_X from gasoline; 49% of PM from stationary sources



www.epa.gov/otaq/invntory/overview/pollutants

USA Emissions Standards – Timeline

- On-highway had more incremental decreases (7 *vs*. 4)
  - Railroad lagging 14 years
  - Next lag expected to be only 5 years
    - But really big change lags 8 years



How to Meet Emissions?

- Tier 0 (1973) & Tier 1 (2002)
  - Fine-tuning
- Tier 2 (2005)
  - New engine designs
  - More efficient combustion
    - Higher pressure injection
    - More electronics
  - Lower oil consumption

How Railroad Met the Limits

- Tier 3 (2012)
  - More fine-tuning?
  - Miller Cycle?
- Tier 4 (2015)
  - Engine re-design?
  - Valve timing?
  - Exhaust Gas Recirculation?
  - Catalysts

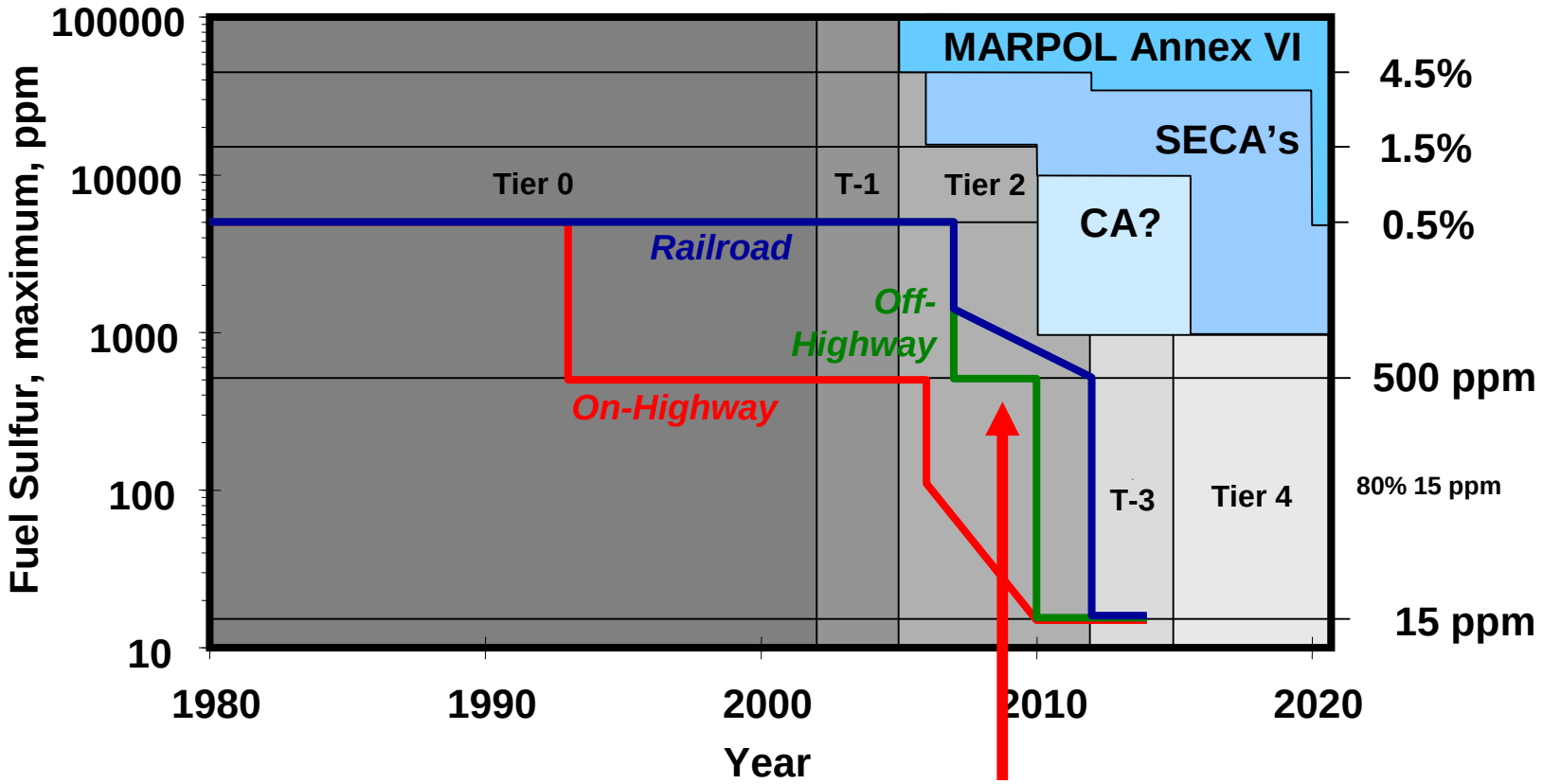
How On-Highway Met the Equivalent Limits

Reasons to Reduce Fuel Sulfur

- Direct Effects
  - Sulfur incorporated into regulated emission species
    - Sulfur Oxides (S_{OX}) measured as particulates
- Technologies That Work Better with Lower Sulfur
  - Exhaust Gas Recirculation (EGR)
    - Less acid formed
  - Diesel Particulate Filters (DPF)
    - Fewer particulates to trap
- Technologies That Require Lower Sulfur
  - Catalysts poisoned by sulfur
    - Diesel Oxidation Catalysts (DOC)
    - Selective Catalytic Reduction (SCR)

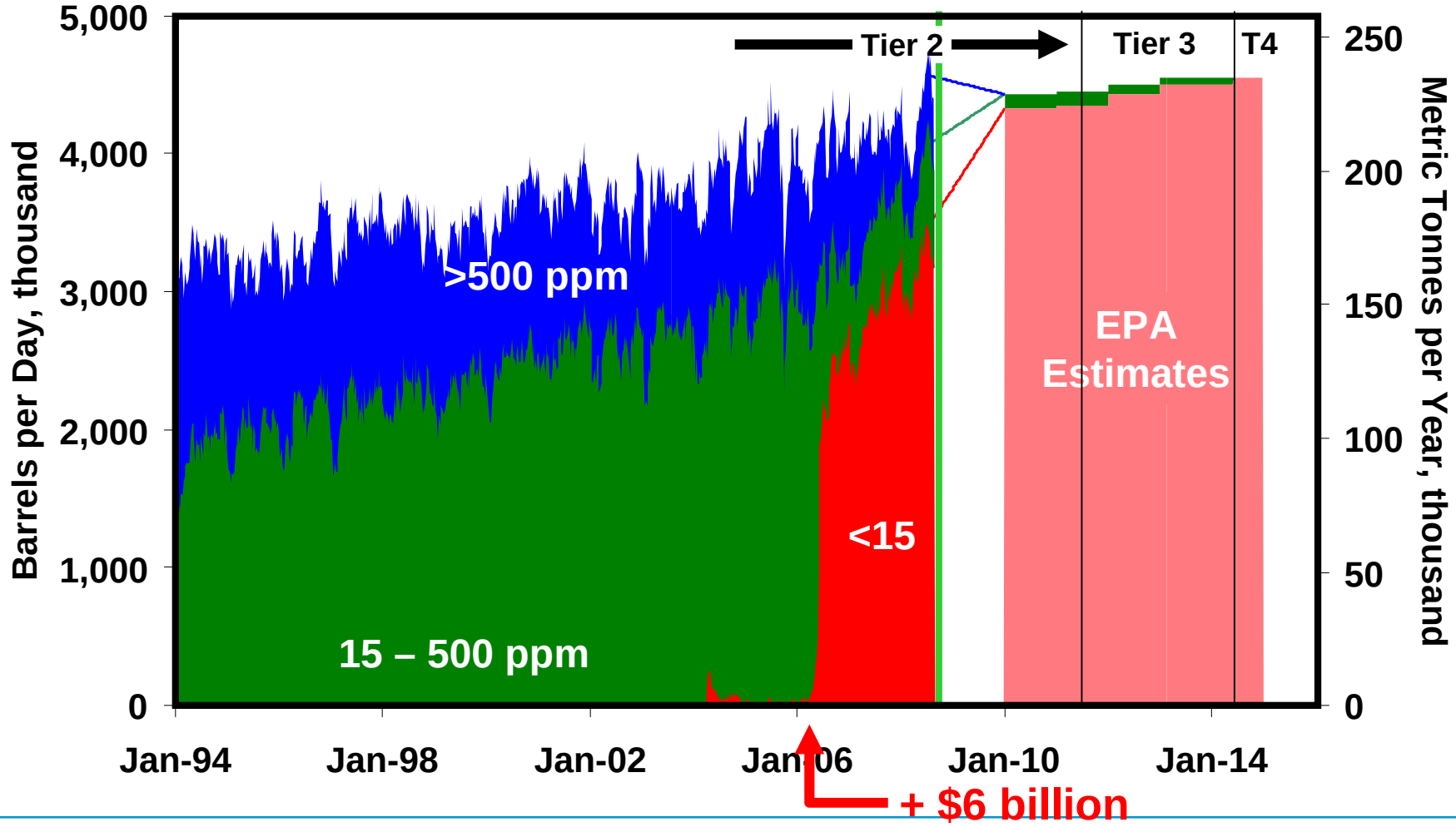
Diesel Fuel Sulfur Limits

- Railroad and Off-highway will follow On-highway
  - Ultra Low Sulfur Diesel will allow aftertreatment for railroad



United States Diesel Fuel Transition

- US Energy Information Agency, www.eia.doe.gov



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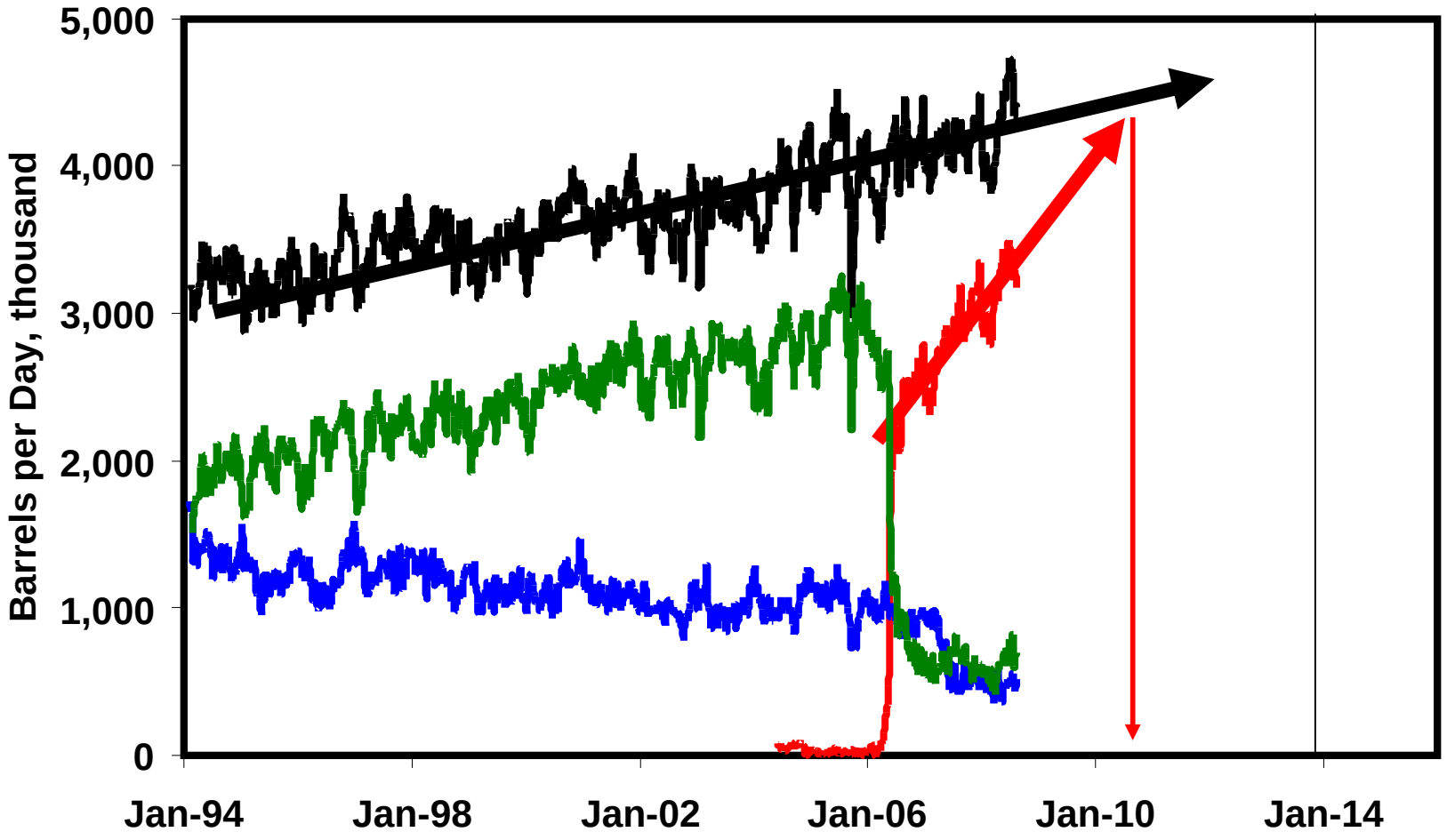
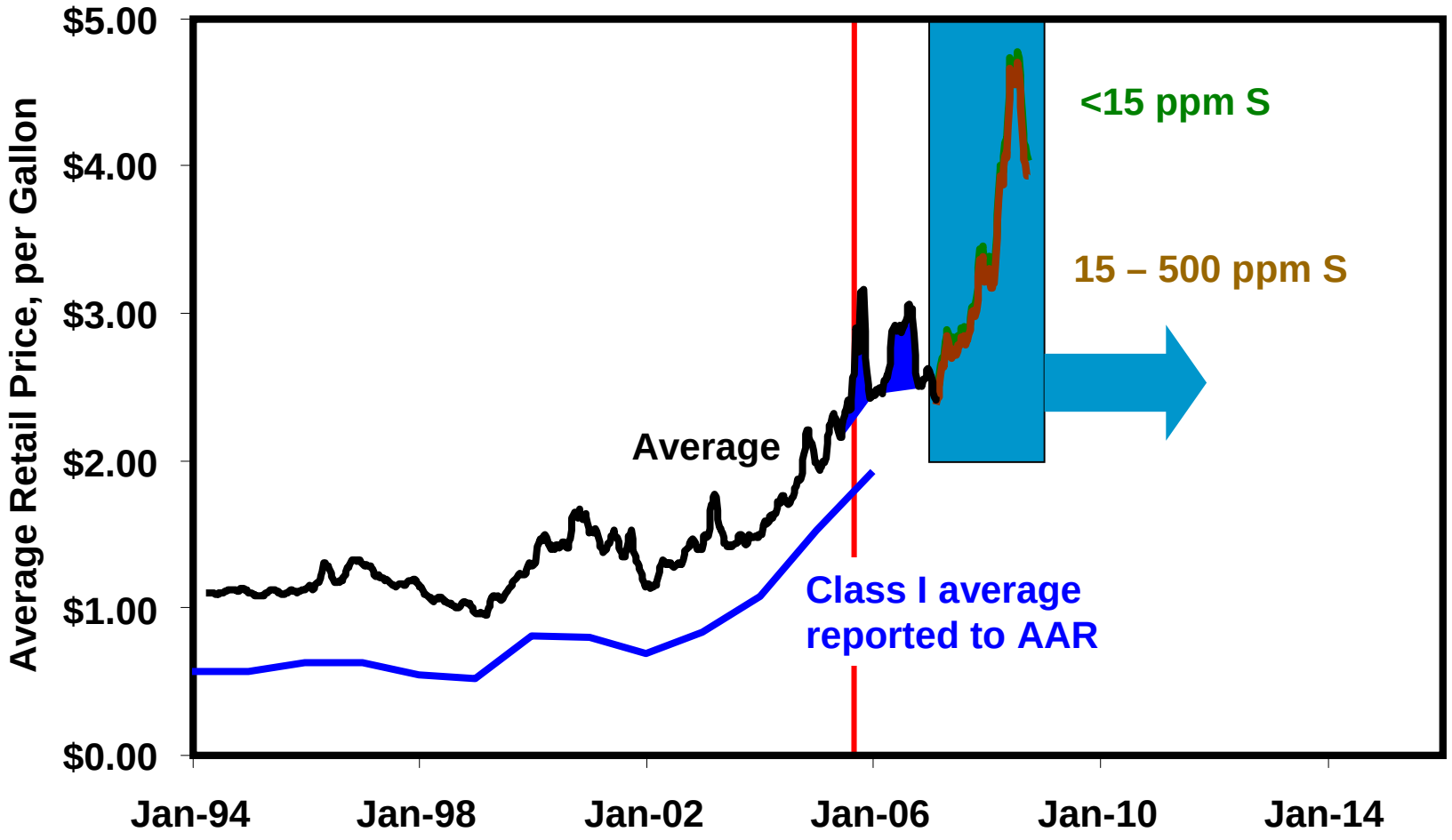


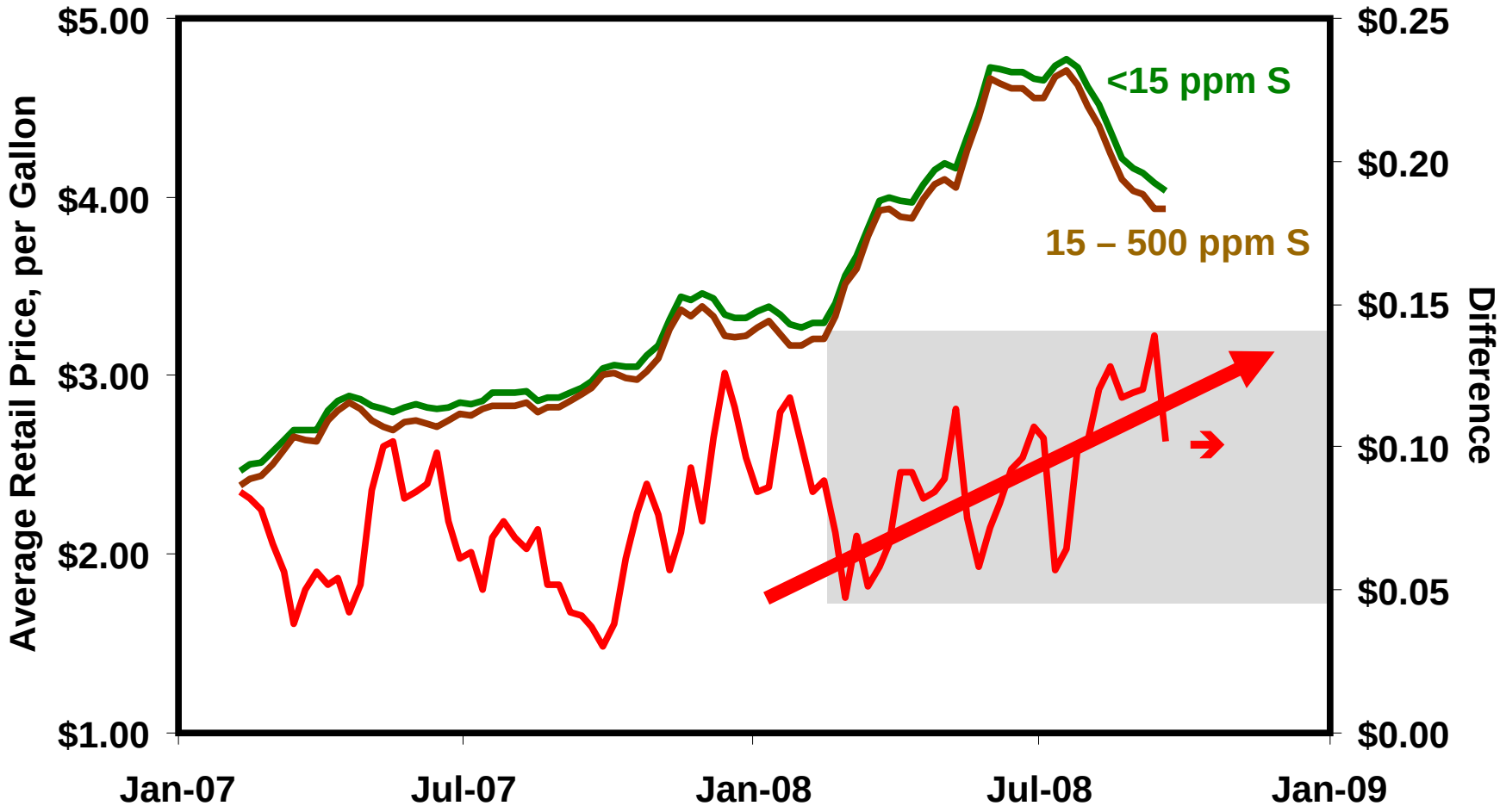
United States Diesel Fuel Prices

- Prices declining after sudden rise?



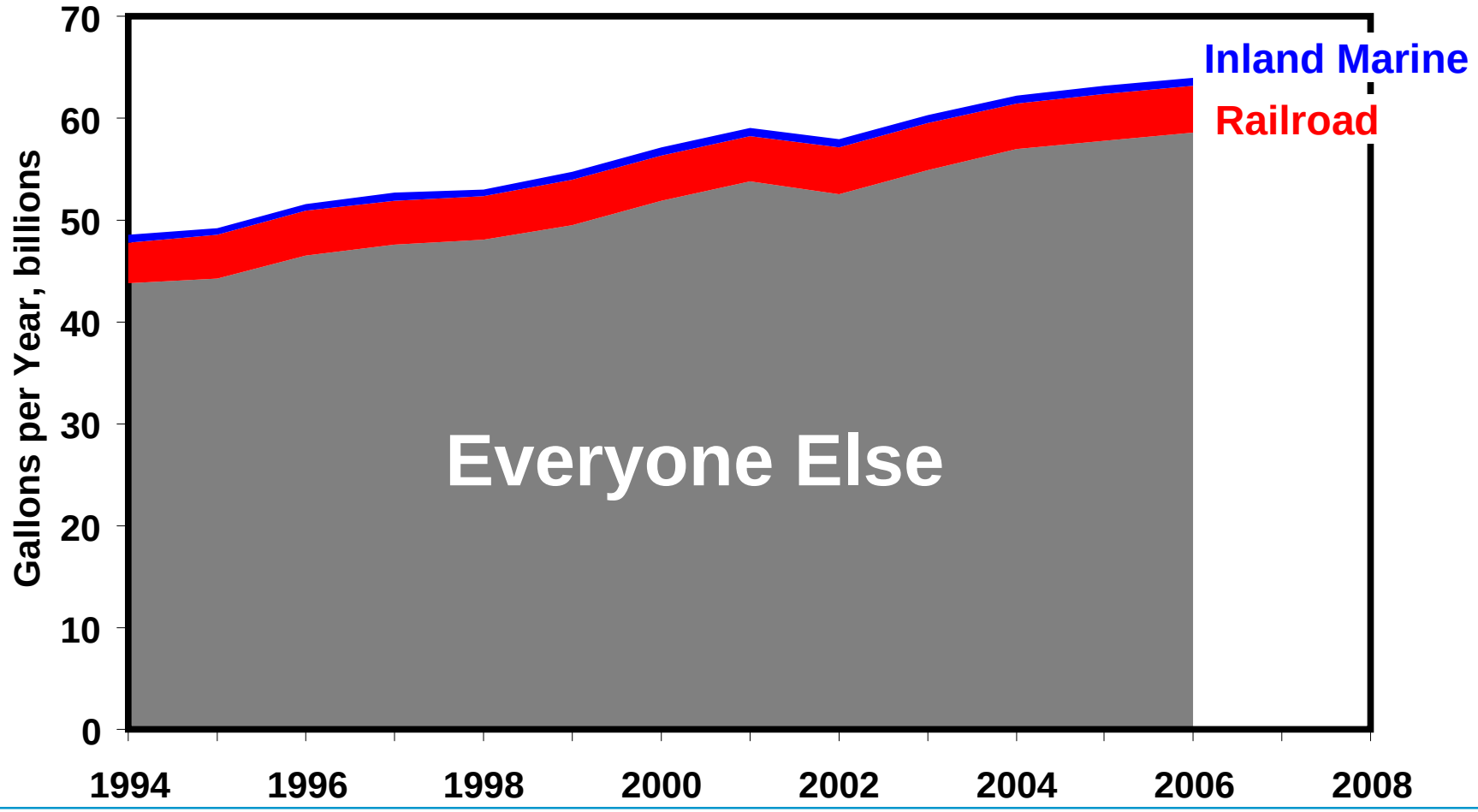
United States Diesel Fuel Prices

- Ultra-low sulfur diesel has 5 – 12¢/gallon premium



United States Diesel Fuel Usage

- Railroad is ~7% of total
  - Inland Marine is ~1.3% of total

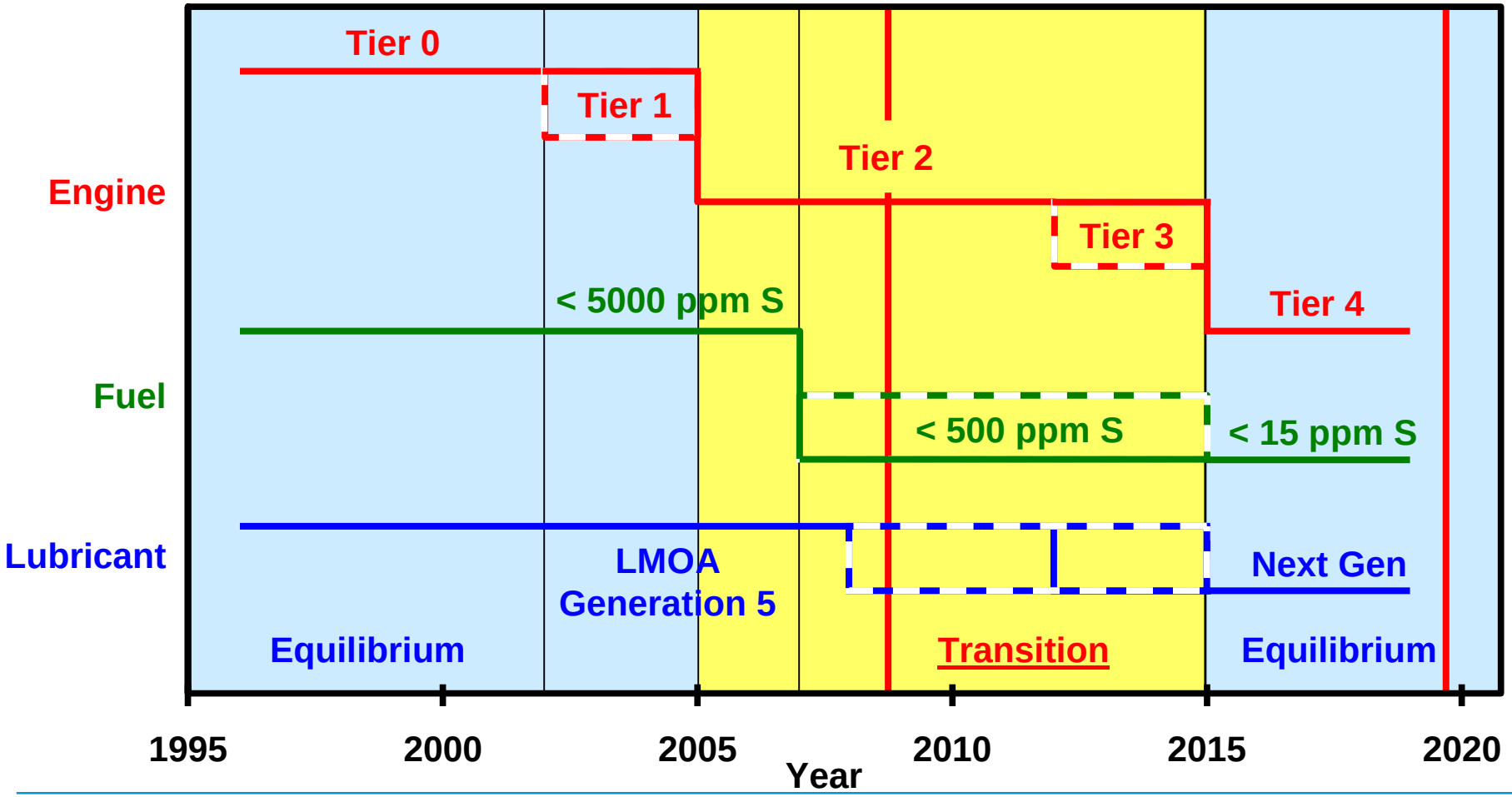


Problems Experienced with Lower Sulfur Fuels

- Direct Effects
  - Lower fuel economy
    - Sulfur in denser, aromatic molecules
    - Results in less energy *per* unit volume
    - No known remedy ➔ change units?
  - Injector Wear (Lubricity)
    - Sulfur compounds are surface-active
    - Other surface-active species removed with sulfur
- Indirect Effects
  - Less Acid Formation
    - Decrease need for base number?
  - Combustion Chamber Deposits
  - Liner Varnish (Lacquer)
    - Bore polishing (liner wear)
    - Oil consumption increase
    - Black smoke

From Equilibrium to Equilibrium

- Possibility for Uncertainty During Transition Periods



Conclusions

- Emissions Regulations for Off-Highway are Increasingly Stringent
- Low Sulfur Fuels Are Required for New Emissions Standards
  - Both direct and indirect reasons
  - May lead to operational problems
    - Data accumulating
- Transition Period
  - Engine, Fuel, and Lubricant All Changing on Different Schedules
  - Potential for Imbalance
- Operators are Advised to Maintain Awareness
  - Potential Operational Problems
- Consult
  - Engine Manufacturer
  - Fuel Supplier
  - Lubricant Supplier
- Fuel additives May Offer an Interim Solution
  - Complimentary to engine lubricants

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