Alternative Fuel and Conventional Vehicle Air Pollutant Emissions

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Clean Cities Webinar

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Outline of Presentation

- Introduction of Air Pollutant Emissions and AFLEET Tool
- Air Pollutant Trends
- Heavy-Duty Diesel and AFV Emissions
- Light-Duty Gasoline and AFV Emissions

Introduction of Air Pollutant Emissions and AFLEET Tool

Vehicles Cause Several Emission/Air Quality Concerns – PM and O_3 Most Widespread Health Threats

- **Carbon monoxide (CO)**
  - At low levels can exacerbate cardiovascular disease, by reducing O_2 delivery
  - At high levels can be poisonous
- **Particulate matter (PM)**
  - Can cause serious health effects impacting the lungs and heart
  - Health impacts depend on size
    - Fine PM (PM2.5) cause more damage than coarse PM (PM10)
- **Nitrogen oxides (NOx)**
  - Contributes to various environmental problems, primary concern is ozone
- **Volatile organic compounds (VOCs)**
  - Contributes to various environmental problems, primary concern is ozone
  - Regulated as NMOG (LDVs) and NMHC (HDVs)
- **Ozone (O_3)**
  - Produced from reaction of NOx, VOCs, and sunlight
  - Can cause serious health effects impacting the lungs and heart

Argonne has Supported DOE's Clean Cities with Tool Development for 15+ Years

- **AirCRED** (1998-2007)
  - Estimated O_3 precursor & CO emission credits from AFVs for SIPs

- **Clean Cities AOI 4 Emissions Benefit Tool** (2009)
  - Estimated GHG & air pollutant benefits of Recovery Act grant proposals

- **AFLEET Tool** (2013-present)
  - Estimates cost of ownership, petroleum use, GHGs, & air pollutants of light- and heavy-duty vehicles
  - AFLEET Tool & user manual available at: http://greet.es.anl.gov/afleet

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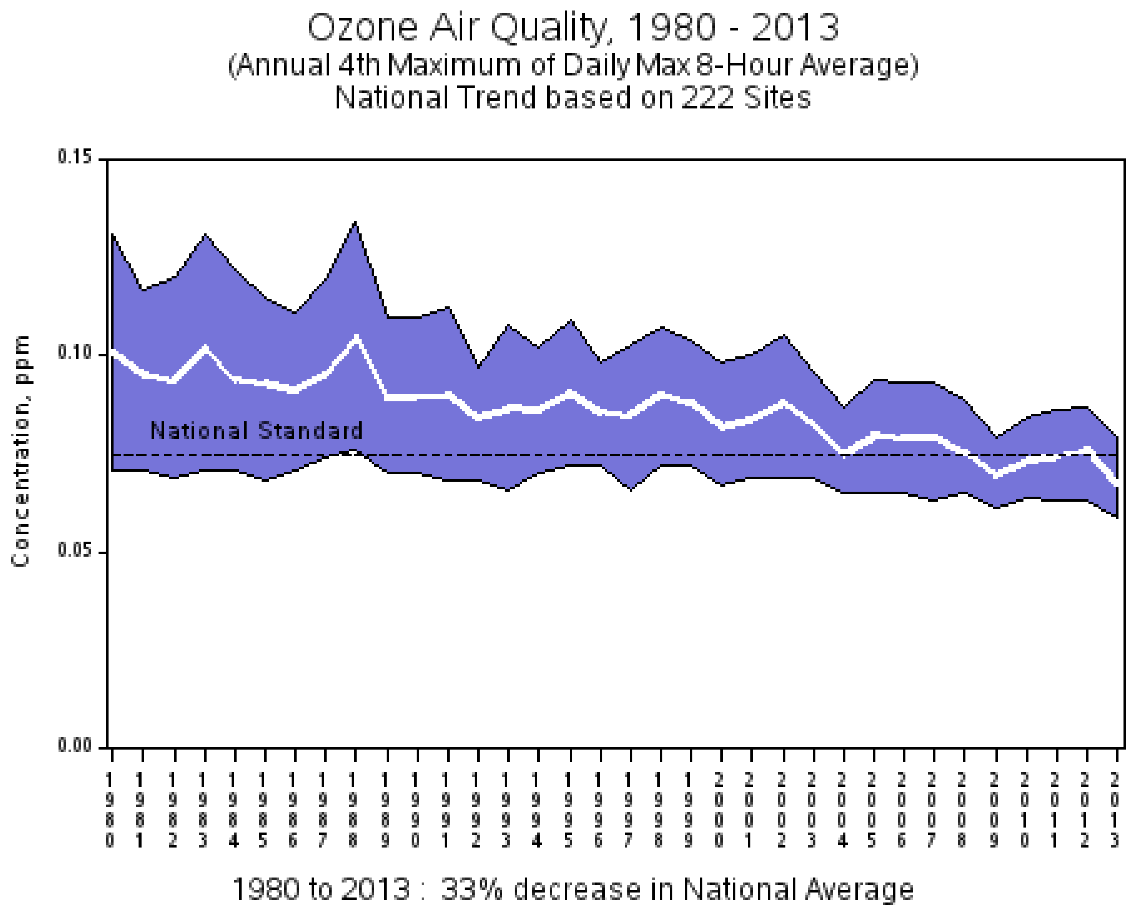
“AFLEET Tool” to Analyze Costs & Benefits of AFVs

- **Developed in 1998, AirCRED was a DOE and EPA co-sponsored tool for Clean Cities Stakeholders**
  - Used EPA’s MOBILE model and annual emission vehicle/engine certification results
    - EPA software focused on gasoline and diesel
    - Certification data used to compare alternative fuels with conventional counterparts

- **AFLEET Tool uses same methodology as AirCRED**
  - Uses EPA’s new MOVES model for gasoline and diesel
    - Incorporates data showing NOx and PM in-use vehicle emissions are much higher than previous estimates
  - AFLEET reviewed by NGVA, PERC, EPRI, NTEA, and NREL

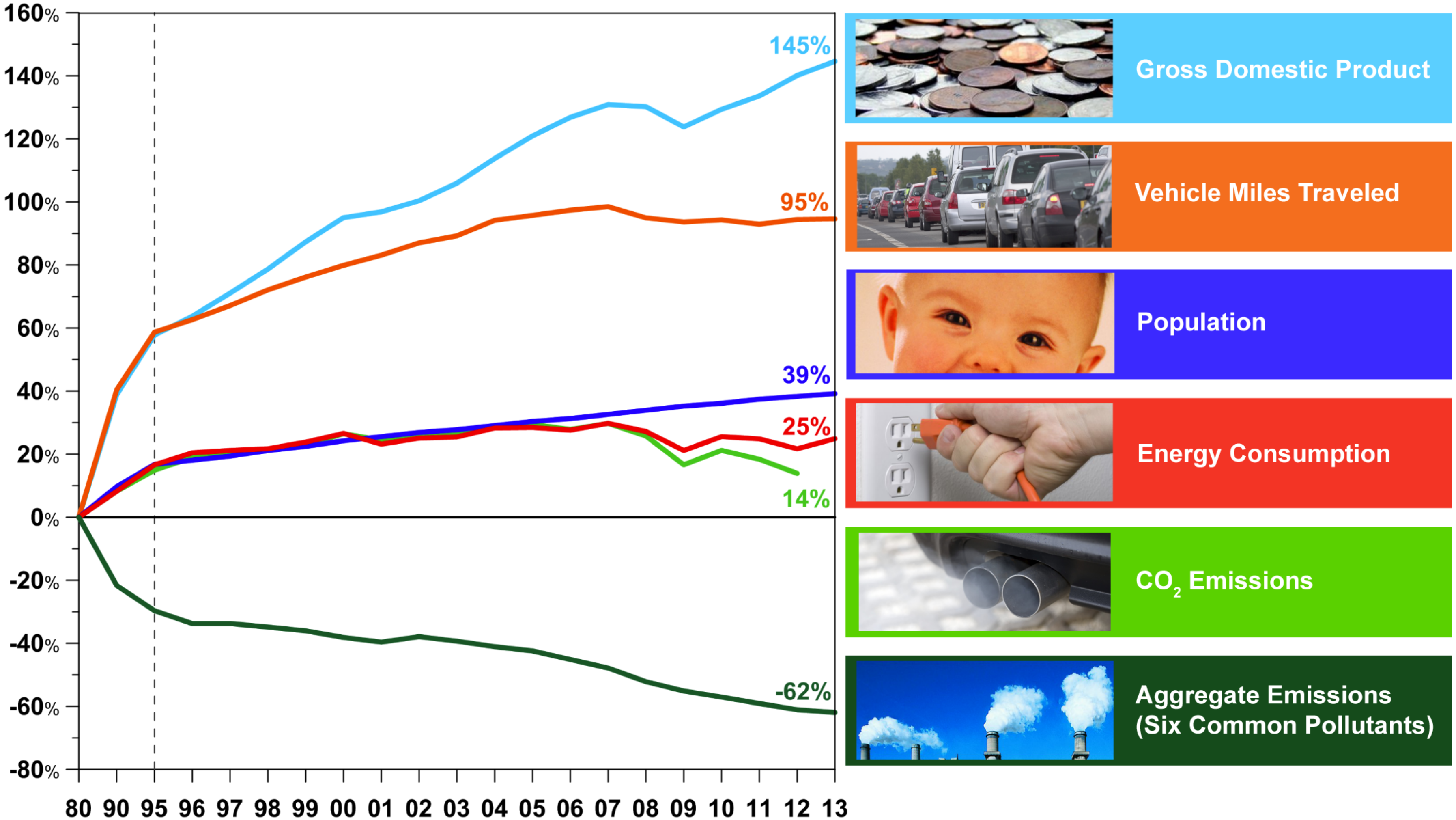
- **Argonne researchers examining latest work HDV emissions**
  - Findings will be implemented into AFLEET

Air Pollutant Trends



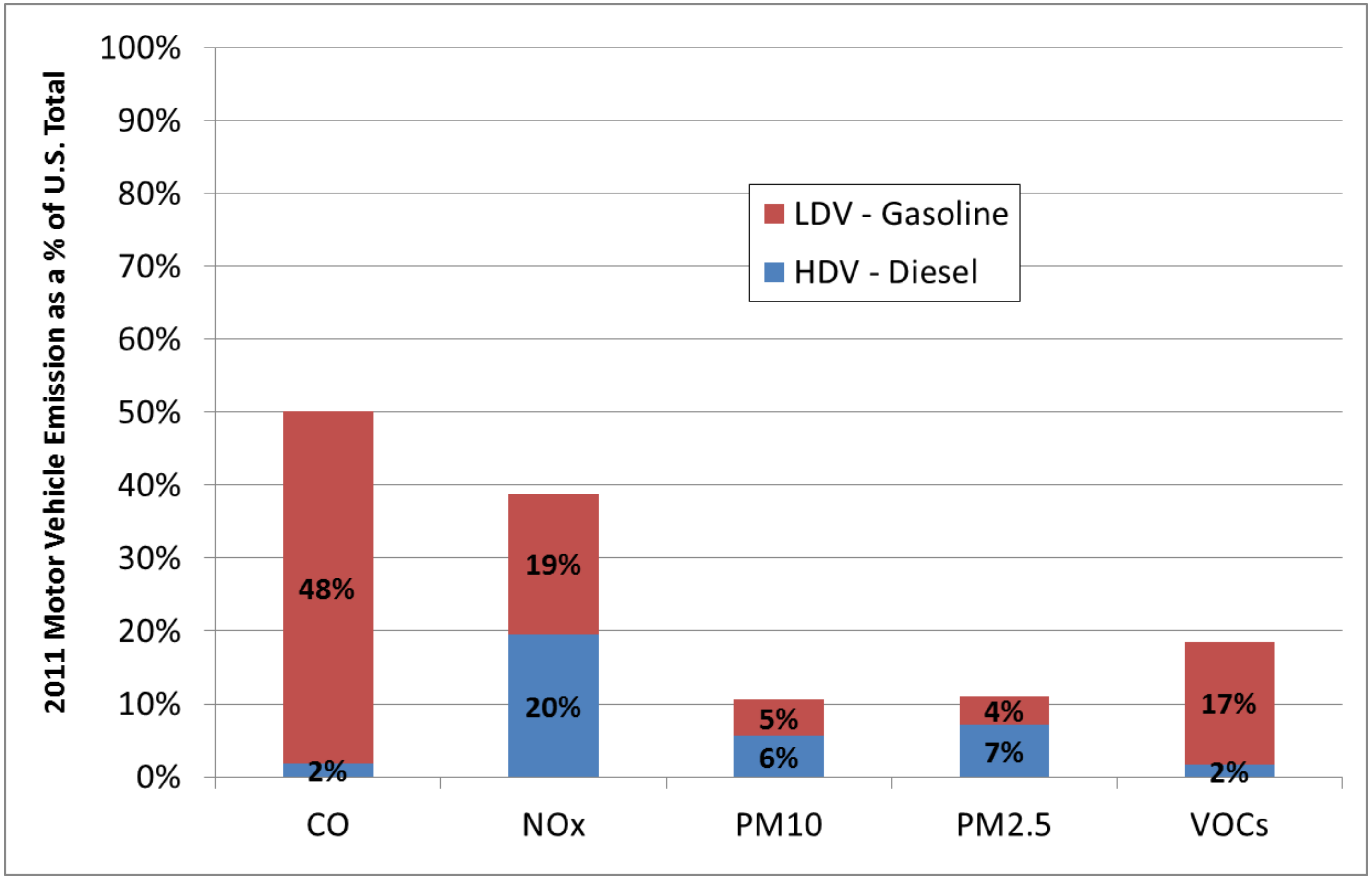
Source: EPA, 2014, National Trends in Ozone Levels

Significant Progress Made Reducing U.S. Total Air Pollutant Emissions



Source: EPA, 2014, Air Quality Trends

Motor Vehicle Emissions as % of U.S. Total Emissions*



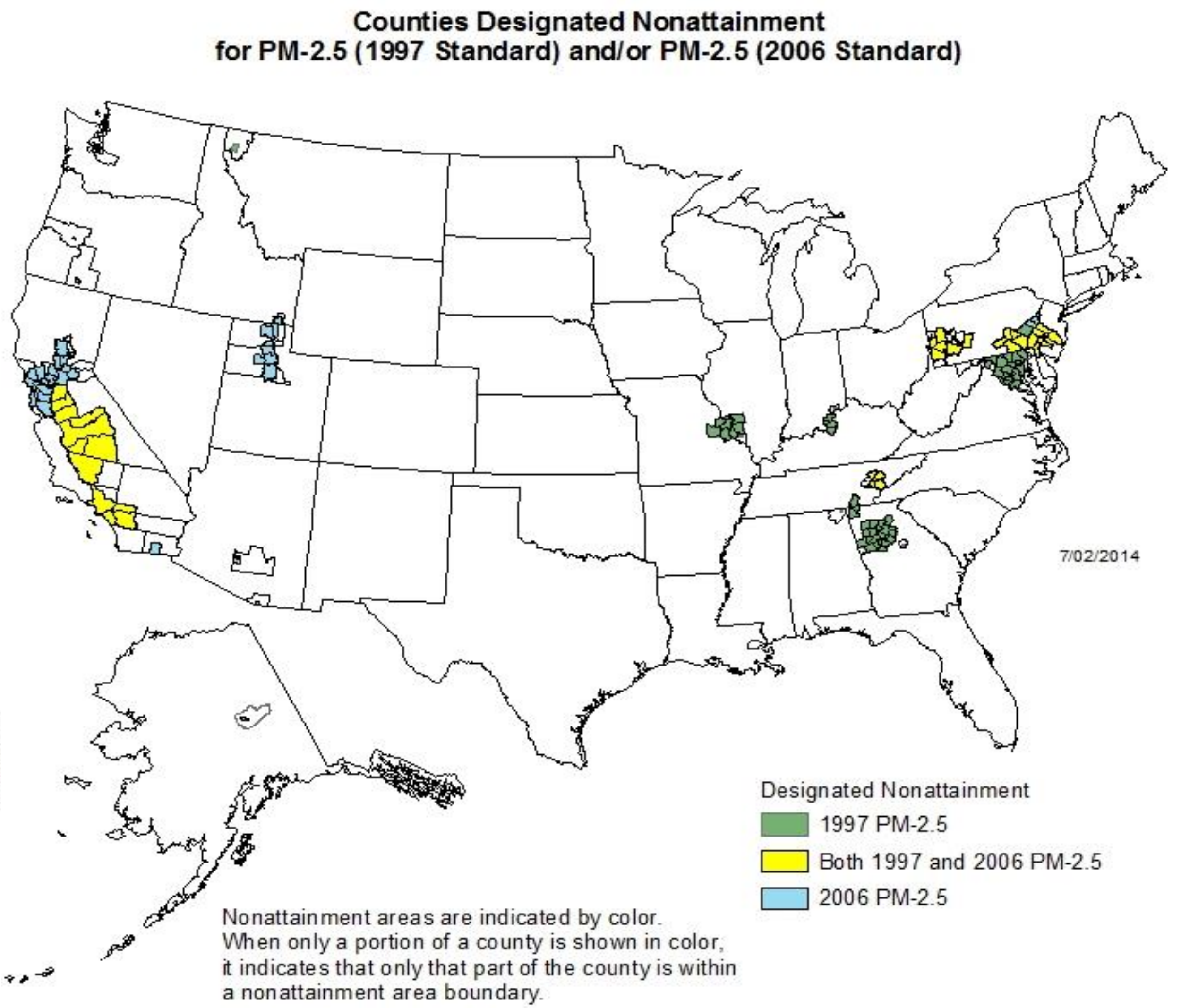
- **Gasoline light-duty vehicles = large source of CO, NOx, VOCs**
- **Diesel heavy-duty trucks = large source of NOx**
- **PM from both are important due proximity of emissions to the public**

*Excluding fires, dust, agriculture, vegetation

Source: EPA, 2015, The 2011 National Emissions Inventory

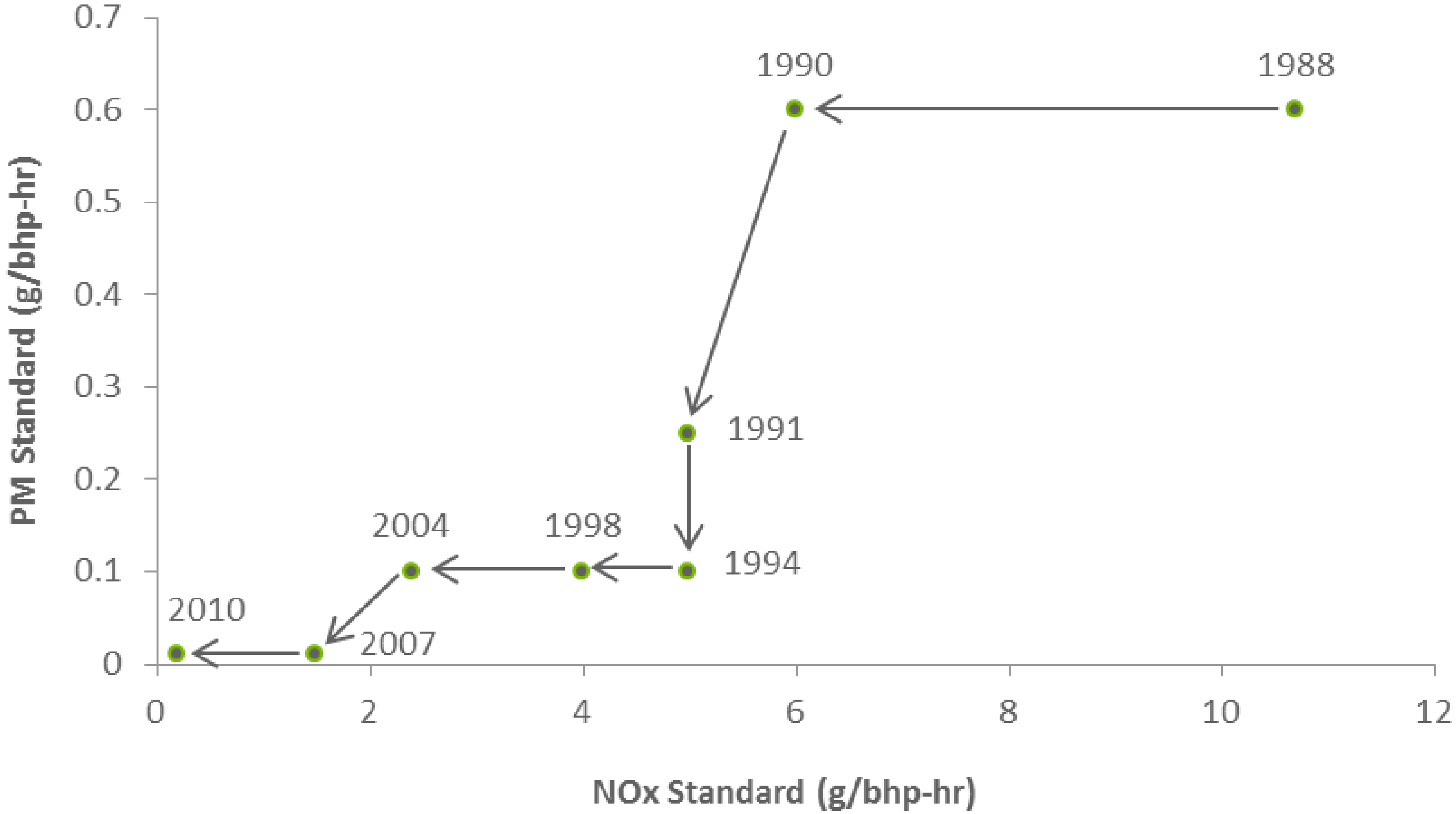
Regulatory Focus for Vehicles Has Been on Ozone (and NOx as its Typical Primary Driver) and PM

- 135 million people in O_3 nonattainment areas
- 63 million people in PM2.5 nonattainment areas
- No counties are in nonattainment for CO



Source: EPA, 2014, The Green Book Nonattainment Areas for Criteria Pollutants

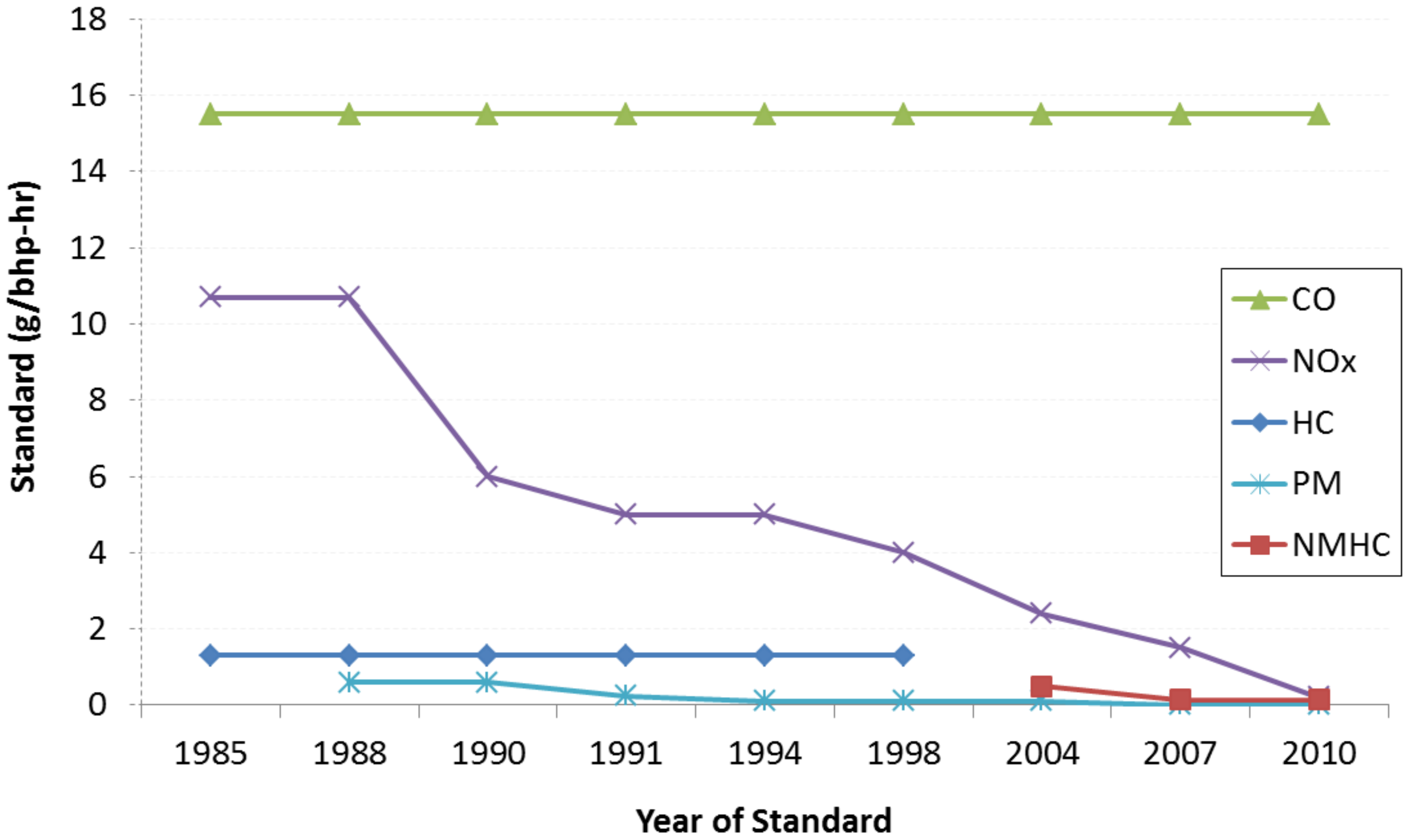
EPA's Heavy-Duty Engine NOx and PM Standards Tightened by 98% since 1988



- **Standards required significant improvements in engine controls and aftertreatment systems for diesel HDVs**
  - Diesel particulate filters (DPFs) for PM & selective catalytic reduction (SCR) for NOx

Source: EPA, 2013, Heavy-Duty HDCI -- Exhaust Emission Standards

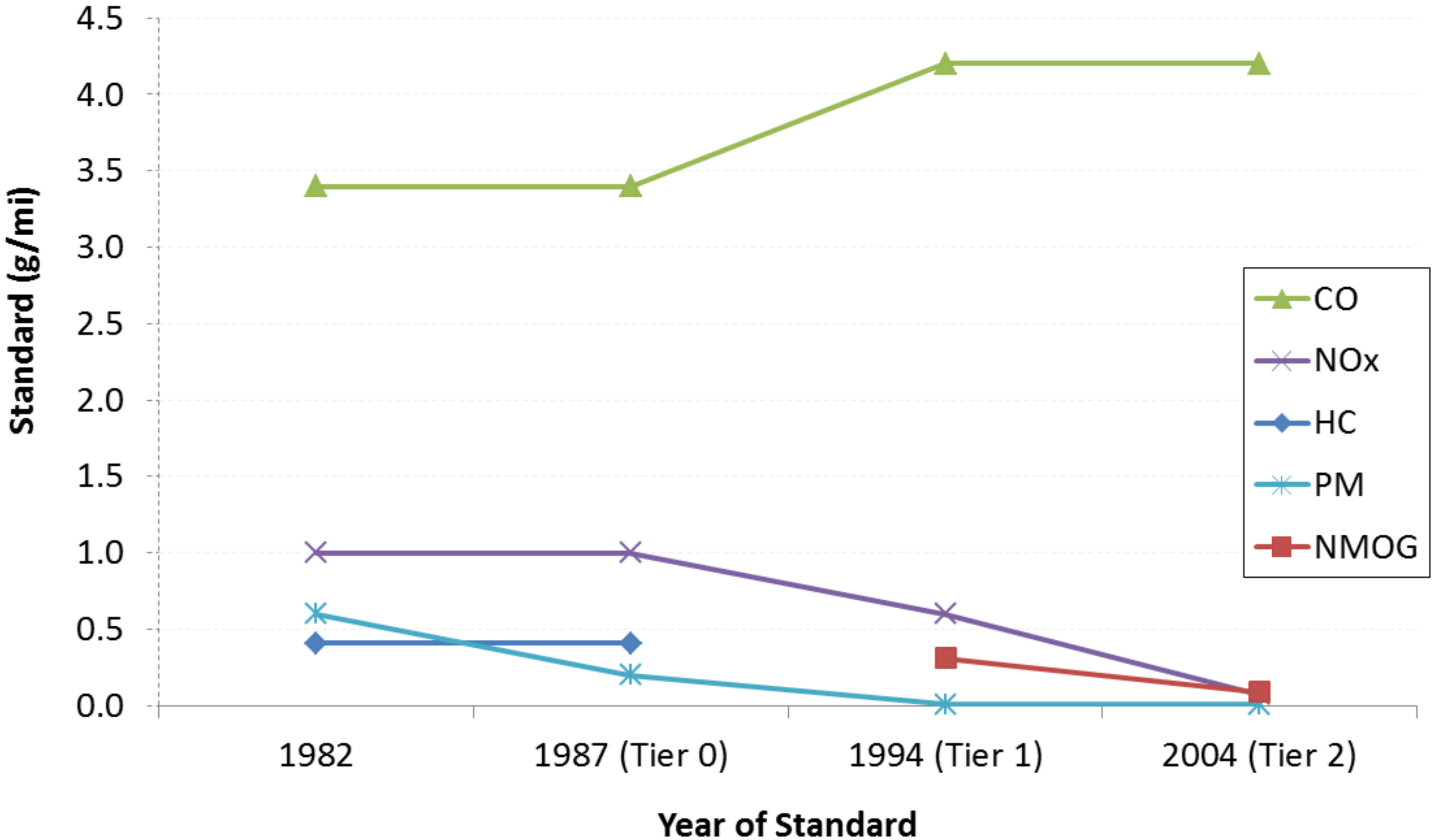
EPA's HD Standard for CO hasn't changed since 1985



- Regulations switched from total hydrocarbons to non-methane hydrocarbons in 2004

Source: EPA, 2013, Heavy-Duty HDCI -- Exhaust Emission Standards

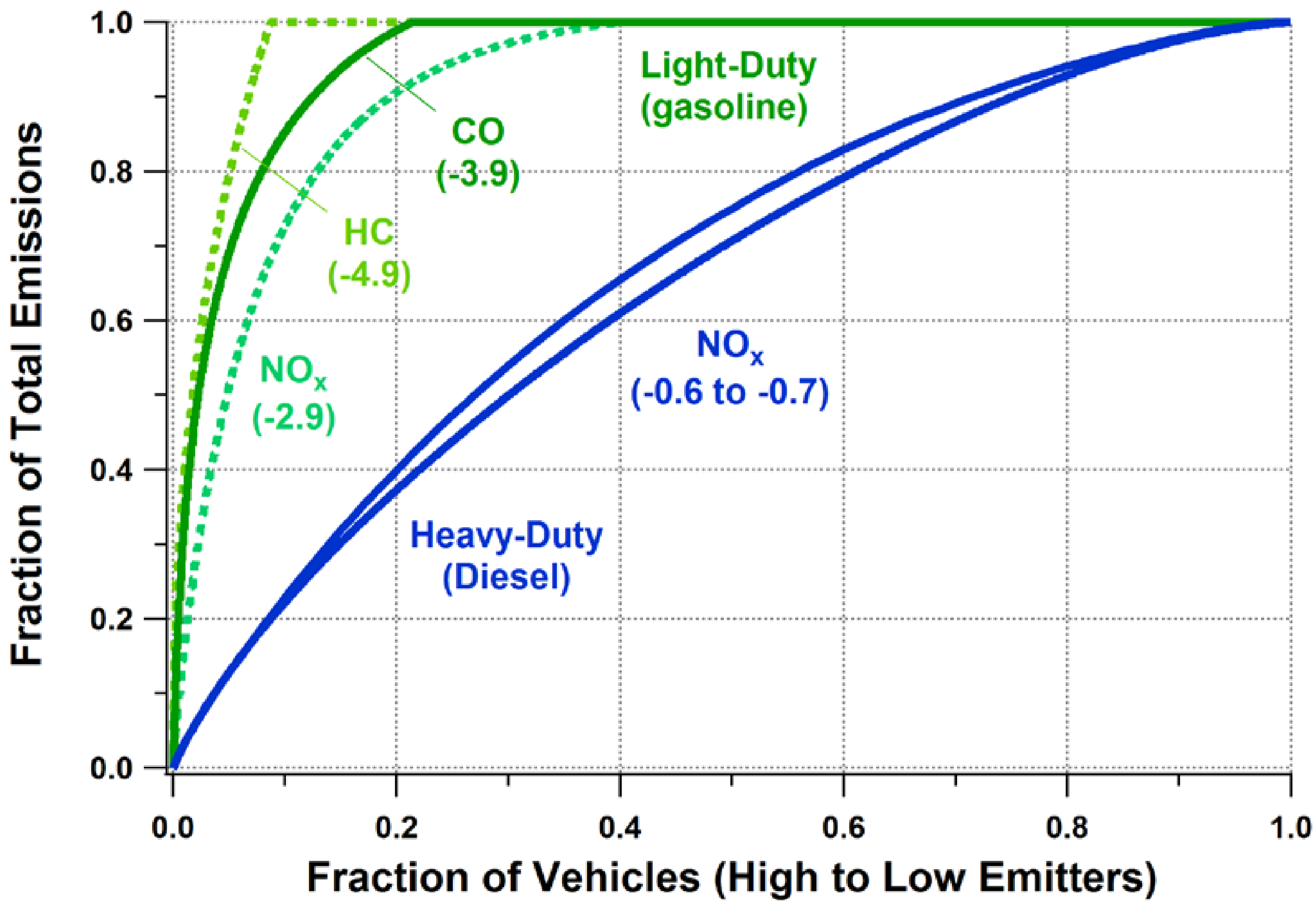
EPA's LDV Standards Similarly Focused on NOx & PM



- **CO standard looks to go up but this is due to changes in testing procedure**
  - Tier 1/2 standards for "full useful life" (100K+ mi); prior for "half useful life" (50K mi)

Source: EPA, 2013, Light-Duty Vehicles and Trucks and Motorcycles

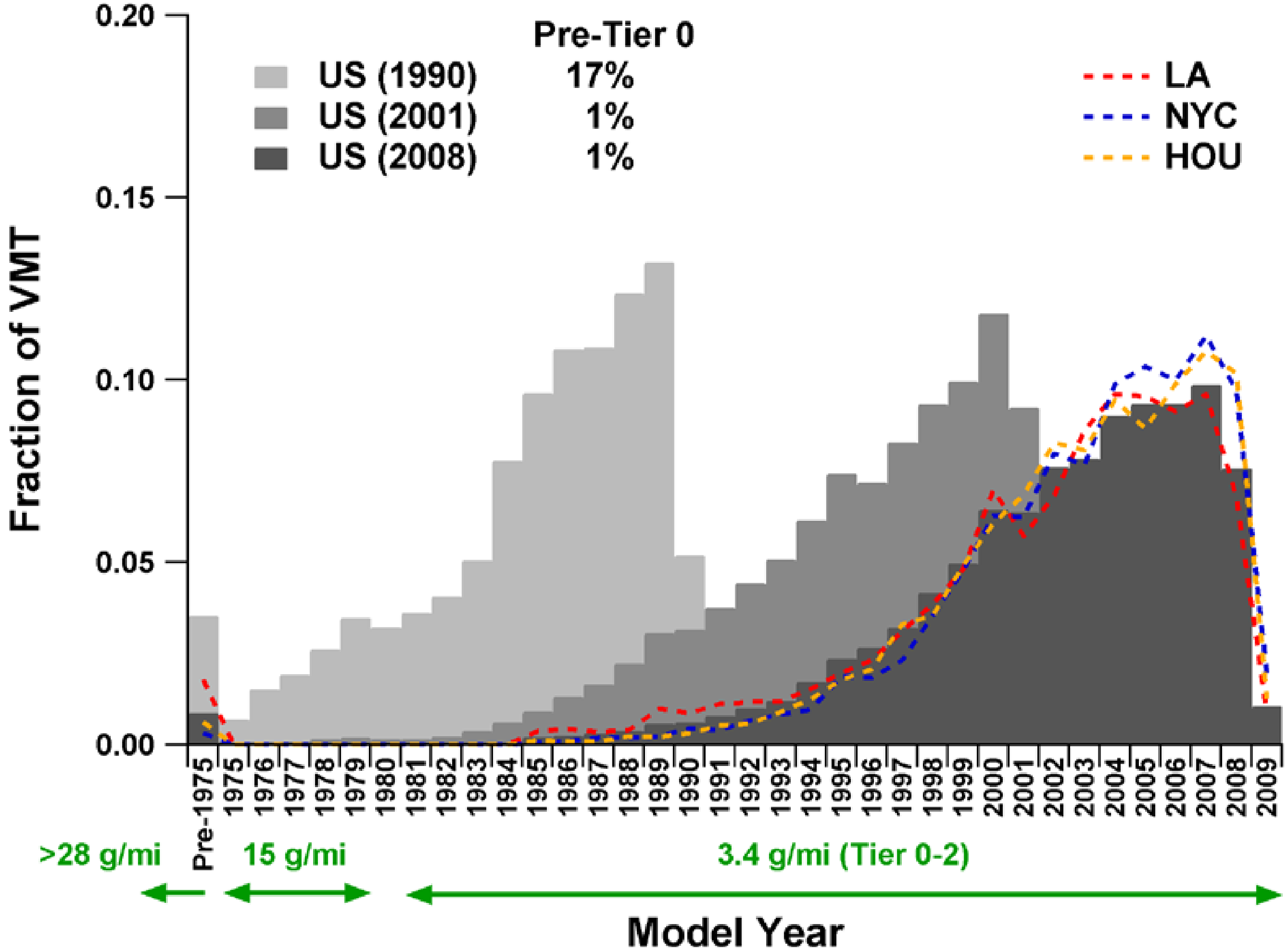
Research Shows "Gross Emitters" Can Attribute for Significant % of Emissions, Especially for LDVs



Analysis in California in 2010

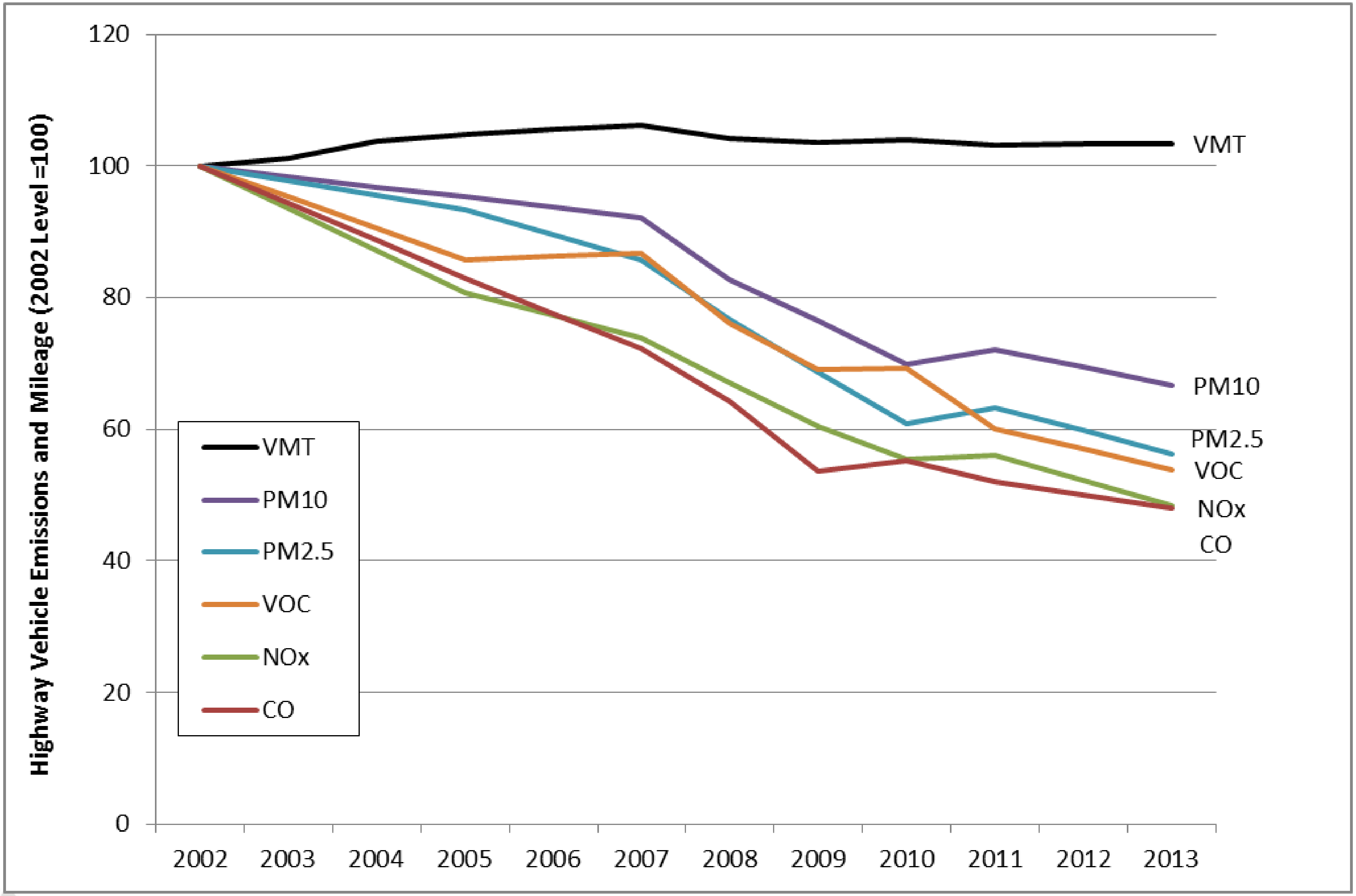
Source: McDonald et al., 2013, Long-Term Trends in Motor Vehicle Emissions in U.S. Urban Areas

Turnover of Older Vehicles with Less Strict Emission Has Helped Reduce Emissions



Source: McDonald et al., 2013, Long-Term Trends in Motor Vehicle Emissions in U.S. Urban Areas

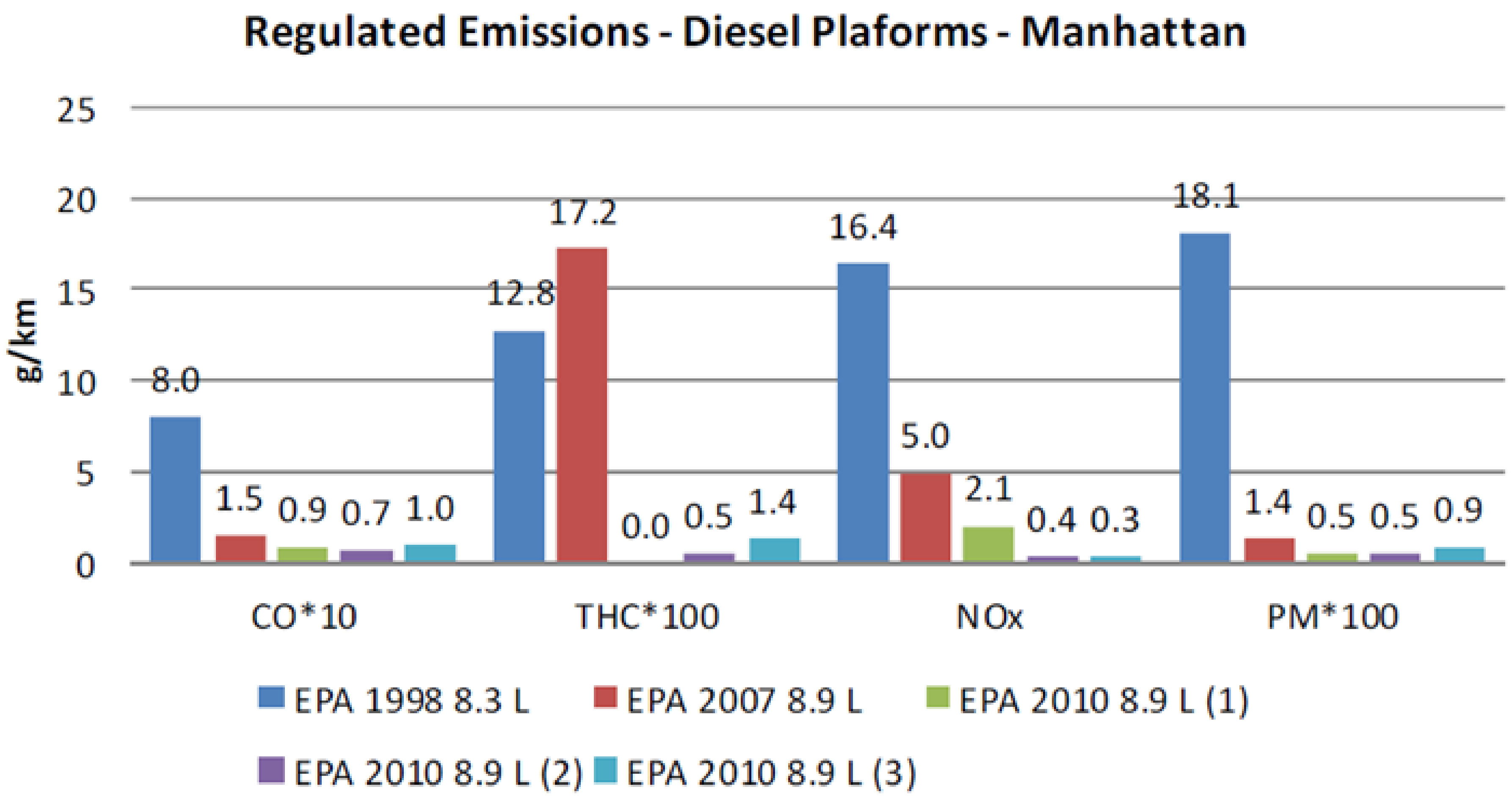
Light- and Heavy-Duty Vehicles Have Made Similar Emissions Progress, Though Still Work To Be Done



Source: EPA, 2015, The 2011 National Emissions Inventory

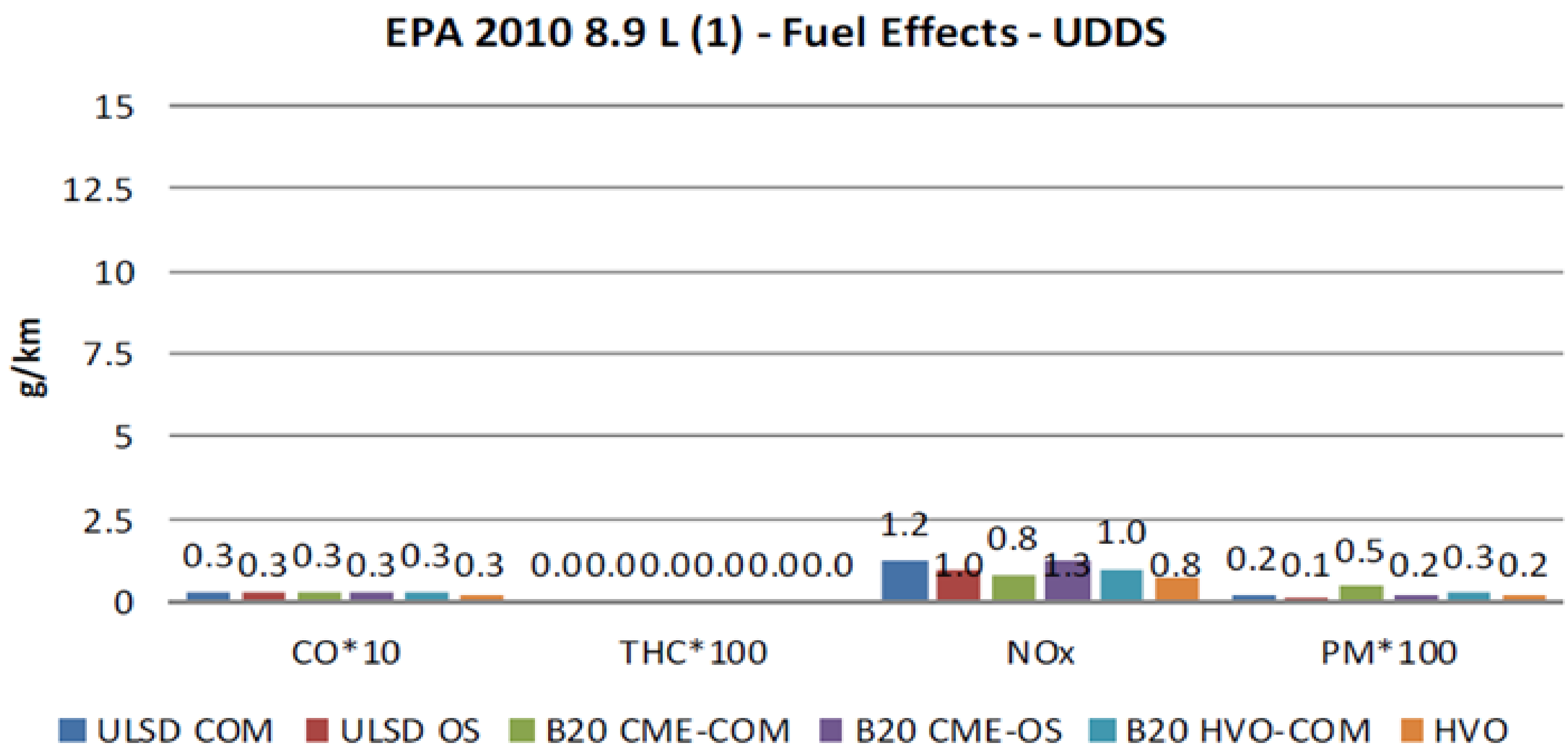
Heavy-Duty Diesel and AFV Emissions

Stricter Regulations have Resulted in Significant Improvements in Diesel Emissions



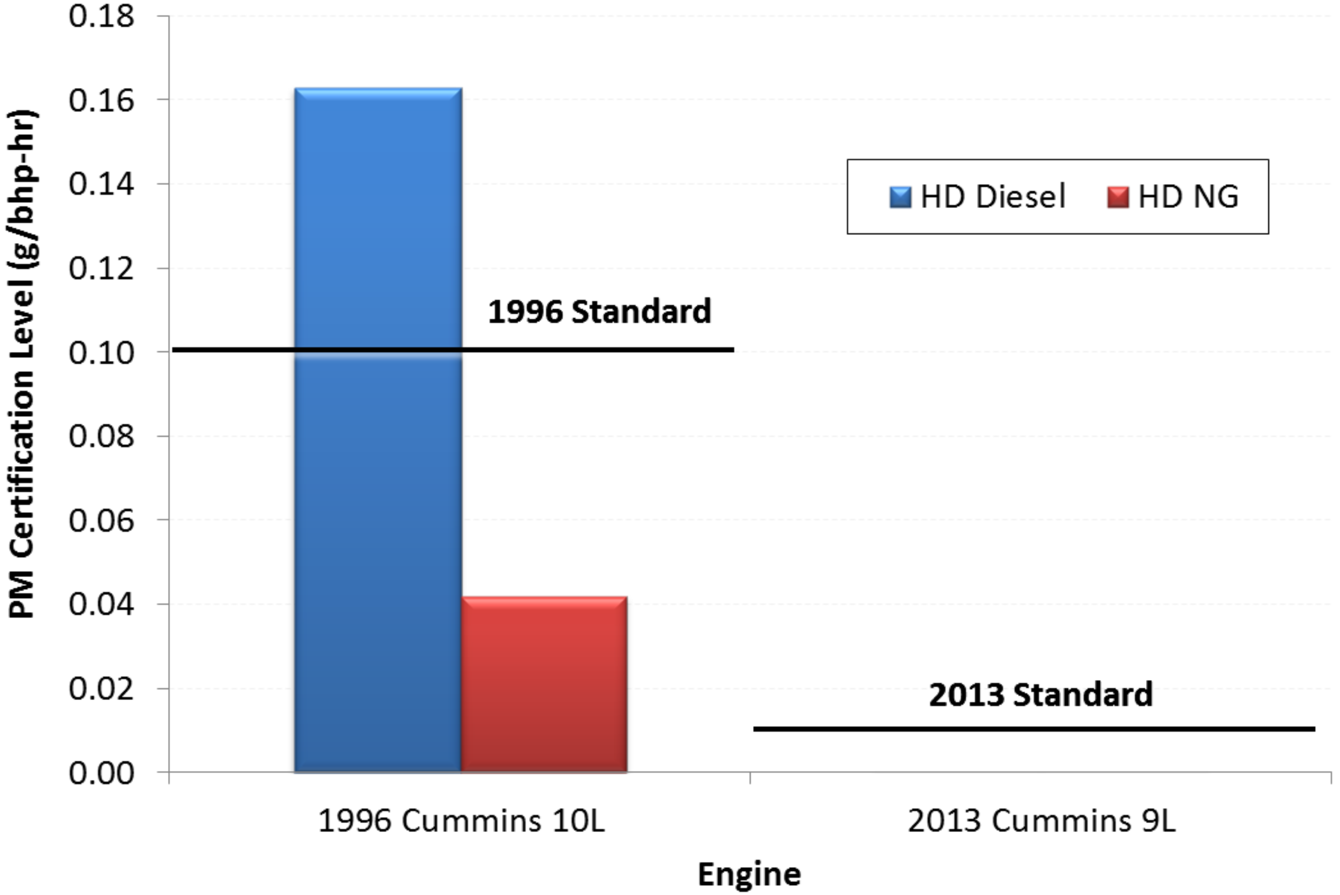
Source: Nylund & Koponen, 2012, Fuel and Technology Alternatives for Buses

Emission Control Technologies Overshadow Fuel Effects on Emissions for Diesel v Biodiesel



Source: Nylund & Koponen, 2012, Fuel and Technology Alternatives for Buses

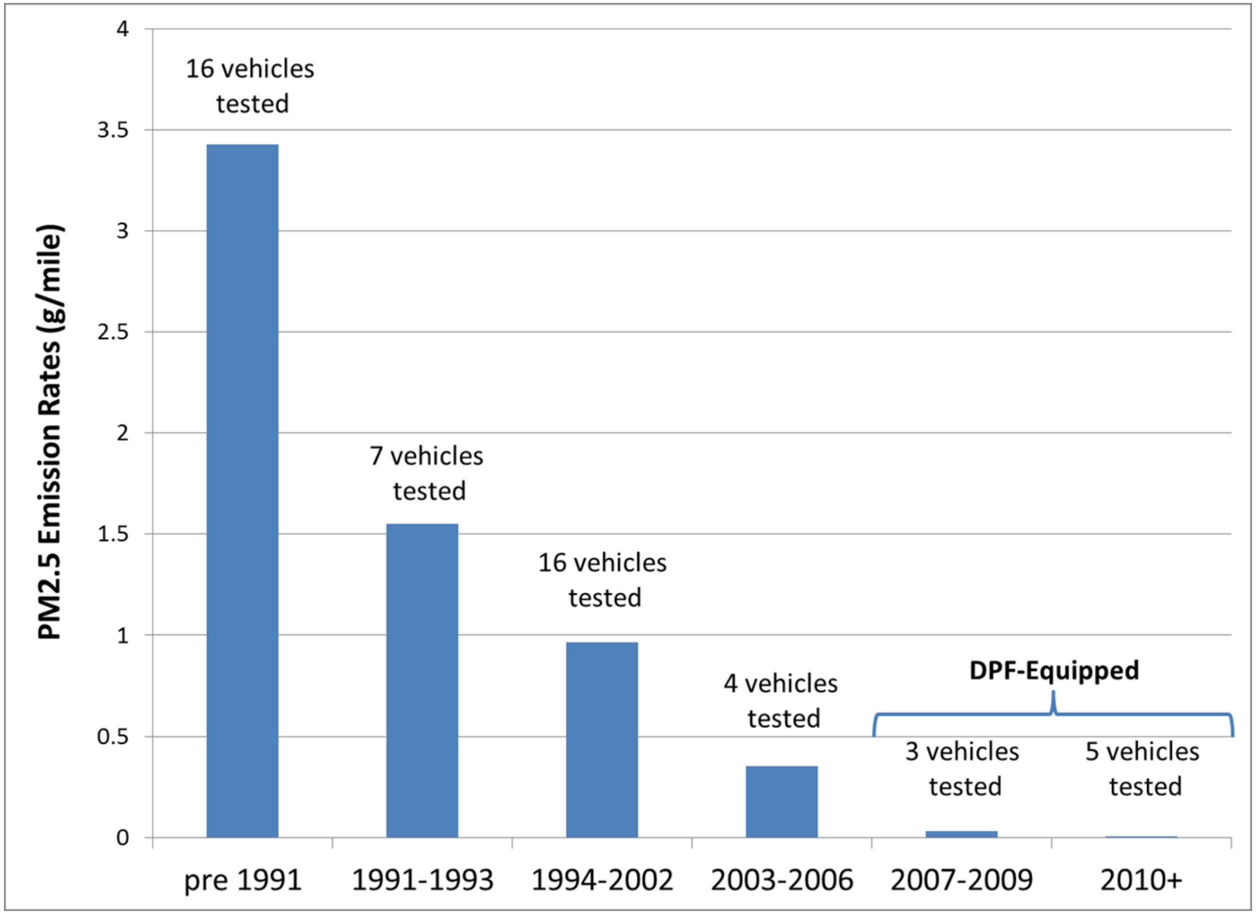
Both Diesel & NG HD Engines Made Great Progress on PM



- **1996 NG engine = 0.04 g/bhp-hr; 75% lower than diesel**
  - 1996 diesel over standard but compliant through averaging, banking, and trading program
- **2013 NG engine = 0 g/bhp-hr; same as diesel**

Source: EPA, 2013, Engine Certification Data

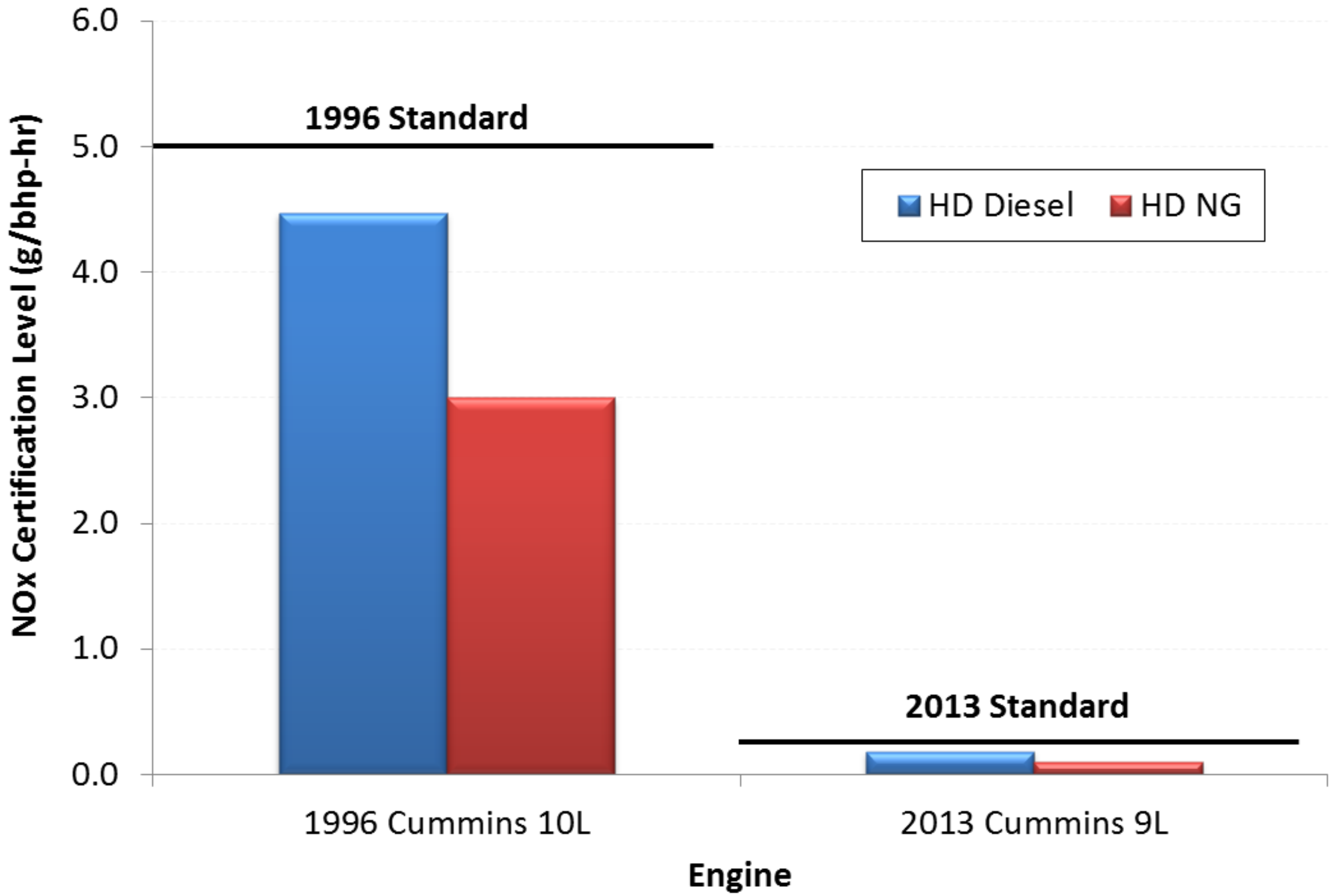
In-Use Testing Has Shown DPFs Are Highly Effective



- **CA has been testing the in-use emissions of new and old diesel and alt. fuel vehicles to compare air pollutant emissions**

Source: CARB, 2014, Truck Sector In-Use Emissions Technology Assessment

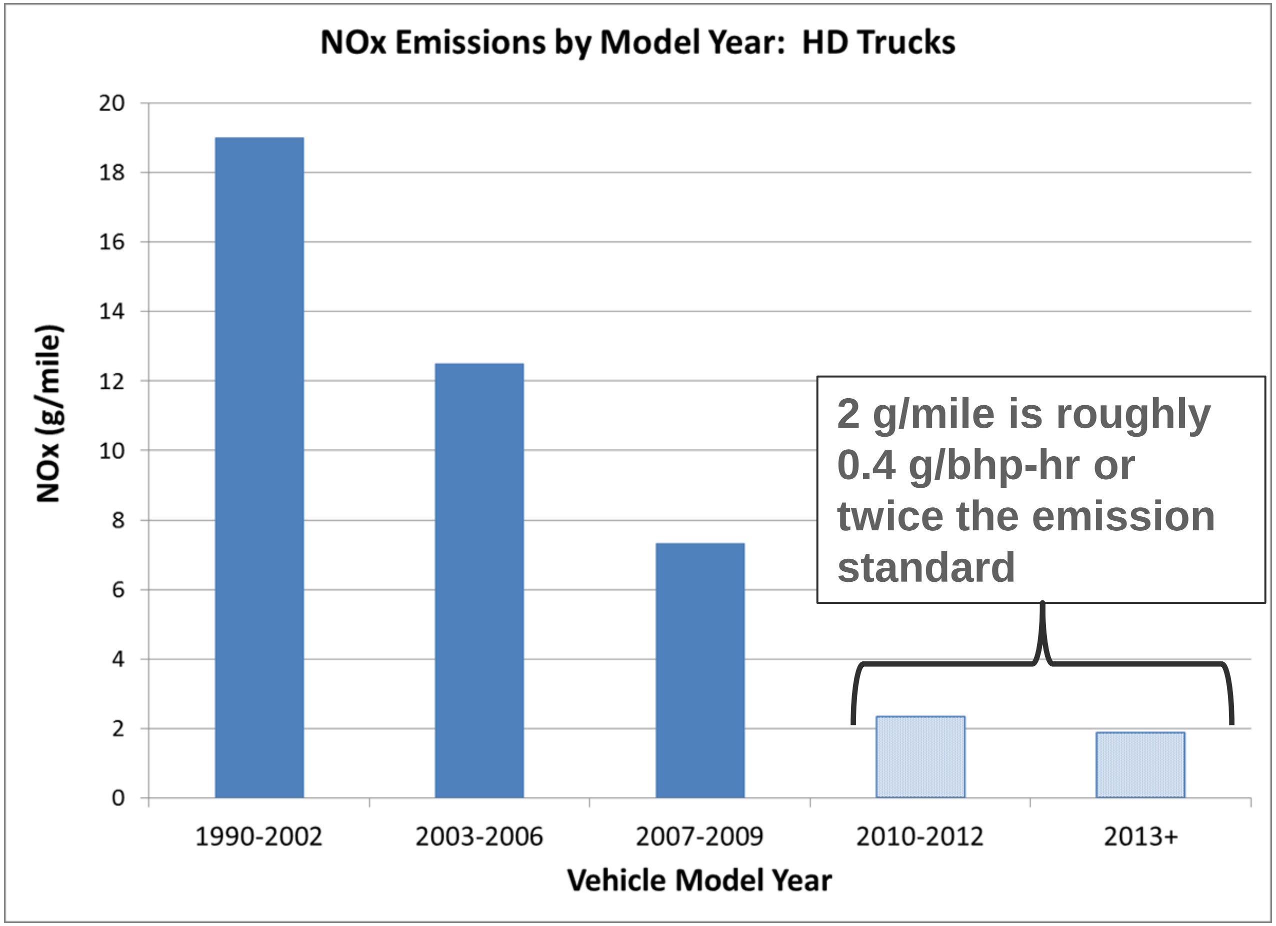
Similar Certification Improvements for NOx



- **1996 NG engine = 1.5 g/bhp-hr; 33% lower than diesel**
- **2013 NG engine = 0.1 g/bhp-hr; 50% lower than diesel**

Source: EPA, 2013, Engine Certification Data

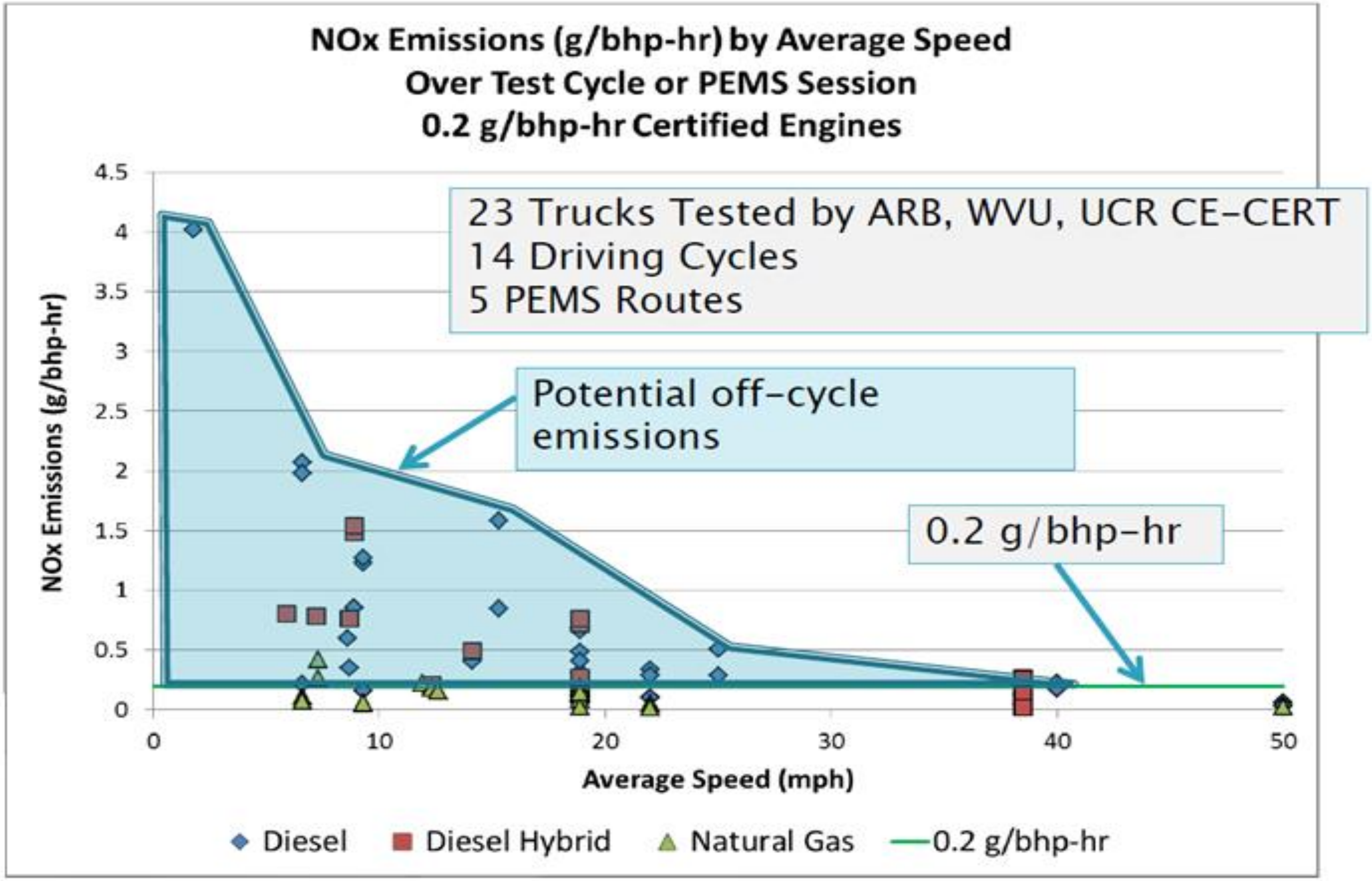
In-Use Testing Shows Progress Needed For Diesel NOx



- **Testing suggests potential issues with SCR performance in the real world**
  - Cold starts
  - Low-load, low-speed operations
  - Deterioration is a concern

Source: CARB, 2014, Truck Sector In-Use Emissions Technology Assessment

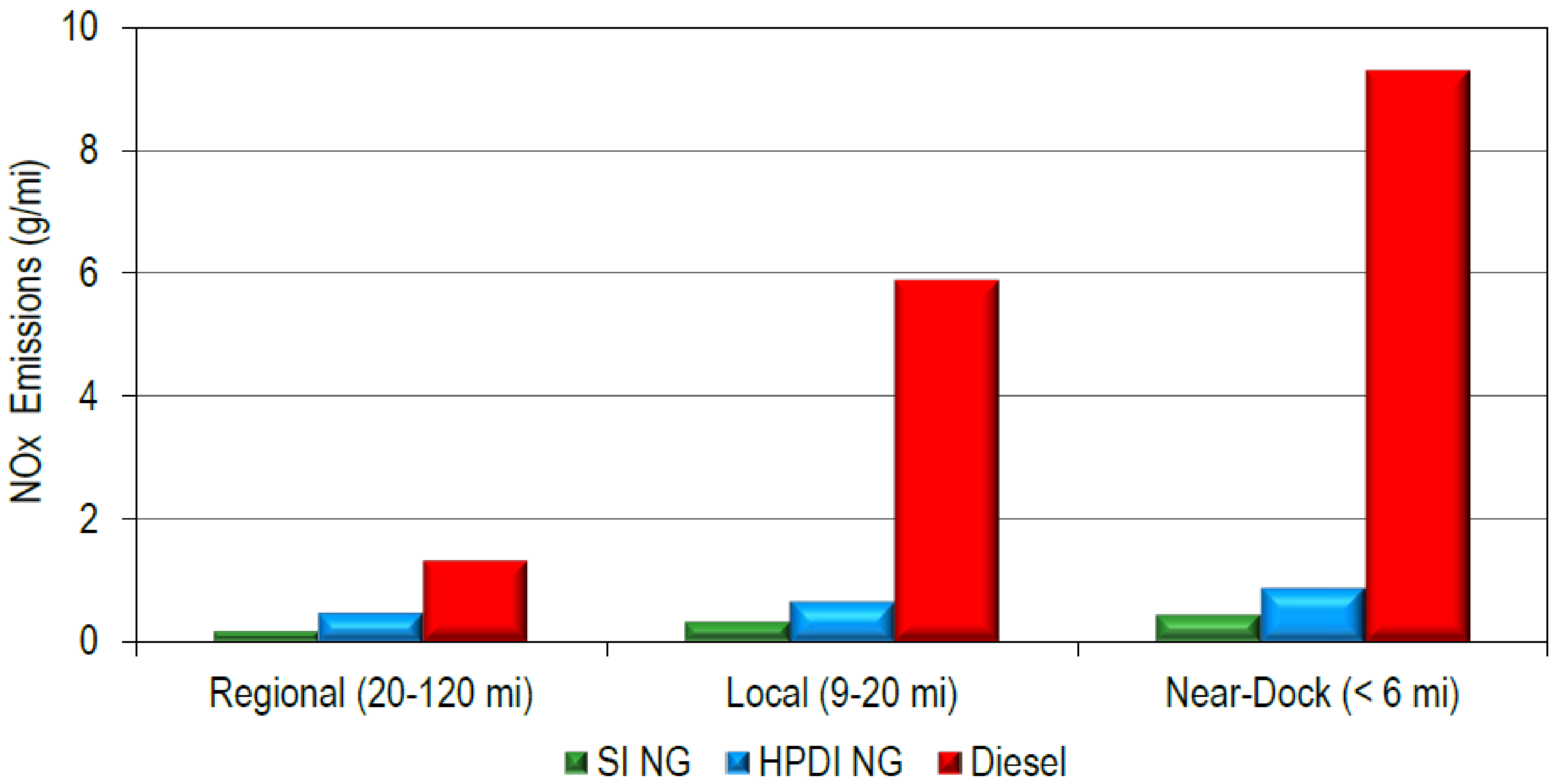
SCR Highly Effective at Highway Speeds but Potential for Off-Cycle Emissions



- SI NGV trucks had much lower off-cycle NOx than diesels

Source: CARB, 2014, Truck Sector In-Use Emissions Technology Assessment

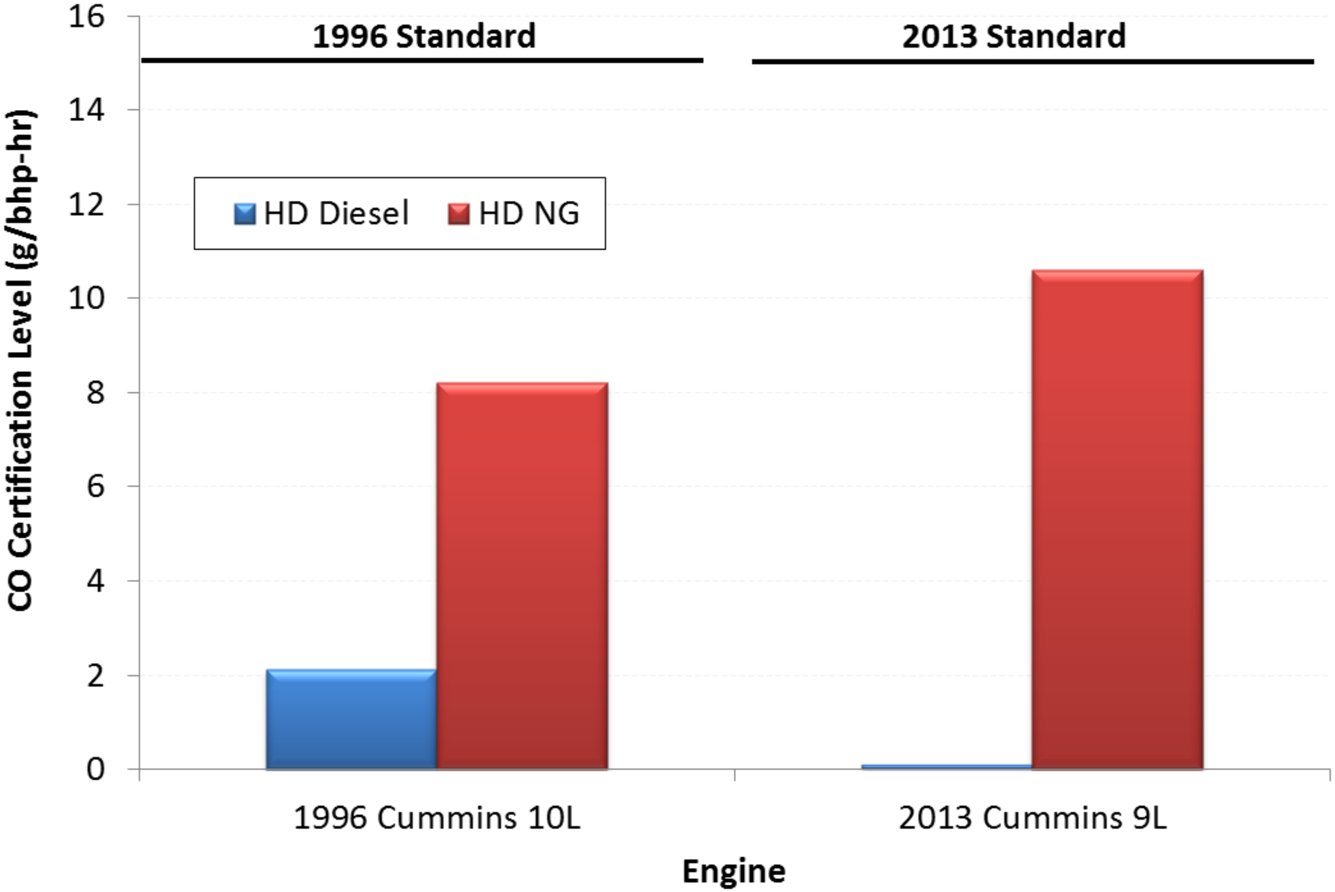
Duty Cycle Significantly Impacted NOx for Diesel Drayage Trucks, NG Trucks Were Consistently Low



- **SI NGV trucks NOx did not increase dramatically in low speed/low load conditions**

Source: Hogo, 2014, South Coast AQMD Update - Natural Gas Vehicle Program

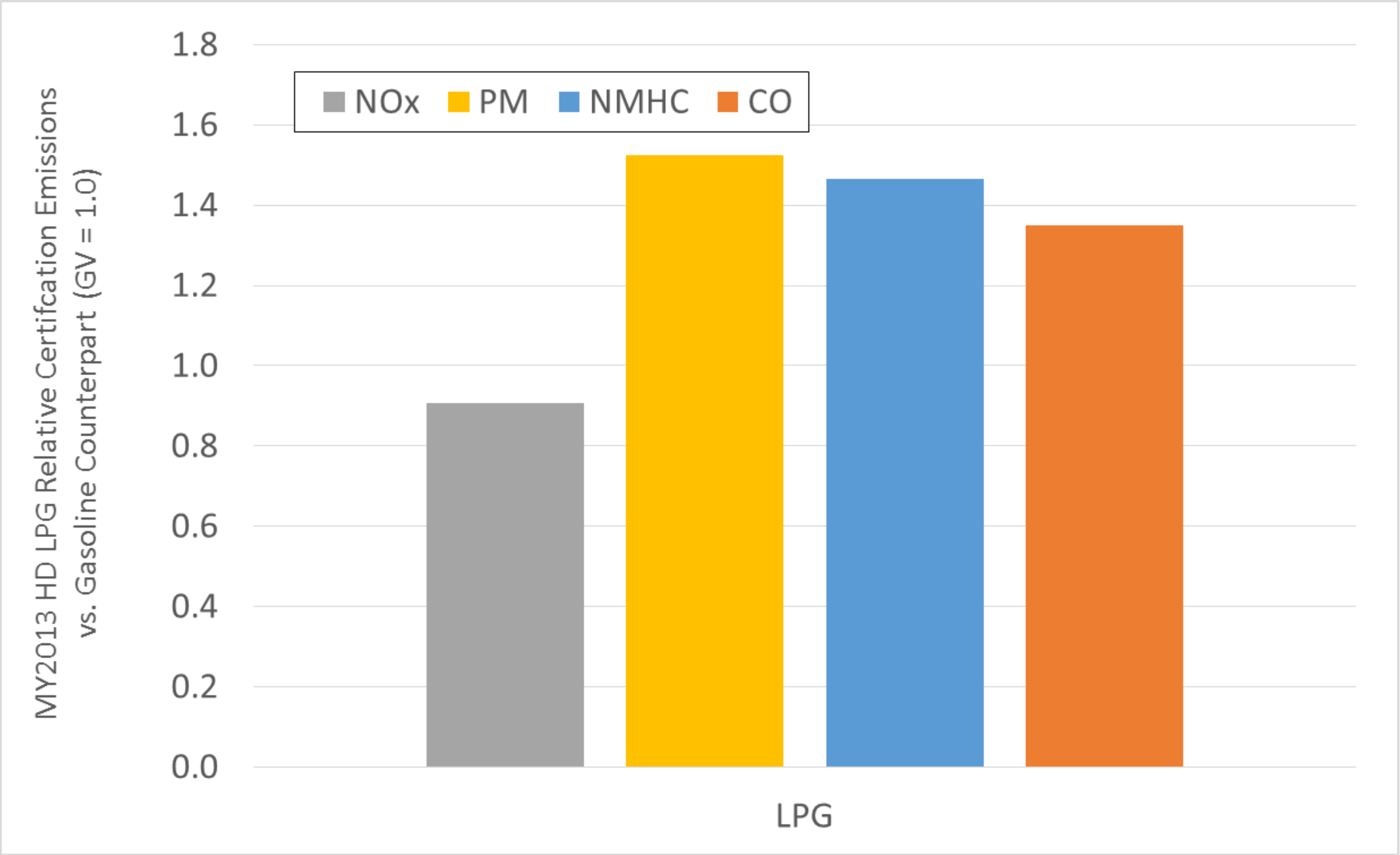
NG Spark-Ignited HD Engines Significantly Higher CO Emissions than Diesel



- **Differences in engine types and aftertreatment cause difference in CO**
  - CI diesel use lean burn (more O_2 to oxidize CO to CO_2) combustion with oxidation catalyst
  - SI NG use stoichiometric (less O_2 available) and no oxidation catalyst

Source: EPA, 2013, Engine Certification Data

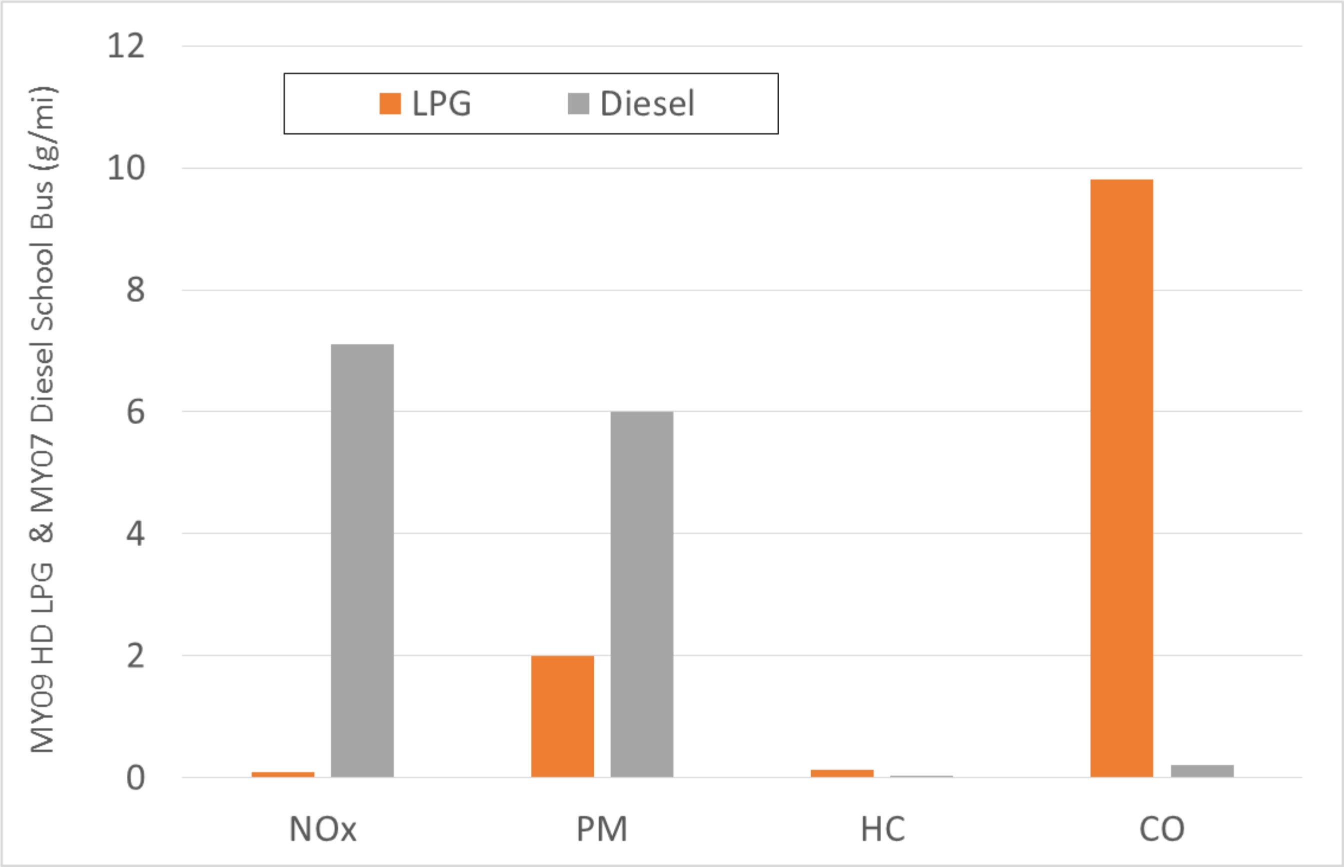
Recent Analysis of Heavy-Duty Propane Have Shown Slightly Higher Emissions vs. Gasoline Counterparts



- **All LPG engines conversion of gasoline engines**
- **Deterioration factors used for LPG are typically higher than gasoline**
  - Direct emission results not always higher
  - More detailed deterioration tests could show LPG benefits

Source: EPA, 2013, Engine Certification Data

Limited In-Use Testing Has Been Done on Propane, but CA Pre-2010 Test Shows Some Benefits vs. Diesel



- **Diesel bus had DPF but not SCR; SCR diesel should have much lower NOx**
  - LPG shows PM benefit and had very low NOx

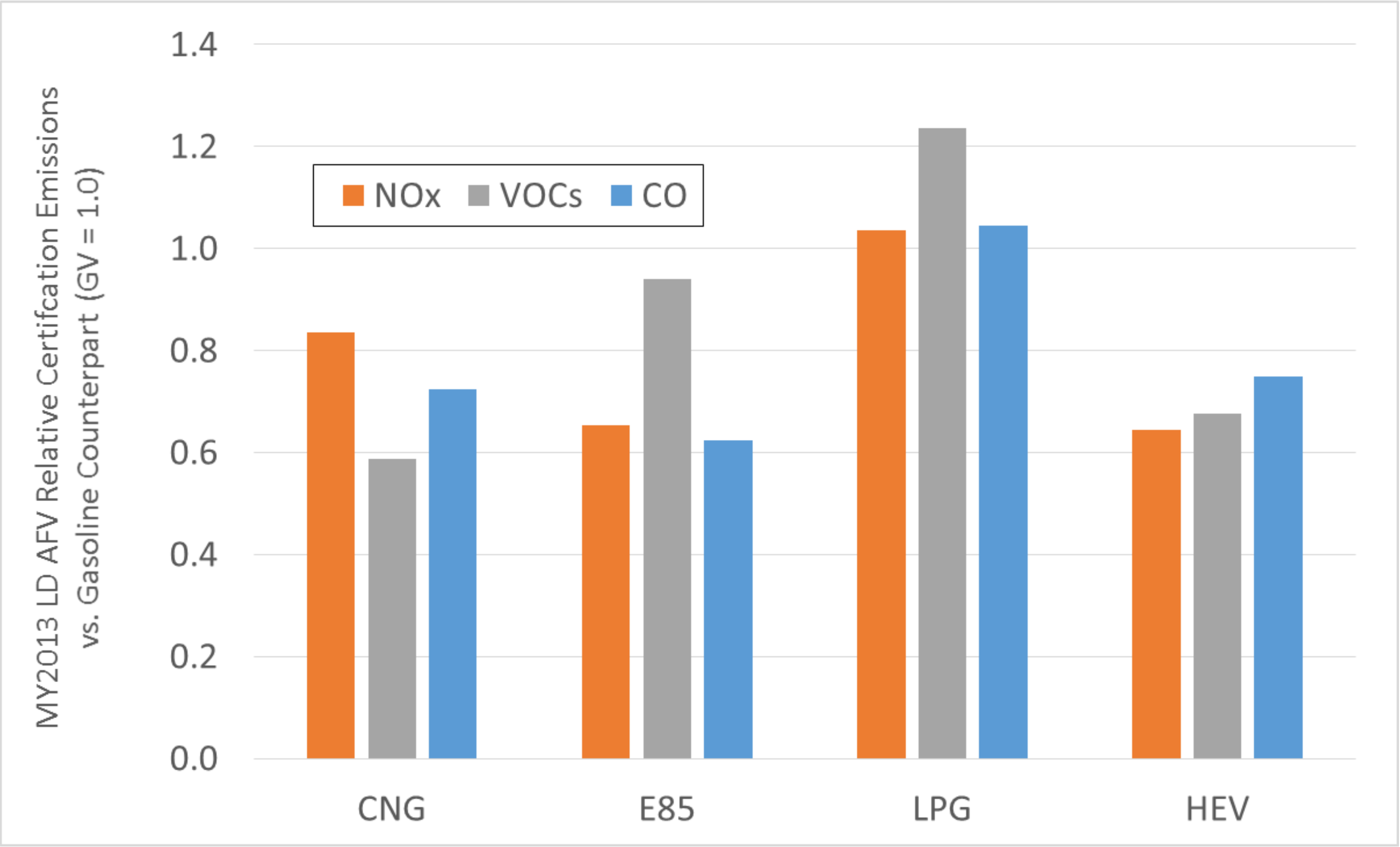
Source: Miller et al., 2014, In-Use Emissions Testing and Demonstration of Retrofit Technology for Control of On-Road Heavy-Duty

Heavy Duty AFVs Can Continue to Provide Benefits

- **Heavy-duty standards has become increasingly strict**
  - Required significant improvements in engine controls & aftertreatment systems
- **Alt fuels may take advantage by having simpler/less costly aftertreatment**
  - Some AFV engines don't require PM filters or SCR systems
- **Absolute certification benefits of AFVs have diminished but still can be relative benefits**
  - In-use benefits are possible as well if diesel controls/aftertreatment don't operate properly
  - Alternative fuels may not always be better for every pollutant
    - Due to differences in engine types, controls & aftertreatment
- **CA adopted optional NOx HD standards to incentivize further reductions**
  - Can certify at 0.10, 0.05 or 0.02 g/bhp-hr
  - Carl Moyer Program provides grants for these engines

Light-Duty Gasoline and AFV Emissions

Recent Analysis of Light-Duty AFVs & HEVs vs. Gasoline Counterparts Have Shown Emission Reductions

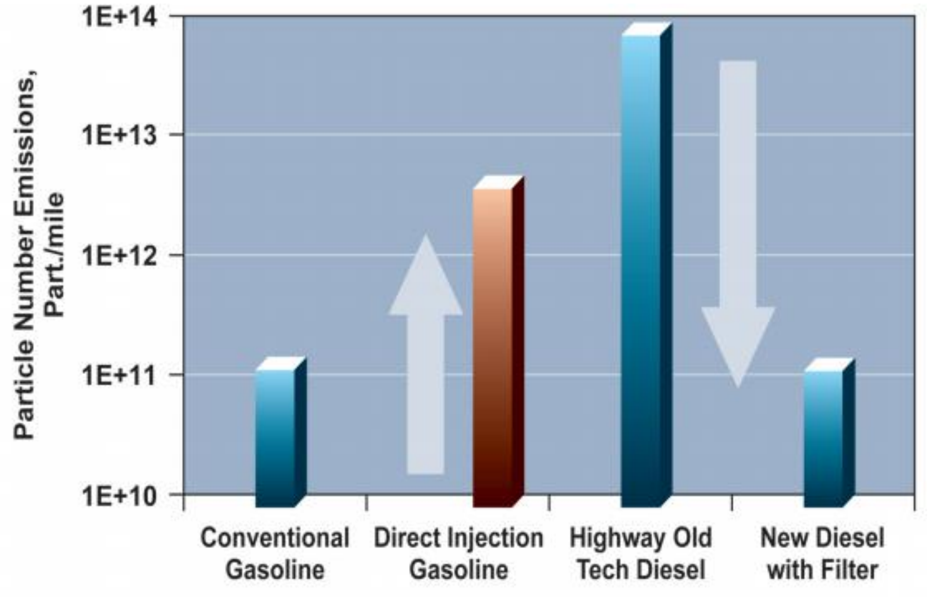


- **Further work needed to examine PHEVs**

Source: EPA, 2013, Light-Duty Vehicle and Engine Emission Certification

Research has Shown Gasoline Direct Injection (GDI) LDVs Increase PM2.5

- **GDI engine market share increased from 4% in MY09 to 38% in MY14**
  - Trend is to use downsized GDI engines with turbocharging
    - Maintain performance while improving fuel economy
  - Testing has show that GDI vehicles can increase PM (mass) by ~10x
    - Also increases the number of fine particulates
  - Technical solutions being developed
    - Particulate filters
  - May provide opportunity for AFVs, HEVs and PEVs
    - Lower incremental cost?



Source: Khalek, 2011, Particle Emissions from Direct Injection Gasoline Engines

Light Duty AFVs Can Continue to Provide Benefits

- **Light-duty standards have become increasingly strict**
  - Required significant improvements in engine controls & aftertreatment systems
- **EPA's Tier 3 passenger car and truck standard will further reduce emissions**
  - Coordinated with CA air pollutant (LEV III) and EPA GHG standards
  - Increases durability testing from 120,000 to 150,000 miles
  - By 2017, reduces gasoline sulfur content by 67%
  - By 2025, reduces NOx and VOCs by 80%, PM by 70%, CO by 75%
- **Alt fuels may take advantage by having simpler/less costly aftertreatment**
  - Gasoline direct injection may require particulate filters
  - Though stricter standards may pose challenges for some AFVs as well
- **Regulatory focus is to have zero emission vehicles (ZEVs) like BEVs and FCVs to reduce air pollutants and other environmental concerns**
  - California and 9 other states have adopted ZEV program

Summary

- **AFLEET uses EPA's MOVES model and annual emission certification results to compare alternative fuels with conventional counterparts**
  - Updating based on latest research

- **EPA light- & heavy-duty standards have becoming increasingly strict**

- **Both conventional and alternative fuels have made significant reductions to meet those standards**
  - Alt fuels continue to have emissions benefits
    - Absolute certification benefits are smaller even if the relative ratio is large
    - In-use emission benefits possible as well

- **Future standards will pose potential opportunities and challenges for AFVs**
  - Potential challenge to meet standards
  - Potential benefit of less costly aftertreatment
  - Ability to get to zero emissions

Thank you!!!

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Backup Slides

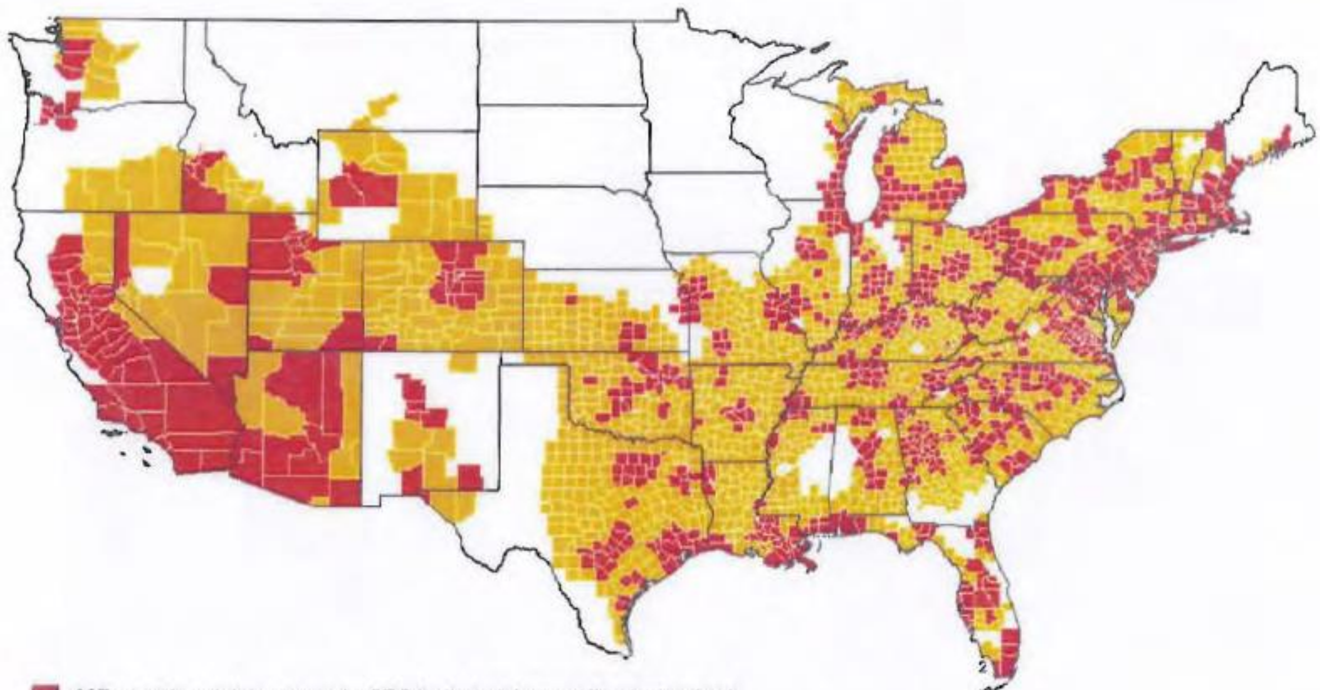
EPA National Ambient Air Quality Standards

Pollutant [final rule cite]		Primary/ Secondary	Averaging Time	Level	Form
Carbon Monoxide [76 FR 54294, Aug 31, 2011]		primary	8-hour	9 ppm	Not to be exceeded more than once per year
			1-hour	35 ppm	
Lead [73 FR 66964, Nov 12, 2008]		primary and secondary	Rolling 3 month average	0.15 μg/m³ (1)	Not to be exceeded
Nitrogen Dioxide [75 FR 6474, Feb 9, 2010] [61 FR 52852, Oct 8, 1996]		primary	1-hour	100 ppb	98th percentile of 1-hour daily maximum concentrations, averaged over 3 years
		primary and secondary	Annual	53 ppb (2)	Annual Mean
Ozone [73 FR 16436, Mar 27, 2008]		primary and secondary	8-hour	0.075 ppm (3)	Annual fourth-highest daily maximum 8-hr concentration, averaged over 3 years
Particle Pollution Dec 14, 2012	$PM_{2.5}$	primary	Annual	12 μg/m³	annual mean, averaged over 3 years
		secondary	Annual	15 μg/m³	annual mean, averaged over 3 years
		primary and secondary	24-hour	35 μg/m³	98th percentile, averaged over 3 years
	PM_{10}	primary and secondary	24-hour	150 μg/m³	Not to be exceeded more than once per year on average over 3 years
Sulfur Dioxide [75 FR 35520, Jun 22, 2010] [38 FR 25678, Sept 14, 1973]		primary	1-hour	75 ppb (4)	99th percentile of 1-hour daily maximum concentrations, averaged over 3 years
		secondary	3-hour	0.5 ppm	Not to be exceeded more than once per year

Source: EPA, 2014, National Ambient Air Quality Standards (NAAQS)

Analysis of Proposed Ozone Standards

CBSA[1] and Rural Counties that Violate an Ozone Standard of 65 ppb based on 2008-2010 Data[2]



897 counties violate, or are in CBSAs that violate a 65 ppb standard

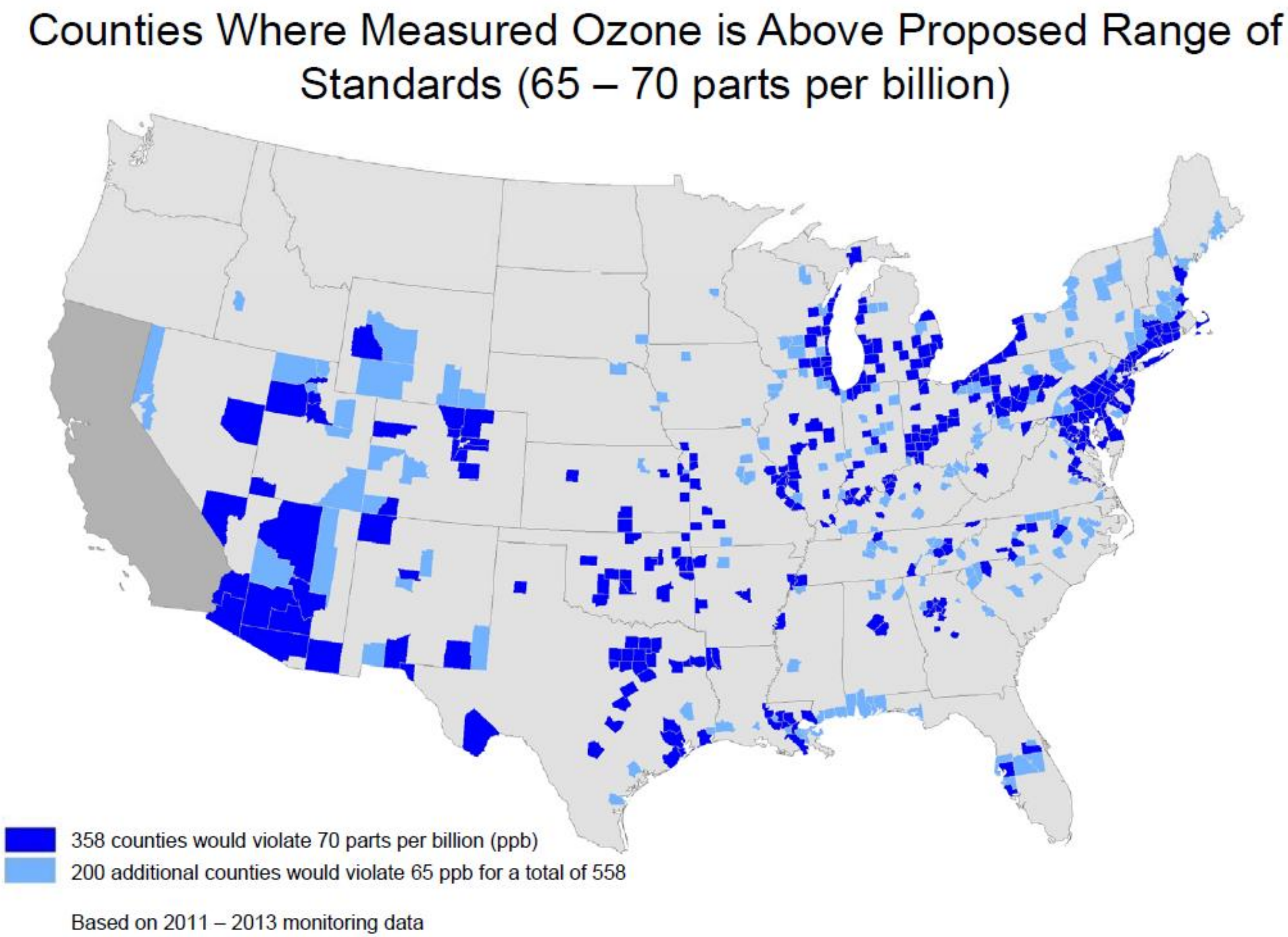
1320 additional counties are anticipated to violate a 65 ppb standard based on spatial interpolation

[1] Core Based Statistical Area (CBSA) refers collectively to both metropolitan statistical areas (MSA) and micropolitan areas

[2] 2217 counties violate a 65 ppb standard (six times the number of counties that violate the 2008 (75 ppb) standard)

Source: URS, 2011

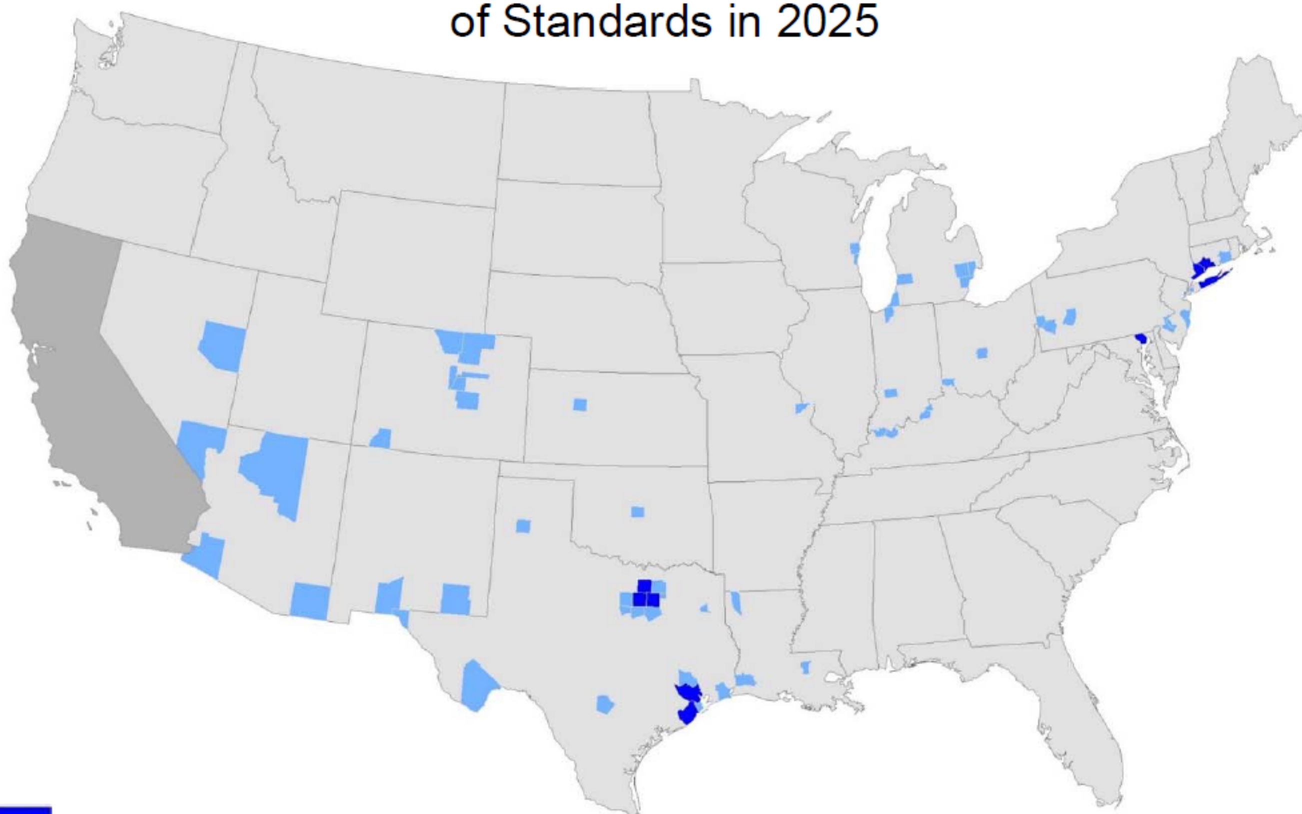
Analysis of Proposed Ozone Standards



Source: EPA, 2014, Proposed Revisions to National Ambient Air Quality Standards for Ozone

Analysis of Proposed Ozone Standards

EPA Projects Most Counties Would Meet the Proposed Range of Standards in 2025



9 counties outside of California would violate 70 parts per billion (ppb)

59 additional counties outside of California would violate 65 ppb for a total of 68

Because several areas in California are not required to meet the existing standard by 2025 and may not be required to meet a revised standard until sometime between 2032 and 2037, EPA analyzed California separately. Details are available in the Regulatory Impact Analysis for this proposal.

Source: EPA, 2014, Proposed Revisions to National Ambient Air Quality Standards for Ozone