On-Road Measurement of Light-Duty Gasoline and Heavy-Duty Diesel Vehicle Emissions

Robert Harley (harley@ce.berkeley.edu)
Department of Civil and Environmental Engineering
University of California at Berkeley

Acknowledgments

Pictured (left to right): John McLaughlin, George Ban-Weiss, Melissa Lunden, Tom Kirchstetter, Andrew Kean

Acknowledgments

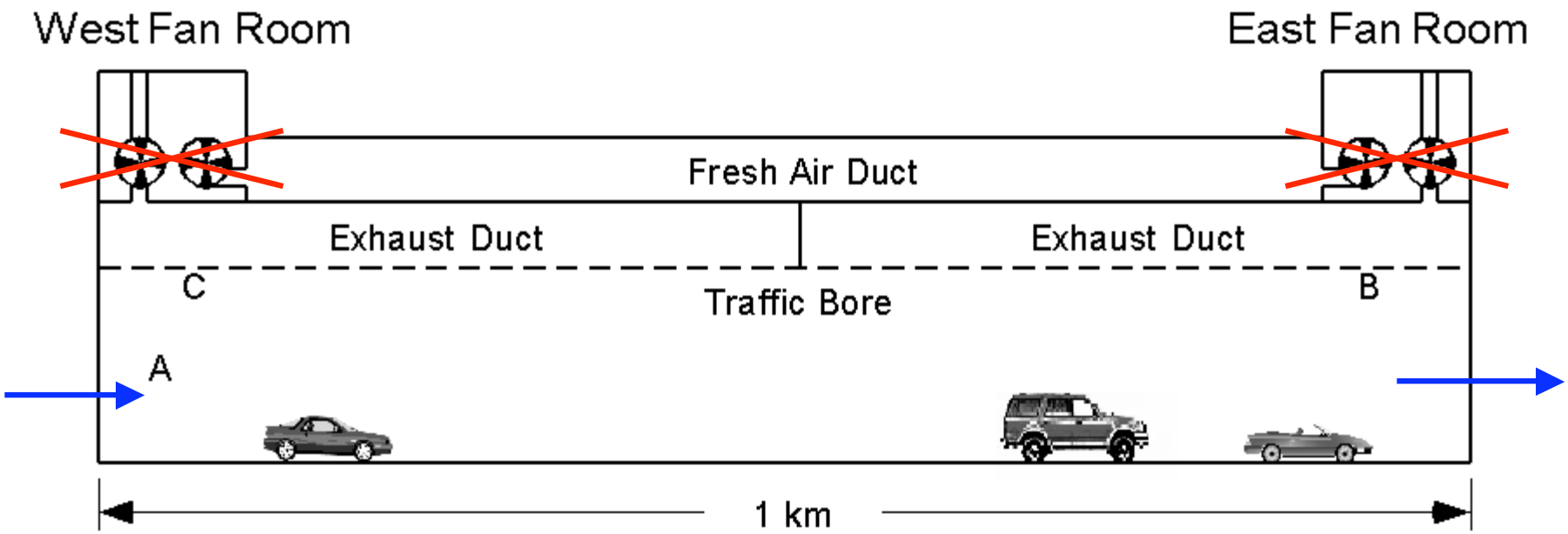
- Jim Pederson, Seungju Yoon, Todd Sax, Tao Huai, Jeff Long & many others (ARB)
- Gary Kendall, Jim Hesson & Eric Stevenson (BAAQMD)
- Caltrans staff at Caldcott tunnel
- Izadyar Dalvand (Chevron)
- Eric Grosjean & Daniel Grosjean
- Tony Strawa (NASA Ames Research Center)
- Funding/support:
  - » California Air Resources Board
  - » Bay Area AQMD (in-kind support)
  - » Chevron (funding + in-kind support)

Motor Vehicle Emissions

- Major source of air pollution in California
- Stringent standards for new vehicles
  - » California LEV program (1994 et seq)
  - » New HD diesel emission standards (2007)
- Recent fuel changes
  - » Phase-out of MTBE in gasoline
  - » Increasing use of ethanol
  - » Ultra-low sulfur diesel fuel
- How have emissions changed since 1990s?

A Highway Tunnel Laboratory

- Caldecott tunnel -- SF Bay area -- Jul-Aug 2006
- 3 separate traffic bores; 4% grade
- HD diesel trucks not allowed in middle bore



Pollutant Measurements

- CO_2 (IR absorption)
- CO (IR absorption)
- VOC (GC-FID)
- NO_x (chemiluminescent)
- NH_3 (IC)
- Aldehydes (LC-MS)
- $PM_{2.5}$ mass
- BC/OC (TOA)
- BC (aethalometer)
- N (water CPC)
- $N(D_P)$ (SMPS)
- b_{ext}, b_{abs}, b_{scat} (Cadenza; neph)

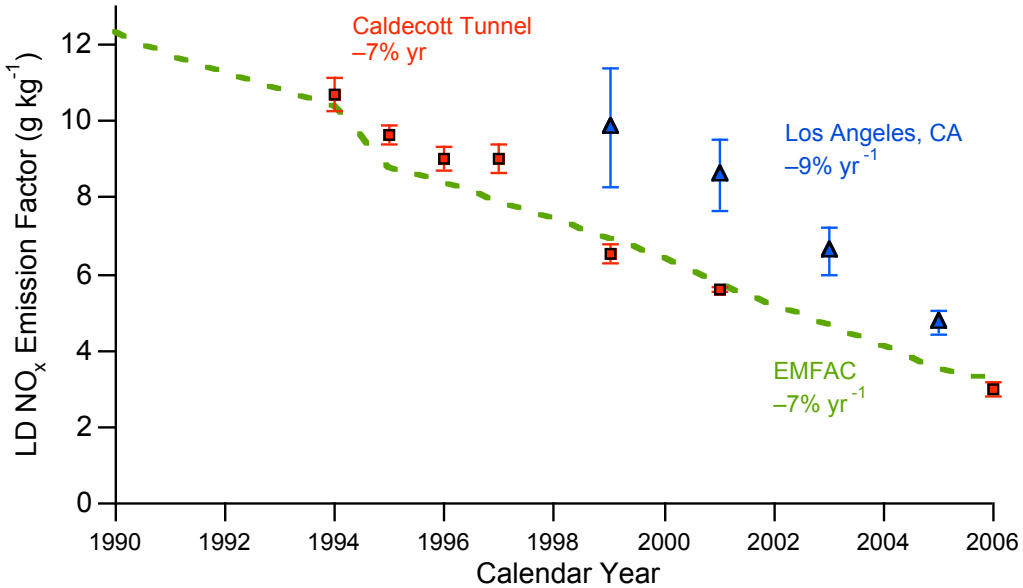
Red color ⇒ online measurement at 1 Hz (tunnel exit)

Study Design & Data Analysis

- Measure pollutant emissions inside tunnel
  - » Bore 1 (12-2 PM): 4200 vehicles; 7.3±0.6% MD+HD trucks
  - » Bore 2 (4-6 PM): 7600 vehicles; 0.6±0.2% MD trucks
  - » 8 weekdays in each bore; uphill driving only (4% grade)

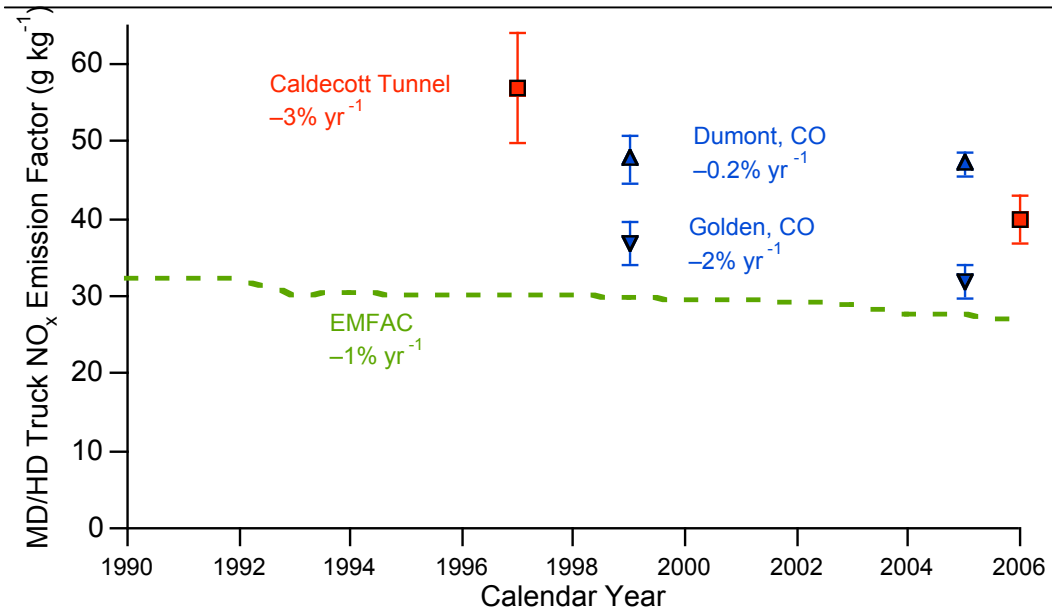
- Emission factors calculated by carbon balance
  - » Light-duty (LD) vehicle emission factors directly from bore 2
  - » Need to apportion bore 1 concentrations before calculating emission factors for diesel trucks

NO_x Emissions



Light-Duty Vehicles
(nearly all gasoline)

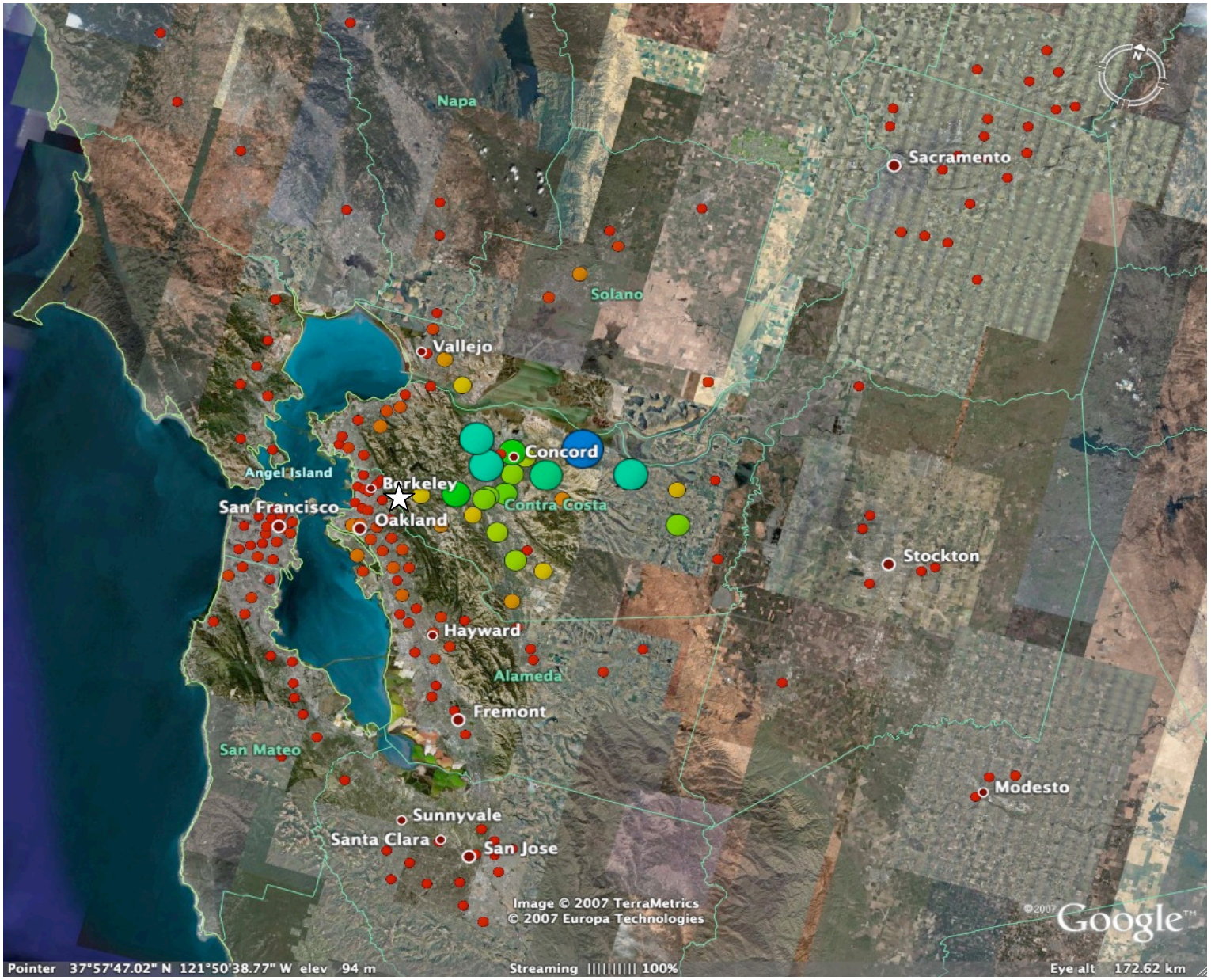
LDV remote sensing data:
Bishop and Stedman (ES&T 2008)



Medium/Heavy-Duty
Diesel Trucks

HDT remote sensing data:
Burgard et al. (ES&T 2006)

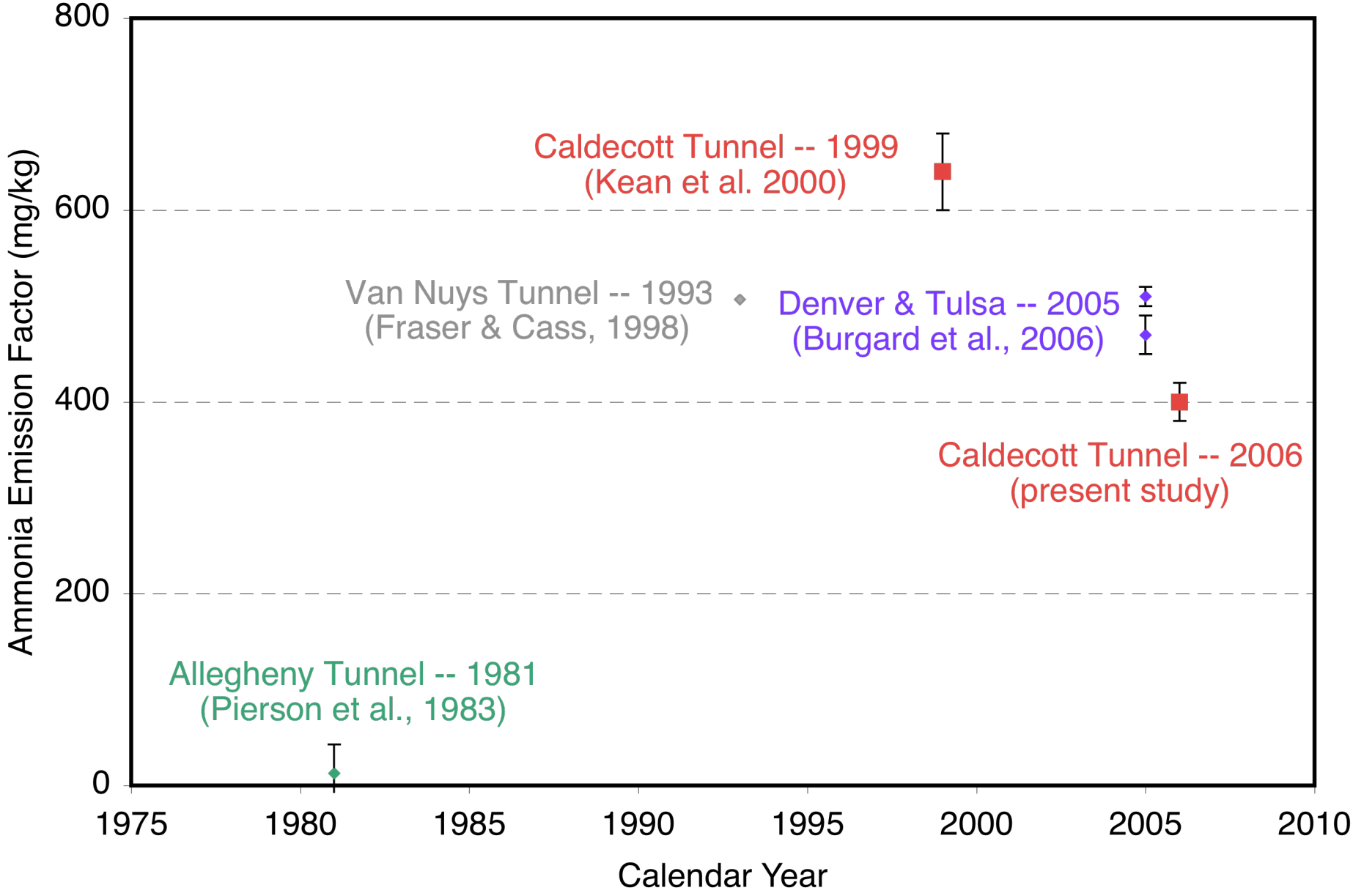
LD Vehicle Registration Data



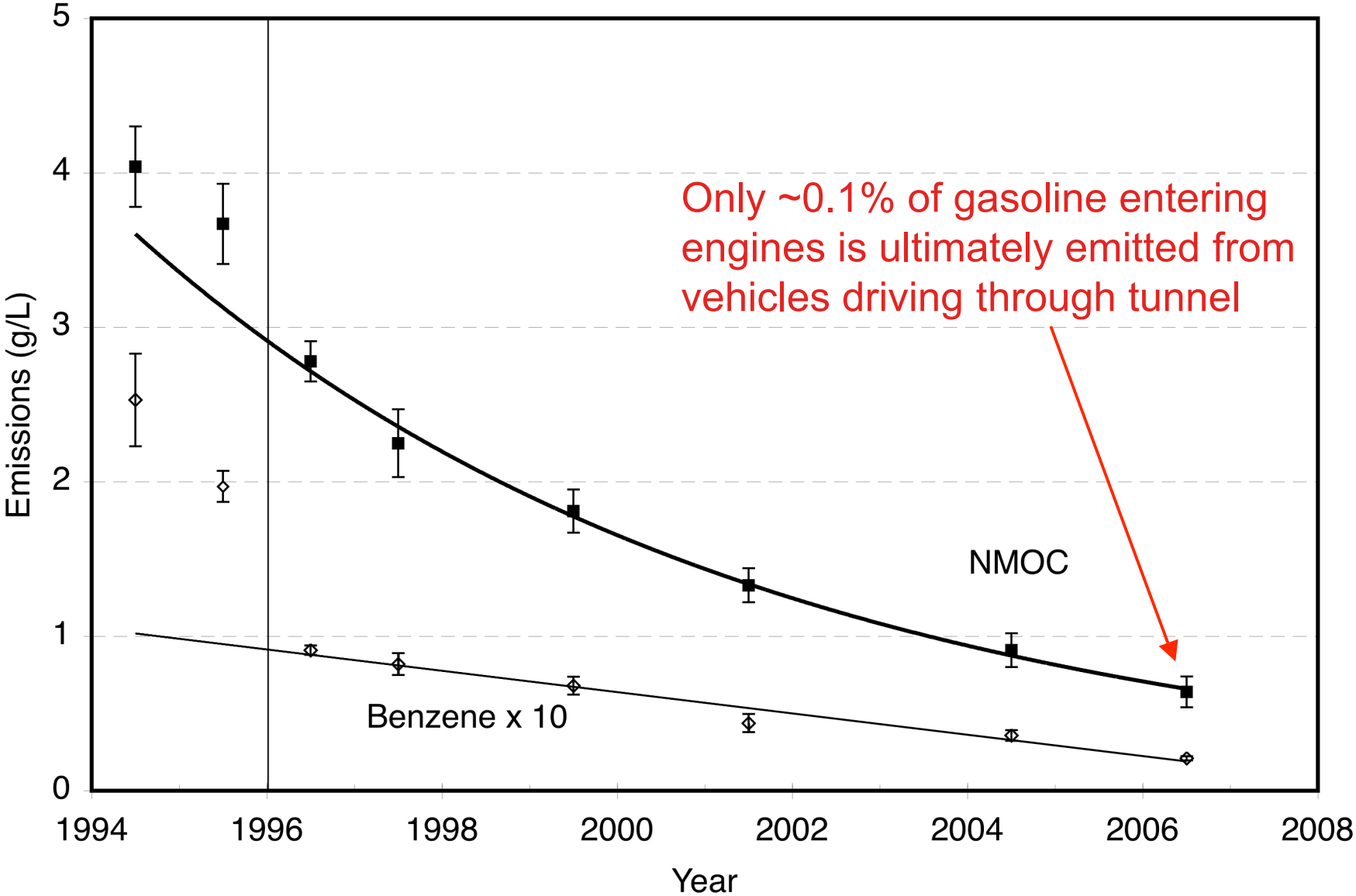
vehicles

- 100
- 80
- 60
- 40
- 20
- 1

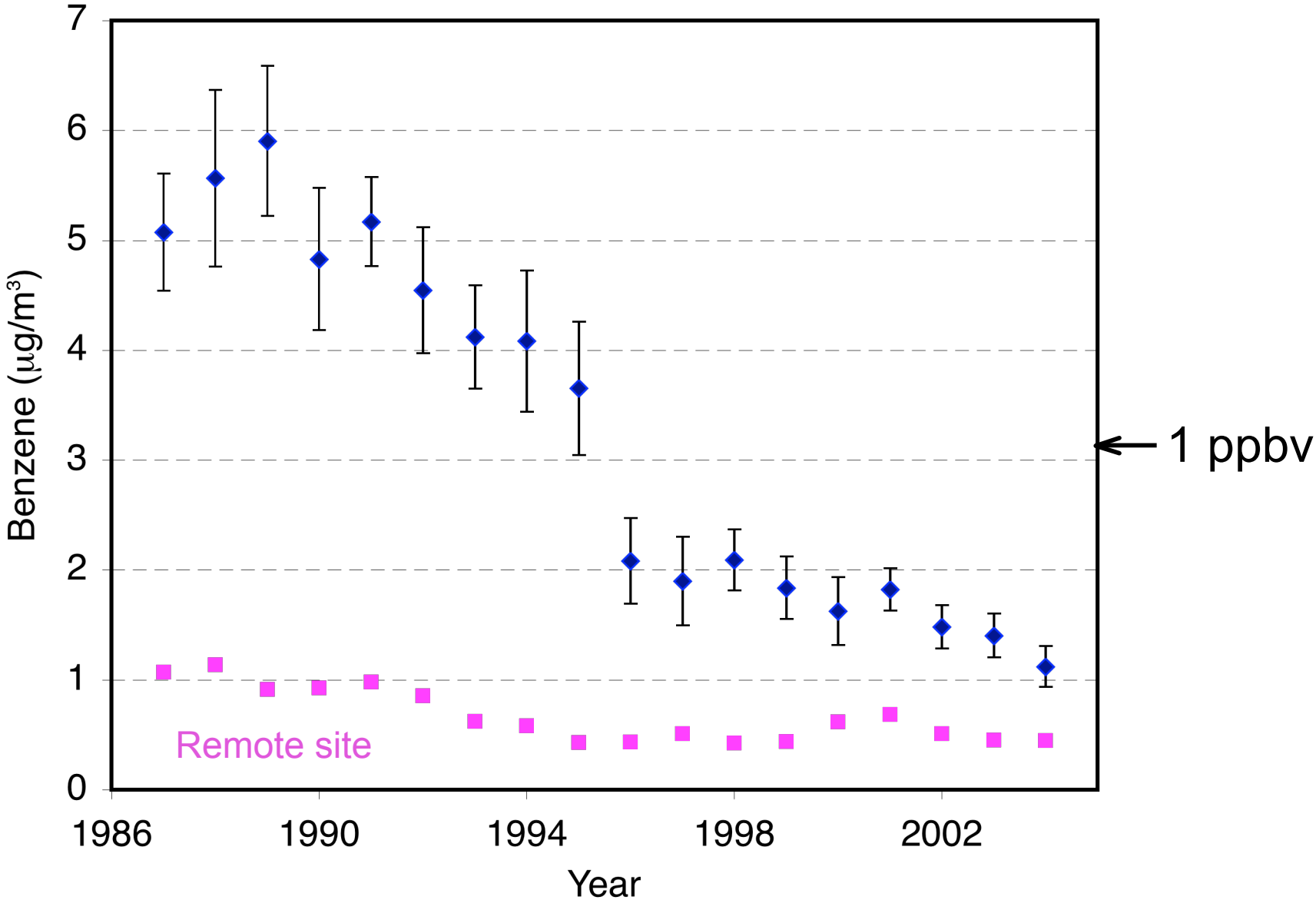
Ammonia Emissions



NMOC & Benzene Emissions

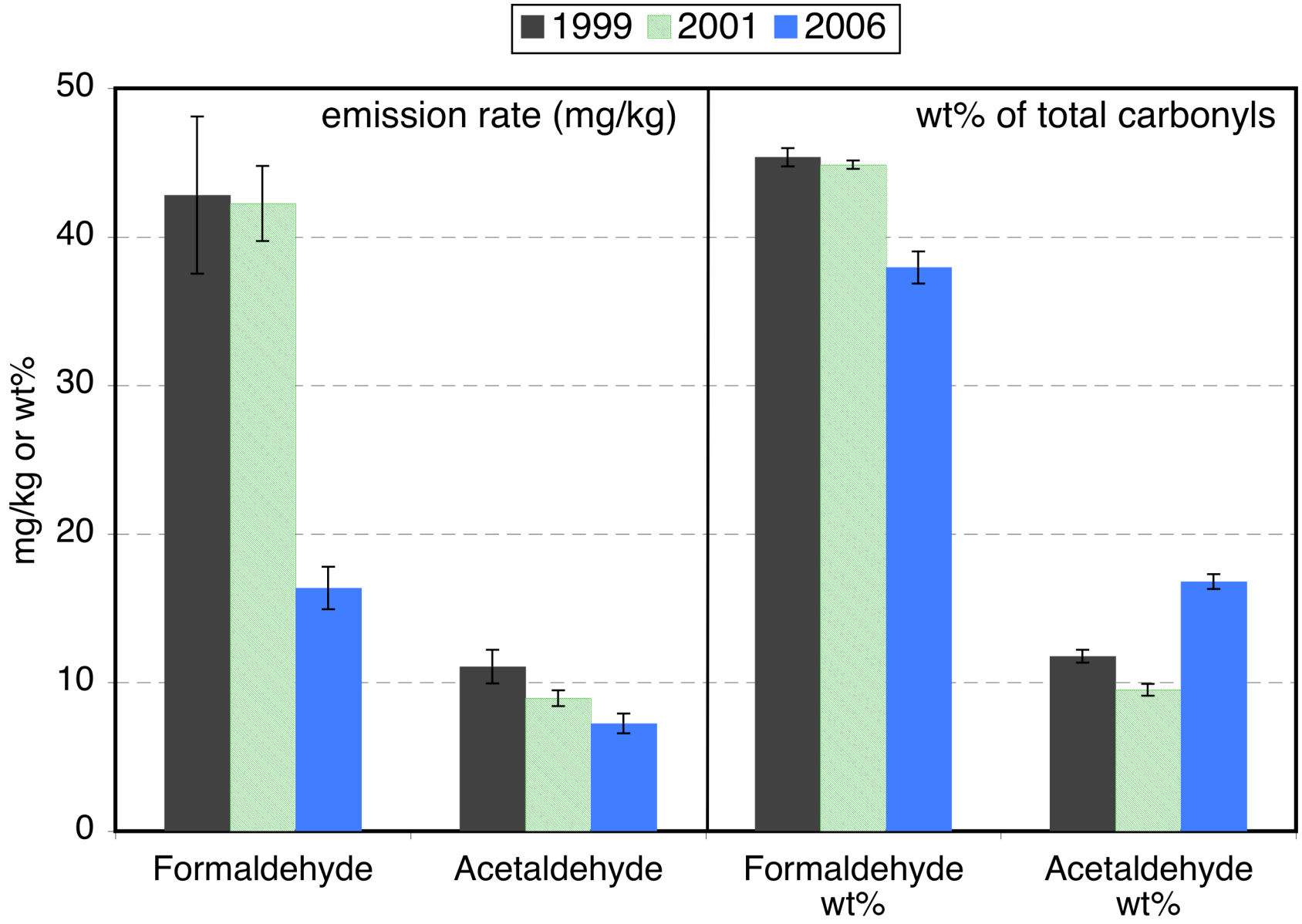


Benzene in Bay Area Ambient Air

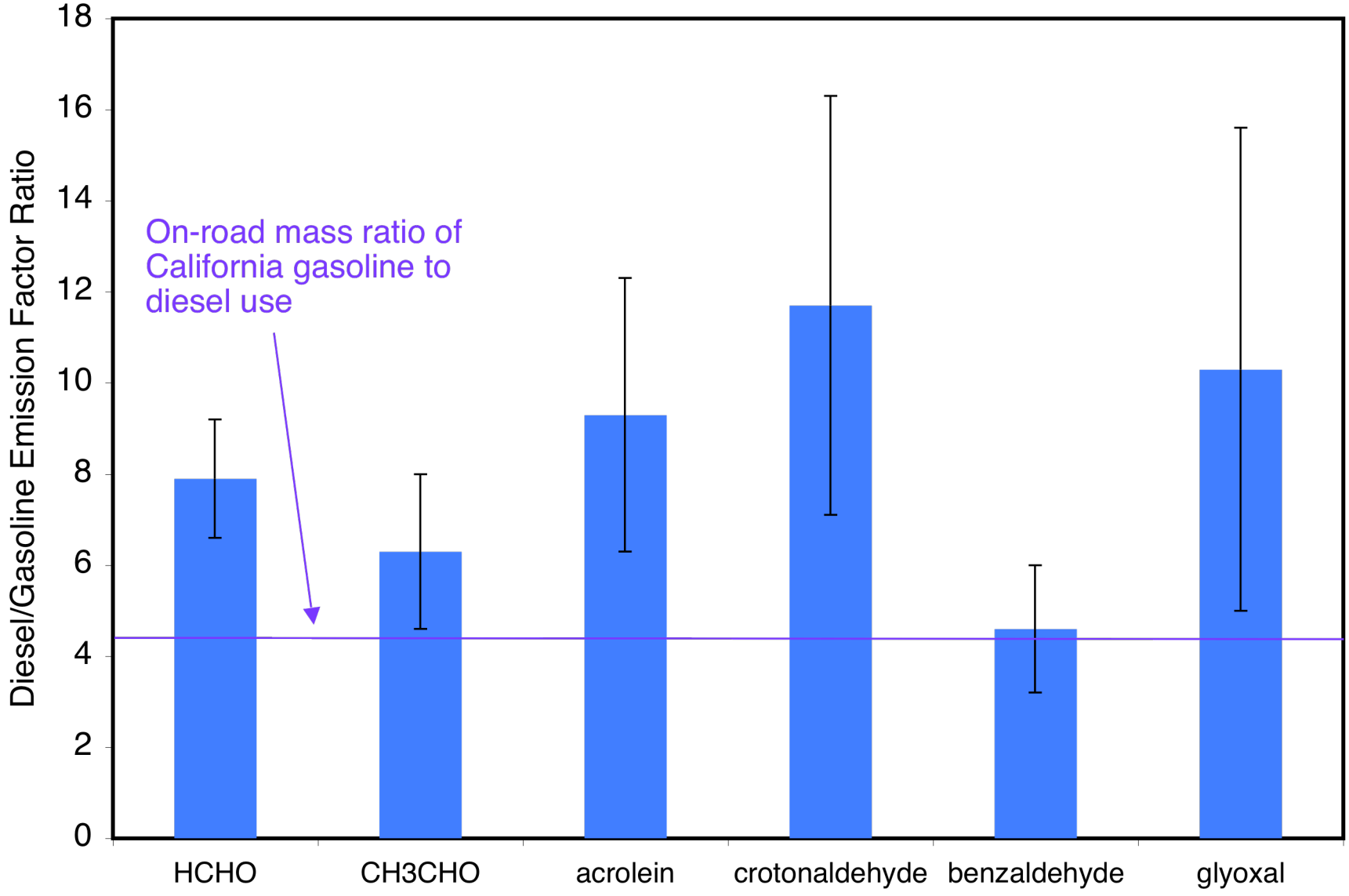


Harley et al. (ES&T 2006)

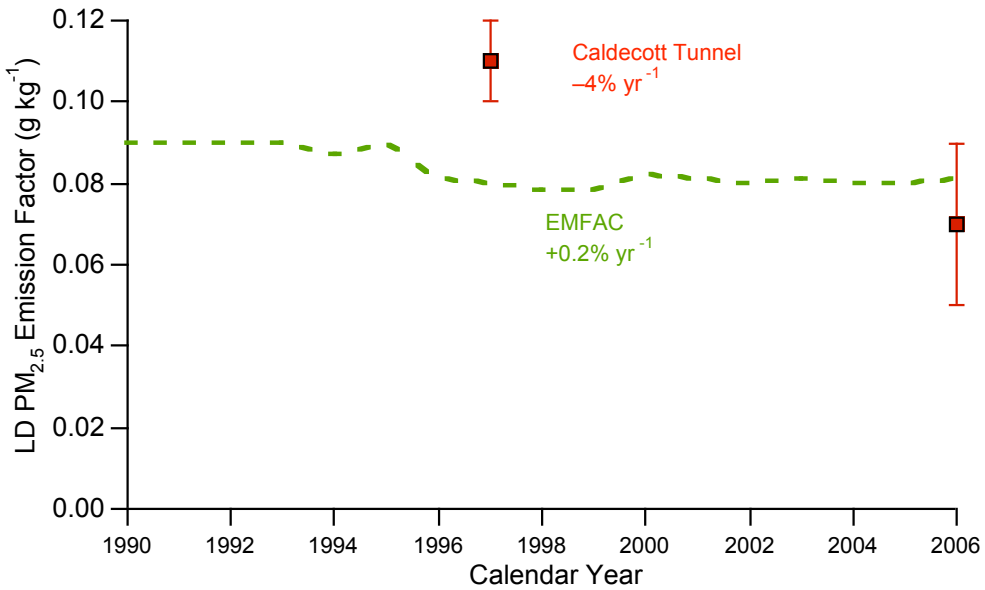
LD Vehicle Aldehyde Emissions



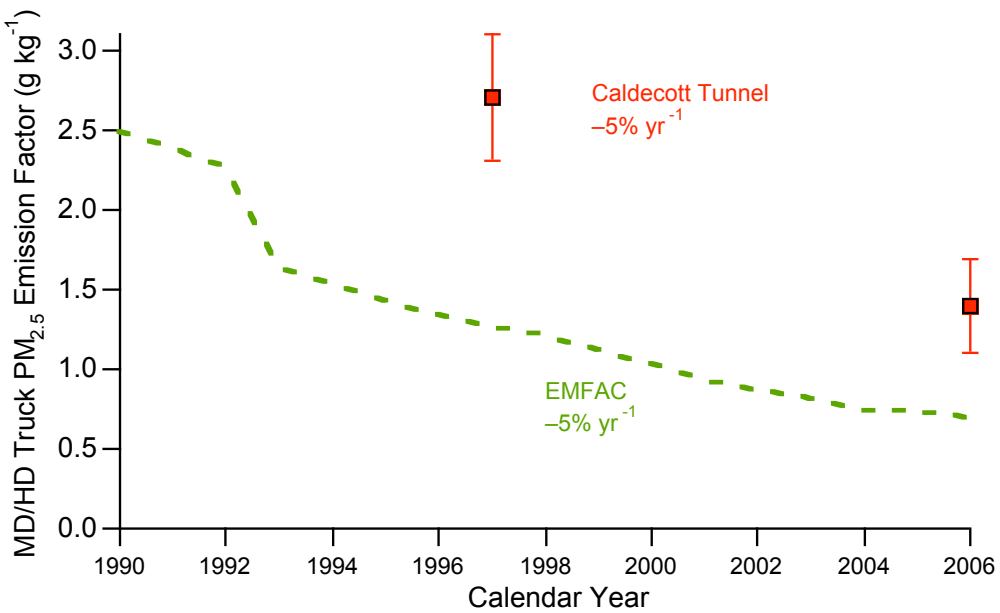
Aldehyde Emission Factor Ratios



$PM_{2.5}$ Emissions

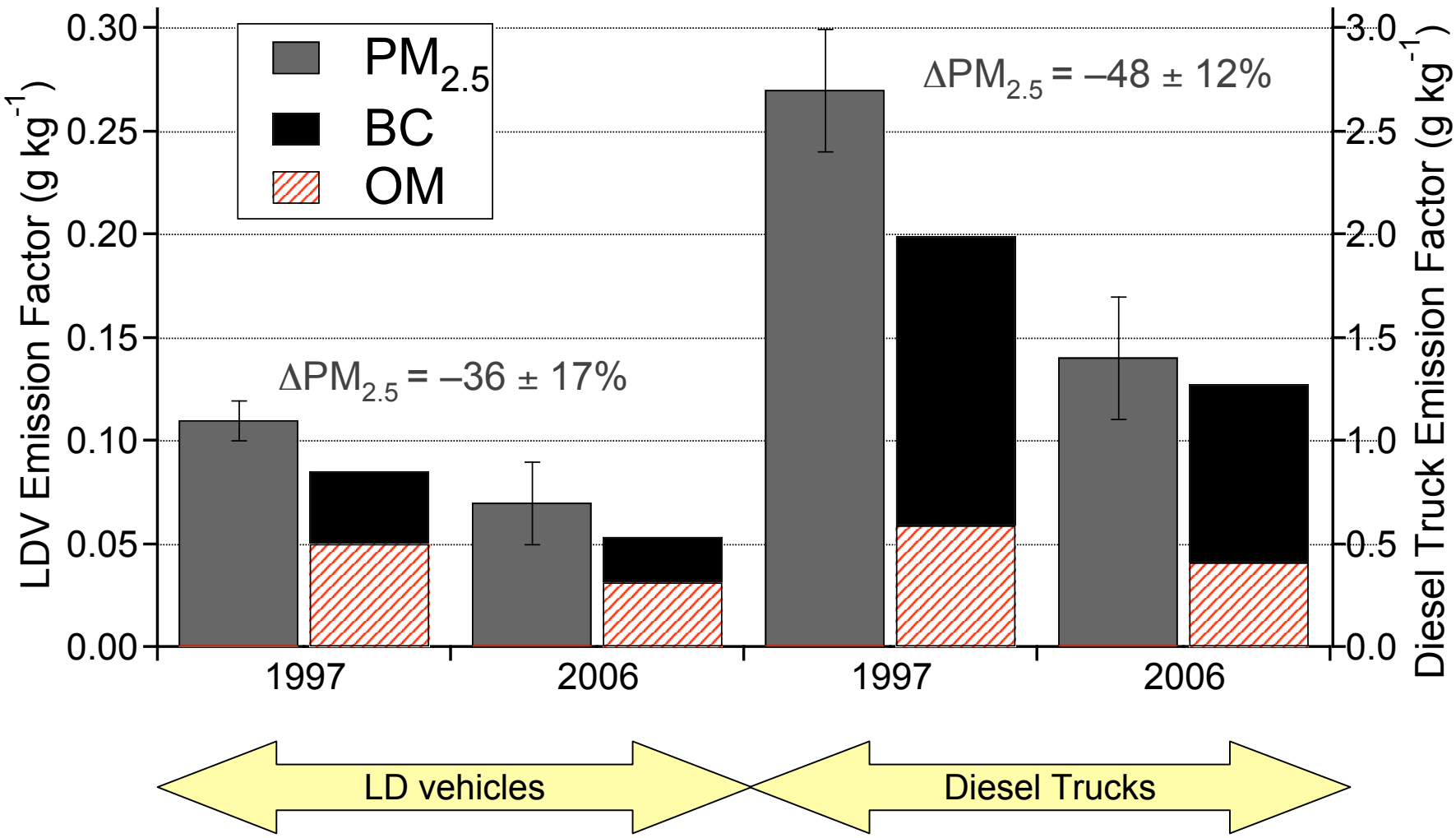


Light-Duty Vehicles
(nearly all gasoline)



Medium/Heavy-Duty
Diesel Trucks

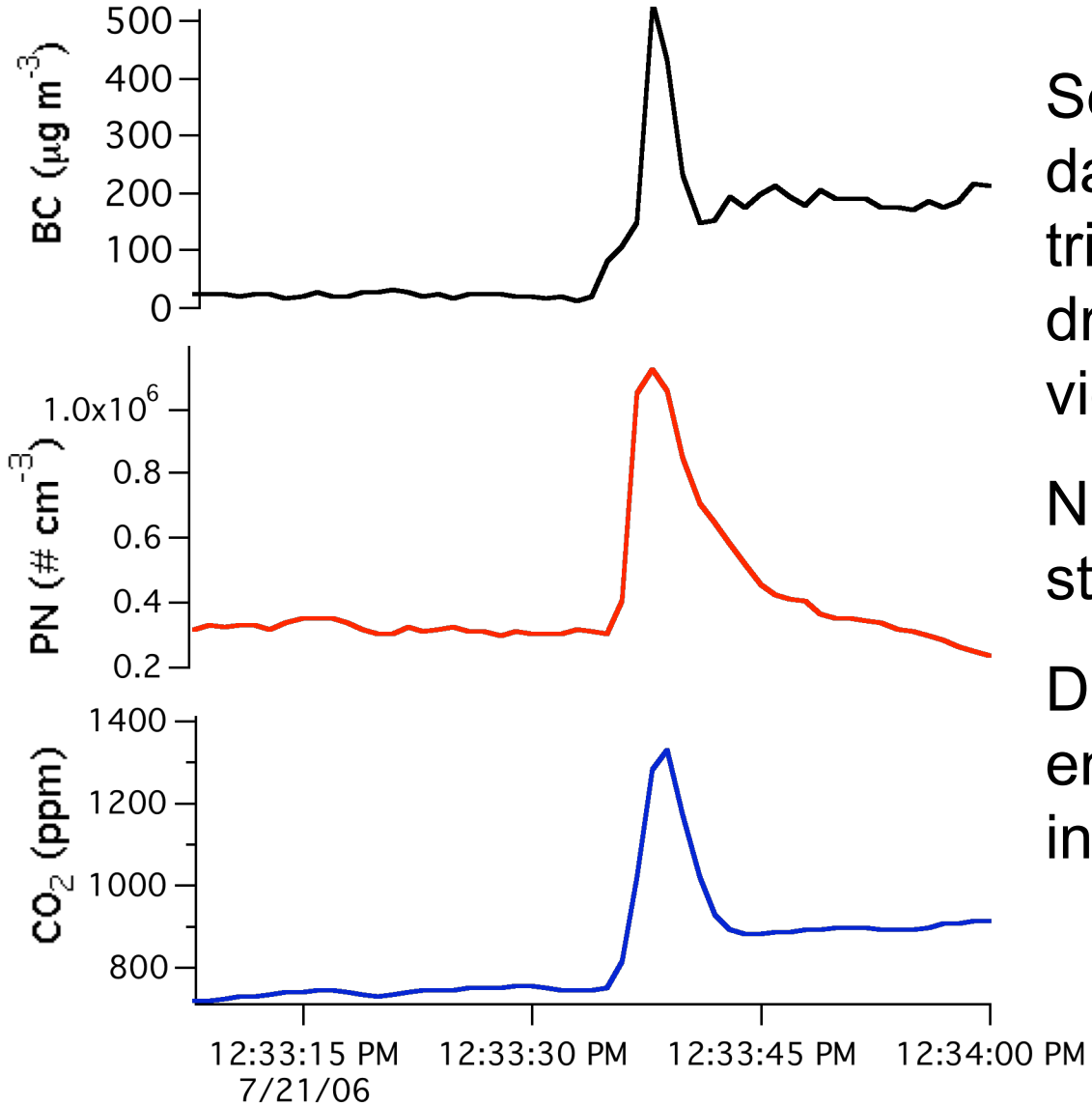
$PM_{2.5}$ Emissions



Particle Optical Properties

Fresh emissions measured by Cadenza at λ = 675 nm	Single scattering albedo (b_{scat}/b_{ext})	Absorption efficiency $m^2\ g^{-1}$ (b_{abs}/BC)
LD vehicles	0.31 ± 0.06	9.1 ± 2.8
Diesel Trucks	0.20 ± 0.05	5.1 ± 1.0

Emissions from Individual Trucks

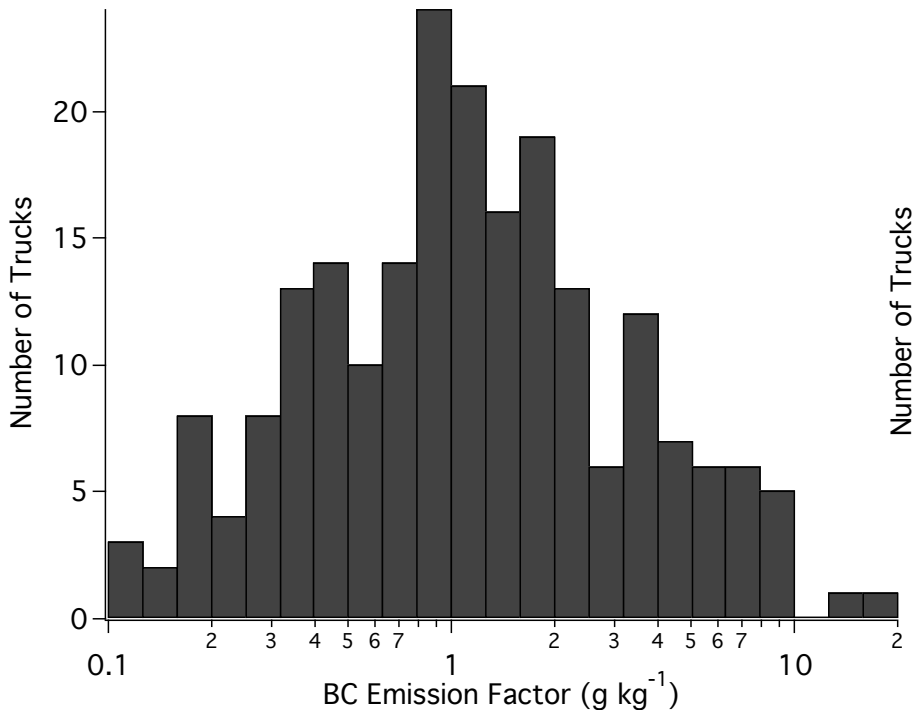


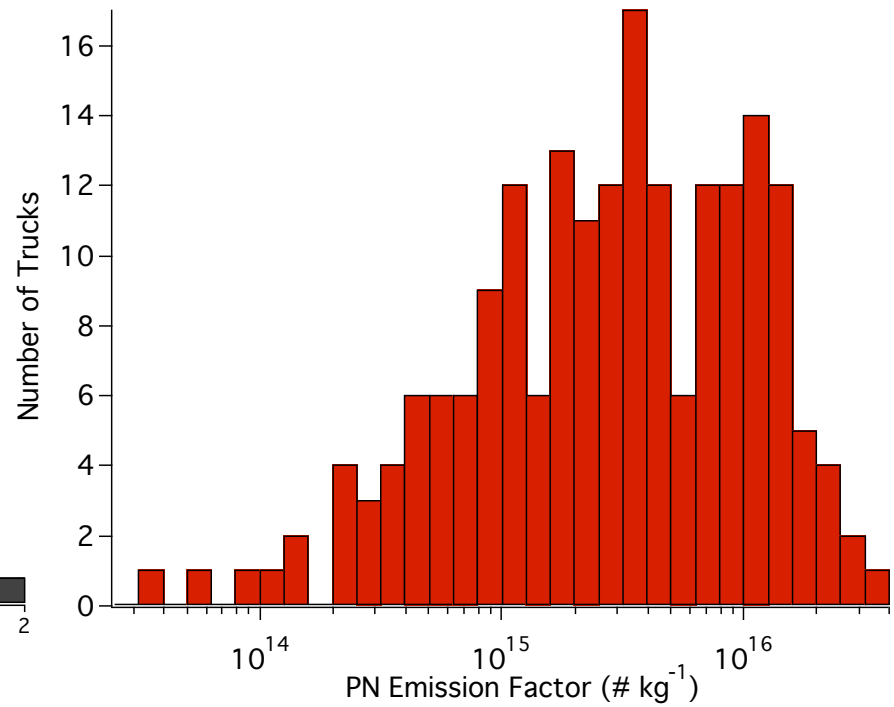
Search 1 Hz pollutant data for truck plumes, triggered by known drive-by times (from video tape)

Need vertical exhaust stack (not under-body)

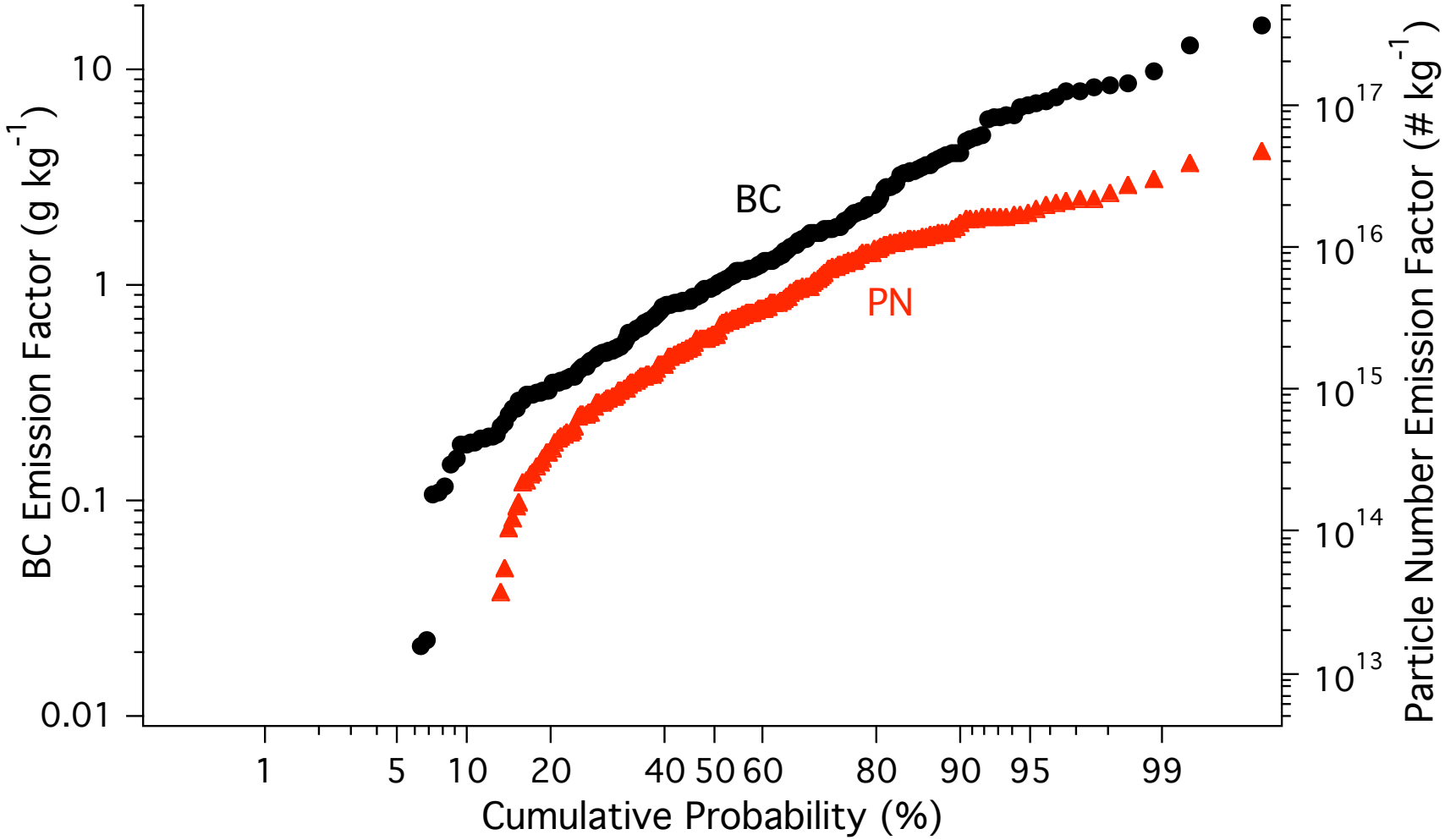
Derive <u>distributions</u> of emission factors for individual HD trucks

BC and PN Emission Factors

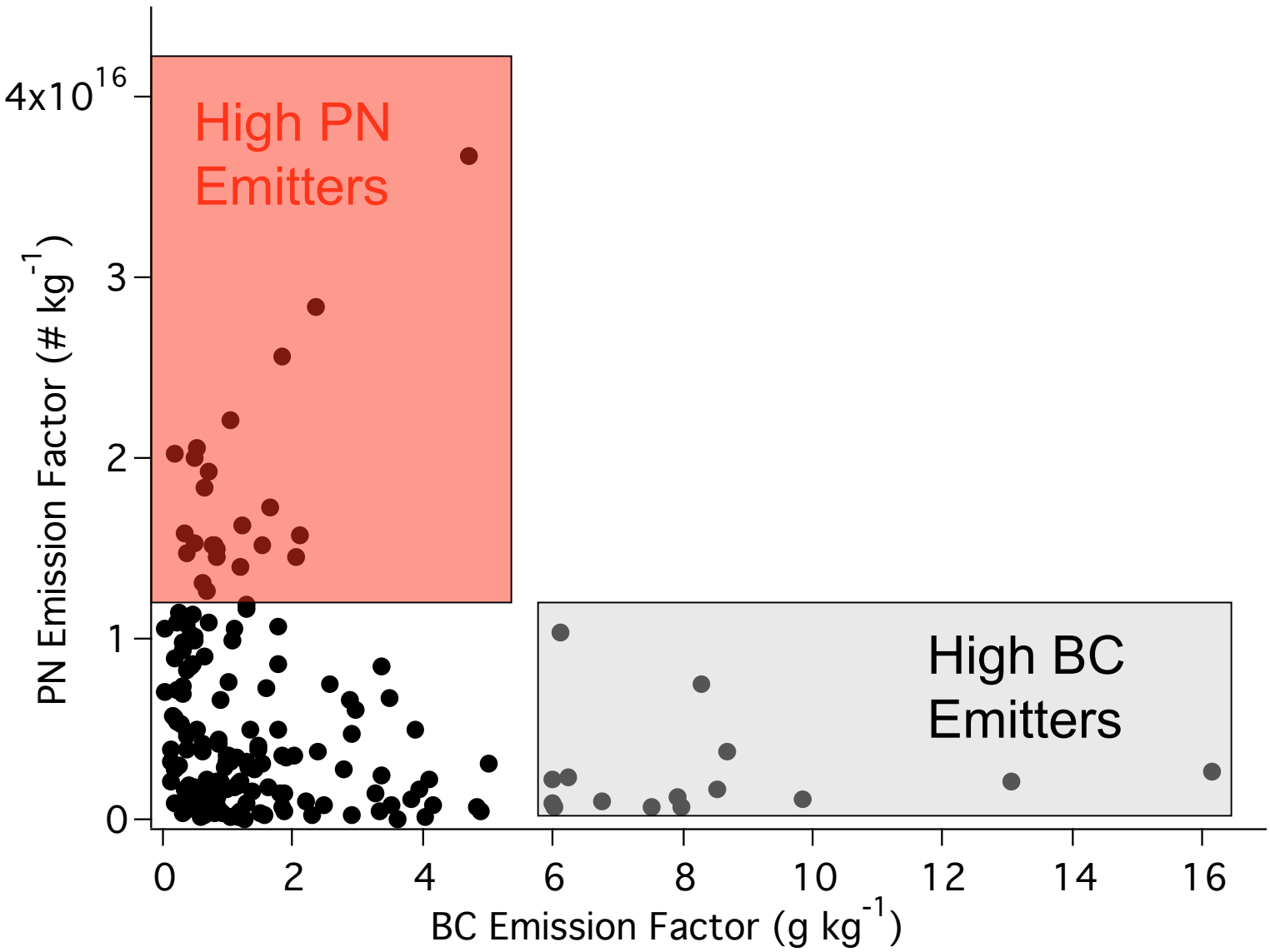




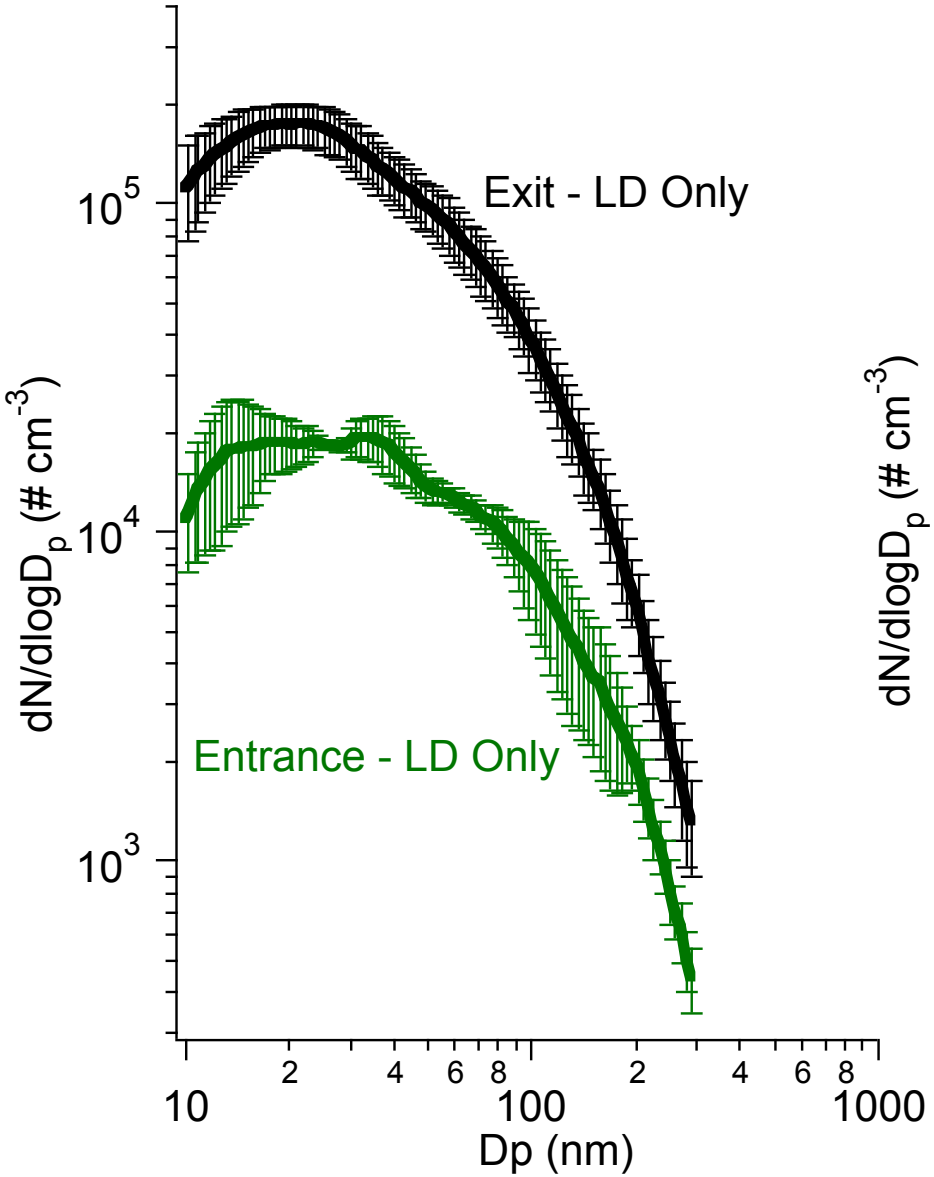
BC and PN Emission Factors

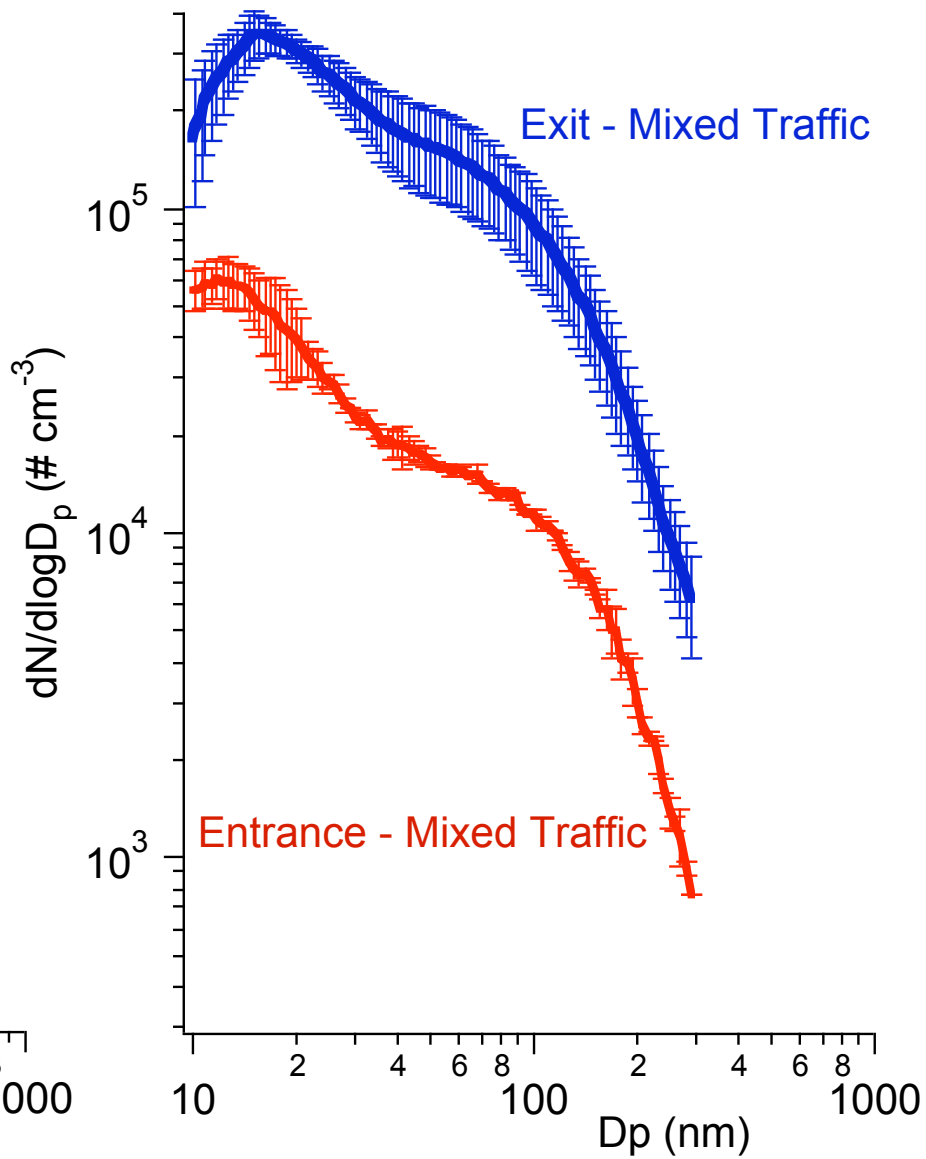


BC and PN Emission Factors

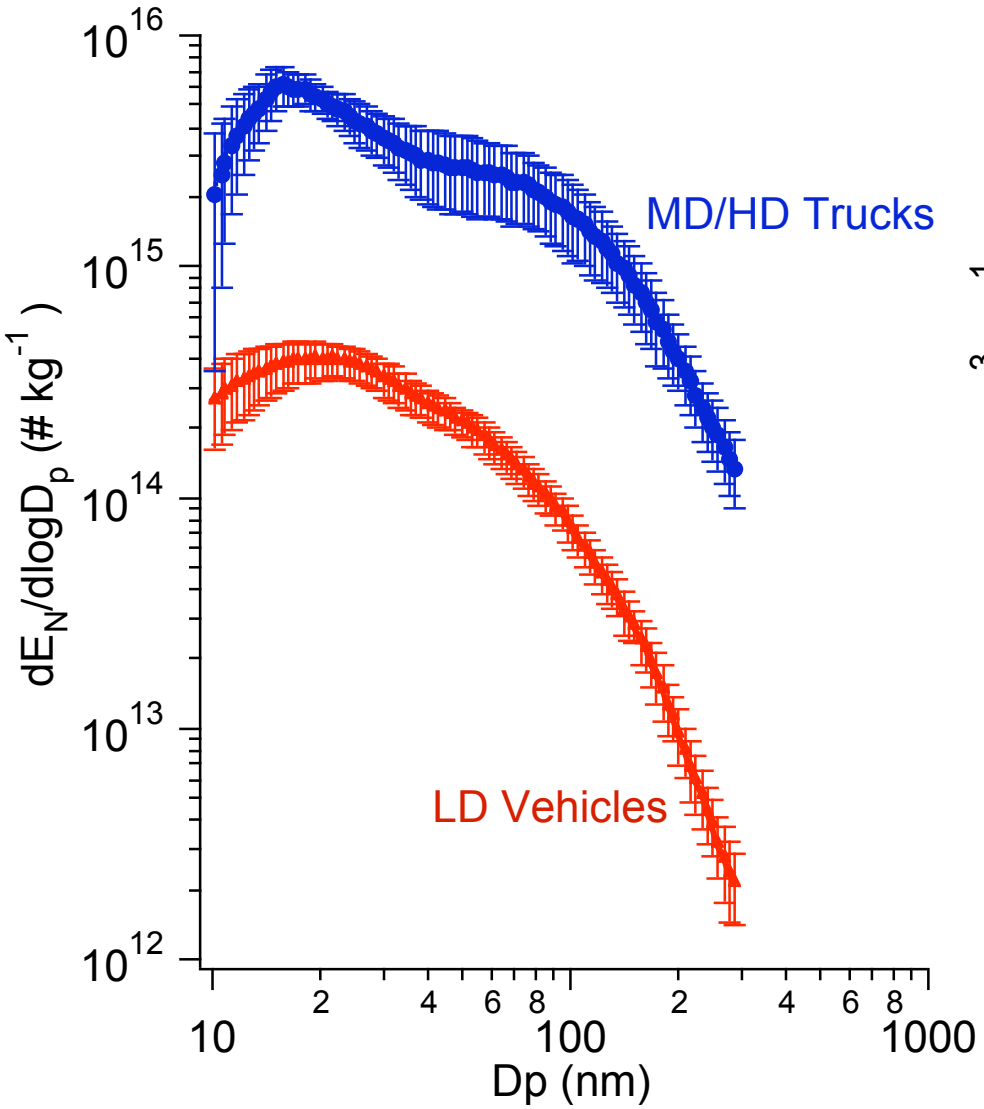


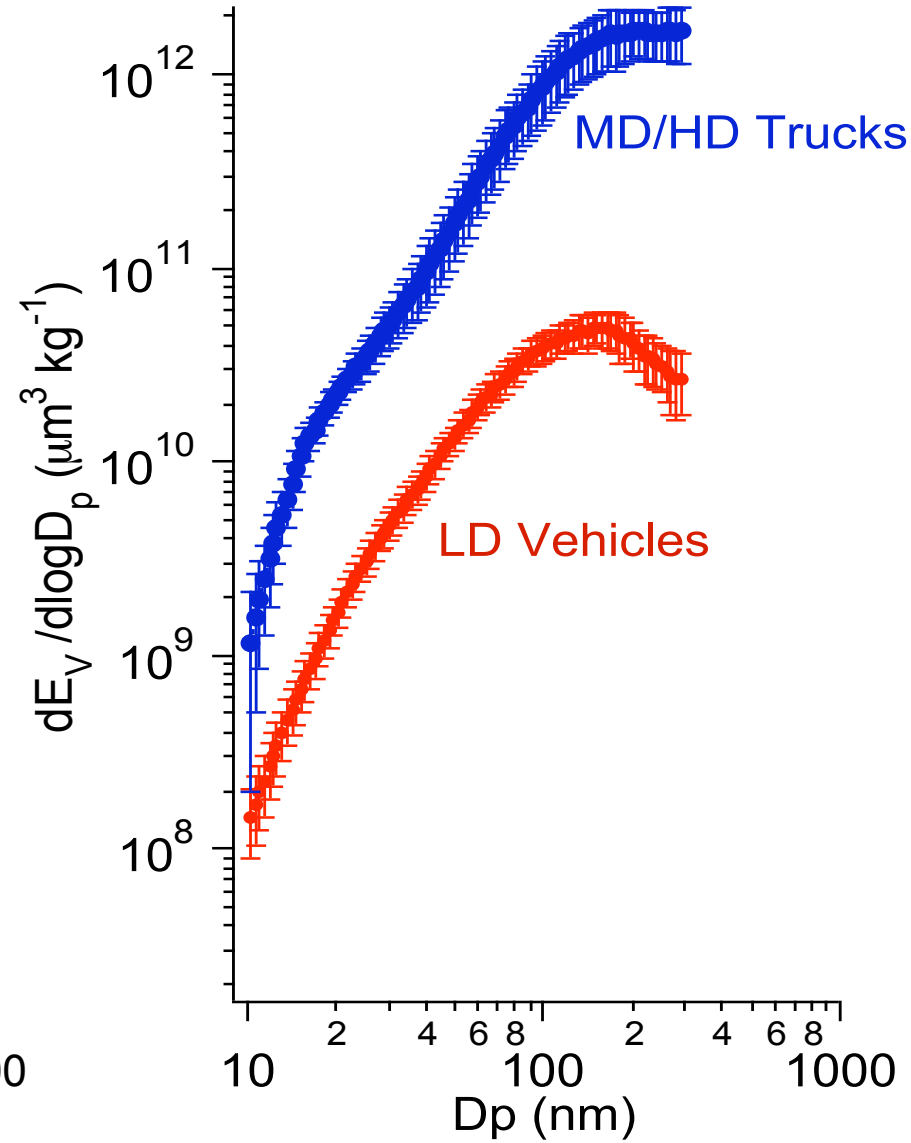
Particle Size Distributions





Size-Resolved Emission Factors

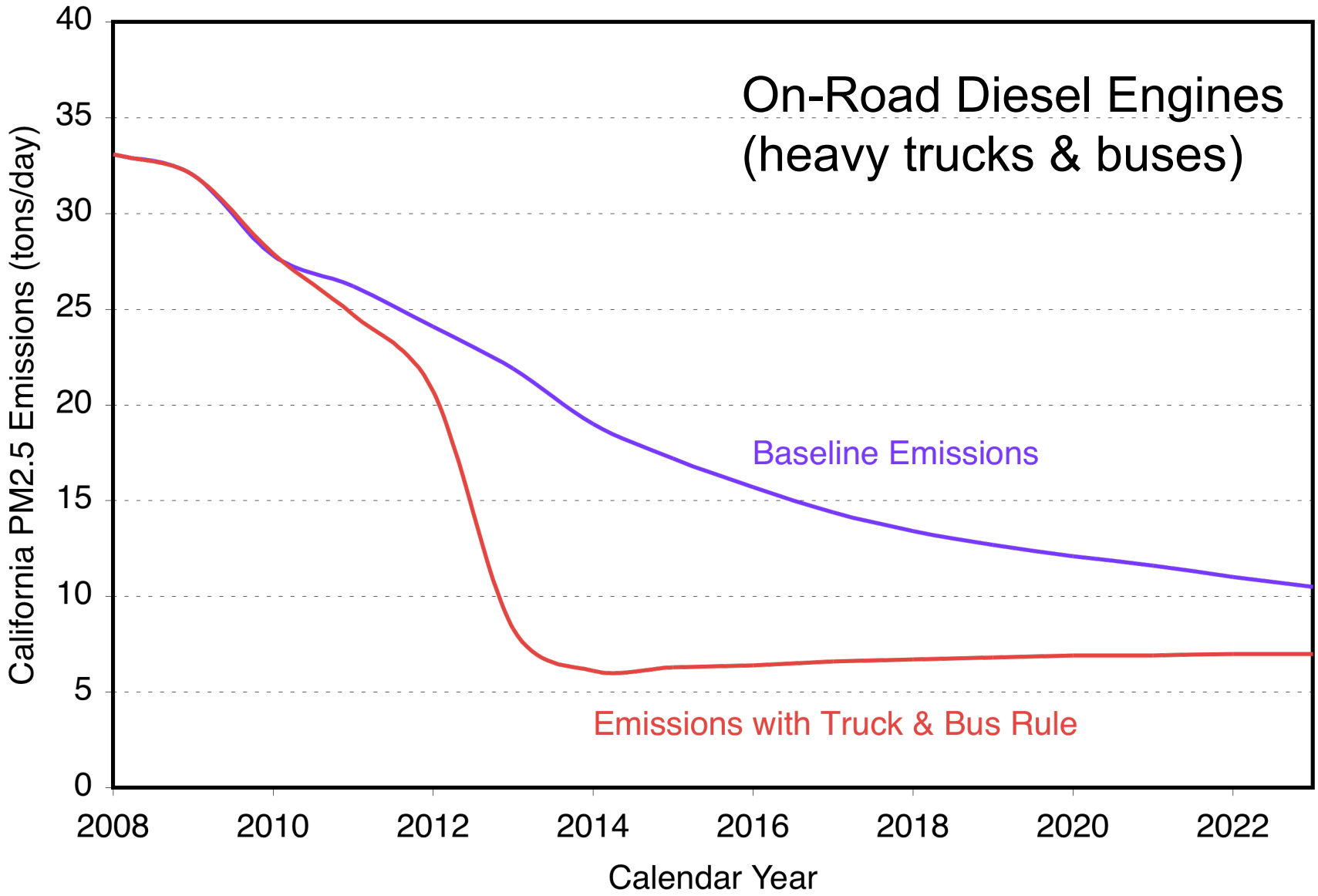




For Further Information…

- Ban-Weiss et al. (*Atmos Environ* 2008). NO_x & PM trends for LD & HD vehicles
- Ban-Weiss et al. (*ES&T* 2008). Carbonyl (aldehyde & ketone) results.
- Ban-Weiss et al. (*ES&T* 2009). BC & PN from individual HD trucks.
- Kean et al. (*Atmos Environ* 2009). Ammonia.
- Harley (2009). Final report to ARB, contract no. 05-309.

ARB Truck & Bus Rule



Source: Todd Sax (CRC 2009)

Suggested Follow-on Study

- Repeat 2006 “plume capture” experiments for individual HD trucks
  - » Measure longer list of pollutants at 1 Hz (NO, NO_2, BC, PM mass, PN, FMPS, …)
  - » Make measurements 2010, 2012, 2014, 2016
  - » Match emissions data to truck license plates
  - » Assess changes in fleet-average emission factors and emission factor *distributions*

Summary

- Diesel engines now dominant mobile source of NO_x (2/3 of on-road emissions + significant off-road contribution)
- Diesels also major source of aldehydes
- Diesel PM emissions decreasing; diesel NO_x fairly stable (offsetting effects of increased fuel use & lower NO_x emission factor)
- On-road gasoline engine emissions of NO_x, VOC & PM have decreased significantly

Summary

- Wide range of BC and PN emission rates from in-use diesel engines
  - » High-emitters of these two pollutants exhibit little overlap
- Further reductions in diesel PM emissions coming soon due to new diesel emission standards and new ARB rules that require retrofit or replacement of older engines