ARPA-E Powertrain Innovations in Connected and Autonomous Vehicles Workshop
Denver, Colorado
May 14 – May 15, 2015

Real-World Vehicle Emissions Measurements

Gary A. Bishop and Donald H. Stedman
Department of Chemistry and Biochemistry
University of Denver, Denver, CO 80208
www.feat.biochem.du.edu

UNIVERSITY of DENVER

Acknowledgements

- Colorado Office of Energy Conservation
- Coordinating Research Council
- California Air Resources Board
- Envirotest Systems Corp. (commercial partner)
- Numerous foundations, city, state, federal agencies, international groups, many students and other professional co-workers.

Our Data, Reports and Publication Repository
www.feat.biochem.du.edu

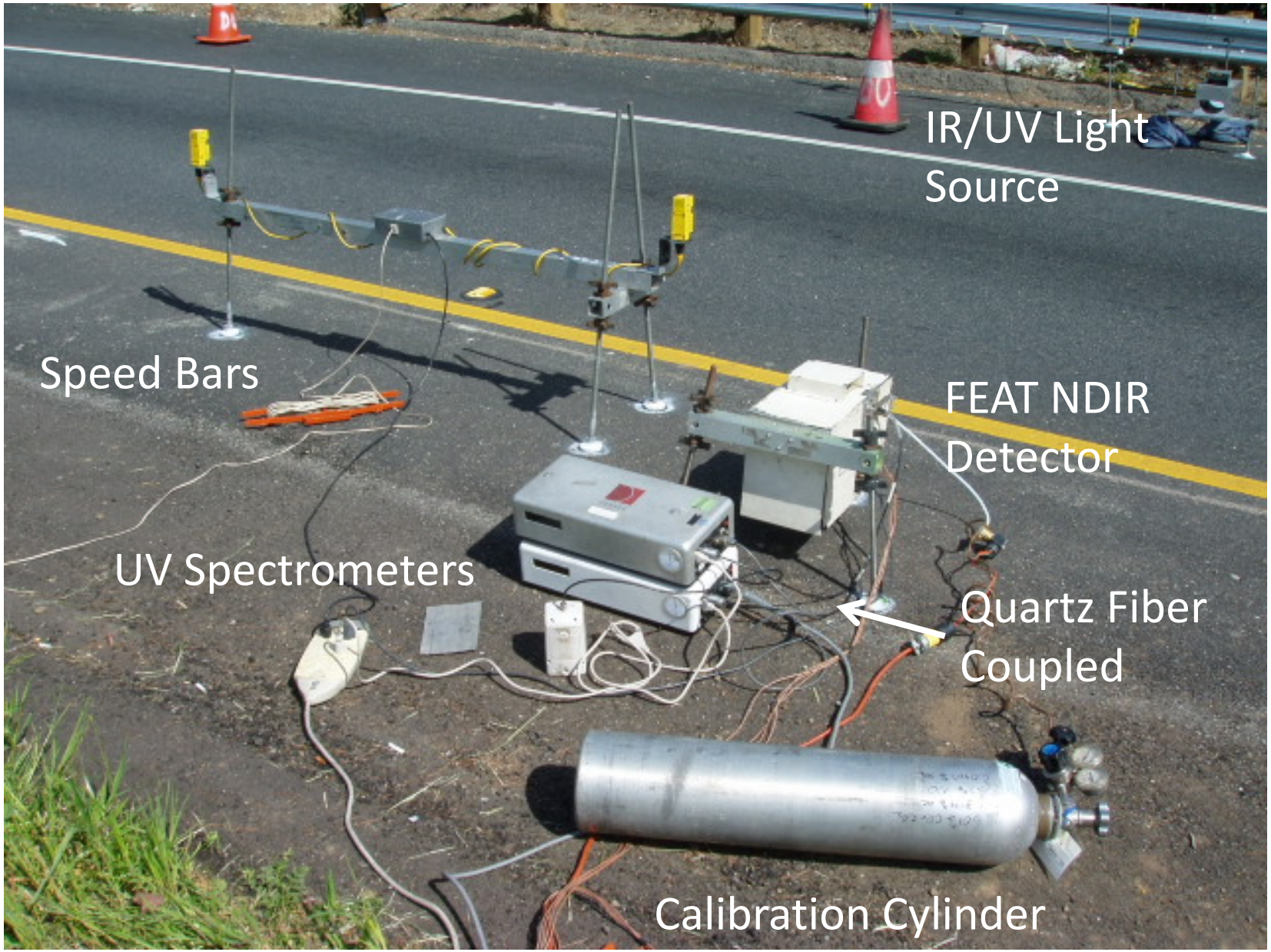
Fuel Efficiency Automobile Test

In 1987, with a grant from the Colorado Office of Energy Conservation, the first successful remote sensor used to test light-duty vehicle emissions was developed at the University of Denver and named **FEAT** (**F**uel **E**fficiency **A**utomobile **T**est).

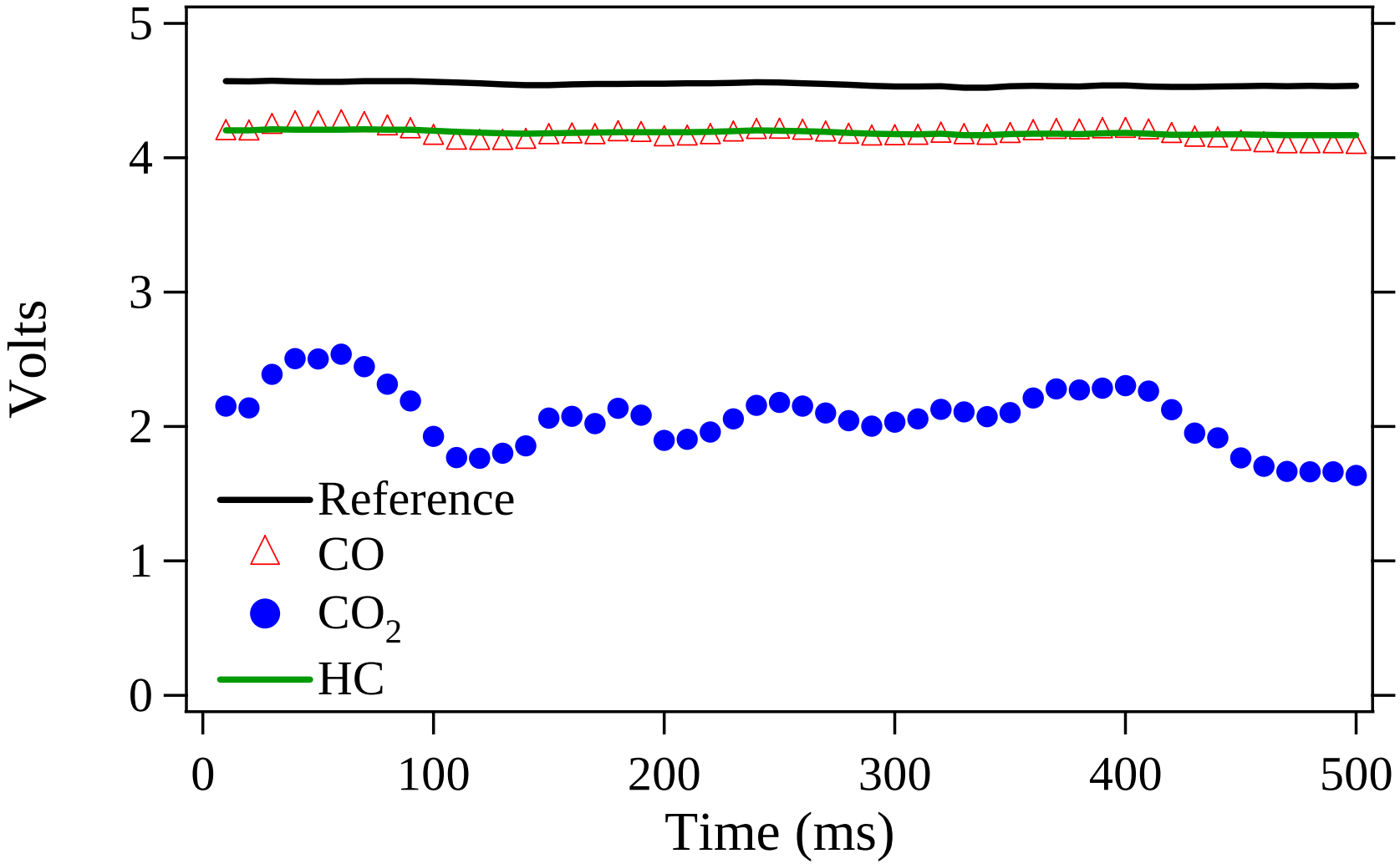
Research concept was to measure the tailpipe emissions of in-use vehicles and find the highest carbon monoxide emitting vehicles and repair them to improve their fuel efficiency.

More than 50 peer reviewed journal articles and an additional 100+ reports

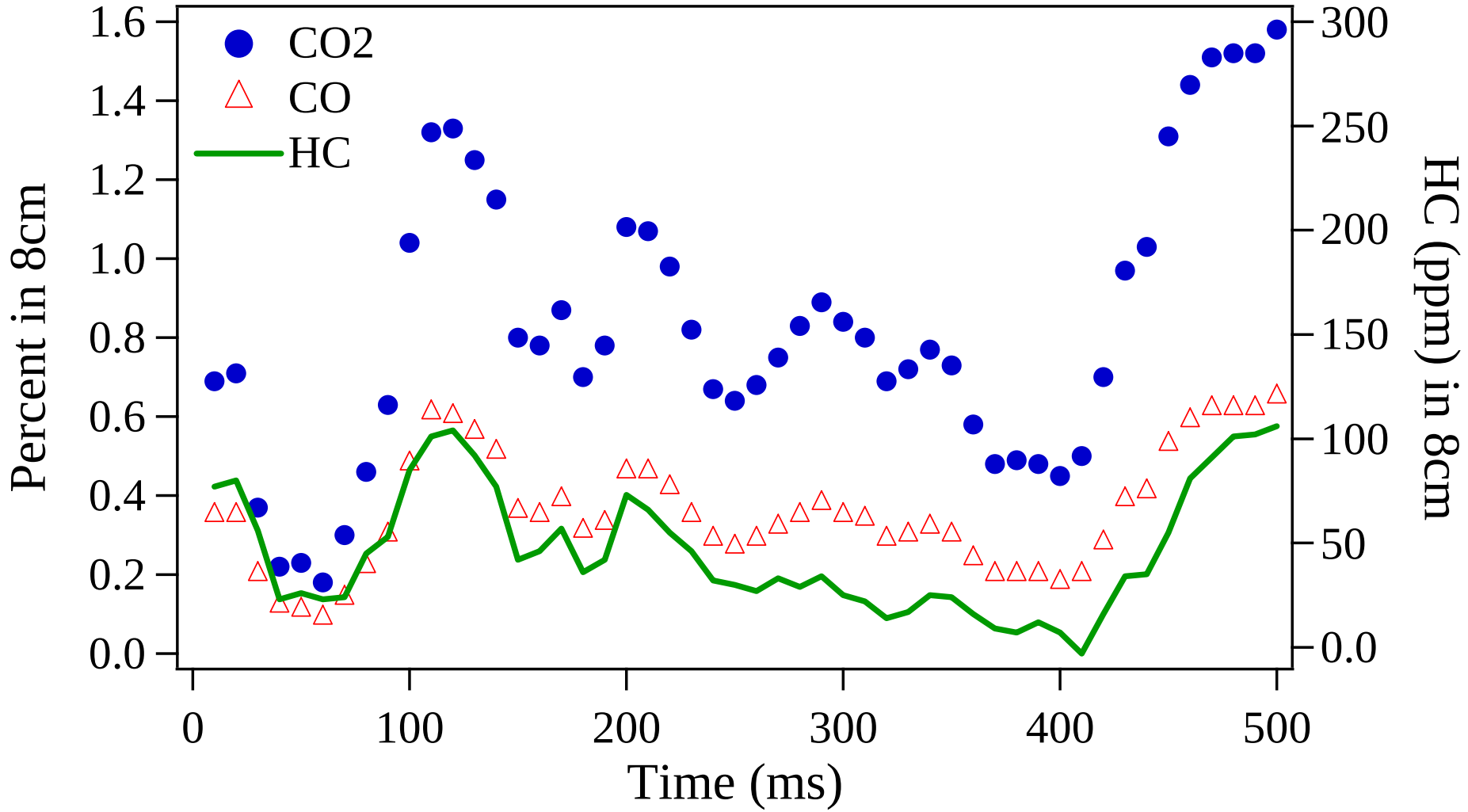
Roadside Instrument Setup



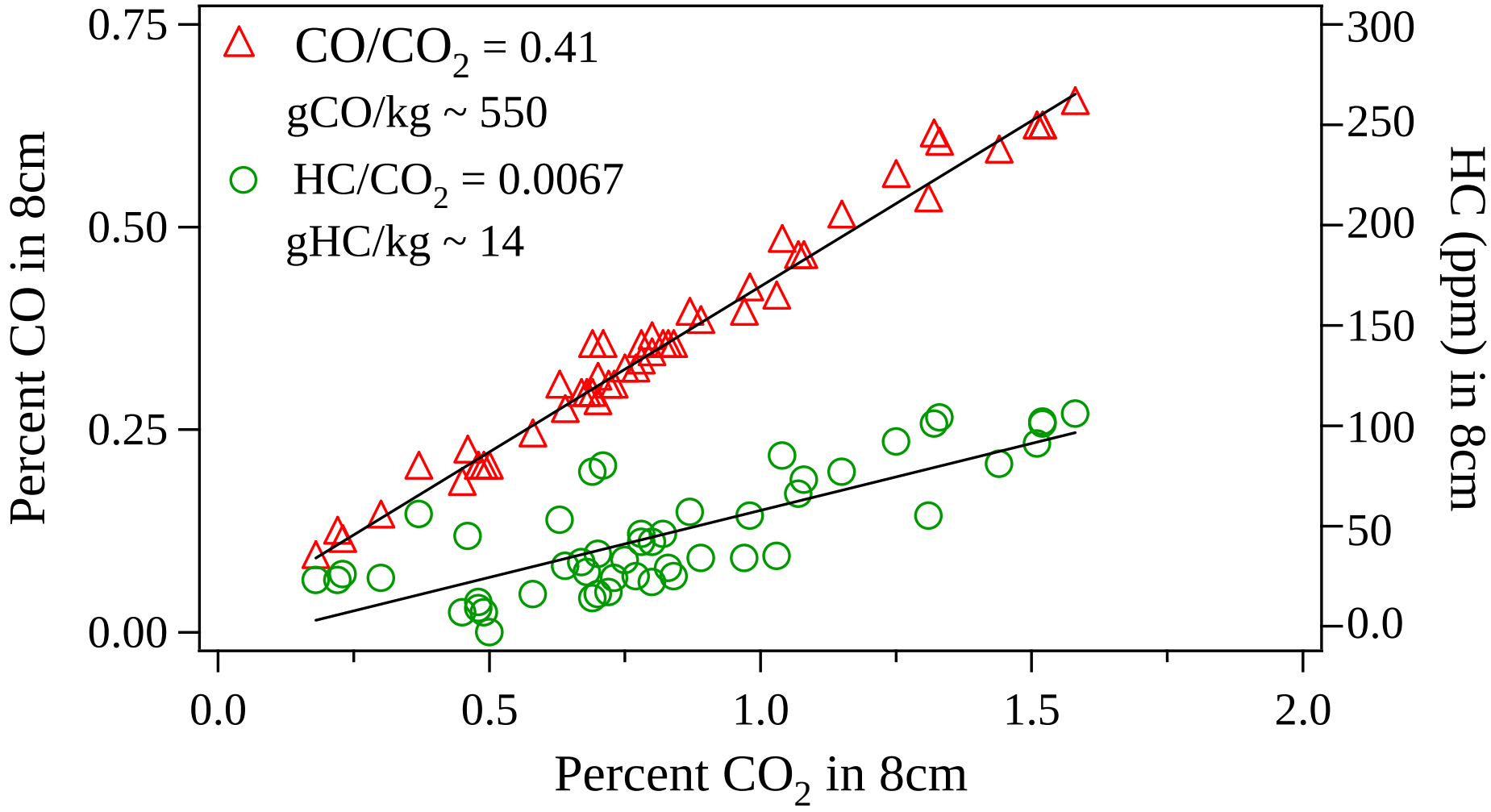
IR Plume Signal vs. Time



Pollutant Readings vs Time



Pollutant Ratio Plots



Current FEAT Remote Sensor

- Measures absorptions using:
  - Infrared (non-dispersive)
    - CO @ 2170 cm^{-1} / CO_2 @ 2330 cm^{-1}
    - HC @ 2940 cm^{-1} / Reference 2560 cm^{-1}
  - Ultraviolet (dispersive)
    - NO @ 226nm, SO_2 @ 215nm and NH_3 @ 205nm
    - NO_2 @ 430 nm
- FEAT compares the pollutant ratios (CO/CO_2, HC/CO_2, NO/CO_2 etc.) in the vehicle exhaust to the pollutant ratios in a certified gas cylinder.

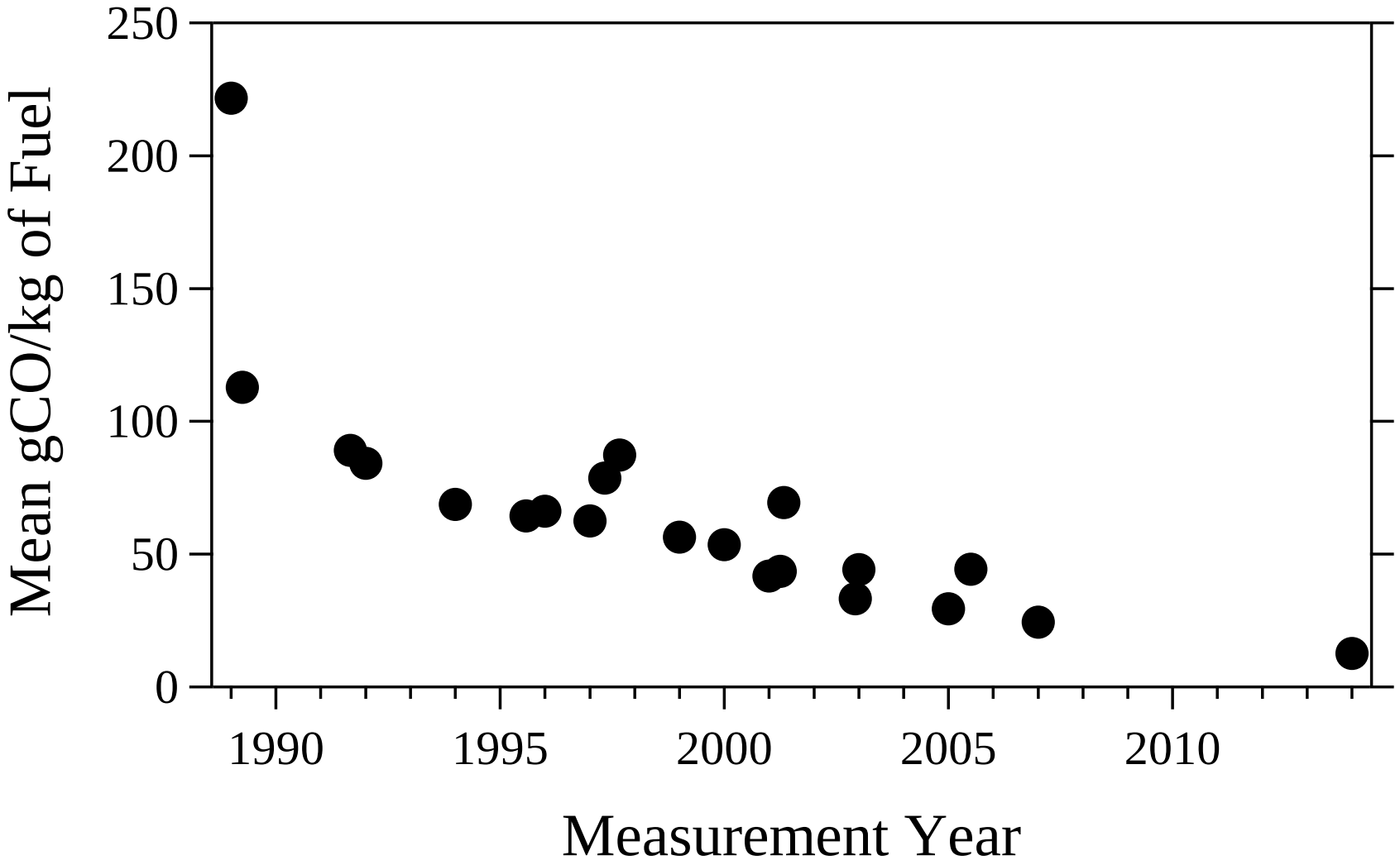

CANADA

Lion’s Gate Bridge, Vancouver BC

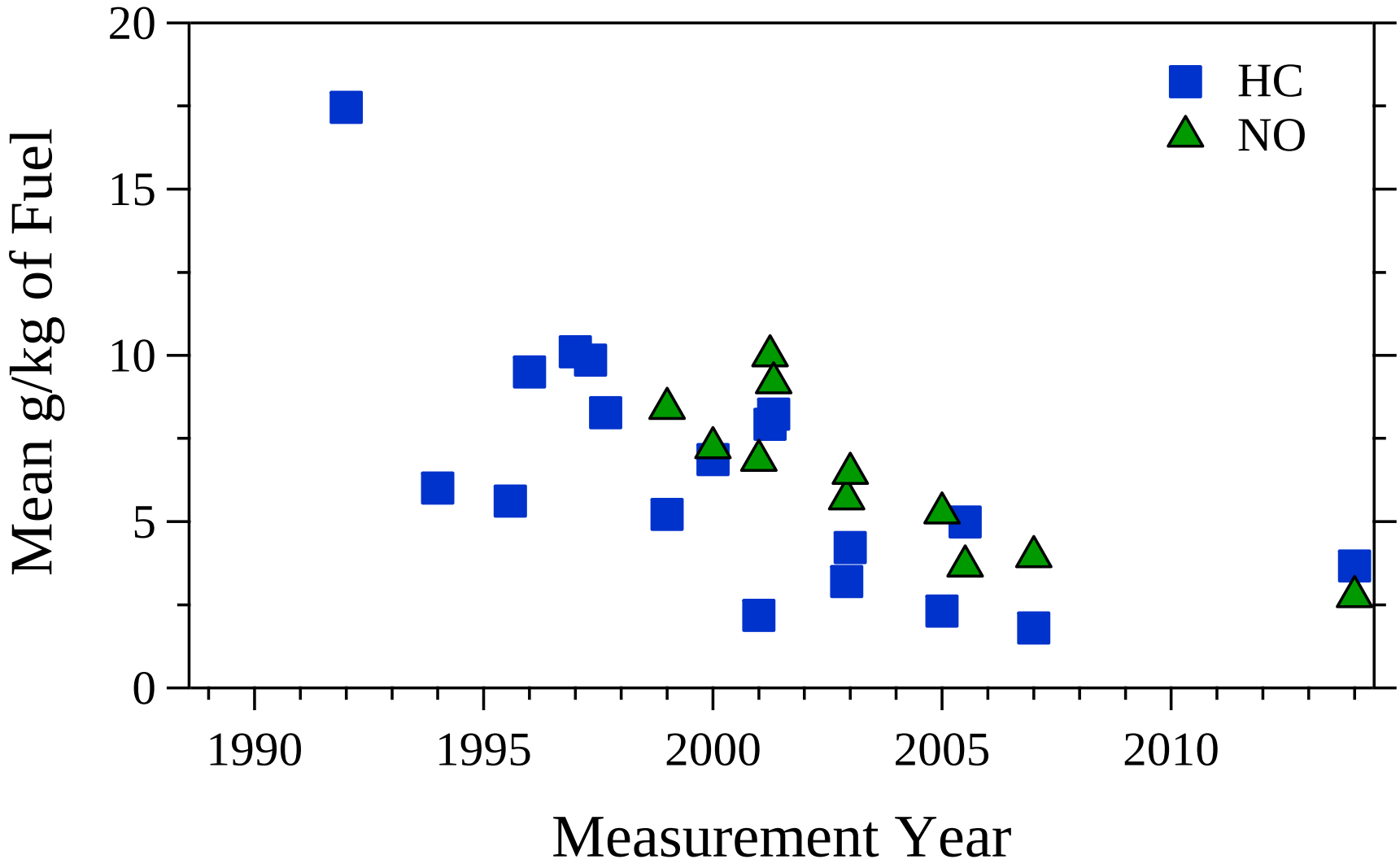
FEAT Record

- More than 1.6 million light-duty car and truck measurements collected from more than 30 locations in the US and 21 countries worldwide.
- More than 27,000 Heavy-duty truck measurements.
- Snowmobile and Snow-Coach measurements in Yellowstone National Park
- Locomotive measurements in NE and WA
- Commercial Aircraft at Heathrow Airport
- Ocean going vessels in Vancouver BC
- Small water craft at a lock in Seattle

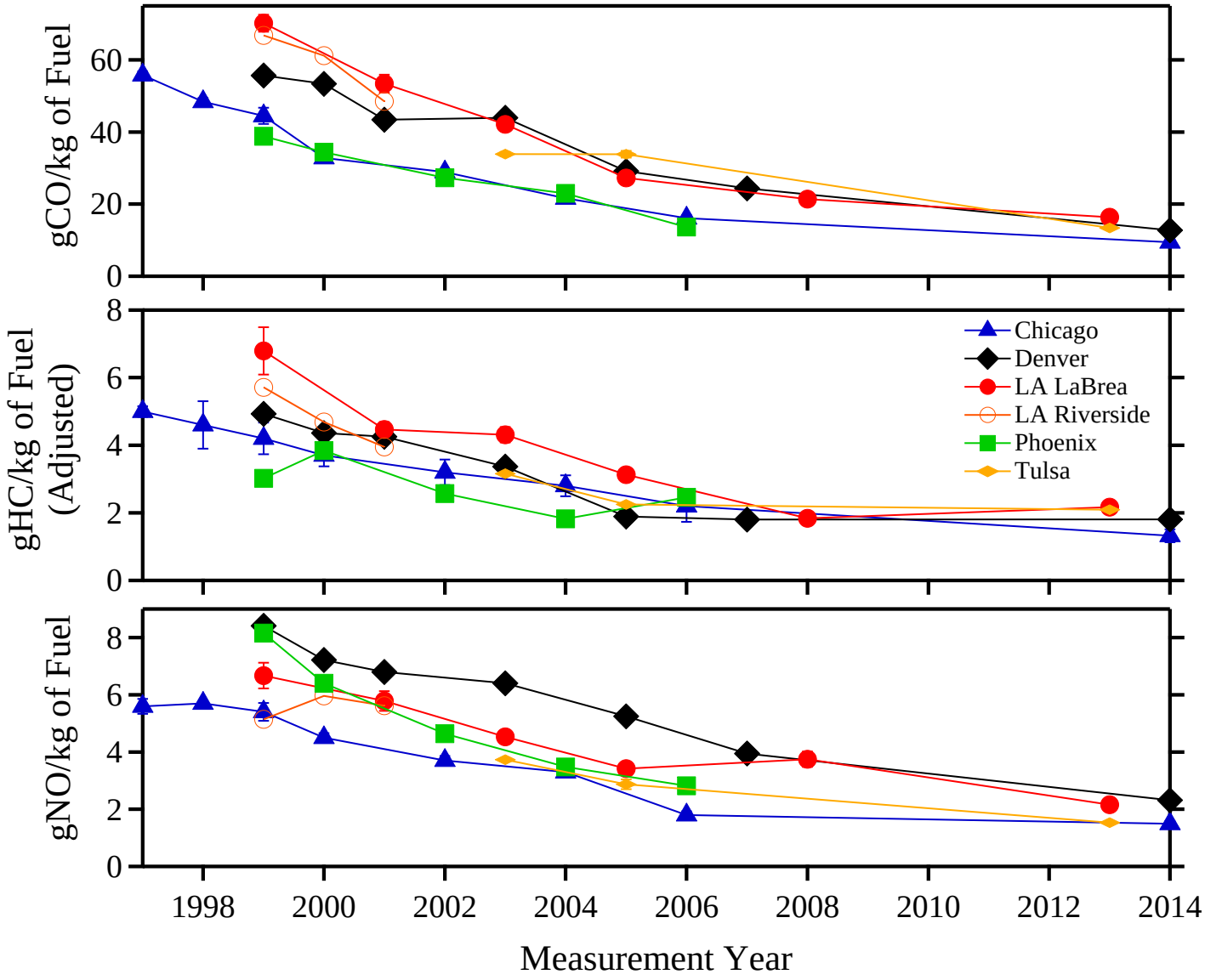
Colorado On-Road Mean CO Emission Trends



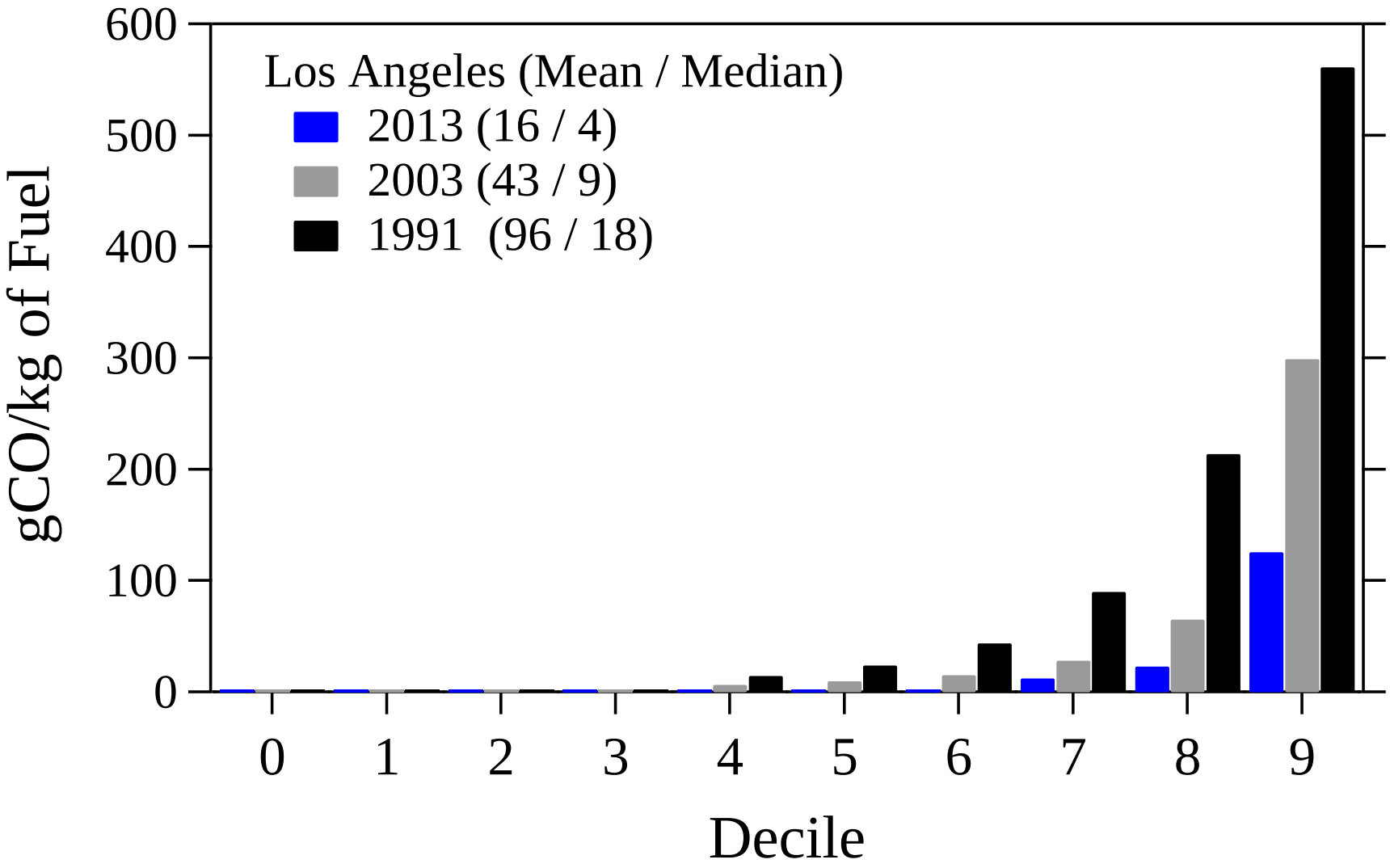
Colorado On-Road Mean HC and NO Emission Trends



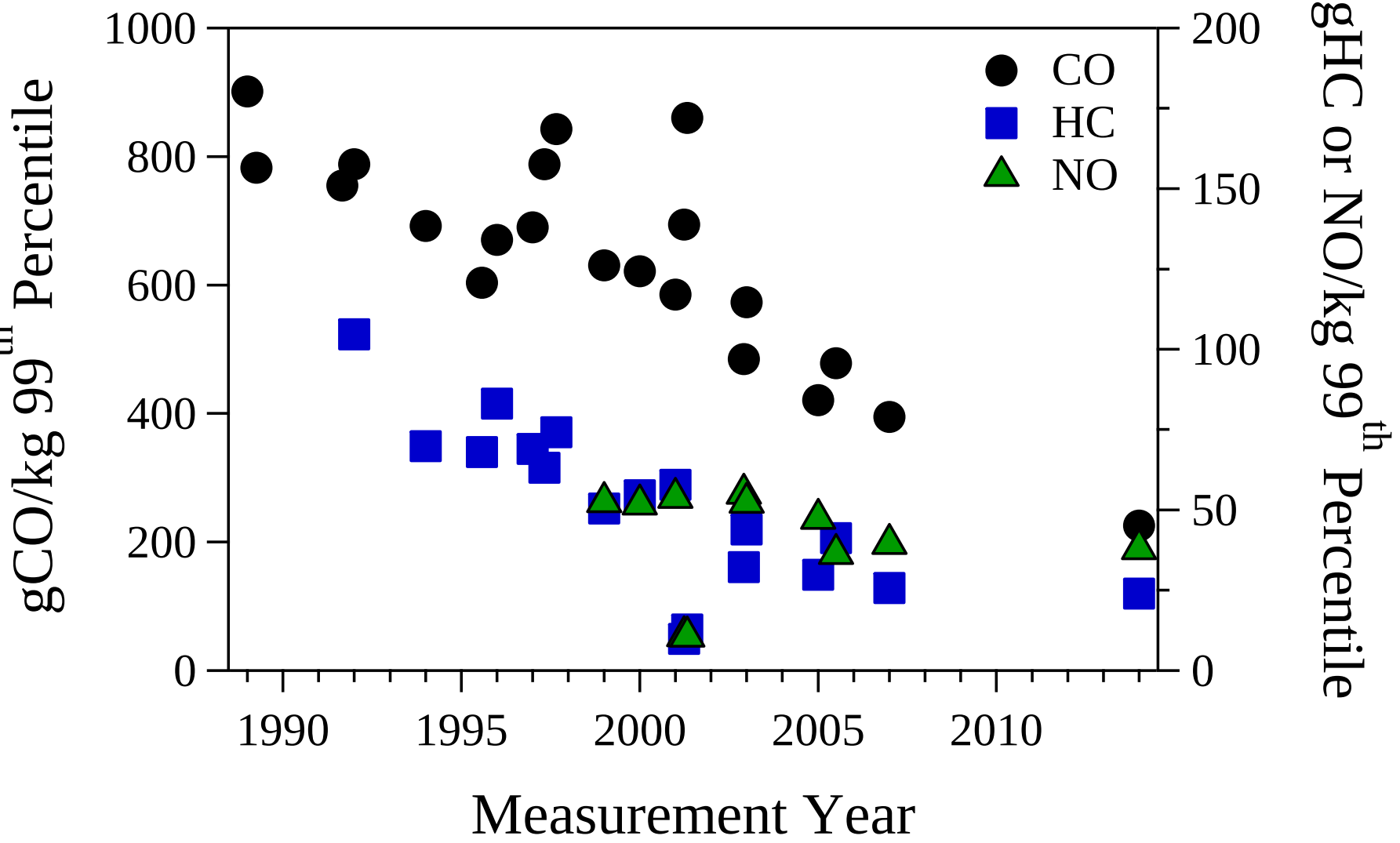
Colorado is not Unique!
Emissions are decreasing Everywhere



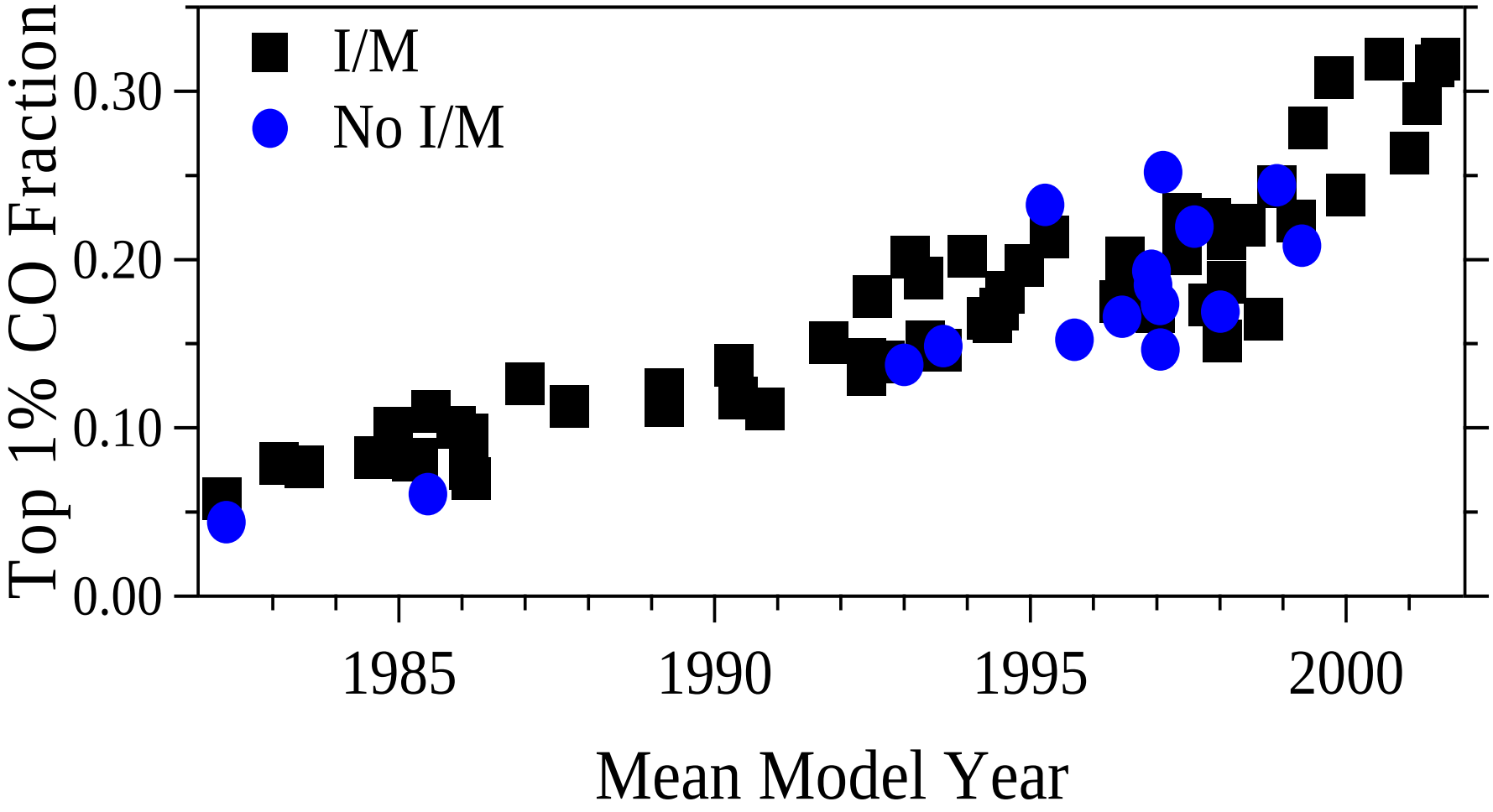
Vehicle Emissions Distributions are Extremely Skewed



Colorado 99th Percentile Trends



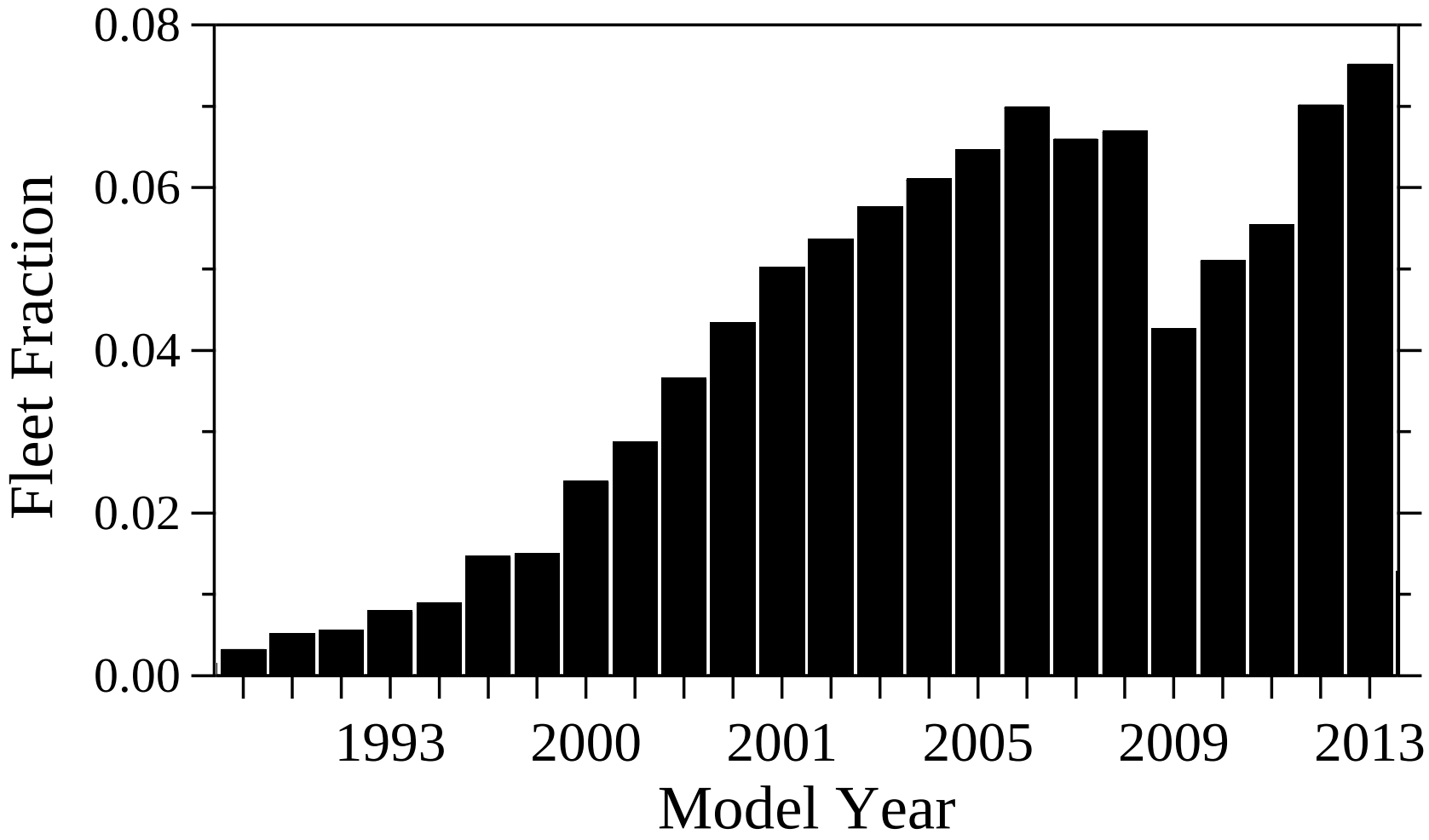
The Tail Wags the Dog



Who are the 99th Percentile?

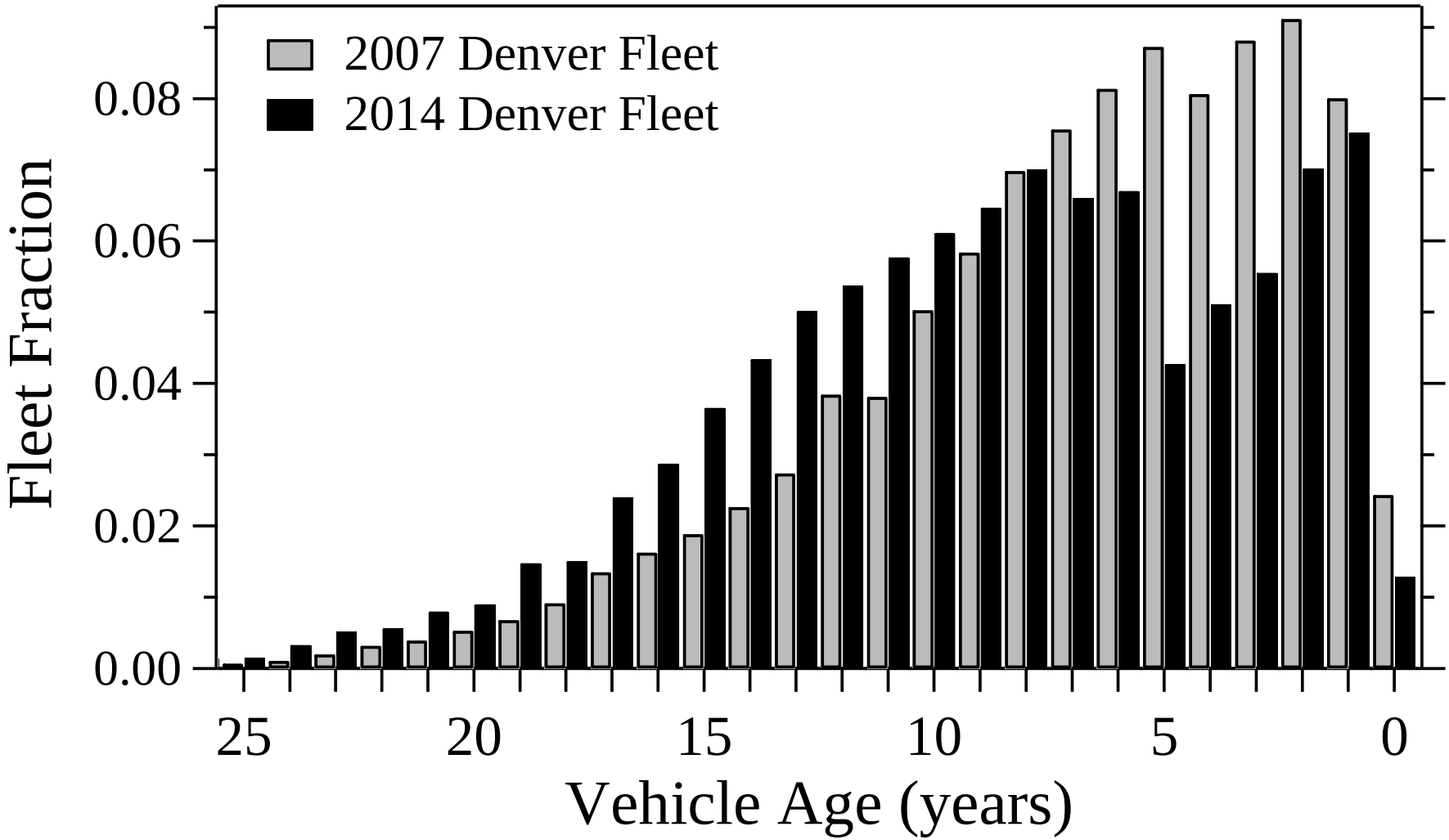

06/07/91
10.35
0.361
7.69

2008 Recession Repercussions seen in the Denver On-Road Fleet

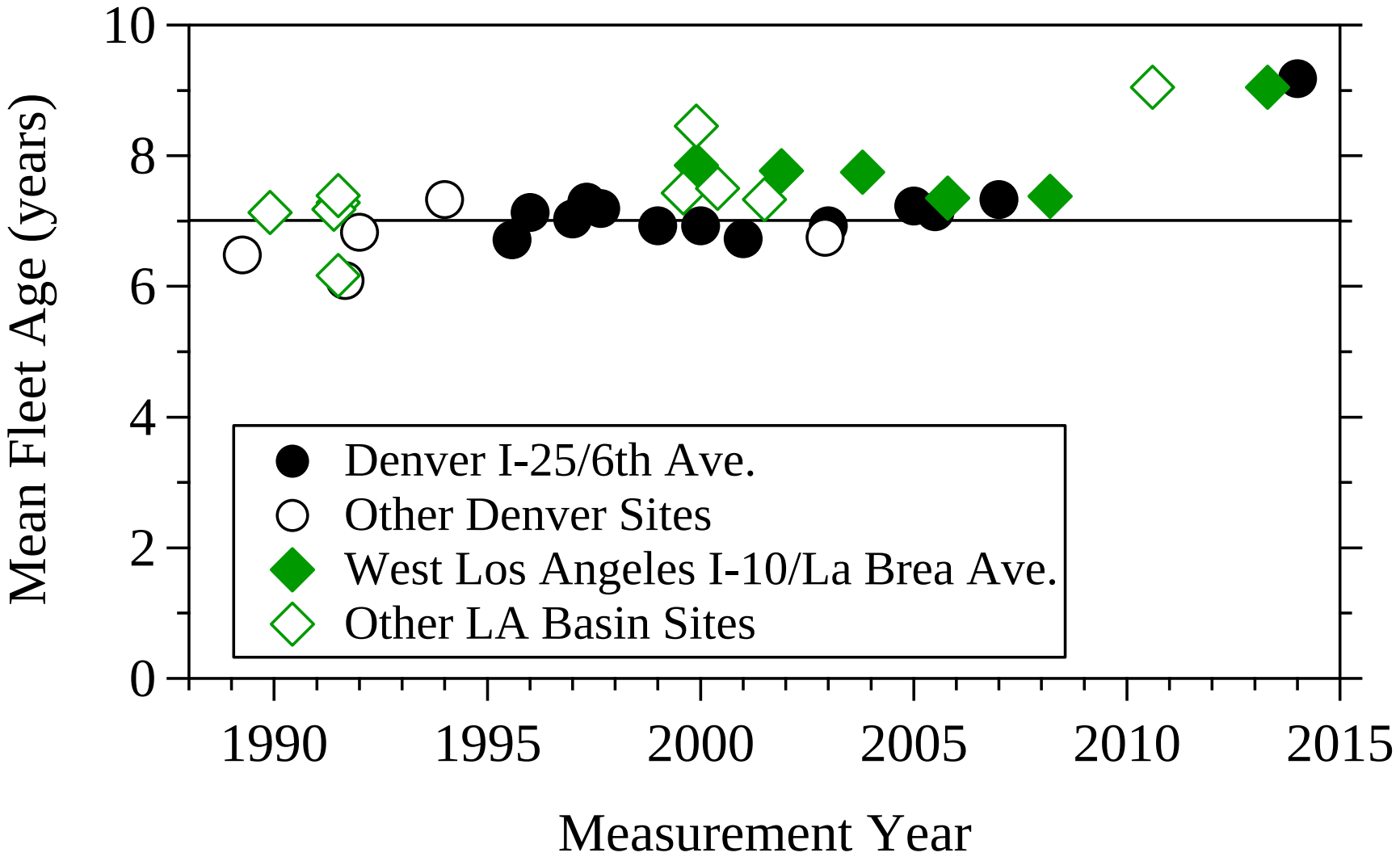


Bishop and Stedman, The recession of 2008 and it impact on light-duty vehicle emissions in three western US cities. *Environ. Sci. Technol.* **2014,** 48, 14822-14827.

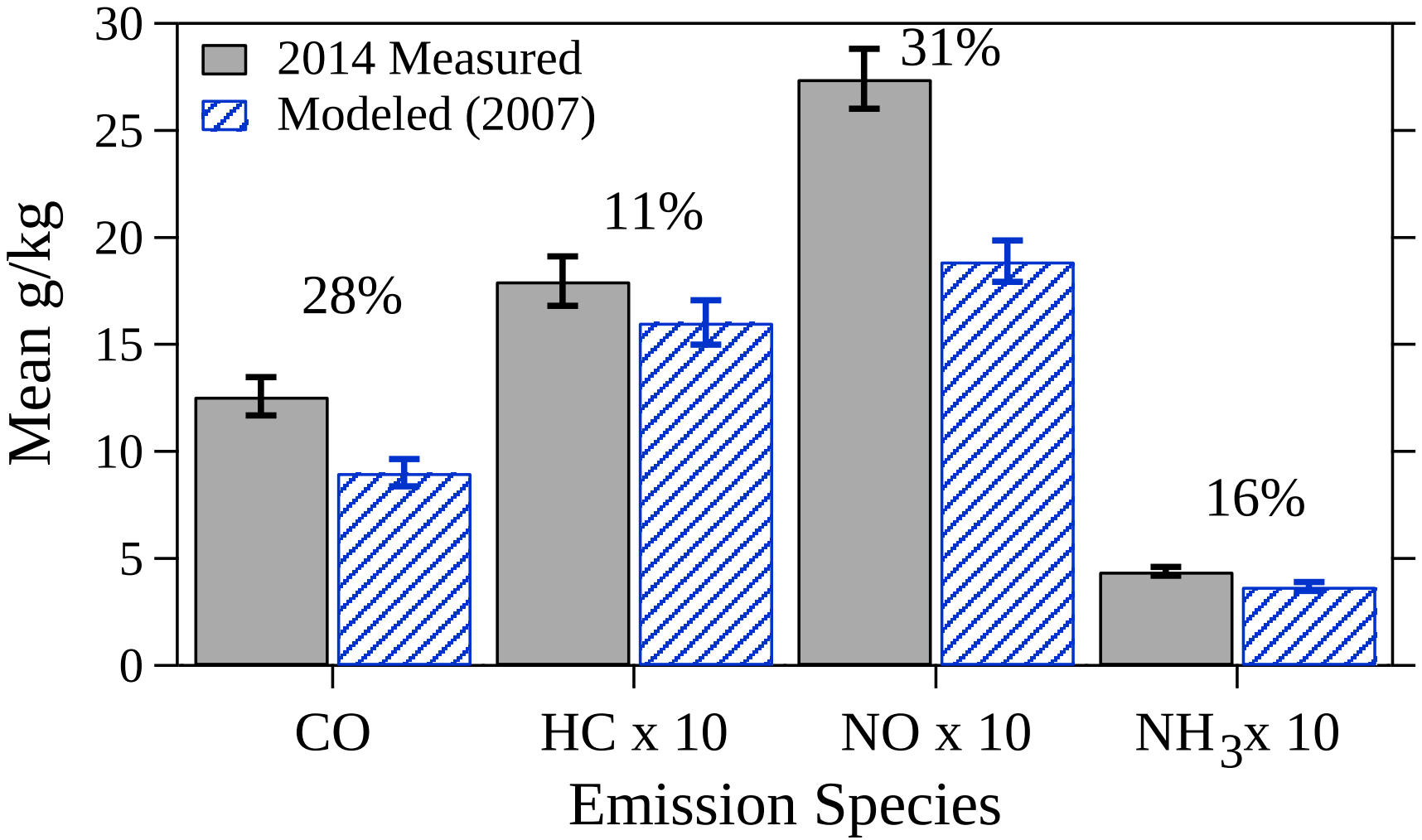
Comparison with pre-Recession 2007 Denver On-Road Fleet



Recession Effects on Fleet Age in Denver and Los Angeles

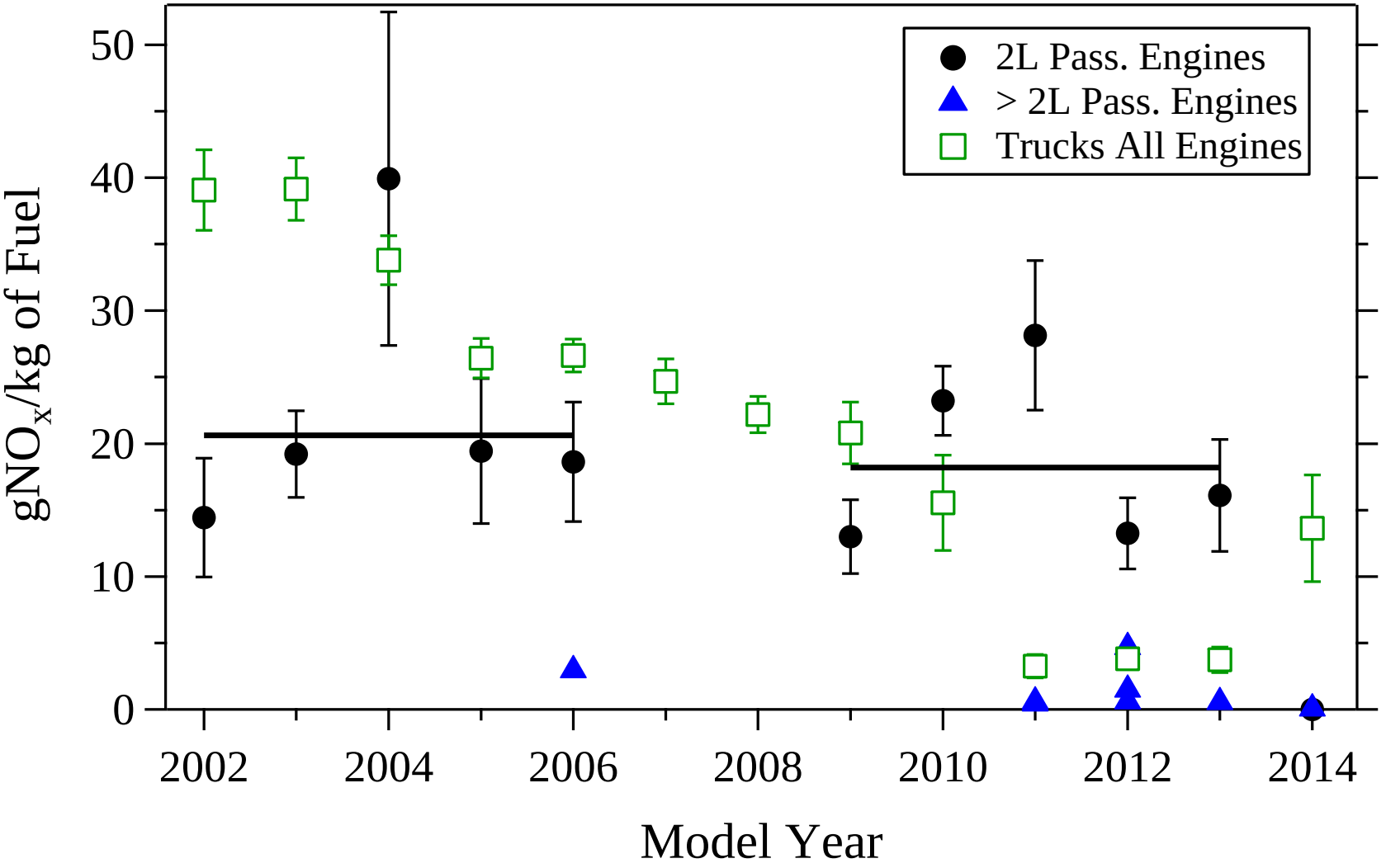


Recession Impacts on On-Road Fleet Fuel Specific Emissions in Denver



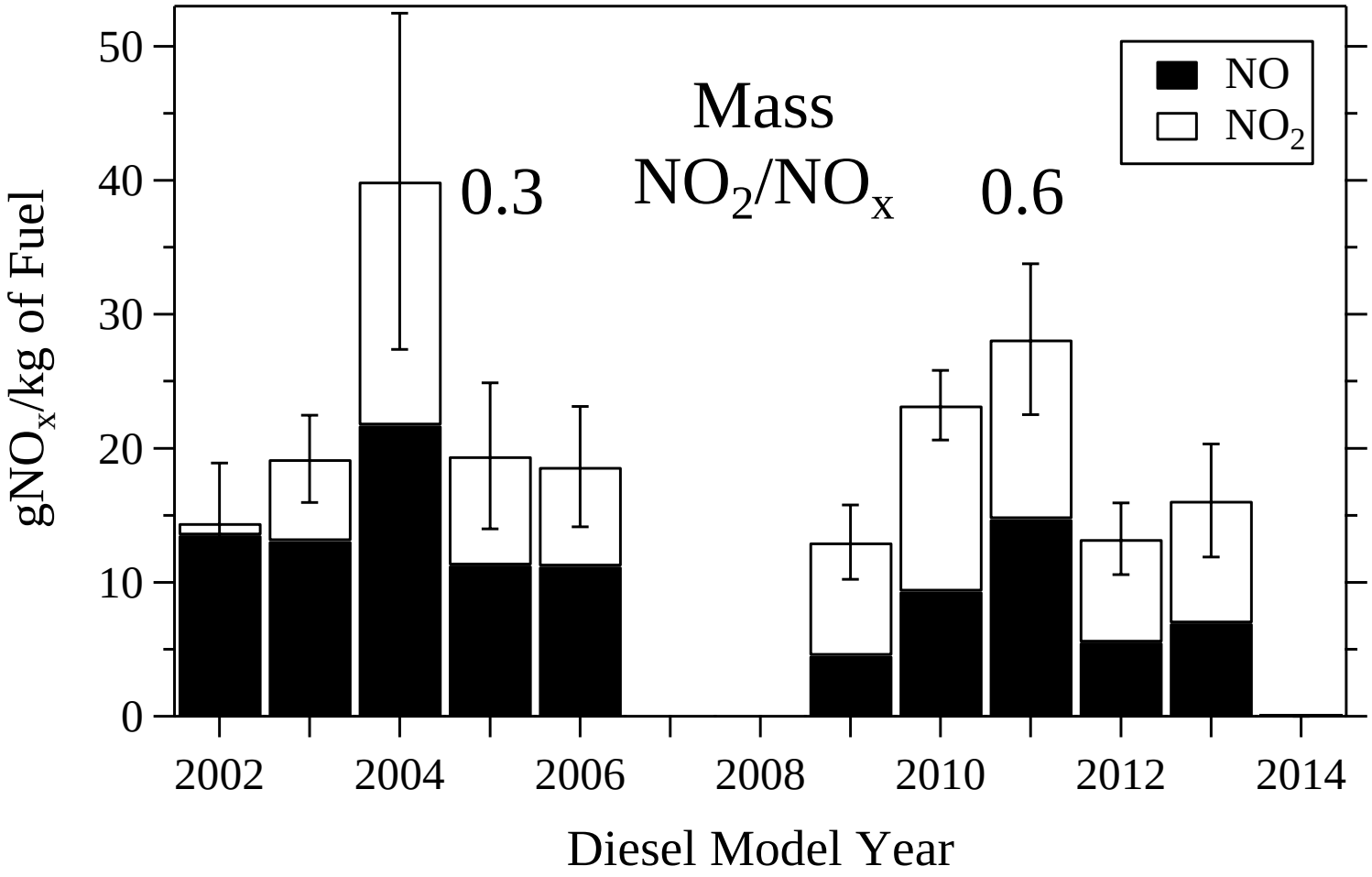
Certification Does not Always Work

2013 LD Diesel Data from Denver, LA and Tulsa



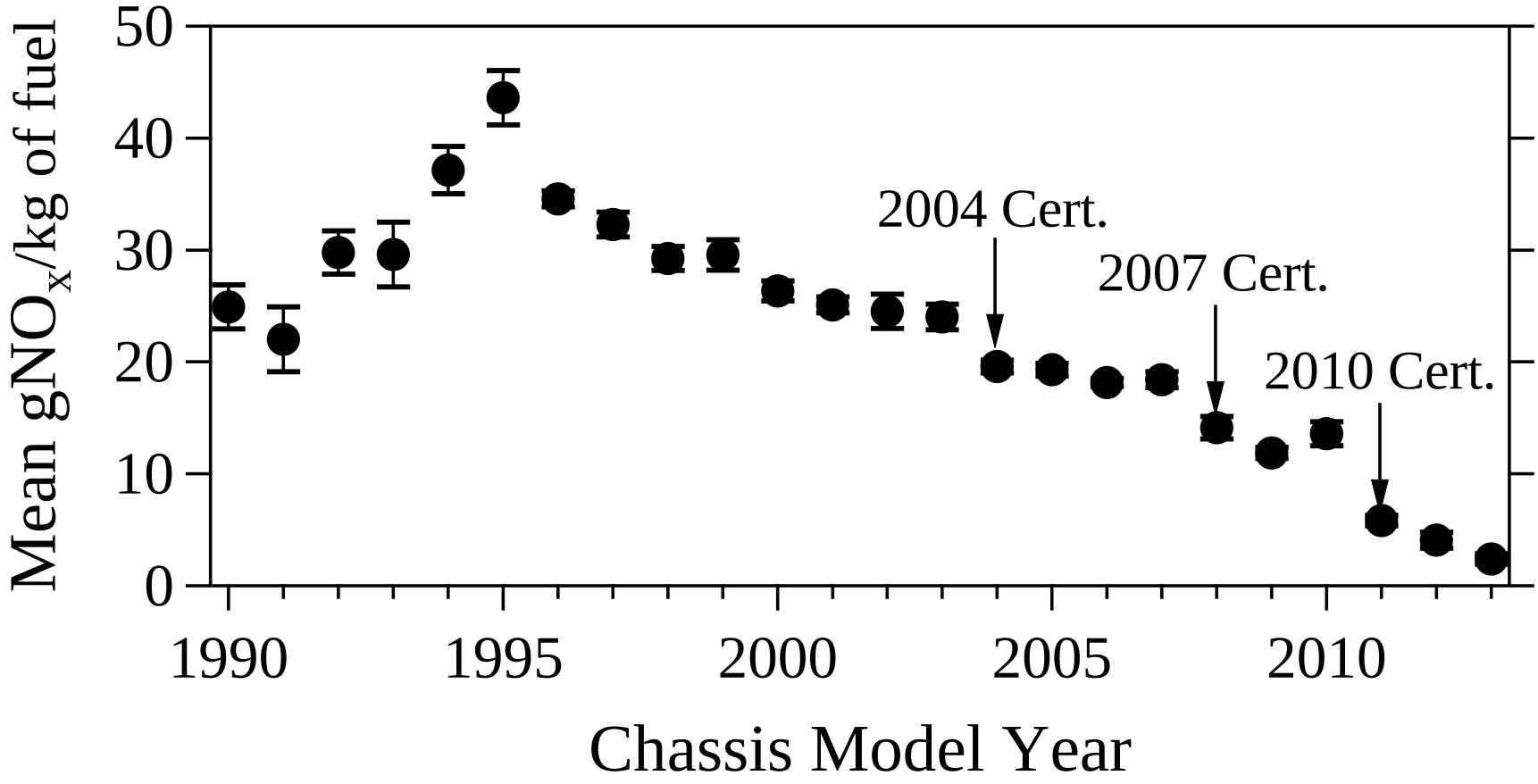
2013 LD 2 Liter Diesel NO_2/NO_x Ratios

2013 Data from Denver, LA and Tulsa



Bishop and Stedman, Reactive Nitrogen Species Trends in Light/Medium Duty U. S. Fleet Emissions. In preparation for ES&T.

2012 Heavy-duty NO_x Emissions Peralta Weigh Station California

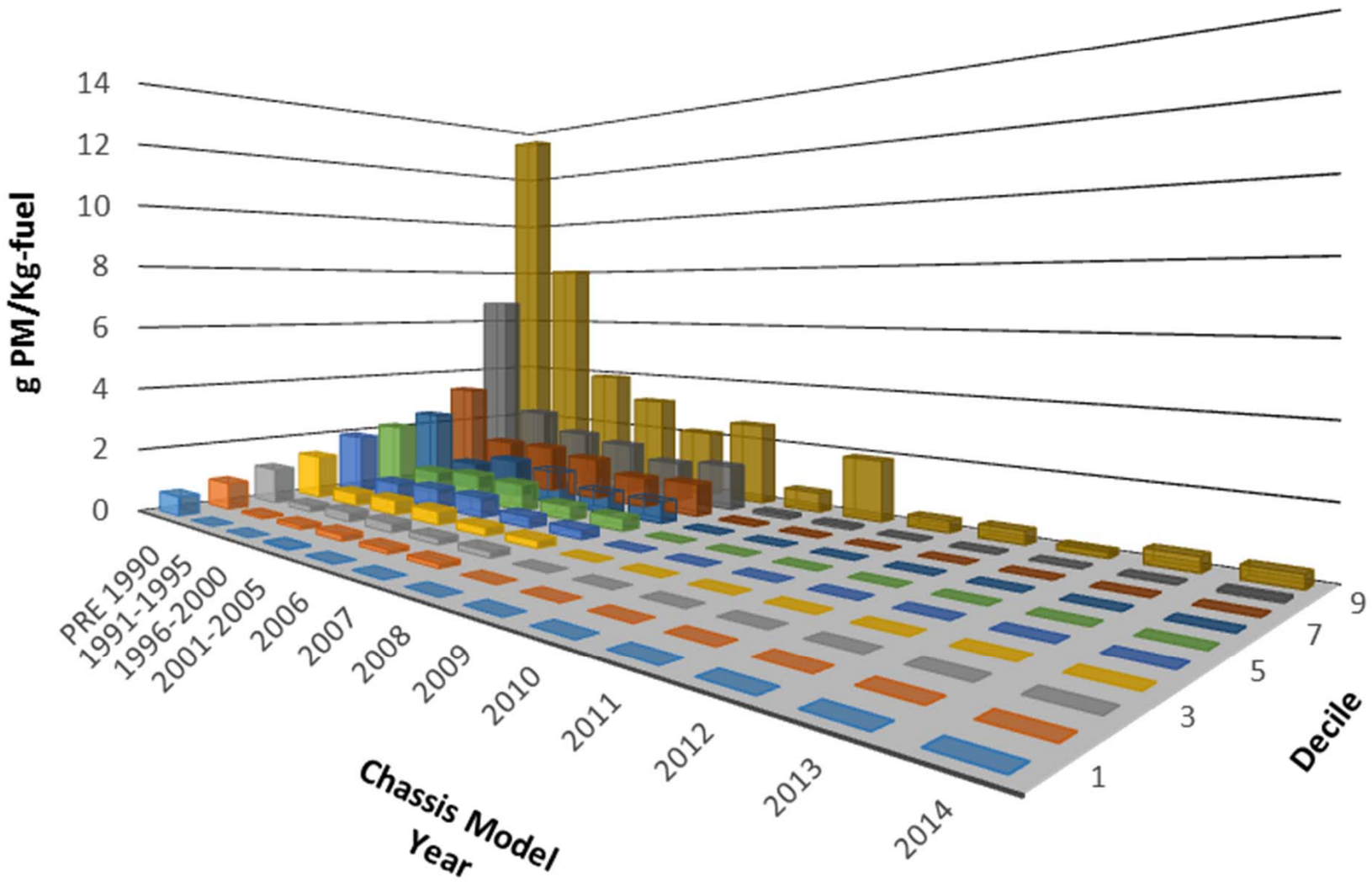


Bishop et al., Heavy-Duty Truck Emissions in the South Coast Air Basin of California. *Environ. Sci. Technol.* **2013,** 47, (16), 9523-9529

On-road Heavy-duty Measurement System

Bishop et al., On-road Heavy-duty Vehicle Emissions Monitoring System. *Environ. Sci. Technol.* **2015,** 49, (3), 1639-1645.

2013 Heavy-duty PM Emissions Cottonwood Weigh Station California



Summary

- We've made lots and lots of vehicle emission measurements with FEAT!
- The "Great News" is that the US transportation fleet continues to have lower and lower emissions.
- The not so great news is that because of the skewed nature of emissions distribution a minority of vehicles (broken ones) holds the fleet back from realizing even lower emission levels.
- Since broken vehicles dominate emission distributions special emission certifications and so-called "clean fuels" are generally irrelevant.
- Regulations that reward the user usually meet great success.
- Those that don't are usually nullified by human nature.

References

- Bishop, G. A.; Starkey, J. R.; Ihlenfeldt, A.; Williams, W. J.; Stedman, D. H., IR long-path photometry, A remote sensing tool for automobile emissions. *Anal. Chem.* **1989,** 61, 671A-677A, DOI: 10.1021/ac00185a746.
- Bishop, G. A.; Stedman, D. H., A decade of on-road emissions measurements. *Environ. Sci. Technol.* **2008,** 42, (5), 1651-1656, DOI: 10.1021/es702413b.
- Bishop, G. A.; Schuchmann, B. G.; Stedman, D. H.; Lawson, D. R., Multispecies remote sensing measurements of vehicle emissions on Sherman Way in Van Nuys, California. *J. Air Waste Manage. Assoc.* **2012,** 62, (10), 1127-1133, DOI: 10.1080/10962247.2012.699015.
- Bishop, G. A.; Schuchmann, B. G.; Stedman, D. H., Heavy-Duty Truck Emissions in the South Coast Air Basin of California. *Environ. Sci. Technol.* **2013,** 47, (16), 9523-9529, DOI: 10.1021/es401487b.
- Bishop, G. A.; Stedman, D. H., The recession of 2008 and it impact on light-duty vehicle emissions in three western US cities. *Environ. Sci. Technol.* **2014,** 48, 14822-14827, DOI: 10.1021/es5043518.
- Bishop, G. A.; Hottor-Raguindin, R.; Stedman, D. H.; McClintock, P.; Theobald, E.; Johnson, J. D.; Lee, D.-W.; Zietsman, J.; Misra, C., On-road Heavy-duty Vehicle Emissions Monitoring System. *Environ. Sci. Technol.* **2015,** 49, (3), 1639-1645, DOI: 10.1021/es505534e.