

*Black carbon controls
in California:
emissions, abatement, and
knowledge gaps*

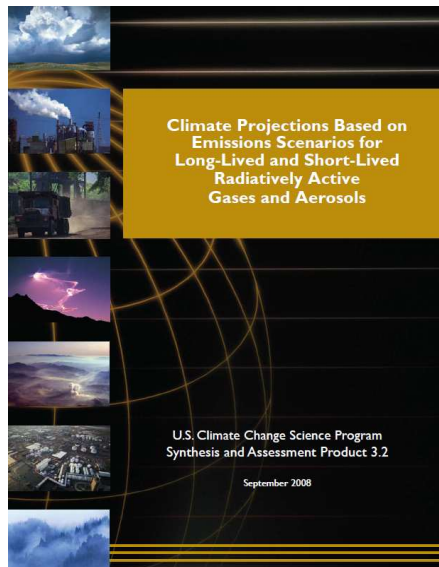
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The case for BC abatement is well made in the scientific/policy mainstream

Air Quality and Health



Reduction of emissions from surface transportation offers greatest potential for substantial, simultaneous improvement in local air quality and reduction of global warming in North America, US CC Sci. Program, Synthesis and Assess. Product 3.2, 2008

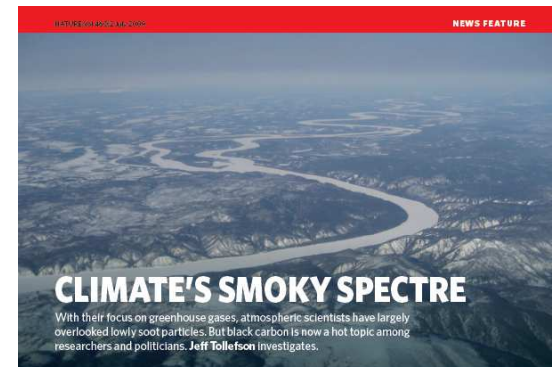
Environ. Sci. Technol. 2005, 39, 5921–5926

Can Reducing Black Carbon Emissions Counteract Global Warming?

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Field measurements and model results have recently

The climatic impact has been known for Earth's radiative balance have a cooling effect (BC) warm the system Earth-atmosphere by field measurements. Recent literature suggests change mitigation to minimize climatic impact. Once both BC are considered agents of positive change: could mitigation reductions in place



American Clean Energy and Security Act 2009 (House)
Carper's Amendment to Interior Appropriations Bill
(Senate)
– direct EPA to find the most cost-effective ways to reduce BC emissions

Steve Warren spent his spring break island-hopping with a couple of friends, but they didn't go to beach in the sun. Instead, his team from the University of Washington in Seattle found the Canadian Arctic, digging pits in the snow and collecting hundreds of samples to take back to the lab. The targets of their expedition, hidden in all the whiteness, were specks of something called black carbon.

These dark particles, the major contributors of soot, are the legacy of incomplete combustion in diesel engines, coal power plants, agricultural burning and wildfires, far to the south. Prevailing winds sweep black carbon and other pollutants into the Arctic, where they circulate in a dirty yellow haze (pictured above), until storms wash them out of the air. Warren's team was collecting those that fell among the snow flakes.

The second haze has long plagued the Arctic, but scientists are only now taking stock of a different and potentially riskier dimension of soot. As in a name would suggest, black carbon absorbs sunlight. These particles heat the atmosphere while aloft, when they settle on the snow, they hasten its melting. This response, the dark land and water, which absorb more of the sun's energy and thereby drive up the regional

temperature. Recent research suggests that black carbon could be responsible for a large fraction of the Arctic warming. Soot also takes a toll elsewhere. In southeast Asia, studies suggest that it is choking the moisture supply for the Indian monsoon and contributing to the extent of mountain glaciers that provide fresh water for more than a billion people.

At this point, scientists lack enough data to definitively conclude how strongly black carbon is affecting the climate. But some studies suggest that it could be second behind carbon dioxide in terms of its contribution to global warming. There is a crucial difference between the two pollutants, however: not particles hanging in the atmosphere for just a few weeks, whereas CO₂ molecules can remain in the air for centuries. This means that efforts to curb soot emissions could reap immediate climatic benefits. That possibility has recently pulled soot, which has conventionally been seen as a public health issue, into the climate-policy arena.

"There's a urgency about this: we still don't have a viable way of cutting down CO₂," says Yoram Ben-Zur, an atmospheric scientist at Scripps Institution of Oceanography in La Jolla, California. By comparison, reducing soot emissions seems remarkably

simple and cheap. "It's not going to take 30 or 100 years to do it. If you halt the black carbon, it will be gone in two weeks."

Many data
Long before the current interest in black carbon, an accidental observation by Warren led him to do some pioneering work on the pollutant. In 1996, he and Vireni Virci, a scientist at the National Center for Atmospheric Research in Boulder, Colorado, were having trouble developing a mathematical model of snow reflectance, or albedo. The two couldn't make their calculations align with the latest albedo measurements in the Arctic because the snow in their study was reflecting less light than expected. "It turned out the snow was being collected downstream from a diesel generator," Warren says.

Warren went on to collaborate with Antony Clarke at the University of Washington, who organized the first survey of black-carbon deposition in the Arctic, largely using samples collected by researchers who were going there for other reasons. On the basis of those data, Clarke concluded in 1999 that soot could have a measurable effect on the Arctic climate. But his paper had little influence until Jim Hansen, the main figure for alerting the world to the threat of CO₂ pollution, pressed the issue years later. In 2006, Hansen, director of New York's Goddard Institute for Space Studies, proposed

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First, the caveats

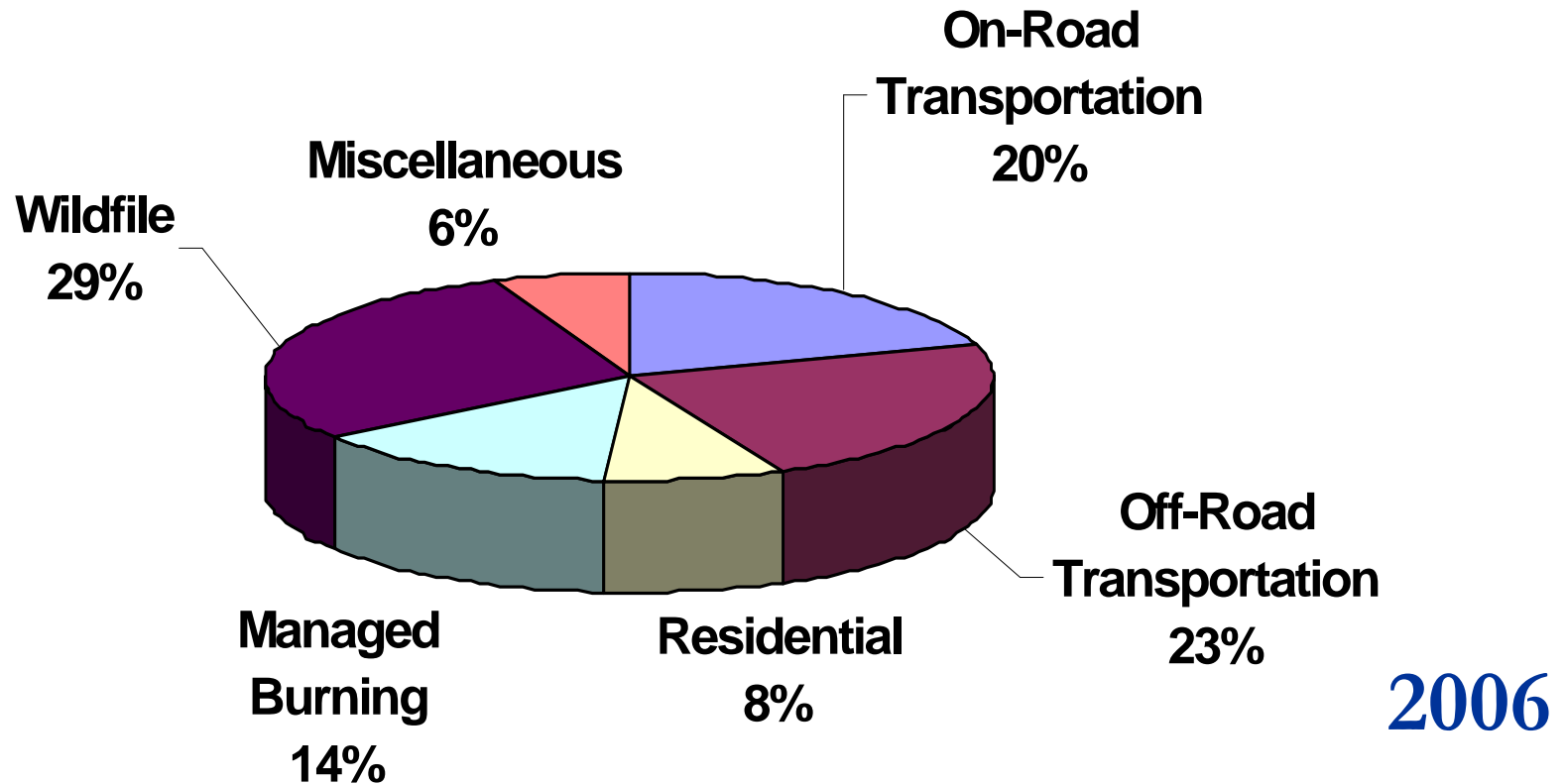
- ❑ **You can't manage it if you can't measure it**
 - Optical and thermal methods (to measure BC and EC) in contradiction
 - No single universally accepted standard (yet!) for BC or EC measurement
 - Separation of organic carbon (OC) from EC is difficult
 - Discrepancies due to local aerosol characteristics and meteorology
- ❑ **Properties most relevant to climate**
 - Optical (absorption), mixing state (aged aerosol), size distribution not yet measured consistently
- ❑ **BC climate impacts differ at global, regional, and local scales**
- ❑ **Principal uncertainties: projection of future emissions and indirect BC effects***
- ❑ **Preferred inventories are bottom-up approaches**
 - Experimental data scant for specific emission factors and activities
- ❑ **California-specific emission factors account for**
 - Unique mix of fuels, combustion technology, operating conditions, and aggressive emission control programs

References:

- 1) Bond, T.C., Bergstrom, R.W. (2006). Light absorption by carbonaceous particles: An investigative review, *Aero Sci and Tech* 40, 27-67.
- 2) M. Moffet, R. C., and Prather, K. A.(2009): In-situ measurements of the mixing state and optical properties of soot with implications for radiative forcing estimates, *PNAS*, 106(29), 11872-11877, doi: 10.1073/pnas.0900040106.
- 3) CARB study (04-307) by Chow et al. (2008).

*4) US Climate Change Science Program, Synthesis and Assess. Product 3.2, 2008

California BC emissions

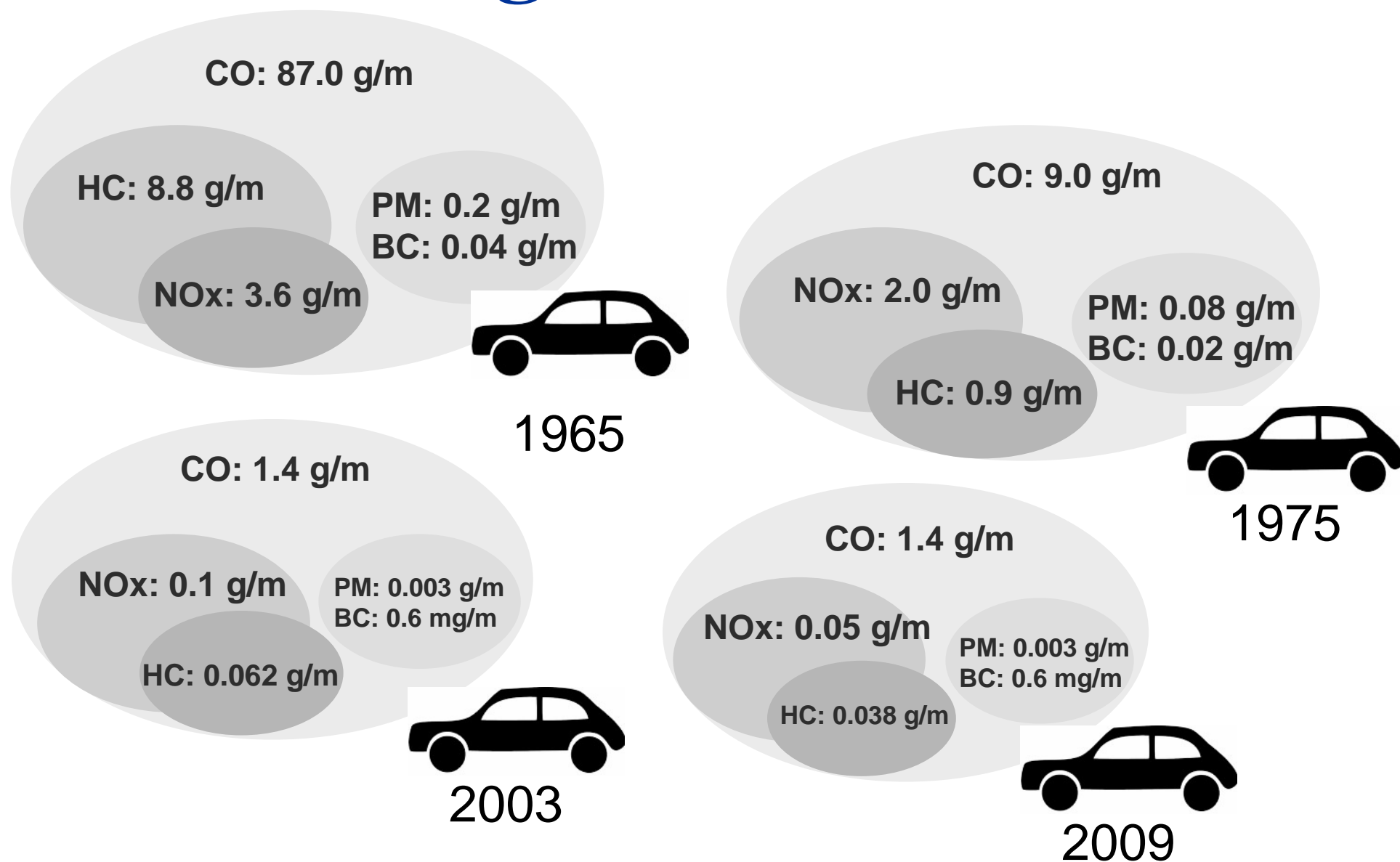


- $PM_{2.5,i}$ from emissions inventory
- $PM_{2.5,i} \times [BC/EC \text{ and } OC]_i$
- $BC/EC \text{ and } OC$ for source_{*i*} (i.e, source profile)

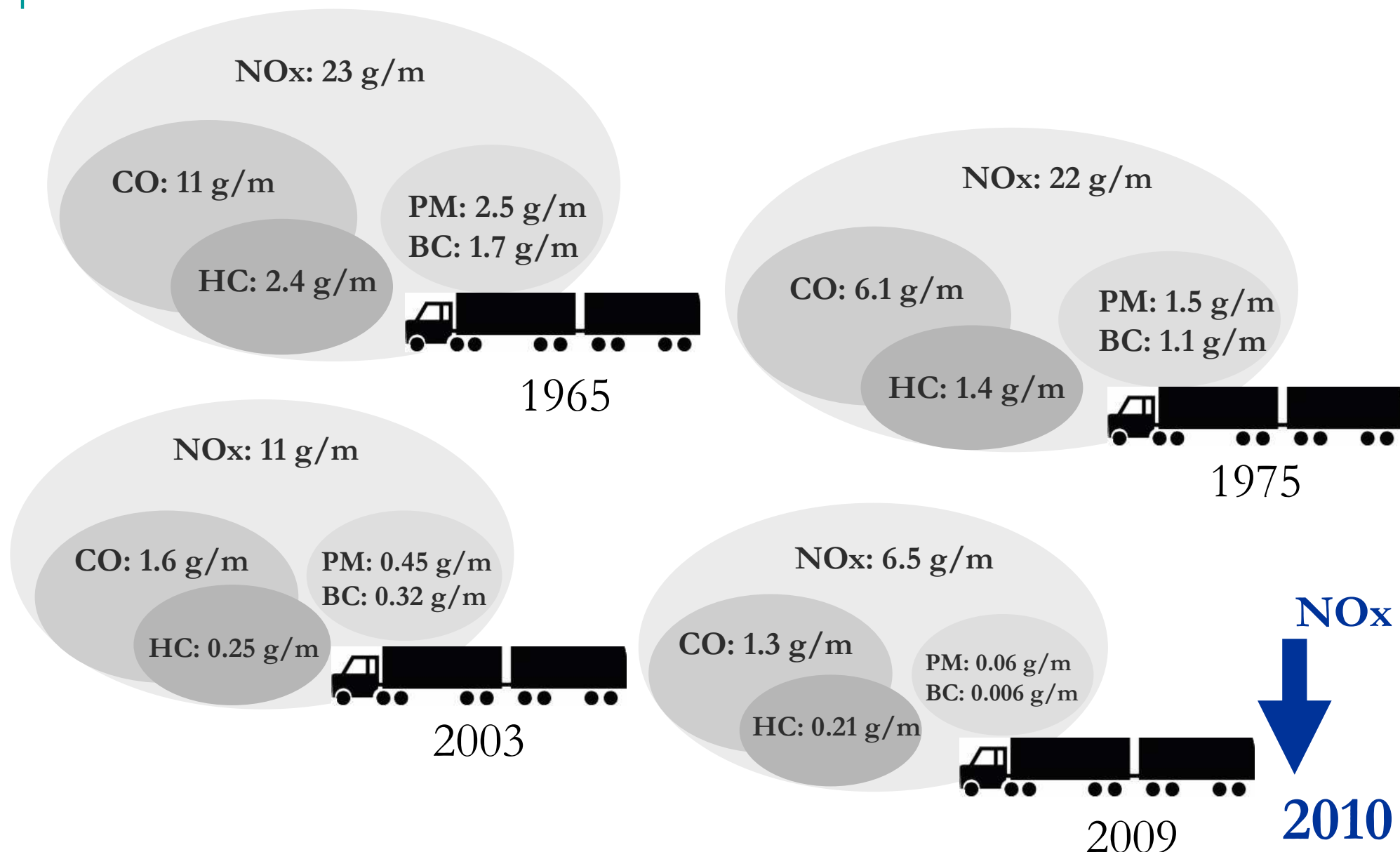
Transportation emissions are key focus for air quality and climate



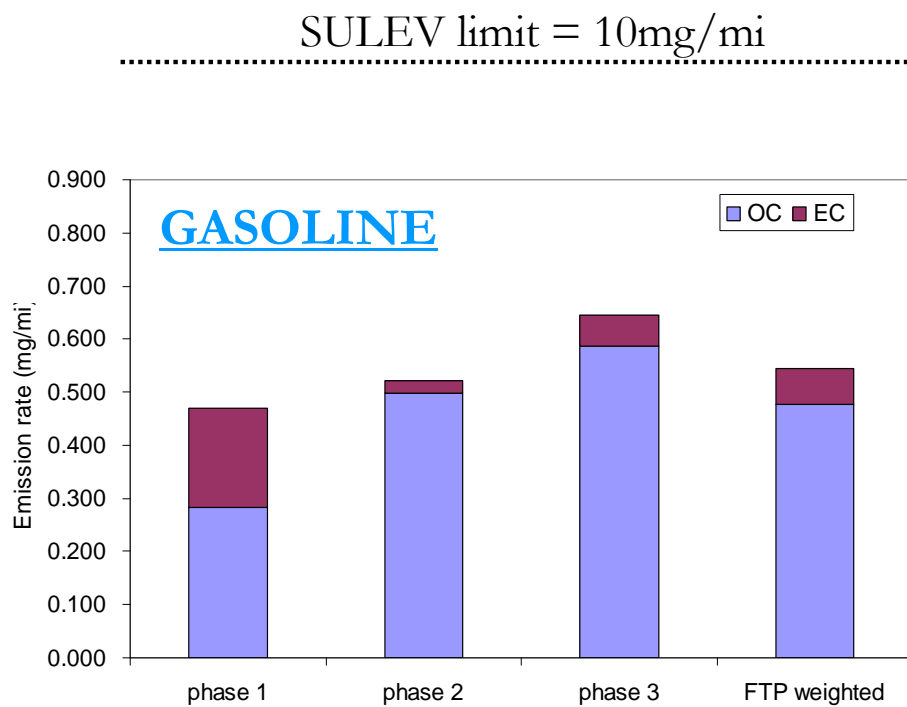
Trends in gasoline car emissions



Trends in diesel truck emissions

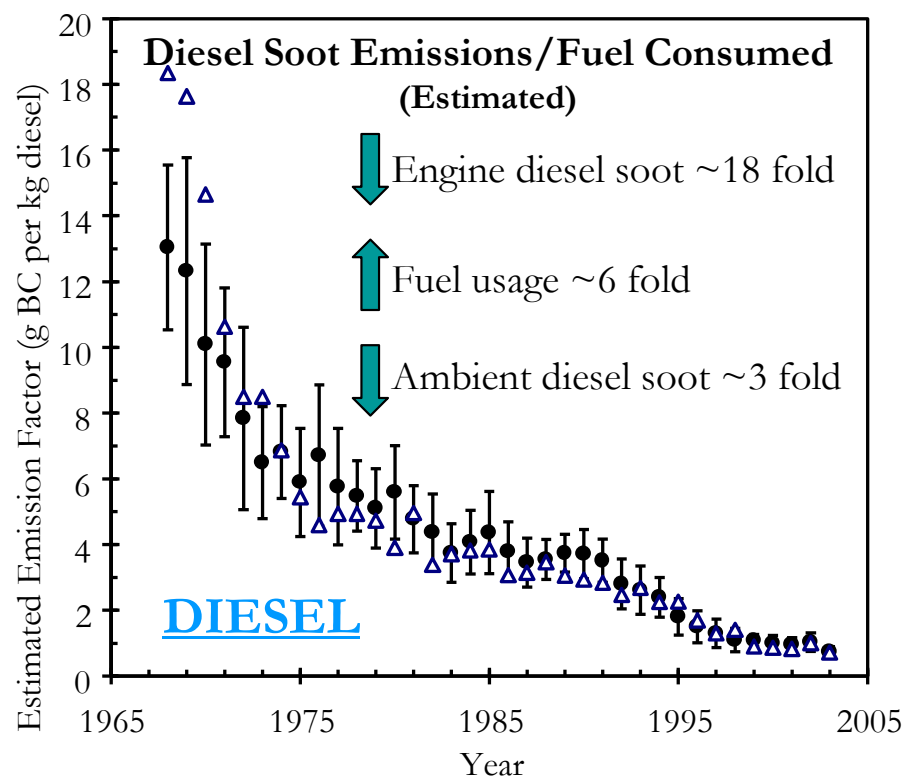


Research confirms progress on PM reductions



Fleet averaged emission rates of OC and EC for SULEVs, not corrected with background.

Li, W., Collins, J.F., Norbeck, J.M., Cocker, D.R., and Sawant, A., "Assessment of Particulate Matter Emissions from a Small Fleet of In-Use ULEV and SULEV Vehicles," SAE Tech. Paper 2006-01-1076



Kirchstetter, T.W., Aguiar, J., Tonse, S., Fairley, D., and Novakov, T., "Black carbon concentrations and diesel vehicle emission factors derived from coefficient of haze measurements in California: 1967-2003," Atmospheric Environment, 42(3): 480-491, 2008

Diesel control



Health = #1 policy driver for diesel PM/BC control

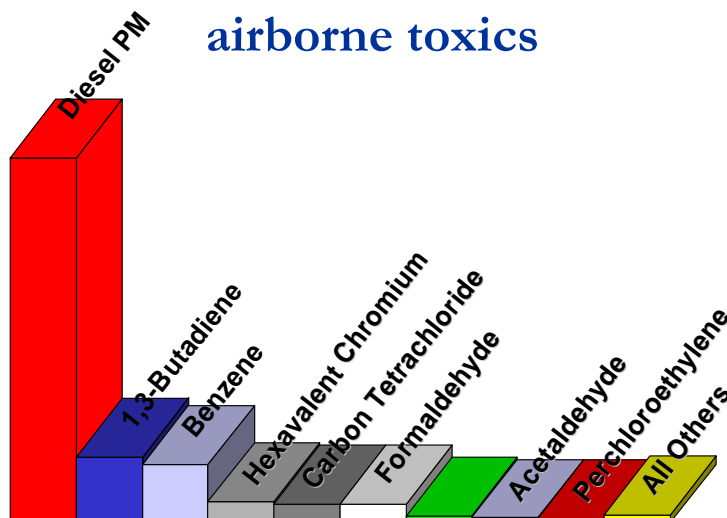
Air pollution and premature death*

California estimates for 2005

Pollutant	Annual Deaths*
PM2.5	18,000
Ozone	540
Toxic Air Contaminants	400

* At least a factor of two uncertainty.

Relative cancer risk by inhalation from airborne toxics



Impact of diesel PM on California*

Premature death (3500 per year*)

Lung cancer (250 per year)

Decreased lung function in children

Chronic bronchitis

Increased hospitalizations

Aggravated asthma

Increased respiratory symptoms

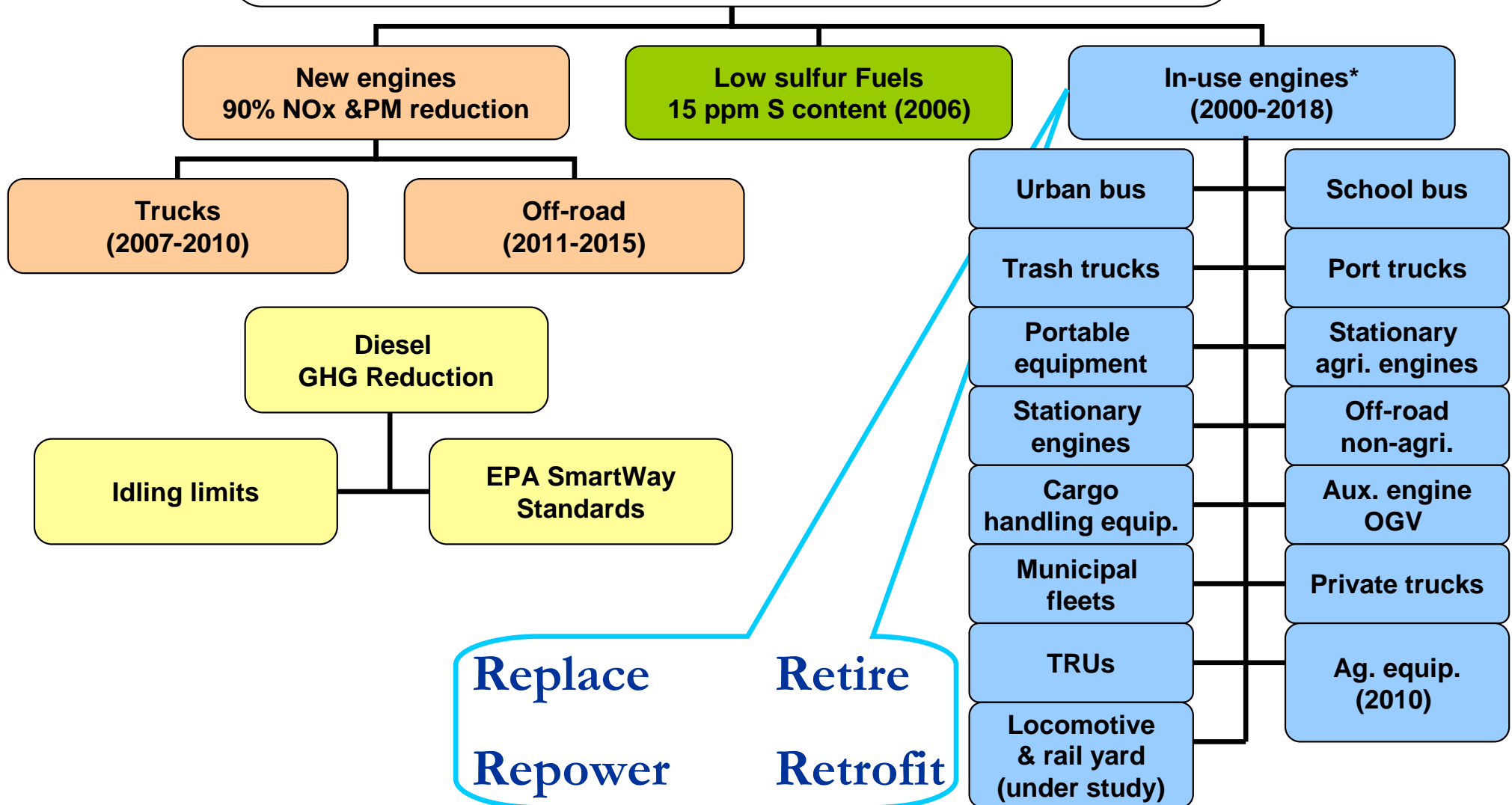
Lost work days

Reduction in visibility (10-75% of total)

* www.arb.ca.gov/research/health/pm-mort/pm-mort.htm

*Source: California Air Resources Board. Methodology for Estimating Premature Deaths Associated with Long-term Exposures to Fine Airborne Particulate Matter in California. May 22, 2008. Staff Report. <http://www.arb.ca.gov/research/health/pm-mort/pm-mortdraft.pdf>

CARB's Diesel Risk Reduction Plan (DRRP) (Diesel PM 85% below 2000 in 2020)



*With millions \$ per year in incentive funding provided

www.arb.ca.gov/diesel/dieselrrp.htm

Diesel engine applications covered by DRRP

On-road Vehicles



On-road Truck



Passenger Bus



Concrete Mixer



Hay Squeeze



Water Truck



Fuel Tank Truck



Reefer Van



Drill Rig

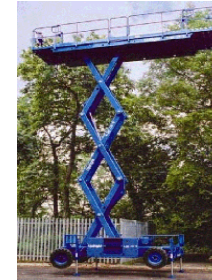


Dump Truck



Tow Truck

Off-road Vehicles



Aerial Lift



Loader



Backhoe Loader



Ground support equipment



Skid Steer



Belt Loader



Dozer



Mast Forklift

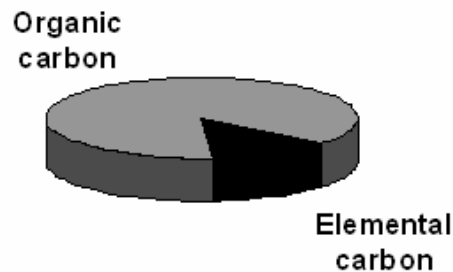


Telescopic Forklift

BC fraction in PM vehicle emissions

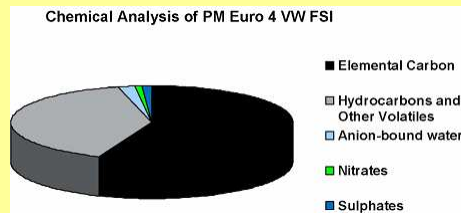
Gasoline Car

Conventional



- PM emissions < 1 mg/mile
- << current SULEV PM standard of 10 mg/mile
- Most PM is OC
- BC increases for high PM emitters

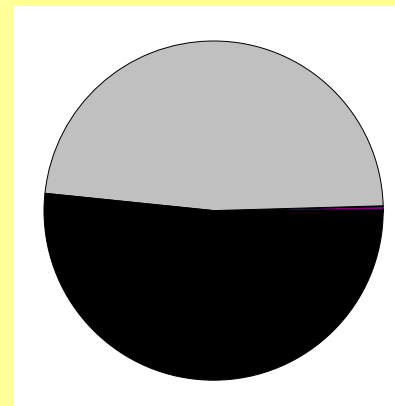
Direct injection



- Very good for CO₂ reduction
- still < current SULEV PM standard
- But PM > conventional gasoline
- Also > particle counts
- Most PM is BC or soot like diesel

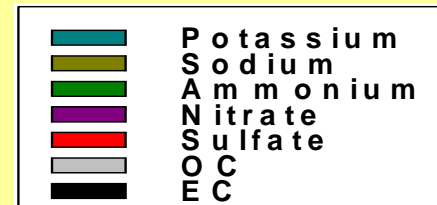
Diesel Truck

Pre-2007



- PM standard at 100 mg/bhp-hr
- Most PM is EC or soot

2010

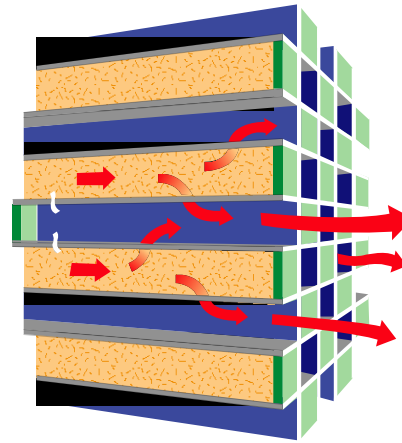
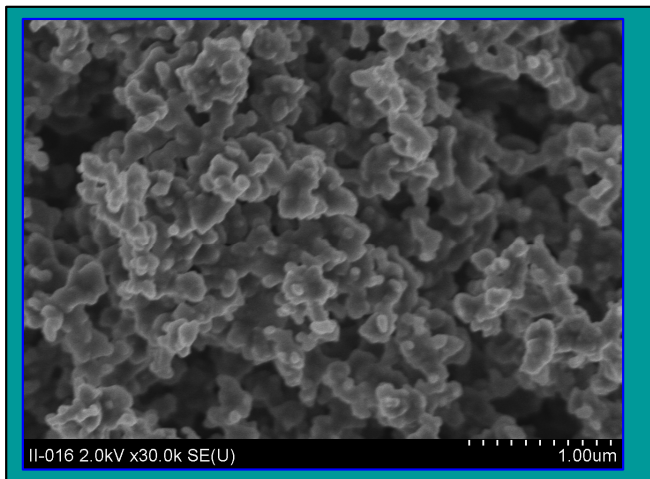


- PM emissions << standard 10mg/bhp-hr
- Little BC (EC or soot)

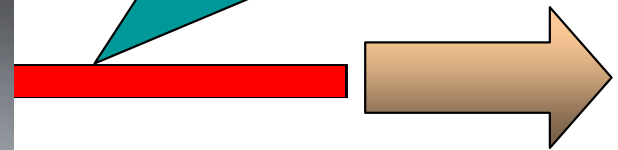
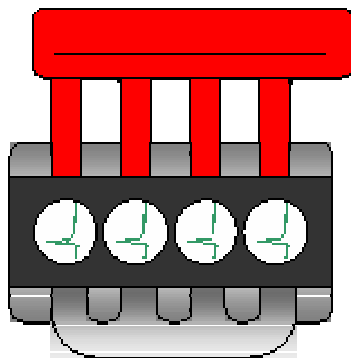
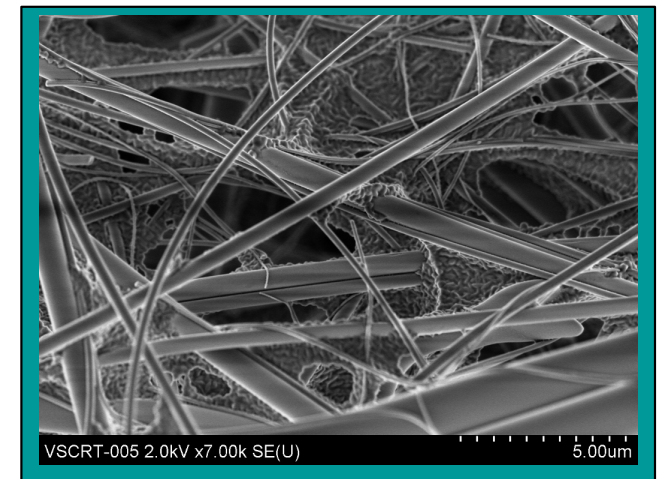
CARB evaluating LEV III (more stringent PM standard)

DPF (for retrofit or OE installation) is game changing solution

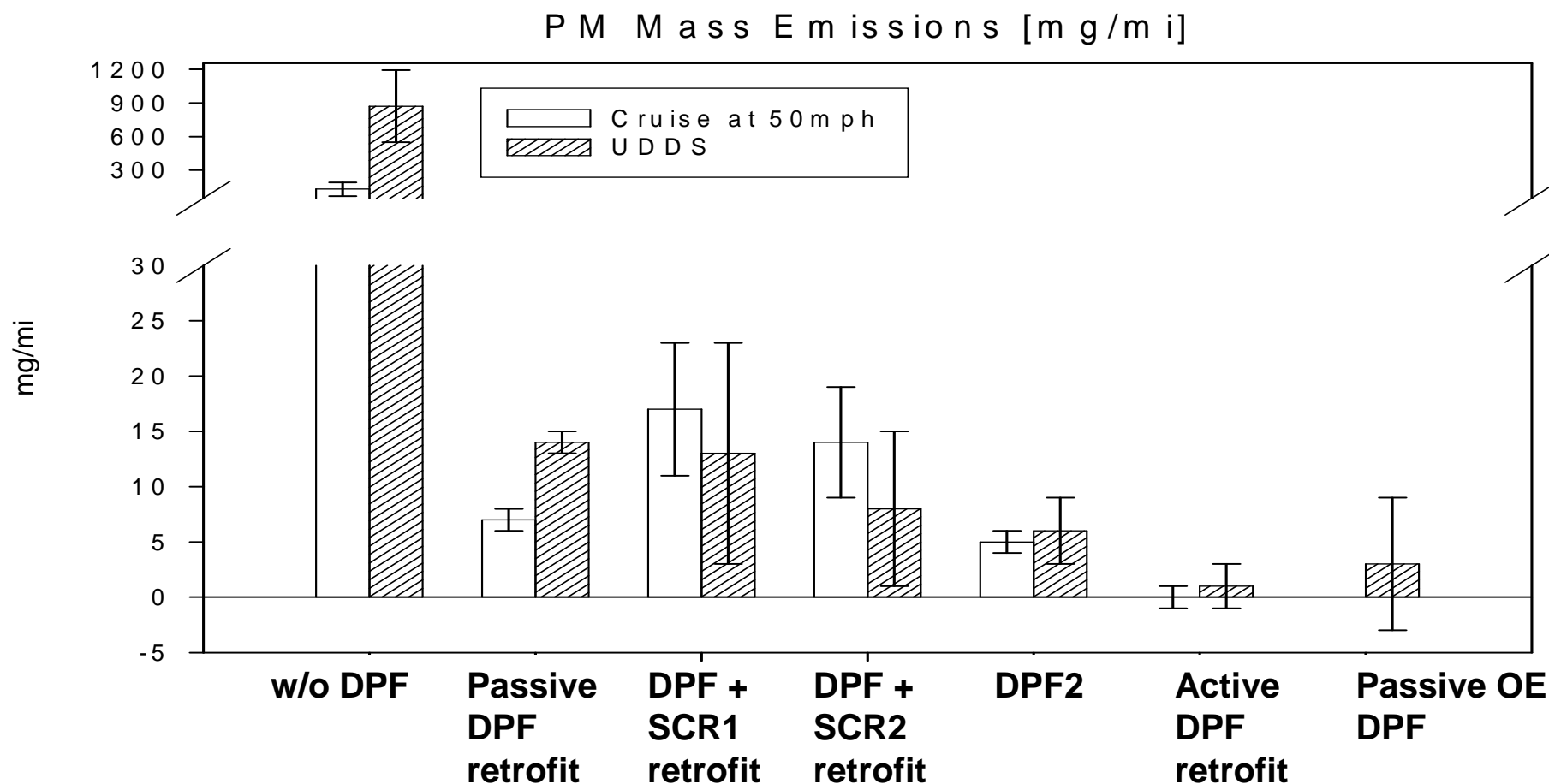
Pre-DPF soot agglomerates



Post-DPF clean sample



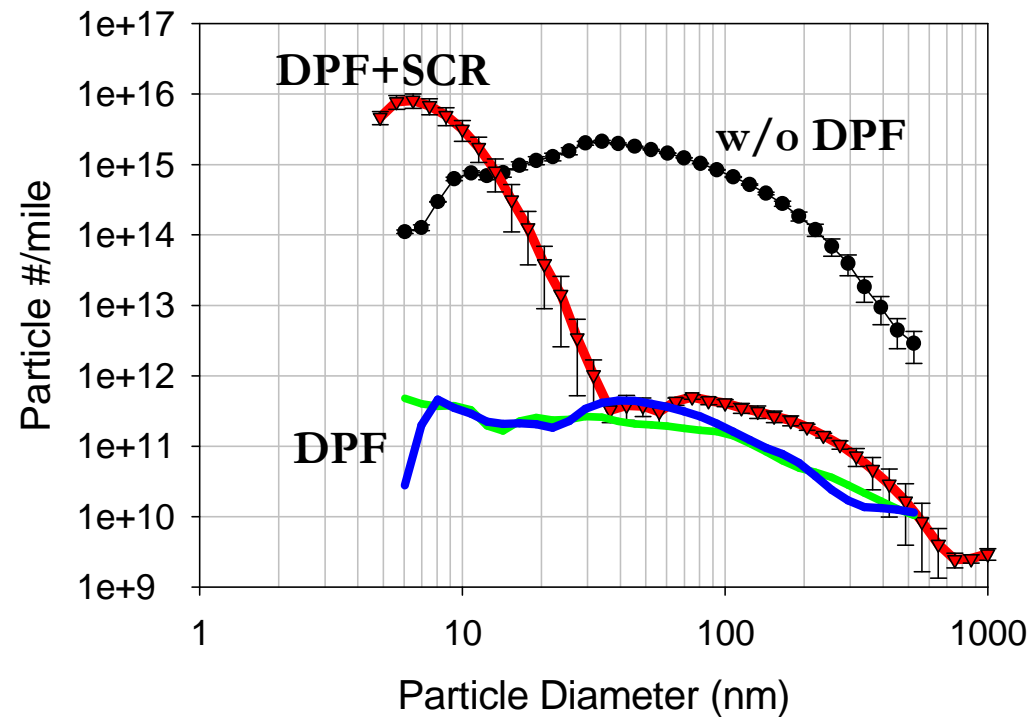
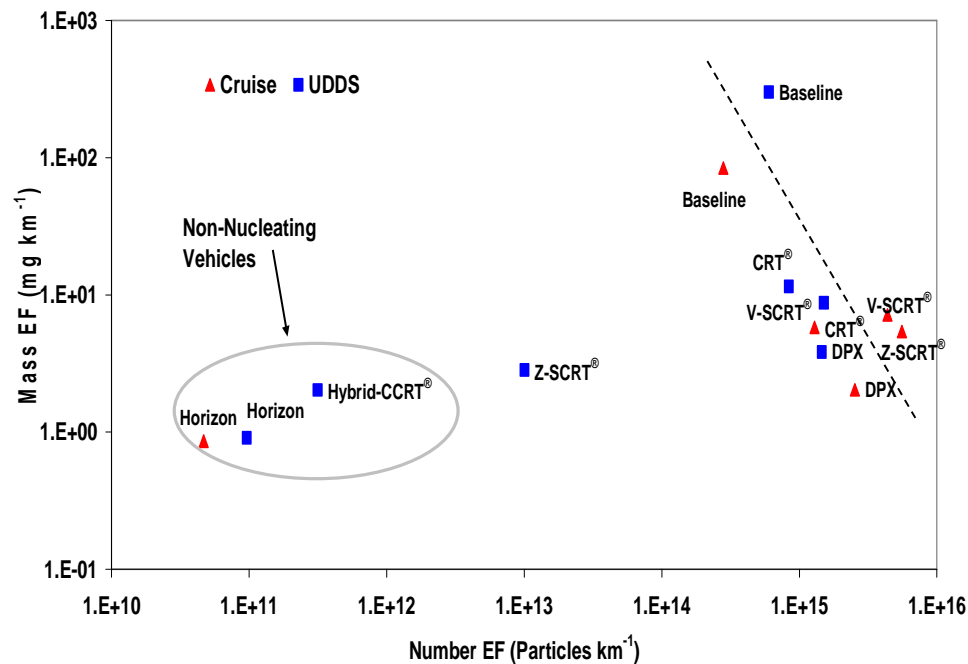
Significant PM(BC) reductions by various types of DPFs



Source: Herner, J.D., Huai, T., Collins, J., Robertson, W., Dwyer, H., Hu, S., and Ayala, A., "The effect of advanced aftertreatment for PM and NOX control on heavy duty truck emissions," *Environmental Science and Technology*, **2009**, 43, 5928-5933

Clean diesel exhaust (Post-DPF particles)

EC(soot or BC) is eliminated; if particles present, they are mostly very small sulfate

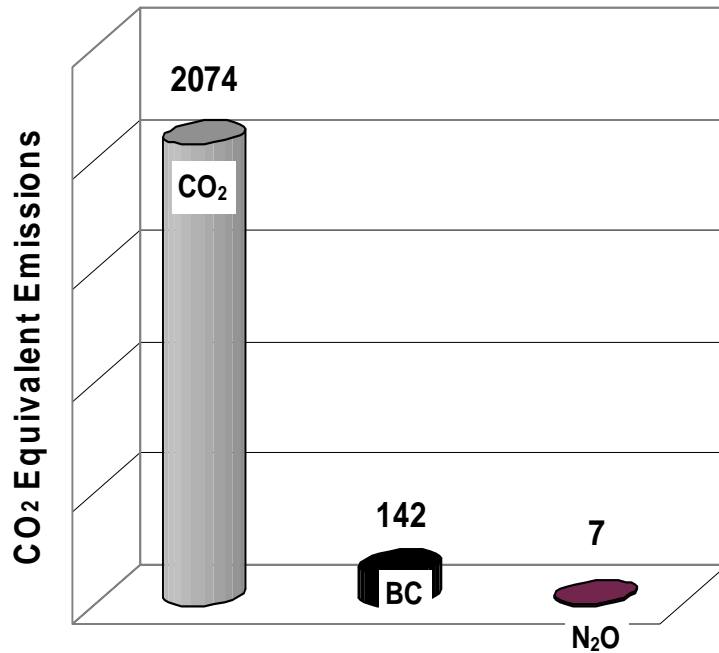


Biswas, S., Hu, S., Verma, V., Herner, J.D., Robertson, W.H., Ayala, A., and Sioutas, C., "Physical Properties of Particulate Matter from Newer Heavy-Duty Diesel Vehicles Operating with Advanced Emission Control Technologies," *Atmospheric Environment*, 42 (2008) 5622-5634.

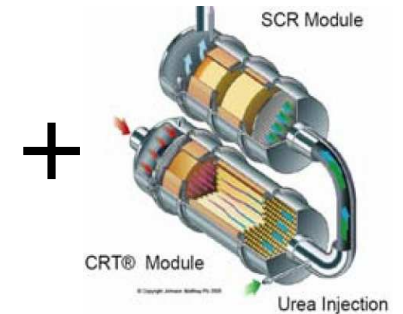
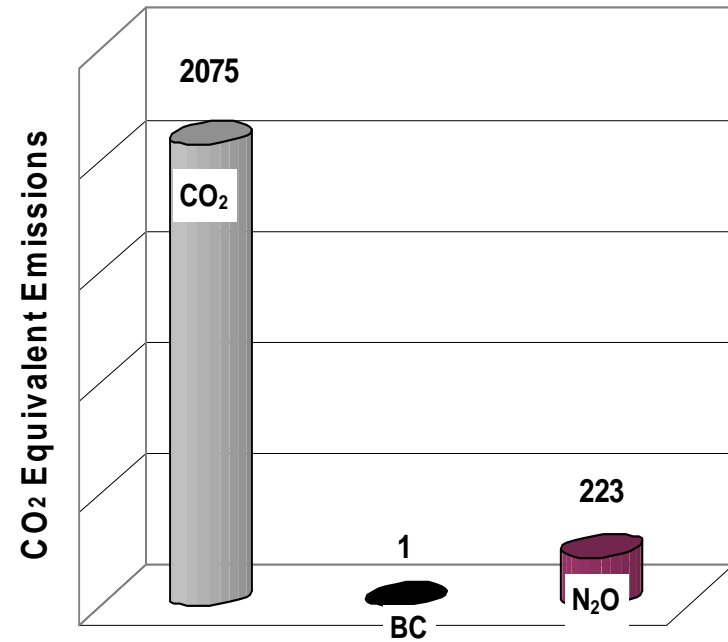
Hu, S., Herner, J.D., Robertson, W., Huai, T., Collins, J., Dwyer, H., and Ayala, A., "Nucleation Mode Particle Emissions from In-use Heavy Duty Vehicles Equipped with Diesel Particulate Filter (DPF) and Selective Catalytic Reduction (SCR) Retrofits," *Environmental Science and Technology*, 2009, In preparation

Global warming emissions

Diesel w/o DPF



2010 Prototype Diesel Retrofit (DPF+SCR)



Other BC sources



Southern California Wildfire



Managed Burning



Residential -Fireplace

❑ Residential wood burning

- ❑ Mandatory wood burning curtailment when air quality is poor in winter (e.g., in Bay Area, Sacramento, San Joaquin Valley, South Coast)
- ❑ Wood stoves & fireplace change out incentive program to replace older polluting units with cleaner units (e.g., \$150-750 voucher in the Sacramento County)

❑ Managed burning

- ❑ ARB Smoke Management Program provides guidelines for agricultural and prescribed burning operations in California (effective in 2001)
- ❑ Agricultural burning prohibited unless no economically feasible alternatives available (e.g., in San Joaquin Valley)
- ❑ Working groups involving different stakeholders to find alternatives to burning (e.g., use as a fuel in biomass plants)

Closing remarks

- Science supports co-benefits of BC reductions for air quality and climate protection
- California implementing clear policies
- Taking aggressive action for reducing PM (and BC)
 - ❑ Major programs in place for mobile sources (gasoline, diesel, etc.)
 - ❑ Tangible progress
 - ❑ Diesel PM reductions is key focus for air quality and health
 - ❑ Concurrent climate benefit from BC reductions
- New policies will emerge
 - ❑ California's LEVIII program
 - ❑ US Congress directs EPA to look into BC