Regional and Near-source Modeling of Increased NO_2 Emissions from Catalyst-based PM Filters for Heavy-duty Diesel Vehicles in California

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The Governor's Targets

- 50% improvement in air quality from 2003 to 2010
- No net emission increase for 2-3 times more goods transport by 2020
- Greenhouse Gases
  - 2000 levels by 2010
  - 1990 levels by 2020
  - 80% below 1990 levels by 2050
- Hydrogen Highway
- Green Buildings

Governor Schwarzenegger's Environmental Action Plan

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Impact of Diesel PM on California

- Premature death (2000 per year)
- Lung cancer (250 per years)
- Decreased lung function in children
- Chronic bronchitis
- Increased hospitalizations
- Aggravated asthma
- Increased respiratory symptoms
- Lost work days
- Reduction in visibility (10-75% of total)
- Global warming (2^{nd} to CO_2)

Source: Lloyd and Cackette (2001) JAWMA, 51, 809-847

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75% Less Diesel PM by 2010
(On- and Off-road Vehicles, Stationary Engines)

- New vehicle and engine standards (90% control)
- Low-sulfur (15 ppmw) diesel fuel and alternative fuels
- Retrofits/re-powering with funding ($65M per year)
- International Diesel Retrofit Advisory Committee
- Anti-idling measures
- Enforcement programs

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

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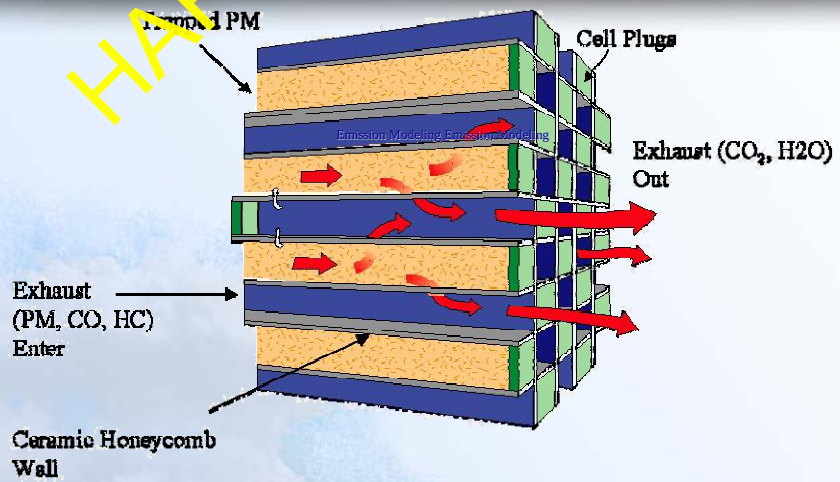
Catalyst-based PM Filter



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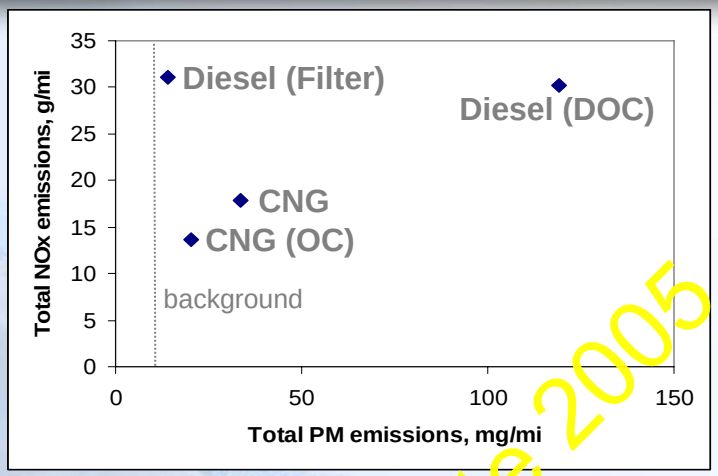
Transit Bus NO_X and PM Emissions
(Central Business District driving cycle)



www.arb.ca.gov/research/cng-diesel/cng-diesel.htm

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Pollutants Reduced by PM Filter

	% Reduction	Study
CO	90%	various
Total PM	85%	various
Total VOCs	90%	various
Total carbonyls	90%	NYDEC
Formaldehyde	93%	MTC
Acetaldehyde	82%	MTC
Benzene	77%	CARB
Total PAHs	80%	NYDEC
nitro-PAHs	95%	NYDEC

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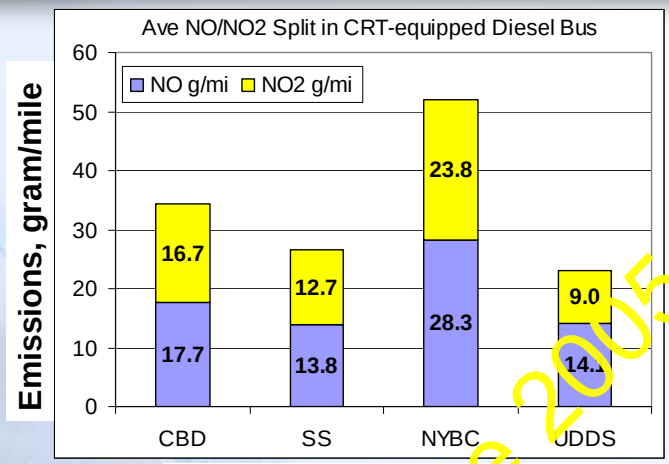
Transit Bus NO and NO_2 Emissions

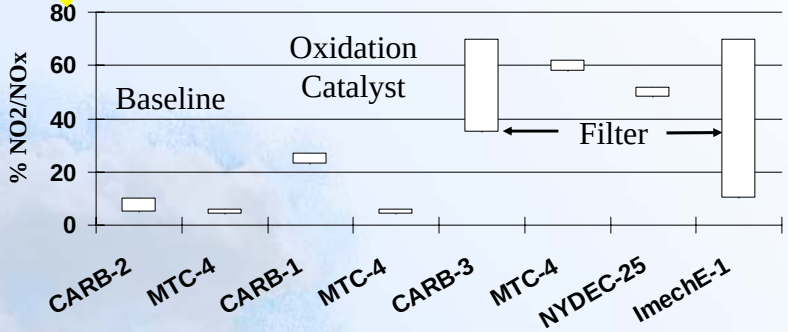


Dynamometer Duty Cycle

Source: Ayala, et al. (2002) SAE, 735-747

Other Diesel NO_2/NO_X Studies

In a catalyst plus soot filter system, the conversion of NO to NO_2 is a function of both exhaust temperature and fuel sulfur content.



Study - No. of vehicles

NO_2 Accelerates Photochemistry

Ozone increases with NO_2/NO ratio and sunlight

NO ⟶ NO_2

a) Tailpipe (~5%)
b) Exhaust Plume (~5%) – NO > 1 ppm, low T
c) Ozone Mixing – limited by available ozone, temporarily destroys ozone
d) VOC oxidation (remaining 90%)

NO_2 ⟶ HNO_3 (nitric acid) ⟷ NH_4NO_3 (secondary $PM_{2.5}$)
(sunlight, ozone, VOCs) (NH_3, low T and SO_2, high RH)

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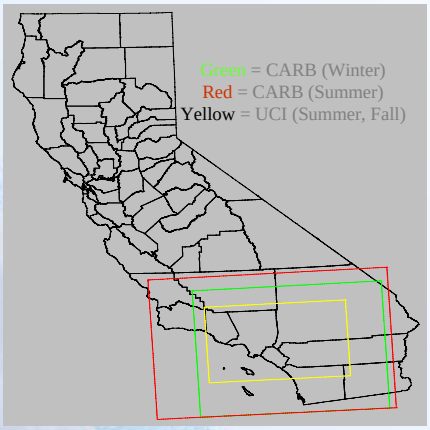
Los Angeles Episodes

Summer (August), Fall (October), Winter (January)



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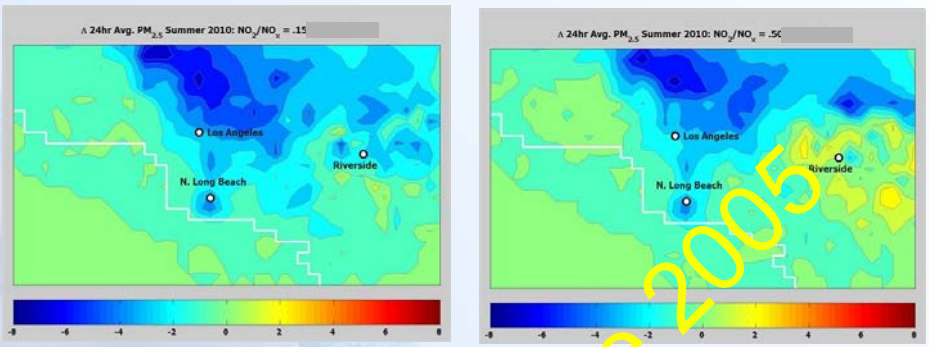
$PM_{2.5}$ Difference Plots ($\mu g/m^3$)

NO_2/NO_X = 15% NO_2/NO_X = 50%



CIT model / Extended-LCC chemistry / SCAPE2

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Photochemical Modeling Results

NO_2/NO_X (exc. 5% formation in exhaust plume)	15%	20%	**25%**	30%	50%
SUMMER	**% change** from baseline (diesel NO_2/NO_X = 10%)				
Peak 1-Hr O_3	-1	0	**0**	0	1
24-Hr O_3 Exposure > 90 ppb	-3	-2	**0**	2	5
Peak 24-Hr HNO_3	0	1	**1**	1	2
24-Hr HNO_3 Exposure	0	0	**2**	2	4
Peak 24-Hour $PM_{2.5}$	-3	na	**na**	-2	-1
24-Hour $PM_{2.5}$ Exposure > 65 ug/m^3	-9	na	**na**	-8	-6
FALL					
Peak 24-Hour $PM_{2.5}$	-6	na	**na**	-5	-3
24-Hour $PM_{2.5}$ Exposure > 65 ug/m^3	-13	na	**na**	-13	-13
WINTER					
Peak 1-Hr NO_2	1	6	**12**	18	41

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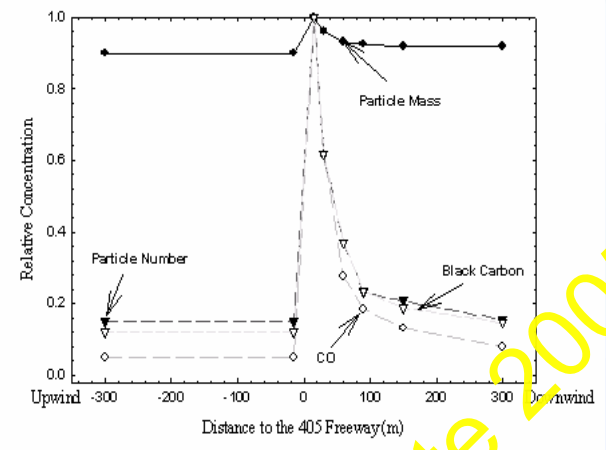
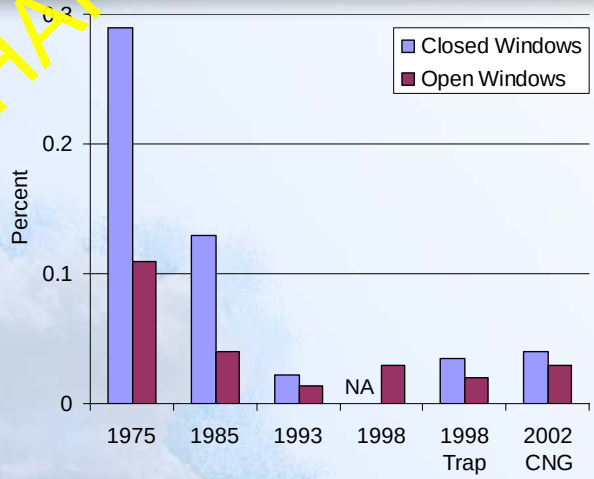
Is there an NO_2 exposure problem on freeways?



Source: Zhu, et al. (2002) JAWMA, 52, 1032-1042

Or from school bus "self-pollution"?



Source: Behrentz, et al. (2004) AE, 38, 3735-3746

NO_2 Exposure Modeling and Screening Analysis

Modeling

- CAL3QHCR and ISCST3
- Assumptions
  - 40% NO_2
  - 90% penetration
  - Hourly truck volumes and AQ
- Results (1-hour peak)
  - 0.180 ppm Freeway
  - 0.170 ppm 20 Idling School Buses

Measurement-based

- In-vehicle field measurements
- Assumptions
  - 20% NO_2
  - 90% penetration
  - Limited background analysis
- Results (15-minute peak)
  - 0.085 ppm Freeway
  - 0.028 ppm Self pollution
  - 0.071 ppm Following
  - 0.184 ppm Total

1-hour California air quality standard = 0.25 ppm (0.37 ppm for 15 minutes)

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Conclusions

- Catalyst-based diesel PM filters provide 80-95% reductions in PM, VOCs, and air toxics, but increased NO_2/NO_X fraction
- Increased NO_2 accelerates ozone, nitric acid and secondary $PM_{2.5}$ formation
- Photochemical modeling shows 15% NO_2 (over 5% baseline) offset by 90% VOC reduction
- No near-source NO_2 exceedances expected with 20% limit.

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Regulatory Efforts

- Revisit NO_2 Emission Standard
  - Account for NO_X aftertreatment
  - Account for pre-filter baseline NO_2 > 5%
  - Increase manufacturer certification flexibility
- Review NO_2 Air Quality Standard
  - Epidemiology (co-pollutant?): reduced lung function, hospital admissions, premature death
  - Human exposure studies: no effects at 0.25 ppm, but asthma effects may be important

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