Diesel Exhaust and Health
Remarkable Progress, Lingering Concerns

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Health Effects Institute

Clean Air Act Advisory Committee
Washington
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Diesel
Remarkable Progress, Lingering Concerns

Diesel Exhaust:

- Health Effects
- Regulatory Progress, Technological Advances
- What's been accomplished?
  - The HEI ACES Study
- New: Diesel and Cancer: The IARC Review
- The Lingering Challenge of Old Diesel, *especially in the developing world*

The Health Effects Institute

Trusted Science – Cleaner Air – Better Health

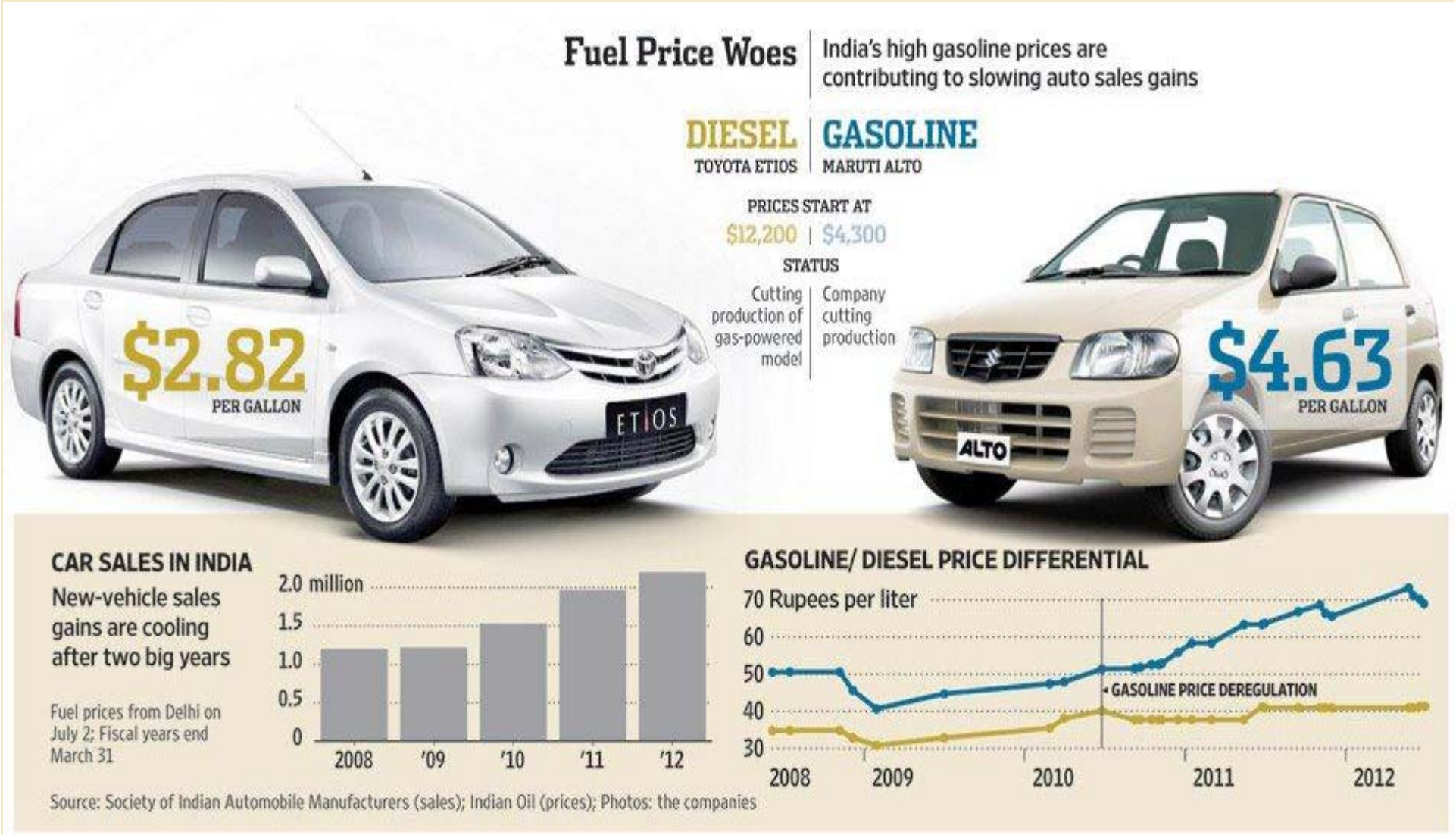
www.healtheffects.org

- Independent Non-profit Research Institute since 1980
- Joint Funding
  - Government (U.S. EPA, U.S. DOE, CARB,
  - Industry (Motor Vehicles, Oil, Chemical, Other)
  - *International (EU, Oil, AD Bank, USAID, Foundations)*
- Independent Board and Expert Science Committees
  - Competitive research selection; separate intense peer review
  - Over 270 studies of effects of many air pollutants, including *Health outcome studies* of health impacts of air quality interventions
- Full Transparency
  - All Results – positive and negative – published
  - All data accessible to others
- Does *not* take policy positions

What has driven steady use of diesel?

- Diesel Engines have substantial advantages:
  - Higher fuel efficiency
  - Lower CO and CO2 emissions
  - Heavy duty hauling capacity
  - Durability
  - Existing fuel and maintenance infrastructure
  - In some countries (Germany, India) tax subsidies

India: Diesel use promoted by government fuel subsidy *(WSJ June 12')*

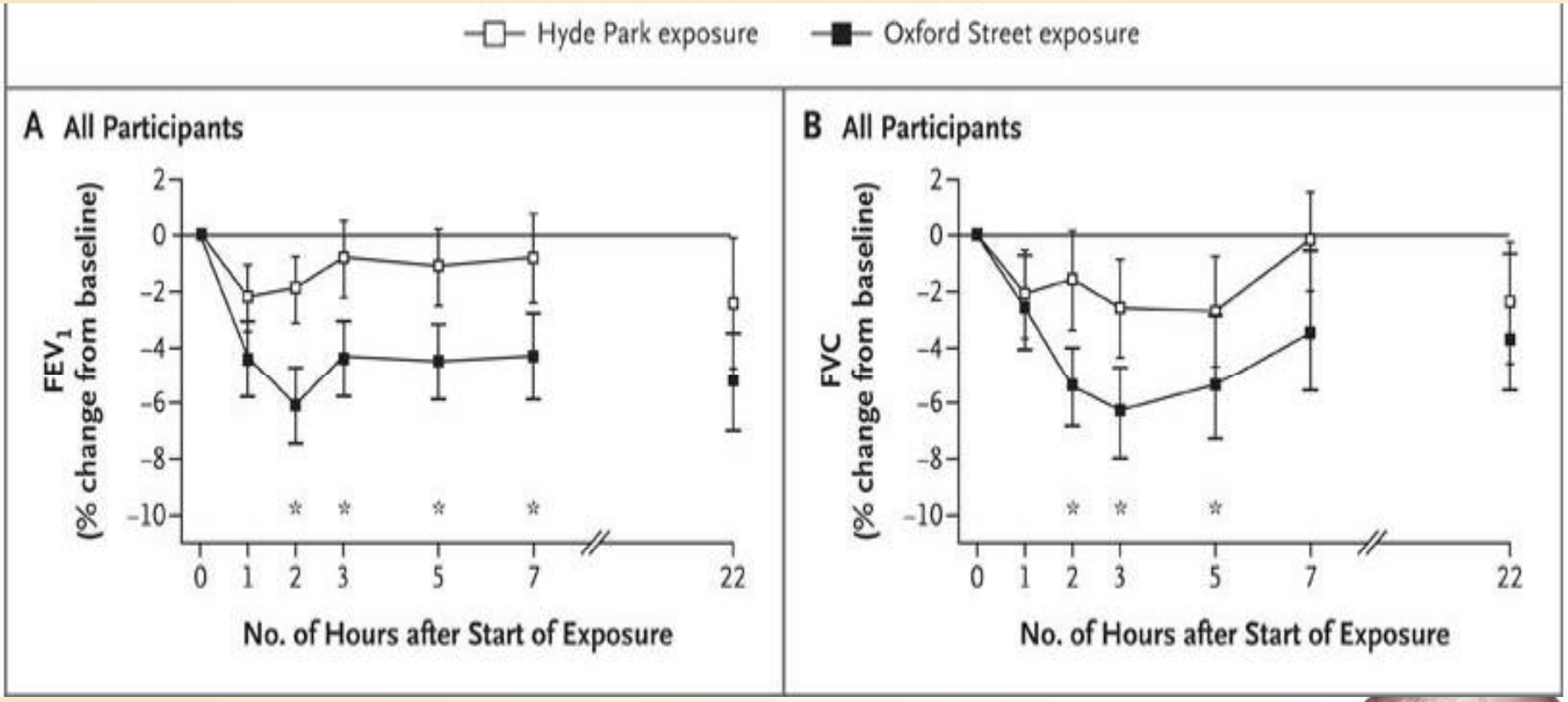


Diesel Health Effects

- Primary concern is exposure to particulate matter (PM, NOx) from older diesel
  - EPA estimates 20,000 fewer premature deaths from retrofitting existing HD fleet in US
- Also, evidence of respiratory effects:
  - r*educed lung function, respiratory irritation, asthma exacerbation*
- Many reviews of diesel and cancer:
  - (California, WHO NIEHS\NTP, EPA, others)
  - Most finding diesel a “probable” human carcinogen
- *New: IARC Review of diesel carcinogenicity June 2012*
- Problem greatest in developing countries

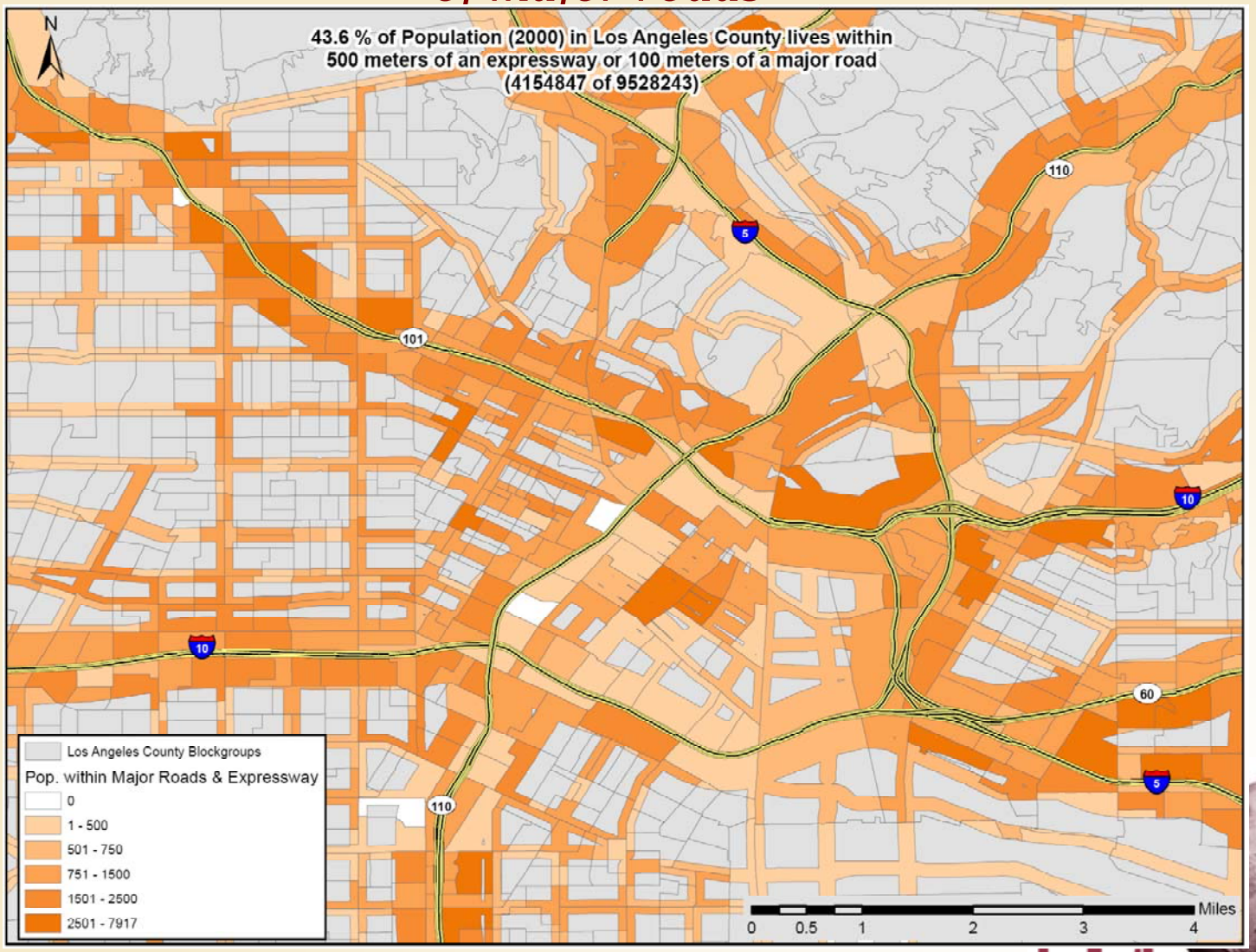
Effects of Traffic Exposure on Asthmatics (Zhang HEI 2009)

Lung function decline in asthmatics comparing Hyde Park and Oxford Street, London (*although symptoms did not increase…)*



The HEI Traffic Review:

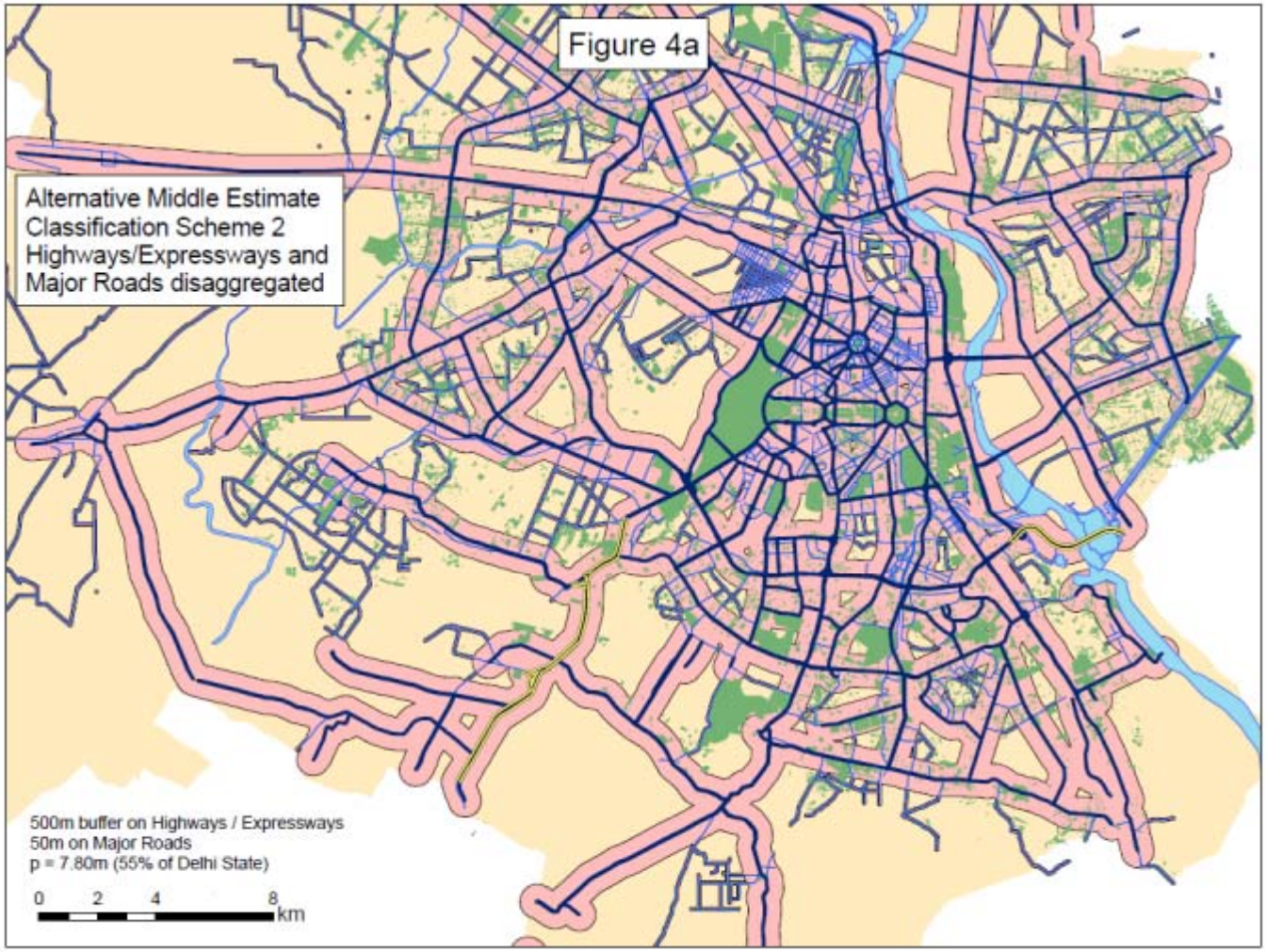
*In **Los Angeles**, **44% of population** live in the maximum zone of impact of major roads*



(within 500 meters of an expressway; 100 meters of a major road)

The Traffic Impact Area in Delhi:

New HEI Analysis: ***55% of the Population*** *within 500 meters of a Freeway; 50 meters of a Major Road*



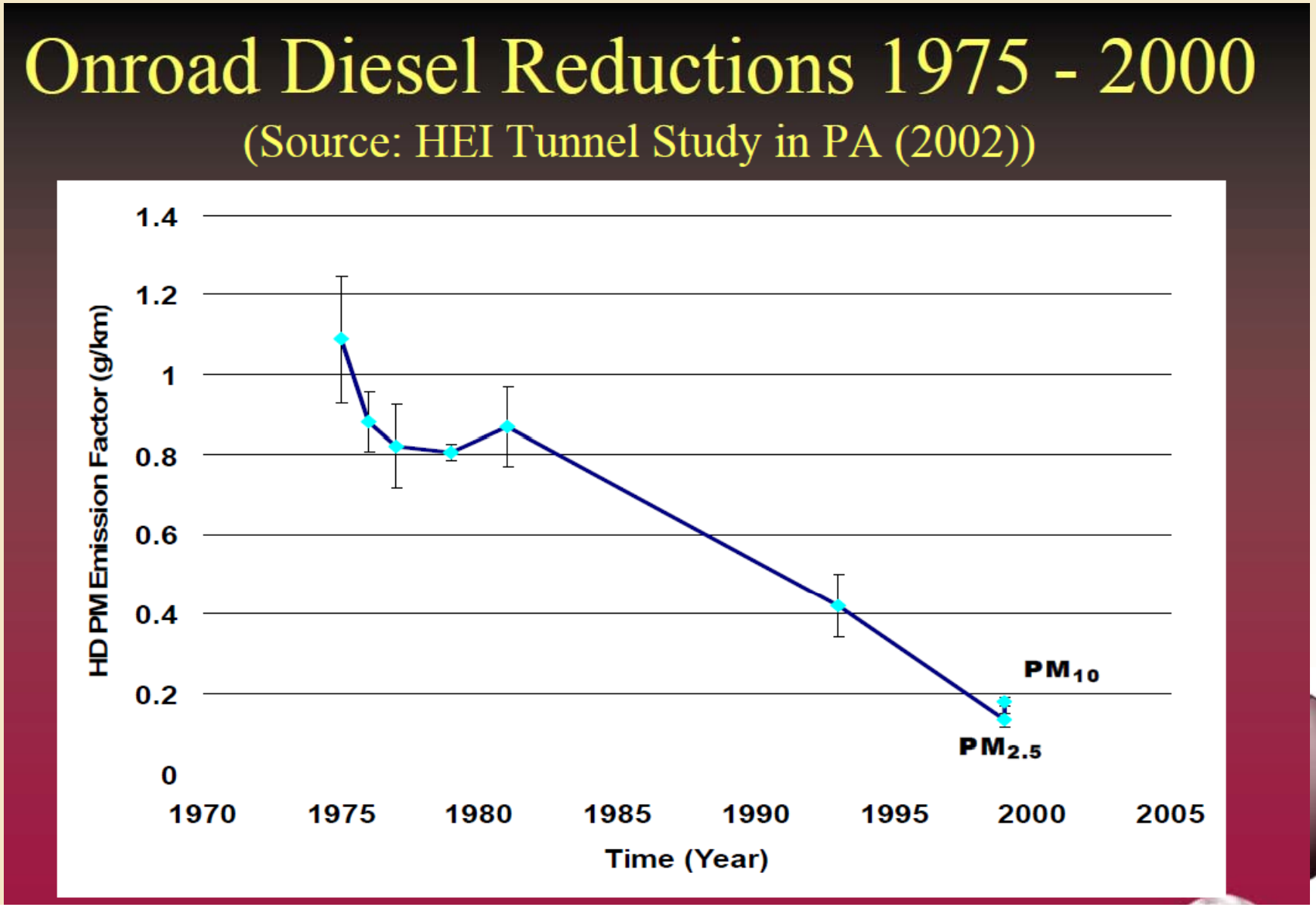
Diesel Exhaust Progression

Exhaust from engines using older technologies:

- **"Traditional" Pre-1988** diesel in use *prior to the US EPA diesel particulate standards* can have high emissions
- "**Transitional" 1988-2006** diesel engines show some improvement
  - Progressive improvements in engine design, but
  - Prior to the full-scale implementation of multi-component after-treatment systems

- ***Diesel longevity mean many of these engines still on the road, especially in developing countries***

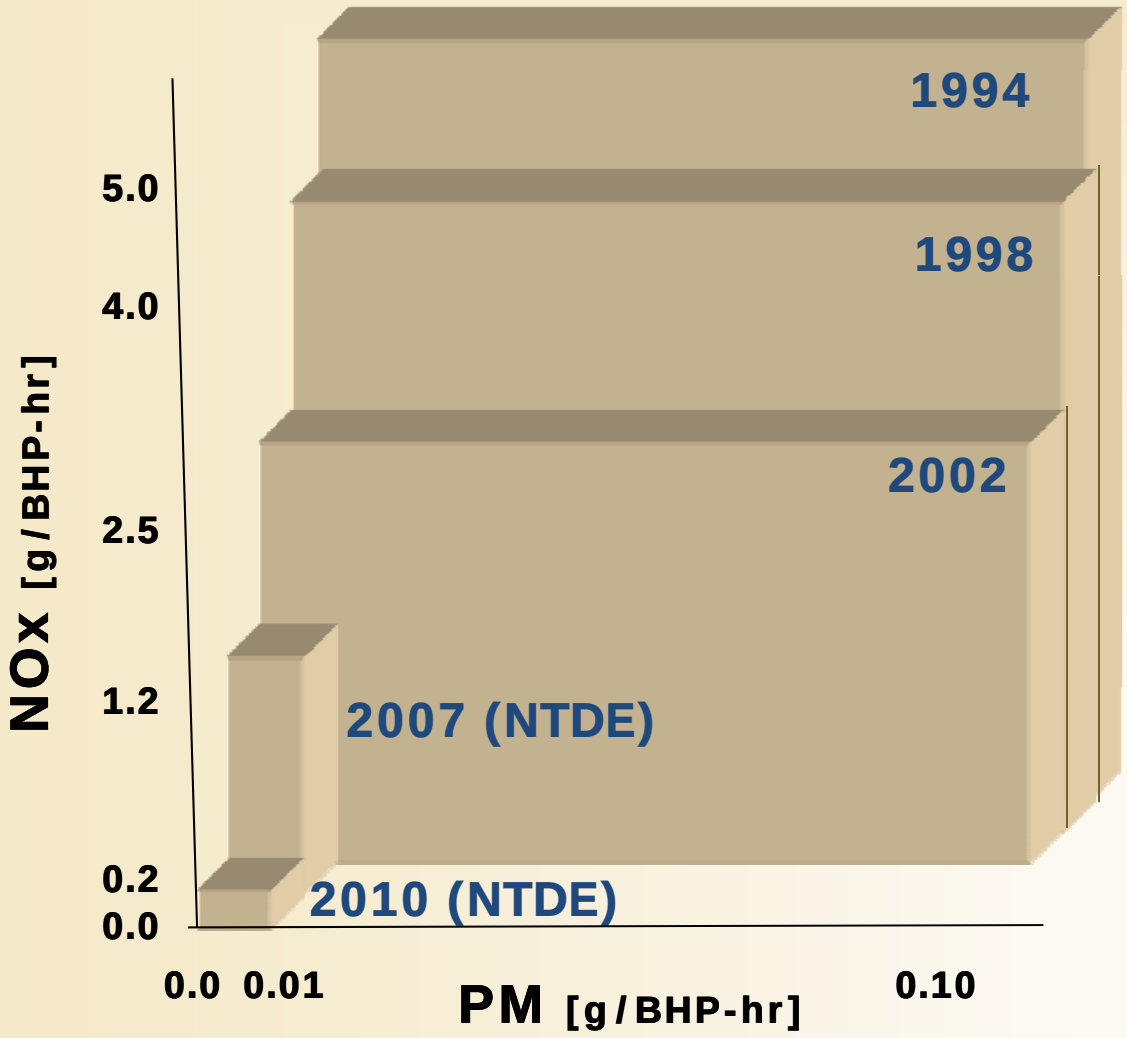
Some Progress with implementation of "Transitional" Diesel



How are Technologies and Fuels Changing?
"New Technology" Diesel

- Heavy Duty Truck and Bus Engines
  - 2007 EPA Requirements
    - 15 ppm sulfur diesel fuel
    - PM control (filter and catalyst)
    - Some NOx control (primarily exhaust gas recirculation)
  - 2010 EPA Requirements
    - *Above plus*
    - *Advanced NOx control (selective catalytic reduction)*
    - Similar changes in light duty, off road vehicles

Evolution of US Heavy Duty Diesel On-Road Emission Standards



Fuel Sulfur

500 PPM
(10/93)

FUEL SULFUR

ULSD 15 PPM
(10/06)

HEI

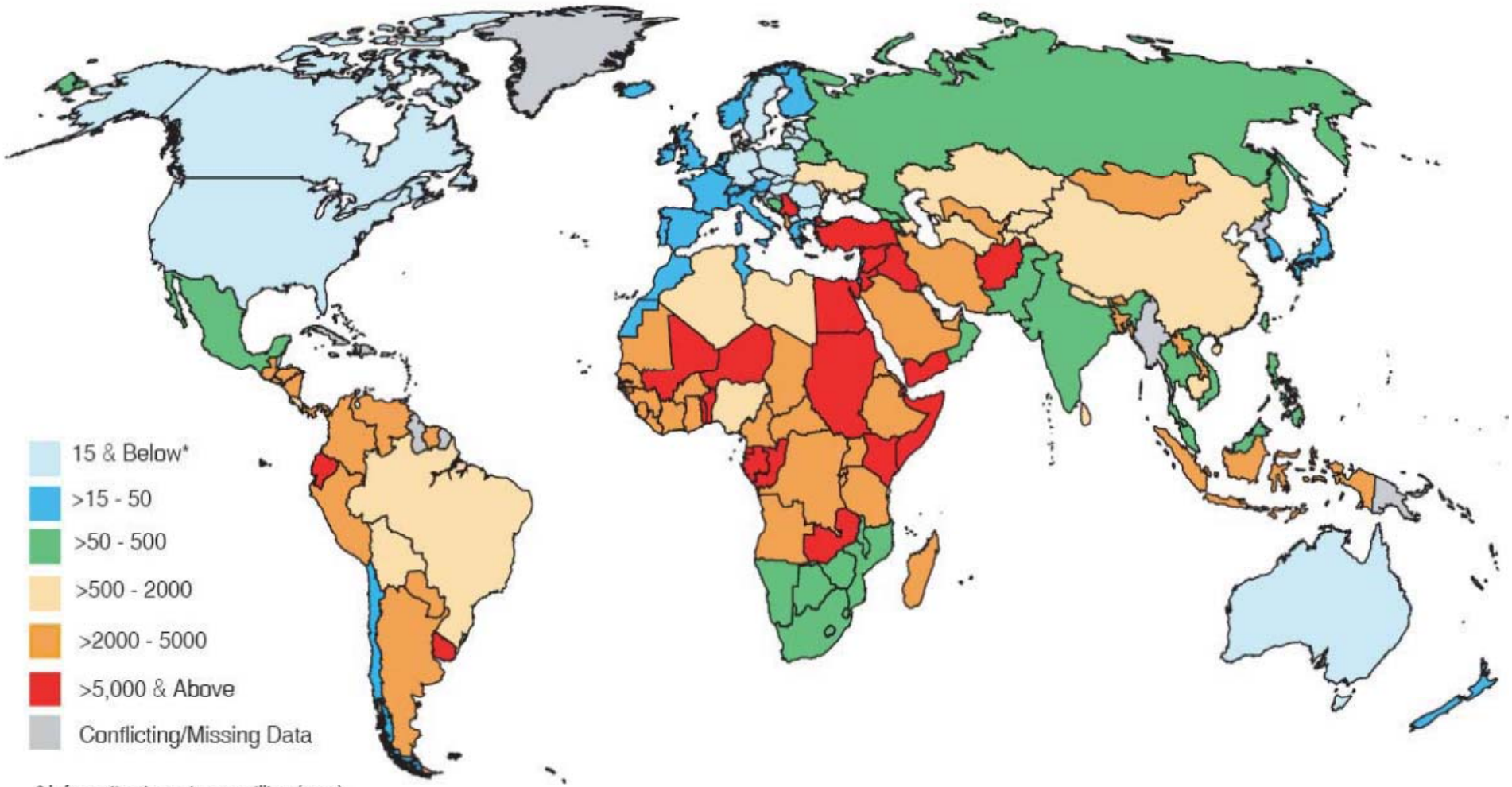
Key Need: Ultra Low Sulfur Diesel

- Clean fuel essential to enhanced control technology
  - Excess Sulfur can
    - Block particle filters
    - Coat NOx controls and cause reduce effectiveness
  - De facto world standard moving to 15 ppm or lower
    - Already in place in Europe, US

Partnership for Clean Fuels and Vehicles

Diesel Fuel Sulphur Levels: Global Status
April 2010

UNEP

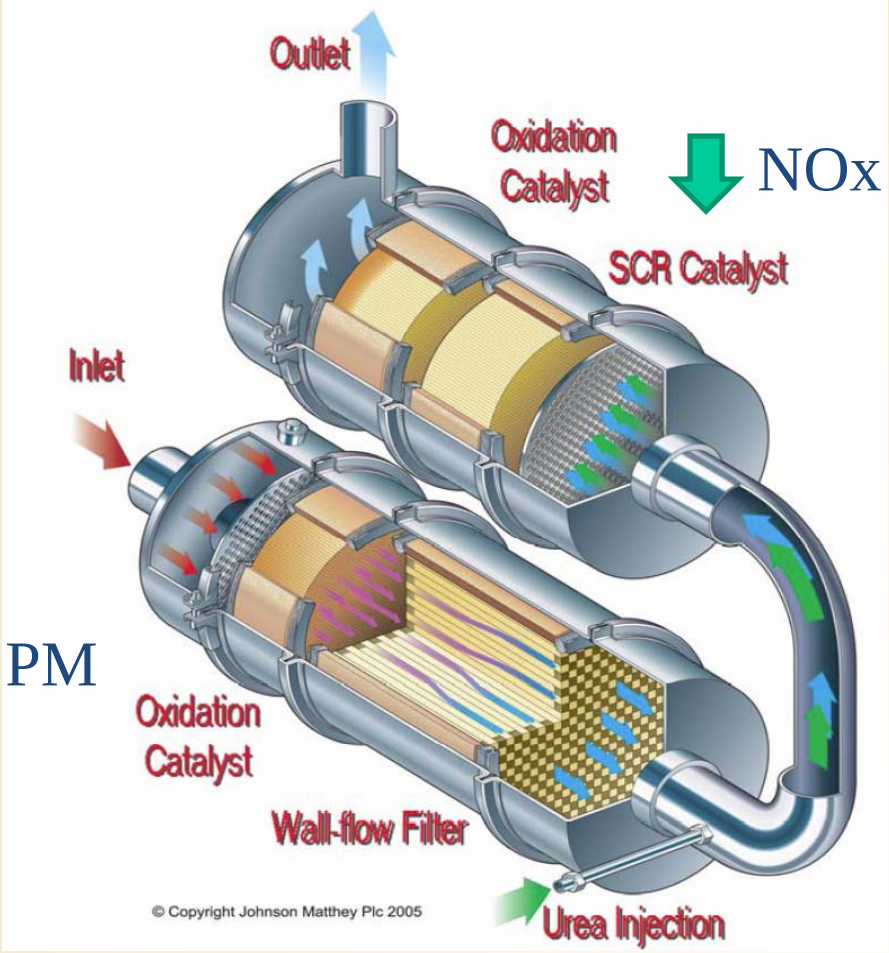


* Information in parts per million (ppm)

Sulphur levels are maximum allowable as of April 2010 For additional details and comments per country, visit www.unep.org/pcfv.

Key Need: Exhaust Treatment Systems

—Particle Removal and NOx Elimination



DOC+DPF+SCR

HEI

Diesel particulate filters achieve dramatic emission reductions

No Retrofit System
Uncontrolled Diesel Exhaust

Retrofitted with
Diesel Oxidation Catalyst (DOC)
(Level 1)

Old technology
Little black carbon removal
Little utrafine PM removal
Does not remove lube oil ash

Retrofitted with
Partial Filter
(Level 2)

Little black carbon removal
Little utrafine PM removal
Does not remove lube oil ash

Retrofitted with
Diesel Particulate Filter (DPF)
(Level 3)

New technology
Used on all new trucks since 2007
>85% black carbon removal
>85% ultrafine removal
>85% lube oil ash removal

Overview: The exhibits above are actual PM collection samples from an engine testing laboratory used to collect and measure diesel particulate matter (PM) emissions. Test conditions are:

- Test Cycle. UDDS (Urban Dynamometer Driving Schedule)
- Test Distance. 5.5 miles over 17 minutes
- Fuel Consumed During Test. ~.1 gallon
- Test Vehicle. Heavy-duty truck with a 370 hp Cummins engine (1999 model year)
- PM material on collection samples is 1/1,000th of actual

HEI

Are new technology diesels meeting the challenge?

HEI “Outcomes” Research Program

Advanced Collaborative Emissions Study (ACES)

Cooperative multi-party effort to characterize emissions and possible health effects of new advanced heavy duty engine and control systems and fuels in the market 2007 – 2010.




PROJECT SPONSORS

US Department of Energy (DOE) OVT and NETL
Engine Manufacturers Association (EMA)
US Environmental Protection Agency (EPA)
California Air Resources Board (ARB)
American Petroleum Institute (API)
Aftertreatment Manufacturers
Coordinating Research Council (CRC)

Evaluating Emissions of Advanced Technology Diesels

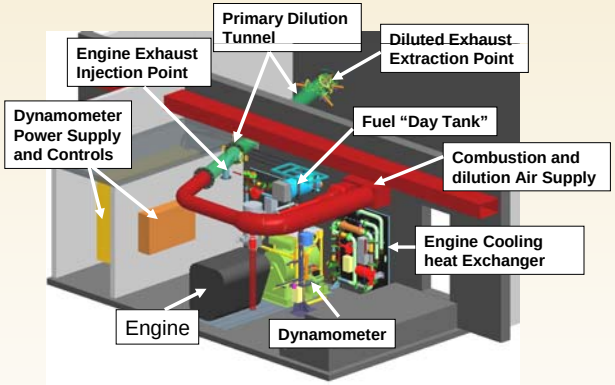
- New 2007/2010 engine/control systems and fuels designed to result in substantially reduced emissions.
- Substantial public health benefits are expected from these reductions.
- *But, w*ith any new technology it is prudent to ensure there are no adverse impacts to public health and welfare.

ACES is moving to *answer these important questions*:

Phase 1: 2007 Engine Emissions Characterization Completed
Dramatic reductions

Phase 2: 2010 Engine Emissions Characterization
Testing Underway; report in 2013

Phase 3: 2007/2010 Engine Emissions Health Effects Testing
-Short term health biological screening complete
-Few to no health effects observed
-Longer term (cancer) testing well underway
-Early results promising
Final report expected 2013



Characteristics of New vs. Old Diesel PM

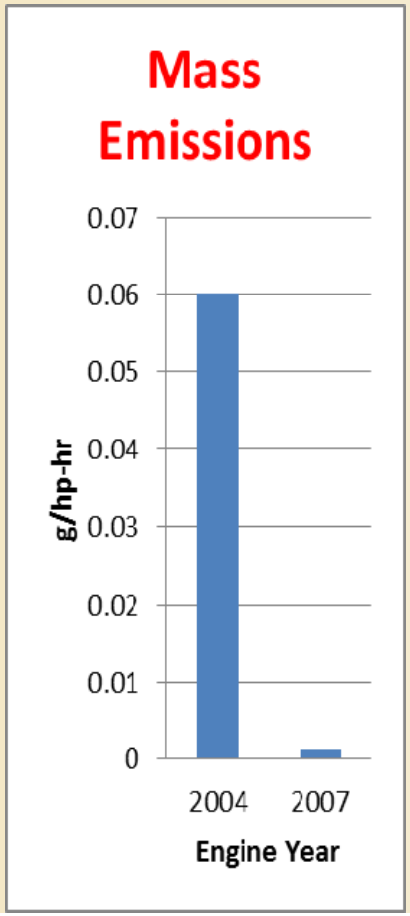
HEI ACES Results Compared to earlier Testing:

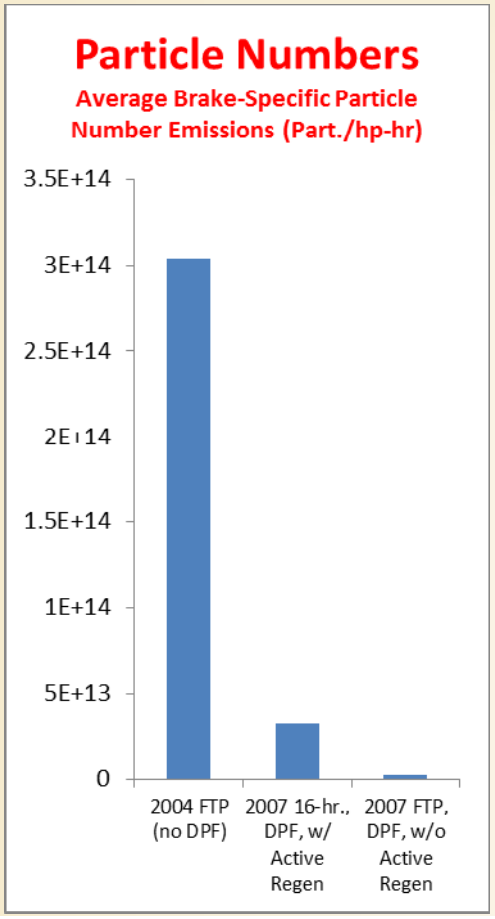
Dramatic Reductions

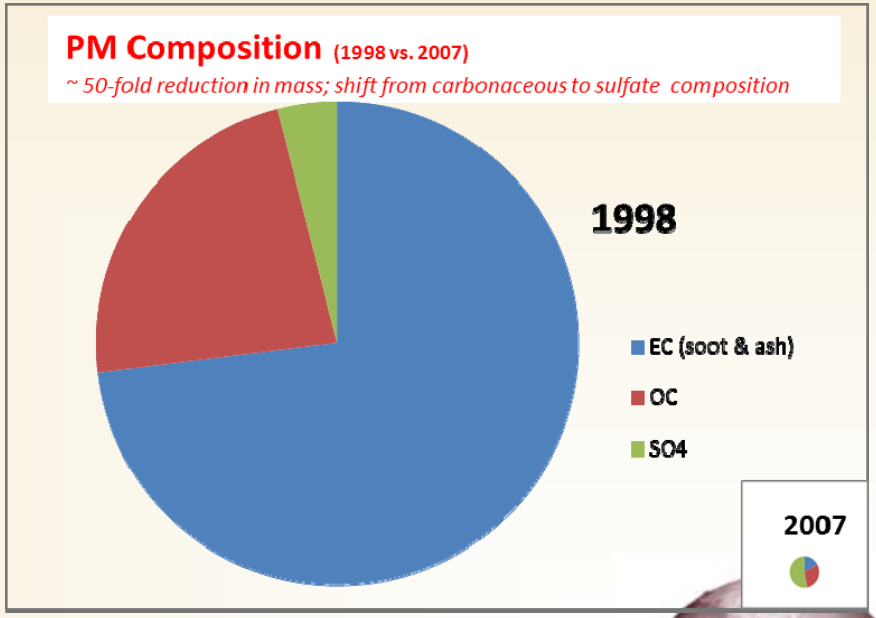
98% reduction in mass

90% - 99% reduction in Ultrafine Particles

Substantial reduction in carbon particles







Greater than 90% reduction in PAHs (including known carcinogens)

Many PAHs now below detection limits (Khalek et al 2011)

- Polycyclic Aromatic Hydrocarbons (PAHs) have been of major concern in diesel exhaust
- Many known to cause cancer
- Some of the most toxic are so low they can no longer be measured

Table 8. PAH and nitroPAH average emissions for all 12 repeats of the 16-hr cycles for all four 2007 ACES engines and for a 2000-technology engine running over the FTP transient cycle.[16]

PAH and NitroPAH Compounds	2007 Engines[a] (mg/bhp-hr)	2000-Technology Engine[a, b] (mg/bhp-hr)	Percent Reduction
Naphthalene	0.0982000 ± 0.0423000	0.4829	80
Acenaphthylene	0.0005000 ± 0.0005000	0.0524	98
Acenaphthene	0.0004000 ± 0.0001000	0.0215	98
Fluorene	0.0015000 ± 0.0009000	0.0425	96
Phenanthrene	0.0077000 ± 0.0025000	0.0500	85
Anthracene	0.0003000 ± 0.0001000	0.0121	97
Fluoranthene	0.0006000 ± 0.0006000	0.0041	85
Pyrene	0.0005000 ± 0.000400	0.0101	95
Benzo(*a*)anthracene	<0.0000001	0.0004	>99
Chrysene	<0.0000001	0.0004	>99
Benzo(*b*)fluoranthene	<0.0000001	<0.0003	>99
Benzo(*k*)fluoranthene	<0.0000001	<0.0003	>99
Benzo(*e*)pyrene	<0.0000001	<0.0003	>99
Benzo(*a*)pyrene	<0.0000001	<0.0003	>99
Perylene	<0.0000001	<0.0003	>99
Indeno(123-*cd*)pyrene	<0.0000001	<0.0003	>99
Dibenz(*ah*)anthracene	<0.0000001	<0.0003	>99
Benzo(*ghi*)perylene	<0.0000001	<0.0003	>99
2-Nitrofluorene	0.00000360 ± 0.00000410	0.0000650	94
9-Nitroanthracene	0.0000148 ± 0.0000213	0.0007817	98
2-Nitroanthracene	0.00000040 ± 0.00000090	0.0000067	94
9-Nitrophenanthrene	0.00002110 ± 0.00002090	0.0001945	89
4-Nitropyrene	<0.00000001	0.0000216	>99
1-Nitropyrene[c]	0.00001970 ± 0.00002430	0.0006318	97
7-Nitrobenz(*a*)anthracene	0.00000020 ± 0.00000020	0.0000152	99
6-Nitrochrysene	<0.00000001	0.0000023	>99
6-Nitrobenzo(*a*)pyrene	<0.00000001	0.0000038	>99

Notes: [a]The significant figures signify the detection limit in mg/bhp-hr; [b]SD data were not provided by ref 15. [c]Previous work showed artifact formation during filter collection of the compounds highlighted in bold.

Diesel and Lung Cancer

Diesel Risk Assessment: Cancer

- Reviews by International, National, State Agencies
  - IARC (WHO,1989)
  - International Programme on Chemical Safety (WHO,1996)
  - U.S. EPA (2002)
  - California OEHHA (1998)
  - NIEHS/NTP (1999)
- Most have called diesel a probable human carcinogen
  - Difficult to quantify precise risk
  - California has found it a known carcinogen
- New IARC Review of diesel carcinogenicity in June 2012

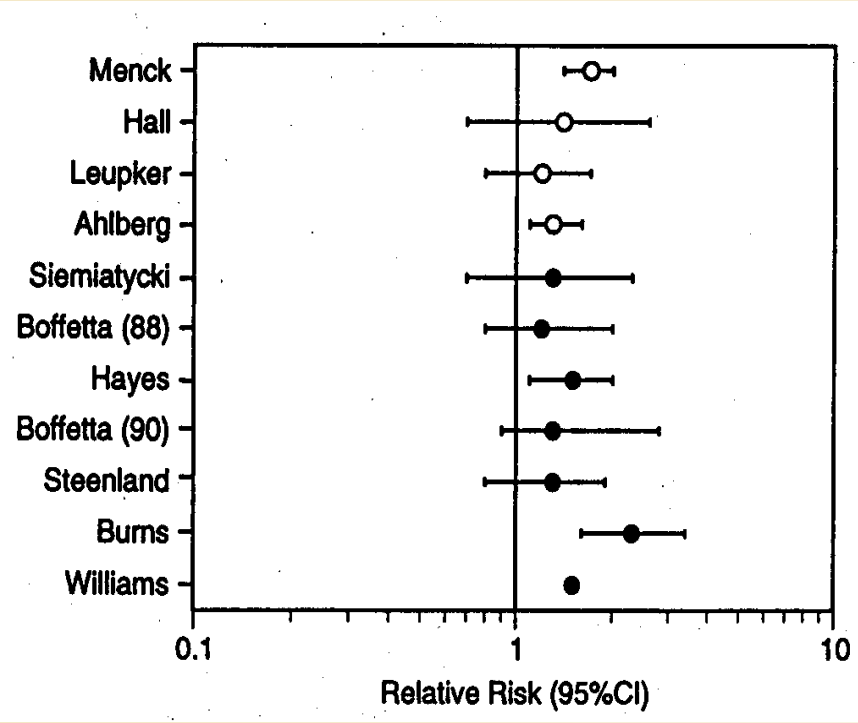
International Agency for Research on Cancer (IARC)

- Agency of the World Health Organization
- Convenes expert working groups for 8 days to review toxicology and epidemiology evidence of whether a substance or source “causes” cancer
- Conducts a *hazard assessment*, not a *risk assessment*
  - Reviews whether a substance can cause cancer (at any level of exposure)
  - Does NOT estimate what risks are for exposure on the street
- Has reviewed many substances and sources, e.g.
  - Benzene and smoking are “known” human carcinogens
  - Cellphones are a “possible” carcinogen (2011)

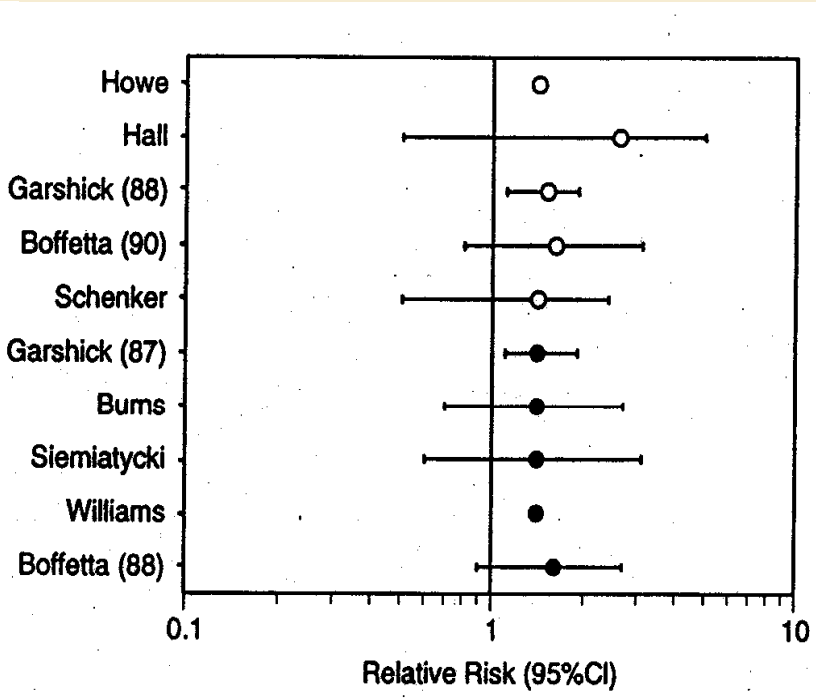
Historically, a Number of Occupational Studies

Small (20%- 50%), Consistent Increase in Lung Cancer Risk

Truck Drivers
11 studies



Railroad Workers
10 studies



solid circle = smoking adjusted
open circle = smoking unadjusted

HEI: Diesel Working Group Special Report 1995

New Diesel Exhaust in Miners Study

(NCI/NIOSH Attfield et al. 2012; Silverman et al. 2012)

- Major new occupational study in deep "non-metal" mines
- Among 12,315 blue-collar workers…. since 1940
- Detailed health records,
- Diesel engine use, relatively enclosed environment
- *Risk of Lung Cancer increased **3-fold to 7-fold** in exposed workers*
  - Some continuing questions on how past exposures were estimated

*Case-control data adjusted for smoking, respiratory disease history, previous work in job at high risk for cancer.

IARC Meeting on Diesel

June 5 – 12, 2012

- Noted substantial >98%) improvements in new technology diesel in US (and soon to be available in Europe)
- Based their review on animal and human exposures to old (and much older) diesel
  - No studies of new technology diesel other than ACES
- Concluded that:
  - Animal studies provided *sufficient* evidence of link between diesel and cancer
  - Human studies (with DEMS added) provided *sufficient* evidence of link
  - Mechanistic studies provided *strong evidence* of plausible mechanisms by which diesel could cause cancer in humans
  - ***Classified diesel exhaust as a "known" human carcinogen***

Next Steps

- *Primary public health impact from diesel exhaust remains PM;*
- *However*, finding that diesel exhaust from older engines is a known human carcinogen raises public health concern *especially in developing countries, some occupational settings and possibly areas with substantial old technology diesel engines*

Next Steps

In the U.S.:

- NTD, now required for new engines, *is delivering on its promise of dramatically lower emissions*
- *To date few health effects identified, full results expected in 2014*
- However, the legacy fleet will take until 2030 to cycle out,
  - *Another reason to accelerate replacement of older diesel engines (e.g. DERA)*
  - In response to IARC, should EPA reopen its 2003 Health Assessment Document for diesel?
    - This could lead to the estimation of a national "unit risk" for diesel
      - albeit a risk that is likely to be smaller than that attributed to PM
    - *May not be necessary given advance of new technology diesel in US*
    - HEI reviewing the new science to determine if cancer impacts can be reliably quantified . Report expected in 18-24 months

In the Developing World:

- Pressure will build to lower fuel sulfur, tighten diesel standards, retrofit

Thank You

Bob O'Keefe
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- Among 12,315 blue-collar workers…. since 1940
- Detailed health records
- Diesel engine use, relatively enclosed environment
- *Risk of Lung Cancer increased **3-fold to 7-fold** in exposed workers*
- Risk is estimated to be linear in full cohort (p=0.001)
  - Some continuing questions on how past exposures were estimated

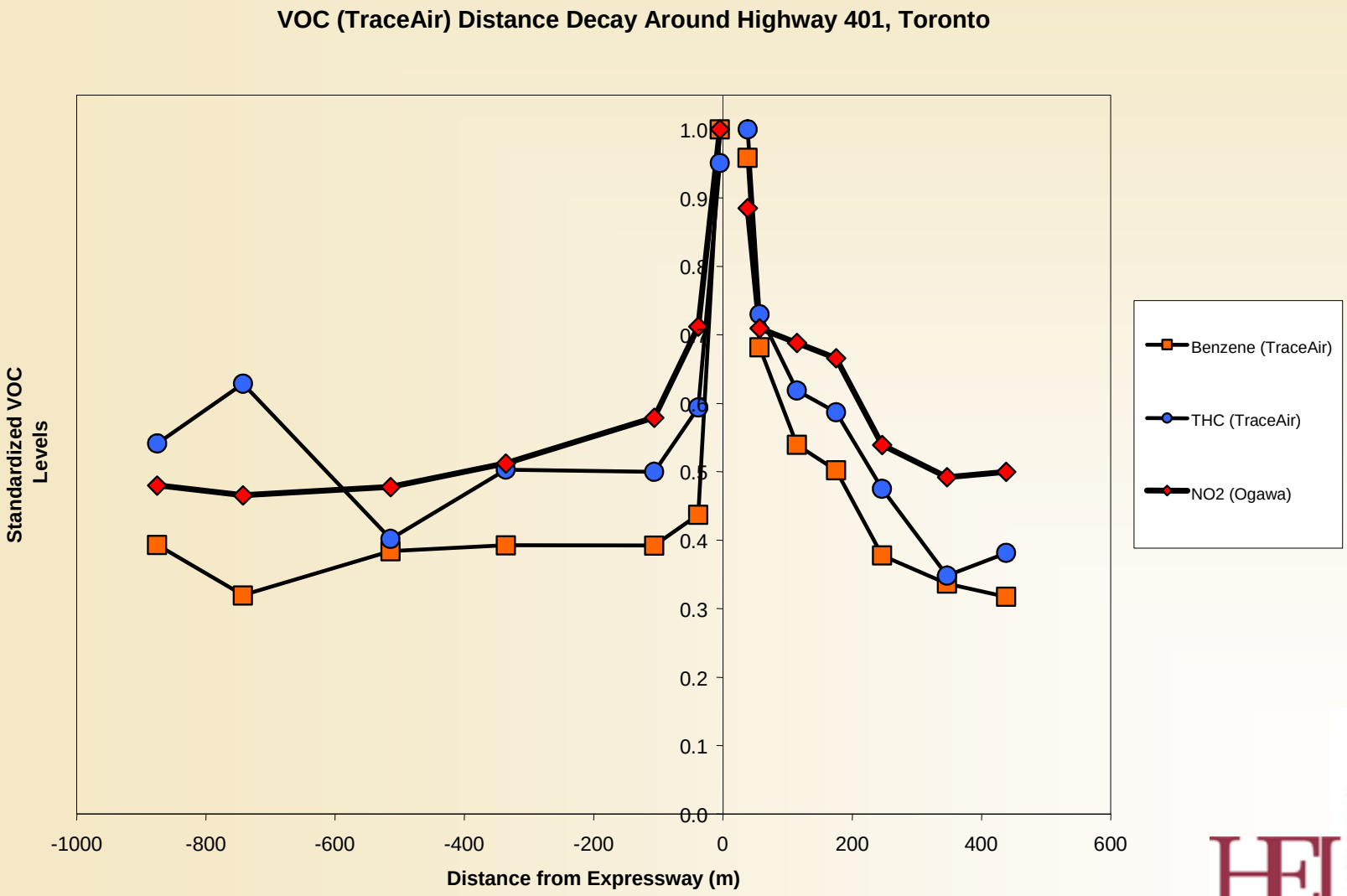
Table 6. Odds ratios (ORs) and 95% confidence intervals (CIs) for cumulative REC lagged 15 years crossed with smoking intensity*

Smoking intensity (packs per day)	Cumulative REC lagged 15 years OR (95% CI), No. of case subjects/No. of control subjects		
	Tertile 1, 0 to < 8 μg/m³-y	Tertile 2, 8 to < 304 μg/m³-y	Tertile 3, ≥304 μg/m³-y
Never smoker	1.0 (referent), 3/59	1.47 (0.29 to 7.50), 4/74	7.30 (1.46 to 36.57), 7/45

*Case-control data adjusted for smoking, respiratory disease history, previous work in job at high risk for cancer.

Who is Likely to be Exposed?

Highest levels within 300 – 500 meters of a major road



Toronto, Beckerman et al. (2008)