Diesel Update:

HEI's Recent Progress - And Looking Ahead

Dan Greenbaum, President
Health Effects Institute

HEI Annual Conference
Denver, Colorado
May 2, 2016

Diesel Health Science

- **Understanding Old Diesel – The HEI Diesel Epidemiology Report**
  - And likely implications for future risk assessment
- **New Diesel - *The Final ACES Results***
- **Looking Ahead: Monitoring Progress**

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SR 19 Diesel Epi 2nd Pages 11-2-2015

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SPECIAL REPORT 19

HEALTH EFFECTS INSTITUTE

November 2015

Diesel Emissions and Lung Cancer: An Evaluation of Recent Epidemiological Evidence for Quantitative Risk Assessment

HEI Diesel Epidemiology Panel

Daniel Krewski, Chair, Diesel Epidemiology Panel

Katherine Walker, Senior Scientist, Health Effects Institute

HEI Diesel Epi Panel Evaluation

Multidisciplinary Panel

Charge:

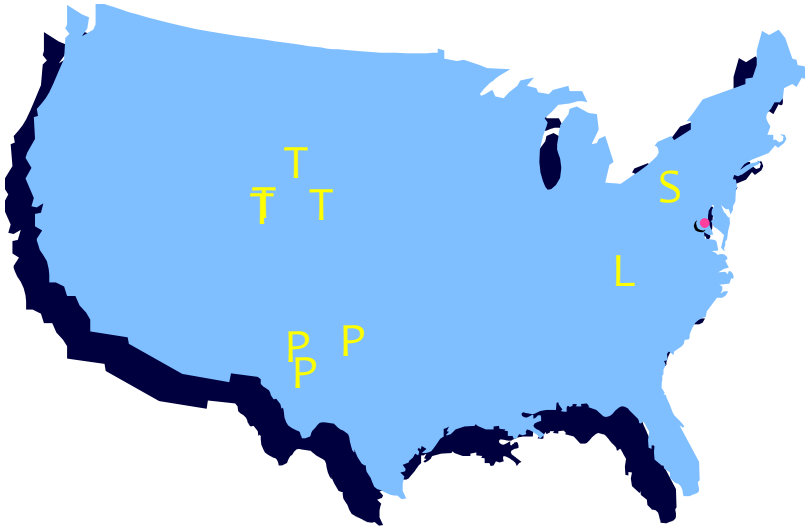
To review and analyze the newest studies of lung cancer risk in workers exposed to older diesel exhaust…

…and assess their potential for use in quantitative risk assessment (QRA)

Chair: Daniel Krewski,
Professor and Director
McLaughlin Center for Population Health Risk Assessment, University of Ottawa

The Diesel Exhaust in Miners Study: A Cohort Mortality Study with Emphasis on Lung Cancer *Attfield et al. 2012*

The Diesel Exhaust in Miners Study: A Nested Case-Control Study of Lung Cancer and Diesel Exhaust *Silverman et al. 2012*



8 Non-metal mines

- 3 potash mines
- 3 trona (soda ash) mines
- 1 salt (halite) mine
- 1 low-silica limestone mine

Adapted from D. Silverman presentation

Cohort: 12,315 males

Diesel marker: Respirable elemental carbon (REC)

Historical exposure estimates: ~1947 to 2001

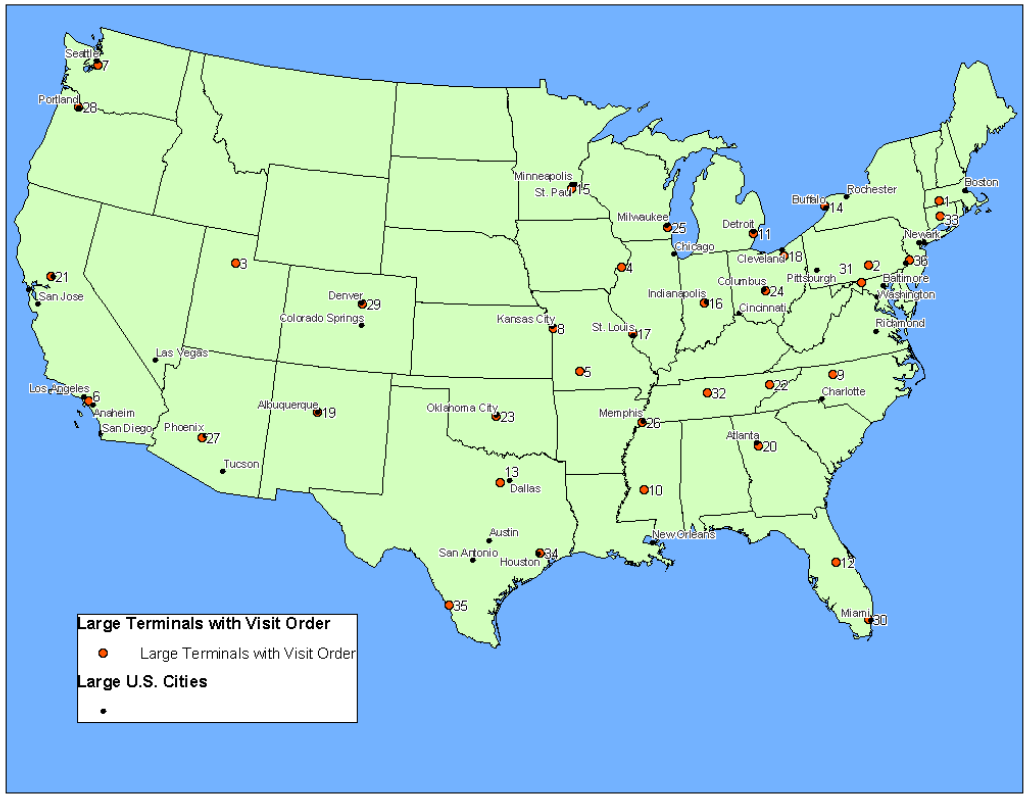
Mortality follow-up: to 1997

Lung cancer cases: 200

Nested Case-Control: 198 cases, 666 matched controls

Lung Cancer and Elemental Carbon Exposure in Trucking Industry Workers

Garshick et al. 2012



Cohort: 31, 135 males employed in 1985

Diesel marker: Submicron elemental carbon (SEC)

Historical exposure Estimates : 1971-2000

Mortality follow-up: to 2000

Lung cancer cases: 779

The Panel Evaluation Process :

1. Considered studies against *attributes of studies of high quality and integrity*

2. Considered studies' progress toward *addressing deficiencies in previous occupational epidemiological studies* (research needs from 1999 HEI report)

3. Considered issues and analyses raised by *numerous critiques* of both studies, *and new analyses of DEMS*

4. *Conducted new analyses* in the DEMS analytical data sets

5. Addressed comments from *independent external peer reviews*

Overall Panel Conclusions

- Both studies were well-designed and conducted according to high standards of epidemiological research.
- The results and data from both the Truckers and the DEMS can be usefully applied in quantitative risk assessments of older diesel engine exhaust.
- However, QRAs will need to take into account some key uncertainties and limitations.

Issues for future quantitative risk assessments to consider…

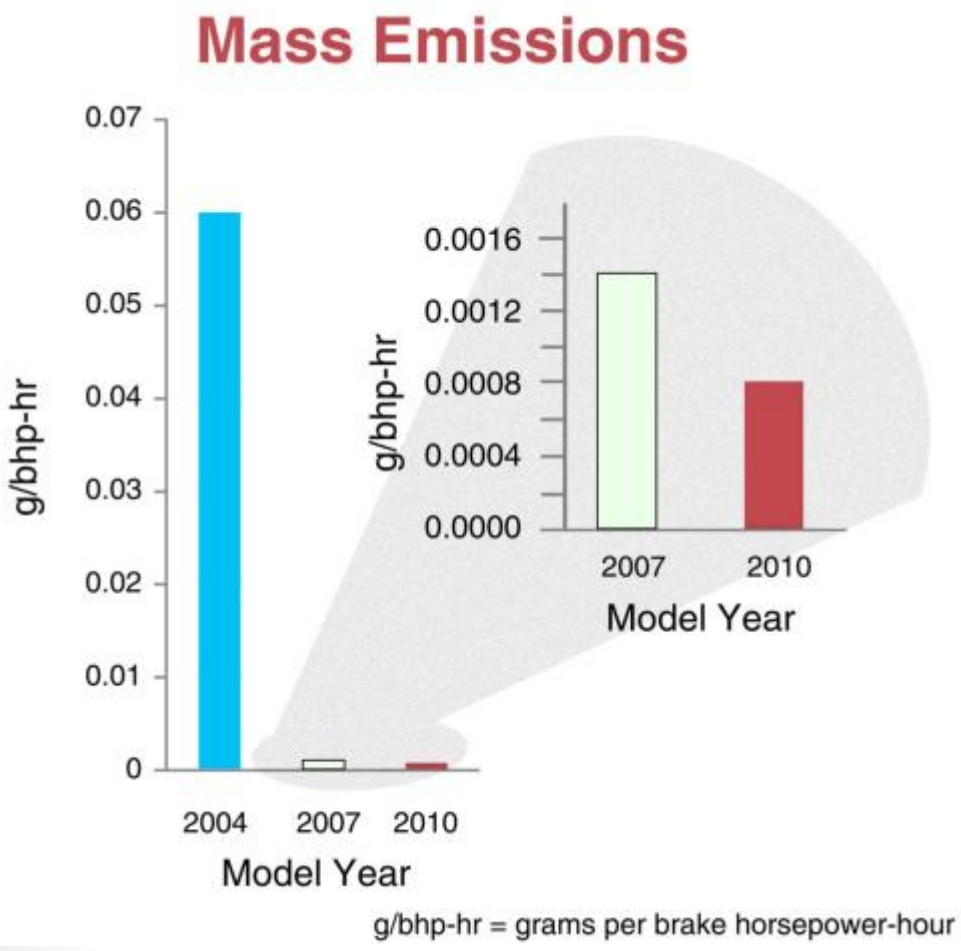
- a systematic framework for evaluating possible direction and magnitude of ***exposure measurement error*** or uncertainty

- an in-depth ***evaluation of a broader set of modeling approaches*** for projecting cancer risk
  - different temporal patterns of exposure and risk
  - applicability of biologically motivated models

- a commitment to ***subjecting all alternative models or assumptions to same degree of scrutiny and validation as those in the original studies***

Further Considerations

Dramatic reductions in new technology diesel PM mass emissions and composition



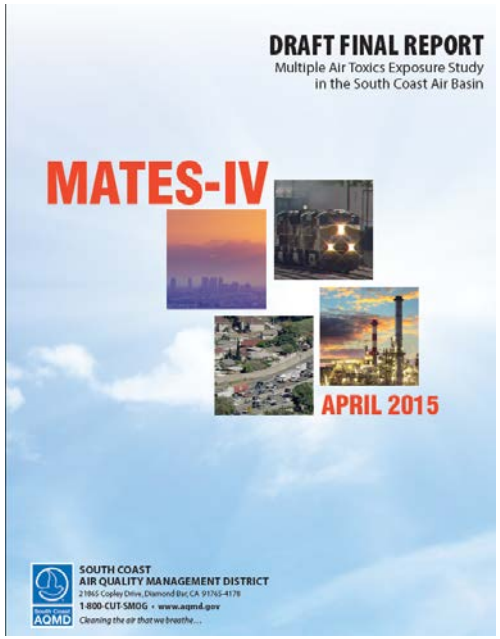
- PM mass reduced by over 99%
- EC reduced from 70% of mass in 1998 to 16% in 2010

Source: Advanced Collaborative Emissions Study (ACES)

Further Considerations….

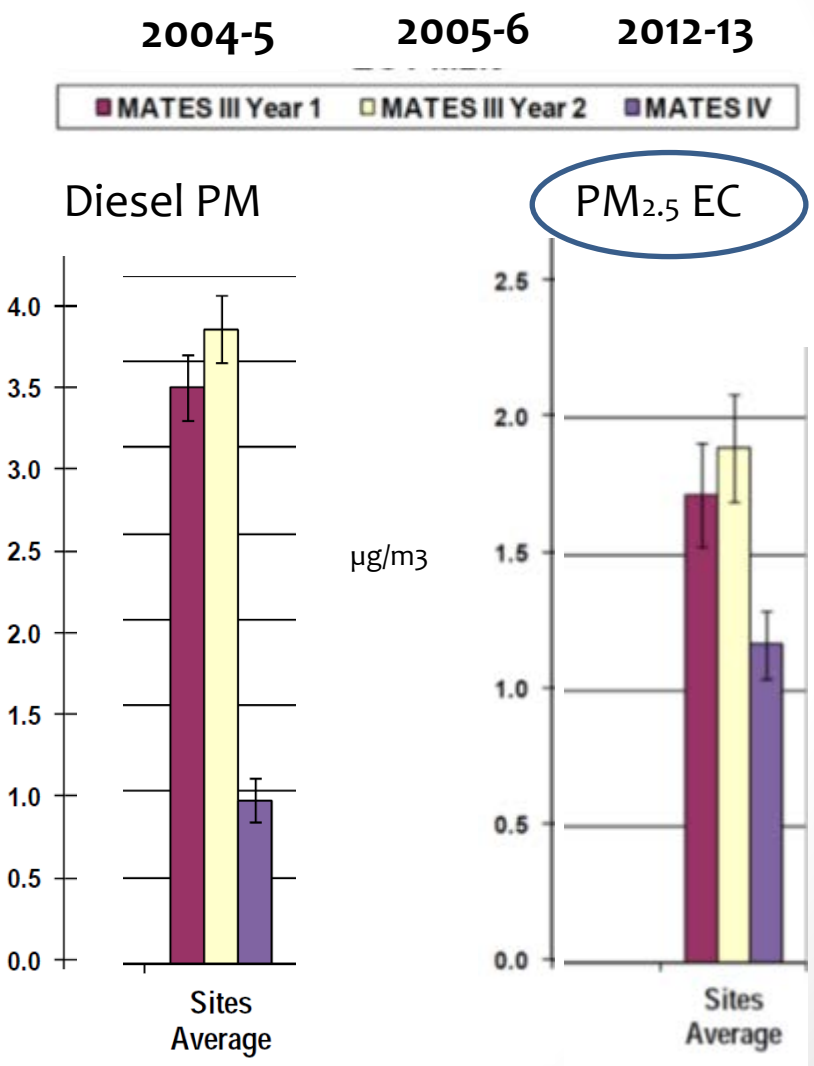
Declining ambient levels of diesel DPM and contributions to EC component of $PM_{2.5}$

Multiple Air Toxics Exposure Assessment



Los Angeles Basin

Monitoring data



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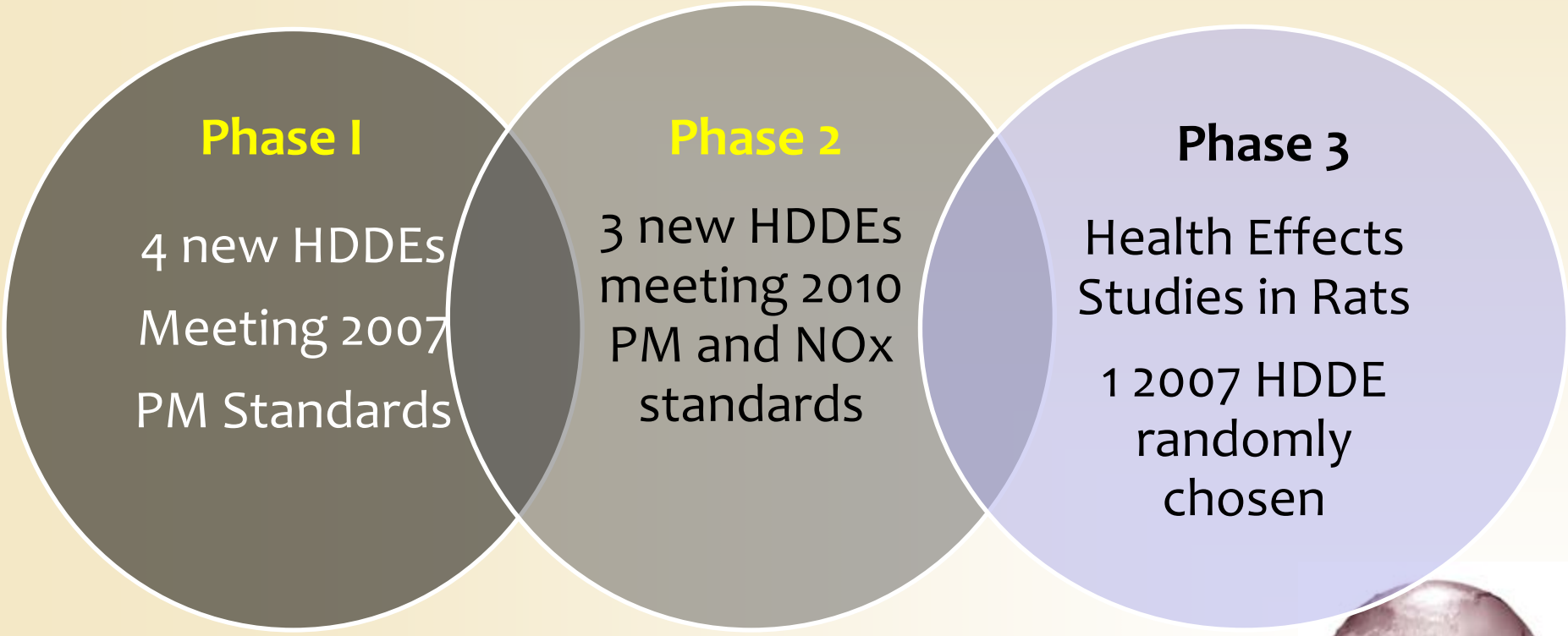
The Advanced Collaborative Emissions Study

Emissions Characterization*

Health Studies

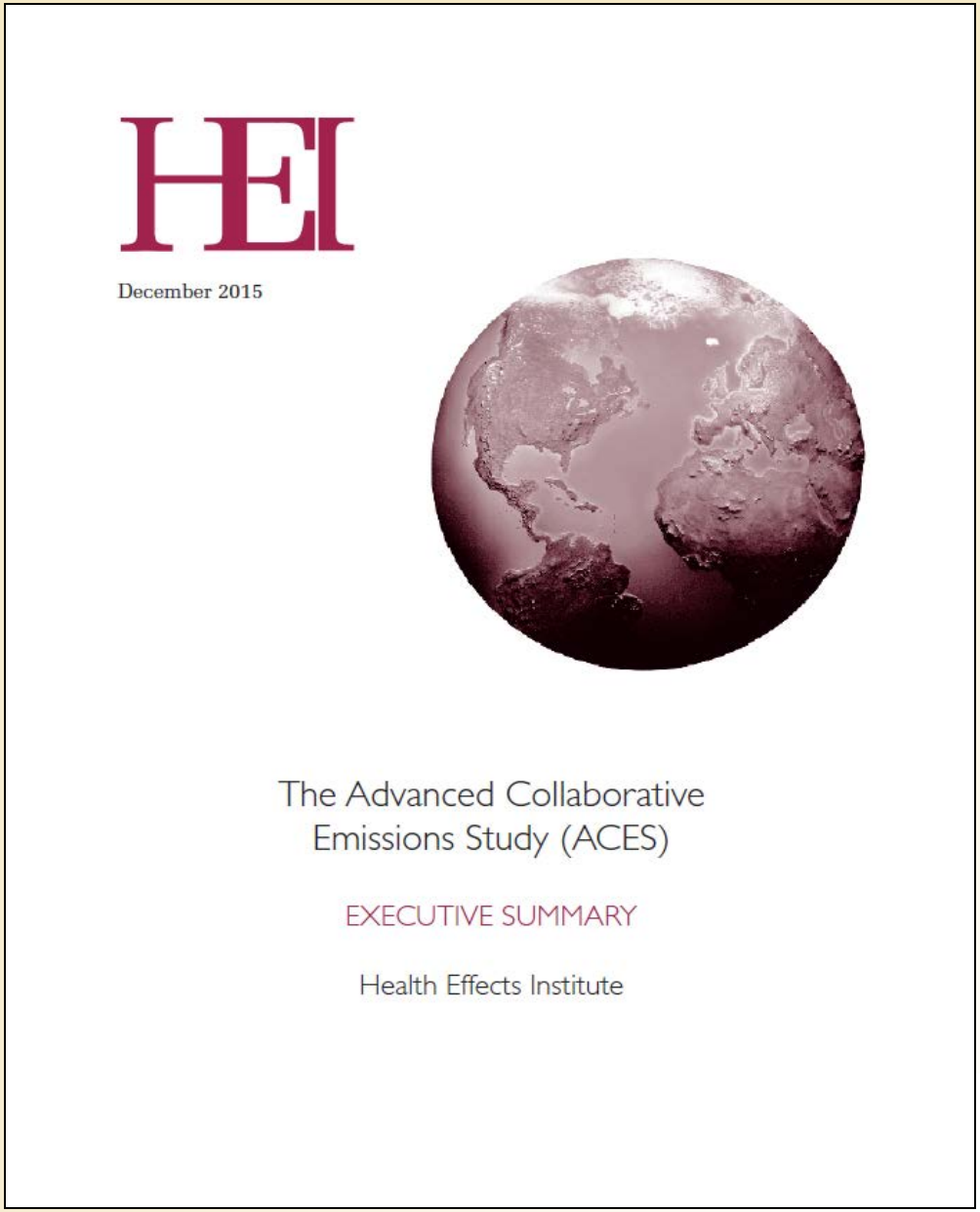


*Overseen by Coordinated Research Council (CRC), conducted by Imad Khalek,(Southwest Research Institute)

Conducted at Lovelace Respiratory Research Institute

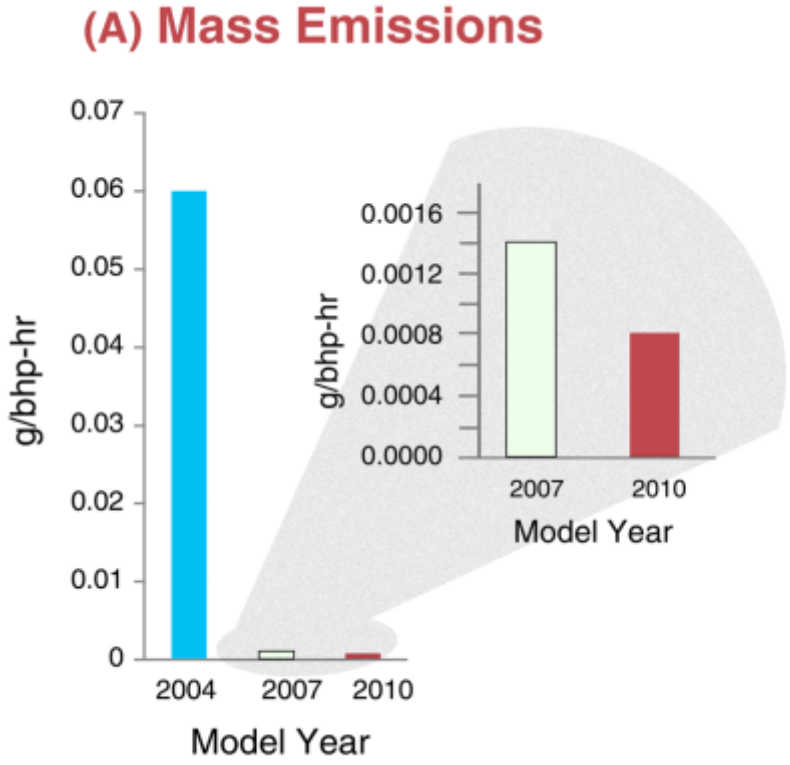
December 2015:

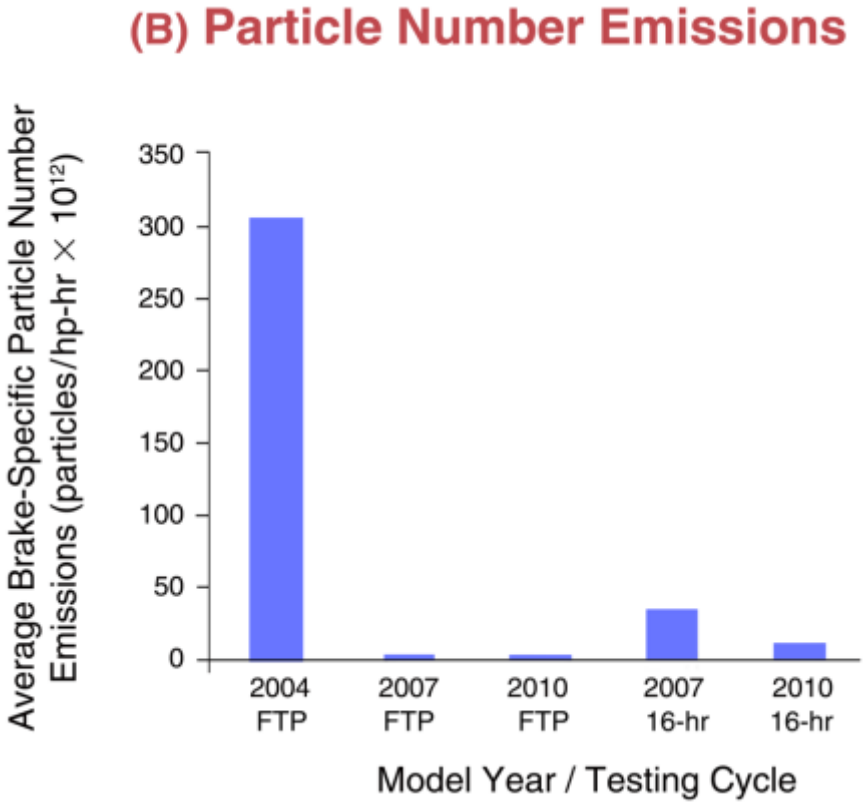
ACES Executive Summary



ACES results

- *Dramatic Progress on Mass and Particle Number*





Phase 1 Results: More than 90% reduction in PAHs

(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

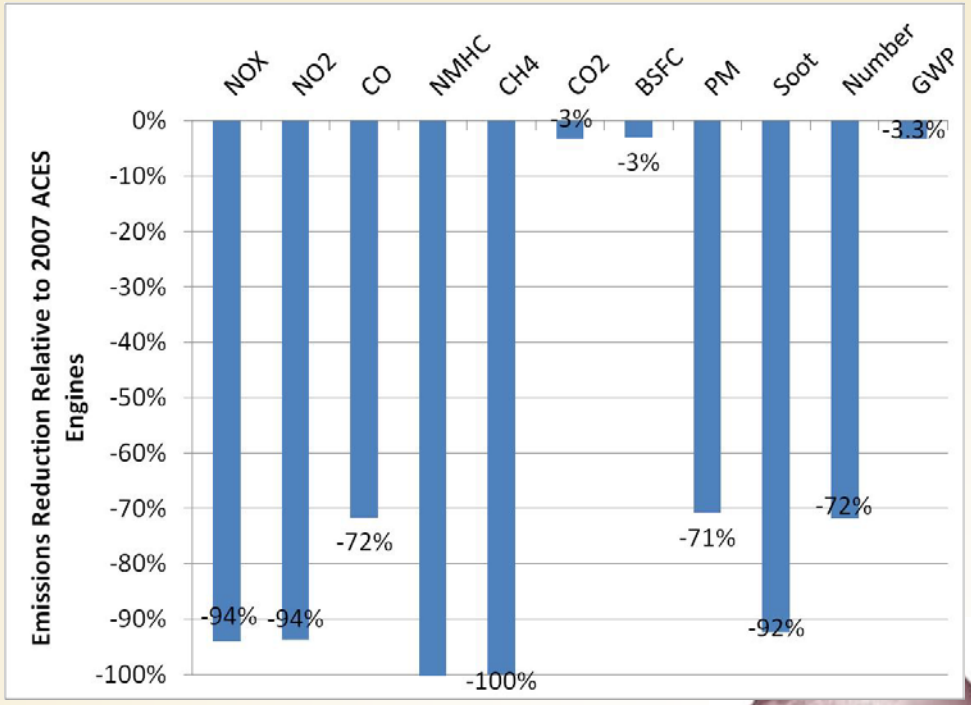
Notes: [a]The significant figures signify the detection limit in mg/bhp-hr; [b]SD data were not provided by ref 15. [c]Previous work showed artifact formation during filter collection of the compounds highlighted in bold.

Phase 2 ACES Results

Average Emissions Reduction of 2010 ACES Engines Relative to 2007

Four 2007 ACES Engines
Three 2010 ACES Engines

- ***Substantial reduction in large number of emissions species was observed with the 2010 technology engines***
  - Even in comparison to 2007 Results



Source Khalek 2013

ACES Phase 3
2007 Engine Health Results

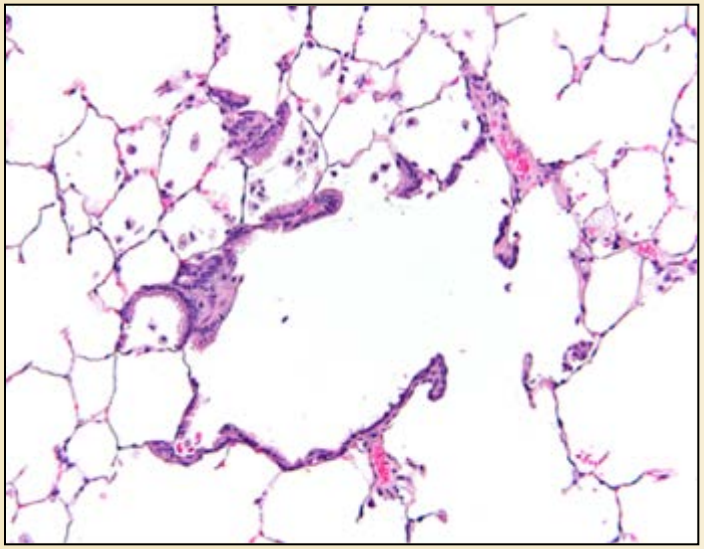
- First-ever lifetime animal study of effects of New Technology Diesel
- Substantially more rigorous than normal National Toxicology Program cancer tests:
  - 80 hours of exposure per week
  - Tough Engine operating cycle
  - Twice as many animals
  - Exposures up to 30 months
- Study found no evidence of lung cancer
  - In contrast to previous studies of older diesel
- Mild inflammation, likely due to NO_2 emissions
  - Which have been further substantially reduced in 2010 and later model years

January 27, 2015

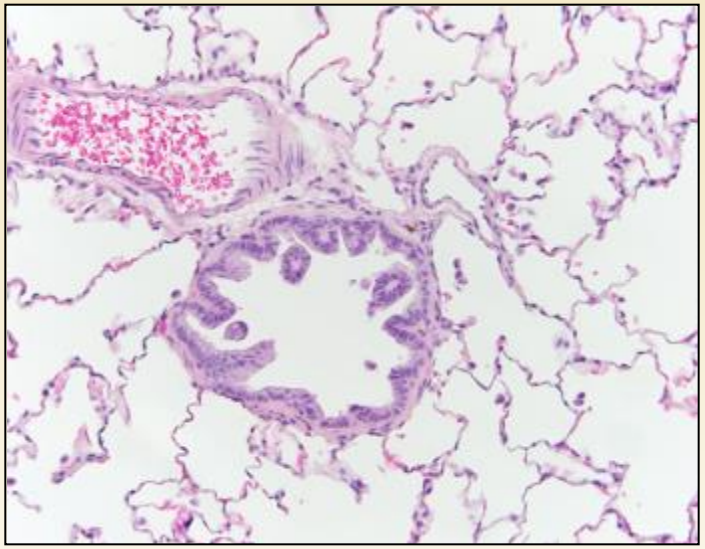
Full Report available at:
www.healtheffects.org

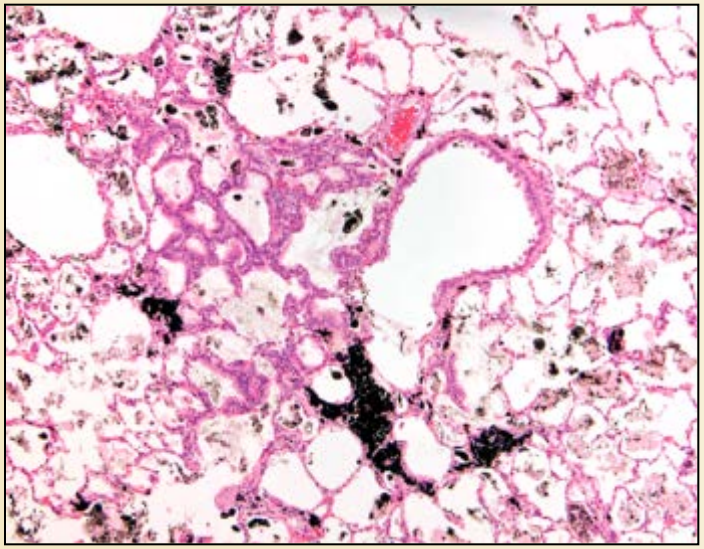
ACES Lifetime Animal Exposure Health Results:

Mild Inflammation (likely NO_2); NO Lung Tumors

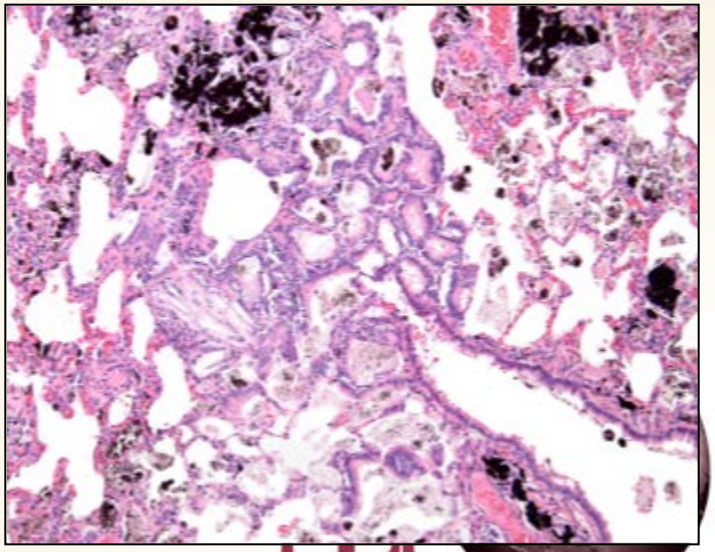


New Technology Diesel Engines (2007)





Traditional Diesel Engines (high particle loading)



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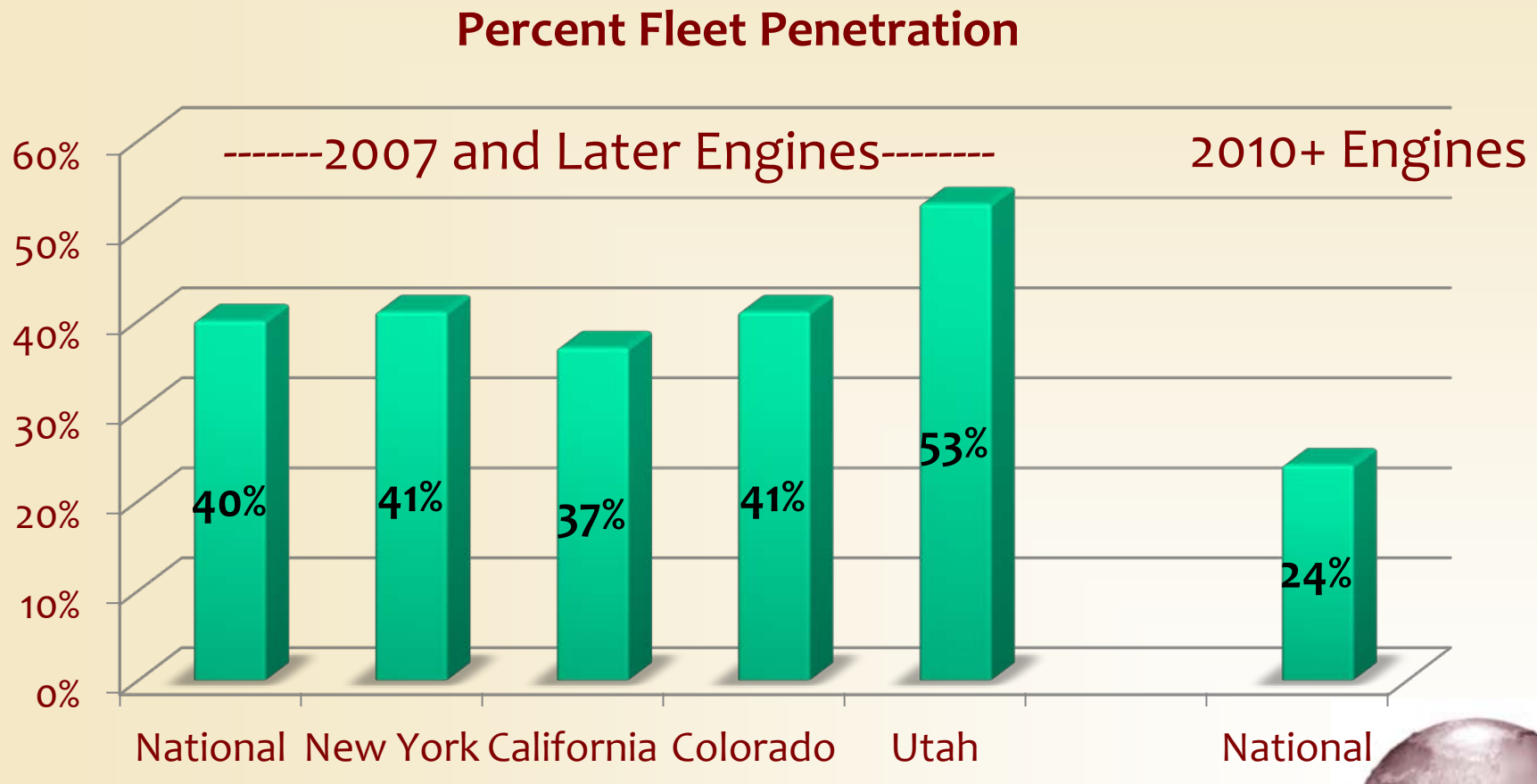
Are the Rules Working?

More new technology clean diesel trucks on the road

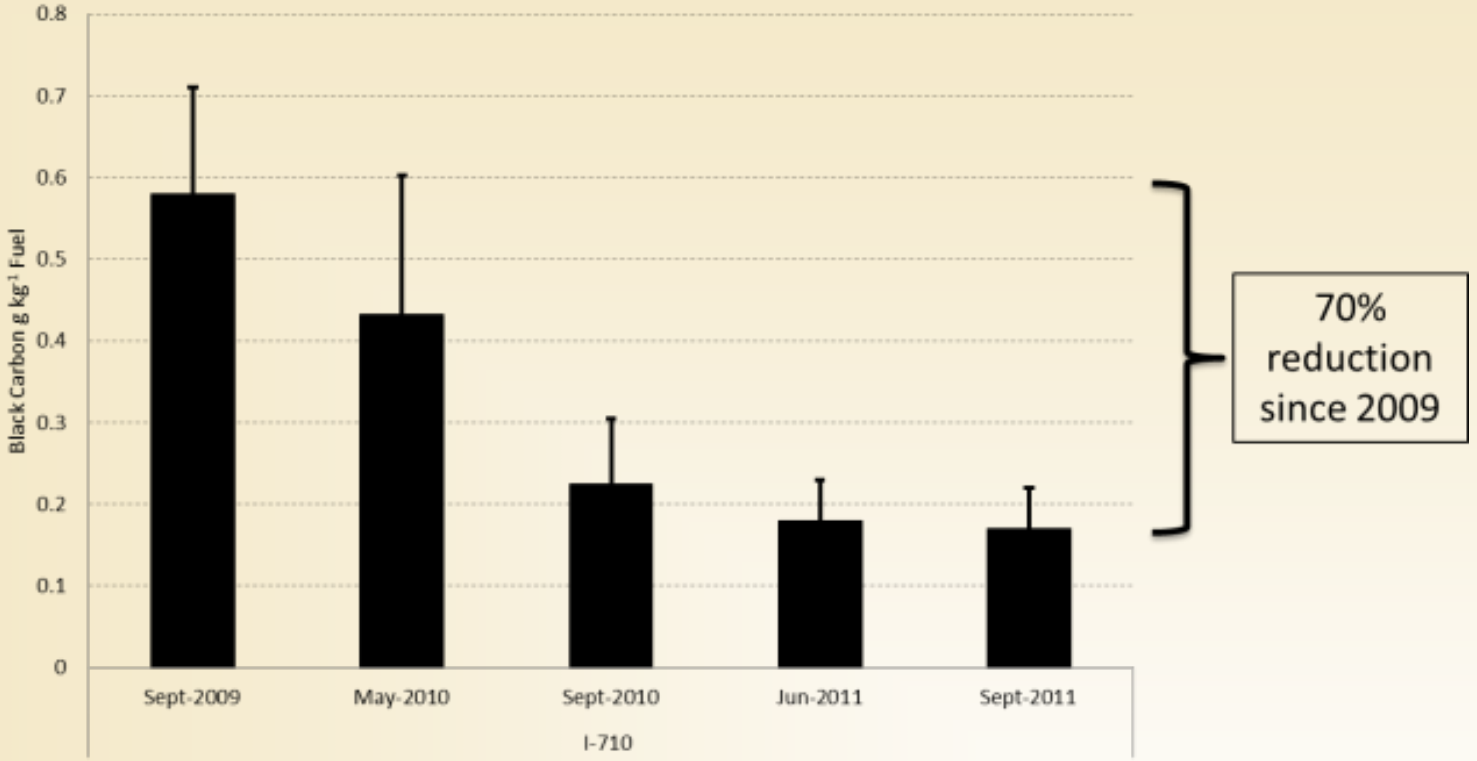


Source: Diesel Technology Forum and IHS/Polk
http://dieselforum.org/in-your-state

HEI

Are the Rules Working?

Effect of Diesel Rules in Southern California



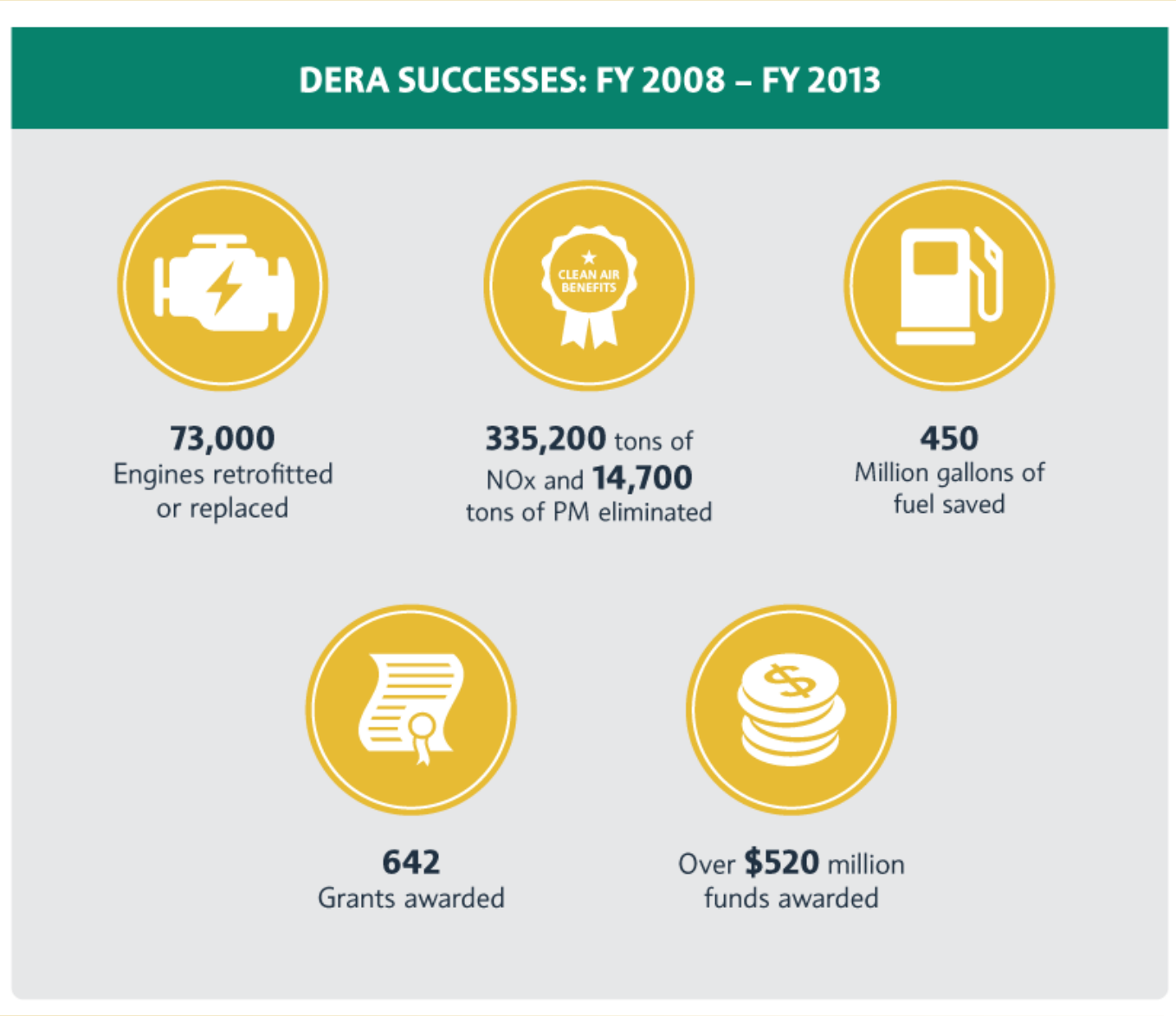
- On-road measurements show diesel rules reducing PM and NO_X on a truck-dominated freeway near the Ports of Los Angeles and Long Beach
- Continued reductions expected as the Truck and Bus Rule is implemented

Kozawa et al. (2014) *Environmental Science & Technology*, 48, 1475-1483

Addressing the Existing Fleet:

Diesel Emissions Reduction Act (DERA): Benefits Across the Country

(Source EPA 2016)



New HEI "Tunnel Study" to measure progress

Real-World Vehicle Emission Characterization for the Shing Mun Tunnel in Hong Kong and the Fort McHenry Tunnel in the U.S.

Xiaoliang Wang[1], Andrey Khlystov[1], Judith C. Chow[1], John G. Watson[1], Barbara Zielinska[1], Lung-Wen Antony Chen[1], Kin-Fai Ho[2], S.C. Frank Lee[3]

1: Desert Research Institute, Reno, NV, USA; 2: Chinese University of Hong Kong, Hong Kong, China; 3: Hong Kong Polytechnic University, Hong Kong, China

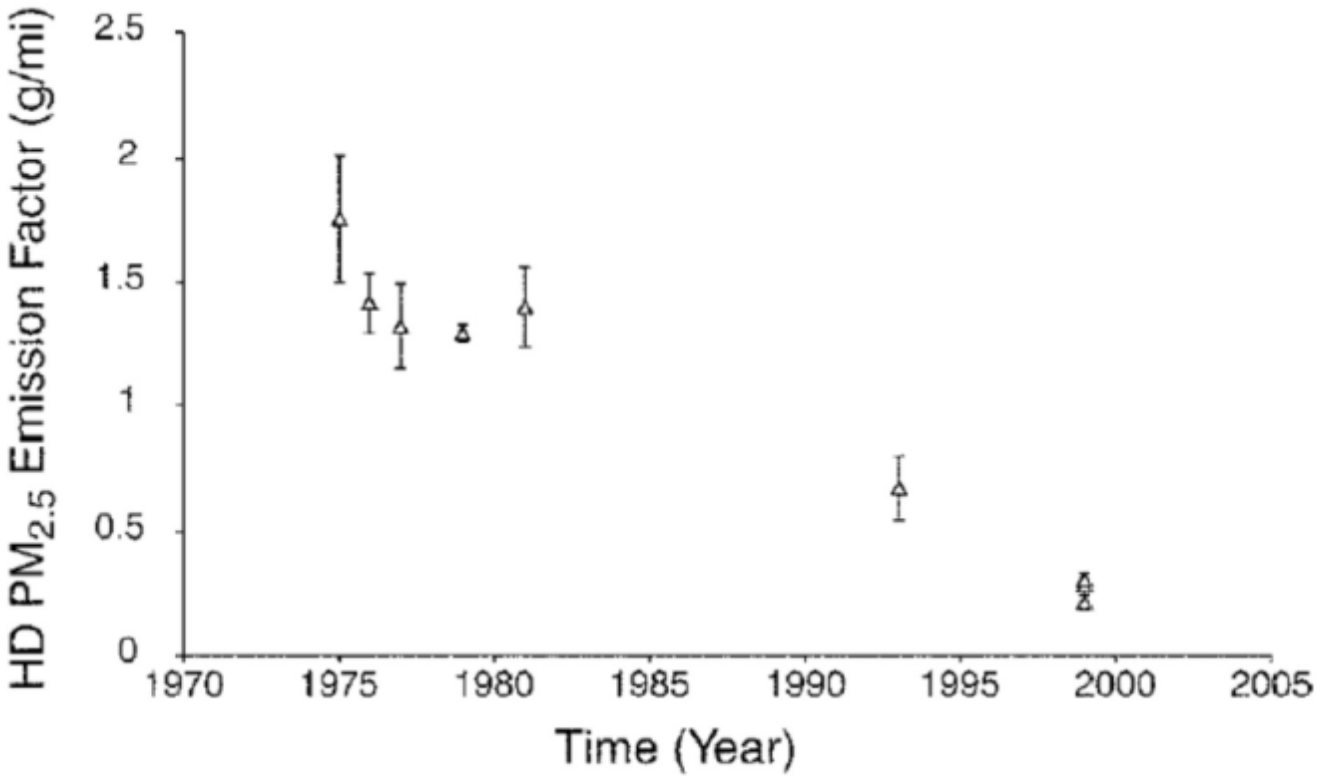
Text

Fort McHenry Tunnel (I-95 Baltimore)

- Four-bore 2.2 km tunnel, with two lanes per bore.
- Light-duty vehicles are allowed in all bores. Trucks (heavy-duty vehicles) are directed into the right-hand bores.
- Tunnel has been studied several times before, allowing comparison/monitoring of change.
- Measurements in winter and spring; poster at this Conference

These studies can have impact…
(HEI Tuscarora Tunnel Study)

Fig. 1.2 Heavy-duty vehicle particulate matter emission factor estimates measured on-road in the Tuscarora tunnel, USA

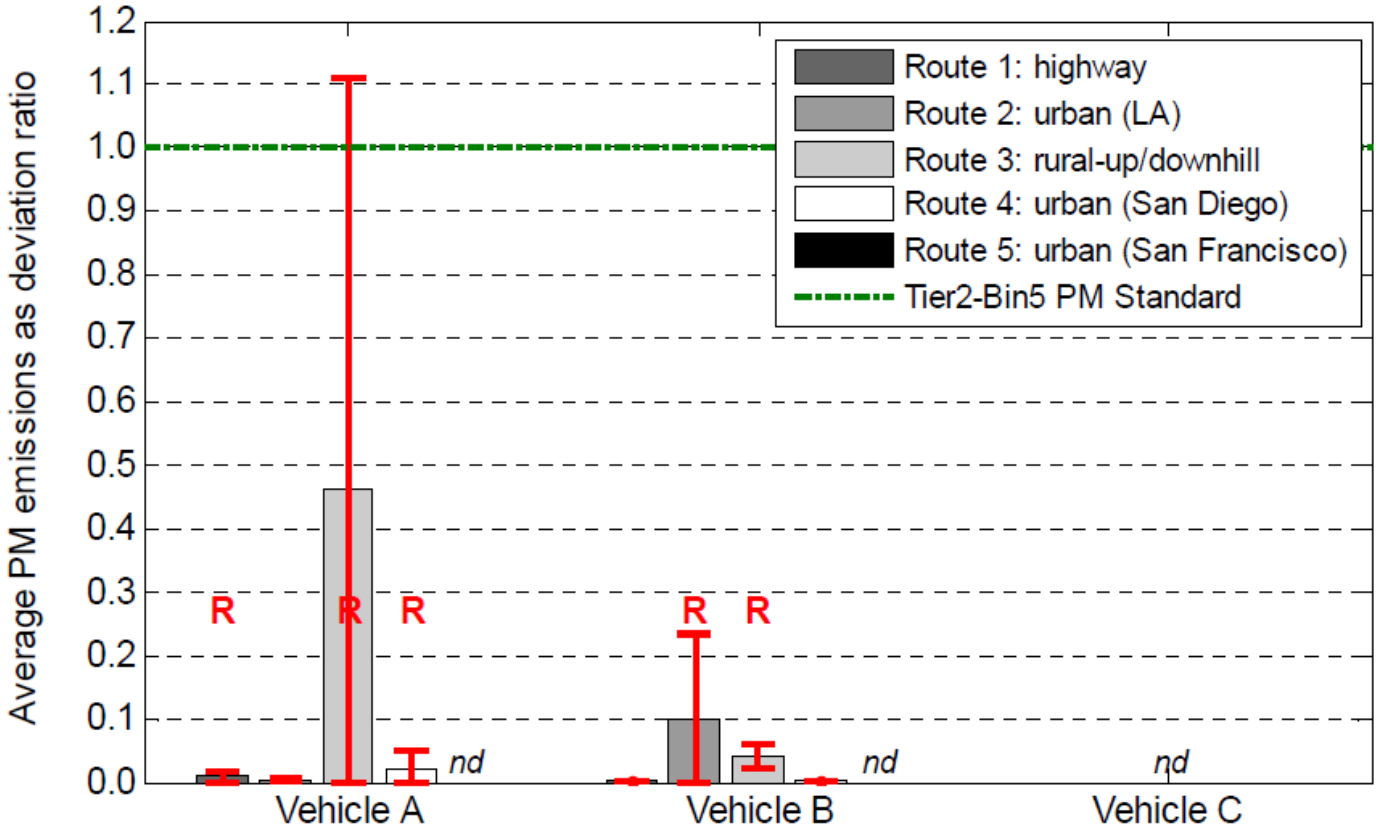


Note: the markers for 1999 include PM_{10}, $PM_{2.5}$, and $PM_{2.5}$ (reconstructed mass).
HD, heavy duty; PM, particulate matter
From Gertler *et al.* (2002). Reprinted with permission from the Health Effects Institute, Boston, MA.

And even recent VW on-road tests demonstrate progress…

PM emissions were dramatically below US EPA Tier 2 – Bin 5 emissions standard (ICCT/WVU tests) (even with widely report NOx issues…)

Figure 4.11: Average PM emissions of test vehicles over the five test routes compared to US-EPA Tier2-Bin5 emissions standard; repeat test variation intervals are presented as ±1σ; Route 1 for Vehicle A includes rush-hour/non rush-hour driving, no PM data collected for Vehicle C, '*R*' designates routes including a test with DPF regeneration event, '*nd*' - no data available



What about the Rest of the World?

EURO VI and US 2007/10 standards require diesel filters and 10-50 ppm sulfur fuel

- Progress Underway:
  - China ULSD starting in 2017
  - India to "leapfrog" to Euro 6 by 2020
  - Mexico on the verge of action
- Though more progress still to be made…

Diesel: Looking Ahead

- Occupational Studies find lung cancer associations with exposure to old diesel
  - Risk assessment will need to take on board key uncertainties:
    - Exposure error
    - Improving technology and reduced exposure
- NTDE is dramatically cleaner
  - And penetrating deep into US market
  - While other markets move to implement fully (though much more needs to be done…)
- Looking Ahead:
  - Growing opportunities to monitor, report progress

Thank You

Dan Greenbaum
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