Old Risks, New Diesel Engine Technologies, and Public Health Impacts

An Introduction

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Clean Air Act Advisory Committee
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The Challenge: Old Diesel

- Primary health concern: *effects on the heart from exposure to* ***Particulate Matter*** *(PM) from older diesel*
  - Significant effects on mortality, life expectancy
  - Strong evidence of respiratory effects: *reduced lung function, respiratory irritation, asthma exacerbation*
- *IARC (WHO) Review of diesel carcinogenicity (2012)*
  - *Diesel a "Known Human Carcinogen"*
  - *Change based on 2 Major Occupational Studies:*
    - *US Diesel Exposed Miners Study (DEMS)*
    - *US Truckers Study*
- ***Technology is changing, though exposure to older diesel still continues***

HEI Diesel Epidemiology Panel Report 2015

- Charged to evaluate DEMS and Truckers Studies
  - Could they stand up to detailed scrutiny and further analysis?
- Daniel Krewski, Chair, Diesel Epidemiology Panel
- Katherine Walker, Senior Scientist, Health Effects Institute

Miners

Truckers

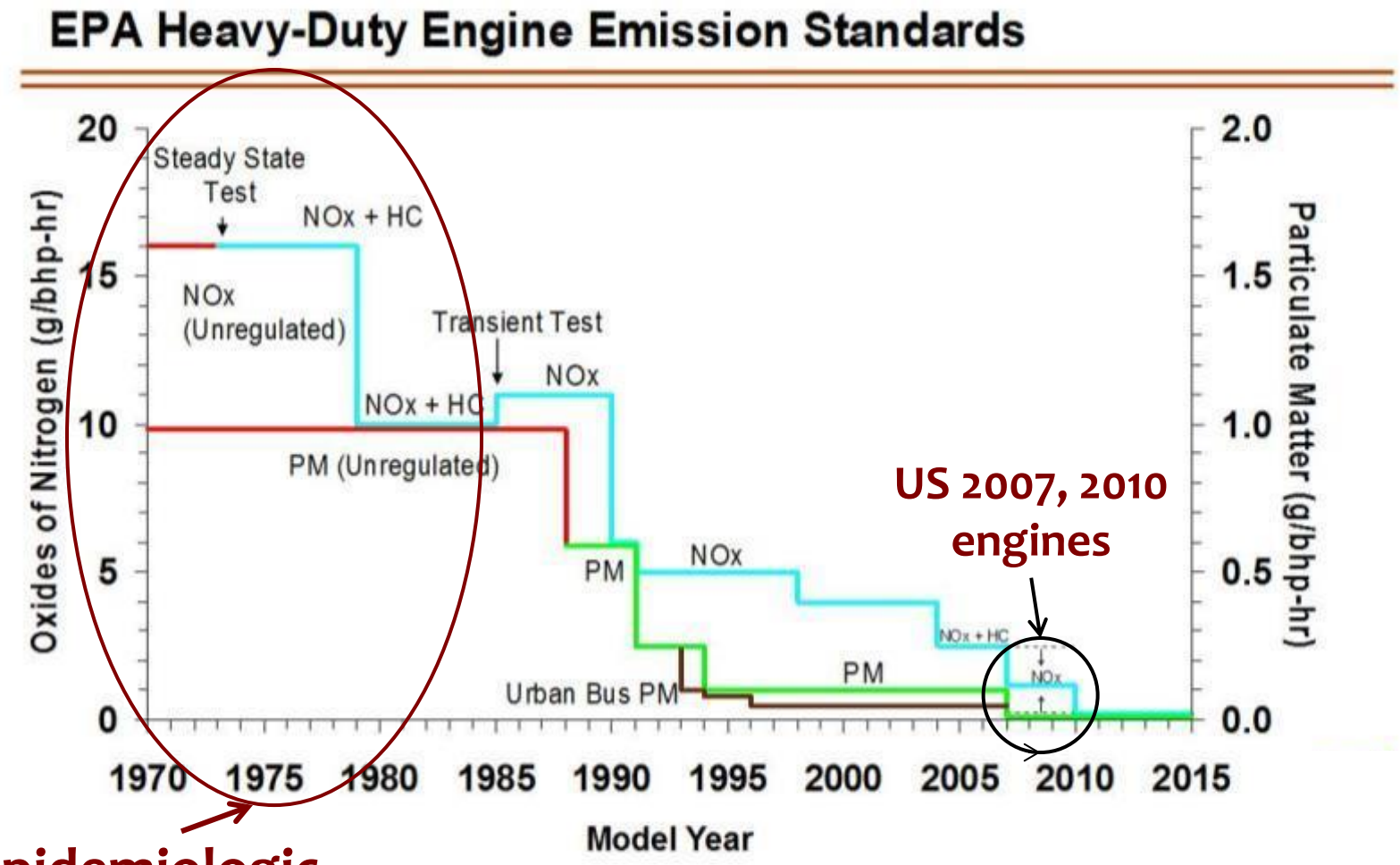
Overall Panel Conclusions

- Both the DEMS and Truckers 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.

- Quantitative Risk Assessments will need to take into account some key uncertainties and limitations (e.g. changing technology).

The Policy Response:
US 2007/2010 Rules

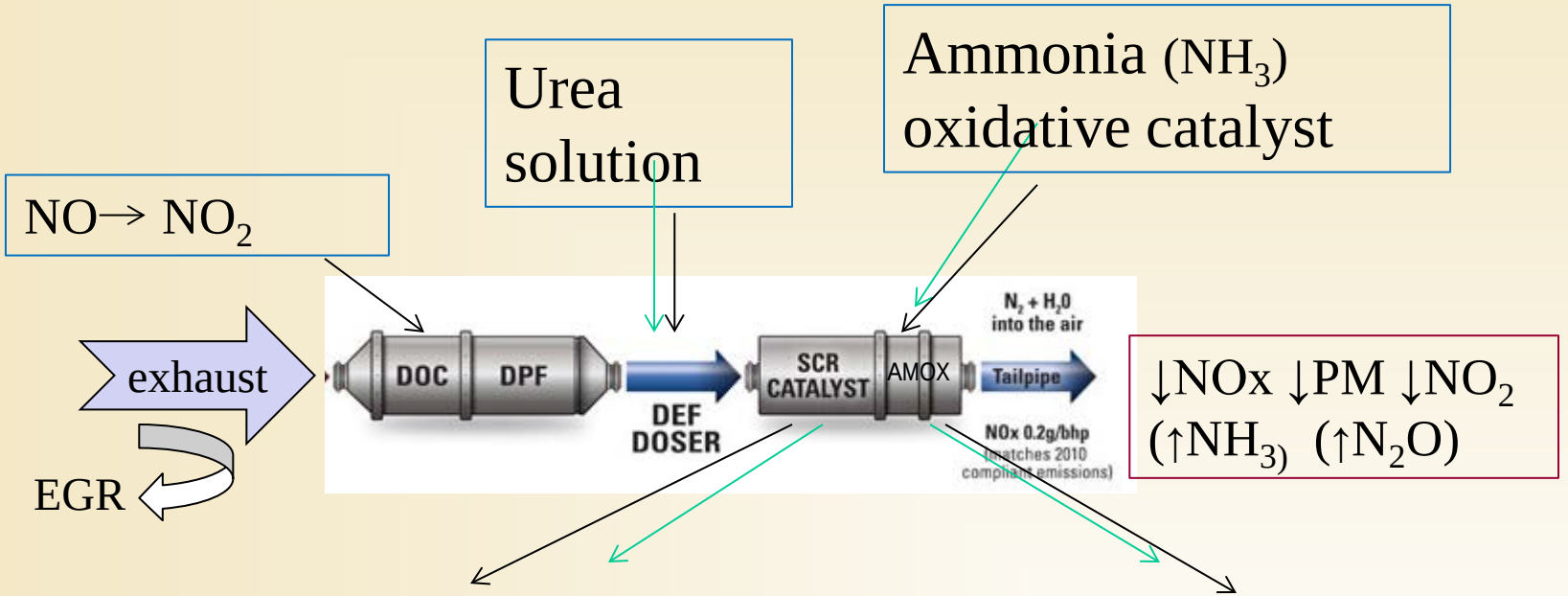


Are the Rules Working?

HEI's Advanced Collaborative Emissions Study (ACES)

- Collaborative multiparty effort to:
  - Characterize emissions from new technology, modern diesel engines (MY 2007 and 2010) (Khalek et al., 2011, 2015)
  - Study the health effects of emissions from such engines (McDonald et al., 2015)
- Supported by a variety of US government agencies and private parties; collaboration with many academic and research organizations

Schematic Representation of New Technology Diesel Engine Emission Controls tested in ACES



$CO(NH_2)2 \rightarrow NH_3$

$NH_3 + NO + NO_2 \rightarrow N_2 + H_2O$ (+NH_3 slip)

$NH_3 \rightarrow NO + N_2O + N_2$

Emission Standards and Average Emission Levels

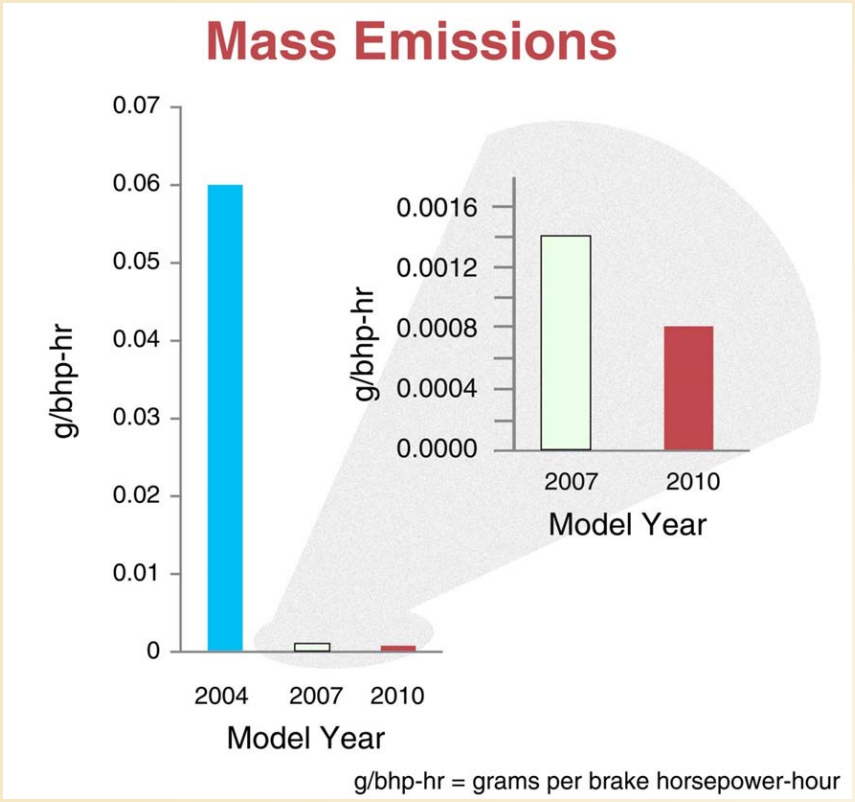
(FTP cycle, g/bhp-hr)

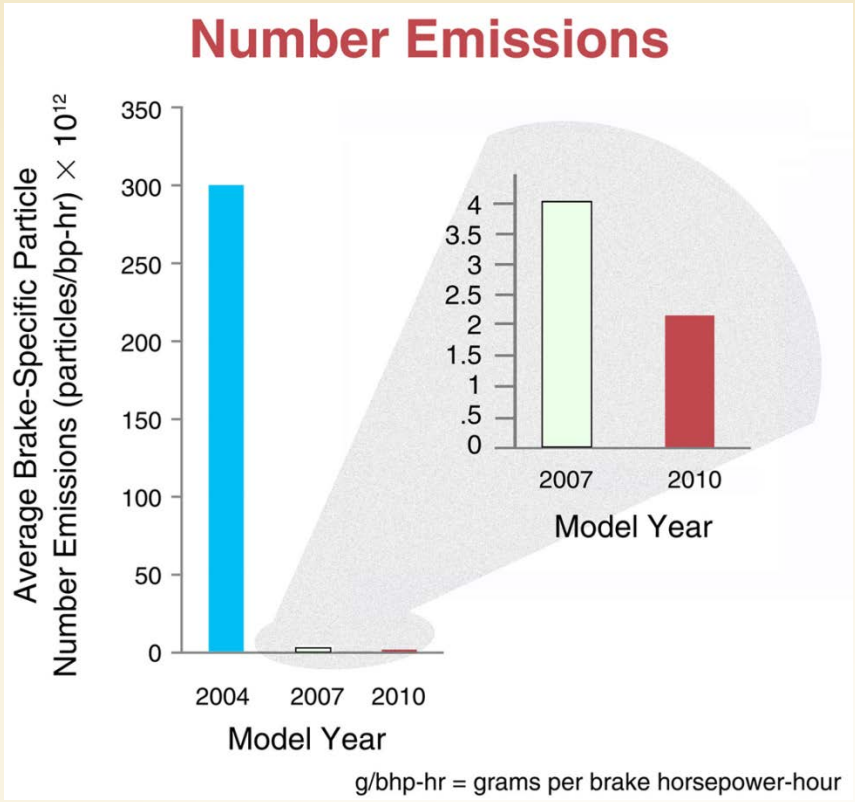
Year	1998	2004	2007[1]	2010[2]
PM	0.1	0.1	0.01	0.01
Measured			0.0014	0.0008
NO2	4	2.4	1.2	0.2
Measured			1.09	0.08

1. Average emissions from 4 engines
2. Average emissions from 3 engines

PM Mass and Numbers Emissions

90% to 99% reduction in Particle Mass and Number (ultrafines)





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

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

- Polycyclic Aromatic Hydrocarbons (PAHs), including nitro-PAHs, have been of major concern in diesel exhaust
- Many known to cause cancer
- *Some of the most toxic compounds 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

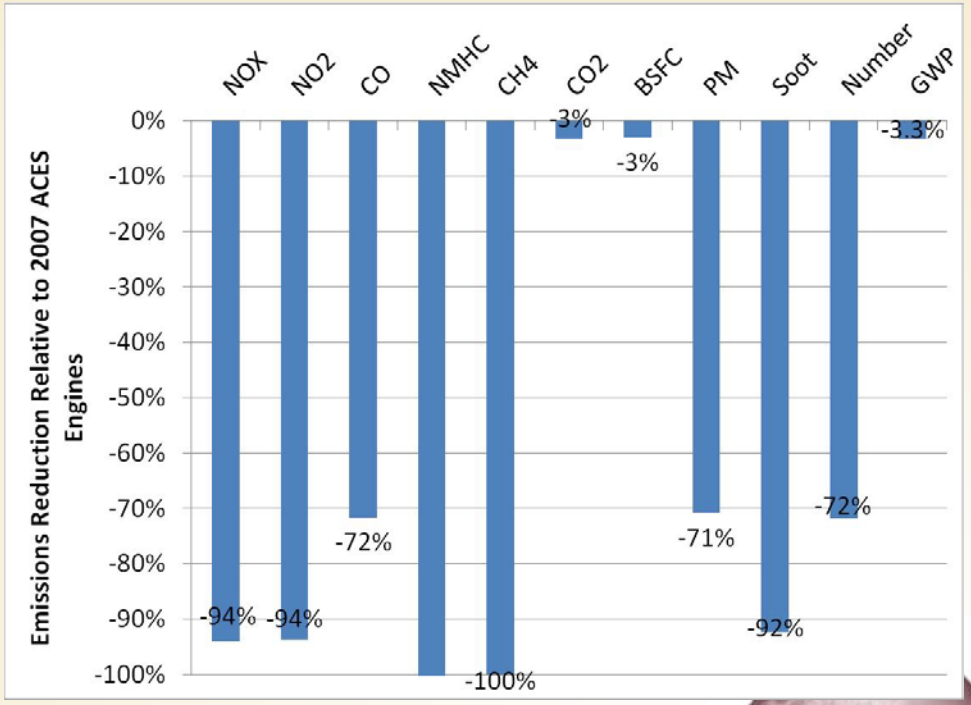
Notes: [a]The significant figures signify the detection limit in mg/bhp-hr; [b]SD data were not provided by ref 15. [c]Previous work showed artifact formation during filter collection of the compounds highlighted in bold.

Phase 2 ACES Results

Average Emissions Reduction of 2010 Engines Relative to 2007

Four 2007 ACES Engines
Three 2010 ACES Engines

Substantial reduction in large number of emissions species with the 2010 technology engines



Source Khalek 2013

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Summary of Emissions Characterization

- The aftertreatment technologies introduced to control emissions from modern diesel engines (US 2007 and 2010) were highly effective and met — and exceeded — the reductions mandated by U.S. regulations.
- Emissions of organic (PAHs and Other) compounds also reduced by >90%
- These regulations, along with the durability requirements and in-use testing are the most stringent in the world

Health Effects Testing Goals

- Health effects of *lifetime* exposure of rats to emissions from 2007-compliant diesel engines
  - Rats had shown tumors after diesel exposure in many previous studies of older diesel

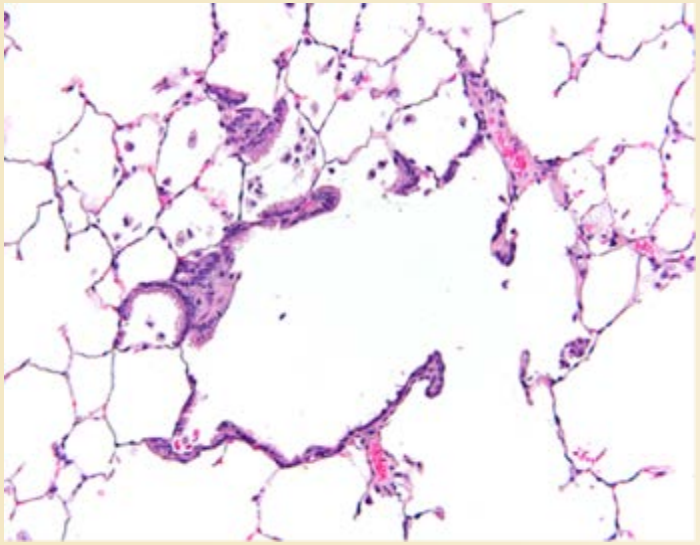
- Hypothesis: *Emissions will not cause an increase in tumor formation or substantial toxic health effects… although some biological effects may occur.*

- Characterize exposure atmospheres throughout the exposure period

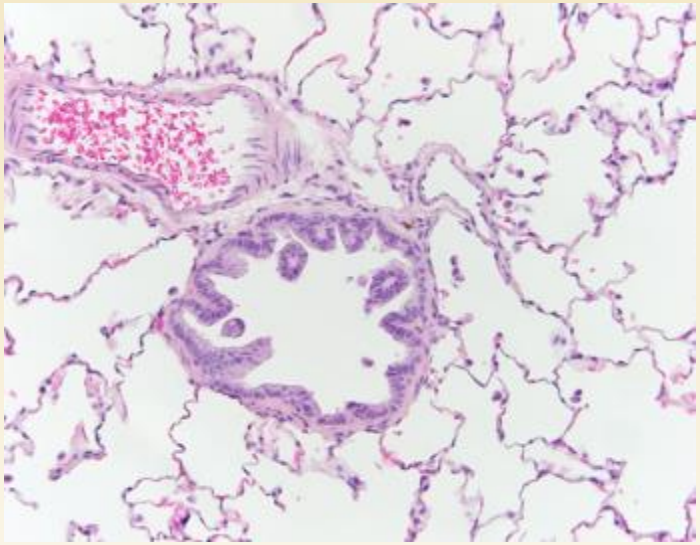
Health Effects Testing -- Methods

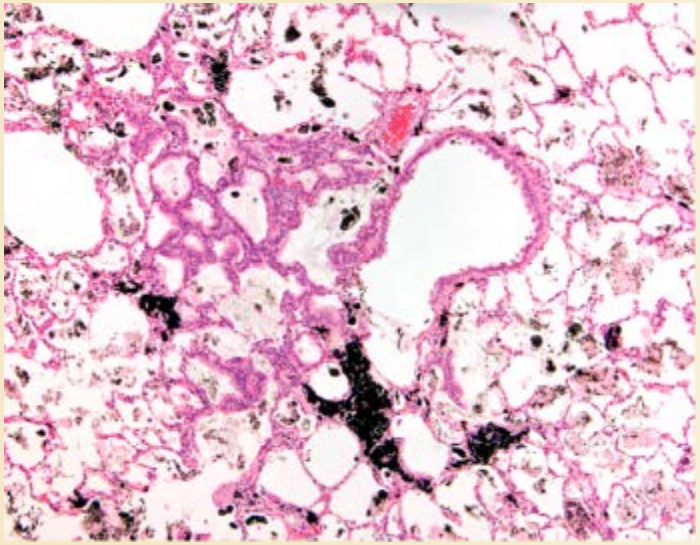
- 2007 model year engine (low PM, NO2 present)
- Expose male and female rats (Wistar Han strain)
- Duration -- Lifetime = 28 – 30 months
- Exposure conditions: 16 hr/day, 5 days/wk
- Engine Cycle: Special 16-hour cycle
- Exposure Levels:
  - PM too low to calibrate for exposures
  - NO2 dilutions used:
    - 4.2 ppm NO_2 = High
    - 0.8 ppm NO_2 = Medium
    - 0.1 ppm NO_2 = Low
    - Clean air control

Health Effects Testing -- Results

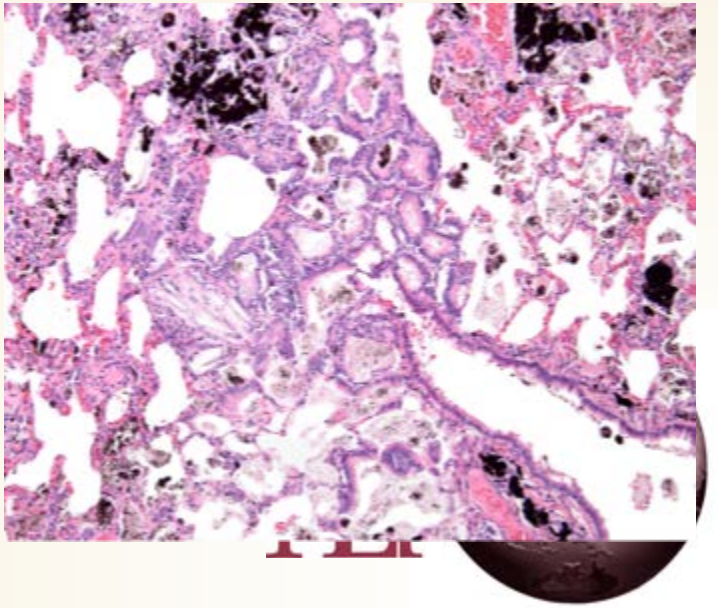


Modern (2007)
Diesel Engine





Old Diesel
Engines
(high particle
Loading, Cancer)



Health Effects Testing: Modern Diesel Engine Emissions

- HEI study is the first-ever lifetime animal study of effects of modern diesel engine emissions
- 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

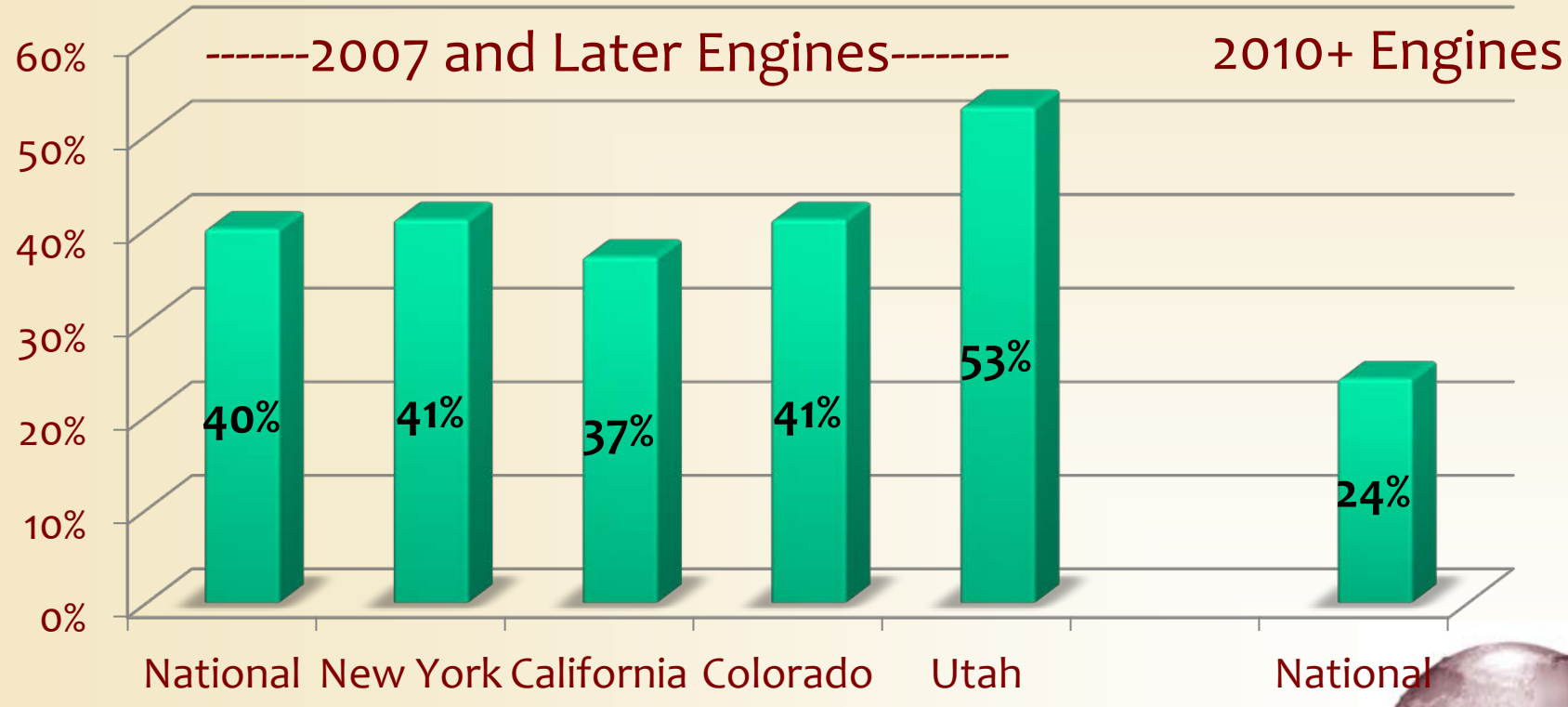
- Study found no evidence of lung cancer
  - In contrast to previous studies with older diesel
- Mild inflammation, likely due to NO_2 in emissions
  - ➢ Which have been further substantially reduced in 2010 and later model years

Full Report available at:
www.healtheffects.org

Are the Rules Working?

Over 40% of trucks on road in US today are new technology clean diesel

U.S. HD Vehicles subject to extensive in-use testing…



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

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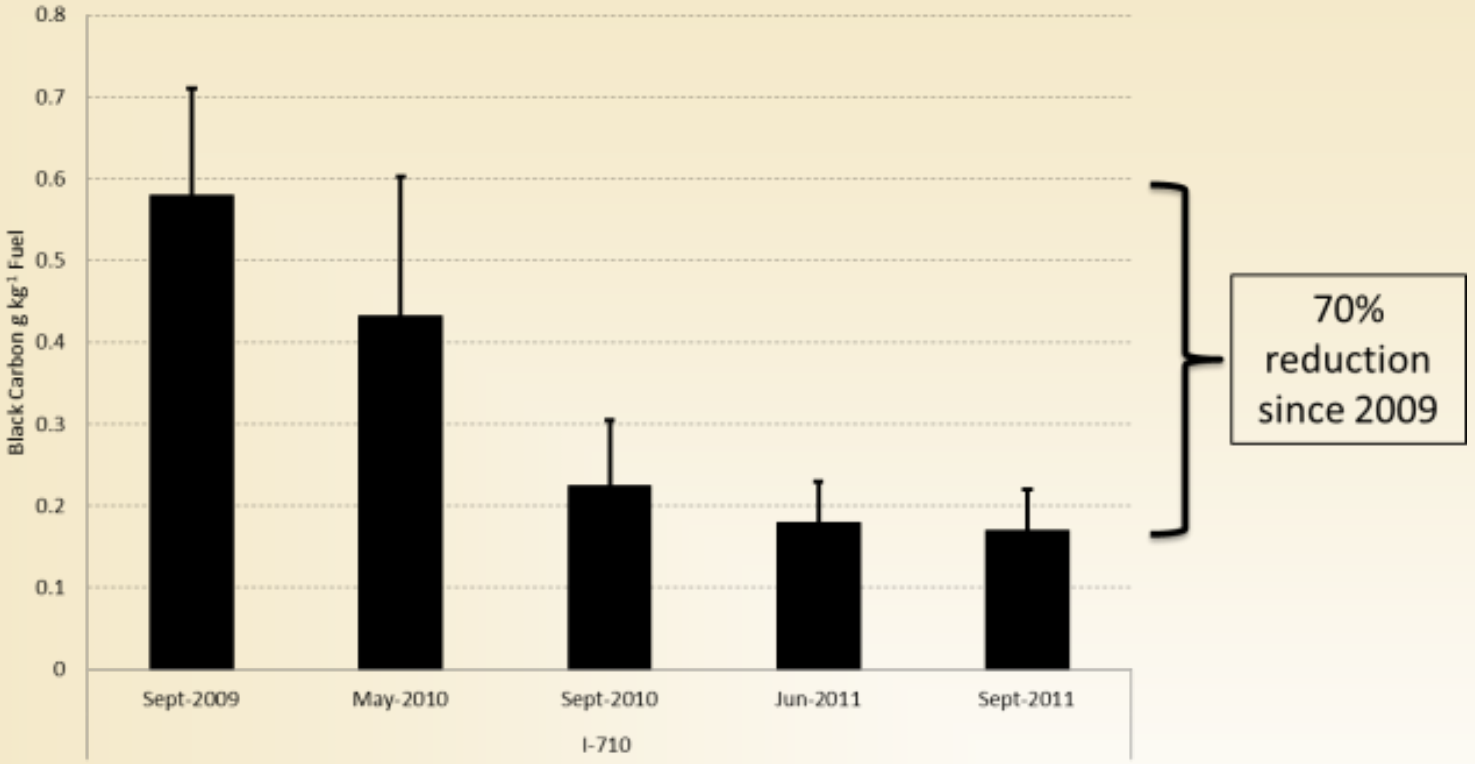
Are the Rules Working?

Effect of Diesel Rules in Southern California



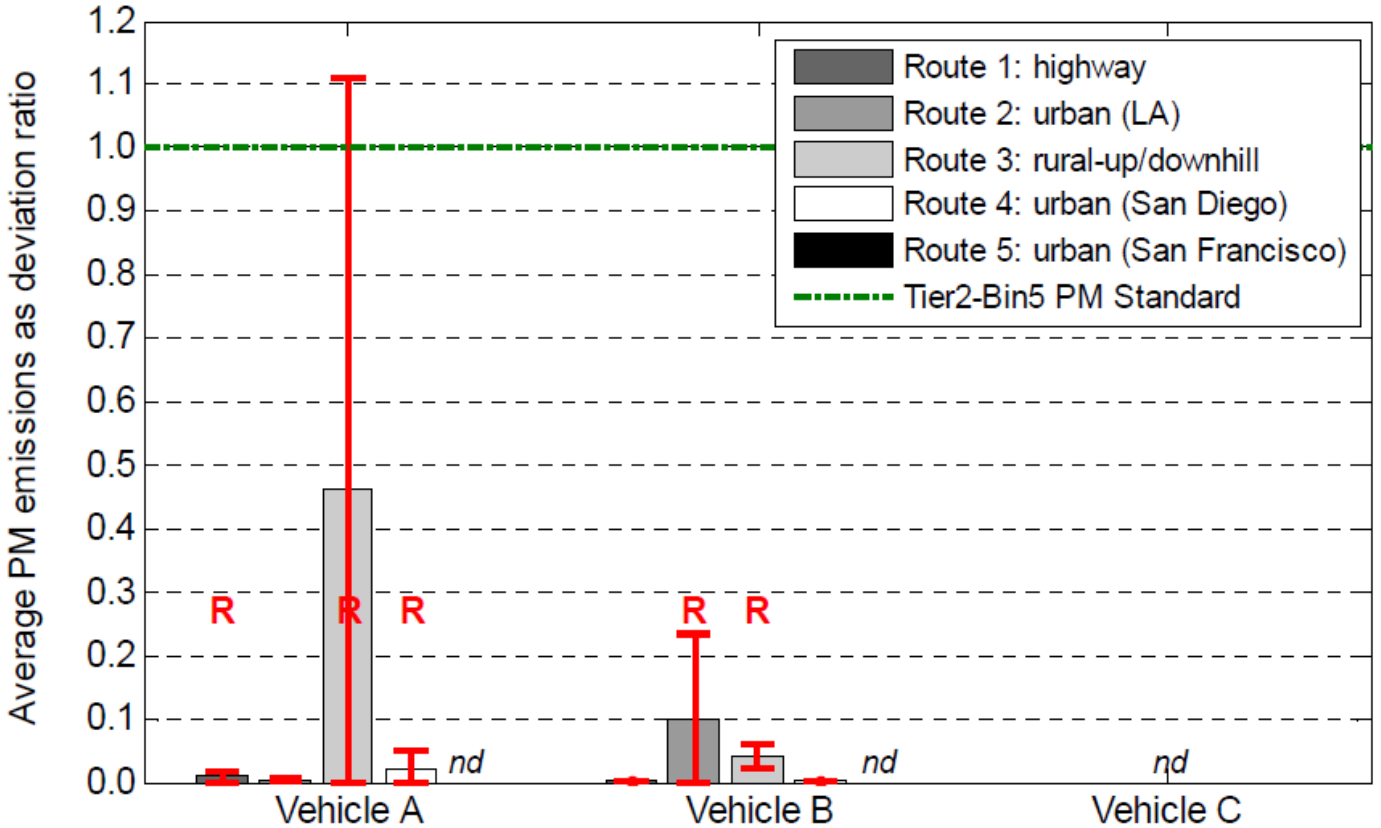
- On-road measurements show diesel rules reducing PM and NO_X on a truck-dominated freeway near the Ports of Los Angeles and Long Beach
- Continued reductions expected as the Truck and Bus Rule is implemented

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

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



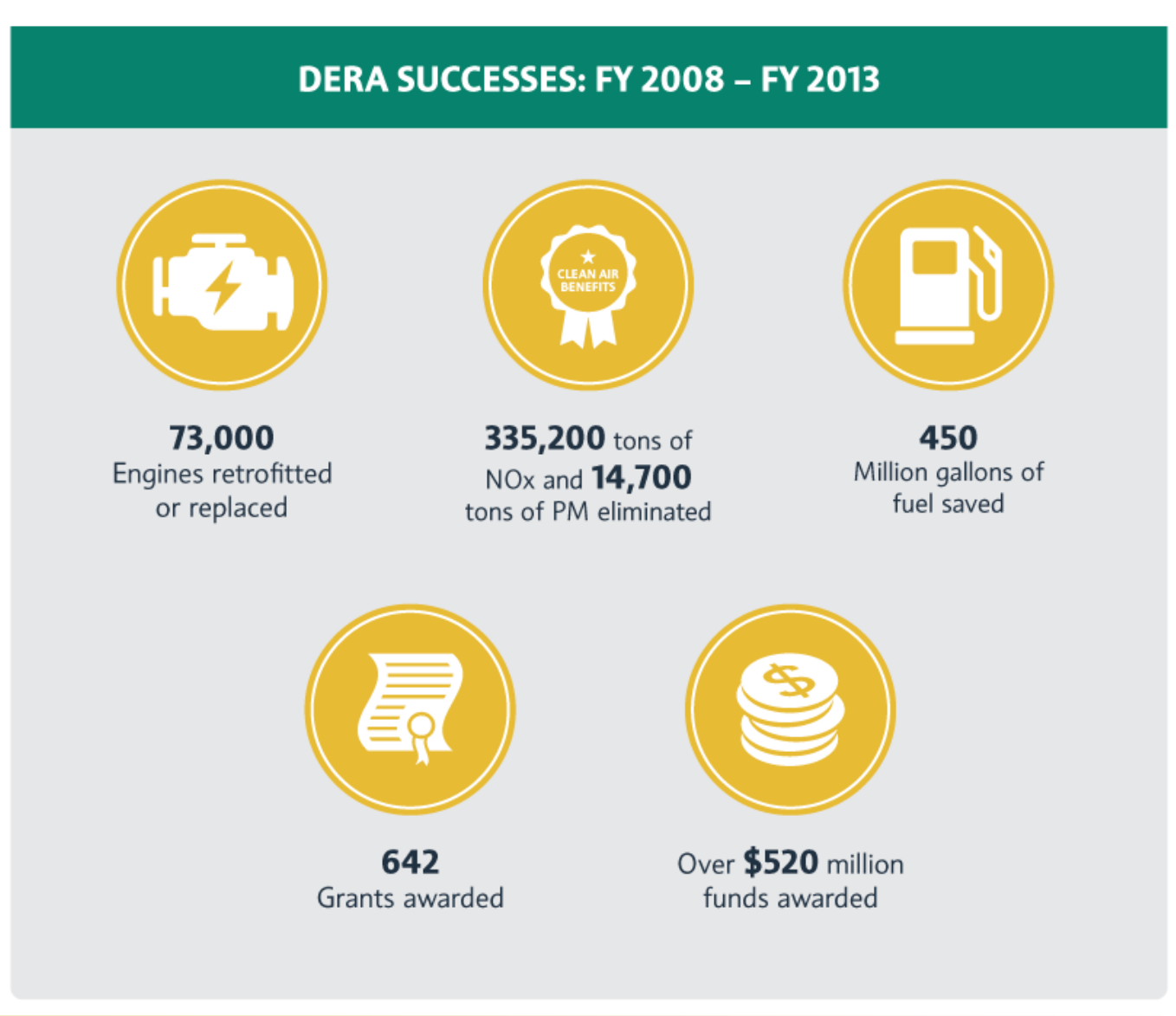
Are there any issues in the Real World?

- EPA and CARB regulations in place for longevity of emissions controls and in-use compliance, and are being toughened up
- PM Filters:
  - Seem to work well under a variety of conditions
  - Robust technology
- NOx Controls:
  - Under certain conditions, SCR may be too cool to work efficiently
    - Manufacturers and others are developing new technologies
  - Lowering of the current Urban Driving 2010 NOx standard: Strong push in California (and Northeast)
    - Technologies and feasibility under development and testing

Addressing the Existing US Fleet:

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

(Source EPA 2016)



Addressing the Existing US Fleet

- The recent VW Settlement
  - $14.7 Billion overall
  - $2.7 Billion for retrofit and replacement
    - Focused on NOx…
    - But will likely have substantial benefits for PM as well
- The CARB rule requiring retrofit and replacement of older diesels

Diesel: Looking Ahead

- The technology now exists for substantially cleaner diesel
  - And much lower population exposure
- Substantial progress in the US:
  - Over 40% of vehicles now meet new technology standards
- More work to be done
  - To accelerate replacement and retrofit, especially of older vehicles in urban centers
  - To refine/strengthen vehicle controls in real world conditions

Thank You

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