

Modern diesel engines: Emissions characterization and health effects

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Diesel Technology Workshop
MSHA/NIOSH Diesel Partnership
January 23, 2019



Outline of Presentation

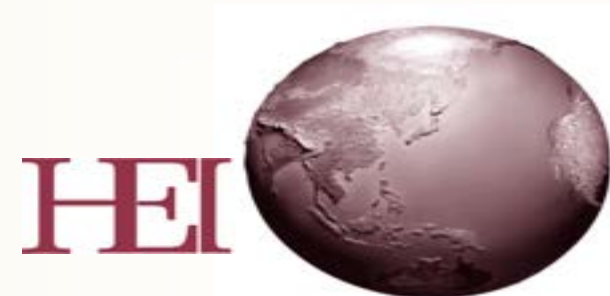
GOAL: Summarize HEI's work that supports controls for diesel engine emissions

- What is the Health Effects Institute
- HEI's program: Advanced Collaborative Emissions Study (ACES)
 - Phase I and II: Emissions characterization of 2007 and 2010 MY HHD engines
 - Phase III: Health effects testing of a 2007 engine
- Conclusions from review of the diesel miners study
- Overall Conclusions



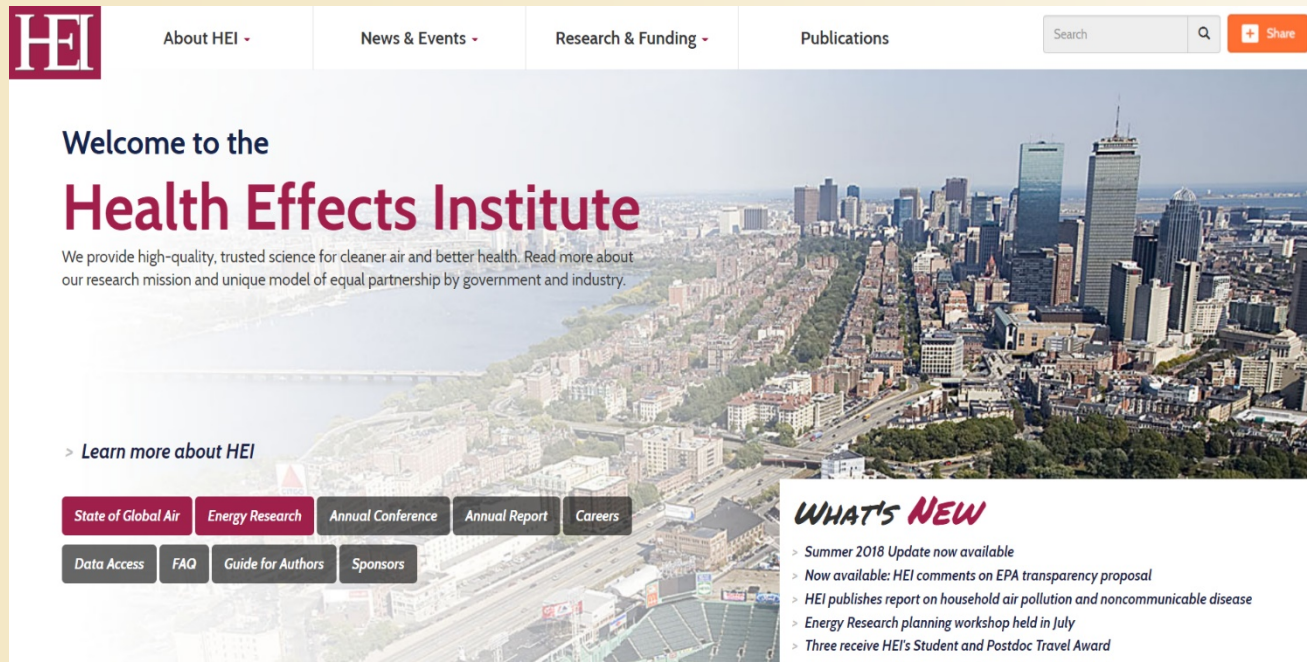
What is the Health Effects Institute

- Independent, non-profit institute, providing high quality, impartial scientific information on the health effects of air pollution, since 1980
- Balanced Core Support:
 - US EPA and Industry (Worldwide Motor Vehicle)
- Additional Partners
 - DOE, CARB, Oil Industry (API, CONCAWE), Foundations
- Governance
 - Independent Board of Directors
 - Expert Scientific Committees – Develop, oversee and intensively peer review all research
- Hundreds of scientific reviews, reanalysis conducted around the world
- Scientific Research Organization:
 - HEI does not advocate policy

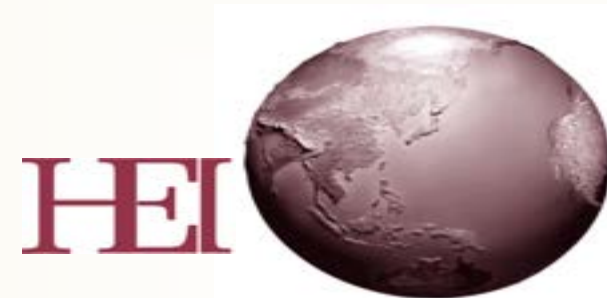


HEI's Activities

- **Targeted Research and Reanalysis**
 - Over 350 Studies on a wide variety of air pollutants: PM, ozone, diesel, air toxics, Exposure, Epidemiology Accountability
 - Reanalysis of critical studies
- **Authoritative Literature Reviews**
- **Global Health**
 - Middle and Low Income Countries
- **NEW Energy Research Program**
 - Potential Exposures and from unconventional oil and gas development



All Publications
available at
[HealthEffects.org](https://www.hei.org/)

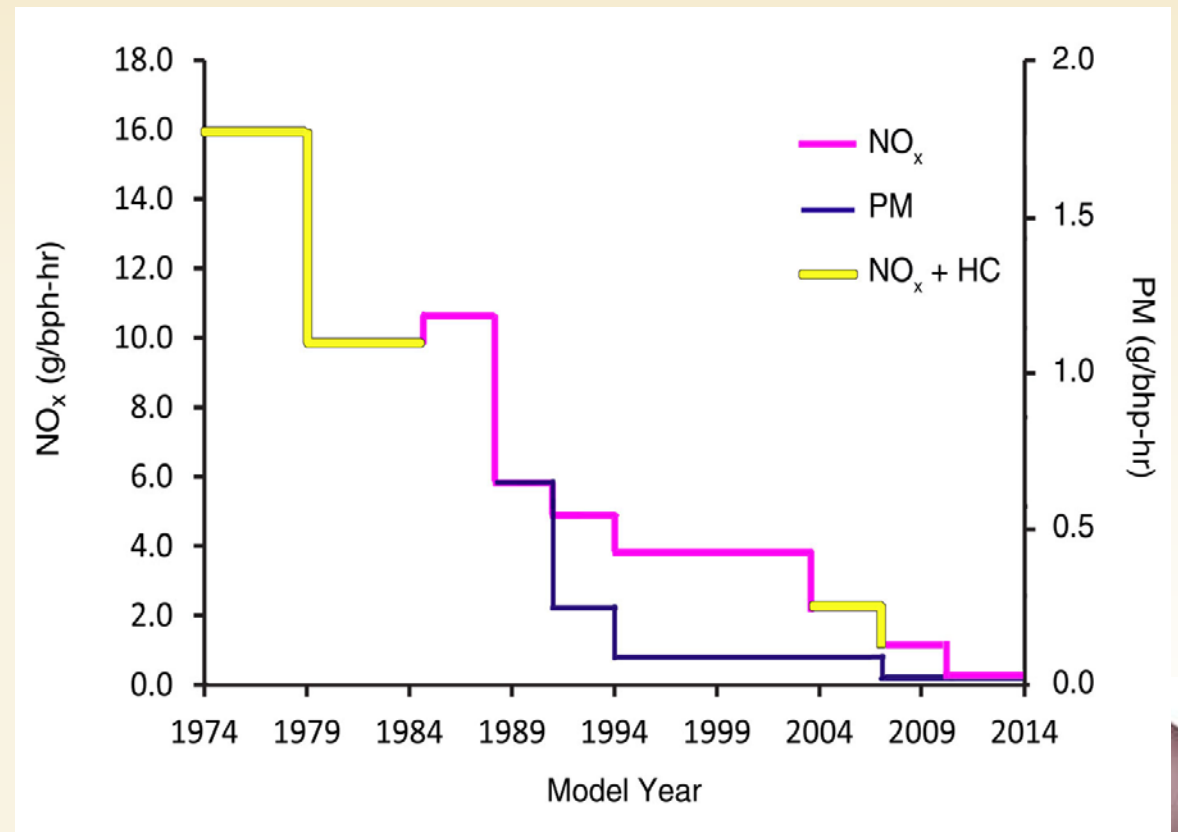


Diesel Emissions

Toxicity of Diesel Emissions

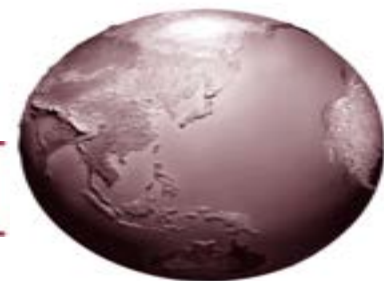
- 1970s and 1980s:
 - In vitro studies with PM and its extracts \Rightarrow Mutagenicity
 - Rat inhalation studies with PM \Rightarrow Carcinogenicity (lung)
 - Epidemiology Studies \Rightarrow Suggestive of Carcinogenicity (lung)
- International Agency for Research on Cancer (IARC)
 - 1988 Panel: DE is “probably carcinogenic to humans (category 2A)”
 - 2012 Panel: DE is a “known human carcinogen” (category 1)
- Other national and regional actions

Regulation of Diesel emissions



Recent HEI Diesel Related Activities

- Advanced Collaborative Emissions Study (ACES)
 - Most rigorous and comprehensive investigation for new tech. diesel engines (DPF and SCR) meeting 2007 and 2010 EPA regs
 - Emissions characterization of four (4) 2007 engines and three (3) 2007 heavy duty highway diesel engines
 - Health effects testing in animals for emissions from a 2007 engine
- Diesel Emissions and Lung Cancer -- Epidemiology
 - Expert HEI panel conducted a detailed analysis and evaluation of the latest [OLD] diesel epidemiological studies
 - Examine utility for quantitative risk assessment
 - Assistance and data access from NIOSH and NCI for DEMS



The Advanced Collaborative Emissions Study (ACES)

Rationale

The new developments motivated HEI's automotive and government sponsors, and others, to ask HEI to undertake ACES research:

- Confirm that advanced-technology diesel engines, after-treatment systems, reformulated fuels and reformulated oils developed to meet the 2007/2010 emission standards will result in substantially reduced emissions
- Substantial public health benefits are expected from these reductions
- Most pollutants will decrease, but new species may be formed
- Although health effects are expected to be reduced, new technologies should be evaluated before widespread introduction

Design

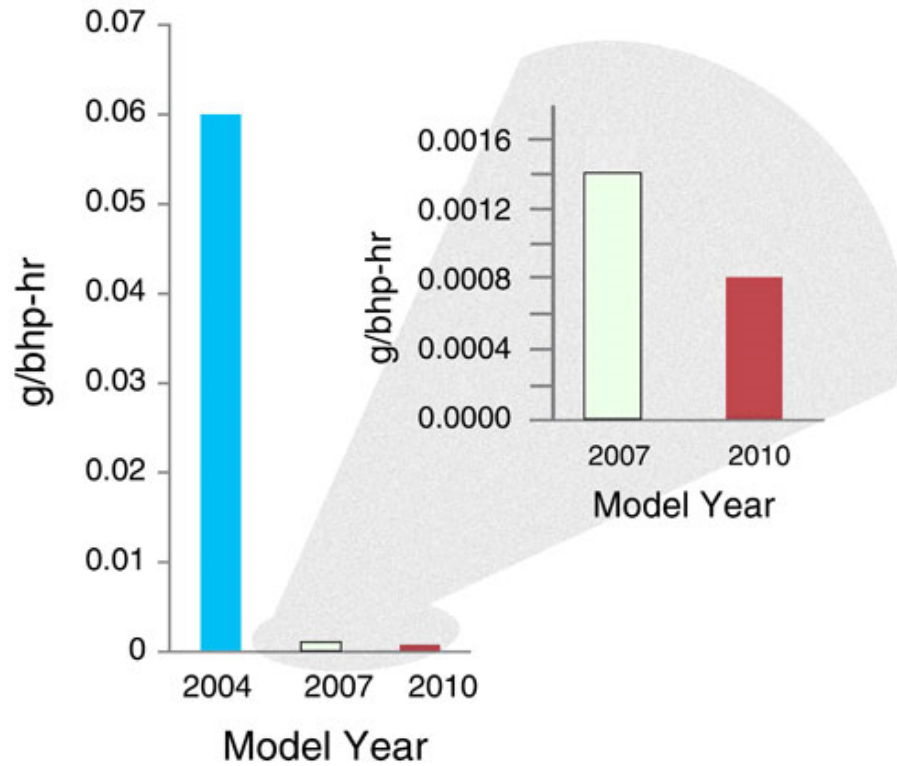
- Emissions characterization (Phases I and II): FTP and 16-hr cycles
 - Four 2007-compliant HD engines that meet the 2007 PM_{2.5} standard
 - Three 2010-compliant HD engines that meet the 2010 std for PM_{2.5} and NOx
- Health Testing (Phase III):
 - Health effects in rodents, chronically exposed to a 2007 engine emission, to study cancer and non-cancer endpoints



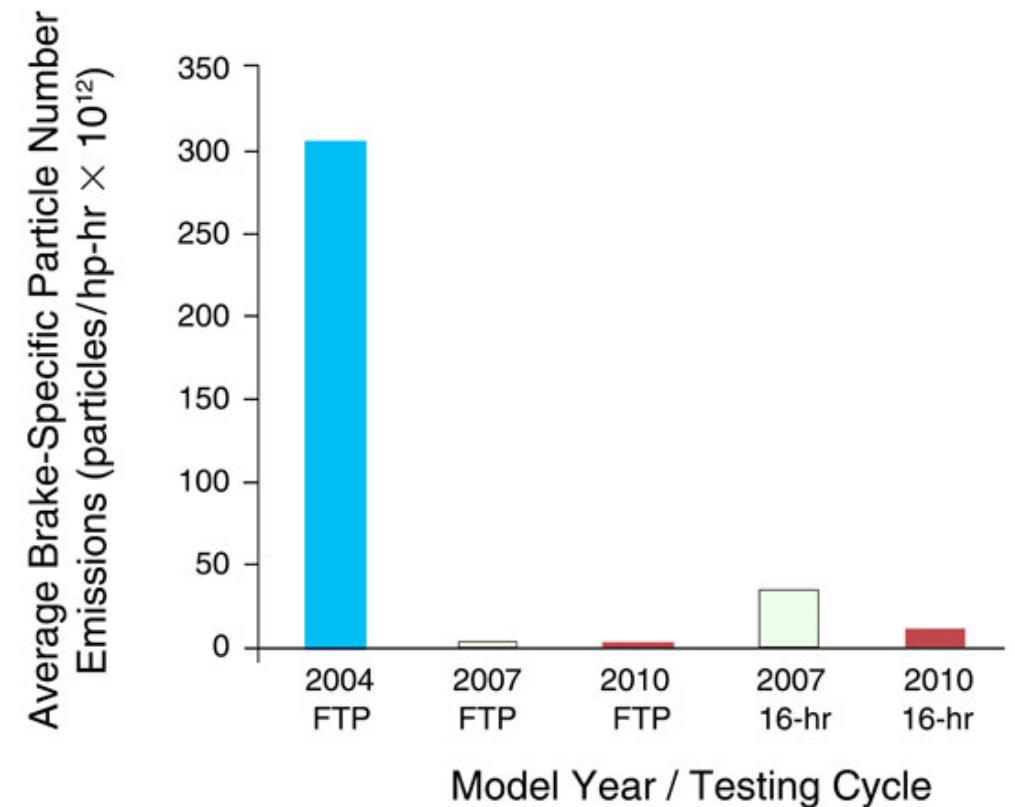
ACES Ph. 1 & 2: Reduction in PM & PN Emissions

Dara from Khalek et al. 2009 and 2013

(A) Mass Emissions

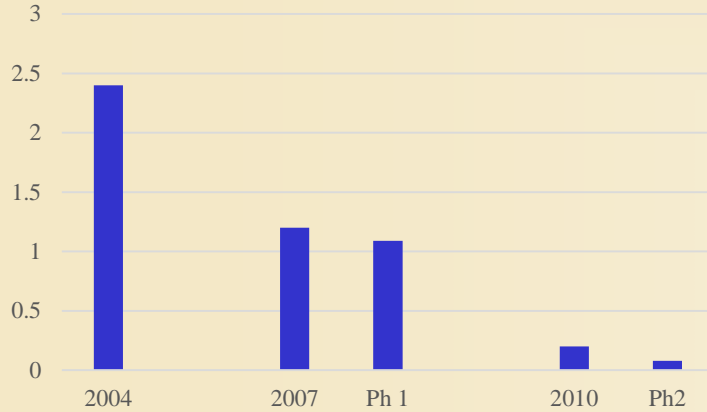


(B) Particle Number Emissions



ACES Phase 1 and 2 results, cont

Reduction in NO_x Emissions
(g/bhp-hr)

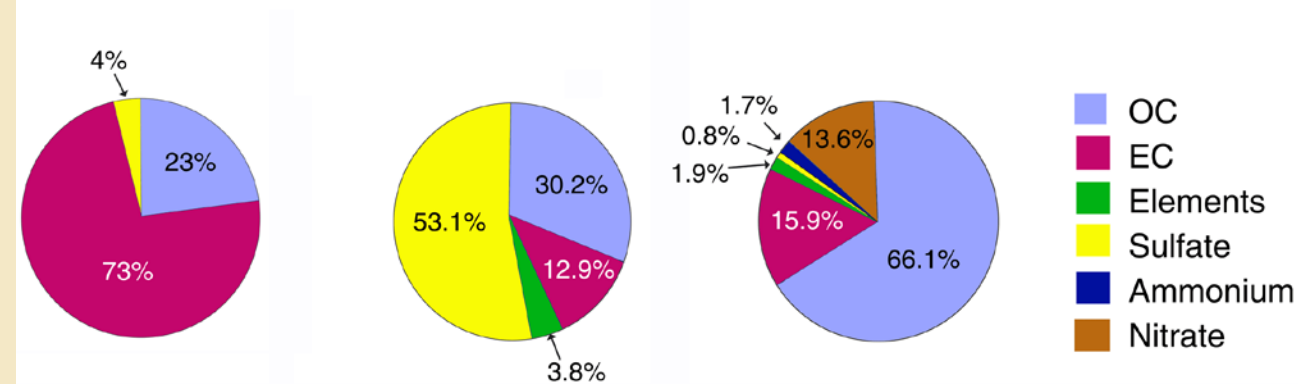


PM Composition

1998^a

2007^b

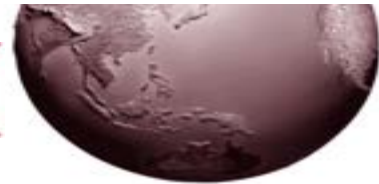
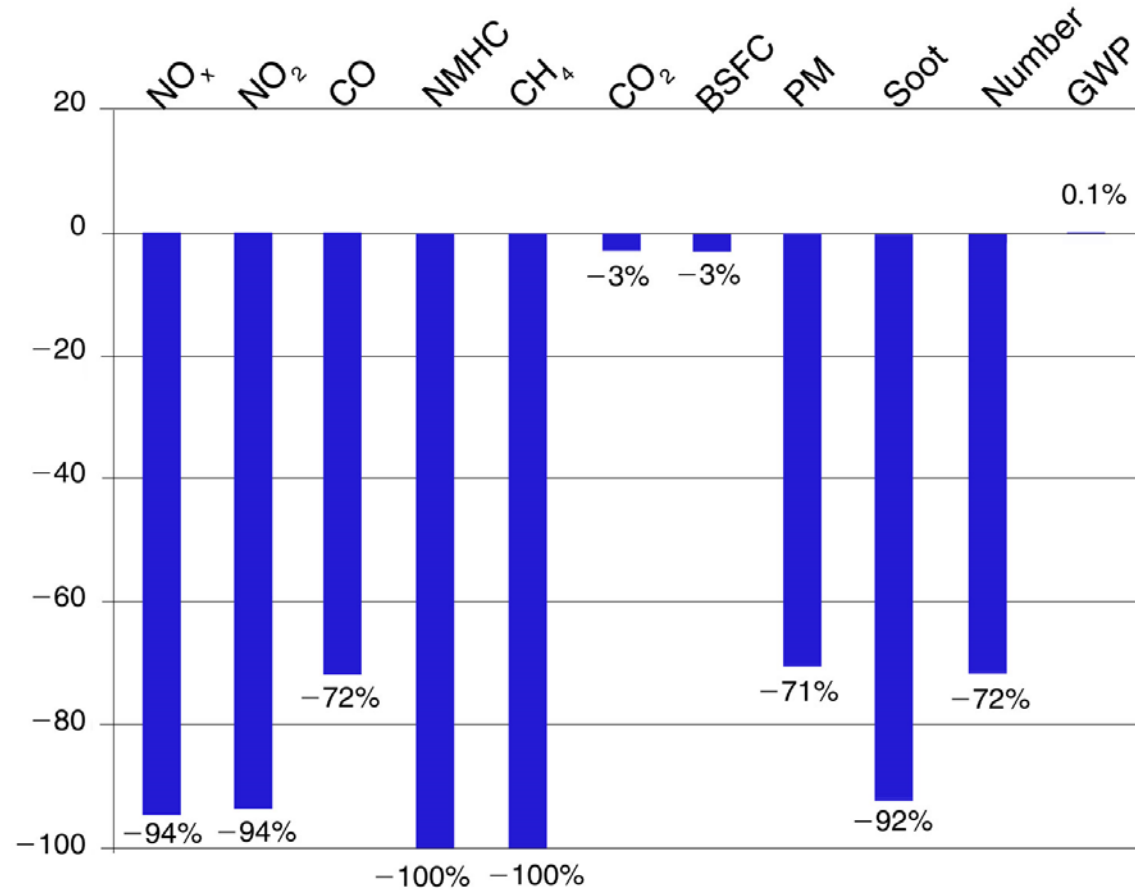
2010^b



^a Personal communication, Imad Khalek, 22 March 2012.

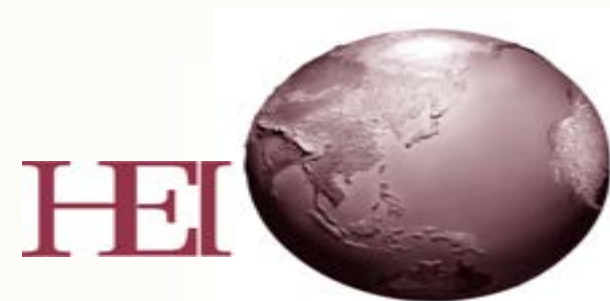
^b Adapted from Khalek et al. 2015.

Emissions Changes Relative to 2007 Engines (%)



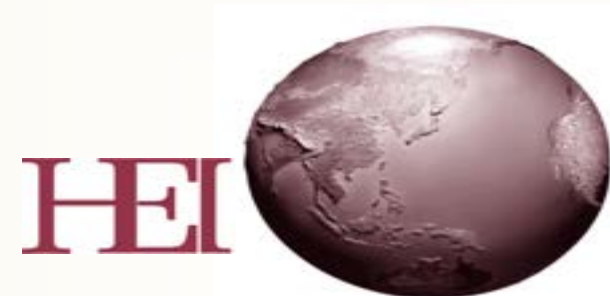
Conclusions of ACES Phases I and II

- After-treatment systems highly effective in lowering emissions:
 - PM and PN lowered by $\geq 95\%$
 - NO_x lowered by $\geq 90\%$
 - All regulated emissions meet or exceed standards
 - Levels of other toxic compounds, VOCs and SVOCs lowered by 80 to 99%; PAHs and nitro-PAHs down by $> 99\%$
 - No new compounds detected
- Limitations:
 - Laboratory and not real-world testing
 - SCR issues under certain conditions



ACES Phase III: Goals and Design

- Hypothesis: Emissions [from a new technology diesel engine] will not cause an increase in tumor formation or substantial toxic effects ... although some biological effects may occur.
- Design: Give as high a dose as possible
 - Lifetime (~ 30 months) inhalation exposure in a rat strain (Wistar Han), susceptible to lung cancer
 - Exposure: A 2007 engine, 30 months, 16 hrs/day, 5 days/week
 - Atmosphere: PM too low, so rely on NO₂ levels; high, medium and low, plus clean air control (4 levels)
- Extensive monitoring and sampling of exposure atmospheres
- Serial sacrifices at 1, 3, 12 and 24 months; terminal sacrifice at 28-30 months

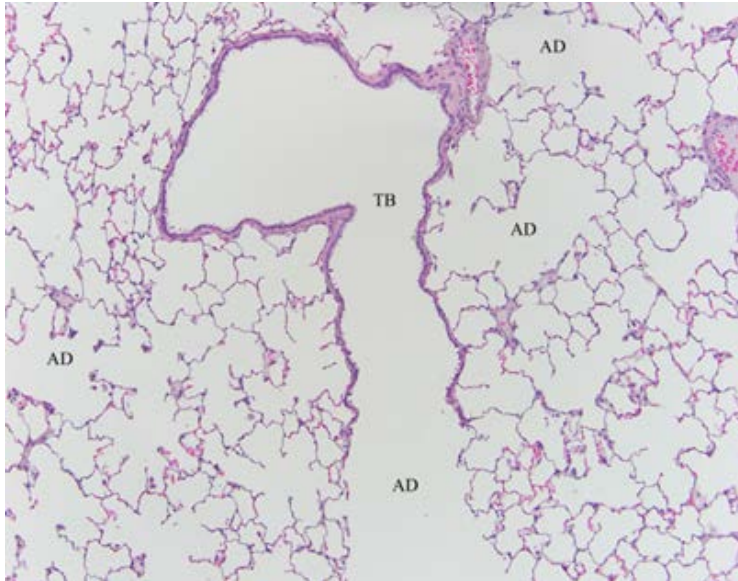


Phase III Major Findings

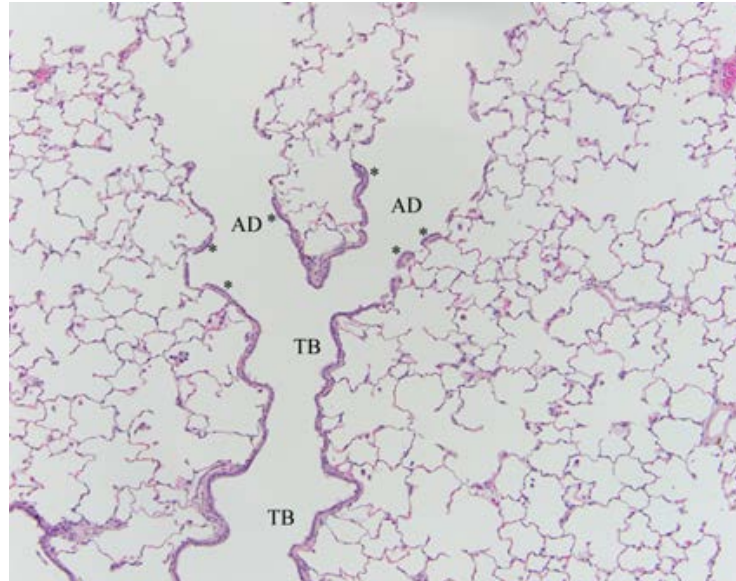
- **No increase in tumors in the lung or at any other site**
 - Some effects on the lung were observed, but most likely related to NO₂ exposure (based on observations in pure-NO₂ exposure studies)
 - Of > 100 endpoints studied, few showed changes, related to mild pulmonary inflammation and oxidative stress
- **MAJOR difference from studies with old-technology diesel emissions** (with very high levels of PM)
 - Lung tumors and other toxic effects are seen in many similar experiments
- Additionally, ancillary studies showed no genotoxic effects, or cardiac or vascular changes
- **Confirmation of the study hypothesis:** Exposure to new tech diesel did not cause an increase in tumors



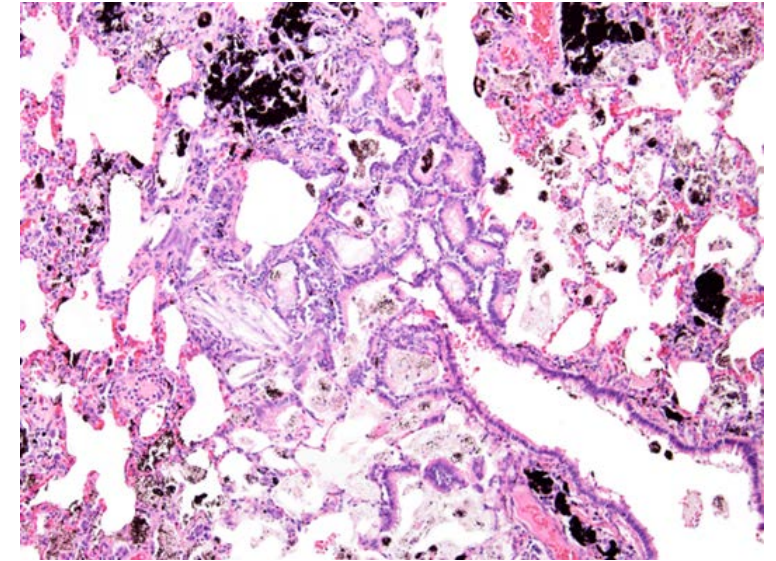
ACES Control: Clean Air



ACES: High Exposure



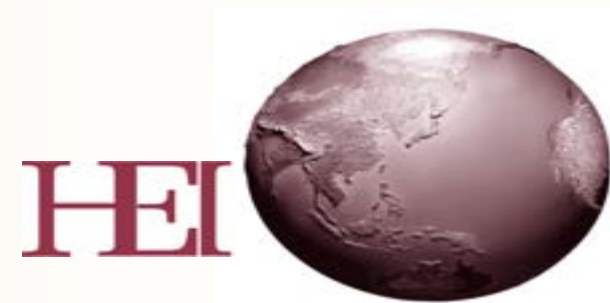
Old diesel exhaust exposure



Courtesy: U. Heinrich

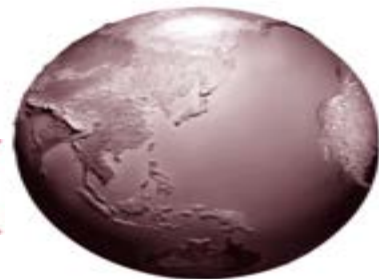
Diesel Epidemiology Studies

- Many past studies – serious limitations made interpretation difficult
- Some recent studies overcame many of the limitations:
- Most important among these: NCI-NIOSH led study among >12,000 miners who worked in non-metal mines (Silverman and colleagues)
 - Data available from NIOSH and NCI
- Additional analysis and commentaries by:
 - HEI DEMS panel
 - Crump, Moolgavkar and colleagues
 - Other critiques



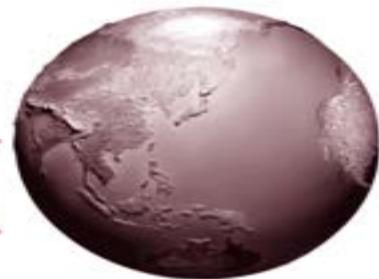
Epidemiology -- Conclusions

- Exposures – from old technology diesel engines as well as retrospective
- DEMS study – worked carefully over an extended period of time to develop historical exposure profiles and collected and analyzed data on lung cancer and addressed confounding
- Association between exposure and lung cancer reported and replicated, and found to be robust
- Uncertainties remain; many explored by Silverman et al as well HEI and other investigators



Where does this leave us

- Old technology diesel emissions:
 - Toxicity, including animal carcinogenicity, of old technology diesel emissions well established; components investigated
 - Human epidemiology studies point to association between exposure and lung cancer
- Many national and international bodies have acted based on such information
- New Technology diesel engines – technology highly effective in controlling PM and other toxic compounds
- Emissions do not produce cancer in an animal test
- Ideal way to reduce air concentrations and exposures

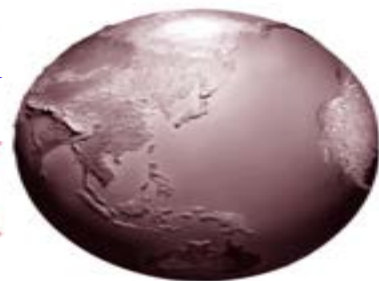


Acknowledgements

- Sponsors: Motor vehicle industry, EMA, DOE, EPA, API and CARB; others
- Partners: Coordinating Research Council; Southwest Research Institute; Lovelace Respiratory Research Institute; and others
- Principal Investigators: Imad Khalek (SWRI); Joe Mauderly and Jake McDonald (LRRI); others
- Over 12 oversight and review committees

All publications and reports at www.healtheffects.org

HEI



THANK YOU

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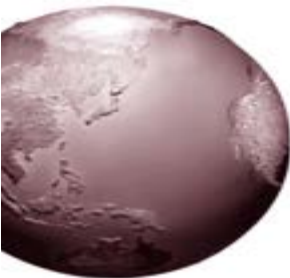
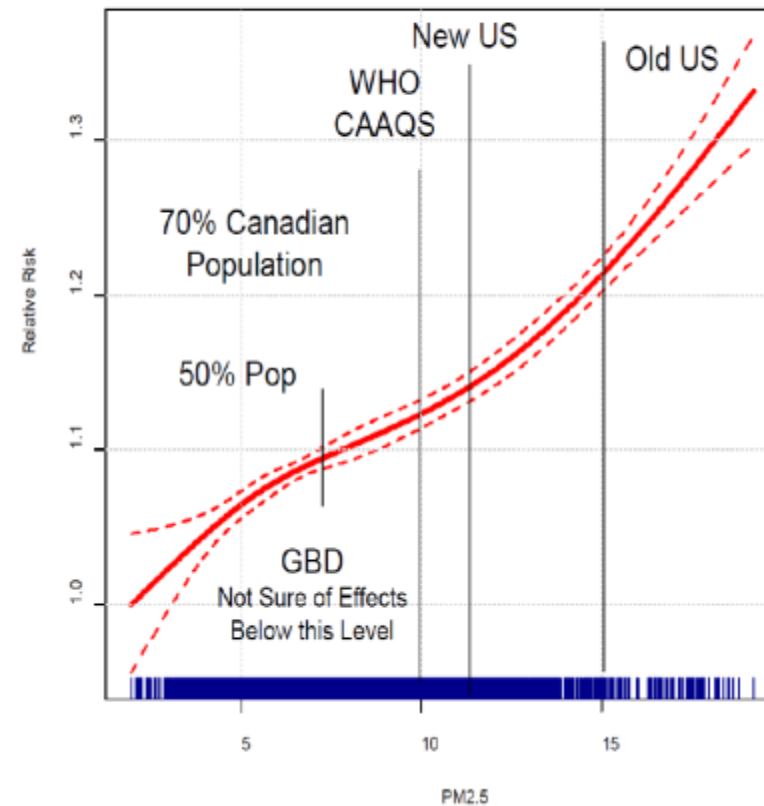


Investigating Health Effects at Very Low levels

- 2012 paper on effects at lower levels in a Canadian Census Cohort (CanCHEC)
- Are they real?
 - Questions about
 - exposure estimates
 - Confounders?
- HEI is funding three teams: US, Canada and Europe
- Goal: rigorous testing of low-level associations

PM associations below 8 $\mu\text{g}/\text{m}^3$

Figure 1 Shape of Canadian Concentration-Response Function
(From Burnett 2013 drawn from Crouse 2012)



Conclusions from the US Study

- Francesca Dominici (Harvard) looked at 66 million Medicare enrollees, exposure estimated using satellite and other methods
- Evidence for Concentration– Response relationships
 - PM: Almost to zero (no threshold?)
 - Ozone: To at least 30 ppb
 - Though wider confidence intervals
- Additional analyses underway
 - Causal and other statistical models
 - More detailed analysis of Medicare Survey population (smaller population but with confounders such as smoking)
 - Medicaid data
- Medicare data are public
- Study findings under HEI Review

