Characterization of Emissions and Health Effects from New Technology Diesel Engines

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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
- Review of the diesel miners' epidemiology study
- Conclusions and Implications

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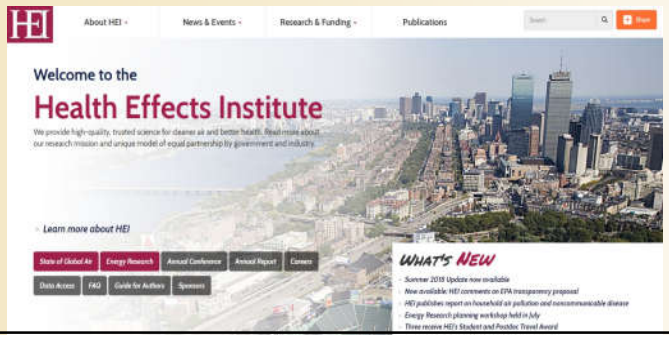
What is the Health Effects Institute

- 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, incl. heavy-duty manufacturers)
- 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, and original research conducted around the world
- Scientific Research Organization: HEI does not advocate policy
- www.healtheffects.org

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



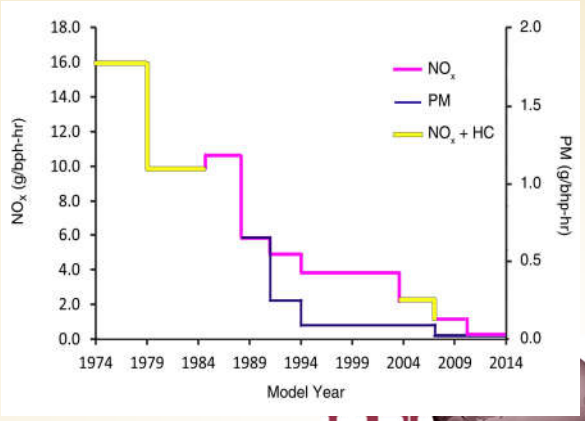
All Publications available for free at www.HealthEffects.org

Diesel Emissions

Toxicity of Diesel Emissions

- 1970s and 1980s:
  - In vitro studies with PM and its extracts ⇒ cause mutations
  - Rat inhalation studies with PM ⇒ cause cancer (lung)
  - Epidemiology Studies ⇒ Suggestive of causing cancer (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



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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

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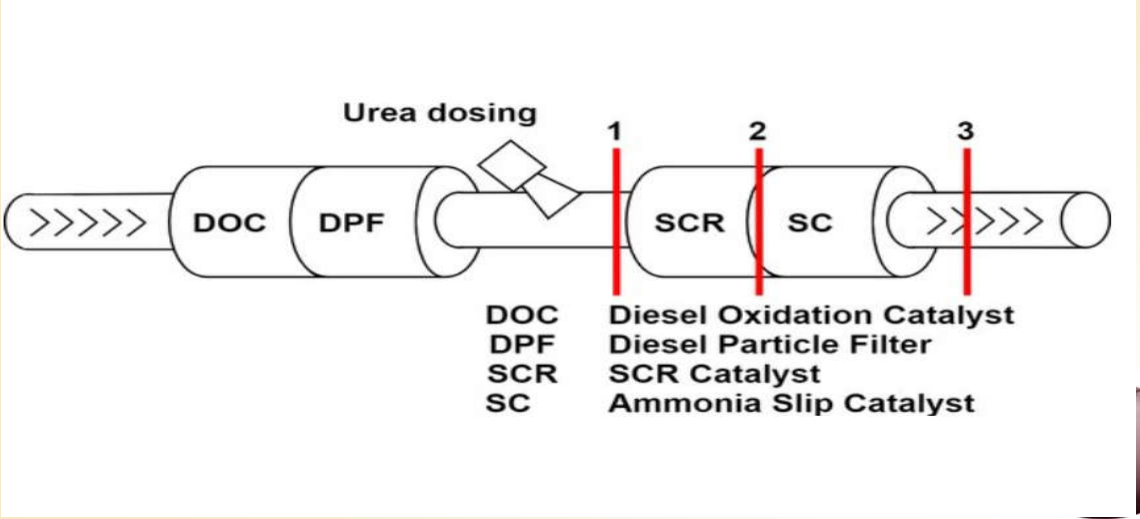
Diesel Emissions Exhaust System



The Advanced Collaborative Emissions Study (ACES)

Rationale

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

- Confirm that advanced-technology diesel engines, after-treatment systems, and reformulated fuels developed to meet the 2007/2010 emission standards will result in substantially reduced emissions
- 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
- Substantial public health benefits are expected from these reductions

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 *(DPF)*
  - Three 2010-compliant HD engines that meet the 2010 std for $PM_{2.5}$ and NOx *(DPF + SCR)*
- Health Testing (Phase III):
  - Health effects in rodents, chronically exposed to a 2007 engine emission, to study cancer and non-cancer endpoints

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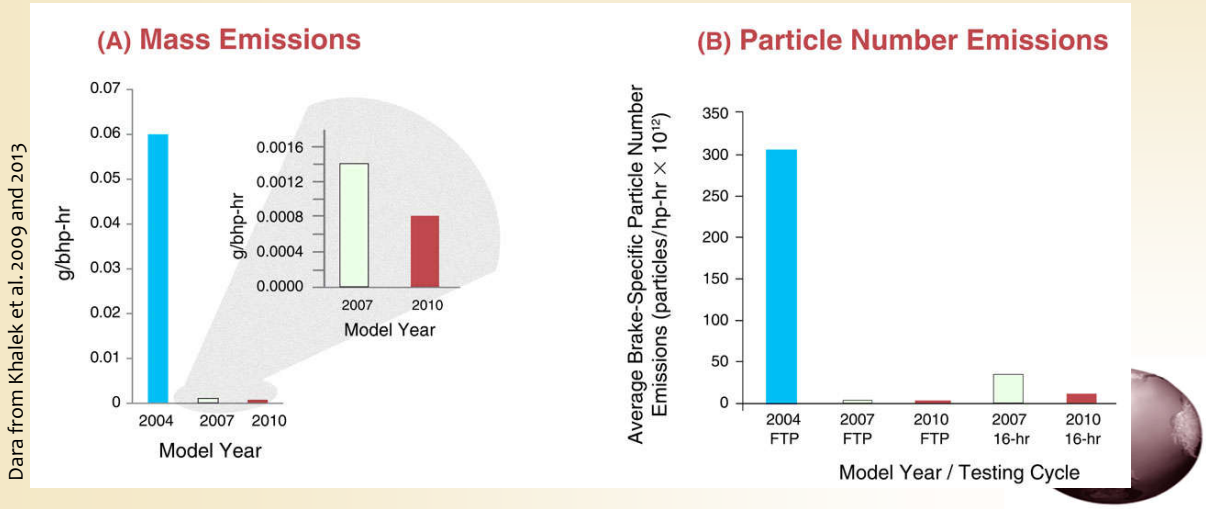
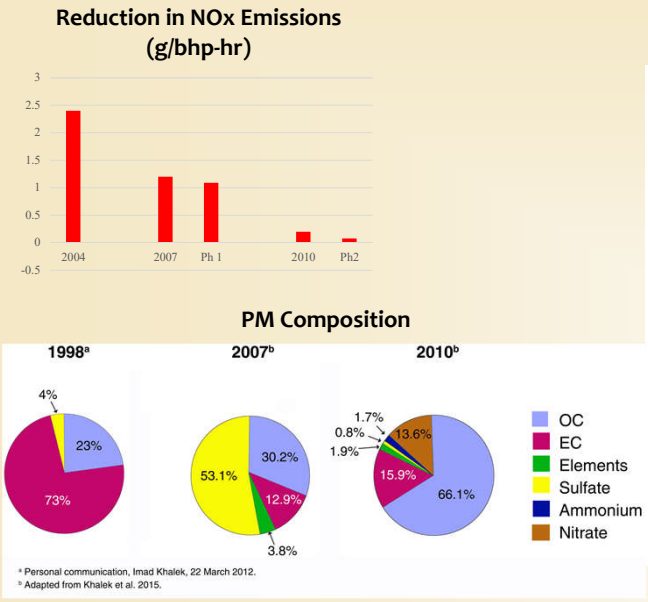
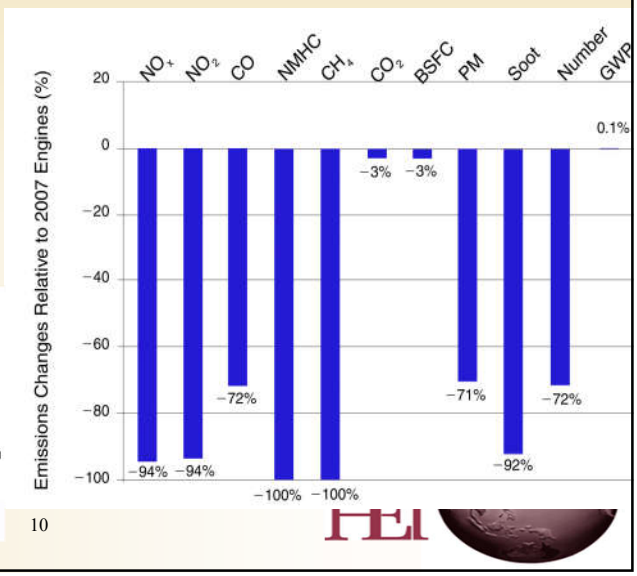
ACES Ph. 1 & 2: Reduction in PM & PN Emissions



Dara from Khalek et al. 2009 and 2013

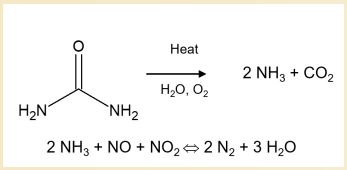
ACES Phase 1 and 2 results, cont

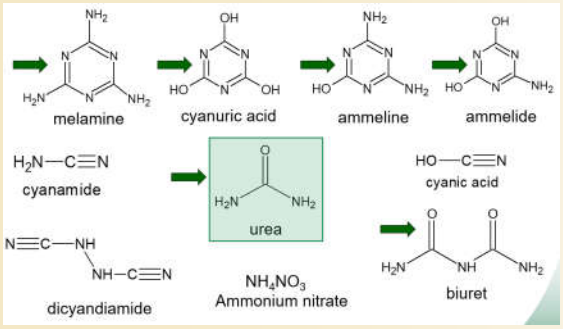




Do Other Toxic Compounds Form in the Exhaust?

Urea and its Decomposition Produces





Results of 2010-engine testing

- Six urea-related compounds analyzed: urea, melamine, cyanuric acid, ammelide, ammeline, and biuret
- Only urea and cyanuric acid detected in 16-hour cycles
- Very, very low levels
- Cyanuric acid at less than 18 ppb in undiluted exhaust; an irritant but not very toxic
- Not a concern

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Do Nitro-PAHs form in the exhaust?

Nitropyrene and Dinitropyrenes

- Long known to be mutagenic and potential human carcinogens
- Found adsorbed to diesel particulates
- Major concern, if present

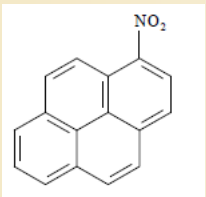

TABLE ES-2. SUMMARY OF UNREGULATED EMISSIONS REDUCTION FOR 16-HOUR

	2010 % reduction relative to 2007 engines	2010 % reduction relative to 2004 engine
Single Ring Aromatics	50	91
PAH	97	99
NitroPAH	99	100
Alkanes	93	99
Polar	96	99
Hopanes & Steranes	89	100
Carbonyls	80	100
Inorganic Ions	87	92
Metals and Elements	81	100
Organic Carbon	36	97
Elemental Carbon	53	100
Dioxins and Furans[a]	88	100

[a]Relative to 1998 Technology Engine

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Conclusions of ACES Phases I and II

- After-treatment systems highly effective in lowering emissions:
  - PM and PN lowered by ≥ 95%
  - NOx lowered by ≥ 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

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Real-World Reliability of DOC-DPF Systems

- Not much published about this
- Small (single-digit percentage) failure rate; but circumstances not understood
- Real-world compliance programs would shed some light on this
- On the whole, highly durable and effective

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Real-World NOx Control Issues

- VW cheating (Dieselgate) most notorious – Not talking about it
- SCR temperature too low for full reduction under low load, stop-and-go and similar other conditions
- After-treatment manufactures employing various ways for control
- Particularly problematic in Europe with a large light duty diesel fleet; has led to high NO2 levels in many cities
- US – a heavy-duty issue in urban areas

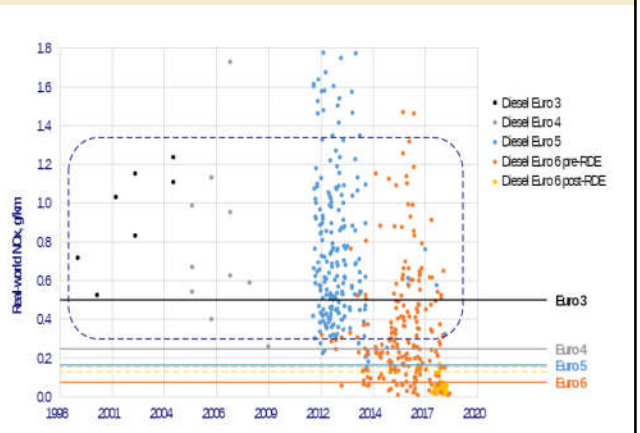

Figure 1. Variation of real world diesel NOx emissions between Euro stages

Test results by Emissions Analytics

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Potential for Health Effects

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: Very low PM so 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, for 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

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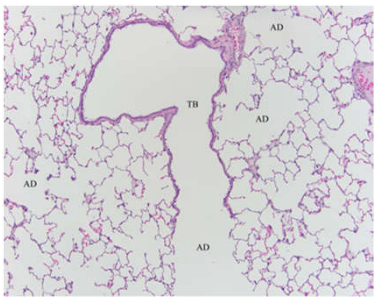
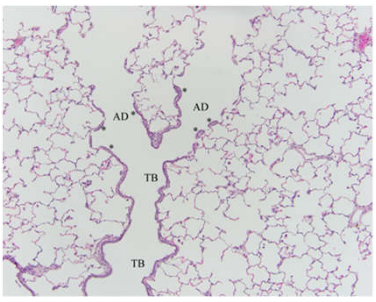
Phase III Major Findings

- **No increase in tumors in the lung or at any other site**
  - Some effects on the lung were observed, but most likely related to NO_2 exposure (based on observations in pure-NO_2 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 in increase in tumors

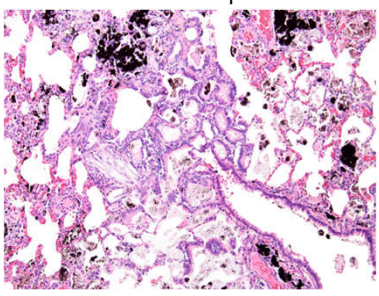
ACES Control: Clean Air



ACES: High Exposure



Old diesel exhaust exposure



Courtesy: U. Heinrich

Diesel Epidemiology Studies

- Many past studies – various 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

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HEI DEMS Panel -- Conclusions

- Exposures – from old technology diesel engines as well as retrospective estimates
- DEMS study – investigators 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

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Where does this leave us

- Old technology diesel emissions:
  - Toxicity, including animal carcinogenicity, well established; toxic components (including PAHs and nitro-PAHs)
  - 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, NO_2 and other toxic compounds
- Emissions do not produce cancer in an animal test
- Ideal way to reduce air concentrations and exposures

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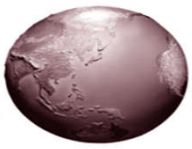

Acknowledgements

- 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

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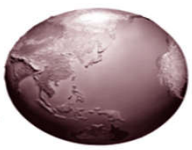

THANK YOU

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