Potentially Toxic Components in New Technology Diesel Exhaust are Dramatically Reduced Compared to Traditional Diesel Exhaust

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Overview

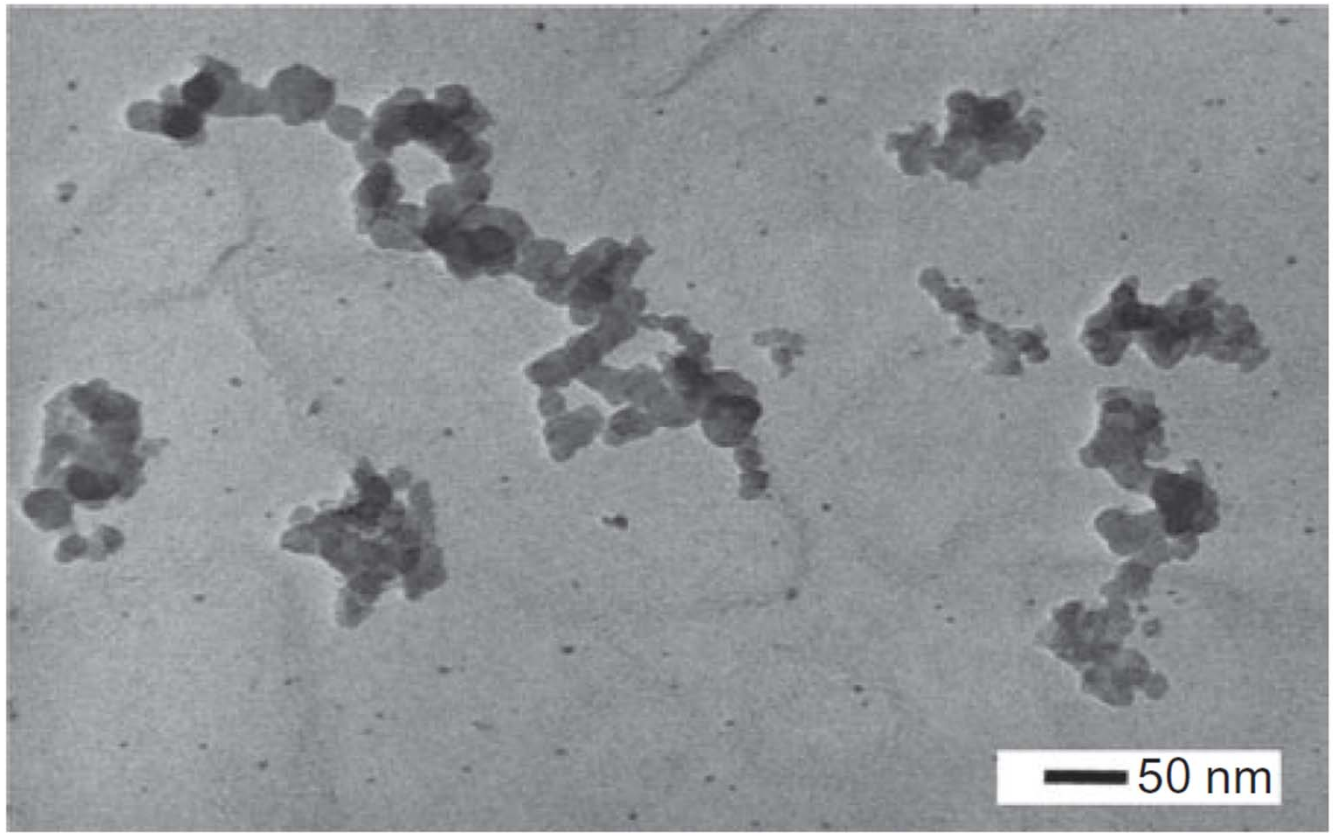
- PM levels in New Technology Diesel Exhaust (NTDE) vs Traditional Diesel Exhaust (TDE)
- Chemistry of PM in NTDE vs TDE
- NTDE compared to CNG and gasoline emissions
- Biological effects of NTDE compared to TDE

Traditional Diesel Exhaust (TDE)

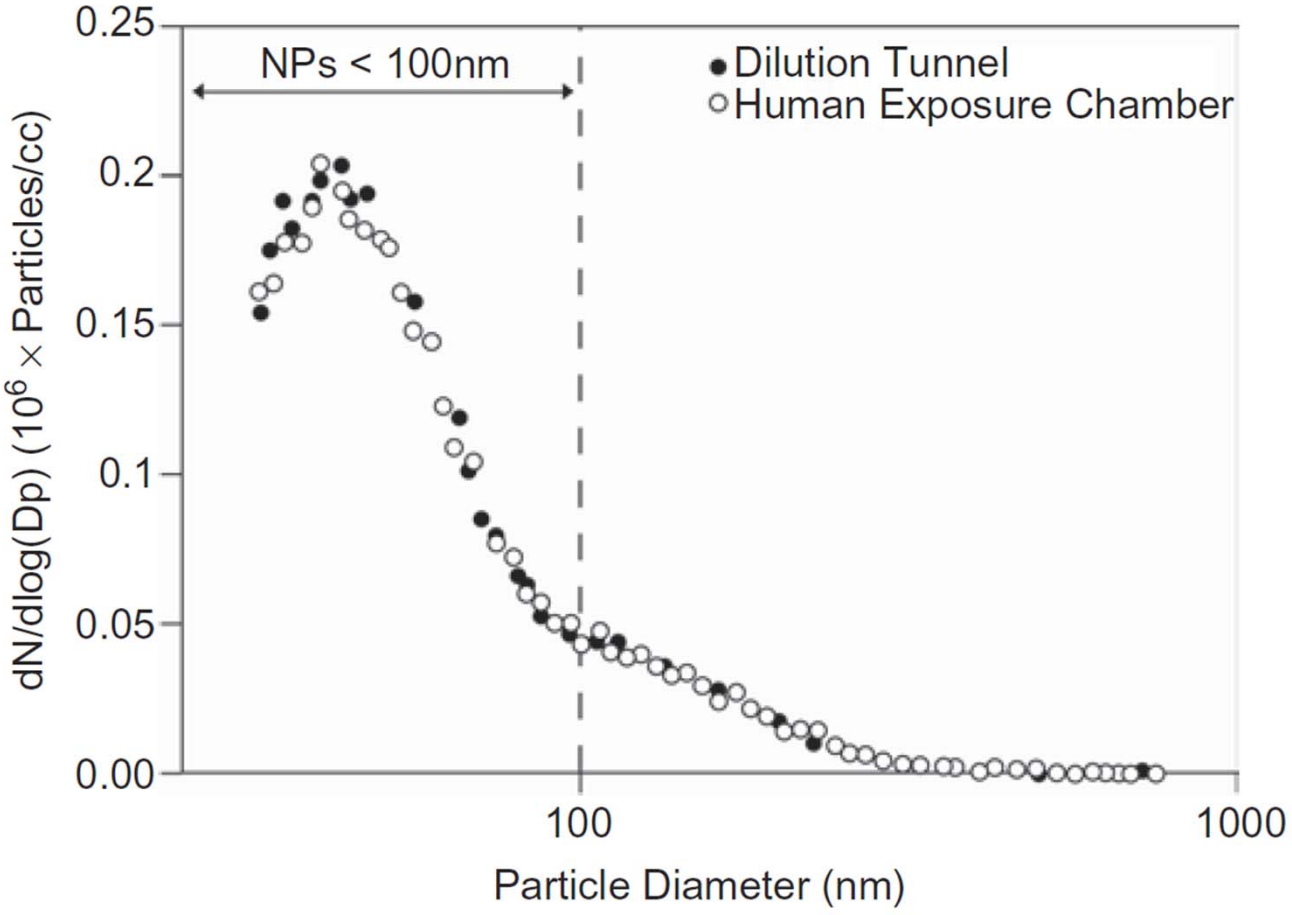
Exhaust from engines utilizing old technologies :

- Pre-1988 diesel engines sold and in use prior to the US EPA diesel particulate standards
- “Transitional“ 1988-2006 diesel engines
  - Progressive improvements in engine design, but
  - Prior to the full-scale implementation of multi-component after-treatment systems

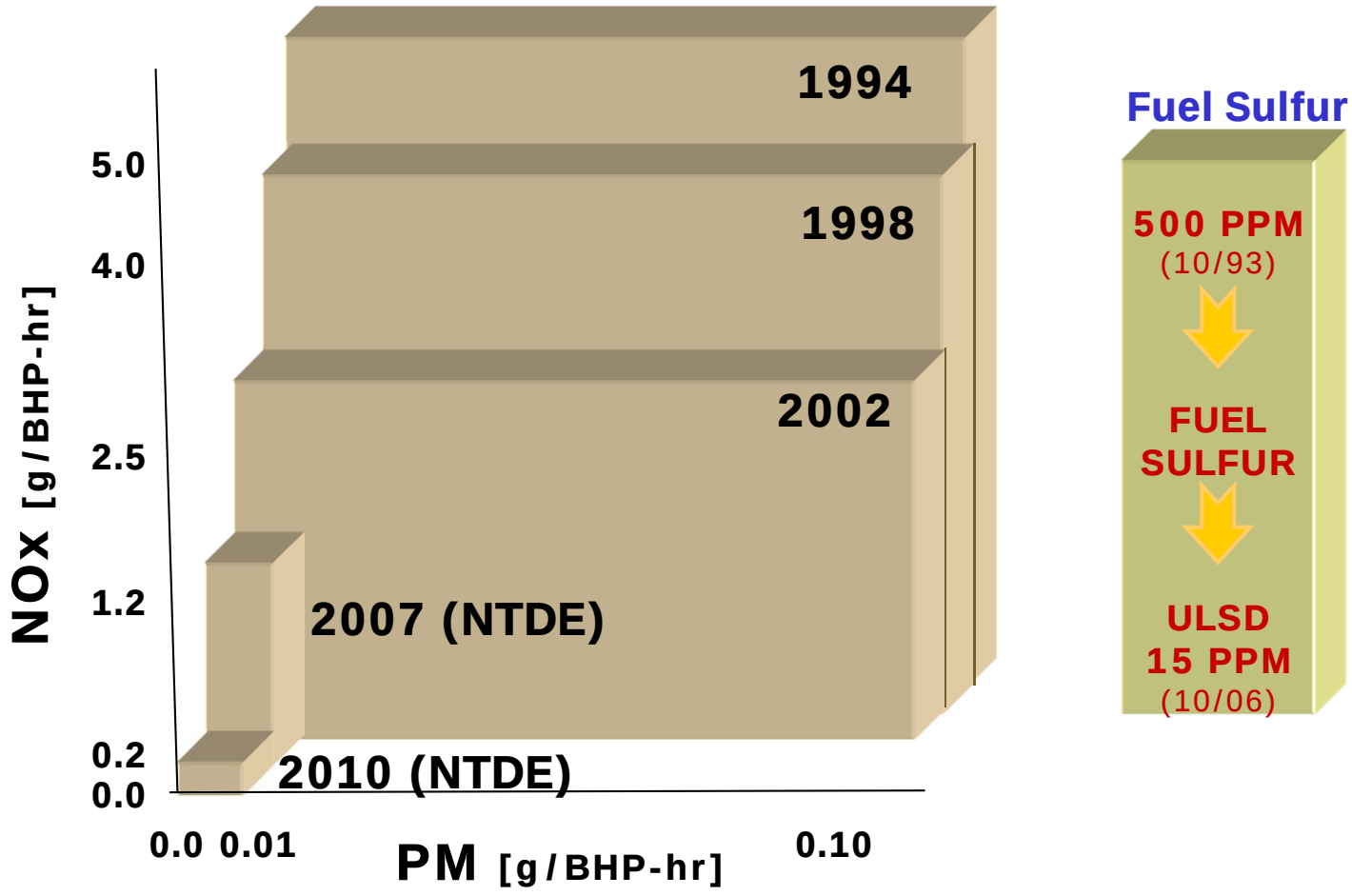
Traditional Diesel Exhaust Particles



TDE Particle Size Distribution



Evolution of US Heavy Duty Diesel On-Road Emission Standards



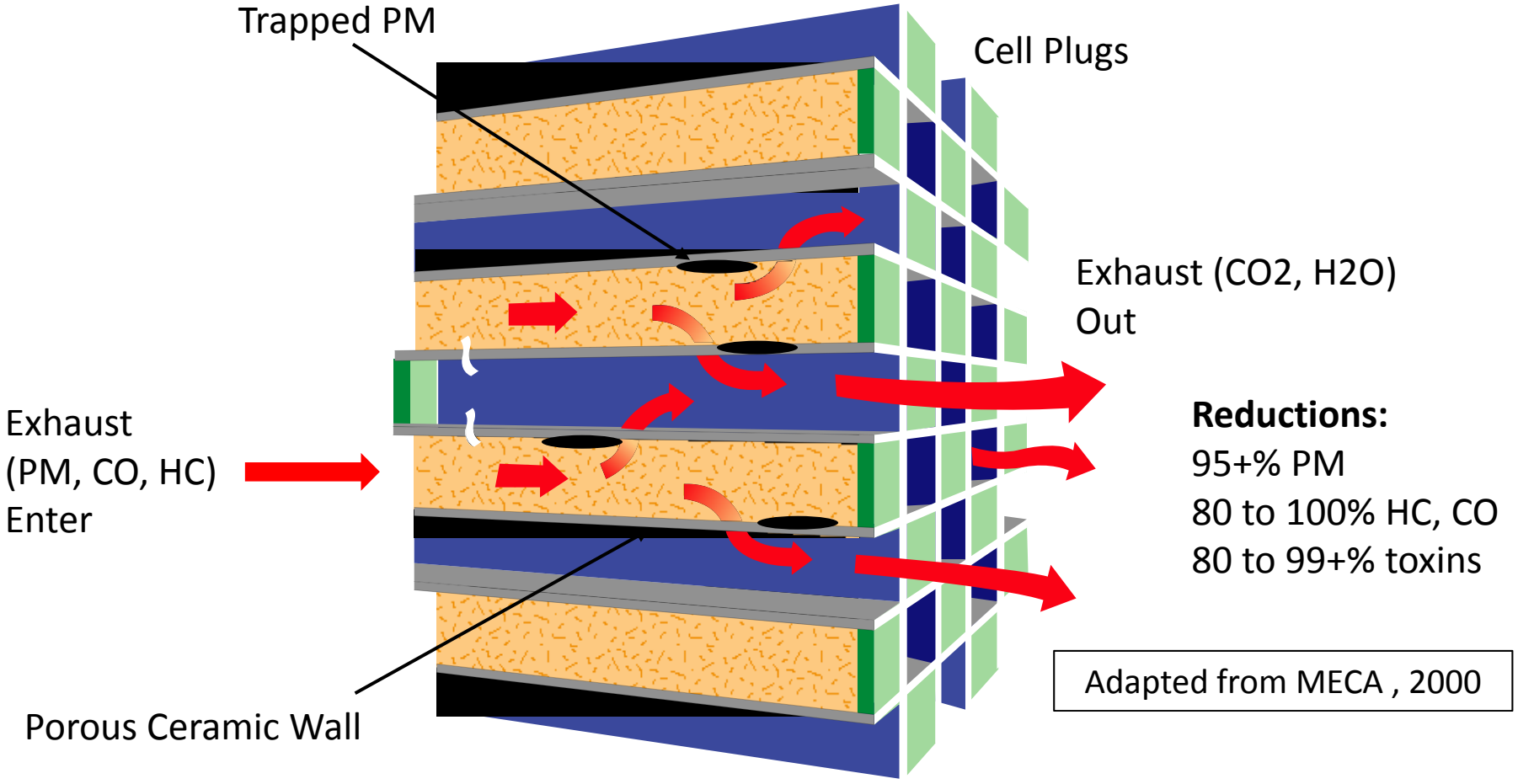
New Technology Diesel Exhaust (NTDE)

Exhaust from engines utilizing new technologies:

- Meets EPA & CARB 2007 emissions standards
- Fully integrated electronic control systems
- Ultra low sulfur diesel fuel (< 15 ppm)
- Oxidation catalysts
- Wall-flow diesel particulate filters (DPFs)
- Applies to both new and retrofitted engines

Key to Emissions Reductions in NTDE

Wall-flow Diesel Particulate Filter



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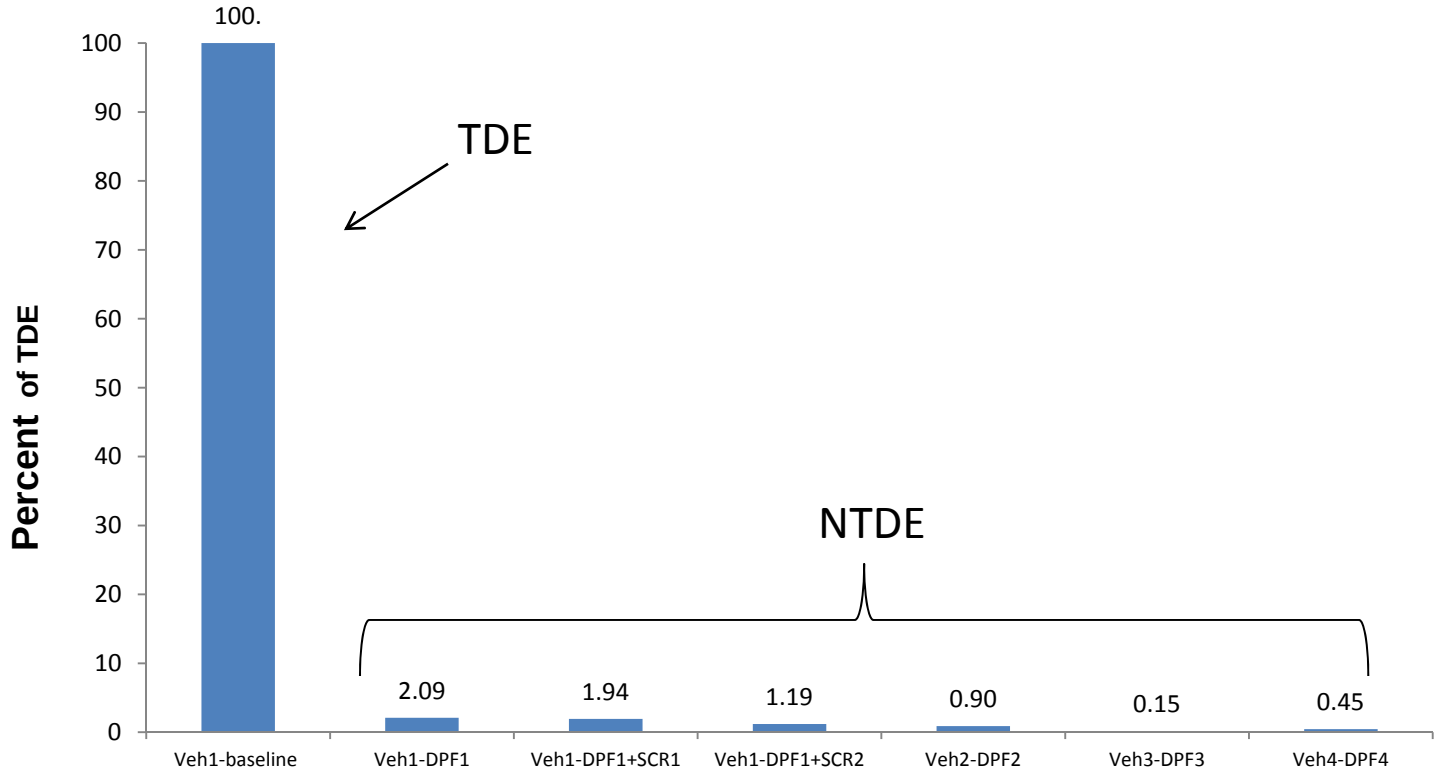
NTDE: Lower Particulate Emissions



CARB Study: Herner et al., EST 43:5928-5933, 2009, data from Table 2. Transit Buses: UDDS Test Cycle

Most Toxic Air Contaminants (TACs) in TDE are Not Found in NTDE

— Others Reduced to Near-Zero Levels —

- Aniline
- Antimony compounds
- Arsenic
- Beryllium compounds
- Cadmium
- Chlorine (chloride)
- Chlorobenzene and derivatives
- Chromium compounds
- Cobalt compounds
- Ethylbenzene
- Inorganic lead
- Manganese
- Mercury
- 4-Nitrobiphenyl
- Nickel
- Selenium
- Styrene
- Xylene isomers and mixtures
- o-Xylenes
- p-Xylenes
- m-Xylenes

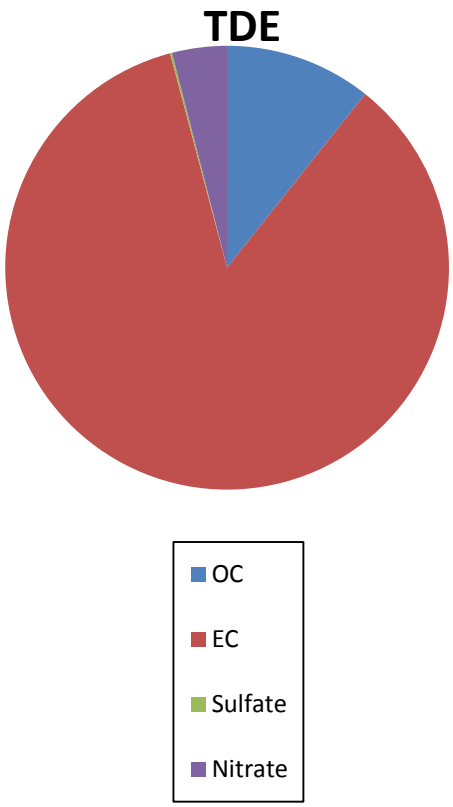
Ullman et al, SAE 2003-01-1381, 2003

NTDE Reduces Emissions Across a Broad Spectrum of Compounds

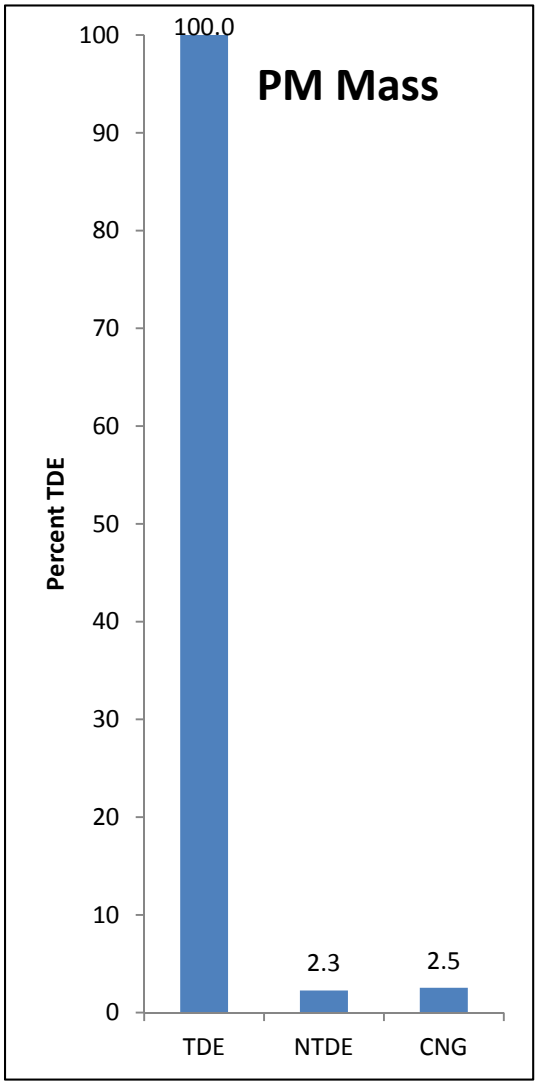
Category	Reduction Relative to TDE
Single Ring Aromatics	82%
PAH	79%
Alkanes	85%
Hopanes/Steranes	99%
Alcohols & Organic Acids	81%
Nitro-PAHs	81%
Carbonyls	98%
Inorganic Ions	71%
Metals & Elements	98%
Organic Carbon	96%
Elemental Carbon	99%
Dioxins/Furans	99%

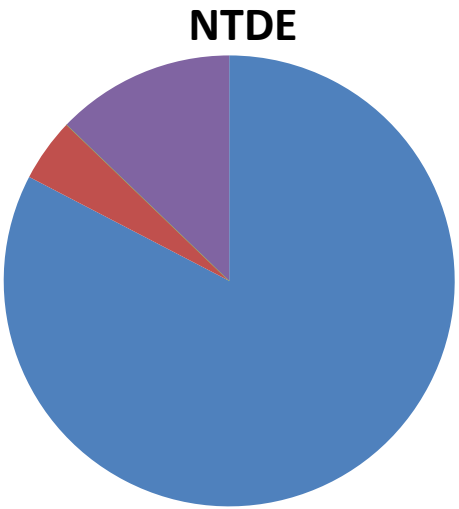
Khalek et al., JAWMA 2011.

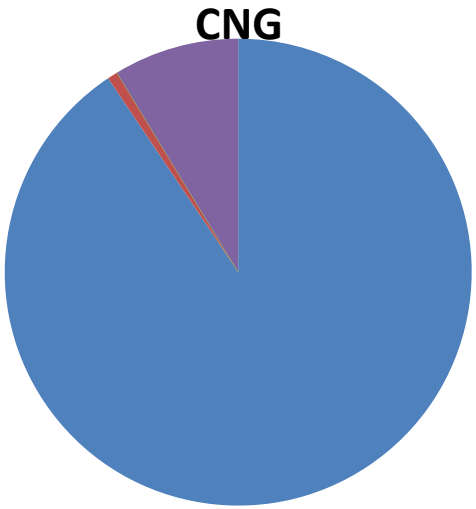
PM Composition and Mass Comparisons



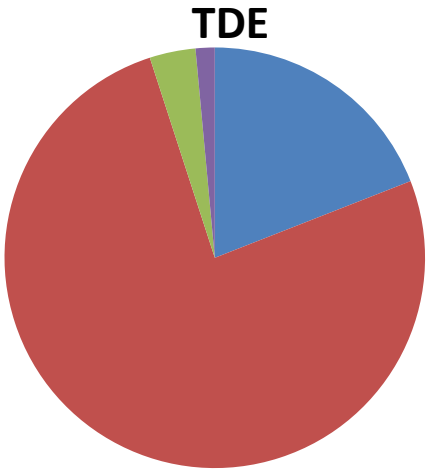
Lev-On et al., SAE 2002-01-0432, 2002. Transit Bus.

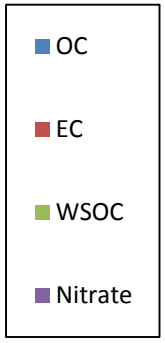




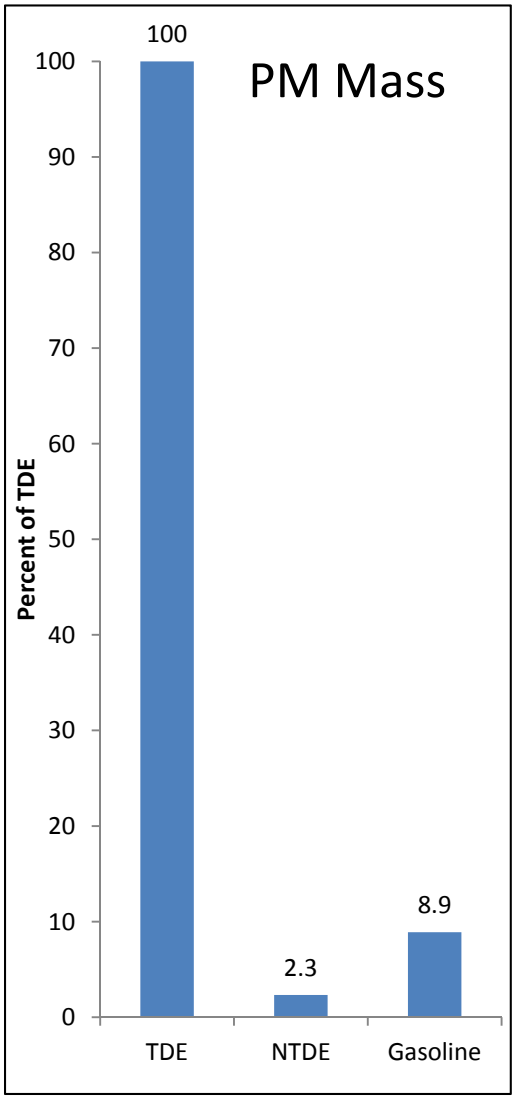


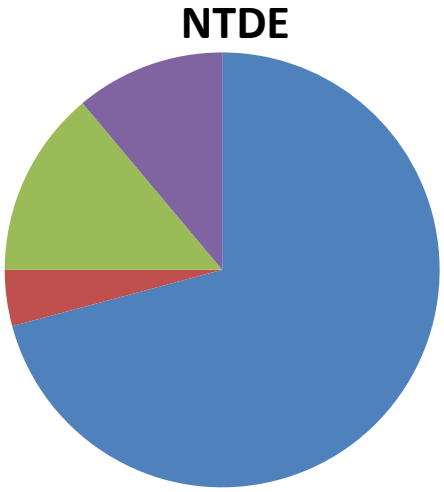
PM Composition and Mass Comparisons

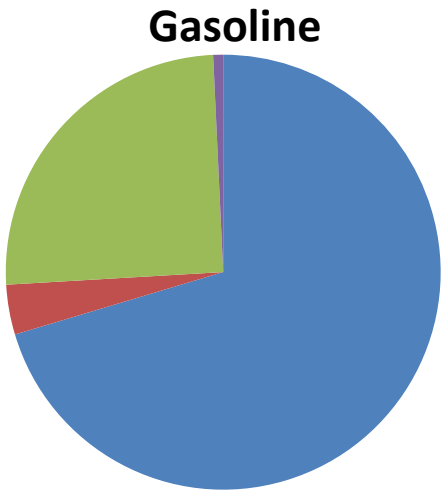




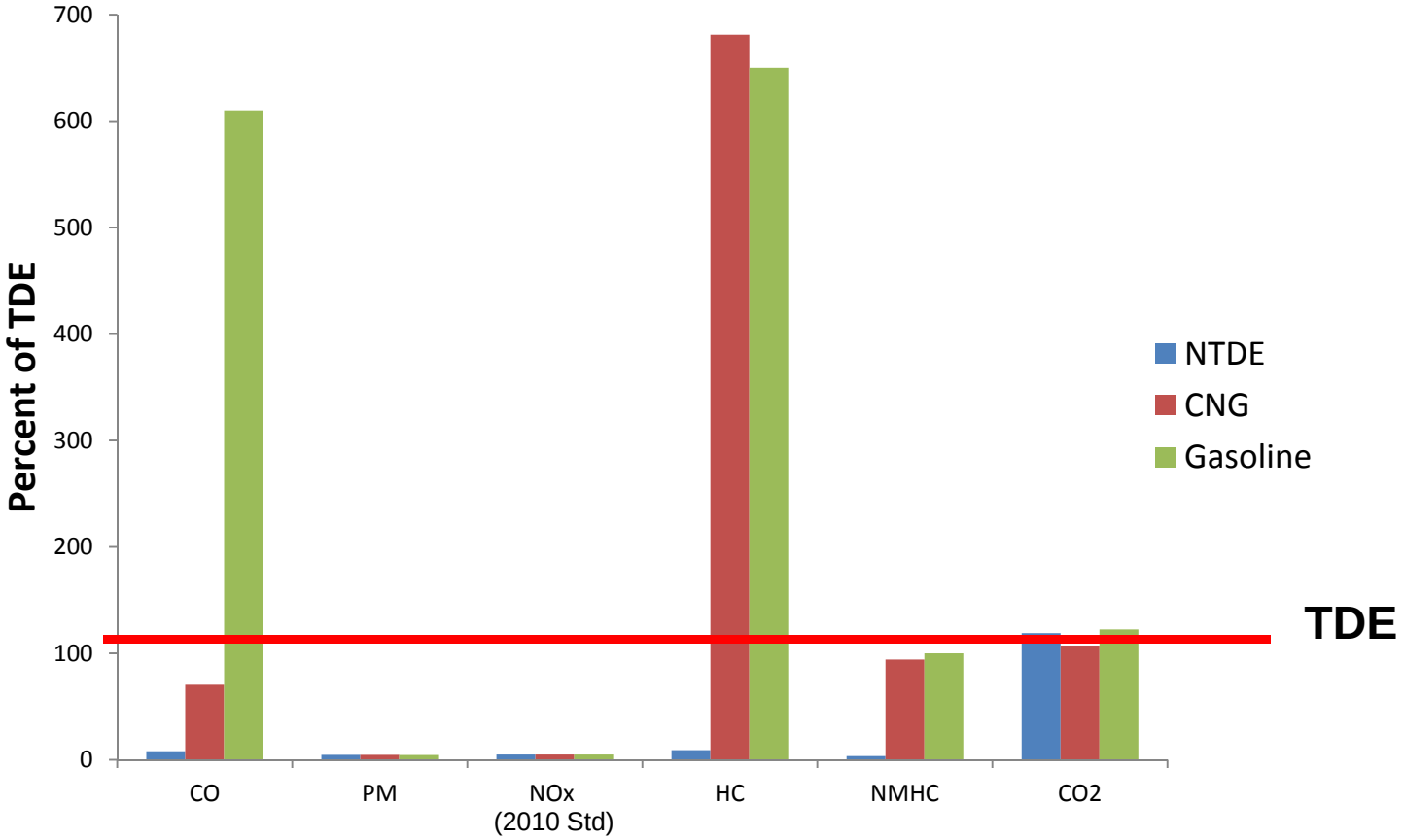
Cheung et al., Env. Sc. Tech. 43:6334-6340, 2009. Passenger







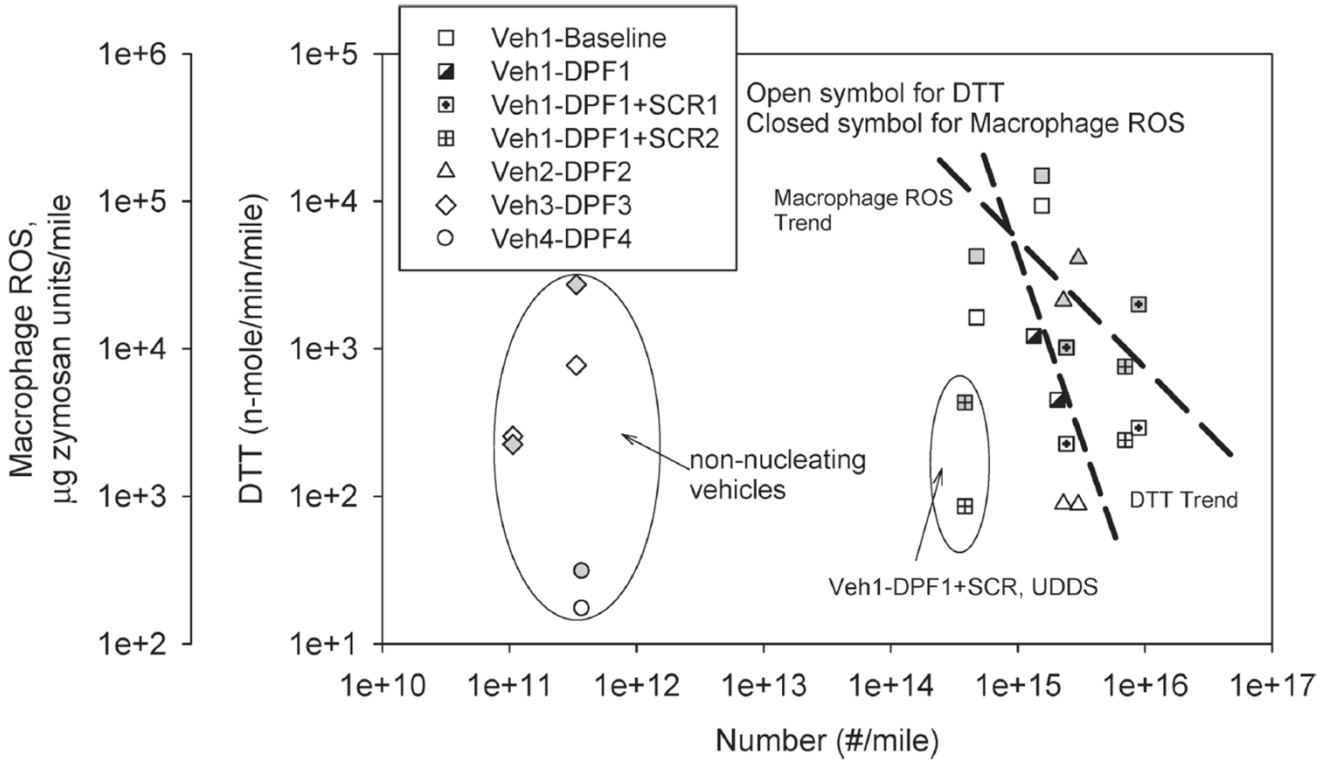
NTDE: Lower for Most Regulated Emissions
Also Similar or Better than CNG or Gasoline



Hesterberg et al., ES&T 42:6437-45, 2008.

Recent NTDE Nanoparticle Study

In Vitro Test Results

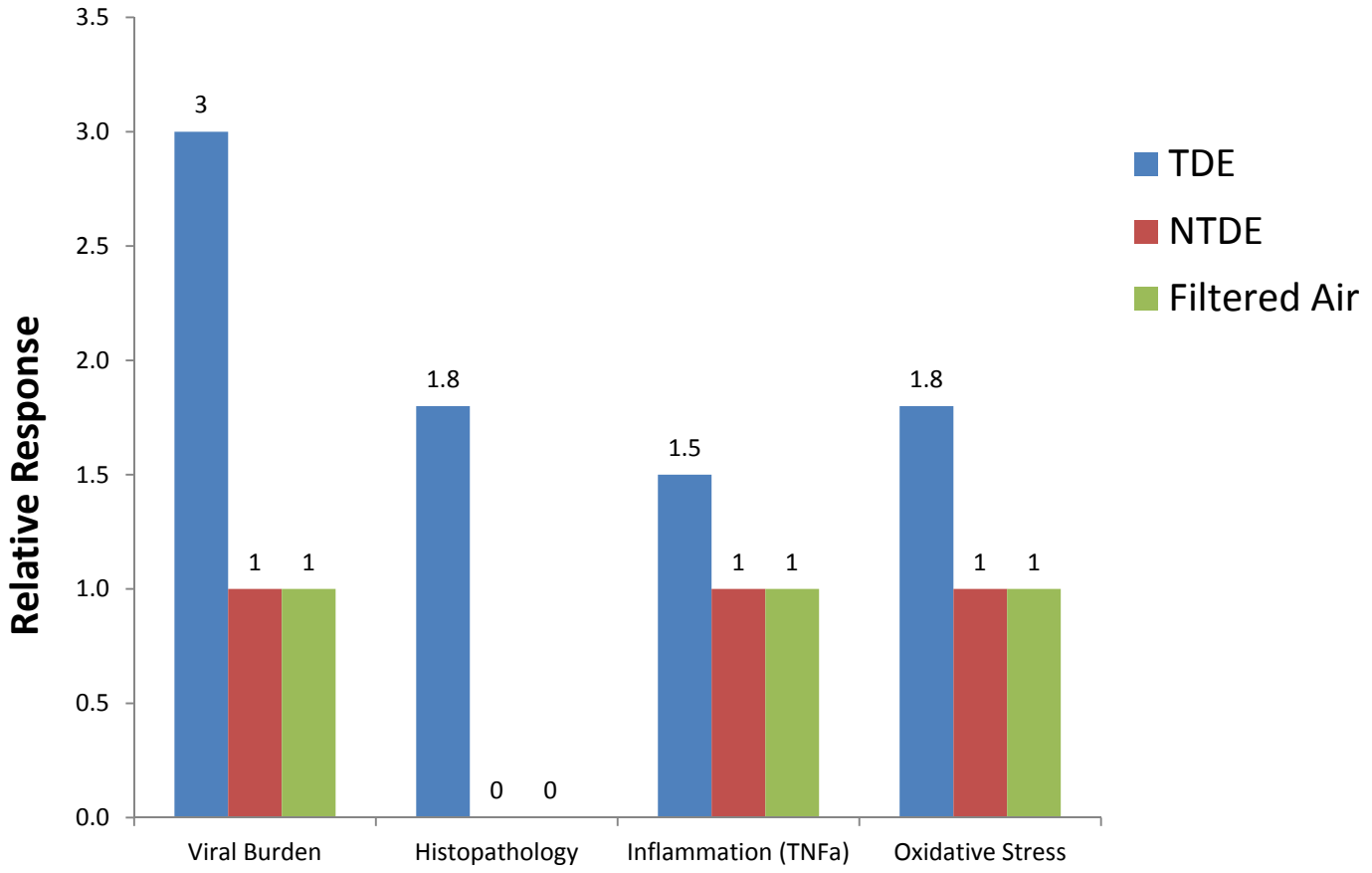


- **Catalytic after-treatment results in higher number of nanoparticles**
- **More nanoparticles associated with lower "toxicity" in DTT and macrophage assays**

Herner et al. ES&T 45:2413-19, 2011

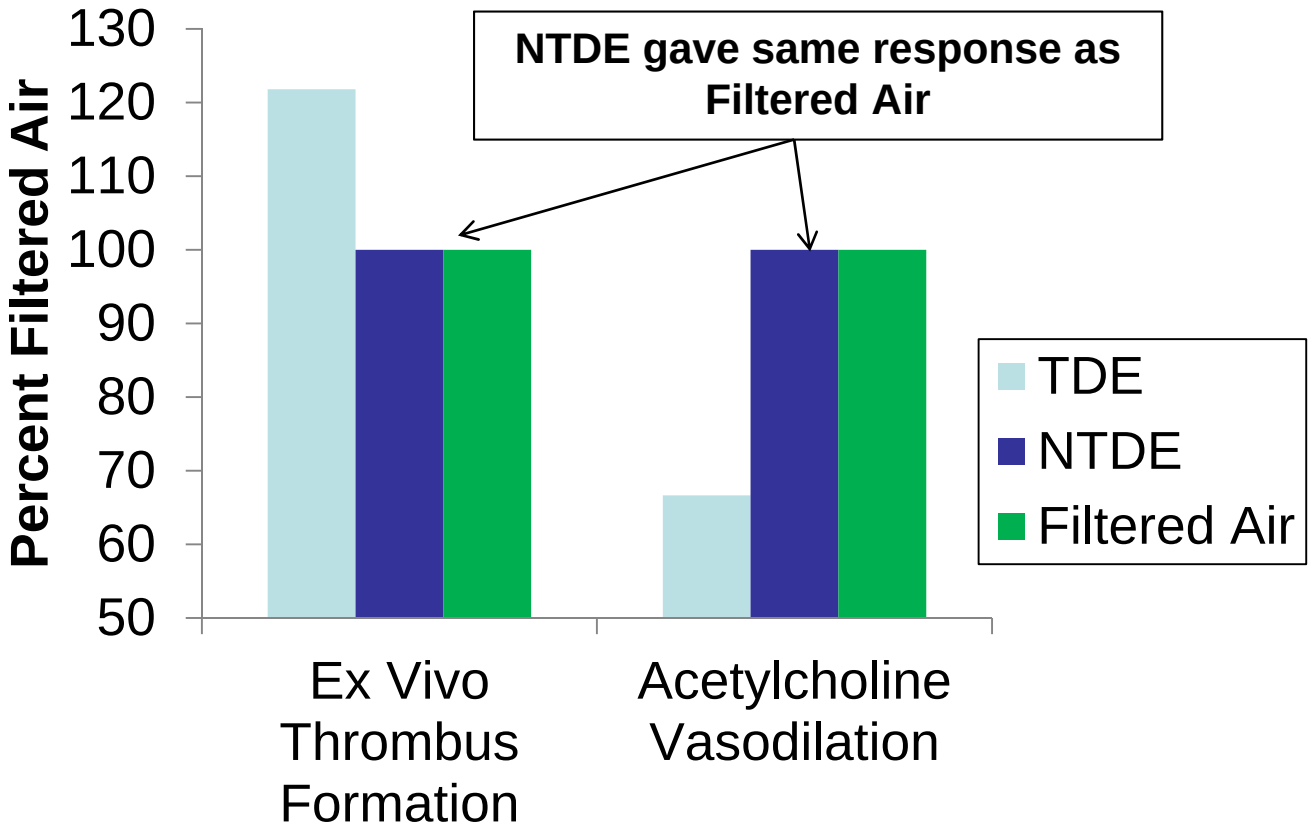
Animal Inhalation Study

NTDE vs TDE



McDonald et al., EHP112:1307-12, 2004.

Human Volunteer Exposure Study
TDE vs NTDE



Lucking et al. Circulation 123:1721-1728, 2011.

Research In Progress

Advanced Collaborative Emissions Study (ACES)

- Managed by the Health Effects Institute
- Funded by government agencies and industry
- Lifespan inhalation study in rodents
- Lung disease and cancer are main endpoints
- Two more years to complete

Conclusions

- PM levels in NTDE are 100-fold lower than in TDE
- NTDE PM is chemically very different from TDE
  - Similar to CNG and gasoline PM
- NTDE emissions generally lower than CNG or gasoline
- Biological effects of TDE were not observed with NTDE
- **NTDE should be evaluated separately from TDE**

Hesterberg et al, JAWMA, In Press, 2011

Diesel Exhaust Lung Cancer Studies
Traditional Diesel Exhaust (TDE)

- Human workplace studies show small increase in lung cancer, but no exposure-response demonstrated
  - Same small increase seen before dieselization of trucks
- Miners, who have highest DE exposures show no increase in lung cancer
- Lung cancer not found in mice or hamsters and only at very high “lung overload” exposures in rats
- Thus, there is little evidence that DE causes lung cancer at occupational or environmental exposures

Hesterberg et al. Critical Reviews in Toxicology 36:727-726, 2006

Diesel Exhaust Human Volunteer Studies

- High diesel exhaust nanoparticle exposures may elicit transient, subclinical effects in human volunteers
- Effects generally less or not seen at lower exposure levels
- Responses similar to those observed with larger particles
- Effects not observed with New Technology Diesel Exhaust
- These studies do not provide evidence of a unique toxicity of nanoparticles compared to larger particles

Hesterberg et al. Inhalation Toxicology 22(8):679-694, 2010