EMA/CARB Meeting to Discuss Clarification and Revision of TAC Listing for PEDE to Exclude NTDE

December 10, 2010

Engine Manufacturers Association

Meeting to Discuss Revision of TAC Listing for PEDE

- Overview - Jed Mandel (EMA)
- New Diesel Technologies – John Wall (Cummins)
- Composition of New Technology Diesel Exhaust (NTDE) Compared to Traditional Diesel Exhaust (TDE) – Tom Hesterberg (Navistar)
- Discussion / Next Steps

Overview

Overview: Focus on the Present and Future – Not the Past

- ***EMA is not seeking to challenge or undo the original TAC listing***,

  but rather to recognize the significant progress we have made together since 1998 to bring about new ultra-clean diesel products driven by technology-forcing regulations

  and to implement a further clarification of the TAC listing for PEDE, as anticipated by CARB, to reflect the regulatory and technological advancements in effect today

Overview:
Summary of Presentation

- In 1998, based on an assessment of traditional diesel exhaust ("TDE"), CARB determined to list "particulate emissions from diesel-fueled engines" (PEDE) as a toxic air contaminant (TAC)

- Extensive scientific data and findings since 1998 establish that ***new diesel emission control technologies have addressed the concerns expressed in the original TAC listing*** so that those concerns do not apply to new-technology diesel exhaust ("NTDE") emitted from today's ultra-clean on-highway and nonroad diesel engine systems

- ***The TAC listing for PEDE should be clarified and revised to reflect these advancements and to exclude NTDE***

Overview:
Original Considerations for TAC Listing for TDE

- CARB's 1998 TAC listing for PEDE was premised on a number of key findings and assumptions regarding the nature and composition of TDE:
  - TDE PM is emitted at high rates and is dominated by carbon and a solid carbon core
  - TDE contains significant amounts of over 40 TACs and HAPs
  - Newer diesel engines emit more fine particles
  - The semi-volatile organic fraction of TDE is significant
  - TDE includes significant amounts of many unregulated pollutants of concern
  - TDE particles carry biologically relevant amounts of potential genotoxins
- **Those key foundational premises simply do not apply to NTDE**

Overview:
Precedent for Clarification of TAC Listing Comes From CARB

- In 1998, CARB determined to "better clarify" the TAC listing for "diesel exhaust" so that it more specifically applied to "particulate emissions from diesel-fueled engines" (PEDE)

- That additional specification was intended:

  to better clarify the components in diesel-fueled engine exhaust that may be responsible for creating a majority of the health risk, and ***recognition should be given to changes in diesel engine technology and fuel formulations that may reduce public exposure to harmful combustion constituents*** (Board Resolution 98-35)

Overview:
CARB Anticipated Need for Future TAC Clarification

- CARB's 1998 TAC listing for PEDE was based on studies of TDE from the 1970s and 1980s, and even earlier

- CARB specifically noted and anticipated in its adopting Board Resolution (98-35) that:

  …the SRP findings, and the related staff reports reflect exposures to exhaust from historical diesel fuel formulations and engine technologies, and… [emerging technology] changes may have had an effect on the particle characteristics and chemical composition of diesel exhaust. ***Therefore, the risk estimates should be updated as more information becomes available***

Overview:
EPA Anticipated Need for Future TAC Clarification

- In its 2002 health assessment document for diesel engine exhaust, U.S. EPA similarly noted and anticipated:

> The health hazard conclusions are based on exhaust emissions from diesel engines built prior to the mid-1990s…. ***With new engine and fuel technology expected to produce significantly cleaner engine exhaust by 2007, (e.g., in response to new federal heavy-duty regulations), significant reductions in public health hazards are expected for those engine uses affected by the regulations***

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Overview: PEDE TAC Listing Should Be Clarified to Exclude NTDE

- Regulatory and technological changes since 1998 have brought about the significant improvements that CARB intended and anticipated
- Today’s NTDE is fundamentally different from TDE (quantitatively and qualitatively), and is equivalent to the emissions from ultra-clean natural gas and gasoline vehicles
- CARB and industry have successfully ushered in ultra-clean diesel technologies and the associated benefits to air quality and public health
- The TAC listing for PEDE should be clarified and revised to exclude NTDE to reflect this “win-win” reality and to foster the continued introduction of ultra-clean diesel technologies

Overview:
EMA Seeks Needed Clarification of TAC Listing

- Data since 1998 support a further clarification that the TAC listing for PEDE "***does not apply to emissions from diesel-fueled engines operating on ULSD and equipped with oxidation catalysts and wall-flow diesel particulate filters (NTDE)***"

- This needed clarification will foster the deployment of ultra-clean new-technology diesel vehicles, which in turn will foster CARB's clean air and climate change programs

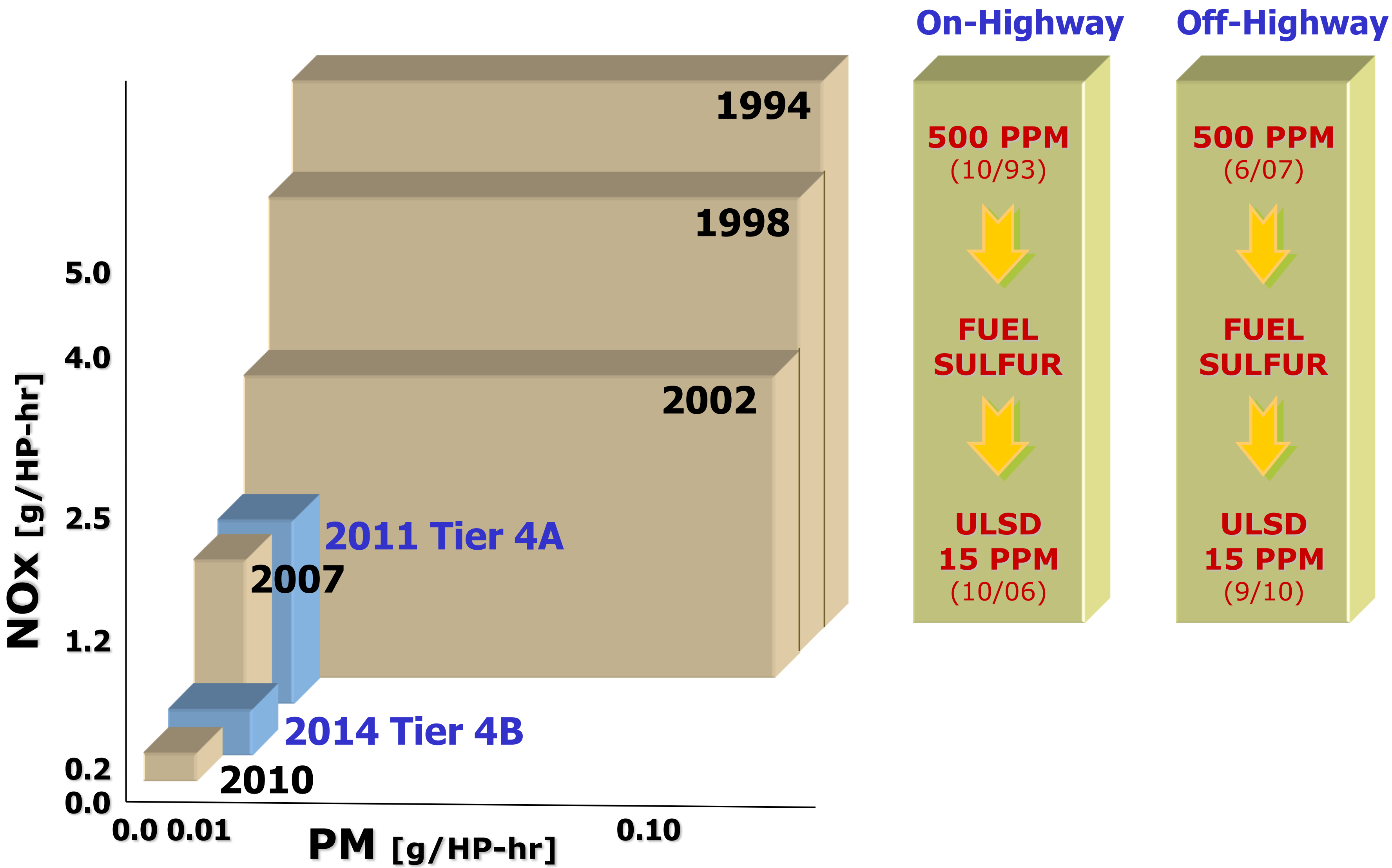
- ***The Board has the ability to make this needed clarification regarding NTDE through a collaborative process, just as was done in 1998***

New Diesel Technologies

"... so much has been written and said about the diesel engine in recent months that it is hardly possible to say anything new."

Rudolf Diesel, c. 1910

Evolution of US Heavy Duty Diesel Emission Standards



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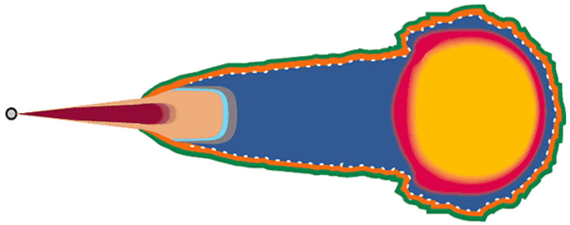
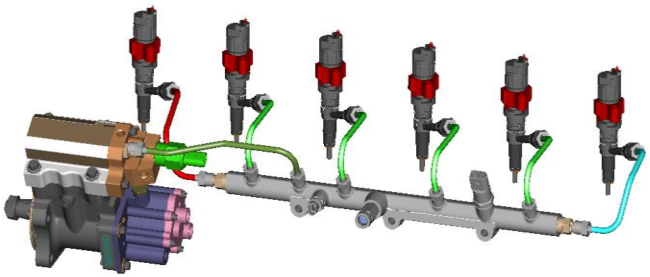
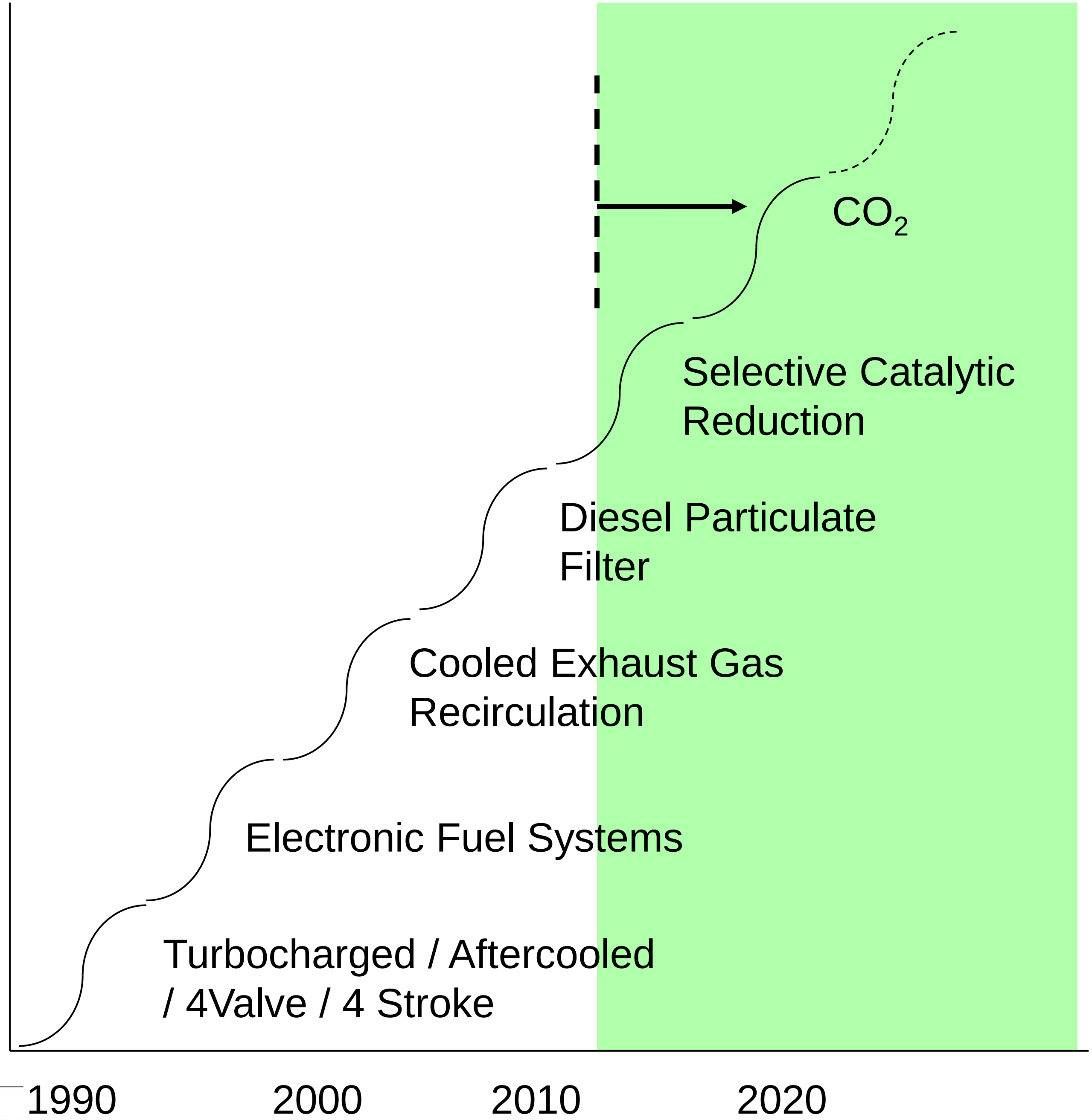
Diesel Technology Development: Critical Subsystems

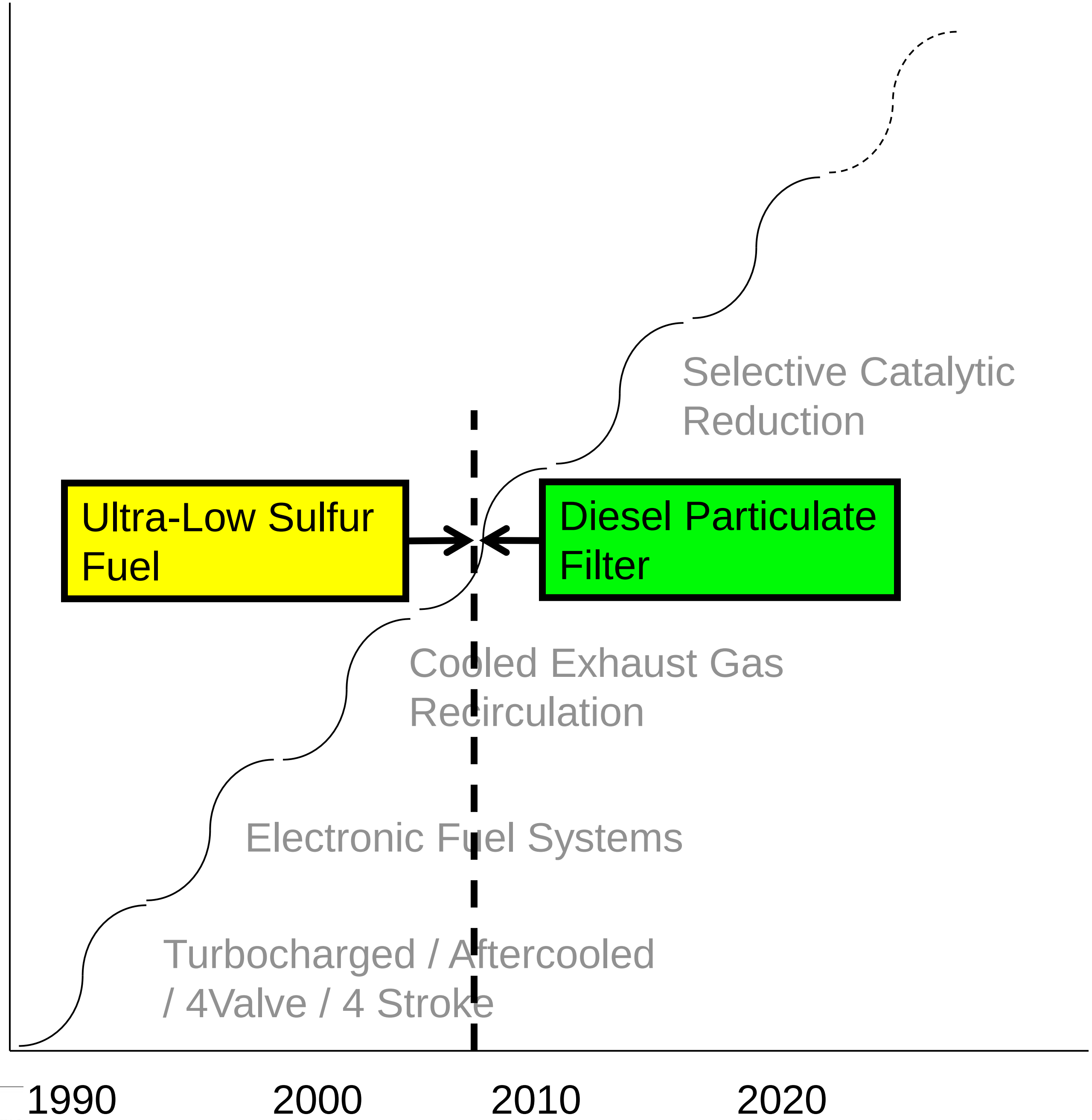




Evolution of Diesel Technology



Evolution of Diesel Technology



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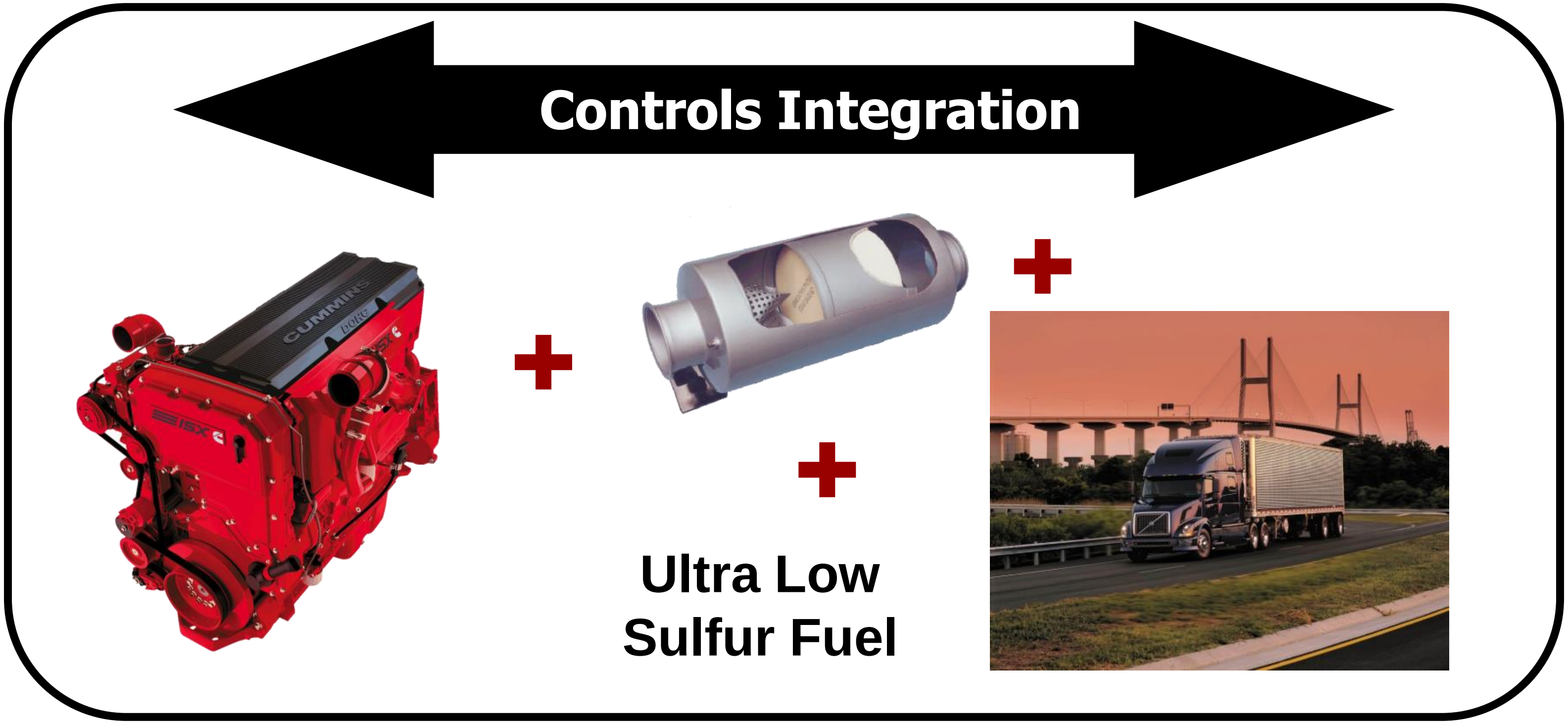
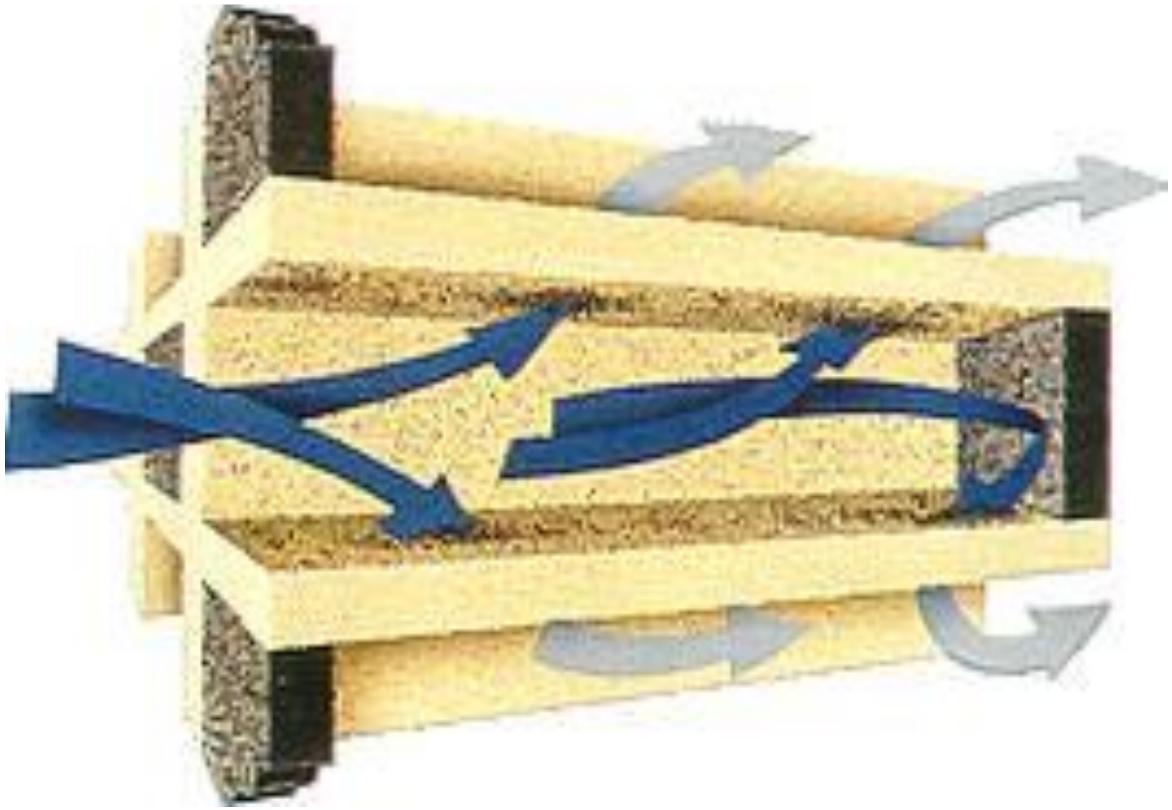
System Integration is Critical



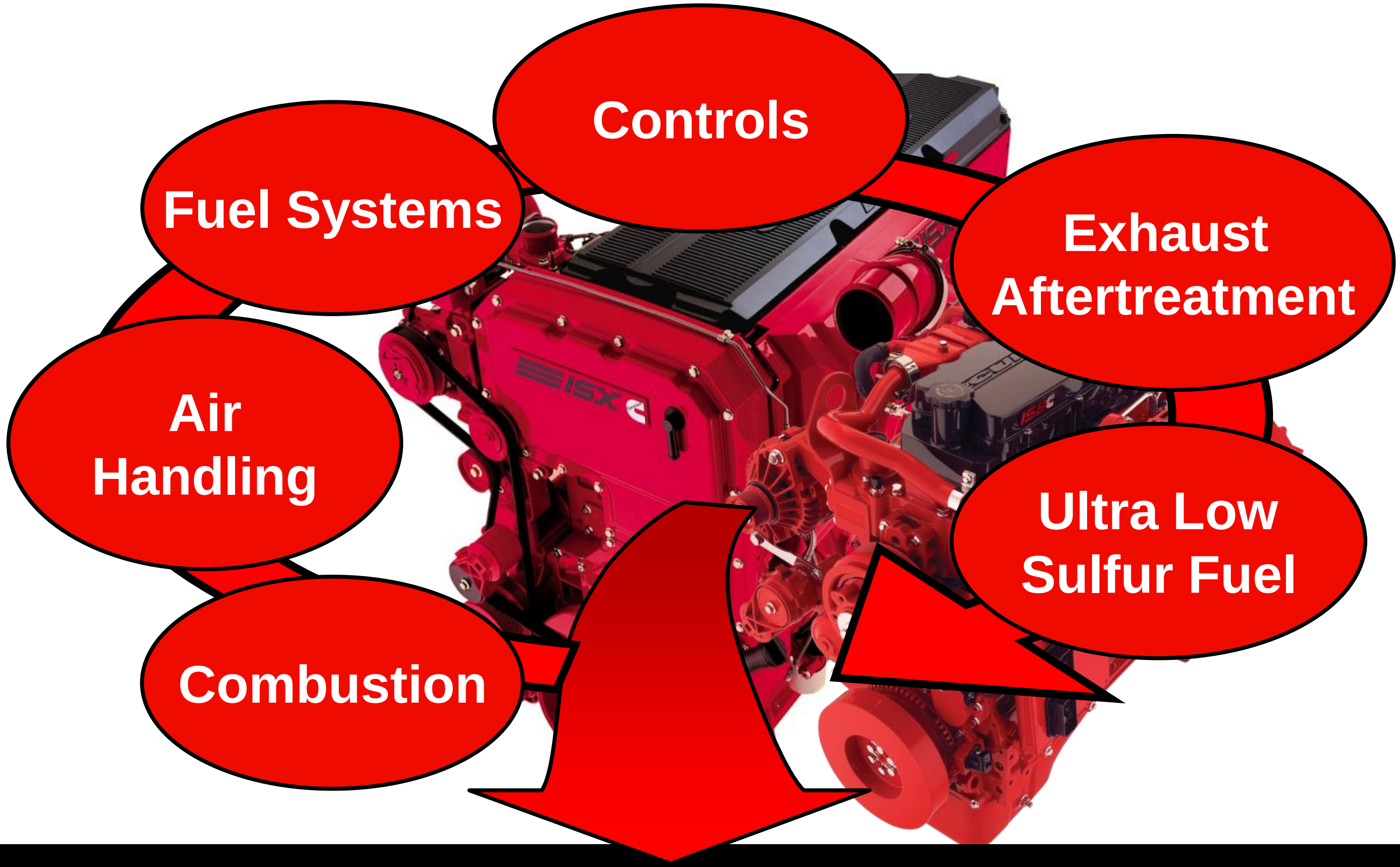
Vehicle, engine and aftertreatment . . .
a single system designed to optimize performance, reliability, cost and emissions

2007 And Beyond . . . Integrating Engine and Aftertreatment

Active Particulate Filter



Transition to Clean “New Technology” Diesel: Advanced Component Technologies and System Integration



Clean Diesel

Ultra-Clean New-Technology Diesels Are On The Road

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The Fundamentally Changed Composition of NTDE

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Overview

Fundamentally Changed Composition of NTDE

- PM levels in NTDE are more than 100-fold lower than in Traditional Diesel Exhaust (TDE)
- NTDE is chemically very different from TDE
- NTDE emissions are similar to or lower than CNG or gasoline emissions
- Biological effects of TDE in human and animal studies not observed with NTDE

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

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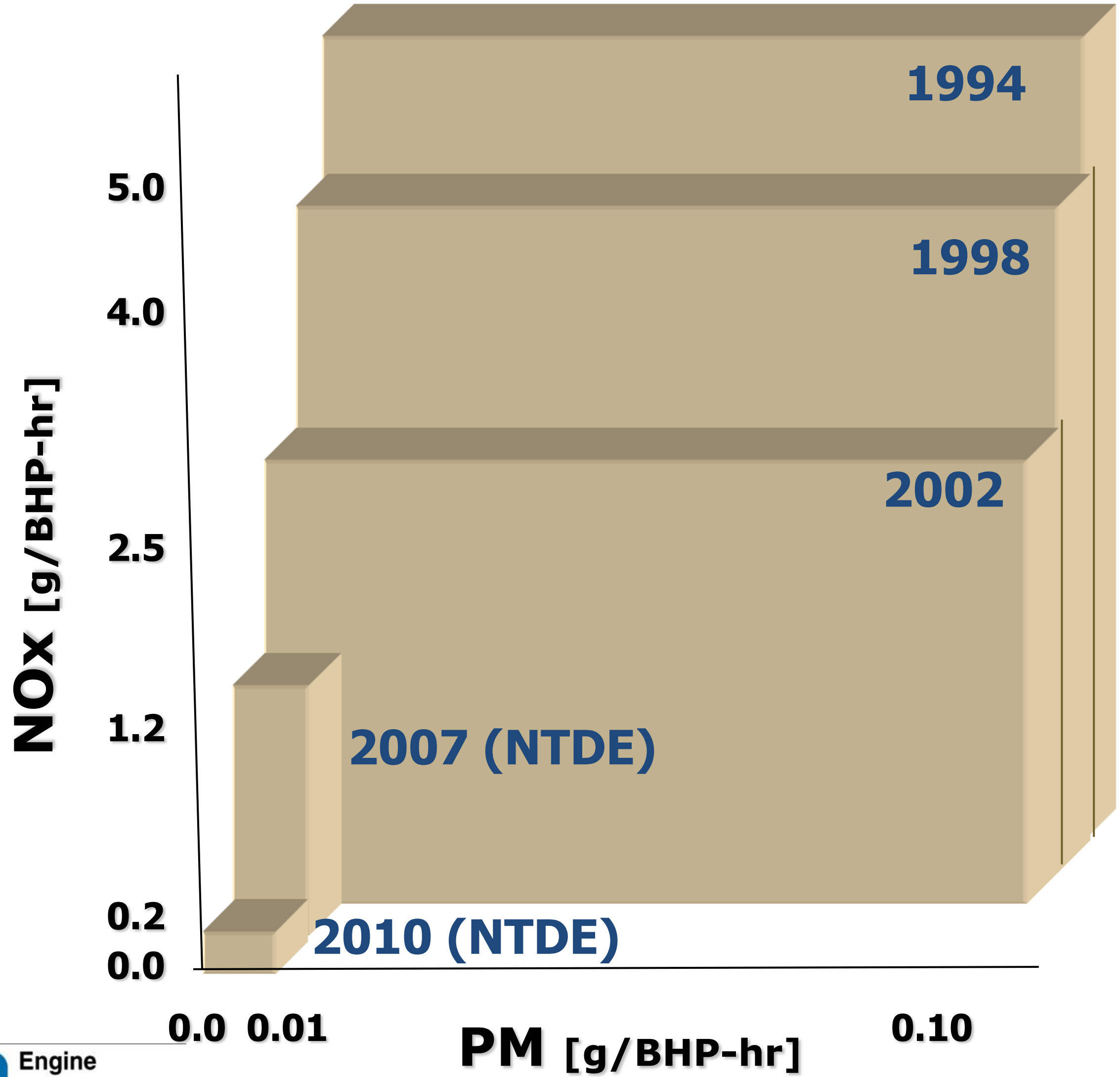
TDE Government Agency Hazard Assessments

- Based on the large toxicological database of TDE from pre-1988 engines
- All earlier epidemiology and most laboratory toxicology studies used TDE
- Concluded that high levels of DE are likely to increase cancer and non-cancer health effects
- In 1989, International Agency for Research on Cancer classified DE as a "probable" human carcinogen
- In 1998, particulate emissions from diesel-fueled engines listed as a "toxic air contaminant" (TAC) by California EPA
- In 2000, US EPA classified diesel exhaust as a "mobile source air toxic"
- In 2002, US EPA classified pre-1995 diesel exhaust as "likely to be carcinogenic to humans“

Evolution of US Heavy Duty Diesel On-Road Emission Standards



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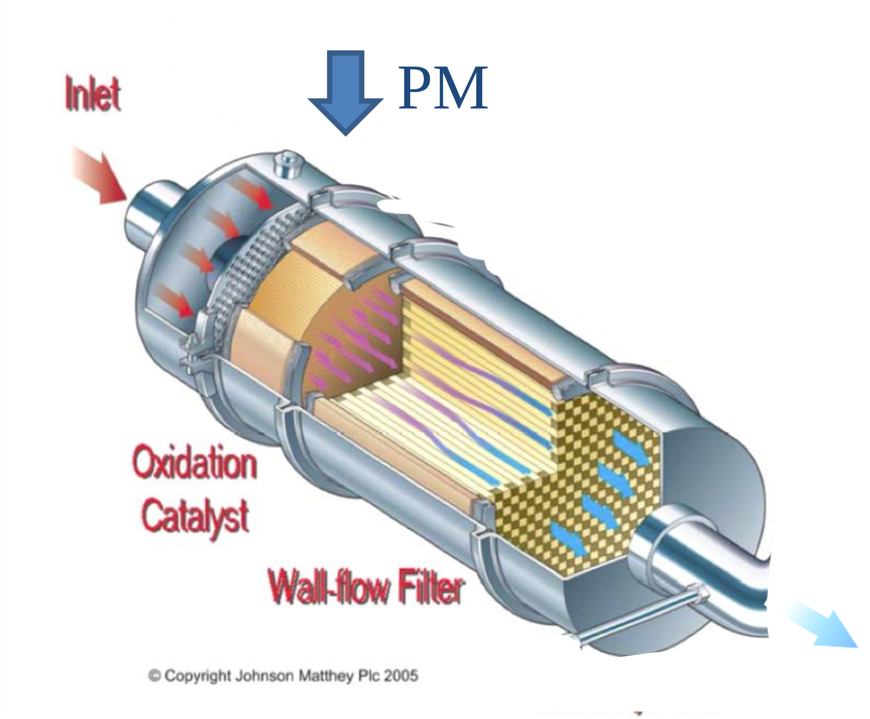
New Technology Diesel Exhaust (NTDE)

Exhaust from engines utilizing new technologies:

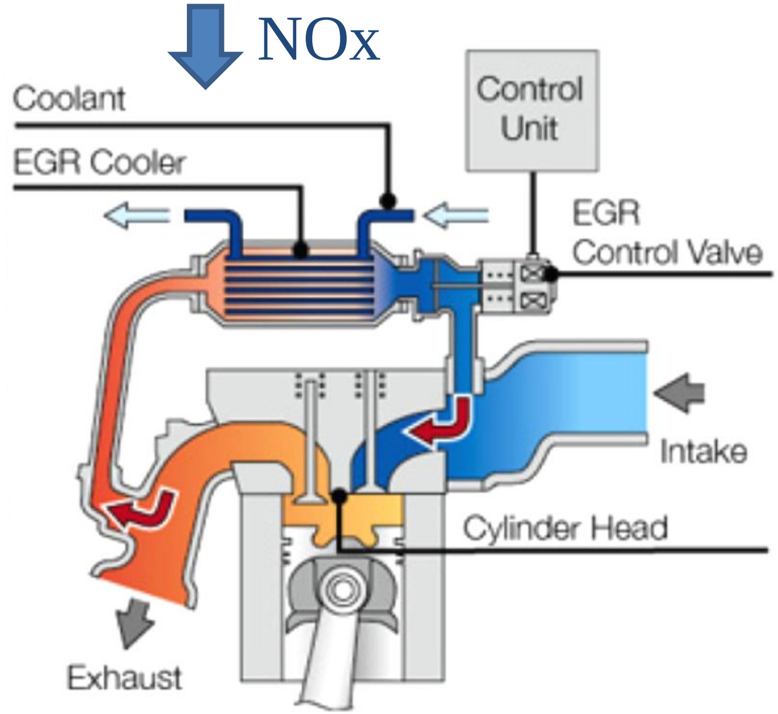
- Meets EPA & CARB 2007 PM and NOx standards
- Fully integrated electronic control systems
- Ultra low sulfur diesel fuel (< 15 ppm)
- Oxidation catalysts
- Wall-flow diesel particulate filters (DPFs)
- Applies to <u>both</u> new and retrofitted engines

NTDE Exhaust Treatment Systems

—Particle Removal and NOx Elimination Using EGR —



DOC+DPF



Exhaust Gas Recirculation (EGR)

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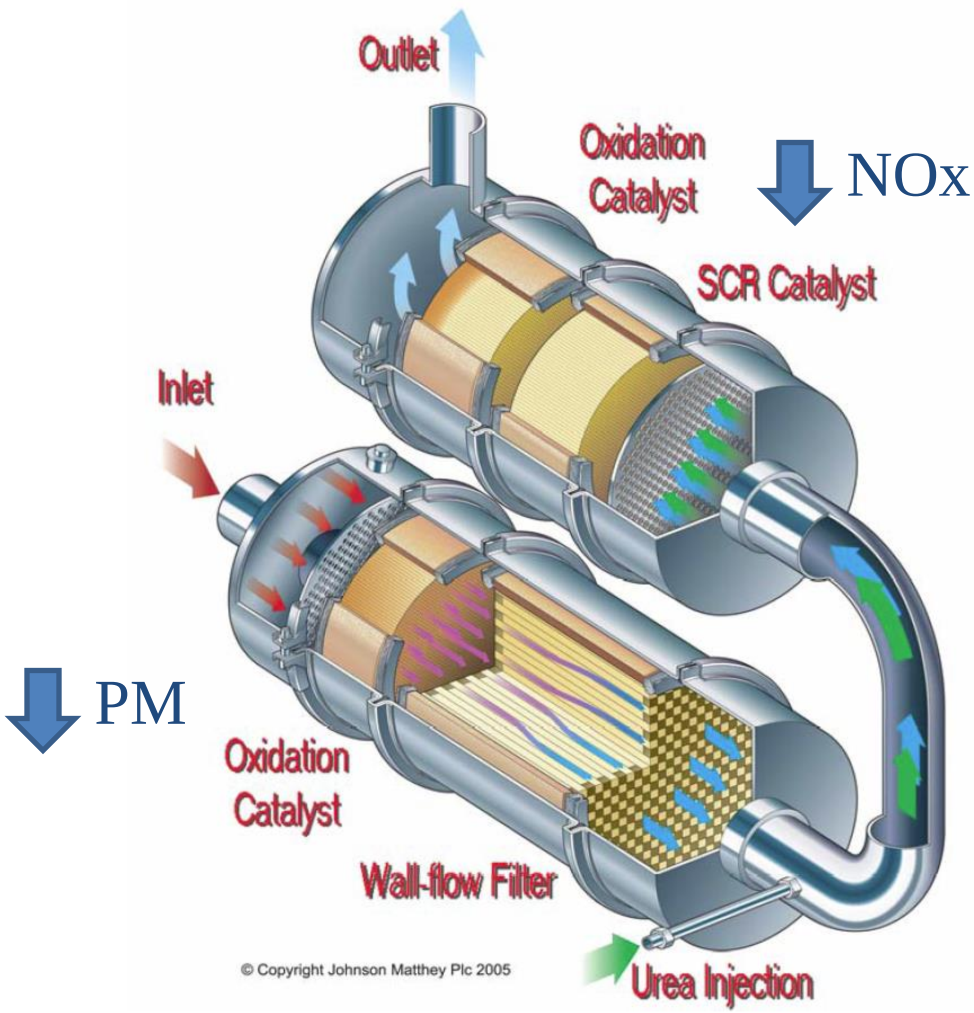
NTDE Exhaust Treatment Systems

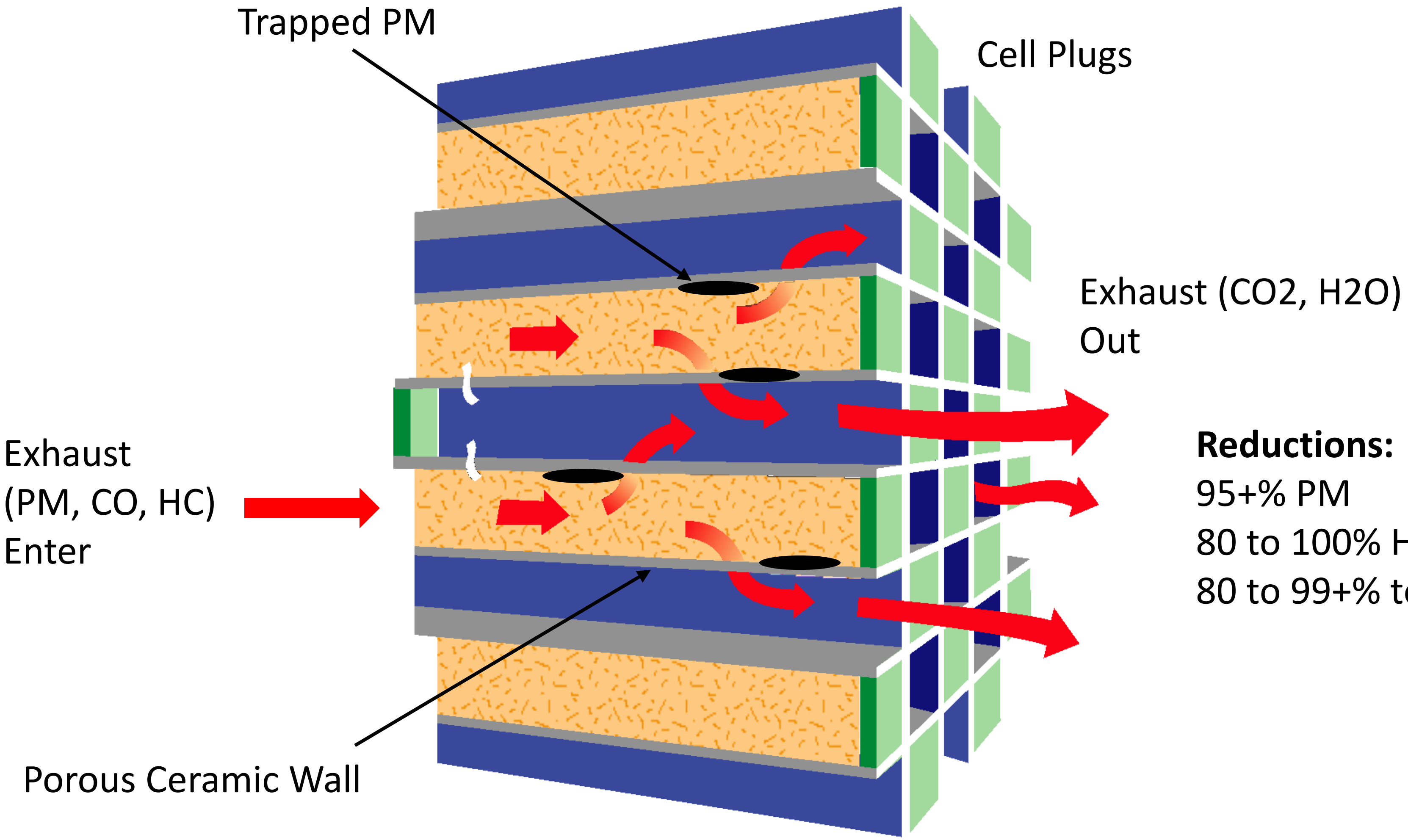
—Particle Removal and NOx Elimination Using SCR-Urea—



DOC+DPF+SCR

Key to Emissions Reductions in NTDE

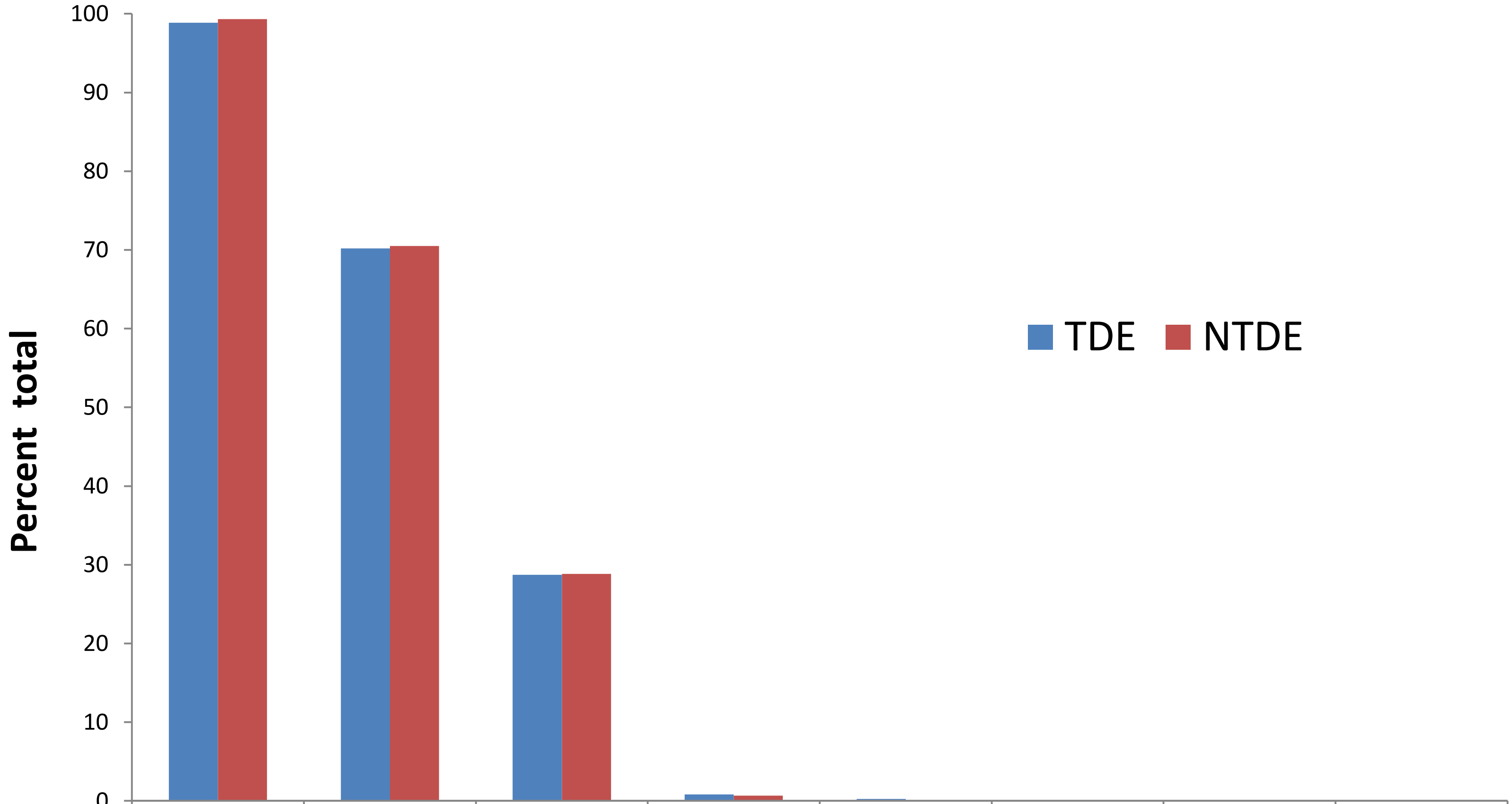
Wall-flow Diesel Particulate Filter



Reductions:
95+% PM
80 to 100% HC, CO
80 to 99+% toxins

Adapted from MECA May 2000

Emission Proportions



	CO2+H2O	CO2	H2O	NOx	CO	HC	PM	NMHC
TDE	98.9	70.2	28.7	0.8	0.23	0.033	0.019	0.025
NTDE	99.3	70.5	28.8	0.7	0.02	0.002	0.001	0.001

Hesterberg et al., ES&T 42:6437-45, 2008, data from Table 1: transit bus. H_2O estimated, see last slide

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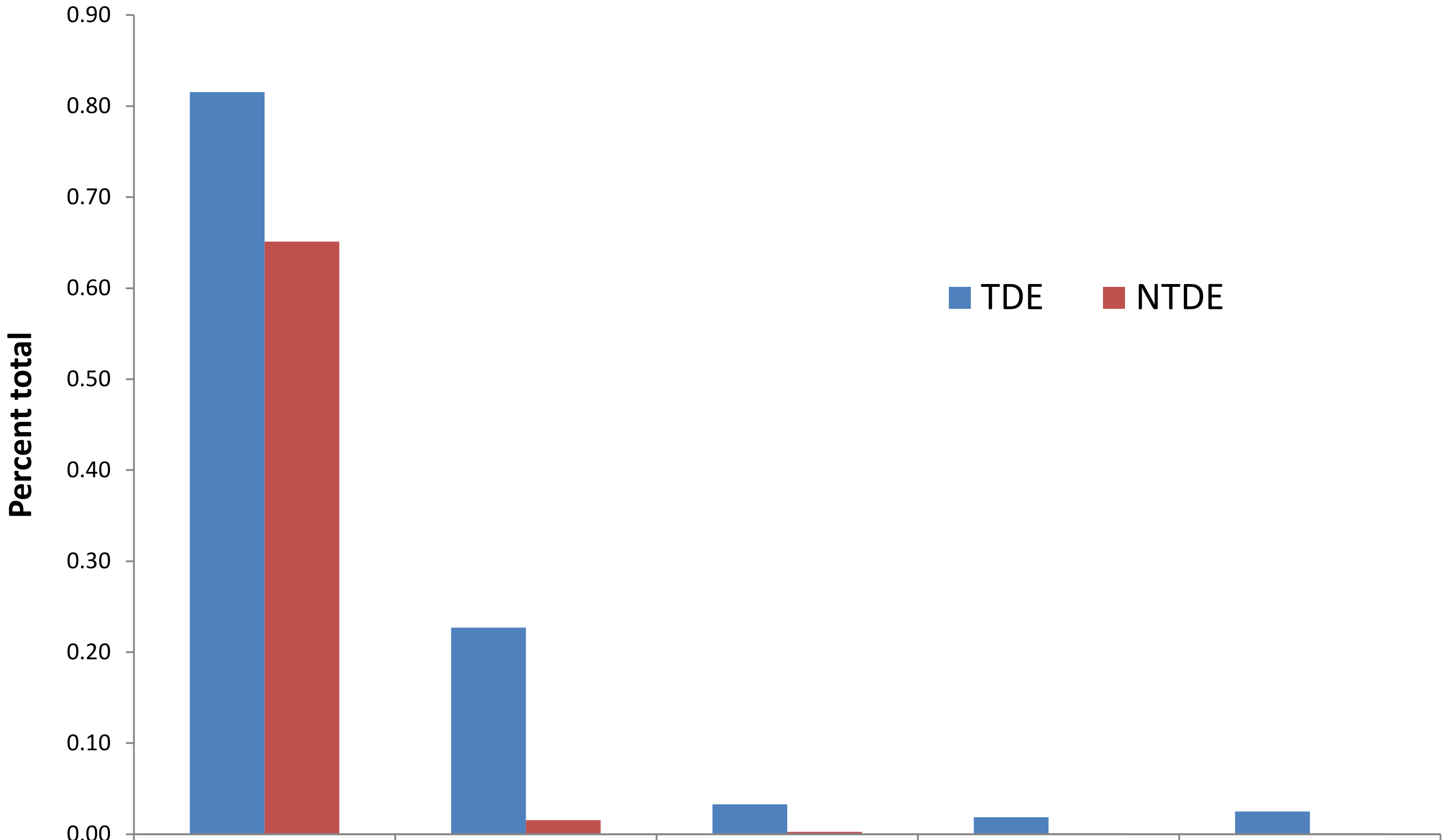
Emission Proportions: Lesser Components



	NOx	CO	HC	PM	NMHC
TDE	0.8	0.23	0.033	0.019	0.025
NTDE	0.7	0.02	0.002	0.001	0.001

Hesterberg et al., ES&T 42:6437-45, 2008, data from Table 1: transit bus. H2O estimated, see last slide

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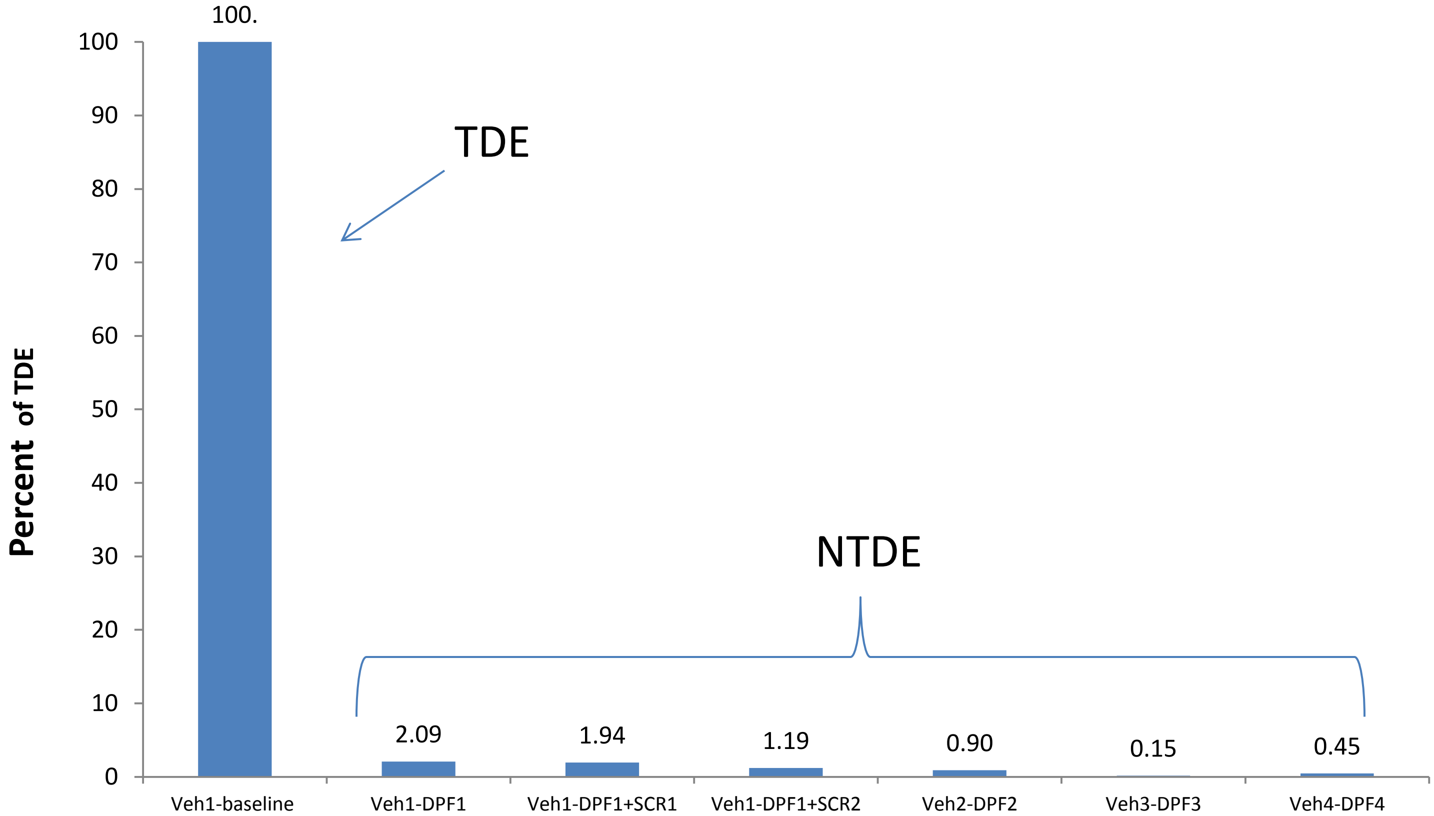
NTDE: Lower Particulate Emissions



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

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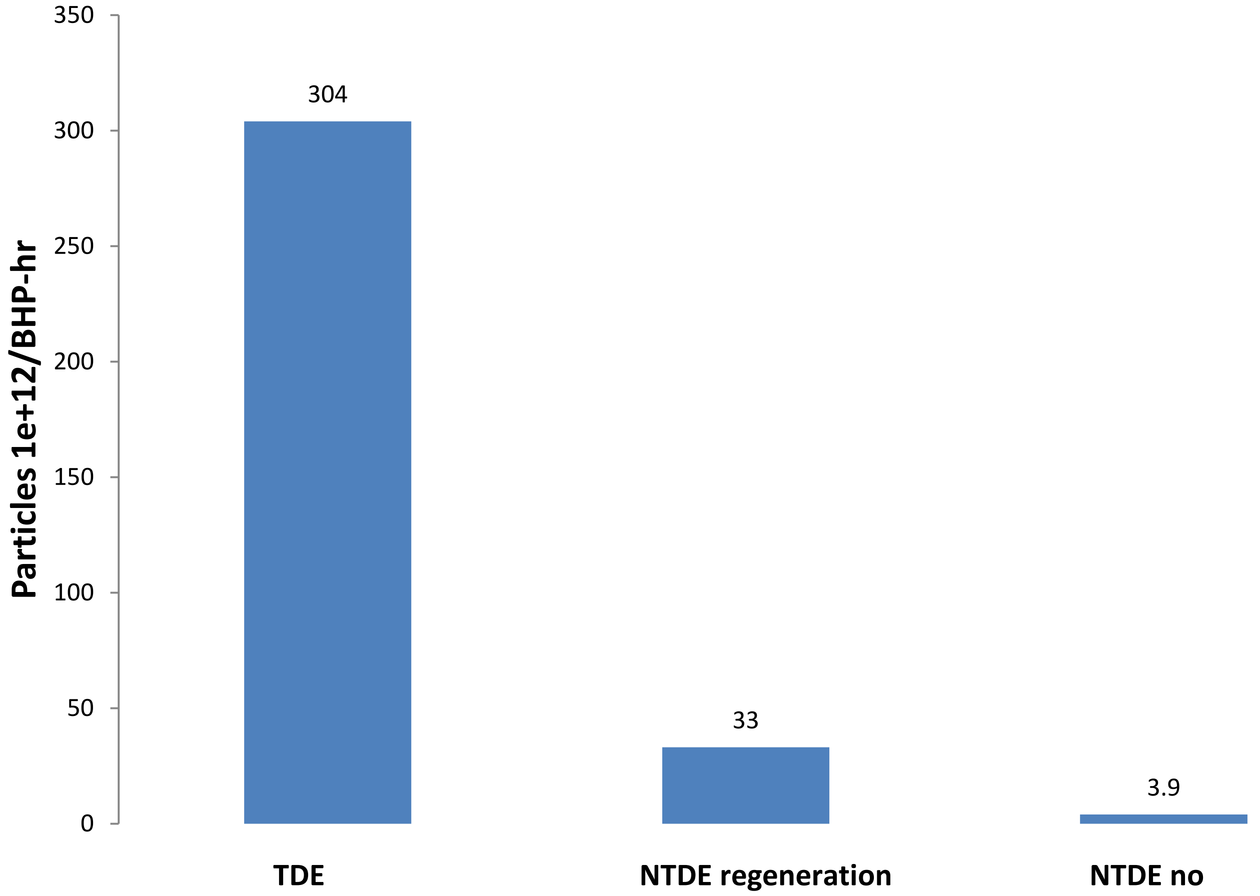
NTDE: Lower Particulate Numbers



ACES Study: Khalek et al., CRC, 2009.

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Comprehensive exhaust chemical assays have been published documenting orders of magnitude reduction in complex hydrocarbon and nitro-PAH concentrations for NTDE …

Compound (carbon number)	2004 Engine[a]	2007 Engine[a]	% Reduced
Elemental carbon	49 700 ± 3550	150 ± 38.2	99.7 ± 7.2
Organic carbon	37 800 ± 4360	213 ± 101	99.4 ± 11.8
Organic mass	45 300 ± 5230	256 ± 121	99.4 ± 11.8
n-Alkanes			
n-Undecane (11)	< 0.01 ± 2.97	1.04 ± 1.76	–
n-Dodecane (12)	<0.01 ± 0.795	0.279 ± 0.286	–
n-Tridecane (13)	2.25 ± 0.859	<0.01 ± 0.186	>99.6 ± 46.4
n-Tetradecane (14)	10.4 ± 2.64	<0.01 ± 0.203	>99.9 ± 27.3
n-Pentadecane (15)	34.4 ± 5.52	<0.01 ± 0.00	>99.9 ± 16.0
n-Hexadecane (16)	84.6 ± 13.4	<0.01 ± 0.00	>99.9 ± 15.8
n-Heptadecane (17)	96.5 ± 10.7	<0.01 ± 0.193	>99.9 ± 11.3
n-Octadecane (18)			
n-Nonadecane (19)			
n-Eicosane (20)			
n-Heneicosane (21)			
n-Docosane (22)			
n-Tricosane (23)			
n-Tetracosane (24)			
Branched alkanes			
Norpristane (18)			
Pristane (19)			
Phytane (20)			
Saturated cycloalkanes			
Dodecylcyclohexane (18)			
Pentadecylcyclohexane (21)			
Hexadecylcyclohexane (22)			
Heptadecylcyclohexane (23)			
Octadecylcyclohexane (24)			
Nonadecylcyclohexane (25)			
Aromatics			
Biphenyl (12)			
2-Methylbiphenyl (13)			
3-Methylbiphenyl (13)			
4-Methylbiphenyl (13)			
PAHs, POM, and Derivatives			
Naphthalene (10)			
2-Methylnaphthalene (11)			
1-Methylnaphthalene (11)			
Dimethylnaphthalenes (12)			

Compound (carbon number)	2004 Engine	2007 Engine	% Reduced
Trimethylnaphthalenes (13)	935 ± 45.9	38.8 ± 3.95	95.9 ± 5.3
1-Ethyl-2-methylnaphthalene (13)	115 ± 14.1	4.25 ± 1.18	96.3 ± 13.3
2-Ethyl-1-methylnaphthalene (13)	6.83 ± 1.59	0.673 ± 0.193	90.1 ± 26.1
Anthracene (14)	7.38 ± 1.00	0.862 ± 0.385	88.3 ± 18.8
Phenanthrene (14)	78.6 ± 11.3	12.3 ± 3.62	84.4 ± 19.0
Methylphenanthrenes (15)	85.4 ± 9.49	3.30 ± 0.460	96.1 ± 11.7
Dimethylphenanthrenes (16)	66.9 ± 5.33	1.17 ± 0.239	98.3 ± 8.3
Fluorene (13)	131 ± 20.6	12.9 ± 3.54	90.2 ± 18.4
Methylfluorenes (14)	0.00 ± 0.00	10.9 ± 3.91	–
Fluoranthene (16)	4.31 ± 0.137	1.13 ± 0.564	73.8 ± 16.3
Pyrene (16)	11.7 ± 1.20	0.979 ± 0.649	91.6 ± 15.8
Acenaphthalene (12)	30.5 ± 1.88	2.18 ± 1.42	92.9 ± 10.8
Acenaphthene (12)	45.5 ± 6.55	22.0 ± 21.1	51.6 ± 60.8
Chrysene + triphenylene (18)	1.05 ± 0.133	0.123 ± 0.109	88.3 ± 23.0
Benz[a]anthracene (18)	0.586 ± 0.0579	0.0632 ± 0.0698	89.2 ± 21.8
Benzo[g,h,i]fluoranthene (18)	0.607 ± 0.593	0.258 ± 0.270	57.5 ± 142
Benzo[b + k + j]fluoranthene (20			
Benzo[a]pyrene (20)			
Benzo[e]pyrene (20)			
Benzo[g,h,i]perylene (22)			
Nitro-PAHs			
1-Nitronaphthalene (10)			
2-Nitronaphthalene (10)			
Methylnitronaphthalenes (11)			
2-Nitrobiphenyl (12)			
4-Nitrobiphenyl (12)			
1-Nitropyrene (16)			
9-Nitroanthracene (14)			
Oxygenated PAHs			
Acenaphthenequinone (12)			
9-Fluorenone (13)			
Xanthone (13)			

Compound (carbon number)	2004 Engine[a]	2007 Engine[a]	% Reduced
Perinaphthanone (13)	29.7 ± 4.33	1.01 ± 0.288	96.6 ± 15.5
Anthraquinone (14)	5.16 ± 0.886	1.30 ± 0.506	74.8 ± 27.0
9-Anthraaldehyde (15)	1.56 ± 0.829	0.0388 ± 0.0291	97.5 ± 55.0
Benzanthrone (17)	1.89 ± 0.109	0.0154 ± 0.00973	99.2 ± 6.3
Aliphatic aldehydes			
Formaldehyde (1)	5160 ± 2440	<0.01 ± 58.1	>99.9 ± 48.4
Acetaldehyde (2)	1480 ± 783	<0.01 ± 43.1	>99.9 ± 55.8
Hopanes			
17α(H)-22,29,30-Trisnorhopane (27)	0.430 0.0658	<0.01 0.00	97.7 ± 15.3
17α(H),21β(H)-Hopane (30)	1.67 0.0558	0.0109 0.0109	99.3 ± 4.0
22S-17α(H),21β(H)-29-Homohopane (31)	0.925 0.0309	<0.01 0.00	98.9 ± 3.3
22R-17α(H),21β(H)-29-Homohopane (31)	0.545 0.284	<0.01 0.00	98.2 ± 52.1
22S-17α(H),21β(H)-29,30-Bishomohopane (32)	2.11 1.60	<0.01 0.00	99.5 ± 75.8
22R-17α(H),21β(H)-29,30-Bishomohopane (32)	0.288 0.144	<0.01 0.00	96.5 ± 50.0
22R-17α(H),21β(H)-29,30,31-Trishomohopane (33)	5.33 5.33	<0.01 0.00	–
Steranes			
20S-5α(H),14α(H),17α(H)-Cholestane (27)	5.89 4.87	<0.01 0.00	99.8 ± 82.7
20R-5α(H),14β(H),17β(H)-Cholestane (27)	0.576 0.0438	<0.01 0.00	98.3 ± 7.6
20S-5α(H),14β(H),17β(H)-Cholestane (27)	0.749 0.0729	<0.01 0.00	98.7 ± 9.7

[a] Values are reported in μg (bhp*h)$^{-1}$, uncertainty is given as the standard error of the test results.

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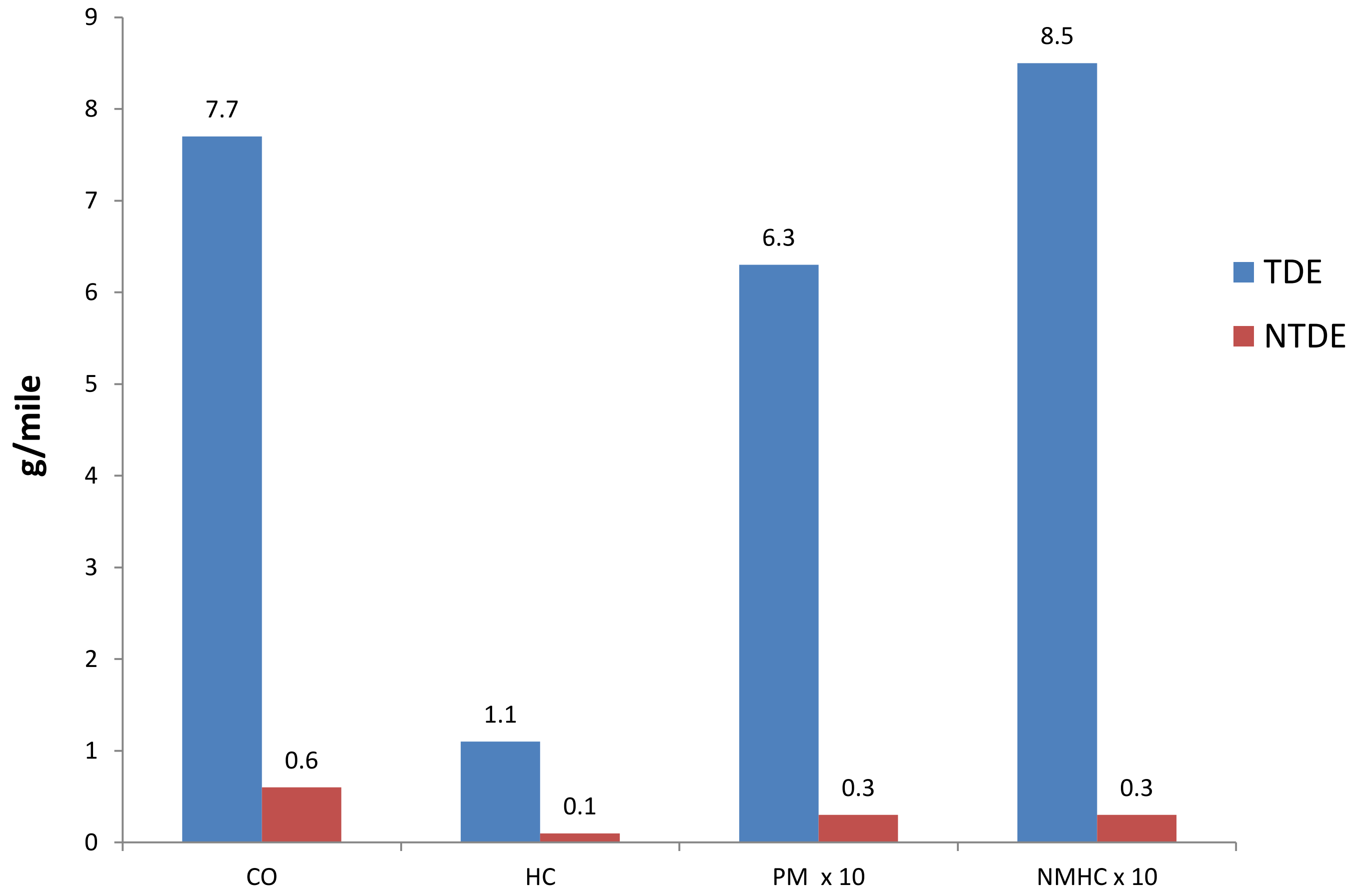
Liu, et al. (2010), Atmospheric Environment, 44: 1108-15.

Publications Comparing NTDE to TDE or CNG (Reviewed in Hesterberg et al., 2008)

1) Ahlvik PJ; Brandberg AL, SAE 2000-01-188
2) Ayala A, et al., SAE 2002-01-1722 and 2003-01-1900
3) Bose RK; Sundar, S., SAE 2005-01-0477
4) Ikonen M, et al., Bus fleet emission evaluation – Annual Report 2003. 3/2004
5) Kado NY, et al., *Environ. Sci. Technol.* 2005, 39, 7638-7649
6) Lann, T, et al., SAE 2003-01-0300
7) LeTavec C, et al., SAE 2002-01-0433
8) Lev-On M, et al., SAE 2002-01-0432 and 2002-01-2873
9) McCormick RL, et al., SAE 1999-01-1507
10) Melendez M, et al., National Renewable Energy Laboratory, TP-540-36355, 2005
11) Northeast Advanced Vehicle Consortium, et al. Defense Advanced Research Projects Agency, NAVC1098-PG009837, 2000
12) Norton P, et al., SAE 1999-01-3525
13) Nylund N, et al. Transit bus emission study: Comparison of emissions from diesel and natural gas buses. VTT Processes, Engines and Vehicles (Finland), 2004
14) Okamoto RA, et al., *Environ. Sci. Technol.* 2006, 40, 332-341
15) Pelkmans L, et al. SAE 2001-01-2002
16) Seguelong T, et al. Diesel Engine Emissions Reduction Conference, 2003

NTDE: Lower for Regulated Emissions



Hesterberg et al., ES&T 42:6437-45, 2008.
Data from Table 1. Transit Bus

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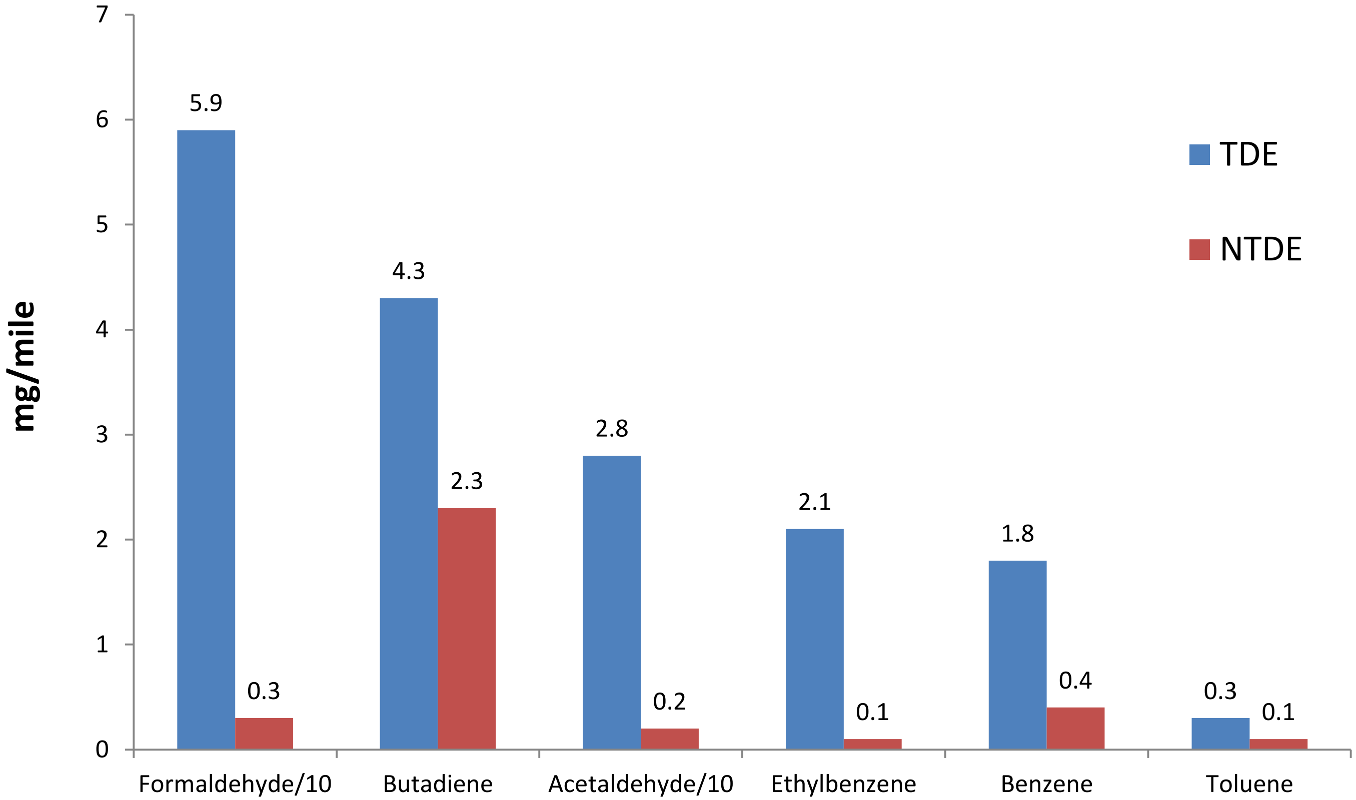
NTDE: Lower Volatile Organic Compound and Aldehyde Emissions



Hesterberg et al., ES&T 42:6437-45, 2008, data from Tables 5 & 7: transit bus

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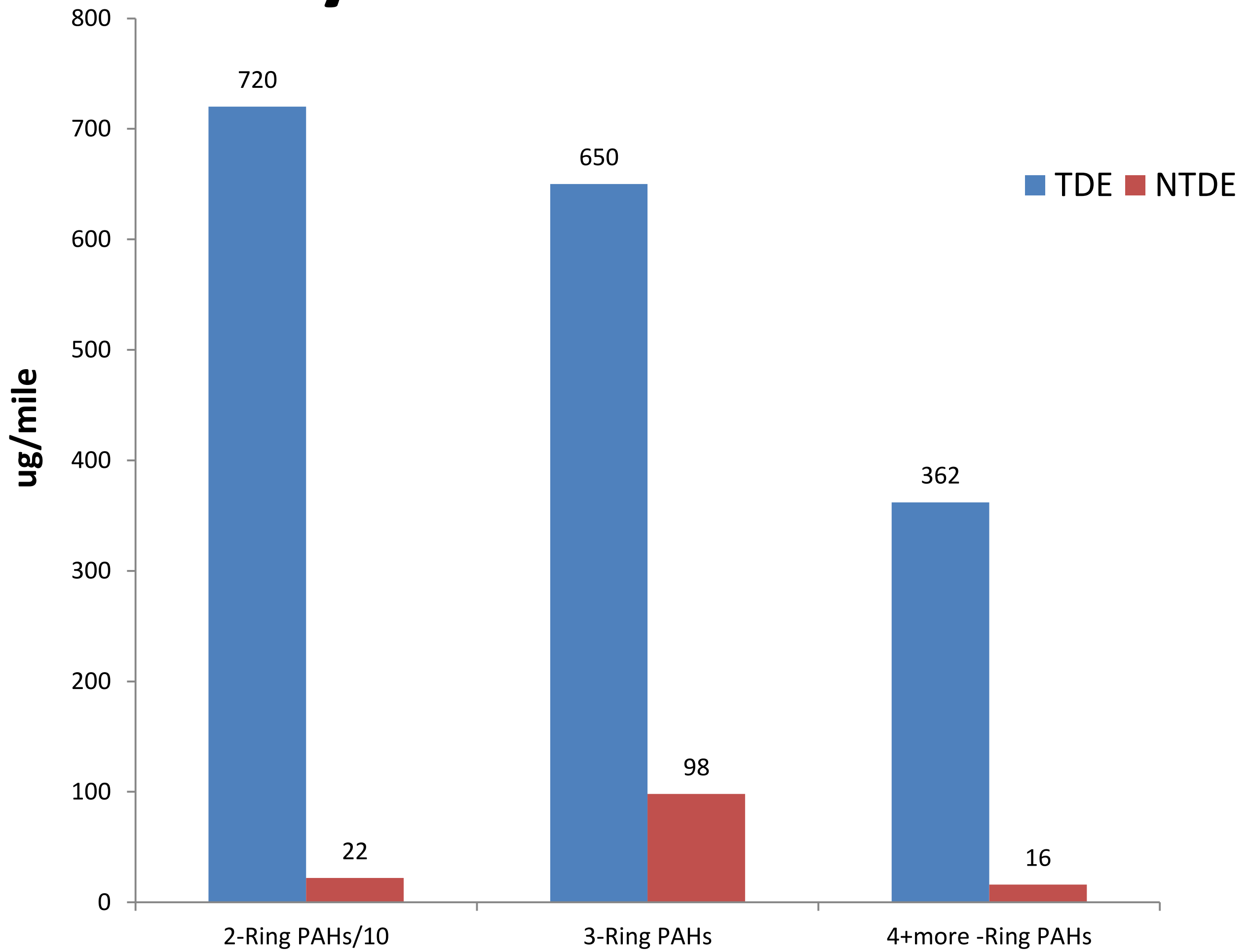
NTDE: Lower Polycyclic Aromatic Hydrocarbon Emissions



Hesterberg et al., ES&T 42:6437-45, 2008, data from Tables 8 & 9: transit bus

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Most of the TACs Associated with TDE are Not Found in NTDE
--Others are 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

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NTDE Reduces Emissions Across a Broad Spectrum of Compounds

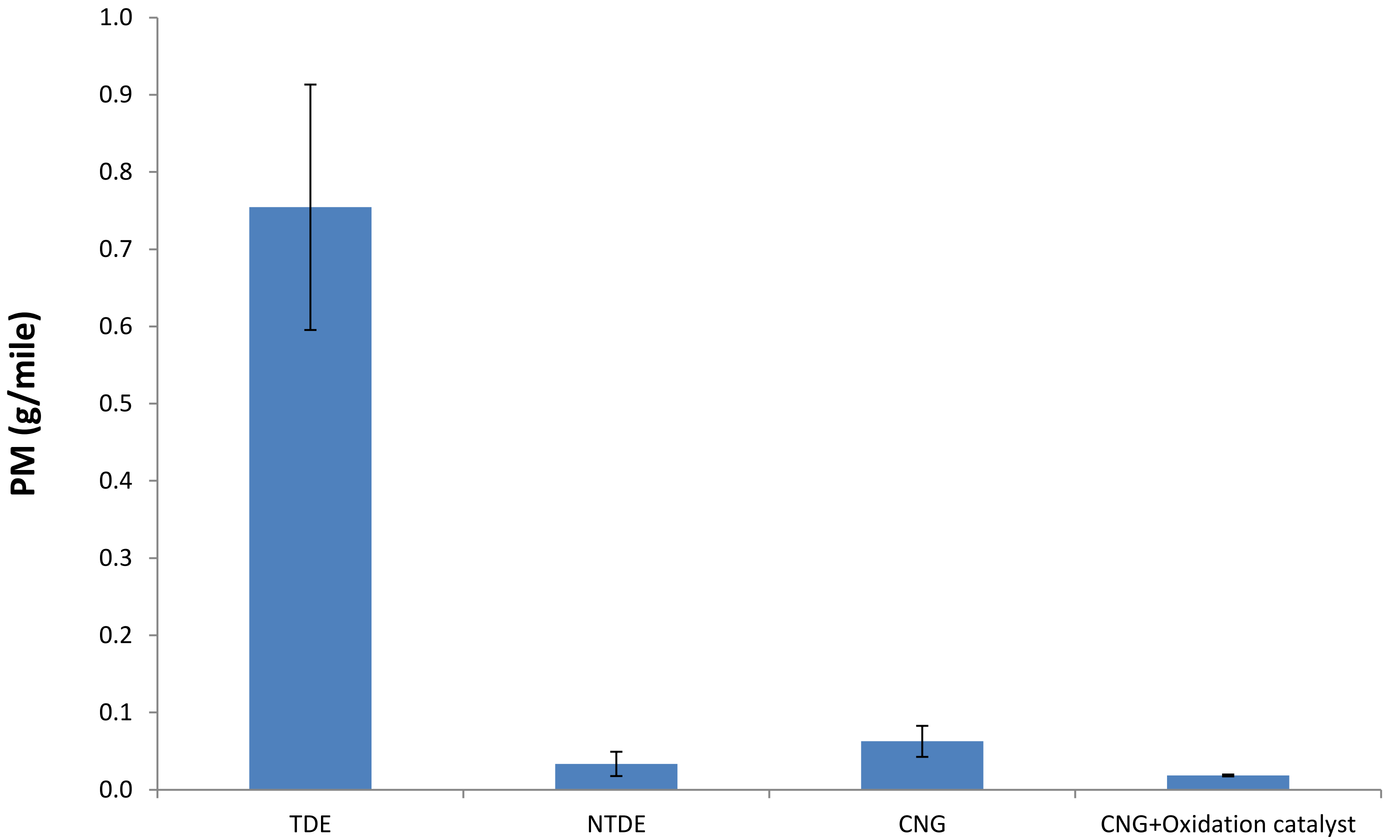
Category	Reduction Relative to TDE
Single Ring Aromatics	82%
PAH	79%
Alkanes	85%
Hopanes/Steranes	99%
Alcohols & Organic Acids	81%
Nitro-PAHs	81%
Carbonyls	98%
Inorganic Ions	71%
Metals & Elements	98%
Organic Carbon	96%
Elemental Carbon	99%
Dioxins/Furans	99%

Khalek et al. 2010, Table 6

NTDE Emissions are Similar to or Lower Than from CNG and Gasoline Vehicles

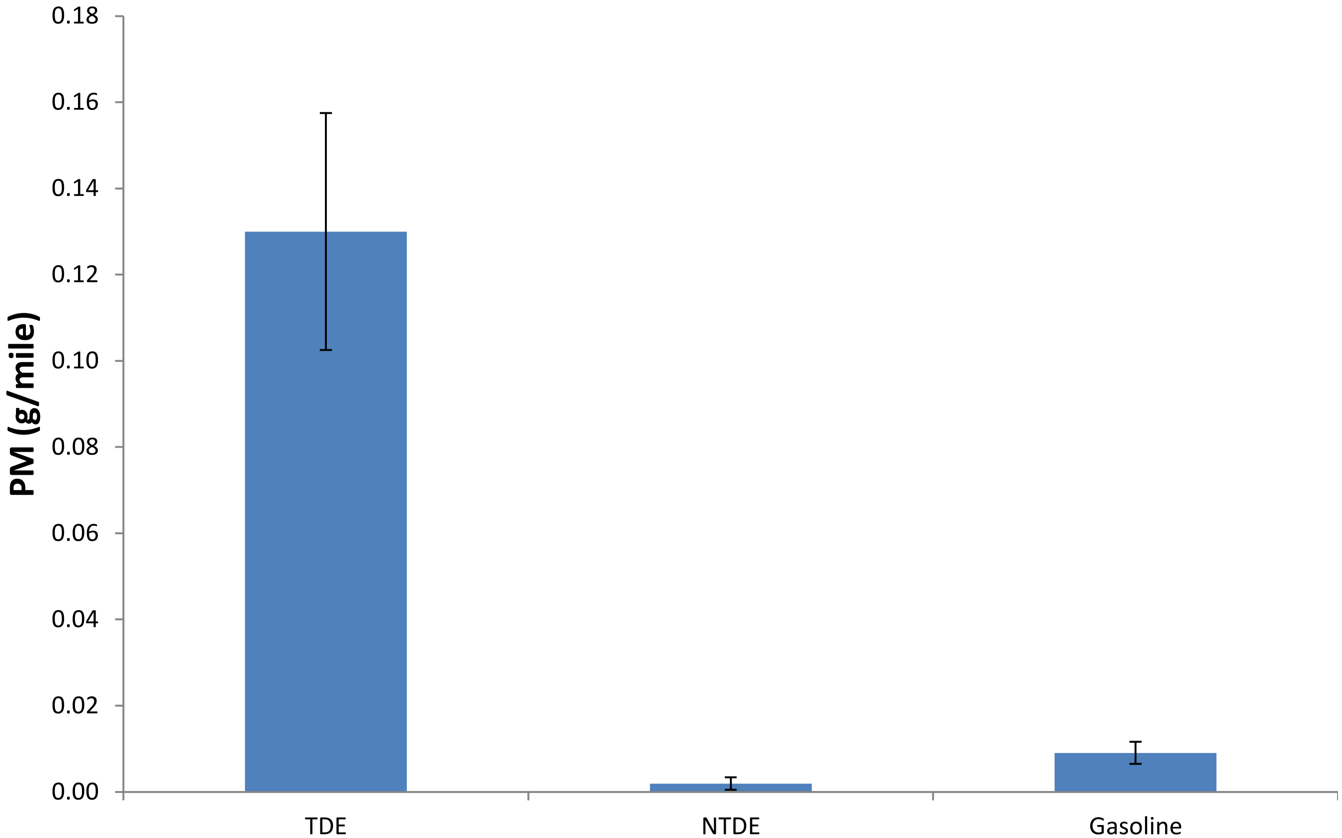
- Similar particle mass emissions
- Similar particle composition
- Similar or lower levels for several components in whole exhaust

NTDE Particulate Mass Emissions Similar to CNG Fueled Vehicles



Hesterberg et al., EST 42 (17), 6437–6445, 2008, data from Table 1. Transit Buses

NTDE Particulate Mass Emissions Similar to Gasoline Fueled Vehicles



Ahlvik, Vägverket, Publikation 2002:62 2002, data from Figure 12. Passenger cars

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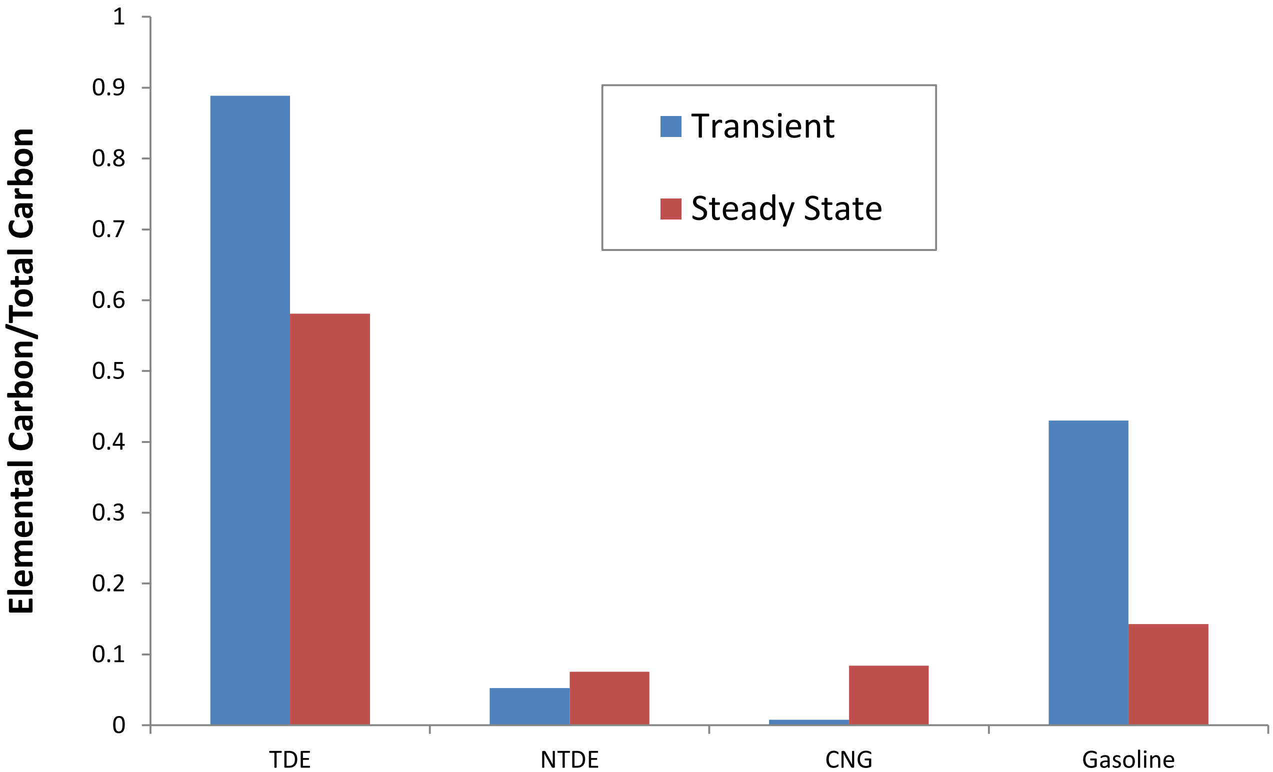
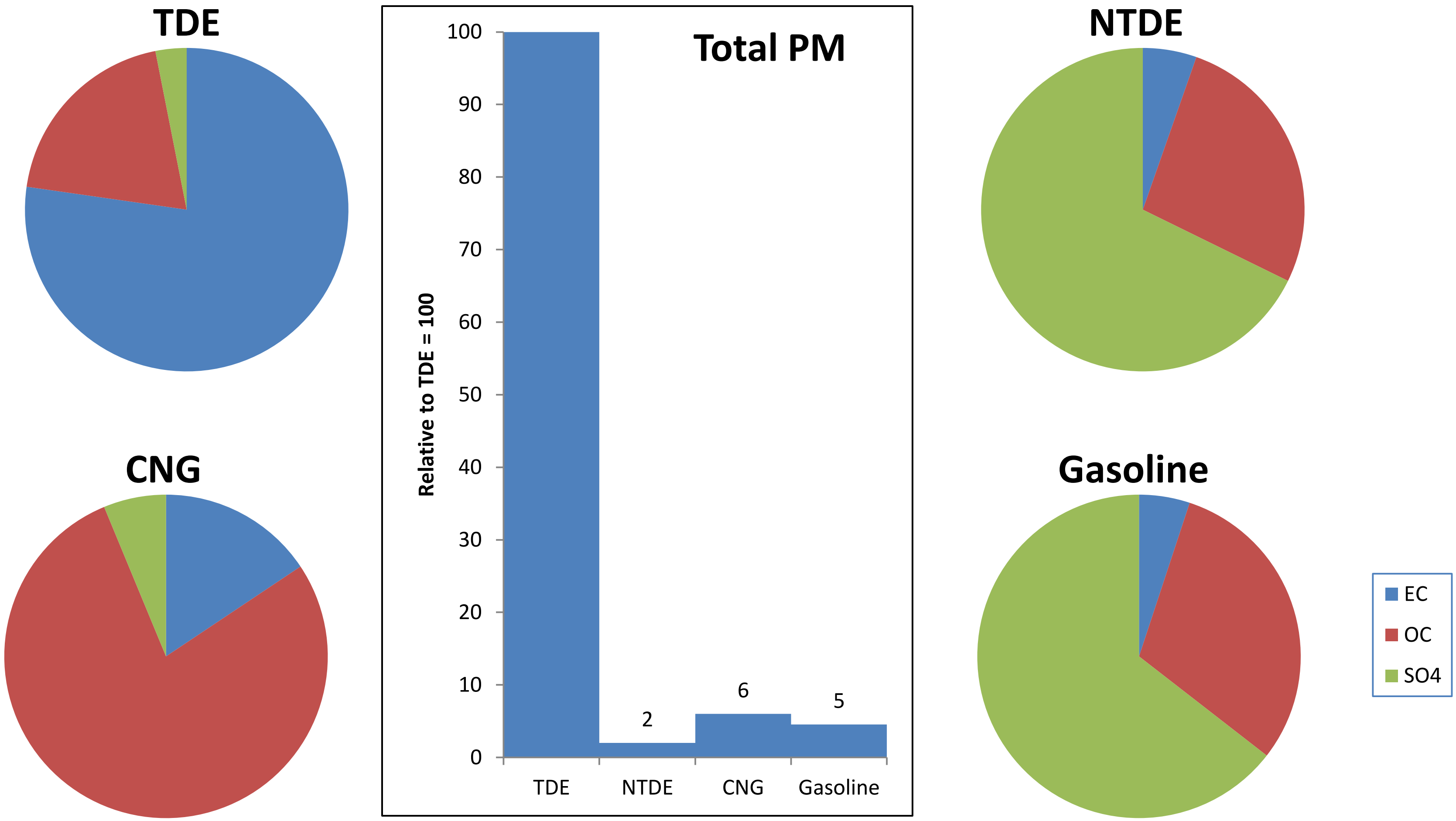
EC/TC Ratio for NTDE PM Similar to CNG and Gasoline Fueled Vehicles



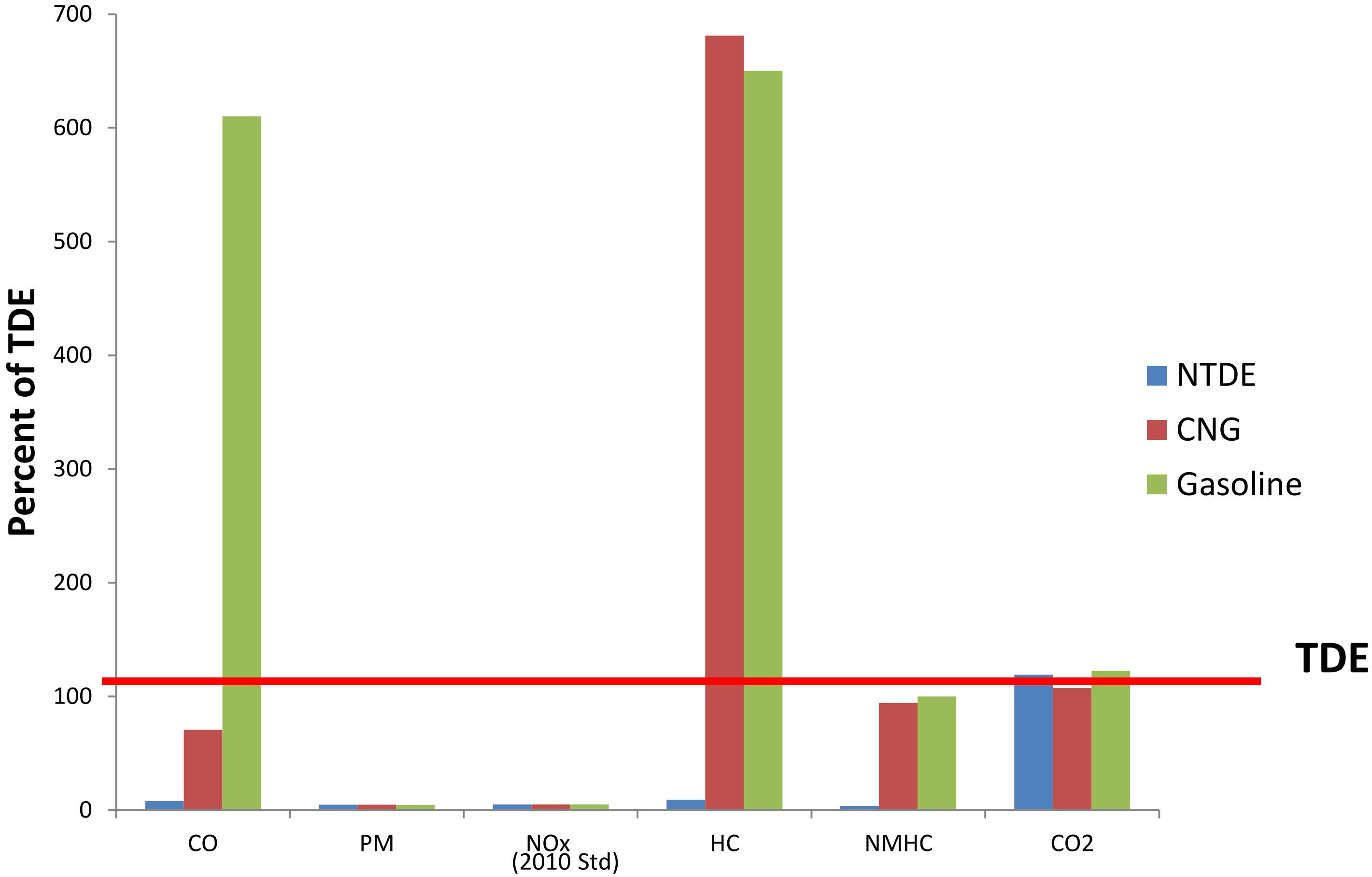
CARB Study: Holmen and Ayala, EST. 2002, 36, 5041–5050, diesel and CNG transit buses. Schauer et al. Aerosol Sci. Technol. 2008, 42, 210-223. Gasoline passenger cars.

PM Composition and Mass Comparisons



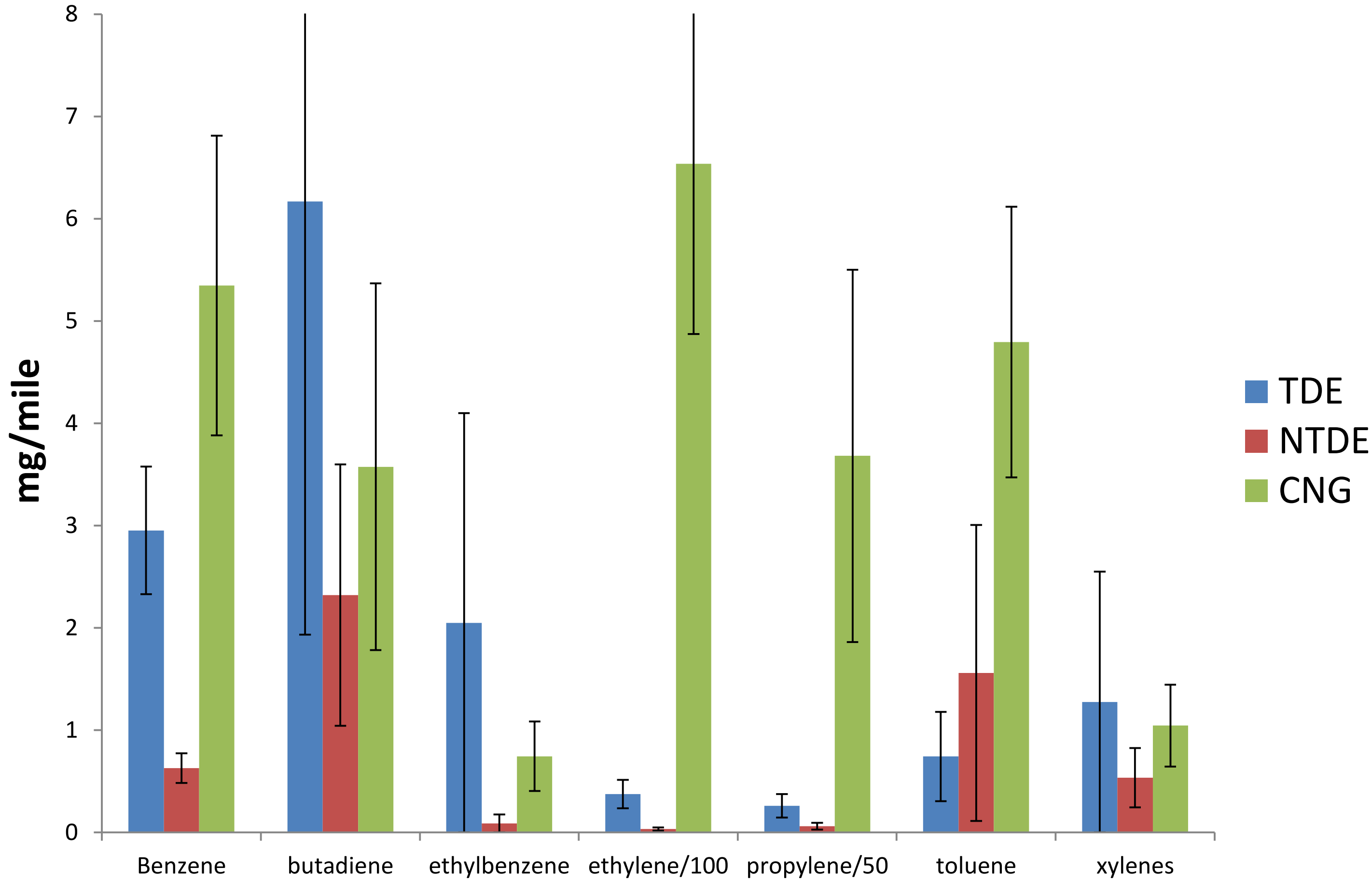
TDE, NTDE, CNG: Lanni et al., SAE 2003-01-0300, 2003. Transit Bus. Gasoline, Steady State: Schauer et al., Aerol Sci Tech 42:210-23, 2008. Gasoline vs. TDE PM: Ahlvik 2002.

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



Hesterberg et al., ES&T 42:6437-45, 2008. Data from Tables 1 &4. US EPA Standards.

NTDE: Lower VOCs than TDE or CNG



Hesterberg et al., EST 42 (17), 6437–6445, 2008, data from Table 5. Transit Buses

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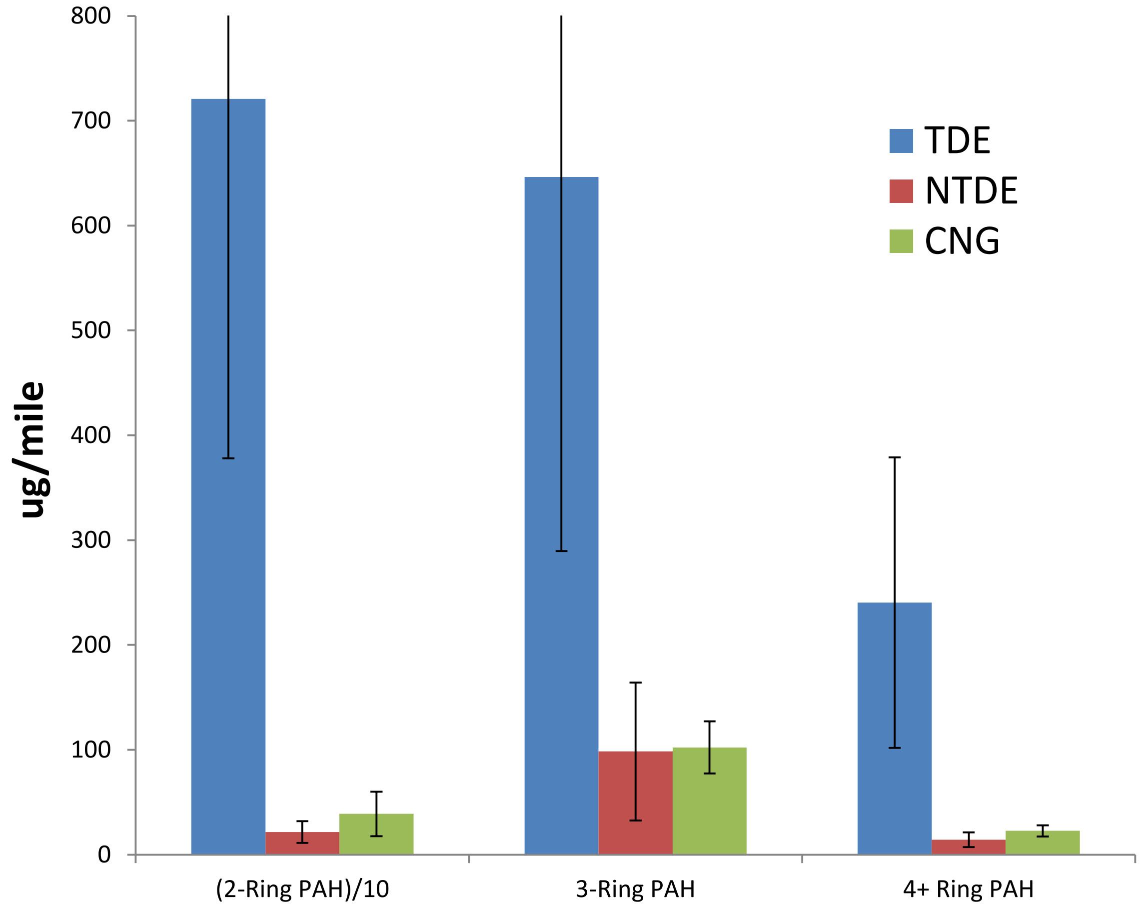
NTDE and CNG: Similar Total PAHs
Both Lower than TDE



Hesterberg et al., ES&T 42 (17), 6437–6445, 2008. Transit bus

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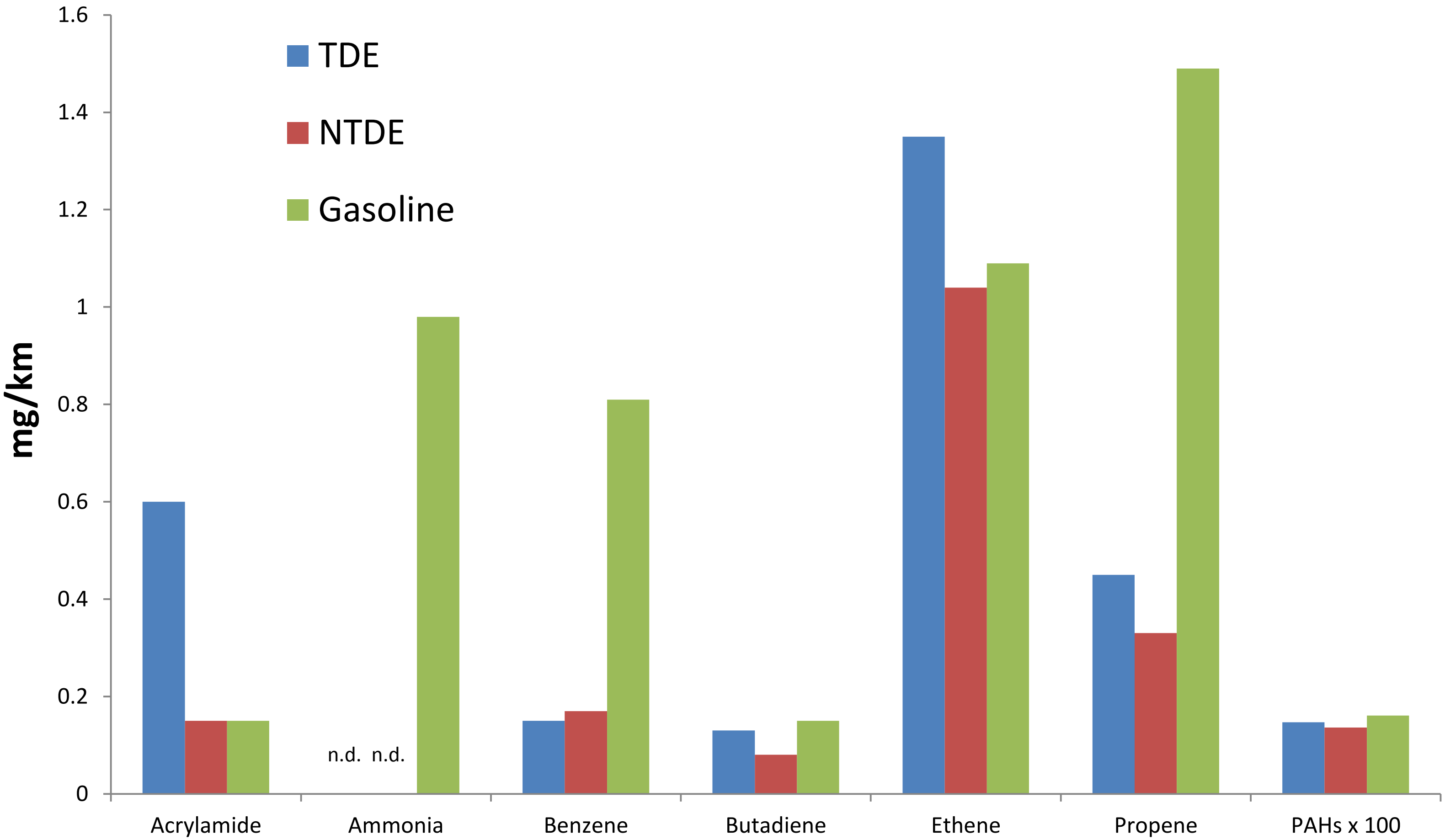
NTDE: Similar or Lower than Gasoline for Several Components of Interest



n.d. = Not detected for TDE and NTDE

Ahlvik, Vägverket, Publikation 2002:62 2002

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Ranking of Health Effects Studies Based on Utility for Human Risk Assessment

Greatest Utility

- Workplace epidemiology studies
- Human clinical studies
- Animal inhalation studies
- Intracavitary injection studies
- In vitro tests

Least Utility

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In Vitro Toxicity Tests – Application for DE Human Risk Assessment

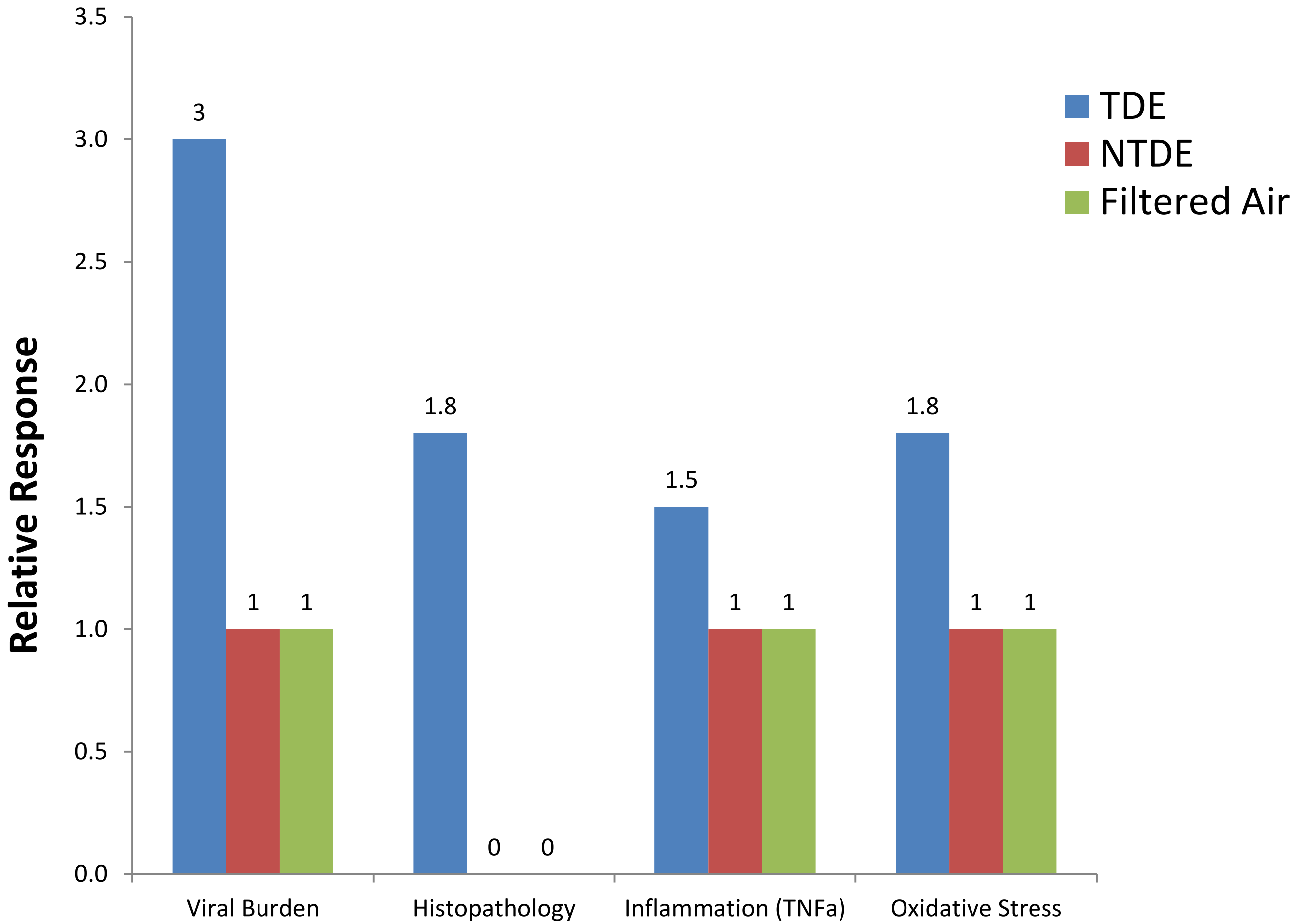
- Most studies only tested TDE
- Mutagens generated during PM collection
- PM components show little bioavailability
- Lung protective mechanisms bypassed
- Dose much higher than after inhalation

California Air Resources Board Evaluation of DE In Vitro Mutagenicity

"The mutagenicity results are only an indication of the presence of potentially carcinogenic compounds in the samples analyzed. Although significant differences are an indication of relative toxicity potential of the samples analyzed, **these results cannot be used to quantify cancer risk**."

Source: Briefing Paper on Interim Results and Tentative Conclusions For ARB's Study of Emissions from "Late-model" Diesel and CNG Heavy-duty Transit Buses, April 2002.

NTDE: No Acute Toxicity in Animals



McDonald et al., Env Health Perspectives 112:1307-12, 2004, developed from Figures 2-4.

Clinical Toxicity Differences: TDE and NTDE

- TDE at high inhalation exposures in human volunteers resulted in
  - Abnormal thrombus formation and
  - Abnormal vasodilation
- Similar dilutions of NTDE did not produce those effects in human volunteers

Barath et al. Am J Respir Crit Care Med 2009, 179, A1634. Lundback et al. Am J Respir Crit Care Med 2009, 179, A1633

Fundamentally Changed Composition of NTDE: Conclusions

- PM levels in NTDE are more than 100-fold lower than in TDE
- NTDE is chemically very different from TDE
- NTDE emissions are similar to or lower than CNG or gasoline emissions
- Biological effects of TDE in human and animal studies are not observed with NTDE

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Summary

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Overall Summary

- In 1998, based on an assessment of traditional diesel exhaust ("TDE"), CARB determined to list "particulate emissions from diesel-fueled engines" (PEDE) as a toxic air contaminant (TAC)

- Extensive scientific data and findings since 1998 establish that ***new diesel emission control technologies have addressed the concerns expressed in the original TAC listing*** so that those concerns do not apply to new-technology diesel exhaust ("NTDE") emitted from today's ultra-clean on-highway and nonroad diesel engine systems

- ***The TAC listing for PEDE should be clarified and revised to reflect these anticipated advancements and to exclude NTDE***

Next Steps?