Fuels and Emissions: Lessons Learned in the U.S.

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Outline

- Air Quality Concerns in the U.S.
- Emissions from Fuels: What we Learned from Emissions Testing
- Fuel Quality Enabling Emissions Control
- Overview of U.S. Fuel Programs
- Conclusions

Air Quality Concerns in the U.S.

Why are we concerned about emissions from motor vehicles?

Air Quality Concerns in the U.S.

- Congress established National Ambient Air Quality Standards (NAAQS) for Pb, SO2, NO2, CO, O3 and PM
- EPA recently revised the standards for Ozone and PM
- Toxics reductions for cars/trucks required since the mid ‘90s

Air Quality Standards in the U.S.

- The NAAQS Standards are:
  - Lead 1.5 mg/M3
  - CO 35 ppm 1 Hr.; 9 ppm 8 Hr.
  - SO2 0.03 ppm Yr.; 0.14 ppm Day; 0.50 1Hr
  - NO2 0.053 ppm Yr
  - Ozone 0.08 ppm 3 Yr. Avg. of 4th Highest 8 Hr.; was 0.12 ppm 1 Hr.
  - PM2.5 15 ug/M3 Yr.; 65 ug/M3 Day
  - PM10 50 ug/M3 Yr.; 150 ug/M3 Day

Air Quality Standards in the U.S.

- NO2 is no longer a health concern
- Pb is not a transportation issue
- SO2 is a secondary pollutant issue
- CO 15 counties still exceed the std.
- O3 26 areas do not or would not meet the 1 hr std.
- PM 15 areas violate the PM 10 std.

Emission Impacts of Fuels

How does changing fuel quality affect emissions of pollutants, or enable emissions control?

Emission Impacts of Fuels

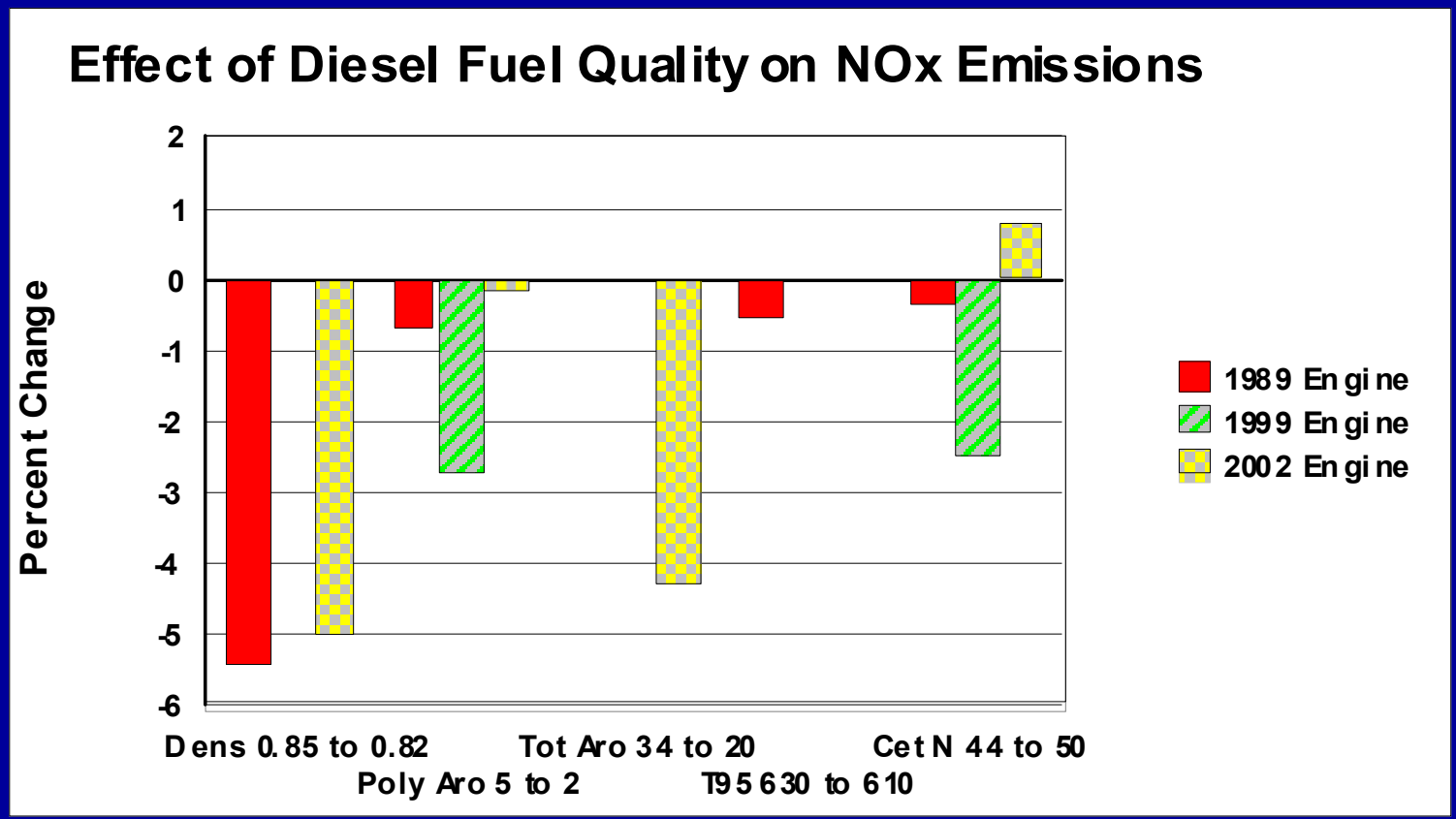
- Both Diesel and Gasoline powered engines have been tested with varying fuel quality.
- The testing has shown how fuel quality affects emissions of HCs, NOx and PM emissions.

Emission Impacts of Fuels

- Fuel quality in diesel engines presented for three different engines:
- 1989 w/Mechanical fuel injection (SAE961074)
- 1999 w/Electronic fuel injection (SAE950251)
- 2002 w/Electronic FI and Cooled EGR (HDEWG http://transaq.ce.gatech.edu/epatac/heavy/heavy.htm)
- All are without aftertreatment, with moderate/high pressure fuel injection.

Emission Impacts of Fuels

Emission Impacts of Fuels



Emission Impacts of Fuels

- Sulfur, Aromatics, T-95 and cetane have been shown to impact PM emissions.
- Density, poly and total aromatics, and cetane number have been shown to impact NOx emissions.
- The emissions effects of changes to each of these fuel qualities are generally between zero and 10%.

Emission Impacts of Fuels

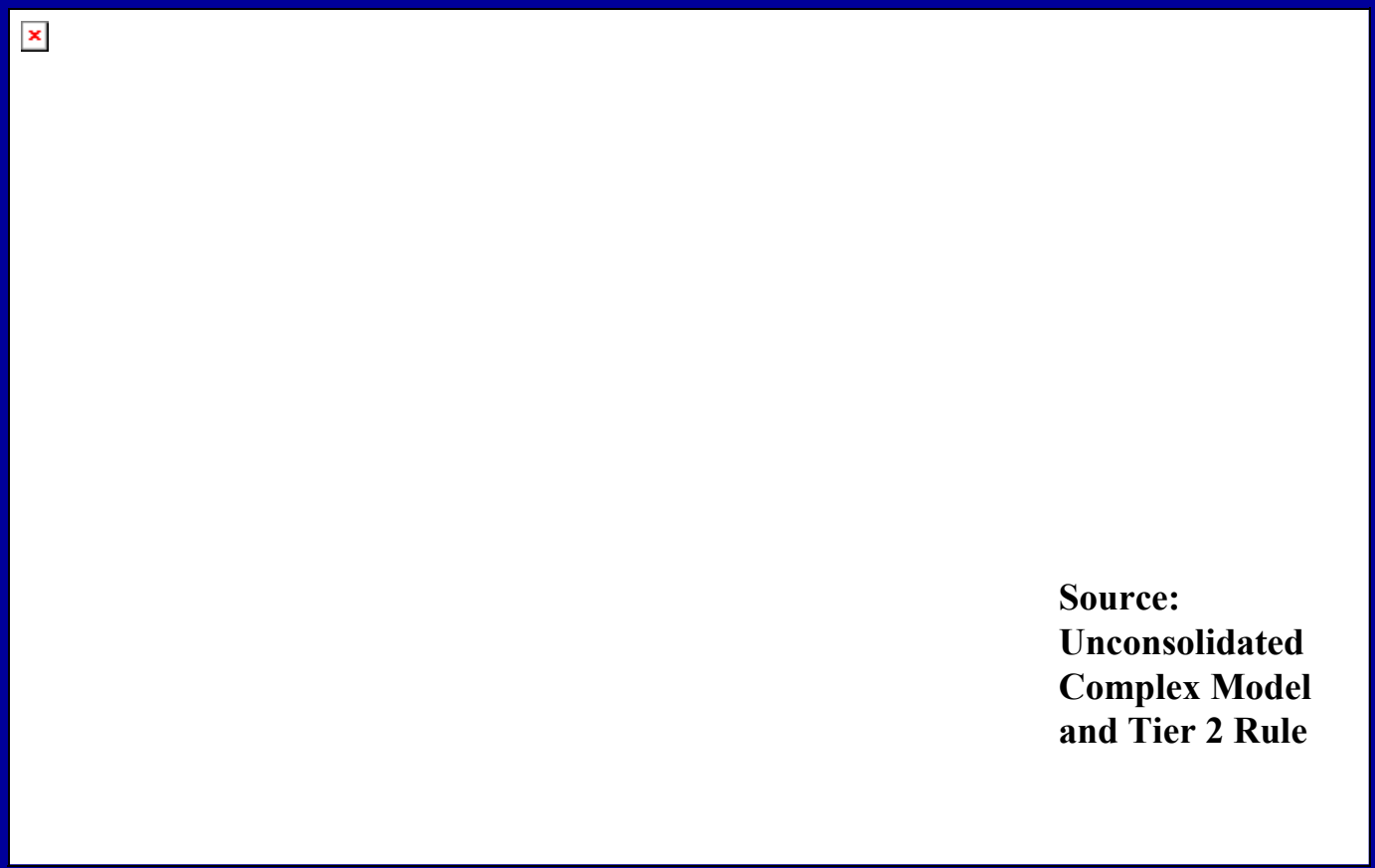
- EPA is evaluating the impact of diesel fuel quality on emissions through a literature search.
- This review is expected to be completed in the next few months.
- The results of the study will be posted on the Web:
- http://www.epa.gov/otaq/models/analysis.htm

Emission Impacts of Fuels

- Significant testing program of 1990 gasoline vehicles was made for the RFG program.
- Vehicles were either FI or Carbureted equipped with catalysts.
- Also, testing of high emitters.
- Testing was later completed on NLEVs.

Emission Impacts of Fuels

Emission Impacts of Fuels



Source:
Unconsolidated Complex Model and Tier 2 Rule

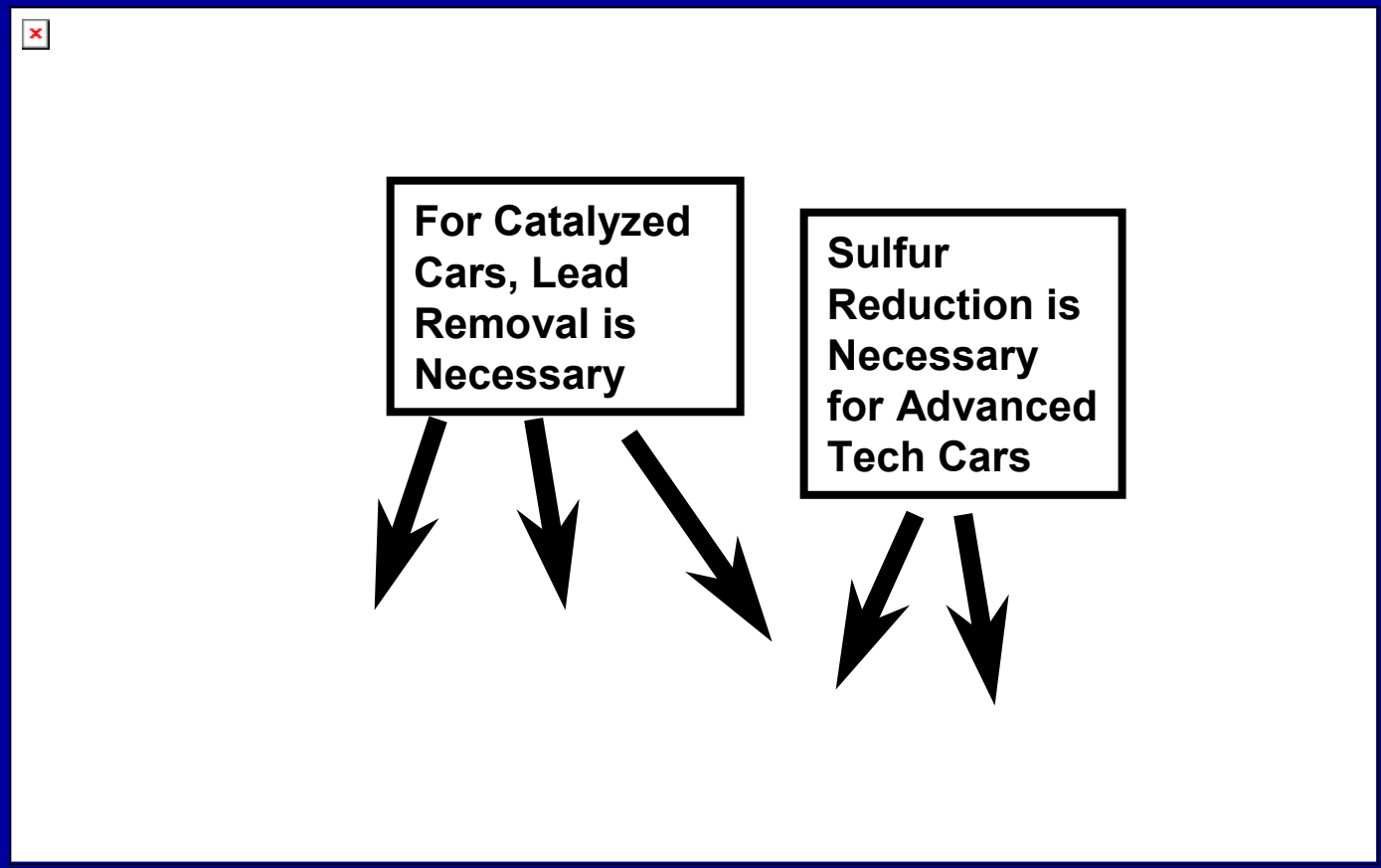
Emission Impacts of Fuels

- Because gasoline powered cars in the U.S. use catalysts, sulfur is important in reducing emissions.
- RVP control is important for evap emissions from nonregulated cars and from high emitters.
- Other fuel qualities are less important.

Enabling Emissions Control

- For emissions control of both diesel fuel and gasoline-powered vehicles, enabling emissions control hardware with improved fuel is crucial.
- Examples:
  - Lead phase-down,
  - Sulfur control of gasoline and diesel fuel,
  - Improved engine oil formulations, and
  - Fuel additives.

Enabling Emissions Control
Gasoline Cars and Trucks



Enabling Emissions Control
Gasoline Cars and Trucks

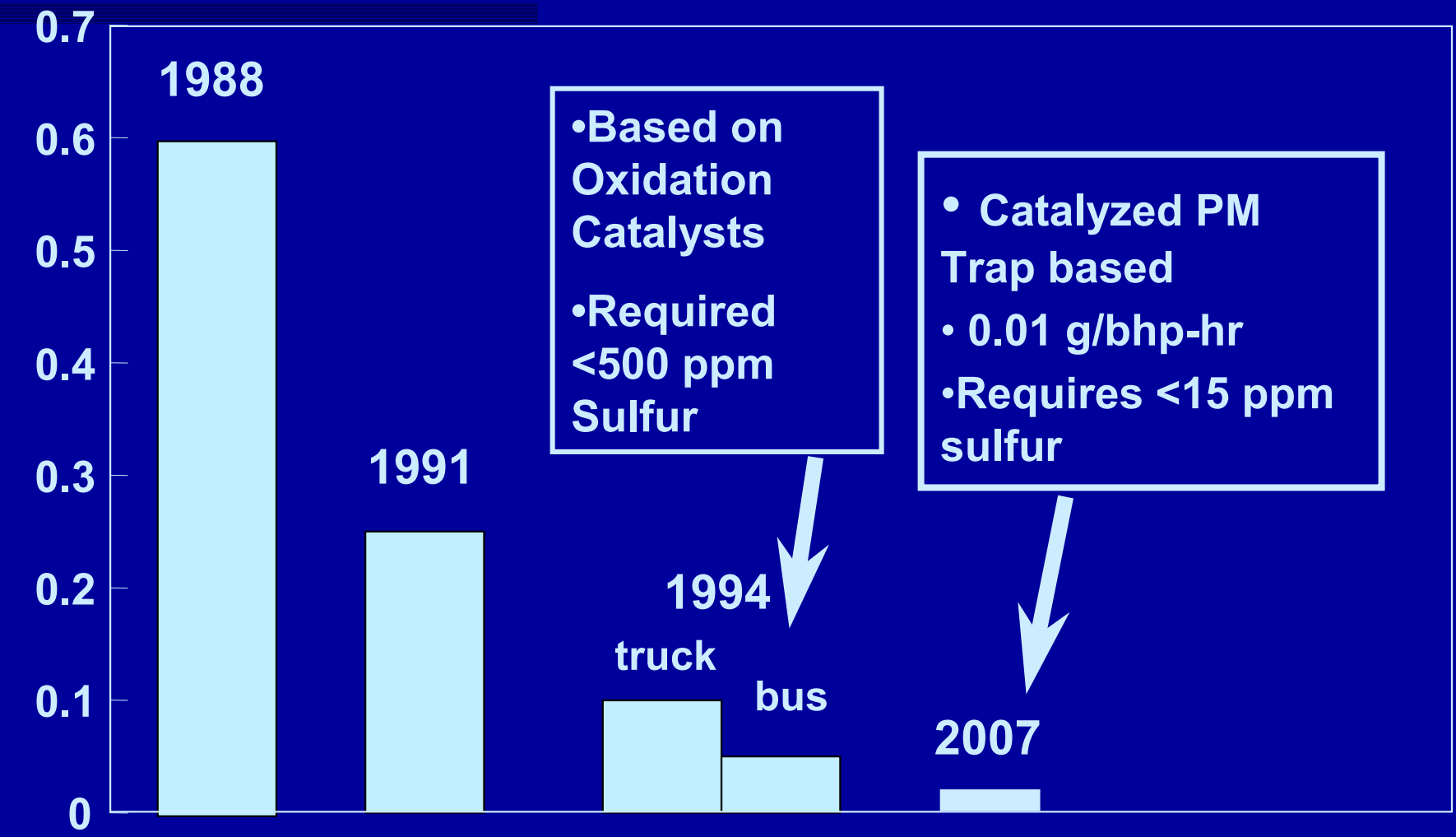
- Phase-down of Lead was necessary to allow the use of catalysts, also it improved spark plug life.
- Lead cannot be added to gasoline and it must be <0.05 g/gal.
- Potential damage to soft valve seats in older cars did not materialize, so phase-in is not necessary.

Enabling Emissions Control
Gasoline Cars and Trucks

- Sulfur reduction allows catalysts and O2 sensors to operate efficiently.
- Lower sulfur is helpful with lower tech engines and is necessary with higher tech engines.
- Lower sulfur reduces NOx, HC and CO emissions.

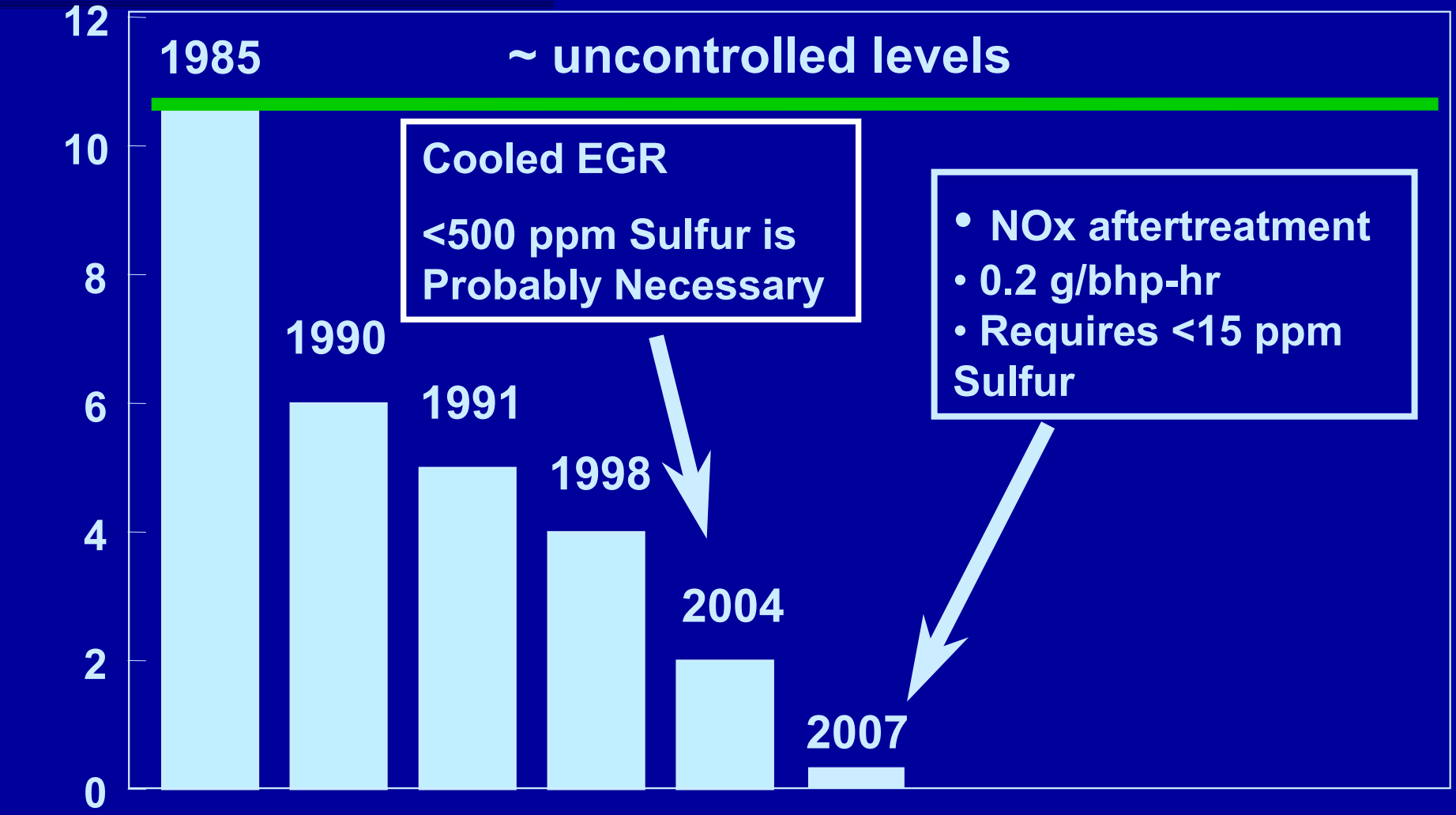
Enabling Emissions Control

g/hp-hr PM Standards for Diesel Engines



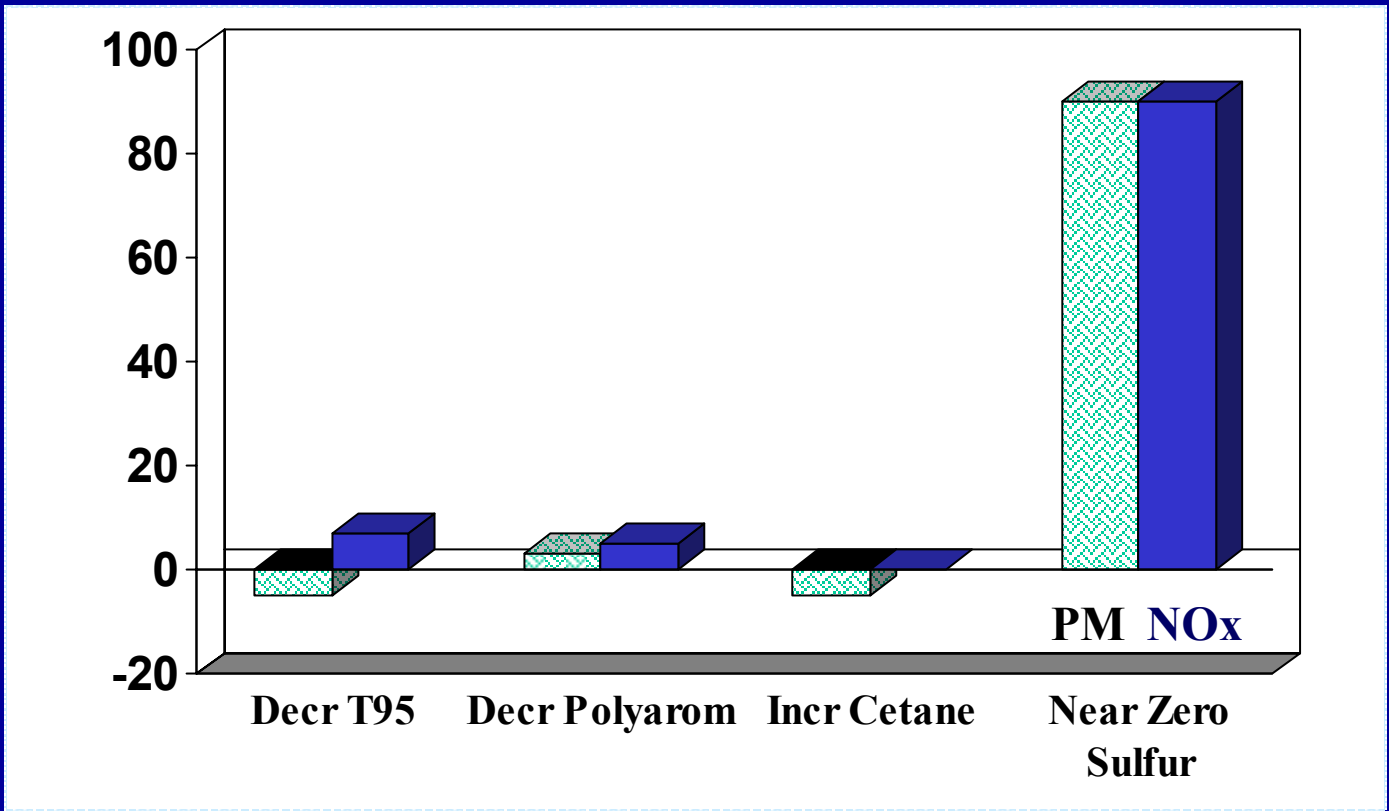
Enabling Emissions Control

g/hp-hr NOx Standards for Diesel Engines



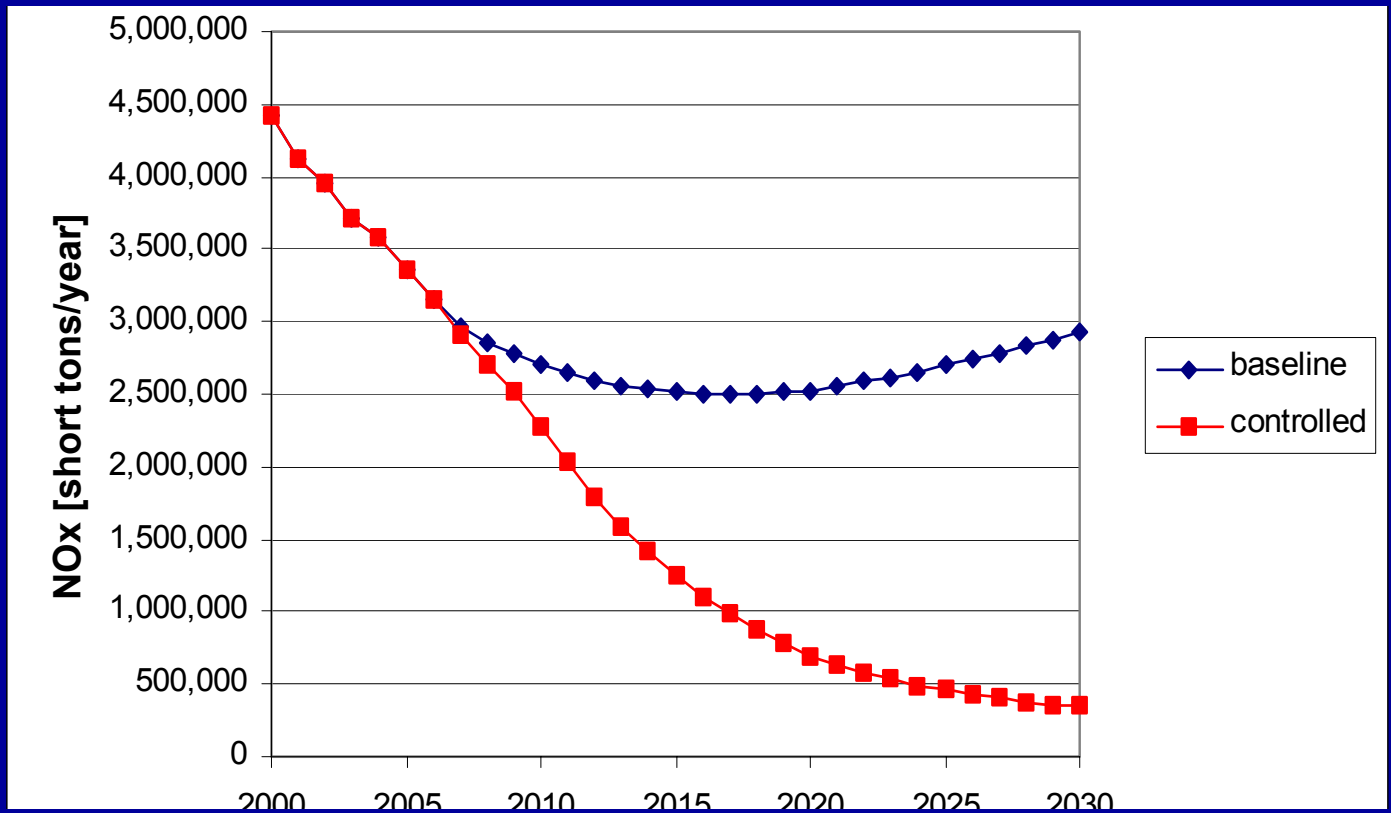
Enabling Emissions Control

Diesel Quality Impacts on Emissions from 2007 Engines



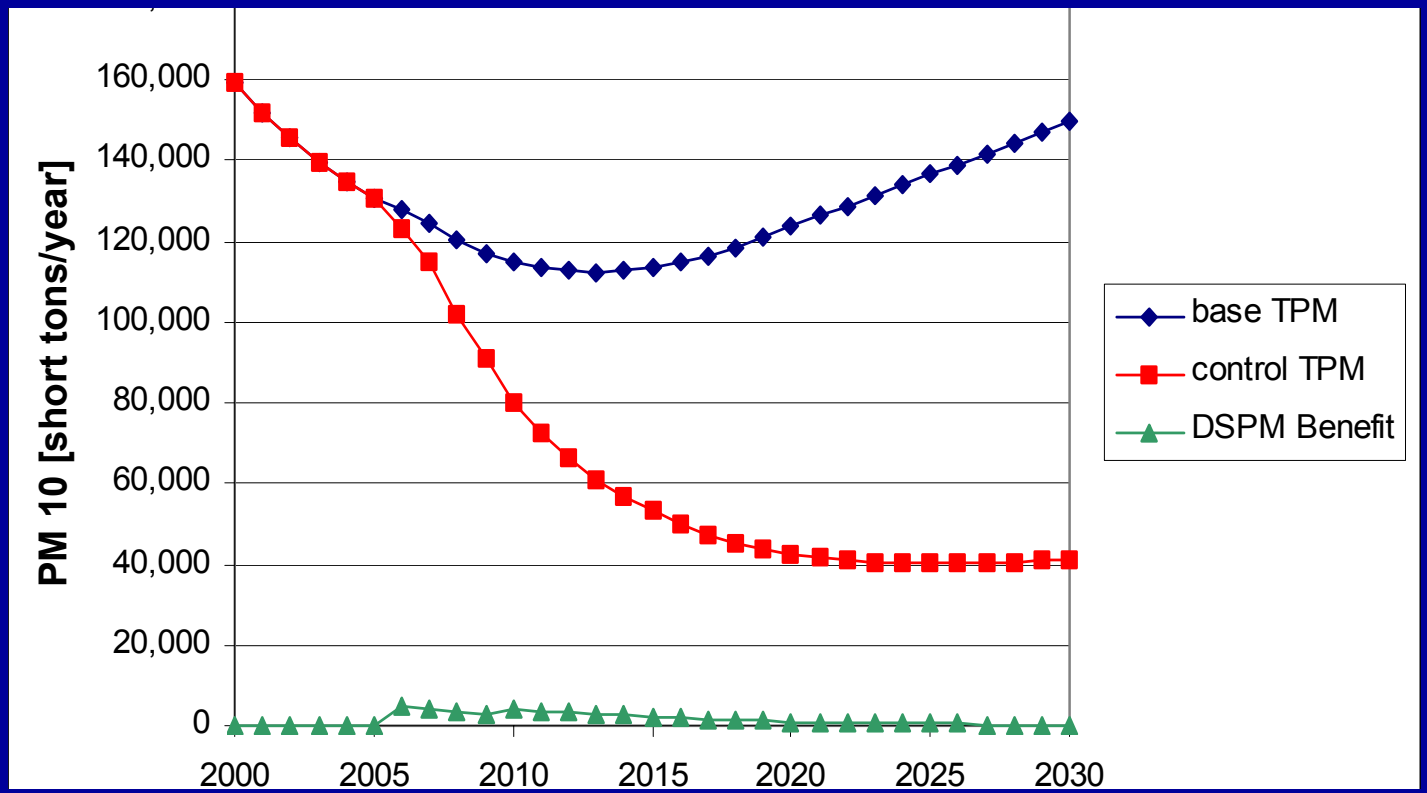
Enabling Emissions Control

NOx Emissions



Enabling Emissions Control

PM Emissions



Enabling Emissions Control
Lower Sulfur and Lower Emissions

- Sulfur reduction helps to enable cooled EGR for NOx control.
- Deep sulfur reduction is necessary for advanced aftertreatment to reduce PM and NOx.
  - To function as designed.
  - To avoid significant sulfate production.

Enabling Emissions Control
Other Benefits from Sulfur Control

- Sulfur reduction reduces SO2 emissions.
  - Less sulfate formation in the atmosphere (about 1/3 of SO2 reacts to sulfate)
  - Reduced acid rain.
- Sulfur reduction reduces engine wear.
  - Reduction from 2500 ppm to 500 ppm reduces engine wear 10 - 20%; about 33% if starting out at 5000 ppm.
  - Greater engine wear with infrequent oil change.

Enabling Emissions Control
Oil Additives

- Small amount of engine oil is combusted along with the fuel.
- Phosphorus (ZDDP) is added to engine oil to reduce engine and valve wear.
- Phosphorus coats catalysts causing conversion efficiency to decline.
- Problem is addressed by reducing P in oil and by limiting oil consumption. P in gasoline is capped at 0.005 g/gal.

Enabling Emissions Control
Silicone

- Silicone also adversely affects catalyst performance
- Silicone can come from a number of sources:
  - Gasoline blending of contaminated toluene
  - Gasket sealants
  - O2 sensor parts
  - Refnery coker antifouling agent

Enabling Emissions Control
Fuel Additives

- Poor fuel quality contributes to compromised carburetor/fuel injector performance and deposit formation on intake valves and in combustion chambers.
- Sulfur, olefins, T-90, aromatics and oxygenates are associated with deposit formation.

Enabling Emissions Control
Fuel Additives

- Carbureted cars experienced:
  - 15% reduction in HC emissions,
  - 10% reduction in CO emissions, and
  - 16% reduction in NOx emissions, with deposit control additives in the fuel.
- FI cars with FID/IVD experienced:
  - 3% - 228% increase in HC emissions,
  - 1% - 668% increase in CO emissions, and
  - 42% to 169% increase in NOx emissions.

Enabling Emissions Control
Fuel Stability/Quality and Deposits

- For gasoline, EPA adopted vehicle tests to set the amount of fuel additives necessary to minimize fuel injector and intake valve deposits.
  - ASTM D5598-95 and D5500-94
- Industry has established:
  - Existent gum limits (ASTM D381),
  - Oxidation stability minimum (ASTM D525),
  - Corrosion limits (ASTM D130).

Enabling Emissions Control
Fuel Stability/Quality and Deposits

- Diesel fuel must not exceed water and sediment standards (D1796), an ash standard (D482), a carbon residue standard (D524), and a cloudpoint standard (D2500). (See ASTM D975 for a summary)
- These industry fuel standards also help the engine to meet emissions standards.

U.S. Fuels Programs

What have we done?

U.S. Fuels Programs

- Summaries
  - Lead Phase-out
  - RVP control
  - Diesel sulfur cap of 500 ppm
  - RFG
  - Tier 2
  - Diesel sulfur cap of 15 ppm

U.S. Fuels Programs
Lead Phase-out

- Program phase-in began 1975 with new cars/light trucks using special nozzles.
- Phase-in was declared complete in 1995.
- Tetra-ethyl lead is replaced by reformate (aromatics), alkylate, isomerate, and oxygenates.

U.S. Fuels Programs
RVP Control

- RVP (volatility) control went into effect starting in the summer of 1989 and the phase-in was completed in 1992.
- 1992 requirements were basically 7.8 PSI for certain cities in the South, and 9.0 PSI everywhere else.
- Program is essentially butane removal.
- Cost was estimated to be 0.5 c/gal.

U.S. Fuels Programs
500 ppm Highway Diesel Sulfur Cap

- 500 ppm cap standard went into effect late 1993, also aromatics <35 Vol% or cetane index >40.
- Requirement was met using fixed bed hydrotreating of distillate blendstocks.
- Desulfurization severity does not address sterically hindered compounds.
- Estimated cost is 4 - 5c/gal.

U.S. Fuels Programs
Reformulated Gasoline

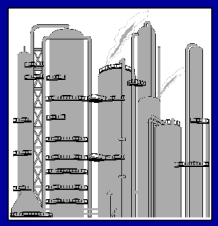
- Went into effect in 1995 and 2000
- '95 - '99 reductions from 1990 gasoline were 15% VOC and 15% Toxics
- Year 2000+ reductions from 1990 gasoline were 29% VOC, 21% Toxics and 7% NOx.
- Link between emissions and fuel is made with the Complex Model.
- Estimated cost was 5 c/gal.

U.S. Fuels Programs
Reformulated Gasoline

- Program is very sophisticated (complicated) to provide flexibility to refiners.
- The program is basically:
  - Summer RVP control down to 7 to 6.5
  - Sulfur control to 130 ppm
  - Benzene control to 0.7 volume percent
  - Oxygen standard not critical to program goals.

U.S. Fuels Programs
Tier 2 Sulfur Control

- Reduces average gasoline sulfur levels nationwide to 30 ppm avg/80 ppm cap.
- Lower sulfur levels would enable lean burn technology to improve fuel economy.
- Includes a phase-in schedule and special provisions for small refiners.



U.S. Fuels Programs
Tier 2 Sulfur Control

Gasoline Sulfur Standards for Refiners, Importers, and Individual Refineries
(Excluding Small Refiners and GPA Gasoline)

Compliance as of:	**2004**	**2005**	**2006+**
Refinery Average, ppm	--	30	30
Corporate Pool Average, ppm	120	90	--
Per-Gallon Cap, ppm	300	300	80

- Effective January 1, 2004 at the refinery gate.
- Cap exceedances up to 50 ppm are allowed in 2004 but must be made up in 2005.

U.S. Fuels Programs
Tier 2 Sulfur Control

- Desulfurizing gasoline is expected to cost about 2 c/gal for a typical refinery.
- Estimated capital cost is $4.5 billion.
- Technology expected to be used includes: fixed bed reactors with caustic extraction, catalytic distillation and adsorption.

U.S. Fuels Programs
15 ppm Highway Diesel Sulfur Cap

- A 15 ppm cap on highway diesel fuel sulfur to enable a 90% reduction in PM and NOx emissions.
- Standard takes effect June 1, 2006 at refineries and Sept. 1, 2006 at retail.
- A temporary compliance option allows up to 20% production of 500 ppm highway diesel fuel until May 31, 2010.

U.S. Fuels Programs
15 ppm Highway Diesel Sulfur Cap

- Meeting the 15 ppm cap standard is estimated to cost 5 c/gal for desulfurization, additizing and distributing the new diesel fuel.
- Estimated capital cost is $5.5 billion.
- Technology expected to be used: revamps using aromatic hydrogenation; also adsorption & oxidation/extraction.

Conclusions

- Fuel quality impacts on emissions are minor to moderate.
- The largest impact occurs when fuel quality is modified to enable engine and aftertreatment function:
  - Gasoline lead phase-out enables catalysts,
  - Severe sulfur reduction enables Tier 2 and highway diesel aftertreatment,
  - Deposit additives can have significant impacts.