Topic Paper #28

Criteria Air Pollutants

On August 1, 2012, The National Petroleum Council (NPC) in approving its report, *Advancing Technology for America's Transportation Future*, also approved the making available of certain materials used in the study process, including detailed, specific subject matter papers prepared or used by the study's Task Groups and/or Subgroups. These Topic Papers were working documents that were part of the analyses that led to development of the summary results presented in the report's Executive Summary and Chapters.

These Topic Papers represent the views and conclusions of the authors. The National Petroleum Council has not endorsed or approved the statements and conclusions contained in these documents, but approved the publication of these materials as part of the study process.

The NPC believes that these papers will be of interest to the readers of the report and will help them better understand the results. These materials are being made available in the interest of transparency.

National Petroleum Council

Future Transportation Fuels Study

Topic Paper

Criteria Air Pollutants Considerations

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Overview

The EPA has identified six criteria air pollutants (CAPs) that present a risk to the environment and human health. The Clean Air Act sets the National Ambient Air Quality Standards (NAAQS) for criteria air pollutants including carbon monoxide (CO), lead (Pb), nitrogen oxides (NO_2), particulate matter (PM_{10}: particles smaller than 10 micrometers in diameter and $PM_{2.5}$: particles smaller than 2.5 micrometers in diameter), ozone (O_3) and sulfur dioxide (SO_2). On-road vehicles, marine engines, rail locomotives and aircraft are sources of CAP emissions that affect air quality and impact human health.[1] Transportation is also a significant contributor to volatile organic compound (VOC) emissions, which is not classified as a CAP but reacts with NO_2 to produce ozone. [2]

Table 1: Criteria Air Pollutants

Pollutant	Contribution from Transportation	Regulation
Carbon Monoxide (CO)	Nationally and, particularly in urban areas, the majority of CO emissions come from transportation.[3]	Exhaust emissions are regulated under EPA Tier 2; the Clean Air Act requires winter oxygenated gasoline in CO nonattainment areas where mobile sources are a significant source of CO emissions. [4]
Lead	The switch to unleaded gasoline has reduced lead emissions from transportation by 95%.[5]	Amendments to the Clean Air Act banned lead from gasoline.[6]

[1] While CAP emissions can have environmental impacts such as acid rain, the reduction of agricultural crop yields, forest decline and restricting natural visibility, this analysis will focus primarily on human health effects.

[2] Nitrogen dioxide (NO_2) is one of a group of highly reactive gasses known as oxides of nitrogen or nitrogen oxides (NO_x). Other nitrogen oxides include nitrous acid and nitric acid. While the EPA's National Air Quality Standard covers the entire group of NO_x, NO_2 is the component of greatest interest and the indicator for the larger group of nitrogen oxides. See "Nitrogen Dioxide Information Page," U.S. Environmental Protection Agency, last updated May 25, 2012, http://www.epa.gov/air/nitrogenoxides/.

[3] "Carbon Monoxide Information Page," U.S. Environmental Protection Agency, last updated April 19, 2012, http://www.epa.gov/airquality/carbonmonoxide/.

[4] "Automobiles and Carbon Monoxide," U.S. Environmental Protection Agency, Office of Mobile Sources, report no. EPA 400-F-92-005, Fact Sheet OMS-3, January 1993, http://www.epa.gov/otaq/consumer/03-co.pdf.

[5] "Lead in Air," U.S. Environmental Protection Agency, last updated April 12, 2012, http://www.epa.gov/air/lead/.

[6] Tristan Fowler, "A Brief History of Lead Regulation," Science Progress, the Center for American Progress, October 28, 2008, http://scienceprogress.org/2008/10/a-brief-history-of-lead-regulation/.

Pollutant	Contribution from Transportation	Regulation
Nitrogen Oxides (NO_x)	Emissions occur throughout the fuel cycle. NO_2 is formed from emissions from vehicles, power plants and off-road equipment.	Exhaust emissions are regulated under EPA Tier 2.
Particulate Matter (PM)	Urban PM emissions are dominated by vehicle operation. Diesel engines are the main source of $PM_{2.5}$ emissions.	Exhaust emissions are regulated under EPA Tier 2 for LDVs and under EPA emissions standards for HDVs and non-road engines.
Ozone (O_3)	Ground-level ozone is created by chemical reactions between NOx and volatile organic compounds (VOCs) in the presence of sunlight. On-road and off-road vehicles are contributors to VOC emissions.	EPA Tier 2 regulates vehicle emissions for NOx and VOCs (as non-methane organic gases) and EPA also regulates evaporative emissions. [7]
Sulfur Dioxide (SO_2)	Most SO_x emissions are generated in the fuel production and upstream feedstock stages of the fuel lifecycle.	EPA Tier 2 defines restrictions for the amount of sulfur content allowed in gasoline and diesel fuel.

Because population exposure can be an important factor in assessing the health effects of criteria pollutants, a distinction should be made between total emissions and urban emissions. Total emissions refer to those occurring everywhere within a set geographic area while urban emissions are a subset of the total that occur within designated urban areas.

The primary CAPs of concern associated with transportation are ozone and particulate matter.[8] Figure 1 illustrates the counties designated as non-attainment for ozone and PM standards. Almost 40% of the population lives in areas where 8-hour ozone EPA NAAQS is not attained such as California and metropolitan and industrial centers in the Northeast, Texas and the Great Lakes.

[7] The volatility (Reid Vapor Pressure or RVP) of gasoline is regulated during the summer ozone season. Reformulated Gasoline (RFG) is mandated in urban areas with high ozone levels. See "Fuels and Fuel Additives: Gasoline," U.S Environmental Protection Agency, last updated November 11, 2011, http://www.epa.gov/otaq/fuels/gasolinefuels/index.htm.

[8] Lead, CO, SO_x exposure levels are within NAAQS levels. See "Our Nation's Air – Status and Trends through 2010," U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, Research Triangle Park, North Carolina, report no. EPA-454/R-12-001, February 2012, available at http://www.epa.gov/airtrends/2011/.

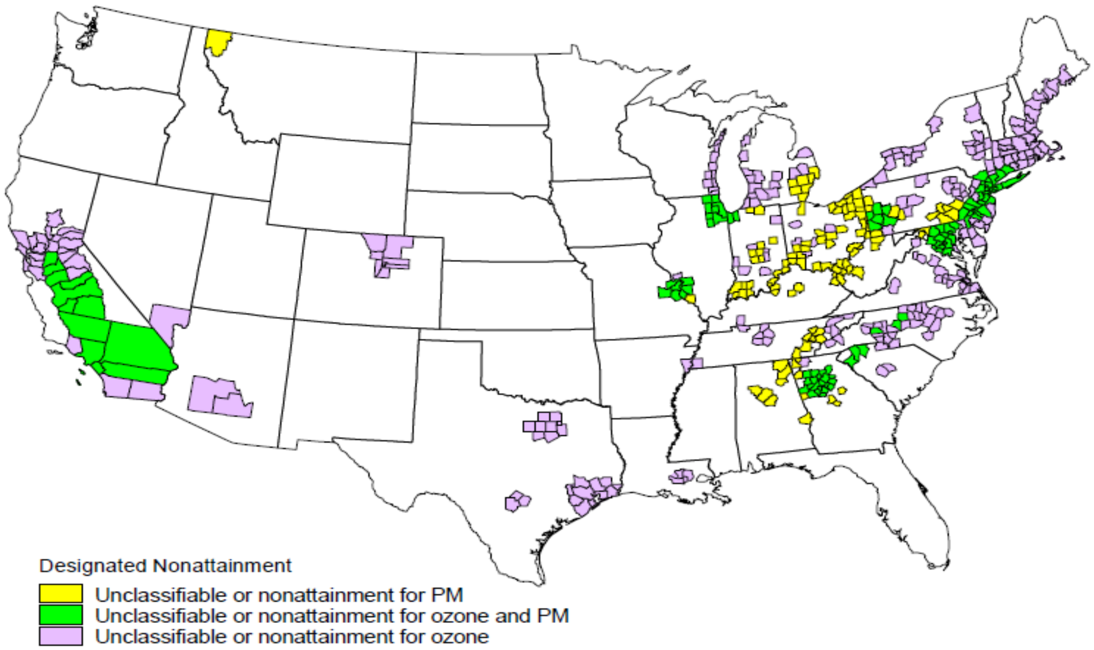


Figure 1 – U.S. Counties Designated as Non-Attainment for Ozone and PM Standards[9]

Criteria Air Pollutants in the Fuel Life Cycle

Criteria air pollutant emissions are dependent on the fuel/vehicle system. CAPs are emitted in the entire fuel cycle from resource extraction through fuel production, storage, distribution, dispensing and vehicle operation. The well-to-wheel (WTW) CAP emissions of vehicle/fuel systems differ significantly in terms of amounts, the fuel type under consideration and method of production. The analysis of emissions over the entire fuel cycle for various vehicle and fuel pathway combinations is a complex process dependent on assumptions about fuel and vehicle technologies, processes and the selection of analysis boundaries. In addition to possible differences in methodology, each of the inputs may have some variability or uncertainty. For example, tailpipe emissions are dependent on the performance of on-board diagnostic systems and vehicle maintenance.

The Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) model includes uncertainty analysis to assess the impact of input variability. Although GREET can calculate urban and total emissions for each of the criteria pollutants, it should be noted that comparing health and environmental impacts requires more than a comparison of the emission numbers. For example, different VOCs have different ozone forming potential and different constituents of particulate matter can have differing health effects. To more accurately assess the impact on population exposure to pollutants would require more detailed geographic modeling of emission locations and atmospheric

[9] U.S. Environmental Protection Agency, "Air Quality Nonattainment Designations," last updated April 20, 2012, http://www.epa.gov/oaqps001/urbanair/designations.html.

transport. Comprehensive studies on criteria air pollutant emissions over the full fuel cycle for a variety of fuel and on-road vehicle combinations include Brinkman et al (2005) and numerous papers by Argonne National Laboratories.[10]

Reducing Transportation's Impact on Air Quality

Numerous regulatory, technological and voluntary mechanisms have been introduced to reduce criteria air pollutants emissions from the transportation sector[11]:

1. The passage of the Clean Air Act in 1970 and the formation of the EPA enabled the regulation of motor vehicle pollution.

Many improvements including catalytic converters, exhaust gas recirculation, the introduction of unleaded gasoline and improved fuel economy standards were introduced in the 1970s. Leaded gasoline was phased out, limits were set on VOCs, the sulphur content was reduced in gasoline and diesel and numerous emissions limits and standards were established in the 1980s and 1990s. Since then, the sulfur content of on-road diesel fuel has been further reduced.

NO_2 concentrations have decreased by over 40% and are expected to decline further as a result of the Tier 2 standards for light duty vehicles and new NO_x standards for heavy-duty engines.[12] EPA fuel and vehicle standards such as the Tier 2 Vehicle and Gasoline Sulfur Program have been effective in reducing CAP emissions from vehicle operations. These stronger standards have been responsible for substantial reductions in total vehicle CAP emissions as illustrated in Figure 2.[13]

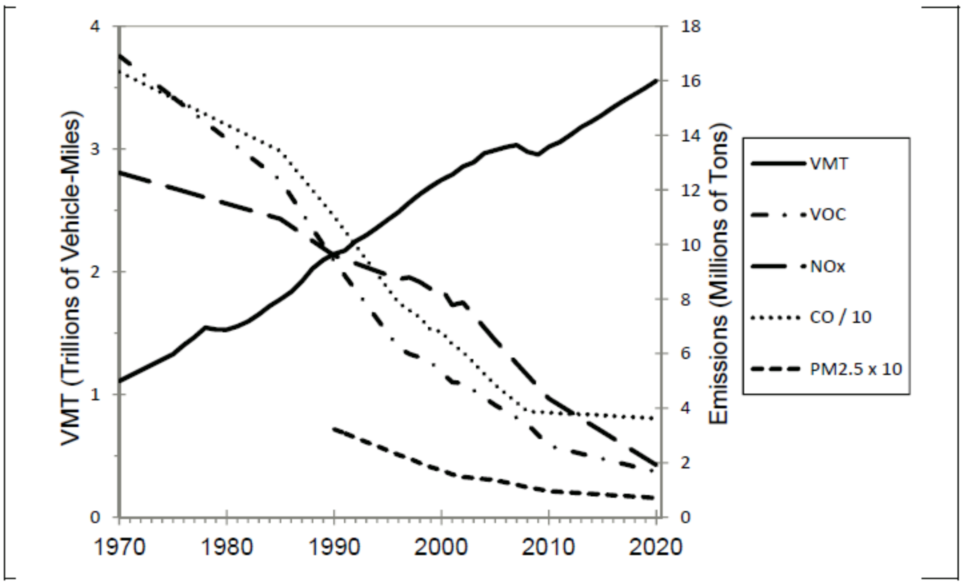
[10] Norman Brinkman et al., "Well-to-Wheels Analysis of Advanced Fuel/Vehicle Systems – A North American Study of Energy Use, Greenhouse Gas Emissions, and Criteria Pollutant Emissions," May 2005, available at http://www.transportation.anl.gov/pdfs/TA/339.pdf. Many of the ANL GREET-based technical publications addressing CAPs can be found on their website, see "Greet Publications Listing," Argonne National Laboratory, Transportation Technology R&D Center, last modified July 05, 2012, http://greet.es.anl.gov/publications.

[11] "Mobile Source Emissions – Past, Present, and Future – Milestones," U.S. Environmental Protection Agency, last updated January 03, 2012, http://www.epa.gov/otaq/invntory/overview/solutions/milestones.htm.

[12] "Nitrogen Dioxide – Basic Information," U.S. Environmental Protection Agency, last updated March 22, 2012, http://www.epa.gov/air/nitrogenoxides/basic.html.

[13] "Corporate Average Fuel Economy Standards Passenger Cars and Light Trucks Model Years 2017-2025 – Final Environmental Impact Statement," National Highway Traffic Safety Administration, docket no. NHTSA-2011-0056, July 2012, www.nhtsa.gov/staticfiles/rulemaking/pdf/cafe/FINAL_EIS.pdf.

Figure 4.1.1-1. Vehicle Miles Traveled Compared to Vehicle Emissions[a,b]



a. Sources: Davis et al. 2011, EPA 2011c, EIA 2011a, IEC 2011.
b. VMT = vehicle miles traveled; VOCs = volatile organic compounds; NO_x = nitrogen oxides; CO = carbon monoxide; $PM_{2.5}$ = particulate matter with a diameter of 2.5 microns or less.

Figure 2 - Reduction in Transportation CAP Emissions Despite Increased Vehicle Miles Traveled. Excerpted from the NHTSA Draft Environmental Impact Statement (November 2011) for the proposed 2017 CAFE standards.

The new fuel economy standards for light-duty vehicles announced in July 2011 should further reduce transportation CAP emissions beginning with the 2017 model year.[14,15] Tier 3 standards are under discussion to further reduce tailpipe and evaporative CAP emissions to address the ozone and PM air quality associated with light-duty vehicles.[16] As tailpipe emissions are reduced, upstream or well-to-tank (WTT) emissions provide an increasing share of total emissions, especially for fuels such as ethanol, FT diesel, electricity, hydrogen, gasoline and diesel.[17] EPA standards under development are expected to reduce CAP emissions in the upstream components of the fuel cycle. Emissions over the entire fuel life cycle are dependent on activities across jurisdictions that may have different emission control

[14] "President Obama Announces New Fuel Economy Standards," Colleen Curtis, The White House Blog (weblog), July 29, 2011, 11:20 AM EDT, http://www.whitehouse.gov/blog/2011/07/29/president-obama-announces-new-fuel-economy-standards. For more details refer to "CAFE – Fuel Economy," Laws and Regulations Description, National Highway Traffic Safety Administration, last updated July 9, 2012, at http://www.nhtsa.gov/fuel-economy.

[15] Improved fuel efficiency reduces the fuel required per mile and thus reduces the per mile emissions from the well-to-tank portion of the fuel cycle. The expected CAP reductions in 2040 due to these proposed standards are 6 – 15% for VOC, SO_x and $PM_{2.5}$ (and less than 2% for CO and NO_x) according to the NHTSA Draft Environmental Impact Statement for the proposed 2017-2025 CAFÉ standards. These CAP reductions are primarily upstream.

[16] EPA/NHTSA *2017 and Later Model Year Light-Duty Vehicle Greenhouse Gas Emissions and Corporate Average Fuel Economy Standards* (proposed), section III A.5

[17] Brinkman et al. (2005), page 8.

regulations for stationary sources. This includes standards/regulations affecting electricity generation and refineries, and for other modes of transportation such as off-road vehicles, rail, marine and air.

Comparing Criteria Air Pollutant Emissions from Alternate Fuel and Vehicle Pathways

An analysis was performed using GREET 1.8d to compare 2020 CAPs emissions of the fuel-vehicle systems in the study to a 2005 gasoline vehicle CAPs emissions on a per mile basis. 2020 was used as the basis of comparison because it is the most forward-looking data available in GREET 1.8d; however, fuel economies were adjusted to the study's forecasts for 2050. While urban VOC and urban NOx contribute most to ground-level ozone in populated areas, all of the fuel-vehicle systems are comparable to or lower than the 2005 gasoline vehicle baseline emissions as shown in Figure 3.

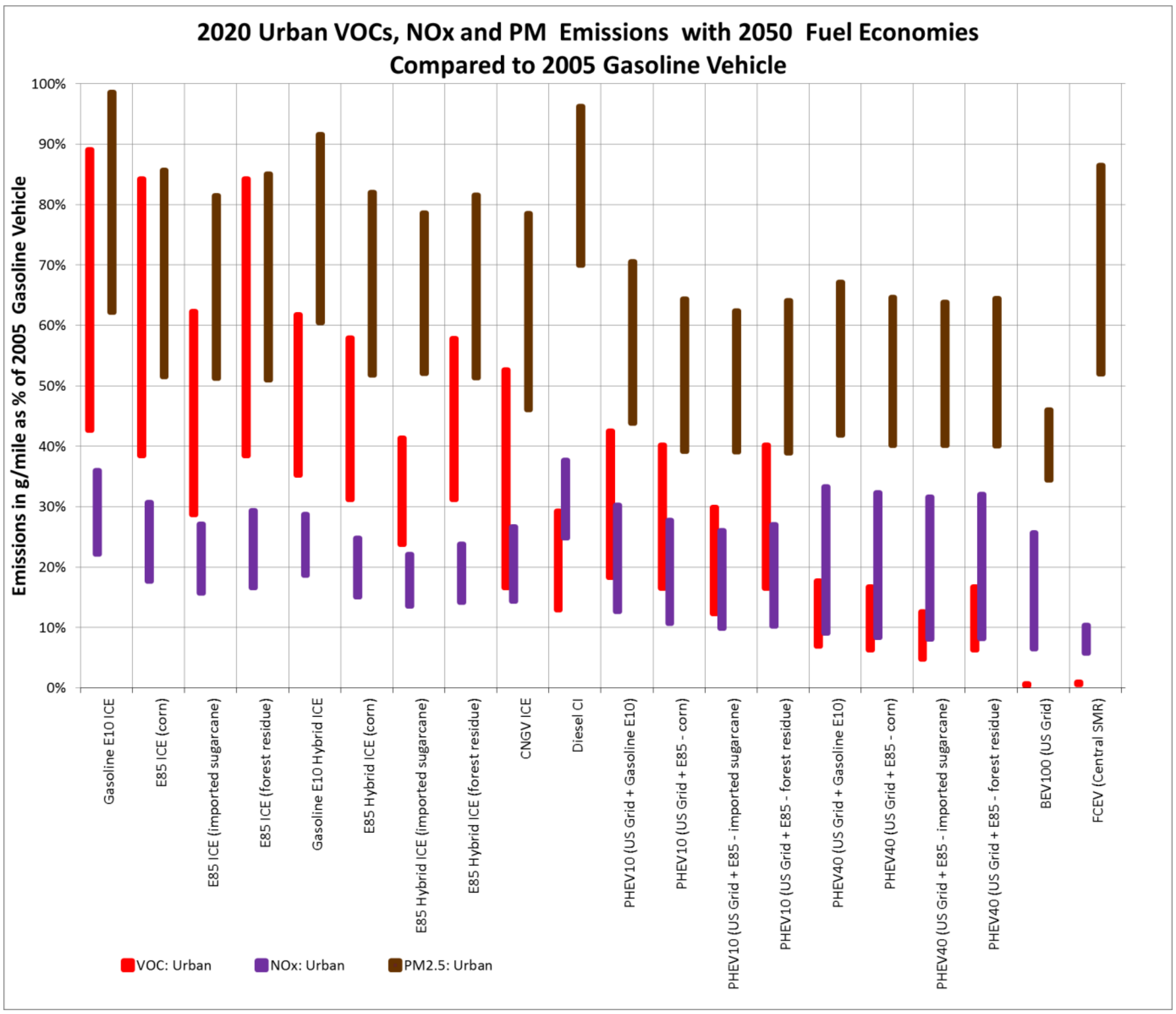


Figure 3 - 2020 Urban VOCs, NOx and PM Emissions Compared to a 2005 Gasoline Vehicle

Criteria Emissions Requirements in Medium-Duty and Heavy-Duty Vehicles

Environmental priorities for MD/HD vehicles have recently shifted from the reduction of CAP emissions to the reduction of CO_2 emissions and other trace gases such as methane and N_2O that have global warming potential. Typical diesel compression ignition (CI) engines produce relatively high emissions of NO_x and PM. Increasingly stringent criteria pollutant limits have resulted in product innovation, systematic changes to the design and operation of diesel engines, and corresponding reductions in vehicle criteria pollutant emissions. Figure 4 shows that both NO_x and PM emissions have been reduced by over 95% between 1988 and 2010.

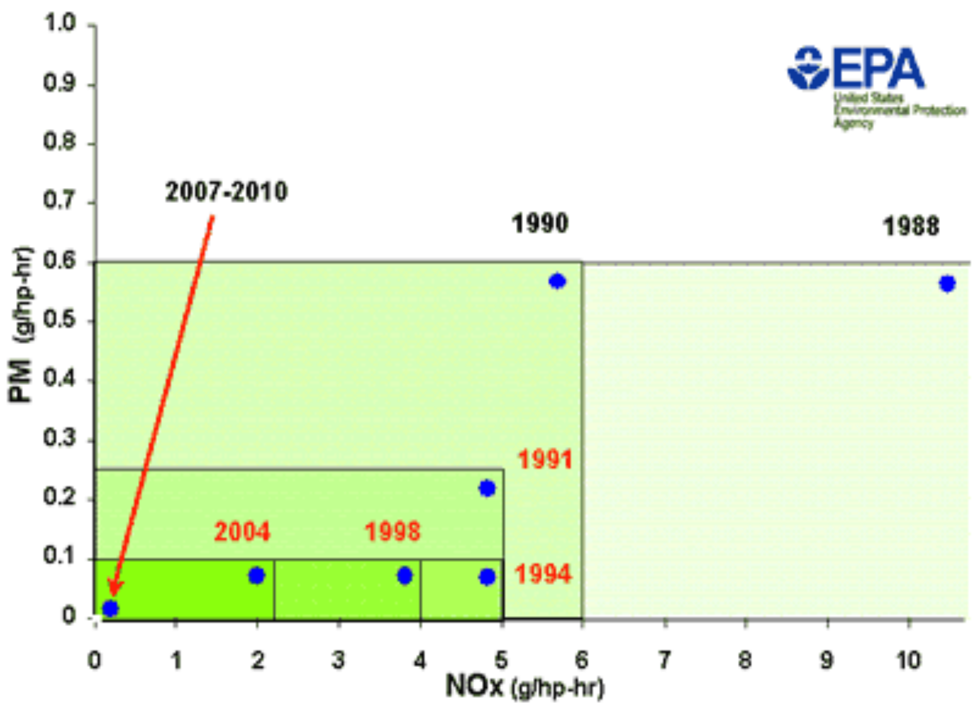


Figure 4 - Reduction in Heavy-Duty Allowable Tailpipe Emissions of Criteria Pollutants PM (vertical axis) and NOx (horizontal axis) over time

A consequence of adding criteria pollutant emissions reduction technologies has been reduced fuel efficiency. This reality has hindered improvements in MD/HD vehicle fuel economy. Figure 5 illustrates an engine's efficiency over time and demonstrates that engine efficiency decreased over the period of time when criteria pollutant emissions reduction requirements increased (2002-2010).

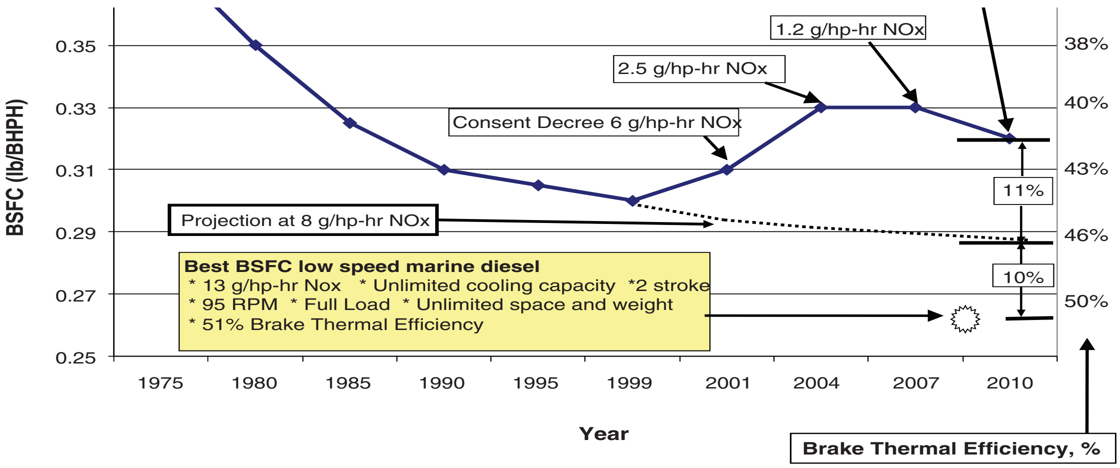


Figure 5 - Brake-Specific Fuel Consumption, an engine-specific measure of fuel use, shown over time for Heavy Duty Diesel Trucks, including the increase in recent years due to criteria emission requirements. Source: Anthony Greszler, Volvo Powertrain, 2009.

Future efforts to reduce greenhouse gas emissions will be linked to improvements to fuel economy. This approach is favored by fleet operators because fuel cost is typically among the top two cost components for MD/HD vehicle fleets, and fleet operators could achieve fuel cost savings as they comply with upcoming regulations.

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