# Quantifying the Effectiveness of Air Quality Mitigation Measures

*Requested by*
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*The Caltrans Division of Research and Innovation (DRI) receives and evaluates numerous research problem statements for funding every year. DRI conducts Preliminary Investigations on these problem statements to better scope and prioritize the proposed research in light of existing credible work on the topics nationally and internationally. Online and print sources for Preliminary Investigations include the National Cooperative Highway Research Program (NCHRP) and other Transportation Research Board (TRB) programs, the American Association of State Highway and Transportation Officials (AASHTO), the research and practices of other transportation agencies, and related academic and industry research. The views and conclusions in cited works, while generally peer reviewed or published by authoritative sources, may not be accepted without qualification by all experts in the field.*

## Executive Summary

### Background

Before Caltrans can deliver any transportation project, the potential air quality impacts from the operation of the project must be disclosed in its environmental document. If the air emissions are deemed significant or would contribute to a violation of one or more federal or state air quality standards, those air quality impacts would need to be mitigated.

Caltrans is interested in compiling mitigation measures—and a quantification of their effectiveness—for reducing the air quality impacts of emissions occurring during the operational phases of transportation projects. Emissions of interest include mobile source air toxics, criteria pollutants like nitrogen dioxide, carbon monoxide, sulfur dioxide, and lead (excluding greenhouse gases), and particulate matter from re-entrained road dust and automobile tire and brake wear.

### Summary of Findings

To gather information on this topic we conducted a survey of state departments of transportation (DOTs) and compiled relevant research citations and other resources. We organized our findings in the following sections:

- Research in Progress.
- Related Research.
    - Mobile Source Air Toxics.
    - Criteria Pollutants.
    - Nonexhaust Particulate Matter.
- National Guidance.
- Survey Results.

Following is a summary of our findings by section.

**Research in Progress**

- Contacts confirmed the paucity of research quantifying the benefits of emissions mitigation strategies for the operational phases of transportation projects. However, Robert O'Loughlin, chair of the TRB's Committee on Air Quality, noted that there is ongoing FHWA-sponsored research in Las Vegas and Detroit to monitor MSATs and criteria pollutants. See FHWA Near Road Study in the **Research in Progress** section.
- Texas is currently working on two projects relevant to this Preliminary Investigation—one to characterize exhaust emissions from heavy duty diesel vehicles, and the other to develop an optimization model capable of determining the most efficient assignment of emission reduction strategies among vehicles and equipment in a large fleet.

**Related Research**

Mobile Source Air Toxics

- The EPA estimates that fuel benzene standard and hydrocarbon standards for vehicles and gas cans would together reduce total emissions of mobile source air toxics (MSATs) by 350,000 tons in 2030, including by 65,000 tons of benzene.
- A 2010 study (Second-by-Second Characterization of Cold-Start Gas-Phase and Air Toxic Emissions from a Light-Duty Vehicle) indicates that extended idling after cold starts prolongs elevated concentrations of MSAT emissions, suggesting that recent policy efforts to reduce vehicle idling behavior could limit potential human exposure to the toxic exhaust constituents.

Criteria Pollutants

- Two studies note significant emissions reductions in Beijing after measures adopted in advance of the Olympics.
- Several studies document a reduction in nitrogen oxide emissions in diesel engines using various control devices, including selective catalytic reduction systems.
- Several studies show biodiesel to have mixed results for nitrogen oxide emissions, while reducing carbon monoxide, particulate matter and hydrocarbon emissions. However, the ultra-low sulfur fuel TxLED and the TxDOT emulsified diesel fuel PuriNOx both seem to be effective for reducing nitrogen oxide emissions.
- An application of an emissions model to Atlanta suggests that its vehicle inspection and maintenance program reduced carbon monoxide, hydrocarbon and nitrogen oxide emission rates by 25.87 percent, 79.12 percent and 11.32 percent, respectively, in 2001; another study estimates that the California smog check program reduced hydrocarbon, carbon monoxide and nitrogen oxide emissions by 26 percent, 34 percent and 14 percent, respectively, in 1999.
- One study quantified and compared the nitrogen oxide emissions of hybrid and nonhybrid New York City buses using a chase vehicle, showing that hybrid vehicles had half the nitrogen oxide emissions of compressed natural gas and diesel vehicles.
- Other studies quantify emissions reductions from idle reduction, managed lanes, vehicle retirement and traffic flow improvement.

Nonexhaust Particulate Matter

- Several studies examine mitigation measures for nonexhaust particulate matter; one study showed that an asphalt rubber friction course overlay can reduce tire wear emissions by up to 50 percent.

**National Guidance**

- National Guidance includes Environmental Protection Agency (EPA) resources on modeling as well as a number of relevant NCHRP studies, including Quantifying Air-Quality and Other Benefits and Costs of Transportation Control Measures, that present potential improvements to the analytical framework for assessing the air quality and other benefits and costs of transportation air quality control strategies.

**Survey Results**

- We distributed a survey to members of the AASHTO Research Advisory Committee for completion by appropriate staff at their agencies. Staff at 17 state DOTs and in British Columbia responded to this survey. With the exception of Texas, none of the agencies had done research on reducing the air quality impacts of emissions during the operational phases of transportation projects. However, Texas provided links to several studies that have been incorporated into the **Related Research** section of this Preliminary Investigation.

## Gaps in Findings

There seems to be little research dealing specifically with quantifying the effectiveness of mitigation measures for projects' operational emissions, and of 17 agency survey respondents, only Texas responded with links to relevant research. However, FHWA-sponsored research and the Texas projects highlighted under Research in Progress both focus on effective strategies and tools to control exposure to air pollution and could feed into new research undertaken by Caltrans.

## Next Steps

Caltrans might consider:

- Contacting Victoria Martinez concerning the FHWA-sponsored Near Road Study, which is monitoring MSATs and criteria pollutants.
- Following up with TxDOT fleet manager Don Lewis and Joe Zietsman of the Texas Transportation Institute's Center for Air Quality Studies, who are working with researchers from the University of Houston on federally sponsored relevant work.
- Contacting Rob Harrison, Nathan Hutson and Ron Mathews of the University of Texas, who are closely following emissions control devices.
- Developing a research project focused on effectiveness of mitigation measures that builds on work currently under way nationally.

# Contacts

During the course of this Preliminary Investigation, we spoke to or corresponded with the following individuals:

**New York Department of Transportation**
John Zamurs
Head, Air Quality Section
New York State Department of Transportation
(518) 457-5646, jzamurs@dot.state.ny.us

Mr. Zamurs is unaware of any studies (in New York or elsewhere) that have monitored or are currently monitoring mitigation measures for their effectiveness.

**Transportation Research Board**
Robert M. O'Loughlin
Chair, Committee on Air Quality
(415) 744-3823, robert.o'loughlin@dot.gov

Mr. O'Loughlin noted that the principal source of MSATs are diesel vehicles, especially heavy duty fleets and construction equipment; the principal way of mitigating their effects is through control devices and fuels for such vehicles. Currently there isn't a good sense of the effectiveness of mitigation measures for nitrogen oxide. And in general, there is a scarcity of before-and-after research on the effectiveness of emissions mitigations measures. However, there is ongoing research in Las Vegas and Detroit to monitor MSATs and criteria pollutants. (See FHWA Near Road Study in the **Research in Progress** section.) This data should provide a better sense of what mitigation measures work best.

**The Center for Air Quality Studies**
Joe Zietsman
Director
zietsman@tamu.edu

Mr. Zietsman is currently conducting emissions testing of particulate matter and mobile source air toxics on TxDOT's heavy-duty diesel vehicle. (See Characterization of Exhaust Emissions from Heavy Duty Diesel Vehicles in the HGB Area in **Research in Progress**.) He also provided links to a number of his authored studies, which are included in **Related Research**.

# Research in Progress

**FHWA Near Road Study**
Contact: Victoria Martinez, Victoria.Martinez@dot.gov
http://www.fhwa.dot.gov/environment/air_quality/air_toxics/research_and_analysis/near_road_study/index.cfm
This joint EPA/FHWA program is focused on providing the scientific knowledge and understanding needed to identify the most effective strategies and tools to control exposure to air pollution, including natural and man-made mitigation strategies to protect people who live, work or go to school nearby (for example, placement of vegetation or man-made barriers near roadways). Researchers are studying the concentration and physical behavior of MSATs, mobile source PM2.5 and other criteria pollutants. The project includes two ongoing studies in Las Vegas and Detroit.

> **Las Vegas, Nevada: Near Roadway Vehicle Emissions Study**
> http://www.fhwa.dot.gov/environment/air_quality/air_toxics/research_and_analysis/near_road_study/nrves08.cfm
> In December 2008, EPA scientists and engineers began a project to measure, define and profile roadway air pollutants along a portion of U.S. Route 95 in Las Vegas to better understand the relationship between traffic emissions and roadway-related air pollution concentrations at various distances from the roadway. Researchers gathered data by placing instruments 10, 100 and 350 meters from U.S. Route 95 near Dean Martin Drive and 100 meters from West Post Road, and also measured meteorological conditions and roadway characteristics such as traffic counts and vehicle types. The data collection phase was completed in December 2009. The results of these research projects will allow EPA to identify the most effective strategies and tools to control traffic emission impacts on exposures and adverse health effects from roadway air pollution. Strategies and tools for reducing adverse effects may include reducing vehicle emissions and placing man-made and natural barriers (including vegetation and variations in topography) near roadways to protect those who live, work or attend school nearby.

> **Detroit, Michigan: Near Roadway Vehicle Emissions Study**
> http://www.fhwa.dot.gov/environment/air_quality/air_toxics/research_and_analysis/near_road_study/nrvesdet.cfm
> In 2010, researchers began monitoring similar to that in Las Vegas.

**Texas-Specific Drive Cycles and Idle Emissions Rates for Using with EPA's MOVES Model**, Reza Farzaneh, Texas Transportation Institut, projected end date: August 31, 2012.
http://rip.trb.org/browse/dproject.asp?n=27687
*From the web site:* The U.S. Environmental Protection Agency's (EPA) newest emissions model, Motor Vehicle Emission Simulator (MOVES), utilizes a disaggregate approach that enables the users of the model to create and use local drive schedules (drive cycles) in order to perform an accurate analysis. However, only the national average drive schedules are currently included in the default database of the model. Furthermore, the cold start and idling emissions and activity data of heavy duty diesel trucks (HDDVs) that are included in the MOVES model are based on a very limited number of data sources even though they are very important components of the total on-road mobile source emissions inventory. Research activities will include the estimated emissions from MOVES for different vehicle classes being compared to real-world on-road emissions measurement. Furthermore, the technical and tactical issues of integrating the results of this study into MOVES for formal emissions analyses purposes will be investigated and recommendations will be made based on the findings.

**Characterization of Exhaust Emissions from Heavy Duty Diesel Vehicles in the HGB Area**, Joe Zietsman, Texas Transportation Institute, projected end date: August 31, 2011.
http://rip.trb.org/browse/dproject.asp?n=19564
This project studies the emissions of TxDOT's heavy-duty diesel vehicles. Unlike many emissions studies, it incorporates random sampling and real-world testing, and takes into account particulate matter and MSATs.

**Optimized Deployment of Emissions Reduction Technologies for Large Fleets**, Mohamadreza Farzaneh, Texas A&M University, project end date: August 31, 2010.
http://swutc.tamu.edu/projectdescriptions/476660-00022.htm
This project is working on an optimization model capable of determining the most efficient assignment of emission reduction strategies among vehicles and equipment in a large fleet, with a focus on the Texas Department of Transportation's fleet of more than 6,000 vehicles. Objectives are to:

- Assess the current emissions reduction practices of large fleet operators.
- Document and evaluate the potential emissions reduction strategies that are applicable to large fleets.
- Identify key factors that influence the distribution of resources of a large fleet owner/operator among its vehicles and equipment in order to reduce their negative air quality impacts.
- Develop and assess an optimization model capable of producing an optimal resource deployment plan aimed at reducing emissions from a large fleet.

**Modeling Vehicle Fuel Consumption and Emissions at Signalized Intersection Approaches: Assessing Available Tools and Research Needs**, Ahmed Abdel-Rahim, Karen Den Braven, University of Idaho.
http://www.webs1.uidaho.edu/niatt/database/Project_Detail.asp?Project_ID=188
*From the abstract:* The objectives of this research project are to relate traffic flow parameters in signalized intersection approaches to real-world vehicle fuel use and pollution emissions and review and validate the output of existing modeling tools. After a complete literature search to determine the current state-of-the-art, a first-order model of the effect of traffic control on fuel use will be created. The rates of fuel use will be evaluated during each "mode" of travel throughout the intersection approach: acceleration, deceleration, cruise, and idle. The relationship between vehicle fuel consumption and commonly used traffic measures, such as control delay at signalized intersections, will be investigated. Based on the results of the preliminary model, later plans call for the collection of real-time fuel use and vehicle emissions data through the use of a portable, On-board Emission Measurement unit (OEM 2100TM). The OEM 2100 allows real-time, field data collection of second-by-second measurement of tailpipe emissions (i.e., CO, HC, and NO) and engine operations (i.e., speed and engine rpm). Data from this research can be used to verify, calibrate and validate values obtained from the newly released EPA MOVES 2010 model as well as other modeling tools available. The output of the analysis will help identify data and research needed to improve the accuracy of vehicle fuel consumption and emissions predictions. The output of the project will provide practitioners throughout the nation with guidelines on how to use the MOVES model as well as other microscopic traffic modeling tools to assess the potential reduction in fuel use and emissions that could result from traffic signal improvement projects.

# Related Research

The following reports, papers and articles document recent research on air quality mitigation measures for projects' operational emissions.

## Mobile Source Air Toxics

**EPA Guidance on Mobile Source Air Toxics**
http://www.epa.gov/oms/toxics.htm
This page has information on MSATs and strategies for reducing risk to the public from these pollutants.

> **Benefits of Programs to Reduce Mobile Source Air Toxics**
> http://www.epa.gov/oms/regs/toxics/420f06021.htm
> This page includes information on benefits of programs to reduce mobile source air toxics. The proposed fuel benzene standard and hydrocarbon standards for vehicles and gas cans would together reduce total emissions of mobile source air toxics by 350,000 tons in 2030, including 65,000 tons of benzene. As a result of this proposal, in 2030, passenger vehicles would emit 45 percent less benzene, gas cans would emit 78 percent less benzene, and the gasoline would have 37 percent less benzene overall. In addition, the hydrocarbon reductions from the vehicle and gas can standards would reduce volatile organic compound (VOC) emissions (which are precursors to ozone and can be precursors to PM2.5) by more than 1 million tons in 2030. The proposed vehicle standards would reduce direct PM2.5 emissions by 20,000 tons in 2030 and may also reduce secondary formation of PM2.5. Once the regulation is fully implemented, these particulate matter reductions will result in 1,000 premature deaths avoided annually. We estimate that most of the benefits of this proposal would come from the reduced direct PM2.5 emissions from the vehicle standards, estimated to be about $6 billion in 2030. Some additional benefits would come from reductions in MSATs and VOCs, although we have not been able to monetize these benefits.

**Mobile Source Air Toxic Emissions: Sensitivity to Traffic Volume, Fleet Composition, and Average Speed**, *Journal of the Transportation Research Board*, Issue 2158, 2010: 77-85.
Abstract at http://trid.trb.org/view.aspx?id=910804
*From the abstract:* This study used a new emissions modeling tool, CT-EMFAC, to assess the sensitivity of mobile source air toxic (MSAT) emissions to changes in traffic volumes, speeds, and fleet composition. The investigation employed a hypothetical 6.7-mi freeway segment located in southern California; activity data were derived from comparable real-world information obtained from the California Department of Transportation. Results show that emissions more than doubled in 2004 and increased by a factor of two to four in 2030 when traffic volumes increased 30% above base case conditions. The nonlinear shift in emissions was a function of decreased travel speeds and increased grams per mile emission rates that accompanied increased traffic volumes. Fleet composition (the proportion of trucks) was also shown to affect MSAT emissions, especially for diesel particulate matter and aldehydes. Under some scenarios, the choice of the speed calculation method had a greater effect on MSAT emissions than 26 years of fleet turnover. The analysis also showed that the type of speed calculation method used could result in large variations in MSAT emissions. Application of one speed calculation method resulted in calculated congested freeway speeds that did not fall below 10 mph. The speed calculation method chosen was highly influential in the 2030 case study when forecasted volumes reached levels at which speeds approached the 10 mph minimum allowed by the speed calculation method; this probably underpredicted emissions.

**Project-Level Air Toxics Analysis**, Jonathan K Ehrlich, Mid-Continent Transportation Research Symposium, 2005.
Abstract at http://trid.trb.org/view.aspx?id=760462
*From the abstract:* As part of an environmental impact statement for a new interstate river crossing near Stillwater, MN, agency and environmental community concerns over the health impacts of transportation air toxics prompted the Minnesota Department of Transportation to perform an unprecedented project-level analysis of six mobile source air toxics: diesel particulate matter, benzene, 1,3-butadiene, formaldehyde, acetaldehyde, and acrolein. Total emissions were quantified on three scales: regional, local, and corridor. The EPA MOBILE 6.2 emissions model was run to determine emission rates for the six priority MSATs for various roadway types, speeds, and future analysis years. These were then combined with output from the regional travel demand forecasts to determine the emission of each MSAT for each link in the regional highway transportation network. Results included:

- Emission rates of 1,3-butadiene, acetaldehyde, acrolein, benzene, and formaldehyde are generally lower under higher operating speeds, and emissions are sensitive to changes in vehicle miles traveled (VMT) and vehicle hours traveled.
- Differences in total emissions between alternatives can be significant and quantifiable on a small area or corridor scale.

**A Methodology for Evaluating Mobile Source Air Toxic Emissions Among Transportation Project Alternatives**, Michael Claggett, Terry L. Miller, *Journal of the Transportation Research Board*, Issue 1987, 2006: 32-41.
http://www.fhwa.dot.gov/environment/air_quality/air_toxics/research_and_analysis/mobile_source_air_toxics/msatemissions.cfm
This paper describes a methodology for computing and evaluating emissions of MSATs among a group of transportation project alternatives. When the future options for upgrading a transportation corridor are evaluated, the major mitigating factor in reducing MSAT emissions is the implementation of EPA's new motor vehicle emission control standards. Substantial decreases in MSAT emissions will be realized from a current base year through an estimated time of completion for a planned upgrading project and its design year some 25 years in the future. Even when anticipated increases in vehicle miles of travel and varying degrees of efficiency of vehicle operation are accounted for, total MSAT emissions are predicted to decline more than 61 percent from 2005 to 2030. Although benzene emissions are predicted to decline more than 35 percent, emissions of diesel particulate matter are predicted to decline considerably more (more than 92 percent). The ability to discern remarkable differences in MSAT emissions among transportation alternatives is difficult, given the uncertainties associated with the forecasting of travel activity and air emissions 25 years or more into the future. In this hypothetical congestion mitigation project, differences in MSAT emissions between the build and no-action alternatives range from more than 6 percent to less than 16 percent.

**Second-by-Second Characterization of Cold-Start Gas-Phase and Air Toxic Emissions from a Light-Duty Vehicle**, Karen M. Sentoff, Mitchell K. Robinson, Britt A. Holmen, *Journal of the Transportation Research Board*, Issue 2158, 2010: 95-104.
Abstract at http://trid.trb.org/view.aspx?id=910889
*From the abstract:* Real-world tailpipe emissions were measured from a 1999 Toyota Sienna minivan with the University of Vermont total onboard tailpipe emissions measurement system. A Fourier transform infrared spectrometer measured 27 gas-phase emissions for cold start, extended idle, and warm-up driving at 1-s temporal resolution. Analysis demonstrated that (a) time to optimal function of emissions control devices was not indicated by one species, but varied for different pollutants; (b) extended idling after cold start produced elevated emissions for MSAT species as compared to warm-up driving; and (c) ambient temperatures ranging from 9.5°C to 38.4°C affected species from each emission category, with the exception of carbon dioxide. Carbon monoxide produced peak emissions three orders

of magnitude higher than hot-stabilized conditions for an average of 90 s, regardless of operating conditions, while nitric oxide peak emissions were over an order of magnitude higher during warm-up driving than extended idle. Peak MSAT emissions, up to two orders of magnitude higher than hot-stabilized idle, were maintained or increased during extended idle and decreased to baseline within 100 to 200 s of warm-up driving. Results indicate extended idling after cold starts prolongs elevated concentrations of MSAT emissions, suggesting that recent policy efforts to reduce vehicle idling behavior could limit potential human exposure to the toxic exhaust constituents.

**Recommended Practices for NEPA Air Toxics Analysis of Highway Projects**, Transportation Land Use, Planning, and Air Quality, 2008: 261-275.
Abstract at http://trid.trb.org/view.aspx?id=872714
*From the abstract:* This study developed best-practices guidance for MSAT assessments under [the National Environmental Policy Act]. Current approaches used by transportation agencies to assess and communicate MSAT emissions and health impacts were compiled and reviewed. A tiered methodology was developed which guides the analyst in identifying the appropriate level of analysis for a transportation project, using typically available information and potential level of exposure based on project characteristics. Five potential levels of analysis are suggested based on both technical and policy considerations. Details are presented on how to conduct the MSAT assessment as well as on the amount of information that should be included at each level of analysis. Recommendations are provided on how best to communicate the findings of the MSAT assessment as part of environmental documents and in public review.

**Diesel Truck Idling Emissions: Mobile Source Air Toxics Measured at a Hot Spot**, James Edgar Parks II, Transportation Research Board 86th Annual Meeting, 2007.
Abstract at http://trid.trb.org/view.aspx?id=802594
*From the abstract:* In this paper, measurements of MSATs at a "hot spot" of poor air quality created by a high population of idling heavy-duty trucks are presented. The study area was the Watt Road-Interstate-40/75 interchange just west of Knoxville, TN, where approximately 20,000 heavy-duty trucks travel along the interstate each day and hundreds of heavy-duty trucks idle at three large truck stops near the interchange. Ambient air quality was measured during summer and winter months of two separate years at three sites: a site in one of the truck stops, a site near the interstate roadway, and a site on top of one of the surrounding ridges chosen as a background site for comparison. The results include measurements of MSATs such as formaldehyde, acetaldehyde, acrolein, and other species obtained via collection on di-nitrophenyl hydrazine (DNPH) filters. They indicate that emissions from idling heavy-duty trucks are a primary contributor of MSATs to local air quality near areas of high static truck traffic; furthermore, higher levels of MSATs were detected in winter months indicating the meteorological effects on engine emissions and pollution transport.

## Criteria Pollutants

### Modeling and Emissions Measurement

**A Comprehensive Examination of Heavy Vehicle Emissions Factors**, Melissa Thompson, Avinash Unnikrishnan, Alison J. Conway, C. Michael Walton, Southwest Region University Transportation Center, Report No. SWUTC/10/476660-00067-1, August 2010.
http://swutc.tamu.edu/publications/technicalreports/476660-00067-1.pdf
*From the abstract:* This report summarizes the findings from reviewing the literature on several topics related to heavy vehicle emissions, including engine and fuel types, vehicle technologies that can be used to reduce or mitigate vehicle emissions, the factors that affect vehicle emissions, vehicle emissions modeling, and current and future policy requiring accurate accounting of heavy vehicle emissions. There are many engine and fuel alternatives that have differing effects on a vehicle's pollutant output. In

addition, new technologies, such as diesel particulate filters, auxiliary power units, and selective catalytic reduction, are being used in the production of new vehicles, and can often be installed on used vehicles, to reduce emissions and/or improve fuel economy. This paper also describes accurate heavy vehicle emissions modeling, which is important in forming policies designed to reduce pollutants from heavy vehicle operation at both the vehicle and regional level. Such policies can include cap-and-trade schemes, carbon taxing, and road user charging. All of these policy types have been implemented in the European Union to varying degrees, but only some have been implemented in the United States. However, all of these are now being considered in the U.S., and could be implemented in the future.

**Emissions Implications and Control Strategies for Old Imported Light Duty Vehicles**, Josias Zietsman, Texas Transportation Institute, August 2009.
http://tti.tamu.edu/group/airquality/files/2010/11/OILDV_FinalReport_v3-_2_.pdf
*From the report:* Five imported light-duty vehicles representing common makes and models were tested with portable emissions measurement systems (PEMS) units for emissions behavior. PEMS collected second-by-second emissions of oxides of nitrogen (NOx), hydrocarbons (HC), carbon monoxide (CO), PM and carbon dioxide (CO2). The collected emissions data were analyzed according to the operating modal bin concept implemented in the Environmental Protection Agency's (EPA) Motor Vehicle Emissions Simulator (MOVES) model. The results show these vehicles are major contributors to THC, CO, and gasoline PM emissions in the border region. It is recommended to consider an inspection and maintenance (I/M) type program to identify these high emitter vehicles.

**Mexican Truck Idling Emissions at the El Paso-Ciudad Juarez Border Location**, Josias Zietsman, Juan Carlos Villa, Timothy L. Forrest, John M. Storey, Southwest Region University Transportation Center, Report No. SWUTC/05/473700-00033-1, November 2005.
http://swutc.tamu.edu/publications/technicalreports/473700-00033-1.pdf
*From the abstract:* This project developed a method for estimating emissions and applied it to trucks crossing from Mexico at the El Paso-Ciudad Juarez border locations. Researchers developed a:

- Border crossing fleet profile of the make, model and year of trucks crossing the two main border bridges.
- Border crossing travel profile of the drive cycles (acceleration, deceleration, cruising, idling and creep idling) of trucks crossing the two main border bridges.
- Border crossing emissions profile estimating the idling emissions and driving emissions of trucks crossing the two main border bridges.

[The Texas Transportation Institute] used portable emissions measurement system (PEMS) equipment along with Tapered Element Oscillating Micro-balance (TEOM) equipment operated by Oak Ridge National Laboratory to measure the truck emissions. The project provided good insight into the fleet, travel, and emissions characteristics of trucks crossing the El Paso-Ciudad Juarez border locations. This research is a first step in developing a Border Crossing Emissions Measurement Model, which will be useful in determining and forecasting commercial vehicle emissions at land border crossings.

## Observed Trends After Mitigation Efforts

**On-Road Vehicle Emission Control in Beijing: Past, Present, and Future**, Y. Wu, R. Wang, Y. Zhou, B. Lin, L. Fu, *Environmental Science & Technology*, Volume 45, Issue 1, January 2011: 147-153.
Abstract at http://trid.trb.org/view.aspx?id=1087603
*From the abstract:* Since the mid-1990s, Beijing has adopted a number of vehicle emission control strategies and policies, including: (1) emission control on new vehicles; (2) emission control on in-use vehicles; (3) fuel quality improvements; (4) alternative-fuel and advanced vehicles; (5) economic policies; (6) public transport; and (7) temporal traffic control measures. Many have proven to be successful, such

as the Euro emission standards, unleaded gasoline and low sulfur fuel, temporal traffic control measures during the Beijing Olympic Games, etc. Some, however, have been failures, such as the gasoline-to-LPG taxi retrofit program. Since 1995, gasoline cars decreased fleet-average emission factors annually by 12.5% for CO, 10.0% for HC, 5.8% for NOX, and 13.0% for PM10. In 2009, total emissions of CO, HC, NOX, and PM10 were 845000 t, 121000 t, 84000 t, and 3700 t, respectively; with reductions of 47%, 49%, 47%, and 42%, relative to 1998. Beijing has been considered a pioneer in controlling vehicle emissions within China, similar to the role of California to the U.S.

**Quantifying the Air Pollutants Emission Reduction during the 2008 Olympic Games in Beijing**, S. Wang, M. Zhao, J. Xing, Y. Wu, Y. Zhou, *Environmental Science & Technology*, Volume 44, Issue 7, March 2010: 2490-2496.
Abstract at http://trid.trb.org/view.aspx?id=1087648
*From the abstract:* This project evaluated the effectiveness of the strict air pollutant emissions controls established by Beijing to ensure good air quality for the 2008 Olympic Games. In June 2008, daily emissions of SO2, NOX, PM10, and NMVOC in Beijing were 103.9 t, 428.5 t, 362.7 t, and 890.0 t, respectively. During the Olympic Games, the daily emissions of SO2, NOX, PM10, and NMVOC in Beijing were reduced to 61.6 t, 229.1 t, 164.3 t, and 381.8 t -41%, 47%, 55%, and 57% lower than June 2008 emission levels. Closing facilities producing construction materials reduced the sector's SO2 emissions by 85%. Emission control measures for mobile sources, including high-emitting vehicle restrictions, government vehicle use controls, and alternate day driving rules for Beijing's 3.3 million private cars, reduced mobile source NOX and NMVOC by 46% and 57%, respectively. Prohibitions on building construction reduced the sector's PM10 emissions by approximately 90% or total PM10 by 35%. NMVOC reductions came mainly from mobile source and fugitive emission reductions. Based on the emission inventories developed in this study, the CMAQ model was used to simulate Beijing's ambient air quality during the Olympic Games. The model results accurately reflect the environmental monitoring data providing evidence that the emission inventories in this study are reasonably accurate and quantitatively reflect the emission changes attributable to air pollution control measures taken during the 29th Olympic Games in 2008.

**<u>Control Devices</u>**

**Assessment of Ring Injectors for Reducing NOx and PM Emissions of Diesel Engines**, Hamid R. Rahai, University of Southern California, August 16, 2010.
http://www.metrans.org/research/final/AR%2007-05-Final%20Report-Rahai-CSULB.pdf
*From the abstract:* An SCR system with a rectangular two-hole ring injector was developed and the system was tested using the exhaust of a 3-cylinder aspired diesel engine under a moderate shaft loading condition, using ammonia gas as the reducing agent. Results show nearly 80 percent reductions in NOx emissions.

**SmartWay Applications for Drayage Trucks**, Josias Zietsman, Texas Commission on Environmental Quality, August 15, 2009.
http://tti.tamu.edu/documents/TTI-2009-5.pdf
*From the abstract:* This study tested three SmartWay strategies for reducing emissions on trucks operating daily across the border between the United States and Mexico: lighter trailers, driving behavior, and diesel oxidation catalysts (DOCs). Five trucks were tested with portable emissions measurement systems (PEMS) units before and after implementation of a SmartWay strategy. PEMS collected second-by-second emissions of oxides of nitrogen (NOx), hydrocarbons (HC), carbon monoxide (CO), PM, and carbon dioxide (CO2). CO2 emissions served as a proxy for fuel consumption testing. The results show that DOCs provide major THC and CO reduction benefits for drayage operations. Lightweight trailers and Eco Driving were also found to decrease CO and THC emissions moderately. Only Eco Driving appeared

to have a positive impact on $CO_2$, fuel consumption, and NOx emissions. All the investigated strategies resulted in lowering PM emissions compared to the baseline.

**Reducing Diesel NOx and PM Emissions of Diesel Buses and Trucks**, Hamid R. Rahai, California State University Long Beach, July 22, 2008.
http://www.metrans.org/research/final/06-04%20Final%20Report.pdf
The objectives of this project were to reduce diesel nitrogen oxides by more than 90 percent and particulate matter emissions by more than 30 percent from diesel truck engines during idling. The study focused on developing a high efficiency selective catalytic reduction (SCR) system for reducing diesel nitrogen oxides and particulate matters of diesel trucks. The study was divided into two parts. In part one, the mixing effectiveness of a coil-shaped injector with different injection ratios was investigated using air as both exhaust and injecting fluid. In part two of the study, an SCR system with an injector-mixer was developed and tested on the exhaust of a three-cylinder diesel engine. While results indicated a more than 80 percent reduction in nitrogen oxide emissions with this injector mixer configuration, further investigations will be pursued.

**Reducing NOx Emissions from a Biodiesel-Fueled Engine by Use of Low-Temperature Combustion**, T. Fang,
*Environmental Science & Technology*, Volume 42, Issue 23, December 2008: 8865-8870.
Abstract at http://trid.trb.org/view.aspx?id=883336
*From the abstract:* In this study, effects of injection timing and different biodiesel blends are studied for low load conditions. It is observed that low-temperature combustion effectively reduces NOx emissions because less thermal NOx is formed. Although biodiesel combustion produces more NOx for both conventional and late-injection strategies, with the latter leading to a low-temperature combustion mode, the levels of NOx of B20 (20 vol % soy biodiesel and 80 vol % European low-sulfur diesel), B50, and B100 all with post-TDC injection are 68.1%, 66.7%, and 64.4%, respectively, lower than pure European low-sulfur diesel in the conventional injection scenario.

## Alternative Fuels and Fuel Additives

**Emissions of Mexican-Domiciled Heavy-Duty Diesel Trucks Using Alternative Fuels**, Josias Zietsman, Texas Transportation Institute, October 2007.
http://tti.tamu.edu/group/airquality/files/2010/11/Emissions-of-Mexican-Domiciled-Heavy-Duty-Diesel-Trucks-Using-Alternative-Fuels.pdf
The overall goal of this study was to quantify emissions produced by Mexican trucks operating on standard diesel and alternative fuels. Results for nitrogen oxides, hydrocarbons and carbon monoxide include:

- Nitrogen oxides: It was found that for idling modes (low and high), the biodiesel (B20) and PEMEX fuels tend to decrease NOx emissions slightly (compared to the ULSD fuel). For on-road modes (drayage and long haul cycles), both the B20 and PEMEX fuels seemed to increase nitrogen oxides. There was no clear correlation between vehicle age and nitrogen oxides emissions rates. The impact of air conditioner usage on nitrogen oxides was mixed, with a notable impact in idle mode and no apparent effect for on-road tests.
- Hydrocarbons: Both the B20 and PEMEX fuels reduced hydrocarbons emissions during all modes of operation when compared to the ULSD fuel with the B20 fuel having the highest reduction. The age of the trucks appeared to have an inverse effect (newer trucks showed higher emissions) on hydrocarbons emissions, which might be the result of finer fuel injection in newer diesel engines. The effect of air conditioning usage on hydrocarbons was not clear because of the mentioned inverse impact of age on hydrocarbons.

- Carbon monoxide: Similar to hydrocarbons emissions, the B20 and PEMEX fuels tended to decrease carbon monoxide emissions compared to the ULSD fuel for all operation modes. It was found having a newer engine does not appear to have a positive impact on carbon monoxide emissions rates in the idling mode as would be expected. The results were mixed for on-road tests: no age impact was observed for long-haul trucks. Newer drayage trucks had lower carbon monoxide emissions than the older ones. There was no obvious correlation between air conditioning usage and changes in carbon monoxide rates.
- MSATs: The formaldehyde and acetaldehyde emissions were significantly lower than observed previously in idling trucks from the U.S. and Mexico. The higher cetane index of all three fuels may be responsible for this observed reduction. No additional aldehyde emissions were detected from the biodiesel fuel, despite its fuel oxygen. Because the new ultralow sulfur rules have improved fuel quality in both the U.S. and Mexico, there is no reason to expect that ULSD or B20 fuels would have a noticeable effect on the aldehyde MSAT emissions.

B20 clearly produced the best results with reductions in carbon monoxide, particulate matter and hydrocarbons emissions. There was no effect on carbon dioxide emissions, and the results for nitrogen oxides were mixed with slight decreases during idling and slight increases during driving.

**School Bus Biodiesel (B20) NOx Emissions Testing**, Josias Zietsman, Texas Transportation Institute, August 2006.
http://tti.tamu.edu/group/airquality/files/2010/11/School-Bus-Biodiesel-B20-NOx-Emissions-Testing1.pdf
*From the abstract:* This study investigated the impact of biodiesel (B20: 20 percent biodiesel, 80 percent conventional diesel) on the oxides of nitrogen (NOx) emissions emitted from diesel school buses. Five buses were selected according to the current model year mix in Texas and were driven following the developed drive cycles for three fuel blends — Texas Low Emissions Diesel as base fuel, B20 market blend, and B20 all soy. A state-of-the-art portable emission measurement system (PEMS) unit was used to measure the NOx emission along with other emissions, ambient weather condition, GPS readings, and vehicle engine data. The data were cleaned and aggregated to represent the current Texas school bus fleet and rural/urban mix of miles driven. The results of statistical analysis showed that using B20 had no significant effect on the level of NOx emissions emitted by the school buses.

**Diesel Emissions Testing, Performance Evaluation, and Operational Assessment; Project Extension to Examine an Ultra-Low Sulfur Diesel Fuel: TxLED**, Ron Matthews, Texas Department of Transportation, Report No. FHWA/TX-05/0-4576-4, July 2005.
http://www.utexas.edu/research/ctr/pdf_reports/0_4576_4.pdf
*From the abstract:* This study evaluates the effectiveness of the ultra-low sulfur fuel Texas Low Emission Diesel (TxLED) in both the TxDOT fleet and their contractors, the Associated General Contractors (AGC). The results from the full load torque curve tests and the operator assessments, together with the properties of TxLED compared to those for 2D on-road diesel fuel, indicate that there should be no performance penalties associated with use of TxLED. It was also found that, as expected, TxLED does not separate into lighter and heavier components over time and does not pose corrosion problems. For all engines tested, TxLED provided a statistically significant benefit in NOx emissions compared to 2D on-road diesel fuel. With the exception of only one engine, the NOx emissions benefits from using TxLED were higher than the benefits claimed in Texas' State Implementation Plan. Additionally, statistically significant benefits in PM emissions were found for three of the six engines tested and small, but statistically significant, benefits in fuel consumption or fuel economy were found for three of the engines. The study concluded that TxLED is a cost-effective strategy for reducing emissions from the TxDOT and AGC fleets.

**TxDOT Emulsified Diesel Final Report**, Rick Baker, Texas Department of Transportation, Report No. FHWA/TX-04/4576-3, January 2004.
http://www.bp.com/liveassets/bp_internet/bp_ecd/bp_ecd_us/STAGING/local_assets/downloads_pdfs/t/Texas_DOT4576_3.pdf
*From the abstract:* This study evaluates the continued use of the emulsified diesel fuel PuriNOx by TxDOT's Houston District, and possible extension to the AGC contractors in the Houston area. The evaluation criteria were: health risks (relative to diesel fuel), safety (both highway safety and fire hazards), performance failure (compatibility of equipment with PuriNOx and ability to perform the required tasks), and cost-effectiveness. It was found that summer-grade PuriNOx is suitable for use in most, but not all, equipment based upon health risks, safety, and ability to perform the required tasks. Therefore, cost-effectiveness is the major criterion for the use of PuriNOx by the TxDOT and AGC fleets in the Houston area. The cost-effectiveness of PuriNOx was also compared to alternative NOx control techniques. It is found that use of Texas Low Emission Diesel is more cost-effective than PuriNOx. However, it is believed that PuriNOx may be an excellent method for NOx control by fleets for which the equipment is used at least twice per week and that do not operate at very high loads often enough that productivity will suffer.

**Impact of Biodiesel Source Material and Chemical Structure on Emissions of Criteria Pollutants from a Heavy-Duty Engine**, R.L. McCormick, *Environmental Science and Technology*, Volume 35, Issue 9, May 2001: 1742-1747.
Abstract at: http://trid.trb.org/view.aspx?id=687049
*From the abstract:* The objective was to understand the impact of biodiesel chemical structure, specifically fatty acid chain length and number of double bonds, on emissions of NOx and particulate matter (PM). A group of seven biodiesels produced from real-world feedstocks and 14 produced from pure fatty acids were tested in a heavy-duty truck engine using the US heavy-duty federal test procedure (transient test). It was found that the molecular structure of biodiesel can have a substantial impact on emissions. The properties of density, cetane number, and iodine number were found to be highly correlated with one another. For neat biodiesels, PM emissions were essentially constant at about 0.07 g/bhp-h for all biodiesels as long as density was less than 0.89 g/cu cm or cetane number was greater than about 45. NOx emissions increased with increasing fuel density or decreasing fuel cetane number. Increasing the number of double bonds, quantified as iodine number, correlated with increasing emissions of NOx. Thus the increased NOx observed for some fuels cannot be explained by the NOx/PM tradeoff and is therefore not driven by thermal NO formation. For fully saturated fatty acid chains the NOx emission increased with decreasing chain length for tests using 18, 16, and 12 carbon chain molecules. Additionally, there was no significant difference in NOx or PM emissions for the methyl and ethyl esters of identical fatty acids.

**Air Quality Effects of Alternative Fuels: Final Report**, P. Guthrie, M. Ligocki, R. Looker, J. Cohen, National Renewable Energy Laboratory, Report No. NREL/SR-540-23896, November 1997.
http://ntl.bts.gov/lib/10000/10300/10387/m98002768.pdf
This report presents the results of Phase 1 of a comparison of the potential air quality effects of alternative transportation fuels. The focus is on reformulated gasoline (RFG), methanol blended with 15 percent gasoline (M85) and compressed natural gas (CNG). The fuels are compared in terms of their effects on simulated future concentrations of ozone and MSATs (formaldehyde, acetaldehyde, benzene and 1,3-butadiene) in a photochemical grid model. The fuel comparisons were carried out for the future year 2020 and assumed complete replacement of gasoline in the projected light-duty gasoline fleet by each of the candidate fuels. The model simulations were carried out for the areas surrounding Los Angeles and Baltimore/Washington, D.C., and other (nonmobile) sources of atmospheric emissions were projected according to published estimates of economic and population growth, and planned emission control measures specific to each modeling domain. The future-year results are compared to a future-year run with all gasoline vehicle emissions removed. The results of this Phase 1 fuel comparison indicate that the

use of M85 is likely to produce similar ozone and air toxics levels as those projected from the use of RFG, both for Los Angeles (using a California definition of RFG) and for Baltimore (using a federal definition of RFG). Substitution of CNG is projected to produce significantly lower levels of ozone and the mobile source air toxics than those projected for either RFG or M85. The relative benefits of CNG substitution are consistent in both modeling domains.

## Vehicle Inspections Programs

**Emissions-Inventory-Based Methodology to Evaluate Vehicle Inspection and Maintenance Programs: Case Study of Atlanta Airshed, 1997-2001**, Zia, Asim, Transportation Research Board 85th Annual Meeting, 2006.
Abstract at: http://trid.trb.org/view.aspx?id=776811
*From the abstract:* A new emission-inventory based methodology, which combines remote sensing data with [Inspection and Maintenance (IM)] program and mileage/fuel-sales data, is presented as a formal model that can be used to evaluate the effect of IM programs on on-road Carbon Monoxide (CO), Hydrocarbon (HC) and Nitrogen Oxide (NO) emissions. The application of the emission-inventory methodology in a case-study of the Atlanta Airshed between 1997 and 2001 is also presented. The application in Atlanta suggests that CO, HC and NO mass emission rates of IM eligible vehicles decreased by 25.87%, 79.12% and 11.32%, respectively, in 2001 as compared to the baseline rate of odd model year vehicles in 1999 and even model year vehicles in 2000. The results of this study can be used to validate the State Implementation Plan (SIP) budgets of vehicular emissions in Atlanta, GA, for the period 1997-2001. Furthermore, the proposed methodology can be applied to evaluate IM program in other serious and severe ozone non-attainment areas.

**Estimated Emission Reductions from California's Enhanced Smog Check Program**, B.C. Singer, T.P. Wenzel, *Environmental Science and Technology*, Volume 37, Issue 11, June 2003: 2588-95.
http://www.osti.gov/bridge/purl.cover.jsp;jsessionid=97452CFF521E8E6F524A00F0AAF385CD?purl=/824835-ylIYm4/native/
This study estimates that in 1999 the California Smog Check reduced tailpipe emissions of hydrocarbons, carbon monoxide and nitrogen oxides by 97, 1690 and 81 tons/day, respectively. These correspond to 26 percent, 34 percent and 14 percent of the hydrocarbons, carbon monoxide and nitrogen oxides that would have been emitted by vehicles in the absence of Smog Check. These estimates are highly sensitive to assumptions about vehicle deterioration in the absence of Smog Check. Considering the estimated uncertainty in these assumptions yields a range for calculated benefits: 46-128 tons/day of hydrocarbon, 860-2200 tons/day of carbon monoxide and 60-91 tons/day of nitrogen oxides. Repair of vehicles that failed an initial, official Smog Check appears to be the most important mechanism of emission reductions, but preinspection maintenance and repair also contributed substantially. Benefits from removal of nonpassing vehicles accounted for a small portion of total benefits. In 1999, more than 90 percent of all hydrocarbons and carbon monoxide benefits and more than 80 percent of all nitrogen oxide benefits were attributed to vehicles more than 10 years old, even though such vehicles represented only half of those tested in the program.

## Signal Control

**A Toolbox to Quantify Emission Reductions due to Signal Control**, Martin Fellendorf, Transportation Research Board 89th Annual Meeting, 2010.
Abstract at http://trid.trb.org/view.aspx?id=911083
This toolbox presents a way to quantify changes in emissions as a result of different actuated signal control strategies and other intelligent transportation systems measures, and has been applied using an urban arterial in Graz. First results indicate that emissions can be reduced by about 5 percent to 12 percent

depending on pollutant and signal control changes. Using the toolbox, the impact of new engine technologies and different penetration rates on emission rates can be evaluated.

## Hybrid Vehicles

**Effects of Plug-In Hybrid Electric Vehicles on Ozone Concentrations in Colorado**, G.L. Brinkman, *Environmental Science & Technology*, Volume 44, Issue 16, October 2010: 6256-6262.
Abstract at http://trid.trb.org/view.aspx?id=1087377
This study used the Comprehensive Air Quality Model to estimate that if plug-in hybrid electric vehicles (PHEVs) had replaced light duty gasoline vehicles in Denver during the summer of 2006, nitrogen oxide emissions would be reduced by 27 tons per day from a fleet of 1.7 million vehicles and were increased by 3 tons per day from power plants; VOC emissions were reduced by 57 tons per day.

**Real-Time Measurements of Nitrogen Oxide Emissions from In-Use New York City Transit Buses Using a Chase Vehicle**, J.H. Horter, *Environmental Science and Technology*, Volume 39, Issue 20, October 2005: 7991-8000.
Abstract at http://trid.trb.org/view.aspx?id=774751
This study used chase vehicles with mobile laboratories to follow and measure emissions from approximately 170 mass transit buses in New York City, repeatedly sampling their exhaust. Emissions from conventional diesel buses, diesel buses with continuously regenerating technology (CRT), diesel hybrid electric buses and compressed natural gas (CNG) buses were compared. Nitrogen oxide emissions from the diesel and CNG buses were comparable, while hybrid electric buses had approximately one-half the nitrogen oxide emissions. In CRT diesels, $NO_2$ accounts for about one-third of the nitrogen oxide emitted in the exhaust, while for non-CRT buses the $NO_2$ fraction is less than 10%.

## Idle Reduction

**Demonstration of Integrated Mobile Idle Reduction Solutions**, Michael Tunnell, American Transportation Research Institute, August 2009.
http://trid.trb.org/view.aspx?type=MO&id=901478
*From the abstract:* This research involved the demonstration and evaluation of mobile idle reduction technologies on heavy-duty trucks, either installed as part of the truck manufacturing process or prior to the truck being placed in service. With the deployment of selected idle reduction technologies, main engine idling comprised from 5% to 22% of total engine operating time. This represented a reduction in idling of 42% to 78% from baseline conditions. Idling continued to be highest during the hottest or coldest months, which may imply that the selected technologies were less effective during extreme temperatures. The estimated emission reductions from the use of the selected idle reduction technologies amounted to more than 27 tons per year of NOx, 0.6 tons per year of particulate matter and 1,265 tons per year of $CO_2$.

**Commercial Bus Emissions Characterization & Idle Reduction: Idle & Urban Cycle Test Results**, American Bus Association, June 2006.
Abstract at: http://trid.trb.org/view.aspx?type=MO&id=786289
*From the abstract:* This report summarizes the results of emissions testing conducted on six motor coaches with engines between model years 1997 and 2004. Each bus was tested while idling and also while driving in simulated low-speed urban traffic. For both idle and urban driving each bus was also tested with and without the air conditioning system on. The intent of this test program was to evaluate the potential effects of idle restriction polices on coach buses, particularly when coaches are forced to circulate in urban traffic to maintain appropriate cabin temperatures if restricted from idling and unable to park. The major findings of this testing include: I - Emissions - (1) All of the tested buses emitted significantly more NOx when driving in simulated urban traffic than when idling with the bus stationary.

For older coaches NOx doubled – increasing by 200 grams/hour (g/hr) on average when driving compared to idling. For newer coaches the increase in NOx emissions from urban driving compared to stationary idling was 40%. (2) If a coach bus is forced to circulate in traffic to maintain appropriate cabin temperatures, rather than idling while stationary, it will emit up to 22 pounds of excess NOx emissions annually for only one hour per day of circulating. For older coaches, NOx emissions from one hour of circulating are equivalent to NOx emissions from two hours of stationary idling. (3) NOx emissions generally increased when the air conditioning was on compared to when it was not on. (4) For both idling and urban driving, as well as with and without air conditioning, the two newest buses (2004 engines) produced significantly less NOx than the four older buses.

**Effects Of Heavy-Duty Diesel Vehicle Idling Emissions on Ambient Air Quality at a Truck Travel Center and Air Quality Benefits Associated with Advanced Truck Stop Electrification Technology**, Guenet Tilahun Indale, Northwestern University, 2005.
Abstract at http://trid.trb.org/view.aspx?type=MO&id=854639
This study continuously measured particulate matter and nitrogen oxide concentrations at two truck travel center locations, and also predicted concentrations using EPA's ISCST3 model. Researchers predicted that if IdleAire electrification units were provided to all trucks that would otherwise idle, the ambient concentrations (not considering background concentrations) would be lower by 70 percent and 48percent, respectively.

## Managed Lanes

**Assessing Air Quality Impacts of Managed Lanes**, Amy L. Stuart, University of South Florida, Tampa, December 2010.
http://www.dot.state.fl.us/research-center/Completed_Proj/Summary_PTO/FDOT_BDK85_977-11_rpt.pdf
*From the abstract:* Impacts on transit bus performance and air quality were investigated for a case study high-occupancy toll (HOT) lane project on a corridor of I-95 near Miami. Trends in air pollutant concentration monitoring data in the study area first were analyzed. Traffic movement prior to and after implementation of the HOT lanes was simulated using corridor microsimulation (CORSIM). Emissions of carbon monoxide, nitrogen oxides, particulate matter, hydrocarbons, and benzene were estimated using MOBILE6.2. Finally, changes in ambient pollutant concentrations were estimated using AERMOD dispersion simulations. Results indicate decreased congestion on the corridor due to the HOT lane implementation, particularly for the northbound direction during the afternoon peak hours. Specifically, bus travel times were reduced by nine minutes, on average, during these hours. Emissions results were mixed, with small estimated increases for CO, NOx, PM10, and benzene and small decreases for HCs. Slightly higher ambient concentrations were found in most of the study area for the pollutants modeled (CO, NOx, and benzene), with the largest increases near the corridor. Overall, changes in both emissions and concentrations were small, indicating small impacts of the managed lane project on air quality.

**Evaluating Air Quality Benefits of Freeway High-Occupancy Vehicle Lanes in Southern California**, Kanok Boriboonsomsin, *Journal of the Transportation Research Board*, Issue 2011, 2007: 137-147.
Abstract at http://trid.trb.org/view.aspx?id=801850
This paper examines operational differences in traffic dynamics between high occupancy vehicle (HOV) lanes and mixed-flow (MF) lanes and evaluates their impacts on vehicle emissions. Four general HOV lane scenarios were identified: underutilized, neutral, well utilized and overutilized. Extensive driving trajectories in both lane types for each scenario were collected. Their speed profile and joint speed-acceleration frequency distribution were analyzed and compared. Vehicle emissions and fuel consumption were then estimated with a state-of-the-art modal emissions model. The results show that HOV lanes produce lower emission rates per vehicle per mile in most cases, except when they are underutilized. When normalized by average vehicle occupancy, HOV lanes produce much lower emission rates per the

same amount of travel demand, on the order of 10 percent to 70 percent. In almost every case, HOV lanes produce less emissions mass on a per-lane basis than MF lanes. Southern California freeway lane performance matrices show that on a typical weekday during the summer of 2005, HOV lanes operated mostly under Scenarios 1 and 2 during peak periods. Overall, they were well utilized about 14 percent to 17 percent of the time. According to the emissions estimates, the HOV lanes are considered effective in reducing vehicle emissions.

**Vehicle Retirement**

**Estimating Emissions Reductions from Accelerated Vehicle Retirement Programs**, J. Dill, *Transportation Research Part D: Transport and Environment*, Volume 9, Issue 2, March 2004: 87-106.
Abstract at http://trid.trb.org/view.aspx?id=699272
*From the abstract:* This paper uses data from two large-scale vehicle retirement programs in California to demonstrate that changing assumptions can significantly alter the assumed benefits of the program. The results show that vehicle retirement programs are likely to reduce emissions, but probably not as much as predicted, particularly for nitrogen oxide and carbon monoxide emissions. The programs may be most effective in reducing emissions of reactive organic gases. Several factors are responsible for the differences in estimates: scrapped vehicles are generally driven fewer miles than other vehicles of the same model year; some of the vehicles would have been scrapped without the program or may have had a shorter life expectancy than predicted; emissions for some pollutants may not be as high as predicted; and replacement vehicles are usually older than the fleet average. The results suggest that current methods of estimating emissions reductions from voluntary accelerated vehicle retirement programs need to be improved, and that such programs should continue to be monitored and evaluated.

**Traffic Flow Improvement**

**Effect of Arterial Signalization and Level of Service on Measured Vehicle Emissions**, A. Unal, N.M. Rouphail, H.S. Frey, *Journal of the Transportation Research Board*, Issue 1842, 2003: 47-56.
Abstract at http://trid.trb.org/view.aspx?id=682232
*From the abstract:* The effect of arterial traffic signal timing and coordination on vehicle emissions is studied. Traffic signal timing improvement is one of the most common practices for congestion management in the United States. Although the benefits of improved signal timing for reduced fuel consumption are well documented, its effectiveness as a transportation control measure for emissions has not been clearly investigated. An empirical approach based on real-world, on-road vehicle emissions measurements was used. A total of 824 one-way runs representing 100 h and 2,020 vehicle miles of travel were conducted involving four drivers and eight gasoline-fueled light-duty vehicles on two signalized arterials in Cary, North Carolina: Walnut Street and Chapel Hill Road. Modal analyses of the data indicate that emissions rates were highest during acceleration and tend to decrease (in descending order) for cruise, deceleration, and idle. A modal approach is used to quantify the effect of arterial traffic signal timing and coordination on emissions. A key result is that signal coordination on Walnut Street yielded measurable improvements in arterial level of service and emissions reduction. For Chapel Hill Road, emissions were substantially lower under uncongested conditions [level of service (LOS) A/B] than under congested conditions (LOS D/E) for travel in the same direction at different times of day. Findings confirm the utility of signal coordination and congestion management as effective tools for controlling emissions.

## Nonexhaust Particulate Matter

**Research for the AASHTO Standing Committee on the Environment, Task 42, Determine Alternative Calculations for Fine Particulate Emission Factors Other Than AP-42 Applicable to Calculate Re-Entrained Dust on Transportation Projects**, AASHTO, November 2008.
http://144.171.11.40/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=1660
The objective of this study is to identify and develop guidelines for the use of more accurate calculation methods or a more accurate modification of the existing AP-42 method to calculate PM 2.5 and PM 10 emission factors for re-entrained road dust for both paved and unpaved roads that will be acceptable to the USEPA and states.

**A Review of Abatement Measures for Non-Exhaust Particulate Matter from Road Vehicles**, P.G. Boulter, M. Wayman, I. McCrae, R.M. Harrison, Transportation Research Laboratory, May 2007.
Abstract at http://trid.trb.org/view.aspx?type=MO&id=810707
*From the abstract:* In this report the authors discuss potential approaches for reducing emissions of particulate matter (PM) from road vehicle non-exhaust sources, such as tyre wear, brake wear, road surface wear and the resuspension of road dust. The measures include improved materials, in situ particle collection and destruction, improved vehicle design, road and vehicle cleaning, and the use of dust suppressants and de-icing liquids. The various measures are rated according to several factors, including the likely impact on PM emissions, cost and technical feasibility. Reducing average vehicle weight and road silt loading (e.g., by vehicle washing, road sweeping, etc.) ought to lead to a reduction in resuspension. However, the evidence indicates that road sweeping or washing is not a particularly effective means of reducing PM10 concentrations. The use of certain de-icing liquids appears to be associated with a reduction in ambient PM10 levels. The application of dust suppressants may also be effective, but there are various concerns about the potential health and environmental impacts of the compounds used.

**Impact of Asphalt Rubber Friction Course Overlays on Tire Wear Emissions and Air Quality Models for Phoenix, Arizona, Airshed**, Olga Alexandrova, *Journal of the Transportation Research Board*, Issue 2011, 2007: 98-106.
http://trid.trb.org/view.aspx?id=802359
This study took advantage of a rare opportunity to sample tire wear emissions at the tunnel before and after the asphalt rubber friction course (ARFC) overlay. The hypothesis was that an ARFC surface results in less tire wear than the existing portland cement concrete (PCC) road surface. This paper reports on the measured particulate matter emissions from the on-road vehicle traffic during typical highway driving conditions for the two different roadway surfaces. It presents the analysis of representative tire tread samples for tire wear marker compounds and a comparison of roughness and frictional surface characteristics as measured before and after the ARFC overlay. The study found that emission rates of tire wear per kilometer driven on PCC road surfaces were 1.4 to 2 times higher than emission rates of tire wear on ARFC road surfaces.

**Non-Exhaust Particulate Matter Emissions from Road Traffic: Summary Report**, T.J. Barlow, Transportation Research Laboratory, May 2007.
http://trid.trb.org/view.aspx?id=810708
*From the abstract:* This report summarises the key findings of a research project on emissions of particulate matter (PM) from road vehicle non-exhaust sources, such as tyre wear, brake wear, road surface wear and the resuspension of road dust. The main aim of the project was to develop improved prediction methods for emissions and air pollution, primarily for use in the UK National Atmospheric Emissions Inventory, and using the existing literature and data. The project involved an initial literature review, the evaluation, development and application of emission and air pollution models, and a review of potential abatement options for non-exhaust PM. The findings and recommendations from each part of

the work are presented in the report. One of the clearest messages from the project was that without new experimental data the emission factors for non-exhaust sources will remain highly uncertain. In order to improve the understanding, a number of general recommendations are provided. These include a review of tyre, brake and road surface materials in use, the chemical characterisation of the source materials, laboratory-based experiments to recreate the particle-generating processes, real-world measurements using instrumented vehicles, source apportionment studies for PM in ambient air, and the experimental assessment of abatement measures.

**Road Vehicle Non-Exhaust Particulate Matter: Final Report on Emission Modelling**, P.G. Boulter, Transportation Research Laboratory, June 2006.
http://trid.trb.org/view.aspx?type=MO&id=787106
*From the abstract:* This Report describes the evaluation and development of emission models for non-exhaust particulate matter (PM). The PM sources covered are three abrasion processes - tyre wear, brake, road surface wear - and the resuspension of road dust. For the abrasion sources the evaluation focussed on the EMEP, RAINS, CEPMEIP and MOBILE6.2 methods. The EMEP method was considered to be the most advanced approach, and was considered to be the most suitable for application in the UK (it is already used in the National Atmospheric Emissions Inventory). The lack of a substantial amount of new source-specific emission factors in the literature meant that no further developments of the abrasion models were possible. Emissions due to resuspension were estimated for Marylebone Road in London, based on PM10 and PM2.5 measurements and the application of different models for the abrasion sources. The results suggested that resuspension accounts for 43-49% of total non-exhaust emissions, and resuspension emissions were found to be around 30% of the magnitude of exhaust emissions. Emission factors for resuspension due to HDVs ranged from 139 mg/vkm to 145 mg/vkm. Much lower emission factors were observed of LDVs. The estimates of abrasion emissions appeared to be quite sensitive to the method adopted. The study has shown that there are few detailed methodologies for predicting emissions of particulate matter from non-exhaust sources. There is clearly a need for more extensive empirical data, and a number of general recommendations for methods of obtaining such data are made. One weakness of the study is that it is based purely on a single street canyon site, and it is important to test the extent to which the results can be generalised to other locations having different characteristics.

# National Guidance

## FHWA Air Quality Website

http://www.fhwa.dot.gov/environment/air_quality/
This site includes pages with guidance and links to resources on air toxics, transportation conformity and the Congestion Mitigation and Air Quality Improvement Program.

## EPA Resources

### Regulations and Guidance

http://www.epa.gov/otaq/stateresources/transconf/conf-regs.htm
This page provides access to all transportation conformity regulations as well as guidance documents that have been issued to facilitate implementation of the conformity program.

### Calculators and Modeling Tools

http://www.epa.gov/otaq/stateresources/tools.htm
This page provides links to calculators and modeling tools to assess the effectiveness of mobile source-based control strategies. State and local agencies can use these calculators and tools to estimate emission reductions or to conduct analyses of the outcome that a specific emission-reduction strategy may produce.

**Modeling and Inventories**
http://www.epa.gov/otaq/models.htm
This page provides links to models for estimating emissions from on-road vehicles, nonroad sources and fuels, including MOVES (http://www.epa.gov/otaq/models/moves/index.htm), the EPA's current official model for estimating air pollution emissions from cars, trucks and motorcycles.

## NCHRP and AASHTO Studies

**Analyzing, Documenting, and Communicating the Impacts of Mobile Source Air Toxic Emissions in the NEPA Process**, Edward L. Carr, Arlene Rosenbaum, Geoffrey Glass, Seth Hartley, AASHTO Standing Committee on the Environment, Project No. 25-25 (Task 18), March 2007.
http://onlinepubs.trb.org/onlinepubs/archive/NotesDocs/25-25(18)_FR.pdf
This study develops information and guidelines on available analytical models and techniques to assess MSAT impacts and how this information can be communicated in the environmental assessment. The study reviews and provides recommendations on available analytical modeling tools to use in MSAT assessments along with the identification of model strengths and weaknesses. A methodology has been developed that guides the transportation analyst in identifying the appropriate level of analysis using typically available information and potential level of exposure based on the size of the transportation project. Five potential levels of analysis are identified based on both technical and policy considerations to guide the transportation analyst in applying a consistent set of criteria for developing a MSAT assessment. Details are presented on how to conduct the MSAT assessment as well as on the amount of information that should be included at each level of analysis. Recommendations are provided on how best to communicate these findings as part of an environmental assessment document.

**Predicting Air Quality Effects of Traffic-Flow Improvements**, Richard Dowling, NCHRP Report 535, 2005.
http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_535.pdf
This report contains a user's guide and case studies, providing a recommended methodology to predict the long- and short-term mobile source emission impacts of traffic-flow improvement projects. Guidance is provided to evaluate the magnitude, scale and duration of such impacts for a variety of representative urbanized areas. It is based on an in-depth exploration of methodologies used to estimate the impacts of traffic-flow improvement projects on mobile source emissions. It evaluates varying strategic approaches used to develop such methodologies, reviews advanced methodologies used by leading metropolitan planning agencies and offers suggestions to improve conventional travel models. The analysis of the effects of traffic-flow improvements on mobile source emissions focuses on four areas: operational improvements, travel time savings impacting traveler behavior, travel time savings increasing total demand for travel, and travel time savings stimulating growth and new development in specific areas within the metropolitan region.

**Short-Term Monitoring for Compliance with Air Quality Standards**, D. Caniparoli, NCHRP Report 479, 2002.
http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_479.pdf
This report contains the results of research into predicting ambient air quality exceedances at transportation project locations. It is intended to provide transportation and air quality planners and decision makers short-term monitoring procedures that can produce accurate and timely input data for predicting air quality exceedances without requiring the collection of large amounts of monitoring data. During the project, the research team developed and tested a statistical procedure to estimate probability of exceedance of the eight-hour carbon monoxide standard through the collection of a limited amount of

data at the project site. This procedure is intended to reliably estimate peak emission concentrations of carbon monoxide near proposed roadway improvements while obviating the need for extensive collection of monitoring data as prerequisite inputs for dispersion models. Requiring only limited monitoring data from the project location, this approach is intended to be used as a tool in transportation planning and air quality evaluations.

**Quantifying Air-Quality and Other Benefits and Costs of Transportation Control Measures**, Cambridge Systematics, Inc., NCHRP Report 462, 2001.
http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_462-a.pdf
This report presents potential improvements to the analytical framework for assessing the air quality and other benefits and costs of transportation air quality control strategies. Short- and long-range improvements are included that will enhance the metropolitan planning models being used and considered in major metropolitan areas. The report also discusses how a monitoring program can augment quantitative analysis to provide a fuller understanding of the air quality impacts of transportation control measures. A CD-ROM containing more detailed research results is included with the report.

# Survey Results

We distributed a survey to members of the AASHTO Research Advisory Committee for completion by appropriate staff at their agencies. The survey consisted of the following questions:

1. Has your agency carried out research quantifying the effectiveness of measures for reducing the air quality impacts of mobile source air toxics and other emissions occurring during the operational phases of transportation projects? If so, could you provide documents with or links to further information?

2. Who in your agency can Caltrans contact for more information?

Staff at 17 state DOTs and British Columbia responded to this survey. With the exception of Texas, none of the agencies had done research on reducing the air quality impacts of emissions during the operational phases of transportation projects. However, Texas has done a significant amount of research in this area and provided links to studies that have been incorporated into the **Related Research** section of this Preliminary Investigation.

## Survey Responses

The full text of each survey response is provided below. For reference, we have included an abbreviated version of each question before the response; for the full question text, please see the summary in the previous section of this report.

### Alaska

**1. Agency Research**
None.

**2. Contact for More Information**
Clint Adler, Chief, Research Development & Technology Transfer, Alaska Department of Transportation & Public Facilities, (907) 451-5321, clint.adler@alaska.gov.

## Arkansas

**1. Agency Research**
None.

**2. Contact for More Information**
Virginia Porta, Staff Planning Engineer, (501) 569-2108, virginia.porta@arkansashighways.com.

## British Columbia

**1. Agency Research**
None specifically. See http://www.bcairquality.ca/ and http://www.env.gov.bc.ca/epd/bcairquality/reports/topic_Transportation.html.

**2. Contact for More Information**
Chris Jenkins, Ministry of Environment, chris.jenkins@gov.bc.ca.

## Illinois

**1. Agency Research**
The Illinois Department of Transportation has not been involved with any research on effective mitigation measures for reducing air quality impacts of emissions during operational phases of construction projects. It has implemented special provisions for use of ultra low sulfur diesel fuel, reduced idling, and the installation of diesel retrofits for construction equipment.

**2. Contact for More Information**
Walt Zyznieuski, Air Quality Specialist, (217) 785-4181, walter.zyznieuski@illinois.gov.

## Iowa

**1. Agency Research**
The Iowa DOT has not carried out such research. Although Iowa is an attainment state, the Iowa DOT does offer CMAQ funds to local sponsors through Iowa's Clean Air Attainment Program where sponsors are required to quantify the expected benefits of congestion mitigation projects. The Iowa DOT has not had a practice of conducting additional research to verify these results beyond the examination of calculations submitted, but we have been considering placing more emphasis on monitoring the program's effectiveness by requiring sponsors to submit data once the project is in the operational phase.

**2. Contact for More Information**
Debra Arp, ICAAP Program Manager, Office of Systems Planning, (515) 239-1681, debra.arp@dot.iowa.gov.

## Louisiana

**1. Agency Research**
None.

**2. Contact for More Information**
Harold "Skip" Paul, Director, Louisiana Transportation Research Center, (225) 767-9101, harold.paul@la.gov.

**Maine**

**1. Agency Research**
None.

**2. Contact for More Information**
Dale Peabody, Transportation Research Division, (207) 624-3305, dale.peabody@maine.gov.

**Minnesota**

**1. Agency Research**
None.

**2. Contact for More Information**
Marilyn Jordahl-Larson, Office of Environmental Services, (651) 366-5801, marilyn.jordahl@state.mn.us.

**Missouri**

**1. Agency Research**
None.

**2. Contact for More Information**
Karen Miller, Senior Organizational Performance Analyst, (573) 526-4800, karen.miller@modot.mo.gov.

**New Hampshire**

**1. Agency Research**
None.

**2. Contact for More Information**
Glenn Roberts, groberts@dot.state.nh.us.

**Ohio**

**1. Agency Research**
None.

**2. Contact for More Information**
Erica Schneider, (614) 387-0134, erica.schneider@dot.state.oh.us.

**Pennsylvania**

**1. Agency Research**
None.

**2. Contact for More Information**
Michael W. Baker, Chief, Federal Initiatives/Air Quality/TE, (717) 772-0796, michaelba@state.pa.us.

**South Carolina**

**1. Agency Research**
None.

**2. Contact for More Information**
Henry Phillips, Environmental Unit, (803) 737-1872, phillipsmh@dot.state.sc.us.

**South Dakota**

**1. Agency Research**
None.

**2. Contact for More Information**
Dave Huft, dave.huft@state.sd.us.

**Texas**

**1. Agency Research**
TxDOT has sponsored both directly and indirectly research focused upon the air quality impacts of mobile source air toxics and other emissions occurring during the operational phases of transportation projects. The following links cover completed work:

1. http://swutc.tamu.edu/publications/technicalreports/473700-00033-1.pdf
2. http://tti.tamu.edu/documents/0-5955-1.pdf
3. http://tti.tamu.edu/documents/0-5955-2.pdf
4. http://www.utexas.edu/research/ctr/pdf_reports/0_4576_4.pdf
5. http://www.nrel.gov/docs/fy99osti/26003.pdf
6. http://swutc.tamu.edu/publications/technicalreports/476660-00067-1.pdf
7. http://www.utexas.edu/research/ctr/pdf_reports/0_5191_1.pd

We also have two projects sponsored by this office under way at this time:

a. 0-6237, "Characterization of Exhaust Emissions from Heavy Duty Diesel Vehicles in the HGB Area," Texas Transportation Institute, Research Supervisor Dr. Joe Zietsman;

b. 0-6629, "Texas-Specific Drive Cycles and Idle Emissions Rates for Using with EPA's MOVES Model," Texas Transportation Institute, Research Supervisor Dr. Reza Farzaneh.

TxDOT (through our fleet manager, Don Lewis) and TTI (Joe Zietsman) have also been teamed with researchers at the University of Houston on federally sponsored work. Further, TxDOT has sponsored a variety of research on truck freight, giving our researchers strong and continuing contacts with the heavy diesel manufacturing and operator communities. Rob Harrison, Nathan Hutson and Dr. Ron Matthews at

UT are contacts there. Harrison & Hutson (as well as Zietsman) are following very closely the application of various add-on emissions control devices.

**2. Contact for More Information**
Duncan F. Stewart, (512) 416-4739, duncan.stewart@txdot.gov.

## Virginia

**1. Agency Research**
None.

**2. Contact for More Information**
Jim Ponticello, Air Quality Program Manager, (804) 371-6769, jim.ponticello@vdot.virginia.gov.

## Washington

**1. Agency Research**
To date, WSDOT has not conducted research to quantify the effectiveness of air emission mitigations. We have been awarded money for reducing operational emissions through the Congestion Mitigation and Air Quality (CMAQ) program and the Diesel Emissions Reduction Act (DERA) that required us to prepare project specific emissions reductions data, but this data doesn't necessarily have wider application. We are also supporting a proposal from the University of Washington for Federal Transnow funding to evaluate potential emissions improvements/effects from facilities using Advanced Traffic Management Systems (ATMS). Washington currently has multiple CO and PM10 maintenance areas and one PM2.5 nonattainment area. For CO, we have altered signal timing on projects to prevent exceeding the standard (based on a very conservative screening tool—WASIST). We follow the most recent FHWA interim guidance for MSATs, which are projected to decrease over time on all projects we've evaluated. Representatives from WSDOT have participated on NCHRP panels that oversee national research on air emissions.

**2. Contact for More Information**
Tim Sexton, WSDOT Air Quality, Noise, Energy Policy Manager, 206/440-4549, sextont@wsdot.wa.gov.

## Wyoming

**1. Agency Research**
None.

**2. Contact for More Information**
Timothy McDowell, State Programming Engineer, (307) 777-4412, tim.mcdowell@dot.state.wy.us.