Symposium Summary:

Vehicles and Air Quality

Sponsored by the MIT Laboratory for Energy and the Environment
and
Northeast States for Coordinated Air Use Management

3-4 August 2005
Endicott House
Dedham, Massachusetts
Massachusetts Institute of Technology
Laboratory for Energy and the Environment
77 Massachusetts Avenue
Cambridge, MA 02139-4307

This Symposium is part of a series established in 1993 to inform decision-makers on scientific aspects of important air pollution issues. Summaries of the symposia since 1996 are available at http://lfee.mit.edu/metadot/index.pl?id=2212&isa=Category&op=show

Policy is discussed in the framework of scientific research. For example, how policy questions might influence research or how limitations of current scientific knowledge might influence policy decisions. Participation in the conference is limited to an invited list of approximately eighty members of the scientific, regulatory, industrial, and public interest communities. The small size of this group promotes discussions that have in the past led to important progress on ideas for improvements in air pollution control.

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Bob Slott, MIT, Chair
Praveen Amar, NESCAUM, Co-Chair

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Session 1: Vehicle Emission Inventory

Bob Slott opened the symposium by noting that the theme for 2005 Endicott House symposium was broader than usual at the request of many of the sponsors.

Gene Tierney, EPA-Office of Transportation and Air Quality (OTAQ)

EPA has developed a National Mobile Inventory Model (NMIM) to estimate mobile source emission inventories. NMIM will be used in-house by EPA to generate inventories to support rules, the National Emission Inventory, etc., as opposed to previous emission inventories which were contractor generated. NMIM integrates two EPA models, namely MOBILE6 and NONROAD. By 2007, EPA is proposing to replace MOBILE6 and NONROAD with the MOVES model.

The main inputs to NMIM include geography, time, on and off road vehicles/equipment, pollutants as well as anticipated growth rates in critical parameters. State and local inputs to NMIM are the same as that used for MOBILE6 and NONROAD. NMIM outputs inventories of criteria pollutants, ammonia, CO_2, and Hazardous Air Pollutants (HAPs).

Results from NMIM show a small increase in CO after 2015. On road vehicles' share of NOx emissions is projected to decrease steadily through 2030 while absolute emissions decrease by a third. Major growth in NOx emissions up to 2030 is projected to come from commercial marine and locomotive sources. Non-road vehicles and equipment are found to be dominant sources of PM2.5. The largest growth in expected to come from C3 marine sources.

Tierney described an on road experiment to assess highway diesel and gasoline PM emissions. Five hundred gasoline vehicles in Kansas City were tested for PM emissions. Heavy duty diesel data were obtained from a study conducted in California. No special focus was placed on "smokers" as these samples were chosen randomly to represent the fleet. The results show a highly skewed distribution.

Recent certification data show that actual cold start HC emissions are much higher than MOBILE6 assumptions for Tier2 vehicles. Also, MOBILE6 assumptions for CO emissions from Tier2 vehicles were high.

Some concerns were raised that a mismatch between MOBILE6 and MOVES might affect state implementation plans. EPA is aware of such problems. These changes are likely to be similar to the change between MOBILE5 and MOBILE6, and EPA will work with the states to ensure a smooth transition.

For more information on NMIM: http://www.epa.gov/otaq/nmim.htm.

For more information on MOVES: http://www.epa.gov/otaq/ngm.htm

Robert Harley, University of California at Berkeley

Harley pointed out that there are two main approaches to calculating vehicle emissions. As opposed to MOBILE, which uses a vehicle mile traveled (VMT) based approach; Harley uses a fuel-based approach. The emissions are estimated based on fuel sales data at the state level, emission factors per unit of fuel, and weigh-in-motion traffic count data. The weigh-in motion counts can distinguish heavy-duty diesels from light-duty vehicles. This is important because on-road diesel use is growing at a much faster than gasoline use, even though in absolute terms, diesel use is much smaller. Harley claims that variation in emission factor per unit of fuel burned is less than variation in VMT data, so it may be possible to more accurately estimate emissions.

Harley described his experimental set up which is actually a kilometer long highway tunnel, the Caldecott Tunnel in California. Fuel burned in the tunnel is determined by measuring CO2 emissions. Harley observed that light duty gasoline vehicles' emissions factors in grams per liter have halved between 1994 and 2001 for NOx and were reduced even more for non-methane organic compounds (NMOC). On-road measurements and truck chassis dynamometer tests show that heavy-duty diesel truck emission factors for NOx were not reduced as expected prior to 2000.

Overall, diesel and gasoline highway emissions patterns vary widely for NOx. The peak in diesel and gasoline NOx emissions occurs at different times during the day. This can be explained by the time of the day when freight movement is carried out as opposed to the heavy commuter traffic times; there is also a large decrease in diesel truck traffic and associated emissions on weekends.

Ozone data from Southern California suggest a large change from 1994-1998, but not as great a reduction since then. The so-called weekend effect still persists where ozone concentrations over the weekend are found to be higher than during the weekday. Harley's work shows that sites with weekend ozone effect have increased significantly in the 1995-1999 when compared to 1980-1984 period, and the effect has spread from the Pacific coast to include inland sites as well. An explanation for the weekend effect can be given by looking at the shape of the ozone isopleth diagram[1]. There has been a decrease in VOC emissions on weekdays in 1990s leading to overall reduction in ozone levels. At the same time, NOx emissions are considerably less on the weekends. Due to the shape of the NOx-VOC isopleth curve, decreased NOx on weekends, overall ozone levels are seen to increase. Thus, some parts of California appear to be a VOC sensitive environment as opposed to other places where reduction in NOx would be the primary method of reducing ozone levels.

Session 2: Vehicle Congestion and its Effects

Joseph Sussman of MIT moderated the session on vehicle congestions and its effects.

Tim Lomax, Texas Transportation Institute, Texas A&M University

Lomax started by noting that congestion has increased by a factor of five in the 20 years since 1982. Congestion in 2003 was estimated to have cost approximately 3.7 billion hours and 2.3 billion gallons of fuel. Forty percent of the peak period congestion can be characterized as either extreme or severe, up from 12% in 1982. Furthermore, congestion seems to be getting worse in cities of all sizes. In general congestion trends in small urban areas lag medium sized cities by 10 years, while medium sized city congestion trends lag that of big cities by 10 years and so on. As the same time, variation in congestion between different cities of same size is large. The severe and extreme congestion also worsens emissions as VOC and NOx emission rates are higher at very low speeds.

Main causes of congestion are bottlenecks (a national average of 40%), traffic incidents (25%) as well as bad weather (15%). Bottlenecks typically occur at freeway to freeway interchanges, lane reductions, high volume entrance ramps, as well as intersections with heavy traffic flow. Addition of capacity and management of signals can have a positive impact on

[1] For a discussion of the ozone isopleth diagram see "Rethinking the Ozone Problem in Urban and Regional Air Pollution (1991) Commission on Geosciences, Environment and Resources (CGER), National Academy Press, 1991, Figure 11-1, page 352

bottlenecks. In terms of capacity addition, there seems to be a growing trend towards some form of a pricing mechanism such as a combination of high-occupancy priority and toll or variable pricing. While additional capacity is needed, it cannot be the only solution to the problem as demand keeps increasing many times faster than supply. In general, bottlenecks can be reduced by a combination of buses, carpool, and pricing measures in addition to capacity expansion, improved operation and demand management.

Traffic incidents, the second major cause of congestion, are characterized by vehicle breakdowns, flat tires, vehicles running out of gas, collisions. Quickly detecting an incident and rapidly responding to it is vital in minimizing the effect of incidents on congestion. Houston's SAFEclear plan is an example of a program aimed at rapid removal of vehicles before they cause congestion. Lomax suggested that drivers involved in collisions should steer their vehicles to clear the road lanes if they can and avoid rubbernecking when they are near collisions or stalled vehicles.

Ramp metering can prove to be an effective method of reducing congestion. The aim of ramp metering is to reduce collisions and thereby make travel time more predictable. This day to day variation in travel time is a source of traveler frustration and can be measured with the concept of buffer time -- the extra travel time (or buffer) that must be allowed for on-time arrivals. An experiment that turned off the ramp metering operation in Minneapolis-St Paul illustrated this concept. Average congestion increased, but the time to accomplish a trip on 19 workdays out of 20 increased much more significantly, showing the effect of the 24% increase in collisions. A modified metering scheme was established after the experiment which nevertheless results in a higher buffer index (more day-to-day variation in travel time) than the original metering scheme.

To reduce congestion in work zones, rapid construction methods and nighttime construction may be useful.

Lomax concluded that in spite of serious efforts, congestion won't go away, and reminded audience of Anthony Downs' principle of triple convergence (traffic flows in any region's overall transportation networks form almost automatically self-adjusting relationships among different routes, times, and modes). Thus, really aggressive efforts are likely to, at most, stall congestion at the current rates. He reminded the audience that this would be a significant advantage relative to the current trend of congestion growth.

During discussion questions were raised about effectiveness and impact of telecommuting. It would be useful to know where telecommuting takes place successfully. A question was also raised about the potential contribution of rail service in relieving congestion. Lomax responded that rail can provide congestion benefits in congested corridors that serve large, densely developed business centers and Bus Rapid Transit (BRT) was emerging as another option. For a city like Houston, with several dispersed major activity centers, regional HOV lanes may be a good solution.

For more information on TTI mobility projects, see http://mobility.tamu.edu/ and http://tti.tamu.edu.

Tom Batz, TRANSCOM

TRANSCOM is responsible for regional coordination and communication between 16 main agencies and over a 100 affiliated agencies from NY, NJ, and CT. These include various departments of transportation (DOT), police and transit authorities. TRANSCOM's three main functions are regional incident management, regional construction coordination, and multi-agency technology development.

As an example of the type of work done by TRANSCOM, Batz presented a case study of a fatal truck fire on upper level of George Washington Bridge, NY in July 2003. While the Port Authority's immediate concern was the fire, related forensic activities, and ensuring the structural integrity of the bridge, TRANSCOM started to think about the implications of the incident for the whole region. TRANSCOM was responsible for notifying all concerned authorities who would be affected directly or indirectly throughout the day as a result of the accident. The next step was to notify consumers using variable Message Signs (VMS) and Highway Advisory Radio (HAR). Having established communication between agencies within the region, TRANSCOM tried to coordinate other DOTs and highway management services to minimize congestion and avoid traffic delays during the day. This involved activities such as slowing down or suspending construction activities in other corridors.

TRANSCOM's work is facilitated by a Regional Architecture system and an Interagency Video Network (IRVN). With these systems, TRANSCOM and its member agencies are able to monitor different locations and corridors, transit and highway readers at the same time. Information from these systems are made available to the public on http://www.trips123.com/ so that commuters can improve their travel plans. Some concern was raised over privacy issues as TRANSCOM collects traffic data from easy pass vehicles. TRANSCOM's approach to protect vehicle user's privacy while collecting data includes scrambling vehicle tag information, refraining from use of toll booth readers for traffic data collection, and deleting the tag data once the tag leaves the system.

Scott Griffith, Zipcar

Car sharing is still a relatively unknown concept in America. Zipcar, established in 1999 in Boston, decided to bring this concept from Europe. Zipcar intends to make *access to a private car as easy and convenient as getting cash from an ATM*. Currently, there are about 40,000 Zipcar users in Boston, NYC and Washington D.C. Zipcar targets consumers who need cars only occasionally, from once a week to once a month for several hours at a time. Thus, it competes with car ownership and taxi services only in a limited sense.

Zipcar services are accessed mainly online. Prospects join at zipcar.com and choose from several plans. Members reserve online or over the phone. At the time the reservation is made, a wireless signal is sent to the Zipcar. When members arrive at the zipcar, their zipcard identifies them and unlocks the door. Gasoline and insurance costs are included in the hourly rate for vehicles. When done, customers return the car to its reserved spot and walk away.

Zipcar users have tended to be young, well educated, and either students or having above median income levels. Zipcar vehicles tend to be more fuel efficient as compared to average vehicle fleet. Zipcar claims that each of its vehicles can be thought of taking 20 vehicles off the roads. With a round of institutional funding and start of its operations on the west coast, Zipcar aims to make car sharing a national urban phenomenon.

Session 3: The Future of Vehicle Emission Testing

Richard Gibbs of NYDEC moderated the session on vehicle emission testing.

Tom Cackette, California Air Resources Board (CARB)

Cackette addressed three issues CARB is currently dealing with in the area of vehicle emission testing. First topic concerns inspection of newer and older vehicles for smog producing

emissions. Second deals with upgrading emission control on older vehicles. The third involves the use of on board diagnostics (OBD) in heavy duty (HD) vehicles.

Since newer cars fail emission inspection very infrequently, testing very new vehicles may not be very productive. Testing two year old cars is counter productive as failure rates are only of the order of 2%, and 95% of the costs of inspection maintenance programs (I/M) for these vehicles are in the testing of them. According to CARB estimates, cost effectiveness of testing 4 year old cars was also quite poor ($44,000 per ton of emissions). Yet inspections on 4 year old cars continued until recently as CARB was reluctant to give up the 2.6 tons per year of HC and NOx emissions predicted to be saved from I/M for these 4 year old cars . More recently, however, California has decided to start inspection at 6 years of vehicle age as failure rate at six years was found to be almost five times that at three years of age. Four year old vehicles are now exempt from testing for a small fee. This fee has helped to generate 60 million dollars per year, which have been used more cost effectively for diesel retrofits at a cost of $3,000 per ton of emission avoided.

Emission rates of older cars are more than 10 times that of 5-6 year old vehicles. Thus by testing older vehicles it is possible to reduce 26 g/day of emissions from one vehicle as opposed to 1.1 g/day for 4 yr old cars. By not testing 30+ year old vehicles, California believes that it may be giving up on more than 16 tons of emissions per day. Thus, it is worthwhile to test older vehicles. California used to exempt vehicles over 30 yrs. of age, but now only vehicles before 1976 are exempt from emission testing. Other states have similar exemptions. For example, Massachusetts exempts vehicles before 1984, where as Connecticut exempts vehicles older than 25 years. California also plans to test middle age cars (>15 years) annually instead of every two years although this will require legislative approval. It is estimated that this testing will affect about a quarter of California's vehicle population and possibly deliver an additional 13% reduction in emissions. While California provides monetary assistance for repairs of older vehicles, study of deterioration rates indicates that up to 40% of the vehicles fail again in 6 months after repairs. It is not clear if cars made during 1980-1985 range have inherently poor emission performance.

Only three states currently require evaporative testing. California has developed a pressure decay test on evaporative systems that costs less than 6 dollars per test and requires less than five minutes. California has shown these tests to have low false positive rates. Typical repair costs for these systems are about $175 and the failure rate has been about 18%.

CARB wanted to explore if retrofitting older vehicles (1980-1994 make) would significantly improve emission performance. Among the emission control measures explored were replacing evaporative canisters, oxygen sensors, and catalysts. CARB thought that oxygen sensor replacement looked promising based on previous studies but new testing has shown that not to be the case. Evaporative canister replacement also doesn't look good. Three types of catalytic systems were evaluated. "Cheap" $100 catalytic converters are found to be less than 40% efficient and don't last more than 10, 000 miles. Original Equipment Manufacturer (OEM) catalysts from a vehicle's original model year have 60%+ efficiency, and last a little longer. New, OBD2 era bench aged catalysts, are found to last a lot longer and have emission reduction efficiencies similar to the OEM catalysts. More evaluation is needed before a catalyst replacement program can be considered.

Currently, there are no heavy duty vehicle on-board diagnostic (OBD) systems, but OBD will be required by 2007. Recall testing on heavy duty vehicles starts after 2007, whereas I/M currently take place only for smoke detection. Heavy duty diesels are adding many emission

controls including PM filters in 2007 and NOx adsorbers or Selective Catalytic Reduction (SCR) systems by 2010. Using OBD on heavy duty vehicles can be expected to lower emissions. In July 2005, California adopted heavy duty OBD requirements effective in 2010, and EPA is expected to follow. It is expected that OBD will replace periodic smoke inspections and lead to better repairs, and cheaper fleet inspections.

John Trajnowski, Ford Motor Company

Trajnowski discussed the industry perspective on CARB's 2010 heavy duty OBD requirements. He advocated a nationwide harmonization of OBD rule as EPA formulates its own OBD requirements. He also cautioned against any OBD requirements that might potentially interfere with 2007/2010 emission standard attainment. He also suggested at least a four year lead time and a three year period of stabilization for the new requirements.

Trajnowski also discussed the technical challenges in meeting the OBD requirements. According to the requirements for Diesel Particulate Filters (DPF), OBD must be able to detect all types of deterioration or failures of the DPF before tailpipe emissions exceed 0.05 g PM in 2010-12, and 0.03 g PM in 2013 and later. Proposed monitoring approach of the requirements is to monitor for sufficient soot loading by looking at pressure drop across DPF and comparing results with expected soot load estimated from soot loading model. It may not, however, be possible to detect all failures at the emissions threshold. Combinations of substrate cracking and melting and other non-homogeneous failures can be missed by pressure-drop monitoring technique. In addition, Trajnowski claimed that soot load modeling may not be sufficiently accurate for OBD monitoring purposes because oil, fuel and other operator variables cannot to be estimated in the model. He also cautioned that soot load models may not be adequately accurate for certain fuels such as biofuels or biofuel blends. This would lead to a greater number of false positives, and potentially unwarranted and costly replacements. He also noted that in order to meet the 2013 threshold limit of 0.03 g for soot measurement, a new monitoring technology such as a soot sensor may be required.

With respect to NOx aftertreatment OBD must detect deterioration or failure of NOx aftertreatment devices before emissions exceed 0.5g in 2010-12, and 0.4g in 2013 and later. The proposed monitoring approach involves utilizing NOx sensor in exhaust system to detect catalyst deterioration. Trajnowski pointed out that the NOx sensors may not be either durable or accurate enough during the useful life of the vehicles. As a result there may be an increased number of false positives. While Ford will make a good faith effort to meet the requirements, Trajnowski wanted regulators to be flexible with the regulations in case certain requirements are found to be not feasible.

Merrylin Zaw-Mon, EPA Office of Transportation and Air Quality (OTAQ)

Zaw-Mon noted that the Tier 2 standards are great, but EPA must ensure effective implementation. The light-duty standards are being phased in from 2004 to 2007. The auto industry significantly exceeded the required number of very clean vehicles sold last year (MY 2004) which were at 35%, rather than the required 25% of sales. Tier 2 Fuel requirements are also bring phased in. Sulfur in gasoline will be reduced from ~300ppm to 30 ppm by January 2006, whereas sulfur in diesel will be reduced from ~500ppm to 15 ppm by June 2006. Heavy duty manufacturers are working with EPA to prepare for certifying 2007 heavy duty trucks. A

large number of pre-production trucks are being tested for their compliance with the 2007 requirements. In the summer and fall of 2005, manufacturers are testing prototypes with American Trucking Association. Testing is also underway for sulfur test variability in a round robin fashion. This will cause only a 45 day delay from final rule.

Emissions certification testing is performed by manufacturers, months in advance of vehicle production. Car manufacturers test emissions of pre-production vehicles on a dynamometer following an "urban" driving cycle. Truck and non-road equipment manufacturers also apply federal test procedures to test trucks and non-road engines on engine dynamometers. EPA audit tests on about 15% of light-duty vehicles in its Ann Arbor lab (~200 tests). EPA issues certificate if data are acceptable.

As vehicles age, EPA continues to assess whether vehicles meet standards. The goal of in-use testing is to ensure compliance through "useful life" (120,000 miles for light-duty vehicles, and 110,000 to 435,000 miles for heavy duty vehicles). This also helps to deter poor quality and poor durability, and also helps to detect and fix in-use problems early. Such testing encourages voluntary action on part of the manufacturers who can order recalls. In 2004 there were 2.7 million light-duty vehicles and trucks recalled for emission related problems. All of these were voluntarily recalled by the manufacturers; however, EPA used its direct influence to obtain 3 of the 38 recalls. 12 of these were OBD system problems. The useful life emission reduction benefits of these recalls are over 3,000 tons of HC, 150,000 tons of CO and 2,000 tons of NOx.

A heavy duty in-use testing program was started in 2001. Trucks are procured for testing from private companies, government agencies, truck rental companies, and private individuals. Testing is carried out under a wide variety of in-use conditions to ascertain emission impact (altitude, temperature, terrain, driver interactions) including marathon tests to/from Denver, CO. In 2004, EPA conducted 105 in-use heavy duty tests (100 on-road, 5 off-road). In general, heavy duty trucks seem to be complying with the NOx/NTE[2] standards. EPA is now encouraging more of the in-use testing to be conducted by the manufacturers under the compliance assurance program (CAP 2000). Manufacturers are now required to test, using portable devices, up to 25% of engine families per year, or 1 engine family per year for small manufacturers.

According to NAS recommendations, EPA is working to characterize the impact of high emitters on today's mobile source vehicle inventory. This is being done by acquiring state I/M modal data and any available remote sensing data. A study in Kansas City collected a random, representative, stratified sample (480 vehicles) of the entire light duty gasoline vehicle fleet and measured all criteria pollutants plus PM and toxics. This comprehensive real-world dataset was collected under a wide array of driving conditions. EPA hopes that the statistical approach in the study will allow them to characterize the distribution of all emitters, and in particular high emitters.

A light-duty vehicle OBD study carried out by EPA on 200 vehicles indicates that most OBD systems are effective and durable with costs per unit of emissions reduction similar to that of I/M programs. These findings are similar to those of California and Colorado. With respect to heavy-duty OBD, EPA and CARB have signed a MOU to recognize each others certification, and on working toward development of a 50-state Heavy-duty OBD program.

Mike Walsh asked whether developments in PM measurement capability are optimistic. Zaw-Mon answered that the developments look promising. There was a question raised whether tailpipe testing may not be required some day with advances in OBD. Zaw-Mon replied that

[2] NTE is the NOx emission levels during normal operating conditions with varying speeds and engine loads.

OBD is proving to be effective, so over time (10+ years perhaps) tail pipe emissions testing may be dropped. One of the questioners was concerned that heavy-duty OBD may not prove to be as effective as light-duty OBD. There was also a clarification on whether EPA selects particular vehicle types for checking high emitters to which Zaw-Mon answered in affirmative.

For more information, please see http://www.epa.gov/otaq/

Ted Kotsakis, State of Oregon Department of Environmental Quality

In a presentation titled "Oregon's OBD Adventures", Kotsakis described the ambitious OBD program undertaken by the state of Oregon since year 2000. Oregon now exempts Oregon vehicles younger than four years from testing, but outside state vehicles are tested after two years. The enhanced I/M dynamometer testing program instituted in 1996 is in the process of being phased out by the end of 2006 as the population of vehicles under enhanced testing is decreasing since the OBD testing program began for vehicles 1996 and newer. Currently, OBD vehicles comprise 56% of all vehicles tested. Oregon's vehicle inspection program does not plan to build any new testing facilities in spite of an increase in total vehicle population requiring emission testing. Customers will be able to test their vehicles without going to a testing facility.

Alternatives to OBD tests at emissions testing stations include self testing, remote OBD sensing, internet transfer of OBD data, and mail in of OBD data. A self testing center would be open 24/7 and access to the center granted by a credit/debit card. A picture of the vehicle taken during the test will help to verify the identity of the vehicle being tested.

Internet or mail-in of OBD data involves a data storage device attached to a data link collector. A red/yellow/green indicator identifies the status of the device. The customer has the flexibility of initiating contact with vehicle inspection program at a suitable time. The device can also be dropped off at a testing facility, mailed in, or the data transfer completed over internet.

Oregon is also planning to allow wireless OBD data broadcast. SysTech Corporation is doing the implementation of the project which is scheduled to start in summer of 2006. Initially, the devices will be tested on fleets such as cabs.

A question was asked about who provides the data storage links for OBD. Kotsakis replied that same device can be used for all types of OBD monitoring. Each device costs about $35. In order to transmit the data, receiver needs power, antenna, and a T5 data transfer capability. Gene Tierney asked whether these devices can be made a part of all vehicles, especially HD trucks. The consumer surveys indicate that consumers were pretty evenly split between people that would use the 24/7 self-test and those using the remote OBD testing paradigm. Another questioner asked Kotsakis whether OBD requirements will have a significant impact on vehicle retirement. Oregon expects that there will be some loss of NOx reductions, since Oregon has not implemented advanced standards for older vehicles. The state, however, is in attainment, and also does not expect any problems with particulate matter emissions.

Chris Stock, Environmental Systems Products (ESP)

Stock warned the participants not to consider OBD devices as a *Magic Box* that will solve emissions measurement and monitoring problems. Generally, people understand the importance of I/M programs in improving air quality, but they dislike the inconvenience of the program. While the OBD magic boxes are easy to use and relatively cheap, the real question we should ask is whether these devices really work. By citing examples from web discussion boards, Stock argued that many people might find ways to circumvent OBD devices.

Since the causal chain from sources of emissions to concentrations to human exposures leads to health effects, Stock argued that future funding for I/M programs may depend on expected/demonstrated health benefits. OBDs form just one step in this causal chain.

With respect to OBD programs being implemented Stock raised a number of questions. If other sources like marine are going to be more important as seen from emission inventories, concentrating just on vehicle OBD may not solve the problem. Thus, different modes of transportation must be addressed simultaneously. As a result, what to test and how to test becomes an important question. A transparent auditing process for hardware, software, data management will be needed. Coordination/harmonization between different state programs will not be easy. Finally, what are the security implications if someone hacks in to OBD system?

In conclusion, Stock stated that it is not the devices and technology, but the program policies and implementation that will matter. He recommended that a stakeholder group be formed consisting of State and Territorial Air Pollution Program Administrators (STAPPA) and Association of Local Air Pollution Control Officials (ALAPCO), along with manufacturers and vendors to examine the complex management issues with OBD.

Session 4: Older Vehicles: Repairs, Retrofit, and Scrappage

Coralie Cooper of NESCAUM moderated the session on older vehicles. She raised four fundamental questions: How to make the move from hundreds to thousands and maybe millions of retrofit systems? In doing so, how are the fleet managers to be supported. Whether voluntary programs work or contractual/mandated programs are needed. What are the major cost concerns as large scale vehicle retrofit programs are undertaken?

Merrylin Zaw-Mon, EPA Office of Transportation and Air Quality

EPA has decided to take a two pronged approach for dealing with diesel emissions. For new diesels there will be stringent new standards for engines and fuels. While more stringent standards are set to take effect in the next decade, over 11 million in-use diesel engines will continue to emit large amounts of pollution over the next twenty years. Reduction in fine particulates from existing diesel vehicles will not be easy, but a variety of retrofit technologies are available. NOx retrofit technologies are also emerging. Thus, the second component of EPA's approach is a voluntary sector based initiative for existing diesels. The different sectors are school buses, ports, construction equipment, agriculture and freight. These sectors were chosen based on numbers of existing diesel engines in these sectors and potential for achieving greatest emissions reductions in the near term. The emission reduction program goes beyond just retrofitting older vehicles and equipment with emissions reduction technology. It also encourages replacement of oldest vehicles and equipment, and reduction in vehicle idling.

Launched in April 2003, EPA's *Clean School Bus USA* program is a public-private partnership to reduce school bus idling, reinforce smart driving practices, retrofit buses with modern pollution control technology, and replace the oldest buses with new, cleaner buses. The target is to modernize the entire school bus fleet by 2010. While the Congress has provided $5 million per year in 2003 and 2004 for this program, requests from communities totaled over $60 million with significant matching grants. In FY03, grants from this program helped over 5000 school buses to upgrade emission performance.

Clean Ports USA initiative encourages port authorities and terminal operators to retrofit and replace older diesel engines with verified technologies and address idling concerns of freight hauling in and out of port, use cleaner fuels, provide economic incentives for ports' contracts with tenants, contractors, and others to be more efficient, and offers assistance to port authorities and terminal operators to help them overcome barriers that impede the adoption of cleaner diesel technologies and strategies. LA and Long Beach ports have done some useful work in the clean ports area. Grants and tax incentives have proved to be useful carrots in ensuring the success of this program.

Given increasing number of major construction activity in major metropolitan areas, EPA's *Clean Construction USA* program is targeting public sector projects in non-attainment areas. Two projects, in Chicago and Denver, have been initiated under this program.

SmartWay Transport program challenges trucking companies to improve the environmental performance of their fleets. The program aims to reduce all unnecessary engine idling, and increase efficiency and use of rail and intermodal operations. In FY05, $5 million were available under this program for an anti-idling grant competition. EPA has also launched a remote sensing project on US-Mexico border to identify the opportunity to retrofit trucks which frequently cross the border.

Promoting the use of biodiesel is the primary strategy for reducing emissions from agricultural diesel engines. A demonstration retrofit project is also underway in Boise, ID.

Overall, diesel retrofit programs include a variety of technologies including PM filters, Ultra Low Sulfur Diesel (ULSD), improved catalysts, compressed natural gas, diesel emulsion, and biodiesel. Partnership with fleet operators is essential to develop confidence about the technology. Retrofit programs also take place in a diverse mix of settings from small rural locations to large metropolitan school districts. Costs of different technologies vary widely, from $500-$2,000 for Diesel Oxidation Catalysts to $10,000-$50,000 for Selective Catalytic Reduction (SCR) systems. Overall program costs depend on many factors including number of vehicles retrofitted, retrofit technology needed, and ease of installation. Future funding for these programs is in the rage of $12-$15 million per year. In spite of these differences, common elements for success in different projects have been a commitment to making a project successful, leadership at many levels, flexibility, and patience.

For more information, please see http://www.epa.gov/cleandiesel/

Tom Cackette, California Air Resources Board (CARB)

Cackette discussed California's experience in reducing emissions of in-use diesel engines. He noted that health impacts from diesel emissions in California alone are estimated to cause approximately 2,900 premature deaths, 240,000 asthma attacks/respiratory symptoms, and 600,000 lost work days. The number of premature deaths alone is comparable to deaths from auto accidents or homicides in California each year.

California's Diesel Risk Reduction Plan (DRRP) aims to reduce exposure to diesel exhaust by 85% by 2020. The plan has formulated standards for trucks and on-road diesels, whereas locomotive and harbor craft standards are planned. Emissions from diesel engines on ships have not been regulated because the ships often fall under international jurisdiction.

Currently, about half of diesel emissions come from engines over ten years of age. Thus, the DRRP is aiming retrofitting of mid-aged engines and replacing older engines. There are a number of verified retrofit devices, but these devices are not applicable to all engines. Cost of a

retrofit varies from $2,000 dollars for a catalyst, $5,000 for a flow through filter, to $8,500 for passive filters.

LA's experience with trash truck retrofit is very good. All 380 trash trucks have been retrofitted with particulate filters. In a million miles driven on these vehicles collectively, no major problems have been reported.

Railroad regulations have not been possible due to federal pre-emption. California has reached a MOU with federal authorities over idle shutoff devices, smoke inspections and repair, use of CARB diesel when refueling in CA, as well as risk assessments and risk mitigation of rail yards. Railroads in the LA area must use 2005 and newer locomotives by 2010.

Heavy Duty diesel engines were found to emit five times as much NOx when not running on a standard test cycle. Engine manufacturers have reached a settlement with EPA/CARB, and agreed to reflash programming on rebuild to reduce in-use NOx emissions. However, only 10% of engines have been reflashed since the settlement. CARB established a voluntary program to speed up reflash, but only one engine manufacturer was on track to meet CARB targets. CARB then mandated reflash after which it was sued by the manufacturers.

There are a number of monetary incentives to fund the incremental cost to install modern engines, or use alternative fuels. Over 5,000 engines have been cleaned up in the past six years at a cost of $6,000 per ton. Funding in the future is of the order of $140 million per year for retrofit projects including PM retrofits and vehicle scrap reduction.

When asked about the cost effectiveness of ARB's programs, Cackette replied that cost of the program is estimated to be in the range of $15 to $70 per pound of PM reduced. Another questioner asked about the effect of NO_2 formed in PM filters. While such NO_2 formation increases ozone emissions, the net benefits of using the PM filters are still positive when considering the large number of premature deaths avoided.

There was also a question about durability of heavy-duty diesel retrofits. CARB has instituted a reporting requirement through its OBD program and will carefully monitor the emissions. The cost of retrofitting 1.2 million diesel engines in CA at a rate of $5,000 per engine is $10 billion, but the current funding is about $140 million per year. So clearly, a lot of cost sharing is required. The Carl Moyer funding program pays for incremental modification costs, but it is not enough. There was a discussion about the amount of emissions reduction from NOx rebuilds. Cackette thinks that retrofits are cheaper, although someone asked if the new NOx retrofit technologies have proven to be reliable.

About the heavy duty reflash, a questioner asked if EPA could formulate regulations mandating reflash. Cackette thinks that EPA would probably not be able to mandate a reflash. ARB has tried voluntary approach in the past, but there is a legal dispute between manufacturers and EPA/CARB over what was permissible under the settlement.

For more information, please see http://www.arb.ca.gov/diesel/dieselrrp.htm

Brian Mormino, Senate Committee on Environment and Public Works

Mormino's presentation focused on the Diesel Emissions Reduction Act of 2005 (S.1265). The Act establishes voluntary national and state-level grant and loan programs for diesel retrofits. While the Act authorizes $200 million annually for fiscal years 2007 to 2011, the actual level of funding will be subject to appropriations. The Act takes a non-technology specific (diesel oxidation catalyst, a diesel particulate filter, fuels, idle reduction etc.), no-sector specific (on-road and off-road, mobile and stationary, ports, agriculture), non-location specific approach

to retrofit, and it was thus backed by a broad coalition of environmental, industry, labor, and public officials. Over a year of dialogue with different stakeholders preceded the introduction of the bill in the Senate. According to Mormino, this Act indicated that people recognize the importance of cleaning up diesel engines in improving air quality and that meaningful progress can be made in the divided political atmosphere in Washington.

Seventy percent of the funds from the program will be allocated to EPA. National program funds can not be used for mandated state level programs, but funds can be used to leverage state level programs such as the Texas initiative ($140 million). All government bodies as well as nonprofit organizations can apply for the EPA grants. There are several priority areas defined in the national program, but at least 50% of the grants are targeted for public fleets. Up to 10% of the funds can be used for development and commercialization of emerging technologies. EPA is required to report on the program biannually.

Twenty percent of the funds will be available to states that apply, and the remaining ten percent is set aside as matching funds for state programs. States will have flexibility is using these funds. There was some discussion on what type of language in a SIP would count as a mandate: If the state does not require, for example, all trash trucks to retrofit, then federal money can still be used. EPA will develop guidelines for the program so that the states can use this program to meet their SIP requirements. There is a 3% retrofit credit available for state programs which is separate from the provisions of this Act.

A question was asked about the kind of considerations that might inhibit states from applying for this program. Mormino answered that there are no limitations, so if significant funding is provided, he expects most states to apply. If all fifty states apply, then each would get 2% of the total money set aside for state programs.

There was a general discussion about funding issues for this program. Currently Mormino indicated that getting the full appropriations will require a large lobbying effort. If insufficient funds are appropriated, then the state portion of the program could be eliminated for that year. Mormino asked the participants to spread the word about the program in order to secure support. He also reminded the audience that the Act also has several non-financial provisions.

Patrick Mohrman, Caterpillar

Caterpillar has made improving emissions of its in-use equipment a part of aftermarket business, and is currently expanding its retrofit operations. Caterpillar considers that aftertreatment, refueling, repowering, repairing/rebuilding, renting or replacing are all parts of a retrofit business. Caterpillar aims to reduce 180,000 tons NOx and 35,000 tons PM emissions by 2010 through its retrofit program which is equivalent to life time emissions from about 45,000 trucks.

For construction equipment owners, equipment is one of their main assets. Hence, residual value management of equipment is quite important. Diesel retrofit programs have proved to be quite cost effective as compared to other Congestion Mitigation and Air Quality improvement (CMAQ) programs. However, due to a large number of in-use diesel engines (about 11 million), and variation in local regulations, there is a proliferation of suppliers of retrofit technology for diesel engines.

Average age of on-highway equipment is about 11 years, whereas that of non-highway equipment is about 18 years. Mohrman pointed out that equipment owners are generally interested in retrofit only when an economic incentive is present. Retrofitting is a complex

process with many different working arrangements, thus requiring a lot of applications engineering. Also needed is experience in installing a variety of retrofit devices. Pre-86 trucks and pre 96 off-road vehicles are not good candidates for particulate filters. While repower and overhaul is the best option for these vehicles, doing the same for Tier 1 to Tier 2 HDDVs is quite challenging. Oxidation catalysts are applicable to most engines.

There are multiple requirements in order to use diesel particulate filters (DPFs). Besides use of ultra low sulfur diesel (ULSD), DPFs require a NOx to PM ratio of greater than 20 to 1 and exhaust gas temperature above 260C at least 40% of time to cause regeneration. This is important as the same equipment used in different applications shows very different ranges of temperature between which DPF needs to operate. The DPF volume is about 2.5 times the engine displacement and DPFs have to meet engine OEM backpressure requirements. Thus, installation of backpressure sensors is also a requirement.

Maintenance requirements for repowers and overhauls as well as oxidation catalysts are not very different from normal engine maintenance, but DPFs require once a year ash removal or more frequently as dictated by backpressure. While OEMs cannot revoke engine warranty because of an original equipment manufacturer retrofit, they do not warrant against engine failure caused by third party retrofit. At the same time, most retrofit suppliers will not pay for engine damage not caused by retrofit.

Caterpillar aims to leverage its extensive dealer and distributor network for outreach through awareness campaigns, customer care meetings, distribution training seminars, and supporting local retrofit policy development.

Session 5: Emission Reductions in Mexico City and US Vehicle Markets

Praveen Amar of NESCAUM moderated the session on vehicle markets.

Adrian Fernandez, Instituto Nacional de Ecologia (INE), México (http://www.ine.gob.mx)

Fernandez started by noting that the peak levels of ground level ozone have dropped by more than 50% in the last decade. In spite of these improvements ozone levels are still in non-attainment for 70% of days in Mexico. Transport sector contributes to over 80% of emissions of criteria pollutants and about half of the greenhouse gases (GHGs), and is thus a continued matter of concern. Fernandez presented several case studies which illustrate several key problems as well as some creative solutions.

The first case study was on Metrobús which is Mexico City's Bus Rapid Transit (BRT). A 19.5 kilometer section of the BRT corridor was inaugurated in July 2005. The corridor consists of 80 articulated buses, each with a capacity of 250 passengers and running between 34 stations along the corridor. The Metrobuses are Euro III compliant and are estimated to replace 250 buses and microbuses formerly plying on this route. The Metrobuses aim to have characteristics similar to a metro system with fares collected before boarding and doors docking at the same level as platforms.

INE has undertaken an analysis of air pollutant exposure before and after BRT, as well as estimating co-benefits from implementation of the full BRT system. An expanded BRT system could reduce personal exposures of commuters in public transportation by improving bus

technologies, lowering pollution inside vehicles, reducing commuting time and congestion as well as reducing the number of bus starts and stops of. Studies conducted by INE have found that exposure to CO and benzene was significantly higher in microbuses than in city buses. The estimation of health benefits suggests that the benefits accrue from reduction in exposure, and not necessarily from reduced emissions at city-wide level.

INE is conducting a vehicle activity and emissions measurement study to support the International Vehicle Emissions (IVE) Model (see http://www.gssr.net/ive/). The objective of the first phase of the study was to collect vehicle activity data pertaining to technology distribution, driving and starting patters. Passenger vehicles and taxis account for 90% of vehicular activity on the road in Mexico City. Based on I/M data, 30% of passenger vehicles have no catalysts, while only 10% of the taxi fleet has no catalysts. In general, congestion lowers the average velocity during the daytime hours by 30 to 60 percent of free flow velocities. A typical passenger cars starts 5-6 times per day with about 30% of the starts occurring between 6 am and 9 am and an equal number occurring between 3 pm and 6 pm. Over half the starts in the morning occur after a soak period of more than 12 hours. Phase I of the project also consisted of conducting on-board monitoring of 110 vehicles of three types. The types of vehicles included were carbureted vehicles, vehicles with fuel injection systems and three way catalysts, and vehicles with multiple fuel injection, 3 way catalysts and EGR. The data from emission monitoring is still being analyzed. Phase II of the project is now underway. Phase II expands on activities in Phase I and also plans to compare different emissions measurement techniques such as I/M, remote sensing, FTP dynamometer tests, and on board diagnostics.

INE also conducted a co-benefit study to estimate the impact of air pollution control strategies. The objective was to quantify the GHG and urban air quality benefits of pollution control measures and help to develop a policy-relevant analysis tool with explicit treatment of uncertainty. Five different control measures (taxis, hybrid buses, metro expansion, LPG leaks from home stoves and co-generation of heat and power) were studied. It was found that the highest net benefit was derived from implementing control measures on taxis, whereas the largest GHG benefit was realized by co-generation.

Mexico City's Secretary for the Environment in collaboration with Center for Sustainable Transport (CTS) has undertaken an EPA funded diesel retrofit pilot project in Mexico City. Thirteen city buses have been retrofitted with either oxygen catalysts or diesel particulate filters. ULSD required for the buses is imported from the US. DPFs were able to reduce particulate matter and CO emissions by up to 90%, whereas oxidation catalysts reduced particulate matter emissions by up to 23% and CO emission by up to 77%.

About 700,000 second-hand vehicles are imported "temporarily" into Mexico every year, of which about 85,000 remain illegally in the country. Such cars are known locally as *Chocolate Cars*. It is estimated that the total number of chocolate cars is about 3.5 million of which about 2 million have been legalized. While the number of chocolate cars is small when compared to the 1.1 million annual sale of new vehicles, chocolate cars contribute up to 30% of total emissions in areas along US-Mexico border, and are thus a significant problem.

Mexico is implementing Tier 2 equivalent emission and fuel quality standards. The standards aim to reduce the amount of sulfur in diesel to 300 ppm by 2006 and 15 ppm by 2010. Low sulfur gasoline (~ 30 ppm) will be available in premium blend by the end of 2006, and on all gasolines sometime between 2008-2011. The estimated health benefits of low sulfur fuel are estimated to exceed 650 million dollars per year with more than 400 lives saved per year in Mexico City alone.

Sales of light-trucks are on the rise in Mexico with current market share of about 15%. Fuel economy of the vehicle fleet in Mexico is about 12 kmpl (~28 mpg) when compared with about 14 kmpl (~ 32 mpg) in Brazil and 9 kmpl (~ 21 mpg) in the US. Mexico is deliberating several incentive programs for cleaner and more fuel efficient vehicles. Such incentives could come in the form of waivers of inspection for smaller engine vehicles, hybrids or other fuel efficient vehicles for 4-6 yrs. A vehicle tax scheme similar to Feebate has also not been ruled out. Alternatively, an incentive may be offered on the level of annual vehicle ownership tax.

INE is a part of multi-institute sustainable mobility initiative in Mexico. In addition to the projects such as those described above, the initiative will focus on capacity building with a multidisciplinary focus ultimately leading to a national research agenda on sustainable mobility.

Eric Sharpe, National Automobile Market eXchange (NAMX)

Sharpe described how environmental objectives could be aligned with industry objectives by taking a systems view of automobile production, distribution and consumption supply chains. NAMX helps to build a system to supply and share information between dealerships, but enabling factors for industry wide application of such a system do not exist now.

There are over 21,000 franchise dealers in the US. They employ more than 300,000 people with a very high turnover rate. The distribution of automobiles from the OEMs has been largely unchanged for several decades. The current vehicle distribution system is highly inefficient. The allocation of new vehicles to dealers is based on historical sales trend. It is unlikely that any new vehicle is distributed to the dealer when the demand for a new vehicle is at the highest. This is in part because consumers want to make choices and purchase vehicles at the dealers' lot without having to wait very long. As an average dealer stocks about 100 vehicles, it is often that a vehicle with an appropriate specification is not available on a particular dealer's lot. As a result it is estimated that there is more than $100 billion of vehicle inventory sitting at dealers' lots across the country. If trading were possible between different dealers, then both the size of inventory and time-to-delivery would be reduced. Since such system does not exist, however, the resulting inefficiency works to negate the gains in production efficiency across the OEM plants.

On the vehicle production side, it is difficult to execute build-to-order strategy affordably since the industry has evolved primarily as a mass production enterprise. Each automobile requires thousands of parts produced by several hundred suppliers. Maintaining the quality of automobiles is an even more challenging task if there is a high degree of variability between orders. At the same time, the automobile industry suffers from a worldwide overcapacity. The industry spent an estimated $72 billion on incentives in 2004. Such incentives help, in part, consumers to accept vehicles available on a dealer's lot rather than waiting for a build-to-order vehicle. Since dealers are primarily interested in reducing their inventory, customer relationship often suffers in this process.

The internet as a source of information helps, but the wholesale market for vehicles on internet is small (0.5 million), and disconnected with other wholesale trade. Sharpe made a similar argument with respect to sales and trade-in of used vehicles. The additional complication in used vehicles business is that the vehicle valuations are often poor.

Sharpe thinks that stability and growth of new vehicle sales depends primarily on new vehicle models, consumer finance, and consumer trade-ins. In spite of the importance of the used vehicle wholesale market, it is an understudied area. It is critical to improve wholesale trade transparency between all the dealers and remarketers.

Sharpe estimates that the disconnected nature of business is leading to inefficiencies of up to $50 billion annually, but thinks that an integrated network providing information to producers, distributors and consumers would become a reality by as early as 2010.

One of the ways in which such a business can help achieve environmental goals is by integrating emissions testing, vehicle services, and scrappage at the dealership. This could also be coupled with vehicle reconditioning and auctions markets.

States with scrappage programs spend up to $800 per vehicle scrapped including administrative costs. A more efficient market may take place if vehicles to be scrapped were obtained from dealers rather than motorists. State agencies would identify which models and model years were to be scrapped. Such a system would reduce transaction costs and lead to a more efficient market. Dealer and manufacturer incentives could be added to subsidize scrappage increasing vehicle turnover and leading to reduced vehicle emissions.

A question was asked if such a model could be applied to heavy duty trucks as well to which Sharpe replied in affirmative.

Session 6: Fuels

Al Mannato, American Petroleum Institute (API), moderated the session on fuels. He stressed the importance of treating vehicles and fuels together as a system.

Mannato began by giving an overview of fuels related issues in the Energy Policy Act of 2005. The Act introduces a renewable fuels standard (RFS) that starts in 2006 at 4.0 billion gallons and grows to 7.5 billion gallons in 2012. This requirement is likely to be filled by ethanol. Each gallon of fuel produced from cellulosic biomass is considered equivalent to 2.5 gallons of renewable fuel for purposes of the RFS. For calendar year 2013 and thereafter, the RFS shall contain a minimum of 250 millions gallons of fuel from cellulosic biomass. RFS allowed banking and trading of credits with a credit life of 12 months.

The Act eliminates the reformulated gasoline (RFG) oxygenate requirement, and limits the number of boutique fuels as of September 2004. These fuels may be replaced by newer, cleaner fuels. Meanwhile, EPA/DOE have been asked to study the effects of SIP-adopted fuels programs on air quality, the number of fuel blends, on fuel availability, fungibility and cost. The Act also requires EPA/DOE to conduct a separate study on fuel system harmonization by June 1, 2008.

The Act has a RFG toxics anti-backsliding requirement to maintain emissions at year 2001 and 2002 levels. If EPA finalizes the Phase II Mobile Source Air Toxics Rule by July 1, 2007, the anti-backsliding requirement will be void. The Act provides Ozone Transport Commission (OTC) states an option to opt any area in a state into a RFG program. Finally, the Act allows states to repeal the 1 lb Reid vapor pressure (RVP) waiver for 10% ethanol blends.

By mid to late 2006, Ultra Low Sulfur Diesel (ULSD) with 15 ppm sulfur will start to become available. The conversion to ULSD is expected to be complete by 2010. ULSD for locomotive and marine applications, however, will not be available until 2012. Implementing ULSD requirement is quite challenging. Jet fuels have little tolerance for lubricant additives other than sulfur. The biggest hurdle perhaps is to maintain integrity of fuel while being transported since multiple products with wide variances in sulfur levels are moved via pipeline. The results of test ULSD movements by MAP, Colonial Pipeline, and others indicate that there is a high probability of contamination at the outset of the program. In response to the concerns

raised by industry, EPA has agreed to shift the terminal compliance date from July 15 to September 1 and the retail compliance date from September 1 to October 15, 2006. During this extended transition period, diesel fuel meeting a 22 ppm level can be marketed as ULSD downstream. EPA will conduct a round robin testing program to determine if the testing tolerance should be increased from 2 ppm, and issue direct final rules to implement these regulatory changes.

Due to contamination issues, refiners may have to keep sulfur level at pipeline receipt lower than 7 ppm. This could result in a decrease in refinery output by about 5% according to Solomon Refinery Survey. If the fuel release specification is less than 5 ppm, then the drop in production would be as high as 22% since 49 refineries (49% of crude capacity) were designed originally with a sulfur release specification of 10 ppm or higher. As far as low sulfur gasoline is concerned, fuel sensor corrosion is perhaps the only major issue of concern before rollout can proceed.

Mannato indicated that in the 2006 revision of mobile air toxics proposal, EPA may move away from individual baselines for RFG to a content limit that could be met with averaging, likely with a per-gallon cap.

Harold Haskew, Consultant

Haskew talked about permeation of fuel in automotive systems due to ethanol. The use of ethanol in vehicles started increasing after California banned MTBE in gasoline. Several state-level bans on MTBE followed. Ethanol was the only suitable oxygenate alternative to meet the federal oxygenate requirement. It was later discovered that evaporative properties of ethanol were causing excessive fuel permeation in vehicles. Haskew conducted a Coordinating Research Council (CRC) and CARB sponsored test program with substantial support from API and the auto industry.

Evaporative emissions take place through *leaks* (fuel dripping on ground*), tank venting* (heating the tank resulting in vapor that can be controlled in the vehicle by carbon canisters) and *permeation* (molecular migration through container material and then evaporating on the outside). Leaks and tank venting have been effectively addressed, but permeation remains to be fixed. Evaporative emissions can account for up to half of total emissions on a hot day with permeation accounting for about two thirds of the evaporative emissions.

Ten vehicle fuel systems were selected for study purpose. The vehicles were selected to be high sales volume vehicles which are representative of California fleet from 1978 to 2001. The cars were sacrificed except for the fuel systems which were suspended from racks and soaked at 105F. The location of fuel system on the racks was approximately the same as on actual vehicles. This was done in order to study only the permeation through the fuel storage and delivery system.

Three different California gasoline blends were tested. Two blends were from Phase 2; one with 11.4% by volume of MTBE, and the other with no oxygenate. The other blend was a Phase 3 fuel with 5.7% by volume of ethanol. The fuels were circulated through the vehicle systems twice weekly with a fuel change taking place every seven weeks. California summer day diurnal test was conducted for all three fuels after stabilization

It was found that ethanol increases the permeation rate compared to MTBE, or no oxygenate. It must be noted that increase in emissions was not all due to ethanol. Non-ethanol permeation increased when ethanol fuel was tested. Permeate specific reactivities from all three fuels were similar. Permeation rates doubled for each 10ºC increase in temperature. Increase in

permeation as a percentage of total emissions is higher with newer systems since overall vehicle emissions are lower. For post model year 1995 vehicles, permeation rates have reduced significantly.

Haskew is conducting a follow up study with five vehicle rigs (two carryover – 3 new rigs) from model year 2000-2005 and five different ethanol blends.

If ethanol is blended in as E10, then Haskew believes that VOC inventory will go up as a result of permeation. In California alone the increase in contribution from permeation was estimated by the CARB Staff to be about 50 tons per day on a hot summer day. For more information, please see:
http://www.crcao.com/reports/recentstudies2004/E65%20Final%20Report%209%202%2004.pdf

Session 7: Fleet Evolution

Dick Gibbs of NYDEC moderated the session on fleet evolution which focused on how technology and fuel transitions are likely to affect emissions.

John Heywood, MIT

Heywood mentioned that Laboratory for Energy and the Environment (LFEE) has previously conducted technology assessments of future light-duty vehicle fuel consumption. Heywood is now continuing to update assessment of different vehicle and fuel technologies with respect to fuel consumption, GHG emissions, and marketability in the context of the total vehicle fleet. The MIT study will develop plausible new technology production scenarios, calculate life-cycle impact with light-duty vehicle (LDV) fleet simulations, and examine policies which could increase impact of new technologies.

According to Heywood, in order to have a significant impact, a new technology has to follow three steps. First, the technology must become market competitive in overall vehicle performance, convenience, and cost. Then the technology must penetrate across new vehicle production to significant fraction (roughly one third) of new vehicle production. Finally the more fuel efficient technology vehicles must account for a substantial in-use fleet penetration and miles driven (roughly one third). Taking this into consideration, time scales for impact of advanced propulsion technologies such as diesels and hybrids is of the order of two to three decades, and longer for emerging technologies such as hydrogen fuel cell vehicles.

Heywood and colleagues have developed a LDV fleet model to estimate fleet fuel use for different scenarios. The model assumes that new technology fuel consumption benefits for cars and light trucks/SUVs are about the same. Vehicle scrappage rates and miles driven per year in the model follow historical trends. New vehicle sales are assumed to grow 0.8% per year and the fraction of light truck sales in new LDVs will level off at 60%.

While the new vehicles have a potential to reduce vehicle fuel consumption in by 50% over a thirty year period, it is assumed that in a baseline scenario only half of these improvements are realized. The rest of technological improvement is assumed to improve vehicle performance and increase vehicle size instead of fuel economy. Advanced internal combustion engine gasoline, diesels and hybrids are assumed to consume 88%, 77% and 62% of the baseline.

In the initial scenario, it is assumed that the market penetration rates of advanced gasoline, diesels and hybrids will be 30%, 15% and 15% respectively by 2035, whereas hydrogen fuel cell vehicles will have a 5% market share by 2035 after coming into the market in

2020. Under this scenario, fuel use in 2035 is projected to be 628 billion liters of gasoline equivalent when compared to 829 billion liters in no change scenario. A delay in implementing such a scenario not only shifts the fuel use problem temporally, but makes it harder to address. Even if the market penetration rates of diesels and hybrids are doubled, the fuel use in 2035 is still 600 billion gallons. It is found that realizing full technological potential for reducing fuel consumption purpose can reduce fuel use in 2035 to about 500 billion liters of gasoline equivalent instead, and thus has a bigger impact than increasing market penetration rates of advanced propulsion technologies. Fuel-cell hybrid potential for reducing fleet petroleum use before about 2035 is small (1.7% of "no change" fleet consumption; 2.2% of projected base technology mix consumption).

Heywood concluded that reducing LDV fleet fuel consumption substantially below the "no change" continuing growth projection will be difficult and take decades! Fleet fuel use reductions for a given technology depend on existing fleet composition, rate of change of fleet composition, and vehicle fuel consumption improvement. For the next 30 years (or more) fleet composition (i.e., high volume use) dominates.

For more information, please see http://lfee.mit.edu/public/el00-003.pdf, http://lfee.mit.edu/public/LFEE_2003-001_RP.pdf, and http://lfee.mit.edu/public/LFEE_2004-001_RP.pdf

Bill Rutecki, Bosch

Bosch is a leading supplier of automotive technology with 2004 sales exceeding 25 billion euros. Bosch expects a 40% increase in vehicle production worldwide from 2001 to 2014. During this period the number of diesel vehicles sold annually is expected to double and account for 30% of the market by 2014 globally. The rapid growth in market share of diesels in Western Europe in 1990s was partly due to significant advances in common rail fuel injection systems and direct injection. In Western Europe, which is a big market for Bosch, the diesel market share may level off in the range of 50% by 2014.

The main drivers of interest in light duty diesels are high specific power along with reduced fuel consumption and exciting driving performance. The main challenges along the way are emissions of NOx and PM, noise, durability of fuel injection equipment (FIE) and exhaust gas treatment (EGT) systems and costs. Bosch's primary focus remains optimizing diesel systems to meet future demands while supporting further improvements in combustion process.

Bosch is advancing the state of the art of common rail systems (CRS) for fuel injection by increasing pressure and flexibility of injection events. Advanced CRS also focus on pressure amplification rate shaping and closed loop control. The 3rd generation system is currently released for 1600 bar, with plans to further elevate to 1800 and possibly 2000 bar whereas 4th generation, if required is expected to boost the injection pressure to beyond 2000 bar. The 4th generation design limits the system component exposure, to the extremely high injection pressures (>2000 bar), to lower end of the injector and injector nozzle.

Flexible injection systems lead to better control timing of injection events, and engine management systems are being further developed to improve injection controls for high precision to further optimize combustion to reduce emissions and combustion noise. This includes the capability to inject late during the combustion cycle for thermal management and/or regeneration of exhaust gas aftertreatment systems.

In order to meet the US Tier II Bin 2/5 standards, diesel aftertreatment systems will require use of Diesel Particulate Filters (DPFs) and either a selective catalytic reduction (SCR)

system or a lean NOx trap (LNT). Rutecki identified six different areas on the engine map with different injection profiles and regeneration strategies.

Rutecki noted that the roadmap for LDV dieselization in North America included meeting the Tier II Bin 5 emission standards, refinement of fuels, combustion process and exhaust gas treatment. An ultimate goal, or concept could include a practical approach of an initial moderate blending of bio-based fuels, (ie 3 to 5% bio), and then the assessment of higher bio blends (ie 10 to 20%), with a longer range potential to go to bio mass to liquid or GTL fuels.

A question was about the state of development of Homogeneous Charge Compression Ignition (HCCI) system. Mixed mode, or HCCI type injection might allow for multiple injections during the power stroke, and presently appears engine speed and load limited. The means to apply an HCCI type of injection strategy across a wider spectrum of speed and load will require substantial development. Another questioner asked why the diesel market share might top out at near 50% in Europe. Rutecki said that this prognosis factored in the development of different competing technologies such as hybrids. Another question asked if late post fuel injection results in fuel consumption penalty. Rutecki answered that there is some penalty when pilot injection is viewed in isolation; however the goal of Bosch's 3ard and 4th generation of fuel injection systems is to increase injection pressure and control capability to offset and reduce any penalty that might be associated with post injections. In short, the overall system capabilities must be assessed to evaluate how significant the impact on fuel economy.

Kevin McMahon, MARTEC

McMahon made a case for light-duty diesels in North America. He stressed that modern diesels deliver more torque at lower engine speeds. This results in better acceleration and towing performance. In addition, new transmission technologies such as six speed automatics enable diesels to stay in peak torque zone longer, thus improving torque and fuel consumption characteristics further.

Torque and horsepower of new US LDVs has grown at 2-3% per year for more than a decade. McMahon believes that a significant number of consumers are willing to pay a premium for even more performance over the standard gasoline engine and sacrifice fuel economy. In the US light duty market, consumers are offered more than 1 engine choice on the majority of vehicles. Once a preferred vehicle is identified, the consumer can select the standard or optional, higher-performance engine. McMahon stated that more than 2 million US car buyers paid an optional premium for engine performance in 2004. In the light truck market, nearly half of the buyers paid a premium for additional performance. On an average, US car buyers might be willing to pay up to $29 more per lb-ft increase in torque, whereas light-trucks buyers might be willing to pay $18 more per lb-ft increase. Diesel engines help to break the tradeoff by offering better performance and fuel economy. Diesel engines are already preferred in the heavy duty segment of the US market with a 60% market share. In Europe, diesels account for roughly half of the new vehicle sales in the past several years. McMahon said that even though fuel prices are much higher in Europe, there are reasons to consider that diesel engines can succeed in the US market. If all 2004 optional truck engines were diesels at 30% consumption reduction compared to a standard gasoline engine, lifetime fuel savings from these trucks would be about 16 billion gallons. This number is comparable to the amount of gasoline that could be produced from the Strategic Petroleum Reserve.

McMahon claims that heavy duty pickup consumers pay up to $6,600 for optional diesel engines in order to gain to gain low-end torque benefits. The added fuel economy benefits of the

diesels recoup up to $5,600 in five years time. At the end of five years, the residual value is very high in the aftermarket when compared to the optional gasoline engines. As a result, the consumers can obtain premium performance from diesels, and still recover their initial investment. McMahon has carried out similar analysis European diesels with results that favor diesel vehicles.

One of the hurdles in the introduction of diesels in US is NOx emissions. US LDV emissions standards from NOx are three times more stringent than Europe. PM standards will force DPFs on all diesel vehicles, but the future of NOx treatment is still not clear. Several "pre-mix" combustion strategies are being researched which seek to reduce engine-out NOx and PM[3]. It is anticipated that these technologies will help to reduce DPF sizes, and allow for greater range of operation for the NOx treatment systems such as SCR and LNT. Yet, NOx treatment technologies are likely to cost $1,000-$1,350 per vehicle by 2010. This cost is substantially higher than $200 for gasoline engine aftertreatment. McMahon believes that overall benefits in terms of performance and fuel economy will justify these cost premiums.

Joe Sussman said that performance should be treated as something more than just torque. He asked if marketplace will continue to value torque just as much in the future. McMahon believes that European experience shows that performance is valued. Unless fuel prices increase substantially in the US, consumer preferences are unlikely to change

A question was asked about higher emissions of toxics due to higher sales of diesels. McMahon said that research suggests that filter equipped diesels are equal or better than older gasoline engines. The main concern is whether older diesels will continue to operate filters efficiently. Joe Mauderly's research at the Lovelace Respiratory Research Institute indicates that toxic impacts of diesel and gasoline emissions are comparable. Another question was asked about maintenance of diesel engines. The modern diesels require no special maintenance when compared to the gasoline engines.

Ben Knight, Honda Motor Company

Knight noted that worldwide fleet of automobiles is doubling every thirty years. Majority of the growth is in Asia where the automobile fleet has doubled in the last 15 years, and is projected to double again by 2020. Over this period climate change and energy supply concerns will gain prominence even as air quality continues as the dominant issue through the end of this decade. Honda is committed to developing clean vehicles with extremely low emissions (ultra-low/near-zero emissions performance), increasing the fuel efficiency of their powerplants, and contributing to alternative fuel pathways.

Knight presented a table comparing different propulsion technologies (gasoline, diesel, CNG, hybrids, electric vehicles and hydrogen fuel cell vehicles) across different environmental and market acceptance factors. Diesel can reduce CO2 by 20%, but NOx and PM must be

[3] For example, researchers at Sandia National Laboratories' Combustion Research Facility (CRF) have discovered methods for producing non-sooting and low-flame-temperature diesel-like combustion. The research is motivated by the need to minimize nitrogen oxide (NOx) and particulate matter (PM) emissions from high-efficiency diesel engines and is being conducted in collaboration with automotive and heavy-duty diesel manufacturers, with funding from the Department of Energy's FreedomCAR and Vehicle Technologies program. Sandia researchers Lyle Pickett and Dennis Siebers conducted experiments at the CRF using reacting diesel fuel jets under well-controlled ambient and fuel injector conditions. They sought to determine what factors affect soot formation during mixing-controlled diesel combustion with flame temperatures less than approximately 2000 K — too low for significant NOx formation. In the course of the work, Pickett and Siebers identified three methods for producing fuel jets that did not form soot in any region of the reacting jet and that simultaneously had a low flame temperature.

addressed. Hybrid gasoline vehicles can reduce CO2 even more in some modes, and have extremely low criteria emissions, though cost limits market demand today. Fuel cell electric vehicles, which can have exceptional environmental characteristics, need to address high cost and infrastructure barriers.

An International Energy Agency (IEA) reference case estimate of global CO2 emissions from automobiles is 5.6 billion tons per year in 2020. Assuming that gasoline vehicle efficiency can be improved by 20% beyond improvements in IEA reference case, emissions can be reduced by 0.2 billion tons by 2020. Assuming further that diesel, hybrids and fuel cell vehicles will achieve a market share of 30%, 30% and 10% respectively; the annual global emissions of CO2 could be checked to 4.3 billion tons per year. This shows that significant improvement will be needed for stabilizing fuel use and greenhouse gas emissions in the future. It also shows the importance of today's efforts to advance FCVs, which can ultimately use a variety of renewable energy sources.

Knight described a variety of advanced gasoline propulsion systems based on variable valve timing and lift electronic control (VTEC) concept under development. The new 1.8 liter i-VTEC engine has significant intake valve delay, and operates closer to an Atkinson cycle. The engine delivers fuel economy gains despite its application to a larger and heavier car. A 2.0 liter i-VTEC engine with direct injection and lean-burn combustion shows a 10-15% improvement in fuel consumption, but needs to tackle the NOx emissions challenge. A 3.5 liter i-VTEC engine with variable cylinder management (VCM) shows 5-12% improvement in fuel consumption, and Honda intends to further increase the cylinder deactivation range to realize its full benefits. The next generation of gasoline engines may be based upon concepts such as HCCI combustion. They will need better ignition control, and operations range expansion, but can deliver a 30% improvement in fuel economy if they are successful.

Honda targets popular high volume models for its hybrid vehicles. Increasing hybrid component efficiency and lightweight design, while reducing costs is a critical issue for development of hybrid vehicles. The 2006 Civic hybrid offers a 50% increase in motor output in same dimension. It has a 3-stage VTEC engine for increasing efficiency at low speeds, high speeds, and increased regeneration capacity. According to a recent study, if the price premium for hybrids is less than $2,500, and gasoline prices are near $2.75 per gallon of gasoline, then hybrids look increasingly appealing to the consumers.

Modern Natural Gas (NG) vehicles have near zero particulate emissions and are thus attractive from emission reduction point of view. NG vehicles deliver gasoline-like performance with a range of up to 220 miles and reduction in CO2 emissions of up to 25%. Honda is marketing Civic GX with Phill home refueling system.

Like other major auto manufacturers, Honda is developing hydrogen fuel cell vehicles, considered key to transportation sustainability long term. Low temperature performance of fuel cells, hydrogen infrastructure issues, and cost are among the many obstacles to the realization of fuel cell vehicles. Honda is working with several fleet customers as well as starting deliveries to individual customers to evaluate the performance of its FCX vehicles and to encourage broad cooperation of industry and government. Freezing weather startup and operation was demonstrated last winter in the New York State fleet, a first for FCVs. Honda is also experimenting with hydrogen station designs where hydrogen is produced more efficiently from energy harnessed via solar panels. Honda is also experimenting with home refueling systems of natural gas which can be used for efficient co-generation of power, heat and hydrogen for vehicles. The well-to-wheels CO2 emissions of 2005 FCX are estimated to be 184 g/mile,

assuming that hydrogen is produced from natural gas. This compares very favorably to hybrids of similar weight.

Robert Wimmer, Toyota Motor Corporation

Wimmer noted that petroleum use and greenhouse gas emissions are projected to rise rapidly, and at the same time oil production is expected to peak in the first half of the century. As the automobile fleet around the world continues to grow, Toyota sees an enlightened self interest in pursuing sustainable mobility which expands personal mobility while trying to minimize the impact of vehicles on the planet. In the near term, Toyota continues to develop and improve mainstream technologies, and expand its hybrid strategy. In the longer term, more radical concepts such as HCCI, biofuels, and fuel cells will become feasible.

Toyota believes that a significant and growing percentage of customers indicate a willingness to buy an environmentally friendly vehicle if and only if, attributes meet or exceed competitive offerings at a reasonable cost. Toyota further believes that hybrids offer a way forward in this respect. Toyota's hybrid synergy drive (HSD) is characterized by high efficiency gasoline engine, a planetary gear power split device, AC synchronous generator, high voltage AC-DC inverter, a nickel-metal hydride battery, and a permanent magnet AC motor. Today's hybrids offer a combination of improved performance, improved fuel economy and lower emissions all at the same time. Toyota has already sold half million hybrid vehicles cumulatively worldwide. An unofficial target is to sell 1 million hybrid vehicles per year globally by early 2010's, with about 60% of those sales in the US. Toyota believes that at least a 10% fuel economy and performance improvement in hybrid performance is possible in the next 5-7 years.

In the longer term, Toyota believes that hydrogen fuel cell vehicles (FCVs) have the potential to remove the automobile from the environmental equation as FCVs offer zero tailpipe emissions, a potential for low carbon hydrogen, and non-petroleum based fuel source. This will be possible when attributes of FCVs meet or exceed conventional vehicles at a reasonable cost, and the society is prepared with respect to infrastructure, codes and standards. This will not happen unless there is a compelling reason for the customer to change. So, while the auto industry is addressing the vehicle, governments and other industries must participate in addressing the other parts of the challenge.

The main challenges in mass introduction of FCVs can be divided in to technical, market and infrastructure challenges. Key technical challenges are low temperature operation and durability of the fuel cell, and on-board hydrogen storage. Key market challenges are cost, range and life of FCVs. With respect to costs, it is necessary to reduce the amount of catalysts in fuel cells by about twenty fold. It appears that liquid or compressed form of hydrogen will be difficult and extremely expensive to commercialize for such a large scale application. Key infrastructure challenge is the uncertainty in production, transportation and storage of hydrogen. It is believed that hydrogen will be generated initially from distributed natural gas networks, but centralized production may be needed if CO2 is to be captured. Thus FCV technology needs several major breakthroughs.

Toyota sees gasoline ICE vehicles as viable options for a considerable future. Diesels are currently facing emission challenges in the US; hybrids are a core technology for Toyota.

Dave Austgen, Shell Hydrogen

Austgen presented Shell Hydrogen's view of the growth in numbers of fuel cell vehicles over the next 30 or 40 years. Shell expects that substantial markets for H_2-powered fuel-cell vehicles will most likely to start developing in the time frame 2015 to 2025. If the conditions are supportive, Shell believes between 5 and 10 million FCV's could be on the road by 2020 and this number could grow to more than 100 million vehicles sometime between 2030 and 2040. Growth of hydrogen market will depend on funding the transition to mass production. Although market takeoff is still at least a decade away, governments, regulatory authorities, competitors, suppliers and customers are already developing policies and positions on hydrogen.

Historical data show that it takes between 25 and 50 years to go from take-off to 50% of the ultimately mature size of a fully developed infrastructure network in the US. Shell Hydrogen views development of a hydrogen transportation infrastructure in five distinct phases. First, there are stand-alone projects like the CUTE projects in which fuel cell buses are fueled out of depots. Examples include the Amsterdam and Luxembourg stations that Shell Hydrogen is supporting. Second generation sites will allow public access but will still be distinct from a petrol refueling station. An example is the Shell branded Reykjavik station. The third phase will involve integration of hydrogen into gasoline fuel stations. Over the next five years, Shell will undertake the fourth phase which involves development of lighthouse projects. Lighthouse projects are integrated stations operating within mainly urban mini-networks of hydrogen supply and other retail stations. Mini-networks are limited number, large scale demonstration projects for fleets of 100+ vehicles. Each network will include 4-6 Hydrogen/gasoline stations in large urban stations. An example of a phase four project is Shell's Washington DC station experiment with General Motors. Shell and GM plan to replicate this experiment in Los Angeles, New York City, San Francisco, and along the DC-NY corridor,. By 2020, Shell expects the mini-networks will be connected with hydrogen stations placed along the corridors between urban areas. Austgen stressed the importance of coordination between government, auto industry and the hydrogen infrastructure developers. In an uncoordinated infrastructure roll out scenario, capacity, supply and demand do not match lowering the capacity utilization, and threatening the success of entire infrastructure.

Austgen noted that one of the advantages of hydrogen is that it can be made from a variety of feedstocks. The primary sources of energy for hydrogen production could be fossil fuels, renewable energy(both bio-based and non-bio based) and nuclear. Routes to hydrogen include high temperature thermolysis, electrolysis, photoelectrolysis, biophotoylsis, fermention, and chemical conversion (steam methane reforming, gasification, etc). An ideal option for producing hydrogen, both from a GHG emissions and energy security point of view is to use non-bio renewables, such as wind, solar, geothermal or hydro, to produce electricity and then use that electricity to produce hydrogen via electrolysis. From a GHG perspective, however, it is best to use renewable electricity as a replacement for coal-generated power than to use it to produce hydrogen for use in fuel cell vehicles. The use of renewable electricity as a coal generated electricity replacement avoids about 2 and a half times as much CO2 as use of renewable electricity to produce hydrogen as a fuel for a fuel cell vehicle. Non-bio renewables should be preferentially used for electricity sector unless renewable energy is a more widely available. As a result, fossil-based hydrogen generation is likely for decades to come. So the question is whether well-to-wheels GHG benefits can be realized by producing hydrogen from fossil sources. The answer is negative unless carbon is captured and stored. So Shell Hydrogen believe that hydrogen will be made from fossil fuels in the near term, from fossil fuels with carbon capture

and storage in the mid-term, and only in the longer term will hydrogen be made from non-bio renewables.

Economics of central versus on-site hydrogen production indicates that medium scale production (500 ton/day) can be justified in short to medium terms if transportation distance is not too great.

Discussion following Session 7

There was a question as to why Toyota and Honda both appear more bullish on hybrids than on diesels, and if diesel hybrids make sense. Toyota believes that emission treatment for diesel makes it difficult to think about diesels; Honda believes that gasoline is the dominant system in the US, and hybrids should follow the gasoline path. A follow up question asked if the picture would be different in Europe. The basic reply was to adopt a wait and see approach for European markets.

There was some discussion on whether today's work on batteries may pave the way for electric vehicles. In general, vehicle manufacturers are cautiously optimistic on this front. Another question pertained to the trade-in value of hybrids. It was noted that residual value for hybrids is currently about the same as traditional vehicles, but as battery technology improves (>150,000 miles life) residual value will increase.

There was a question about safety of hydrogen as a transportation fuel. The answer is that safety is still a concern about hydrogen as a vehicle fuel as well as refueling safety issues. If hydrogen is used at high pressures (10,000psi) safely will be a challenge.

A question about hybrids was about waitlist for obtaining hybrid vehicles. Supply has caught up by now for Toyota Prius vehicles, but there still is a wait list for highlander and Lexus hybrid.

Session 8: Reducing Greenhouse Gas Emissions from Vehicles

Jason Grumet, National Commission on Energy Policy (NCEP), moderated the session of reducing GHG emissions from vehicles. Grumet noted that while the 2005 energy bill has passed, and does a lot of good things, the bill fails to address two big problems of climate change and oil usage. NCEP recommends an economy wide cap-and-trade program to slow the growth of GHG emissions. It also recommends strengthening the CAFE standards with a safety valve, and allowing trading of CAFE permits between vehicle manufacturers.

Marginal cost of CO_2 reduction in sectoral terms shows that transportation is most expensive to reduce emissions. Thus transportation sector is likely to be least affected, and GHG emissions from transportation may continue to grow in the event of overall stabilization of GHG emissions. Even then, numerous technology assessment studies indicate that cost effective solutions are available today that could be implemented to improve efficiency. Grumet demonstrated an example of a full-size hybrid vehicle efficiency improvement. The cost of making incremental improvements to reduce CO_2 emissions can be recovered from the fuel savings achieved by using the more fuel efficient technology.

Mike Walsh, Consultant

Global demand for mobility is increasing rapidly. This is reflected in growing number of vehicles, and vehicle miles traveled (VMT) globally. Transportation is the fastest growing CO_2 emissions source. The growth in China is particularly striking. China currently ranks 2nd in oil consumption in the world after US. China has become into a net importer of oil since 1993, and in 2004 the net import of oil reached 40% of the total oil use.

There are multiple policy approaches available to address greenhouse gas emissions. Many countries around the world have some combinations of different policy measures in effect. Most countries have much higher prices for road vehicle fuels than the US. Many countries have significantly lower prices for diesel fuel than for gasoline. Denmark has a yearly car tax which is calculated for 24 different car classes based on kilometers per liter of fuel consumed by the vehicle. European vehicle manufacturers have signed a voluntary agreement on reducing GHG emissions from motor vehicles. These voluntary targets will not be easy to achieve. Mandatory regulations are likely if these targets are not achieved. Tax incentives on emissions and fuel economy are coupled in Japan for gains in both. Japan is also looking at heavy duty fuel economy standards. China has also instituted a two phase vehicle fuel consumption standard program. California has adopted GHG emissions standard for motor vehicles which considers all greenhouse gas emissions, not just CO_2 or fuel consumption.

Criteria emission standards and performance are improving worldwide although at different rates. Motorcycle standards are also being worked on in many parts of the world. In about ten years, emissions control standards on about 85% of gasoline vehicles around the world will be at Tier2/Euro 5 level. Walsh also noted that the number of ultrafine particles emitted from particle trap-equipped diesels is similar or lower to comparable advanced gasoline vehicles.

In general, criteria pollutant regulations were technology forcing, whereas greenhouse gas emission regulations are much more modest in what they try to do. CO_2 equivalent reductions from non-CO_2 emission reductions are quite significant. Walsh believes that GHG standards for motor vehicles should be mandated for all vehicle categories. The aim of the standards should be to push the envelope of technologies while providing sufficient lead time for compliance.

Tom Cackette, California Air Resources Board (CARB)

Cackette noted that the effects of climate change on California might be multidimensional. Apart from public health concerns due to air quality, and a possible increase in infectious diseases, California's agriculture is especially vulnerable to regional climate changes. There are concerns about reduction in the Sierra Mountain snow pack which provides irrigation to the California's Central Valley. Possible new pest problems could result from climate changes. Climate change would also affect forest ecosystems in ways that increase fire hazards and that make forests more susceptible to pests and diseases.

California would be the 9th largest emitter of greenhouse gases in the world if it were a separate country. Thus, action on climate change in California can make a difference. Governor Schwarzenegger has adopted statewide targets for GHG emission reductions. The California targets are to reduce emissions to 2000 levels by 2010, reduce emissions to 1990 levels by 2020, and reduce emissions to 80% below 1990 levels by 2050. CalEPA believes these targets are ambitious yet achievable. California has established a climate action team that meets monthly and reports to the governor biennially on progress towards meeting targets, global warming impacts on California, and mitigation and adaptation plans. California has already established

several programs that address half of the emission reductions needed by 2020. More regulations and programs are under consideration.

California Assembly Bill 1493, also known as Pavley bill, directed ARB to adopt regulations that achieve maximum feasible and cost-effective reduction in passenger vehicle greenhouse gas emissions in California. ARB has adopted GHG emission norms for motor vehicles which require a 22% reduction in GHG emissions by 2012, and 30% reduction in GHG emission by 2016. The standards were set so as to be feasible for the manufacturer with the heaviest fleet to comply without altering their fleet mix. The standards also aim to preserve consumer choice and force several advanced gasoline technologies in to market. ARB estimates that the resulting increase in retail price per vehicle will be between $300 and $1,000, but more fuel efficient technologies will also result in fuel savings making the standards cost effective. Overall, ARB believes that the regulations will have net benefit for consumers, state and local governments and the economy. The Alliance of Automobile Manufacturers has sued ARB on the grounds that the California GHG standards are preempted by the federal fuel economy rules (CAFE standards). In addition, there are state level administrative procedural issues that are being challenged in the state court. If a restraining order is issued, ARB may have to delay the rulemaking which is to go in to effect starting January 1, 2006 and affects model year 2009 and subsequent vehicles.

For more information, please see: http://www.climatechange.ca.gov/index.html and http://www.arb.ca.gov/cc/cc.htm

Jason Mark, Union of Concerned Scientists (UCS)

Mark noted that significant reductions in greenhouse gas emissions are required soon if dangerous levels of climate change is to be avoided. US passenger vehicles are a significant contributor to the global CO_2 emissions, currently emitting more CO_2 emissions than all of CO_2 emissions from India. US lags the world in terms of reducing CO_2 emissions from motor vehicles. While there is inaction at federal level, state and local initiatives are increasing. California has adopted GHG emission standards for motor vehicle and states from the Northeast may follow suit. Together, California and the Northeast account for about 25% of US market, and can have a significant impact. While passenger car emissions must be addressed, looking beyond passenger cars is also important. The growth in freight and air travel sectors, which are currently responsible for about 27% of US transportation GHG emissions, is large, and these sources must be controlled too.

EIA analysis of NCEP/Bingaman and McCain/Lieberman proposals shows that cap-and-trade system will have limited impact of transportation emissions unless backed by transportation fuel consumption standards. Mark suggested that a combination of economy wide cap-and-trade and fuel economy standards is needed to effectively address the problem.

A **discussion** followed Mark's presentation that covered different topics from the session. Praveen Amar asked about the effectiveness of market-based approaches in reducing emissions as opposed to regulations. Mike Walsh replied that current market based approaches have been used to speed up the penetration of off-the shelf technology, but not to force new technology. So regulations are needed. Gene Tierney said that we need to change the tone of discussion. The cost of fuels is likely to increase in the future, and, unless demand is moderated, we might have to pay a huge cost of not acting. In addition, domestic industry might be a laggard and might suffer competitively globally if it is not stimulated to act about climate change. A follow up

question asked if the US is already starting to fall behind in terms of cleaner technology. It is not clear that this is the case, but there is concern that there may not be enough resources to address new technology development. One of the comments noted that if permits under a cap-and-trade system were auctioned off, some of the money could be used to fund research and development needed to bring cleaner technology to fruition. In general, there is a need to establish architecture for climate change policy. With respect to motor vehicles, there is a framework in the form of CAFE standards, but there is a deadlock over any changes in CAFE. One of the concluding comments was that we first must acknowledge that we have a problem.

Session 9: Vehicle Health Effects

Maria Costantini, Health Effects Institute (HEI), moderated the session on health effects of traffic air pollution. Studies have looked at a variety of health outcomes such as asthma exacerbation and allergic symptoms, cardiac and respiratory function changes, lung function growth, reproductive system effects, and cancer. These studies have raised concerns among the public and regulators. Costantini noted that there are several challenging questions while designing a study to observe the health impact of vehicular pollution. The study must consider the most appropriate measure and location of air pollution monitors, the lag time between exposure and effects, sample population of interest, and control for confounding factors such as socioeconomic status, noise, stress etc. Spatial variability of the pollutant is also an important factor when interpreting results from central monitoring sites. Studies have shown that ultrafine PM number, elemental carbon, NO_2 levels decrease with distance from roadways. Elemental carbon levels are correlated with vehicle counts while PM2.5 varies modestly with traffic counts and distance from roads. In future studies, there is a need to quantify the magnitude of risk and which components of the mix may be responsible for the associations observed.

Annette Peters, GSF-National Research Center for Environment and Health

A myocardial infarction, commonly known as a heart attack, is an obstruction of blood supply in the coronary arteries. If the occlusion of coronary arteries remains for a while, then the heart cells start to die which can be fatal for the patient. Chronic risk factors, such as high cholesterol, hypertension, smoking, sedentary life-style, stress, age, gender, diabetes, and genetic predisposition, increase the baseline risk of a heart attack. Acute risk factors such as strenuous activities, extreme anger, air pollution, drug abuse can temporarily increase the risk of or trigger a heart attack. This leads to the question of whether time spent in traffic is a risk factor for heart attacks. In general, particulate matters seem to be affecting clots, clot rupture, and stopping of heart beats, so further study is warranted.

Peters conducted a study of nonfatal heart attacks of 691 patients aged 25 to 74 years based on the Coronary Event Registry at Augsburg. The study conducted bedside interview of all cases between 1999 and mid 2001, and recorded details of activities during the four days before the event. It was found that time spent in traffic was more frequent on the day of heart attack than on the three days before. Attacks more often than not followed one hour after time spent in commute. When adjusted for strenuous exercise, outdoors, and the effect of getting up, the effect reduced somewhat for both traffic and bike related attacks. Exertion and the risk of a heart attack had effects similar to other studies.

Peters decided to measure number and concentration of PM2.5from a central monitoring station. Individual level of exposure may deviate based on activities and living conditions as well as impact of hot spot exposures. From interviews and measurements of PM, Peters could not find immediate (1 hr) effect in Augsburg as opposed to Boston data. So, no conclusive relationship between measurement of PM2.5 and heart attacks could be established. In another study, however, of 300,000 people using PM10 measurements and onset of heart attacks a positive correlation could be seen. Another Dutch study showed correlations between time spent in traffic and personal soot concentrations indicating increased exposures during these periods.

There are many limitations of the research study design used by Peters. No data on exposure, stress level or driving conditions such as congestion were available. On the other hand the interviews reveal individual level information in a surrogate of exposure within hourly bins. Exposure frequency can be estimated for potentially susceptible individuals in a critical time window using this information. There is a need to further investigate effects of traffic on stress and particle exposure. Peters believes that linking particle properties such as size and chemical composition to different pathophysiological pathways will allow us to judge their relative contributions to cardiovascular disease exacerbation.

Helen Suh, Harvard School of Public Health

Suh conducted a traffic related study in St. Louis aimed at understanding the health effect motor vehicle particles. The main objectives were to examine whether particles from motor vehicles are more toxic as compared to other particles, investigate whether the elderly are particularly sensitive to routine exposures to traffic particles, determine the relevant averaging time or exposure window for particle exposures, and provide insights regarding biological mechanism. Suh conducted the study on a panel of subjects. A panel study allows more intensive data collection, increased magnitude and variability in traffic exposures, and allows examination of particle effects on multiple biological pathways.

The study took groups of older adults on day trips to downtown St. Louis via diesel-powered bus. Bus trips included two one-hour trips on local highways (one during AM rush hour). Between the trips, the participants spent time in an urban area affected by local traffic-sources. The study measured track air quality and health indicators before, during, and after field trips. Each of the participants undertook four such trips. The study monitored exposure measurements of different groups continuously by following them everywhere. In general, a dramatic increase in particle concentrations was observed while aboard the bus. Sometimes the high concentrations were due to smoky vehicles nearby.

Suh believes that potential PM exposure pathways are through nervous systems as well as pulmonary inflammation. For Autonomic Nervous System (ANS) exposure fresh traffic related particles are no more effective than day old traffic related particles. Particles are believed to cause oxidative stress in the lungs and pulmonary inflammation. Exhaled NO (ExNO) testing is a non-invasive method to detect pulmonary inflammation. Past investigators have shown elevations with air pollution using this method. Suh collected all ExNO measurements at same time of day to correct for diurnal variation according to the protocol of American Thoracic Society.

In single pollutant models, significant positive associations were found for both ambient and bus PM2.5. While the level of pollution aboard the bus was higher than ambient daily concentrations, both models indicated a 14% increase in exhaled NO per 10 μg/m3 of PM2.5.

The similarity of these effect estimates may indicate that fresh traffic particles are not more toxic than aged ambient particles for this outcome. Further support for this was provided by the finding that PM2.5 is more strongly associated with exhaled NO than the other more-specific traffic-related markers such as black carbon, CO, and NO.

Suh also collected blood and ECG samples at same time of day, and analyzed them for markers of systemic inflammation and heart rate variability. For pulmonary exposure the risks increase dramatically for people who are diabetic, obese, or hypertensive. Finally, five minute averages indicate that bus exposures are quite important.

Bob Devlin, EPA

Although PM is currently regulated on the basis of mass in different size ranges, a standard based on regulating specific sources of pollution might be more effective. Some recent studies have suggested that emissions derived from mobile sources (e.g. cars, buses, diesel trucks) may be particularly potent in inducing health effects. Individuals whose jobs involve driving for several hours each day may be exposed to high concentrations of toxic air pollutants from vehicle emissions.

Devlin's hypothesis is that people who spend several hours a day in a motor vehicle will have a high exposure to PM derived from mobile sources, which will alter cardiac function and affect vasoactive mediators in the plasma. North Carolina highway patrol troopers spend an average of 8 hours per day in vehicles on heavily traveled roads, and are a good candidate for testing this hypothesis. To study this cohort a collaborative research team was formed which included researchers from the US EPA, the University of North Carolina, and the North Carolina State Highway Patrol. The sample population had characteristics that would not be expected to be susceptible to PM.

Troopers were monitored for a six week period during the summer and fall 2001. Subjects participated on four consecutive evening-shifts (15:00 – 24:00). Troopers spent an average of 35% of their time outside the cars. The patrol cars were equipped with portable air quality monitors. Each car had an aluminum board with air pollution monitors strapped to the back of the passenger seat while on patrol. In addition data were collected from roadside monitors and fixed site community monitors. Spirometry was performed, blood drawn, and Holter monitoring was performed. In addition, activities of the troopers during their shift and the routes of the patrol cars were recorded. Pairwise Spearman correlations between the exposure variables were calculated. The effects of exposure (individual air pollutants and source factors) on cardiac and vascular parameters were assessed using mixed effects regression models with restricted maximum likelihood estimation. None of the parameters showed a time trend for increased or decreased levels throughout the week.

Two different methods were used for measuring PM2.5 inside vehicles. The passive light scatter device measures data continuously, whereas mass spectroscopy is used for integrative data collection. In vehicle PM levels were about 24% lower than outside, probably due to the use of recirculating air conditioning. Ozone and humidity were lower inside the car, but otherwise air inside the cars was enriched in compounds representative of mobile source emissions. Copper was present inside cars in much larger number than ambient. In general, there are stronger associations between in-vehicle PM concentrations and cardiovascular endpoints than between roadside or ambient PM measurements and these parameters. In most cases there are stronger associations between PM2.5 measurements using mass spectroscopy and vascular endpoints than

between PM2.5 measured using light scatter and these endpoints. The opposite is seen for heart parameters. Devlin concluded that in-vehicle measurements were significant with health effects.

The results could be confounded by several factors. Humidity, CO, and NO_2 were tested as possible confounders by including them in the bivariate models with PM2.5. There were minimal changes in most effects estimates but confidence intervals for out of place ventricular beats broadened for humidity and NO2 and made the effect estimate non-significant. A similar relationship was observed with CO and supraventricular beats. None of the effects estimates for humidity, NO2, or CO were significant in any of the models. Controlling for stress was not found to make a difference in the results as well.

Devlin also sought to characterize the sources that are linked to physiological changes. Factor analysis revealed that soil and road surfaces, fuel combustion and stop-and-go traffic could be possible sources. Copper particles might have been emitted in braking. Cardiac as well as vascular effects were correlated to stop-and-go traffic.

A question was about the pathway of brake dust into an air-conditioned car. Brake dust can come from different sources, not necessarily from the vehicle being driven. Another question wondered if it was stop-and-go traffic or the pollutants from stop-and-go traffic that had a significant impact. Finally a question was asked about averaging time for metal measurements. The measurements were made for an eight hour average from start to end of shift.