8th Diesel Engine Emissions Reduction Conference

Sponsored by
the U.S. Department of Energy,
Freedom Car and Vehicle Technologies

San Diego, California
August 25-29, 2002

August 25, 2002

Dear DEER 2002 Conference Participants:

On behalf of the U.S. Department of Energy's Freedom Car and Vehicle Technologies, welcome to the 8th Diesel Engine Emissions Reduction (DEER) 2002 Conference in San Diego, California! This year promises to be very rewarding for you as an attendee. Through the course of the week, you will hear about "cutting edge" research results on both in-cylinder and exhaust aftertreatment emission reduction technologies, diesel combustion analysis, health effects, fuels and lubricants, and waste heat utilization -- all designed to help move the Department's emissions reduction effort forward. You will also have a chance to ride in and drive SUVs and autos equipped with clean diesel engines that comply with Tier 2, 2007 emission standards but require additional work to achieve the required 120,000 miles durability.

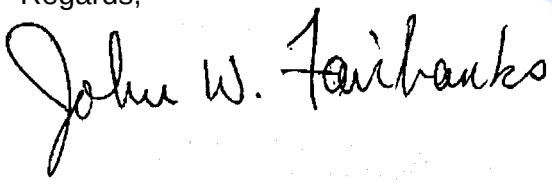
I am pretty sure that each of you will want to visit some of the local attractions. You will find enclosed in your conference book information pertaining to area attractions.

A special thank you goes out to our corporate sponsors for ensuring that the DEER 2002 Conference is a success. Corporate sponsors and the events that they are sponsoring are as follows:

Platinum	**Cummins**	**Co-sponsor of Welcome Reception Monday night dinner Boat Cruise**
Gold	**Caterpillar**	**Boat Cruise and Tuesday night dinner**
	Delphi	**Tuesday breakfast and Thursday breakfast**
	Detroit Diesel Corporation	**Monday afternoon break and Tuesday lunch**
Silver	**Corning**	**Wednesday lunch and co-sponsor of Old Towne**
	Diesel Technology Forum	**Tuesday afternoon break and Wednesday breakfast**
	John Deere	**Wednesday afternoon break and Thursday lunch**
	Shell	**Monday lunch and co-sponsor of Old Towne**
	SINOx® Emissions Control	**Monday breakfast and Thursday lunch**

Your participation in DEER 2002 is very much appreciated. This year's conference is shaping up to be the most informative and successful yet!

Regards,



John Fairbanks, Chair
Diesel Engine Emissions Reduction Conference

Platinum

Cummins, Inc. *http://www.cummins.com*

Cummins Inc. is a leading supplier of diesel- and alternate-fueled engines for heavy-duty trucks, medium-duty trucks, buses, motorhomes, and specialty on-highway vehicles, and the exclusive supplier of diesel engines for the Dodge Ram pickup truck. Cummins is also a leading global supplier of diesel engines for the agriculture, construction, government, marine, mining, rail, and oil and gas markets. Cummins is a global supplier of diesel- and natural gas-powered generator sets and generator set components from 3kW to multi-megawatt installations. Cummins supplies advanced integrated filtration systems for heavy-duty equipment, both on- and off-highway, and is a leading North American supplier of filtration and silencing systems for gas turbine, industrial, small engine, and passenger car applications. Holset, is a global provider and leading technologist of turbochargers for a wide range of applications. Cummins has a retail distribution network for Cummins' products and provides related services and broader solutions that enhance the end users' overall experience.

Cummins is co-sponsor of the Welcome Reception with DOE Freedom Car and Vehicle Technologies and is sponsor of the Monday night dinner and the Boat Cruise.

Gold

Caterpillar *http://www.cat.com*

For more than 75 years, Caterpillar has been building the world's infrastructure and, in partnership with our independent dealers, is driving positive and sustainable change on every continent. Caterpillar is the world's largest maker of construction and mining equipment, diesel and natural gas engines and industrial gas turbines. The company is a technology leader in construction, transportation, mining, forestry, energy, logistics, financing and electric power generation. More information is available at http://www.CAT.com/.

Caterpillar is sponsor of the Boat Cruise and the Wednesday night dinner.

Delphi http://www.delphi.com

Delphi Automotive Systems is a world leader in transportation and mobile electronics components and systems technology. Delphi's three business sectors—Dynamics & Propulsion; Safety, Thermal & Electrical Architecture; and Electronics & Mobile Communication—provide comprehensive product solutions to complex customer needs. The company is headquartered in Troy, Michigan, U.S.A., with regional headquarters in Paris, France; Tokyo, Japan; and São Paulo, Brazil. Delphi maintains a global presence consisting of wholly owned manufacturing sites, joint ventures, customer centers, sales offices, and technical centers. Delphi can be found on the Internet at www.delphiauto.com.

Delphi is sponsor of the Tuesday breakfast and the Thursday breakfast.

Gold (continued)

Detroit Diesel Corporation *http://www.detroitdiesel.com*

Detroit Diesel Corporation (DDC), headquartered in Detroit, Michigan, is engaged in the design, manufacture, sale and service of heavy-duty diesel and alternative fuel engines, automotive diesel engines and engine-related products. The company offers a complete line of engines from 22 to 13,000 horsepower for the on-highway, off-road and automotive markets and is a QS-9000 certified company. Detroit Diesel services these markets directly and through a worldwide network of more than 2,700 authorized distributor and dealer locations. Detroit Diesel is a subsidiary of DaimlerChrysler AG, the world's leading manufacturer of heavy-duty diesel truck engines. Within DaimlerChrysler AG, DDC is part of the Powersystems Business Unit.

Detroit Diesel Corporation is sponsor of the Monday afternoon break and the Tuesday lunch.

Silver

Corning Incorporated *http://www.corning.com*

Corning Incorporated - Diesel Overview
Corning is a leading supplier of catalytic converter substrates and particulate filters.

Established in 1851, Corning Incorporated (www.corning.com) creates leading-edge technologies for the fastest-growing markets of the world's economy. Corning manufactures optical fiber, cable and photonic products for the telecommunications industry; and high-performance displays and components for television, information technology and other communications-related industries. The company also uses advanced materials to manufacture products for scientific, semiconductor and environmental markets. Corning revenues for 2001 were $6.3 billion.

Corning is sponsor of the Wednesday lunch and co-sponsor of the Old Towne excursion.

Diesel Technology Forum *http://www.dieselforum.org*

The Diesel Technology Forum is the nation's leading information resource and promoter of clean diesel technology, its value, economic importance, environmental progress and promise for the future. The Forum promotes clean diesel solutions for existing diesel engines (on/off road), conducts technology demonstrations and works with stakeholders to modernize and upgrade existing diesel engines. Members include leaders in diesel engine, vehicle, component manufacturing, fuel refining and emissions treatment systems. *Offices in Washington DC, Frederick MD and San Carlos, CA.*

Diesel Technology Forum is sponsor of the Tuesday afternoon break and the Wednesday breakfast.

Silver (continued)

John Deere *http://www.johndeere.com*

As one of the World's oldest and most respected enterprises, John Deere creates smart and innovative solutions, in the form of advanced machines, services and concepts, for customers on the farmsite, worksite and homesite worldwide. John Deere is concerned with air quality and has participated in efforts to improve it. During the 6th National Clean Cities Conference it was awarded the 2000 Clean Cities National Partner Award by the U.S. Department of Energy.

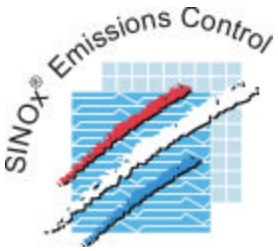
John Deere is sponsor of the Wednesday afternoon break and the Thursday lunch.

Shell *http://www.shell.com*

Shell Gas & Power is among the world's largest private gas and power businesses, having a leading position in Liquefied Natural Gas (LNG) and Gas to Liquids (GtL) conversion and a rapidly growing world power business. The Shell Middle Distillates Synthesis (SMDS) facility in Malaysia commenced production in 1993 and its high specification, clean GtL products are traded around the world. In partnership with Shell Global Solutions, work has commenced towards achieving a further four GtL operational plants by the end of the decade.

Shell is sponsor of the Monday lunch and co-sponsor of the Old Towne excursion.

Silver (continued)



SINOx® Emissions Control *http://www.siemens.com/sinox-catalysts* AND *http://www.hydraulik-ring.com*

SINOx®, the recognized leader in stationary and mobile NOx emission applications is your trusted partner addressing customer needs with proven experience and expertise. When it comes to supplying catalyst or system components, we have the ability to offer a comprehensive solution for your automotive application. Systems allow an engine to be tuned for maximum fuel economy while reducing NOx and particulate emissions.

SINOx® Emissions Control is sponsor of the Monday breakfast and the Thursday afternoon break.

Attractions & Sightseeing

SEA WORLD: Located on beautiful Mission Bay, a 150 acre marine life, entertainment park. Featuring shows, exhibits and attractions the whole family will enjoy. Come and visit with Shamu.

> **Hours:** Daily from 10:00 a.m. (619) 226-3901. **Regular prices:** 1 Day Adults: $42.95, 1 Day Child: $32.95, 1 Day Senior: $39.95 / 2 Day Adults: $46.95, 2 Day Child: $36.95. **Parking:** Cars $7.00, R.V.s $8.00, Motorcycles $3.00

WORLD FAMOUS SAN DIEGO ZOO: Home to the only **baby panda bear** in the U.S. and over 4,000 rare birds, mammals, reptiles and amphibians. New exhibits including Hippo Beach habitat, Tiger River, Sun Bear Forest, Children's Zoo, Gorilla Tropics, Reptile House, and award winning gardens.

> **Hours:** Open daily from 9:00 a.m.-dusk. (619)234-3153. **Regular prices:** Adults: $32.00, Child: $19.75, Seniors $28.95. **Parking:** Free.

SAN DIEGO WILD ANIMAL PARK: Take a journey through the world's most exotic places. See wild animals roaming freely in habitats resembling their native homelands.

> **Hours:** Open daily 9:00 a.m.- dusk. (619) 231-0251. **Regular prices:** Adults: $26.50, Child: $19.50, Seniors: $23.85. **Parking:** $6.00

LEGOLAND: Legoland offers a world of rides and attractions where the child is in the drivers seat. Located in beautiful Carlsbad just 30 minutes North of downtown San Diego and 1 hour South of Disneyland. Take I-5 to the Cannon Road exit and proceed to Legoland Drive.

> **Hours:** Summer - open daily 9:00 a.m.- dusk, Winter - open daily 10:00 a.m. - dusk, closed Tuesday and Wednesday. (760) 918-5346. **Regular prices:** Adults: $39.95, Child: $33.95. **Parking:** $7.00.

SAN DIEGO HARBOR EXCURSION: All in one sightseeing fun! Come enjoy 1 or 2 hour narrated harbor tours. Dinner and dance cruises along San Diego Bay, and 15 minute ferryboat tours to Coronado also available. Whale watching available in season *(usually December - March).* Call (619)234-4111.

> **Regular prices:** 1 hour: $13.00, 2 hour: $18.00, *Whale watching: $23.00.*

HORNBLOWER CRUISES & EVENTS: The Hornblower experience provides nightly dinner and dance cruises, Sunday champagne brunch cruises, and harbor tours, call (619) 686-8715 .

> **Regular prices:** 1 hour: $13.00, 2 hour: $18.00.

OLD TOWN TROLLEY TOURS: See the best of San Diego on a completely narrated two hour tour covering over 100 points of interest Leaves every 30 minutes. Make it an all day experience by visiting each stop or take a two hour continuous tour. (619) 298-8687.

> **Regular prices:** Adults: $24.00, Child: $12.00.

SEAL TOURS: It's a boat! It's a bus! A Hydra-Terra amphibious vehicles for the adventure of a lifetime! 90 minute, fully narrated SEA and LAND tour.

Regular prices: Adults: $24.00, Child: $12.00.

GHOST & GRAVESTONES: Join us for a "FRIGHTSEEING" adventure. Hear ghost stories and visit some of San Diego's most beautiful and historic sites.

Regular prices: Adults: $28.00, Child: $12.00.

SAN DIEGO SIGHTSEEING: Coach USA's all loop tour. Hop-On, Hop-Off Double Decker Sightseeing Bus. Professionsally Narrated Tour.

Regular prices: Adults: $25.00, Child: $15.00.

BALBOA PARK: Located just north of downtown, 1,400 acres composed of museums, theaters, open areas for sport facilities, gardens and home of the world famous San Diego Zoo. Listed below are just some of the centers in Balboa Park:

- **REUBEN H. FLEET SPACE SCIENCE CENTER:** Put your "Hands-On" the wonders of science in our state-of-technology exhibits featuring Brain Games that will blow your mind. Also visit their space theater. (619) 238-1233
- **SAN DIEGO MUSEUM OF ART:** includes several collections from all around the world. Come and explore the different eras of art. Open Tuesday.-Sun. 10:00 a.m.-4:30 p.m. (619) 232-7931.

EMBARCADERO: The San Diego Maritime Museum, anchored along Harbor Dr., is a great place to begin exploring the waterfront Home of the Star of India.

CABRILLO NATIONAL MONUMENT: This Point Loma site commemorates Cabrillo's exploration of the California coast in 1542. A spectacular view of San Diego may be seen from the Old Point Loma Lighthouse. Open daily 9:00 am -5:00 pm (619) 557-5450.

MISSION BASILICA SAN DIEGO de ALCALA: This is the first Mission in a chain of 21 missions along the California coast. Founded on July 16, 1769. Located in Mission Valley. Open daily from 9:00 a.m. - 5:00 p.m. (619) 281-8449.

SAN LUIS REY MISSION: Founded in 1798, a historic landmark including a museum and gift shop. Open daily 10:00 a.m.-4:00 p.m. (760) 757-3651.

Leisure

BARONA CASINO: Vegas-style excitement right here in San Diego. Large gaming rooms with over 800 video and poker machines, bingo tables, satellite wagering and a large buffet. Open 24 hours a day, located 1000 Wildcat Canyon Rd., Lakeside. 1-888-7Barona

SYCUAN CASINO: Come and try your luck with bingo, poker, satellite wagering, blackjack and video machines. (619) 445-6002.

VIEJAS CASINO, TURF CLUB & OUTLET CENTER: High-stakes bingo, poker, Indian blackjack, off track betting, Pai gow, music & dancing all under one roof. (619) 445-5400.619) 443-2300.

BAZAAR DEL MUNDO: In historic **Old Town**, enter a world of shopping and dining unlike any other. Sunny gardens invite you to listen to mariachi bands as they keep rhythm to the music of splashing fountains.

SEAPORT VILLAGE: 75 One of a kind shops. Dine seaside in one of our fine dining restaurants. Located downtown on San Diego bay. (619) 235-4014.

GASLAMP QUARTER: From Horton Plaza to the San Diego Convention Center the 16- block Gaslamp Quarter is downtown's hottest place to visit. Also known as San Diego's premier dining and entertainment district, with several shops, galleries, coffee houses, and theaters

MISSION BAY PARK: The largest facility of its kind in the world and is enjoyed by millions of people each year. Swimming, boating, fishing and sailing all occupy separate areas for each enthusiast. It consists of 27 miles of bay front and 17 miles of ocean front beaches, great for bicycling, rollerblading, jogging, or a leisurely stroll. San Diegans and visitors alike enjoy the beautiful beaches and sparkling water year round, while an extensive wetlands area, provides habitat to many species of plants and waterfowl. In addition to the beautiful coastline, there are accommodations, dining and shops.

CATALINA PASSANGER SERVICE: The fastest way to reach Catalina Island. The Catalina Flyer, leaving from the historic Balboa Pavilion in Newport in Orange County. Reservations required. (949) 673-5245

DEEP SEA FISHING & WHALE WATCHING: Seaforth Sportfishing (619) 224-3383, Hornblower and H&M Landing (619) 222-1144 boats also offer whale watching tours, December through March. Local and long-range sport fishing tours run daily. Experience the wonderful world of the sea on 1/2 day , 3/4 day and full day boating trips.

H2O JET SKI RENTALS & TOURS: Fun for the whole family! Best prices on the Bay! Friendly and helpful attendants. (619) 226-2SKI (2754).

SAN DIEGO PARASAIL ADVENTURES: Experience the combined thrills of an offshore power boat ride, parachuting, ballooning and gliding all in one adventure. Open daily, call (619) 223-4FUN.

SEAFORTH BOAT RENTALS: Largest selection and best prices, sailboats 14' to 36', powerboats 10' to 26', jet skis, fishing skiffs, kayaks, paddleboats between 3 locations: Mission Bay (619) 223-1681, Downtown (619) 239-2628, Coronado (619) 437-1514.

Shopping

KOBEY'S SWAP MEET: San Diego's Best Bargains! Jewelry, Clothes, Used Items, Plants, Produce, Crafts, Sunglasses, T-shirts. 3500 Sports Arena Blvd. 619-226-0650. Open Thurs. through Sunday, 7 am to 3 pm.

CAMPING WORLD: Everything you would ever need for your R.V., all in one spot! Stop by our new San Marcos location where you will be greeted by our friendly and helpful staff, or visit our web site. 1-800-874-4346.

SAN DIEGO VISITOR INFORMATION CENTER GIFT SHOP: Our gift shop sells a variety of souvenirs. Please visit us for a wide selection of gifts for the entire family including "San Diego Video Postcard". A comprehensive, entertaining and informative television program on San Diego and its surroundings. Also detailed San Diego Street Maps, including places of interest.

MAIL BOXES ETC: Mail all of your gift and souvenir purchases right up the hill from our center. Located at 4735 Clairemont Dr. 619-490-1690. Notary Public on site and internet access available.

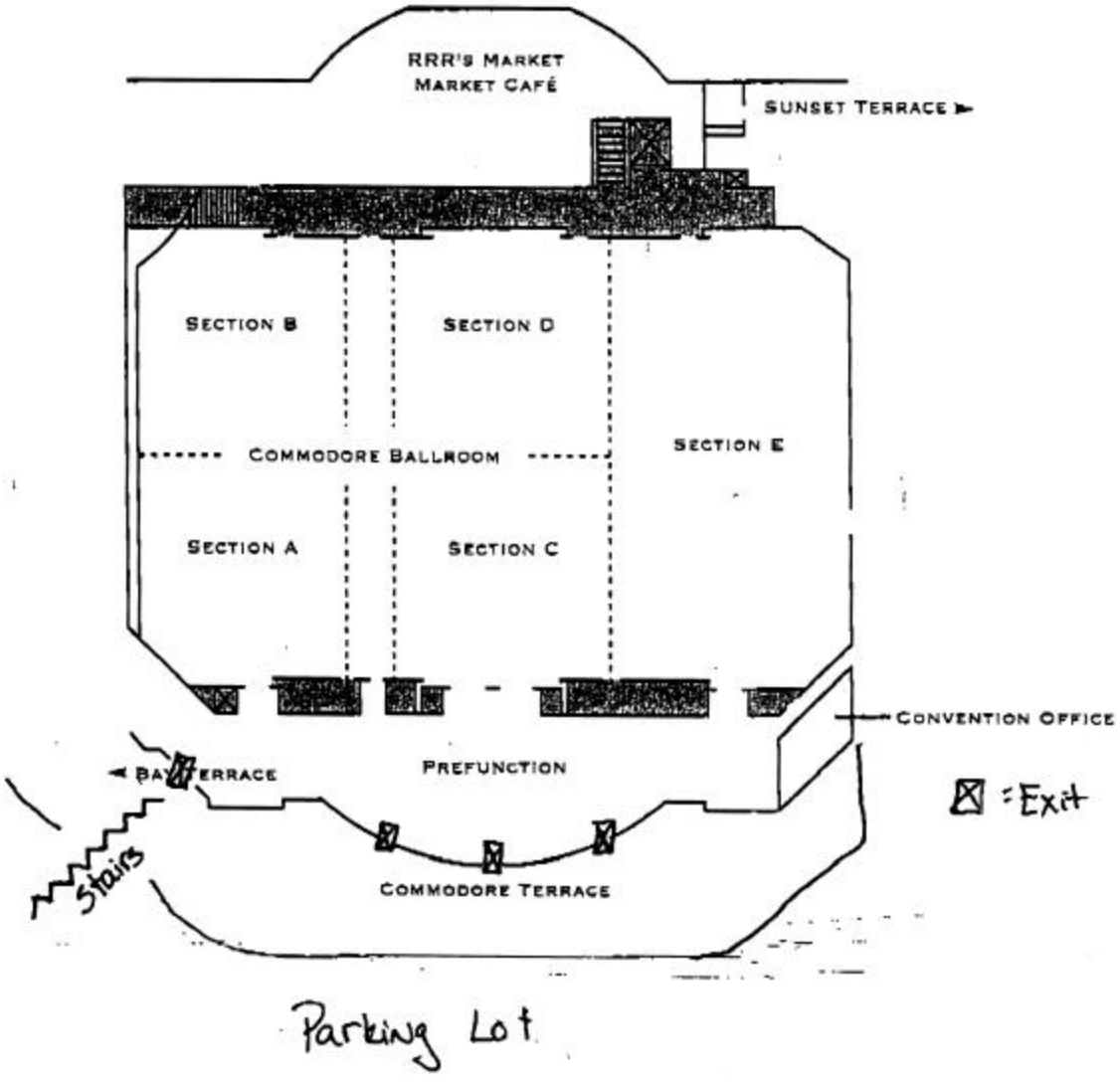
VIEJAS OUTLET CENTER: A new addition to Viejas, a $30 million factory outlet shopping center. (619) 445-5400.619) 443-2300.

THE GOLF MART: San Diego's largest Golf supermarkets. Seven locations throughout San Diego. Guaranteed lowest prices on Taylor Made, Ping, Cobra and Callaway Golf. (619) 298-9571.

Emergency Numbers

- Dial "0" for PBX
- Dial "4421" for Security

Emergency Exits



Abstracts

Session 1 – Diesel Engine Emissions Reduction Strategies

FUELS OF THE FUTURE FOR CARS AND TRUCKS

Dr. James J. Eberhardt
U.S. Department of Energy

The transportation sector, because of the requirement to carry its energy supply onboard so as to attain the freedom of mobility, is almost totally dependent on high energy density liquid hydrocarbon fuels, i.e., currently conventional petroleum-based gasoline and diesel fuel. This has resulted in an ever-growing reliance on imported oil as domestic sources of crude oil production have declined. The United States has begun to make use of other non-petroleum fuels, such as renewable ethanol, biodiesel, and domestically producible gaseous fuels (such as methane and hydrogen), to meet its transportation energy demand and to reduce its reliance on imported oil. For example, the Department of Energy's FreedomCAR Partnership is focused on hydrogen-powered fuel cells for light-duty vehicles. However, specific performance requirements on heavy trucks are more demanding than those of passenger vehicles. Because of the heavy loads and long distances that they travel, it does not appear likely that hydrogen or electricity will be able to provide what long-haul trucks require because of the low energy density of these energy carriers.

The important role that heavy trucks play in the transport of goods and services, which is essential to a healthy economy, coupled with a requirement for carbon neutrality in order to mitigate the impact of transportation on global climate change, may make it necessary to sustain the operation of heavy trucks with biorenewable liquid fuels. Such a scenario implies that, left with no known alternatives, heavy trucks will likely continue to be powered by high-efficiency combustion engines well into the 21st century.

Abstracts

Session 2 – Applied Thermoelectric Generator R&D

PROSPECTS FOR A BROADENED USE OF THERMOELECTRICS IN VEHICLES

Lon E. Bell
BSST, LLC

Very large strides have been made recently in the performance of solid-state thermoelectric (TE) systems, due directly to substantial efficiency gains at the system level and through the development of hetrostructure materials. Combined, these result in at least a factor-of-two improvement in system performance with the prospect of significant additional gains in the near future. The prospect is that such systems will have advantage over today's devices within the next several years. As a result, TE's are projected to become serious contenders for cooling, heating, temperature control, and waste power recovery applications in vehicles. The characteristics and performance requirements to meet present and projected usage for specific applications are discussed. Requirements for achieving these targets are analyzed.

Present and near-term vehicle applications include small, on-board refrigerators and Amerigon's seat cooling and heating systems. Amerigon's product is given as an example of a TE product that has exhibited very good consumer acceptance, through a direct increase in personal comfort. Manufacturers have adopted the technology since it increases consumers' perceived performance of current heating, cooling, and air-conditioning (HVAC) systems and reduces vehicle energy consumption by decreasing HVAC power demand.

NANO-STRUCTURED THERMOELECTRIC MATERIALS

R. Venkatasubramanian, E. Siivola, K. Coonley, P. Addepalli, M. Mantini, B. O'Quinn, T. Colpitts, J. Posthill, R. Alley, and M. Puchan
Research Triangle Institute

Thermoelectric (TE) device technology offers several advantages, such as solid-state reliability, CFC-free refrigeration and air-conditioning, noise-free operation, and ability to convert waste-heat to electricity These traits are highly desirable from an environmental standpoint. However, for the last 40 years, the performance of these devices has been limited by the so-called figure-of-merit (ZT) of the bulk materials. The materials' limitation stems from the fact that an ideal TE material has to be a good electrical conductor in order to minimize Joule heating during current flow, but also a bad thermal conductor in order to minimize parasitic heat flow between the hot side to cold side from where the heat is pumped. Such a requirement of properties, not easily found in nature, forced us to look at engineered nanomaterials several years ago. We have recently demonstrated a ZT of about 2.4 at room temperature in nano-structured Bi_2Te_3/Sb_2Te_3 superlattices compared to a typical ZT of 1 in bulk materials. In addition to the enhanced ZT for potentially higher efficiency in refrigeration or power conversion, the thin-film TE technology offers tremendous possibilities in the area of rapid cooling and heating as well as in very lightweight, compact portable systems. In addition, thin-film technology requires minimal active materials, about 1/40,000 of bulk approach, thereby potentially reducing concerns about materials availability and recycling for a vast array of applications. We will discuss the state of the technology development, our effort in prototype devices, and progress towards various applications, such as automotive waste-heat recovery, microscale heating and cooling for biotechnology applications, cooling high power density electronics, and powering wireless sensors.

QUANTUM MATERIALS DEVELOPMENT AND SCALE-UP

Saeid Ghamaty and Norbert Elsner
Hi-Z Technology, Inc.
and
Peter Martin and Larry Olsen
Pacific Northwest National Laboratory

Si/SiGe and B_4C/B_9C quantum well materials have been under development at Hi-Z for more than 5 years, and very favorable thermoelectric properties have been achieved. An efficiency of 14 percent has been measured at a DT of 190°C, and efficiencies of greater than 25 percent are expected with thicker films.

Pacific Northwest National Laboratory will describe their recent progress in depositing superlattice films by magnetron sputtering and efforts to scale up the sputtering deposition process to deposit larger area films with much lower costs. Initial results on deposition of p-type Si/SiGe superlattices and release layers will also be described.

QUANTUM DOT SUPERLATTICE THERMOELECTRIC MATERIALS AND DEVICES

T. C. Harman, P. J. Taylor, M. P. Walsh, and B. E. LaForge
Massachusetts Institute of Technology Lincoln Laboratory

PbSeTe-based quantum dot superlattice structures grown by molecular beam epitaxy have been investigated for applications in thermoelectrics. We have demonstrated improved values relative to the conventional bulk $(Bi,Sb)_2(Se,Te)_3$ thermoelectric materials using an n-type film in a one-leg thermoelectric device test setup. The typical device consists of a substrate-free, bulk-like (typically 0.1 mm in thickness, 10 mm in width, and 5 mm in length) slab of nanostructured PbSeTe/PbTe as the n-type leg and a metal wire as the p-type leg. This paper also describes the growth and characteristics of n-type and p-type quantum dot superlattice materials. Projections of future thermoelectric performance expectations for PbSeTe-based quantum dot superlattice materials will be presented.

This work was sponsored by the Department of the Navy and the Defense Advanced Research Projects Agency (DARPA) under Air Force Contract No. F19628-00-C-0002. The opinions, interpretations, conclusions and recommendations are those of the authors and are not necessarily endorsed by the U.S. Government.

Abstracts

Session 3 – Diesel Engine Policy at the State, National, and International Level

GLOBAL CLIMATE CHANGE AND THE UNIQUE (?) CHALLENGES POSED BY THE TRANSPORTATION SECTOR

James J. Dooley
Joint Global Change Research Institute

This presentation will describe findings from the first phase of the Global Energy Technology Strategy Project (GTSP). The GTSP is a unique international, public/private collaboration designed to address the role that technology can play in addressing the long-term risks of climate change. The program began in 1998, and Phase I of GTSP culminated in the publication of a document summarizing key findings, which were presented at the sixth meeting of the Conference of the Parties to the United Nations Framework Convention on Climate Change as well as in testimony before the U.S. Senate and in numerous other policy and scientific venues. This work has laid the foundation for developing a long-term technological response to climate change in the United States. The presentation will also include early highlights from ongoing research in Phase II of the GTSP (which was initiated in the spring of 2002) that is specifically focused on the challenge associated with decarbonizing the transportation sector. The sponsors of the GTSP include the Battelle Memorial Institute, BP, Electric Power Research Institute, ExxonMobil, General Motors, Kansai Electric Power, National Institute for Environmental Studies (Japan), New Energy and Industrial Development Organization (Japan), North American Free Trade Agreement -- Commission for Environmental Cooperation, PEMEX (Mexico), Tokyo Electric Power, Toyota Motor Company, and the U.S. Department of Energy.

MEETING THE CO_2 CHALLENGE

Douglas Graham
Ricardo, Inc.

With a new California CO_2 law now passed, it is time to think about this soon-to-be regulated greenhouse gas. Adding to the challenge is the fact that many NO_x-PM emissions reduction strategies cause an increase in CO_2 emissions. This presentation outlines a strategy for reducing CO_2 emissions by the use of advanced direct injection diesel engines. Specific methods discussed are increasing diesel engine penetration in the fleet, downsizing the diesel engine, using advanced boosting systems, increasing the specific output of the engines, controlling P_{max}, using light engine structures, and applying diesel engines in hybrid vehicles. The CO_2 reduction using this strategy can reach 50 percent in city driving cycles. The technology involved will be generally available within the next few years. The remaining challenges are in cost and customer value.

EPA'S PERSPECTIVE ON THE 2007 HEAVY-DUTY TRUCK DIESEL ENGINE EMISSIONS COMPLIANCE

Byron Bunker
U.S. Environmental Protection Agency

The U.S. Environmental Protection Agency (EPA) has completed a comprehensive technology review of the progress that industry is making toward meeting the requirements of the 2007 Highway Heavy-Duty Clean Diesel Program. This Program will help achieve public health benefits through the introduction of new emission standards that will result in significant reductions in particulate matter (PM) and oxides of nitrogen (NO_x) from diesel trucks and buses. The report, "Highway Diesel Progress Review," provides EPA's review of the progress of manufacturers of diesel engines and emissions control systems in developing technology to reduce engine exhaust pollutants. In particular, the report documents progress to develop the NO_x adsorber technology and the catalyzed diesel particulate filter technology. The Agency found that the industry has made significant progress to develop and commercialize the technologies needed to comply with the Program's requirements.

THE U.S. NAVY'S CONCERNS FOR DIESEL ENGINE EMISSIONS AND ASSOCIATED TECHNOLOGIES

Michael Osborne
NAVSEA

Development of environmental technologies for diesel engines is a U.S. Navy priority, but declining budgets have constrained Navy investment in recent years. Emerging environmental regulations for marine engines have established clear trends toward more stringent standards in the future. Unique Navy operational requirements, the marine environment, and distinct marine engine models render the operating mechanisms of some land application technology concepts ineffective and enhance the viability of other technology concepts. Some of the attractive technologies may not be suitable for global operations and the varied missions of national security. Marine operation, Navy constraints, and appropriate technology investments will be reviewed.

MARITIME ENERGY AND EMISSIONS PROGRAM: BACKGROUND, STATUS, AND LESSONS LEARNED

Dan Gore
U.S. Maritime Administration

The *Los Angeles Times* recently published an article entitled “Finally Tackling L.A.’s Worst Air Polluter” concerning the city’s twin ports. Officials in Texas briefly considered shutting down the Port of Houston for 12 hours every day as one method of reducing area NO_x emissions. Efforts to dredge the channels at Port of New York/New Jersey are delayed by Clean Air Act-induced red tape. The EPA is currently considering applying new proposed marine engine regulations to foreign vessels entering U.S. territorial waters. Considering that U.S. ports and waterways handle more than 2 billion tons of cargo every year, the need to squarely address maritime-related air pollution issues is becoming clear.

The U.S. Maritime Administration (MARAD) foresaw the probability that air-quality pressures and regulations would carry over into the marine industry and created the Maritime Energy and Emissions Program. The primary objective of the Program is to foster the demonstration of marine engine technologies that maintain efficiency while significantly reducing air emissions. Components of the Program include technology selection, systems installation, performance testing, formation of public-private partnerships, policy analysis, and information dissemination.

The presentation will describe the nature of the Program, provide a status of activities, and discuss lessons learned. A numerical description of the maritime industry in terms of vessels, engines, power, and fuel consumption will be provided. Demonstration technologies covered will include diesel auxiliaries, alternative fuels, and fuel cells. Finally, future goals and plans will be outlined.

2007-2009 EMISSION SOLUTIONS FOR HEAVY-DUTY DIESEL ENGINES

Jeffrey A. Leet
Southwest Research Institute

Manufacturers of heavy-duty diesel engines for sale in the United States face achieving an unprecedented reduction in emissions in 2007 and in 2010. A 90-percent reduction in PM must be achieved by 2007, and a full 90-percent reduction in NO_x must be implemented by 2010 across 100 percent of the on-highway product line.

This presentation will focus on the technology solutions possible for engine makers for the interim 2007-2009 timeframe as well as discuss the additional NO_x reduction strategies for a 2010-compliant engine. The ability to achieve the interim 2007-2009 NO_x fleet average standard of 1.18 g/hp-hr via in-cylinder control methods, including diluent control, modified combustion, variable valve actuation, and model-based control strategies, will be presented. The possible means of achieving a larger portion of the required emissions reduction through in-cylinder control rather than by exhaust treatment will be discussed. The issues of oil consumption and closed crankcase ventilation systems and how they impact PM-control technologies will be discussed.

REDUCING CALIFORNIA VEHICLE FUEL CONSUMPTION WITH INCREASED USE OF HIGH-EFFICIENCY CLEAN DIESEL TECHNOLOGY

Richard McCann and Eric Cutter

M.Cubed

California is assessing various options to reduce petroleum consumption over the next several decades. Increased use of diesel vehicles is one such option. Light-duty diesel vehicles use on average about 38 percent less fuel per mile than a comparable gasoline vehicle. However, these vehicles have not been able to meet current California emission standards and do not represent a significant share of the California car market. On the other hand, light-duty diesel vehicles compose up over 40 percent of the current market in Western Europe. These cars comply with European emission standards, which tend to focus on a different set of pollutants, including carbon dioxide. The introduction of ultra low-sulfur diesel fuel in the U.S. market and new emission control technologies may make diesel automobiles a competitive option to reduce fuel use in California by 2007. The potential success of diesel cars may depend on some policy choices related to means of complying with future emission standards.

Under a market scenario allowing for a 25-percent market penetration rate in diesel automobiles, California could save over 530 million gallons of gasoline-equivalent fuel per year by 2030. If diesel automobile and light truck penetration reaches 32 percent, a level akin to that seen today in Europe, then California could save up over 930 million gallons per year by 2030. Given the state's exposure to market risks with the shift from MTBE to ethanol as the oxygenate additive for reformulated gasoline, diesel delivers an even larger benefit in reducing gasoline consumption directly. Under the price-driven scenario, diesel light-duty vehicles could reduce gasoline consumption by 70 million gallons as early as 2010. With early introduction and rapid adoption under the European scenario, savings could rise to 110 million gallons by 2010.

A SUMMARY OF THE SOUTH COAST AIR QUALITY MANAGEMENT DISTRICT INCENTIVE PROGRAMS

Fred Minassian
South Coast Air Quality Management District

The South Coast Air Quality Management District's (AQMD) Technology Advancement Office is responsible for the implementation of the agency's incentive programs. Funding for these programs mostly come from the State of California, in addition to local matching funds provided by the South Coast AQMD from its Clean Fuels Fund. The current incentive programs are:

- Lower Emission School Bus Program
- Carl Moyer Program
- NO_x and PM Reduction Programs
- Rule 2202 Air Quality Investment Program
- ZEV Incentive Program
- Infrastructure Program.

The implementation of the above-mentioned programs is targeted to reducing criteria pollutant emissions from the on- and off-road fleet with a preference for alternative fuel technologies.

THE POSSIBLE ROLE FOR DIESELS IN CALIFORNIA

James Boyd
California Energy Commission

The Energy Commission is the State's primary energy policy agency that is responsible for addressing the energy challenges facing California. With a strong economy and growing population, the California Energy Commission is faced with a daunting task of ensuring that California has a reliable supply of energy and transportation fuels that are clean and affordable.

Through an AB 2076 legislation directive, we are examining the potential benefits from various options and future technologies. Through this rigorous analytical effort the Energy Commission, jointly with the Air Resources Board, will be recommending policies and strategies that ensure energy and environmental objectives are balanced. One strategy that may help to meet our near-term energy needs is increased use of light-, medium-, and heavy-duty diesel vehicles. We remain committed to seeking ways that government can help to expand the use of more efficient fuels and vehicle technologies while maintaining our commitment to meeting clean environmental standards.

NO_x CREDIT AND SCR

Daniel Sloan
Emission Credit Brokers

The U.S. Environmental Protection Agency (EPA) has mandated emissions levels that no polluting sources can exceed without penalties. When a company voluntarily spends money to reduce pollution below those mandated levels, emission credits are given as incentives. The emission credits are nearly equal to the amount of pollution abated. For example, if a company reduced 80 tons per year at one of its facilities, the company would receive approximately, in all probability, 64 tons of emission credits. Normally, 20 percent is retired for the benefit of the environment. Emission credits, other than greenhouse gases, can only be bought and sold in the same Air Resources Board (ARB) Region in which they were created.

The amount of money the emission credit is worth depends on supply and demand. As an example, in the height of the California energy crisis, NO_x reclaim credits were trading at $110,000 a ton. By creating emission credits, a company can offset the cost of applying technology, and sometimes profit, to lower pollution below mandated levels, while the environment benefits from the 20 to 30 percent of the pollution that is retired.

One source of emission credits is through retrofitting diesel engines. To date, however, it has been particularly prohibitive due to the cost of the technology. Using natural gas vehicles and dual-fuel vehicles as an alternative is expensive and has enormous obstacles to overcome in order to truly be effective.
Conversely, by utilizing aftermarket devices such as selective catalytic reduction (SCR) systems, companies can retrofit their on-road and off-road diesel fleets or stationary generators early, create emission credits, and profit.

New technologies such as SCR systems are incredibly cost effective and will now allow companies to retrofit their mobile and smaller stationary sources at a much lower cost and, with market-based incentives like emission credits, actually be able to profit. Retrofit devices can also be purchased using emission credits. For example, by implementing an emission reduction device, using an SCR system, as an example the following steps would be taken:

1. Company determines purchase price from vendor.
2. Emission Credit Brokers (ECB) negotiates with local ARB.
3. Retrofit provider installs SCR device.
4. ECB sets up monitoring.
5. ECB pays vendor for device.
6. After first year, ECB starts receiving compensation from EPA for NO_x reduction from installed device.

Abstracts

Session 4 – Fuels and Lubrication

RENEWABLE DIESEL FUELS: STATUS OF TECHNOLOGY AND R&D NEEDS

Robert McCormick
National Renewable Energy Laboratory

Renewable diesel fuel development has begun to focus on a portfolio of fuels because no single fuel option offers adequate petroleum displacement benefits on its own. In the near term, these options include biodiesel and ethanol-diesel blends. Medium- and longer term options include biomass-derived Fischer-Tropsch (FT) diesel, esters of levulinic acid (produced from cellulosic biomass), and certain other oxygenates. This presentation will review the technical status of these renewable diesel options and their position in the fuels development pathway.

Biodiesel consists of the methyl esters of fatty acids and can be produced from a variety of vegetable oil, animal fat, and waste grease resources. The potential production of biodiesel is from 2 to 6 billion gallons per year in the United States. Biodiesel is a fully commercial fuel based on the development of the ASTM D6751 quality standard and completion of EPA 211b testing requirements. Most engine and fuel injection equipment (FIE) manufacturers believe that use of up to 5-percent blends of biodiesel in petroleum diesel will have no adverse effects and can result in a significant improvement in fuel lubricity. There is little significant change in pollutant emissions at this level. The biodiesel industry supports the use of 20-percent blends, which produces a significant lowering of PM emissions (15-20 percent) relative to conventional diesel. However, there are several technical barriers to the use of 20-percent and higher blend levels. These include the potential for poor oxidative stability, incompatibility with fuel system elastomers and other materials, low-temperature flow properties, and increased NO_x emissions.

Ethanol-diesel blends, or e-diesel, are mixtures of up to 15-percent ethanol in conventional diesel fuel with cosolvent or microemulsifier additives at levels of 0.5-2 percent. E-diesel is an experimental fuel, and most engine and FIE manufacturers are opposed to its use because it exhibits a low flashpoint (13°C), and fuel tank vapor is flammable under most conditions. However, if these safety issues can be overcome, e-diesel offers the potential for significant PM emissions reductions and petroleum displacement. Current U.S. production of fuel ethanol is about 2 billion gallons, and some projections suggest more than 20 billion gallons could be produced at some point in the future.

Longer term, the potential exists to produce on the order of 10 billion gallons of FT diesel via biomass gasification. Biomass FT diesel will be very similar to natural gas- or coal-derived FT diesel. The main technical barrier to this fuel is high cost. A second longer term option is esters of levulinic acid, which is produced via acid hydrolysis of cellulose. Some analyses suggest that levulinic acid could be produced for $0.04-$0.10/lb. The ethyl and methyl esters of this acid exhibit high flashpoint and lubricity. Blends of up to 10 percent in conventional diesel appear to be stable. This potential

renewable blending component is in the initial stages of the fuel development pathway. Potential production capacity is on the order of billions of gallons. Several other oxygenates with potential as fuel-blending components can also be produced from renewable resources and will be briefly discussed.

FUEL REQUIREMENTS FOR HCCI ENGINE OPERATION

Thomas W. Ryan III and Andrew Matheaus
Southwest Research Institute

Researchers at Southwest Research Institute (SwRI) have been working for the past several years on the fundamental and practical aspects of homogeneous charge compression ignition (HCCI) operation of reciprocating engines. Much of the work has focused on the use of diesel fuel. The work at SwRI has, however, demonstrated that there are fundamental limitations on the use of current diesel fuels in HCCI engine. Some of these fundamental limitations were discussed in a paper presented at the THIESEL 2000 Conference.

One of the most difficult aspects of fuel specification for HCCI engines is the characterization of the fuel characteristics that adequately defines the ignition or reactivity of the fuel. The results of the SwRI program are summarized in this paper and used to define the fuel requirements of HCCI engines. A newly defined fuel ignition property for HCCI fuels is introduced, and preliminary constant volume combustion bomb results are presented and discussed.

OPPORTUNITIES FOR THE EARLY PRODUCTION OF FISCHER-TROPSCH DIESEL FUEL IN THE UNITED STATES - - AN OVERVIEW

John Shen and Edward Schmetz
U.S. Department of Energy (Germantown, MD)

Gregory J. Kawalkin, Gary J. Stiegel, John C. Winslow, and Robert M. Kornosky
U.S. Department of Energy National Energy Technology Laboratory (Pittsburgh, PA)

Venkat K. Venkataraman, Joel S. Chaddock, Daniel C. Cicero, Suresh C. Jain, and Jenny B. Tennant
U.S. Department of Energy National Energy Technology Laboratory (Morgantown, WV)

Fischer-Tropsch (F-T) diesel fuels have been of interest to a wide range of industries in recent years because of their desirable attributes, including zero sulfur and aromatics and high cetane number. This paper will discuss the highlights of the industrial projects being co-supported by the Office of Fossil Energy within the U.S. Department of Energy. These projects are to analyze the feasibility of, and to develop the technology for, processes to produce F-T fuels from domestic feedstocks, including natural gas and solid hydrocarbons (coal, petroleum coke, and biomass). F-T fuel production is scheduled to begin in 2003 for natural gas feedstock from two commercial demonstration plants located in Oklahoma. The prospect for commercial production of F-T fuels from solid hydrocarbons will also be discussed.

AN EVALUATION OF SHELL GAS-TO-LIQUIDS DIESEL – THE ENVIRONMENTAL BENEFITS

Richard H. Clark, Jim D. Evans, and Ian G. Virrels
Shell Global Solutions (US) Inc.

The Shell gas-to-liquids (GtL) technology, better known as the Shell Middle Distillate Synthesis (SMDS) process, converts natural gas into diesel or kerosine and speciality products via a modern, improved Fisher-Tropsch synthesis. The diesel cut has very good cetane quality, low density, and virtually no sulphur and aromatics. The environmental credentials of SMDS diesel continue to be evaluated in terms of vehicle and engine exhaust regulated emissions. Other key environmental properties of SMDS diesel, including ecotoxicity, biodegradability, and product sustainability, have also been investigated.

Data from both ecotoxicological screening and biodegradation tests show positive outcomes for both SMDS diesel and certain blend combinations with conventional diesel.

The sustainability of the SMDS process has been studied to encompass all aspects from production to the end use of all products. From the specific viewpoint of diesel usage, test programmes indicate benefits in both mass fuelling and CO_2 emissions when compared with conventional diesel. A proportion of these benefits can be derived in SMDS diesel blends.

DEVELOPMENT OF A DIMETHYL ETHER-FUELED SHUTTLE BUS

Jennifer Stefanik, Elana Chapman, Shirish Bhide, Louis Boehman, Howard Glunt, David Klinikowski, Joseph Perez, and Andre Boehman
Pennsylvania State University

and

Ed Heydorn,
Air Products and Chemicals, Inc.

Dimethyl ether (DME) is a potentially ultra-clean diesel fuel; however, its unique characteristics require special handling and accommodation of its low viscosity and low lubricity. In this project, DME was blended with diesel fuel to provide sufficient viscosity and lubricity to permit operation of a 7.3-liter turbodiesel engine in a campus shuttle bus with minimal modification of the fuel injection system. A pressurized fuel delivery system was added to the existing common rail injection system on the engine, allowing the DME-diesel fuel blend to be circulated through the rail at pressures above 200 psig to keep the DME in the liquid state. Fuel returned from the rail is cooled with heat exchangers and recirculated to the rail using a gear pump. A modified LPG tank (for use on recreational vehicles) stores the DME-diesel fuel blend onboard the shuttle bus, and a small cylinder of helium is used to provide a blanket of inert gas above the fuel mixture to keep the DME in the liquid state and to push the mixture to the fuel rails.

A significant challenge is posed by the rapid increase in DME vapor pressure with increasing fuel temperature. As the fuel mixture passes through the rail, it is heated by the surrounding surfaces in the cylinder head. The target for maximum fuel rail temperature was set at 50°C, which corresponds to a DME vapor pressure of 150 psig. Refueling is accomplished by mixing the diesel fuel and DME onboard the bus, with diesel fuel delivered from the existing diesel tank and DME delivered by 1000-lb cylinders at a small refueling station. The shuttle bus operates on the Faculty/Staff Loop at the University Park campus of the Pennsylvania State University.

INVESTIGATION OF THE EFFECTS OF FUELS AND AFTERTREATMENT DEVICES ON THE EMISSION PROFILES OF TRUCKS AND BUSES

Dave Smith
British Petroleum

A multi-year technology validation program completed in the spring of 2001 evaluated the use of ultra-low sulfur diesel fuels and passive diesel particulate filters (DPF's) in several different diesel fleets operating in Southern California. The fuels used throughout the validation program were ultra-low sulfur diesels, dubbed ECD and ECD-1. These CARB-compliant fuels are produced by ARCO, a BP company, with less than 15-ppm sulfur content. The trucks and buses participating in the study were retrofitted with two types of catalyzed DPF's and operated for over 1 year.

As part of this program, a special study was undertaken to chemically characterize exhaust emissions from a subset of vehicles operated on a multitude of fuels. This select group of vehicles was tested with and without DPF's to obtain detailed emission profiles for a wide range of compounds. The test vehicles included a school bus, two grocery truck tractors, and three transit buses. The fuels used included a representative CARB diesel, ECD, ECD-1, Fischer-Tropsch (F-T) diesel, and motor vehicle-grade compressed natural gas (CNG).

Results from the program provided vehicle emission profiles for nitrogen oxides (NO_x), carbon monoxide (CO), total particulate matter (TPM), PM_{10}, $PM_{2.5}$, particulate-bound elements, inorganic ions, and elemental /organic carbon. Also provided are data for gas phase volatile organic compounds (VOC's), poly aromatic hydrocarbons (PAH), nitro-PAH's, and carbonyl compounds. All emission results are presented relative to the average CARB diesel fuel to highlight emission reduction potentials. In addition to results for the various compound classes, specific detailed chemical data will be presented for highly reactive or toxic compounds. These include compounds such as ethene, benzene, toluene, xylene, formaldehyde, and acetaldehyde.

The results will illustrate the impact of the fuel and hardware combinations on exhaust emissions and will compare emission profiles for controlled diesel vehicles vs. those fueled by CNG.

FUEL ADDITIVES FOR IMPROVED PERFORMANCE OF DIESEL AFTERTREATMENT SYSTEMS

David Human
Ethyl Corporation

In response to increasingly stringent diesel engine emissions standards, the industry has accelerated its investigation of technologies that can significantly lower NO_x and particulate matter emissions from diesel engines and exhaust. At the 2001 DEER conference a paper was presented on the use of a fuel-borne additive's ability to improve catalyst durability by scavenging sulfur and phosphorous from the exhaust stream before they had the opportunity to react with catalytic surfaces in lean No_x traps. Work has continued on the use of fuel-borne additives to not only protect NO_x traps but also to improve the efficiency of soot oxidation in particulate control devices. While being able to scavenge sulfur and phosphorus, this additive technology has also been found to significantly effect the conditions for particulate trap regeneration. This presentation will show the benefit of a fuel-borne catalyst on lowering the balance point temperature and exhaust back pressure in particulate traps.

STATUS OF APBF-DEC NO_X ADSORBER / DPF PROJECTS

Brian West
Oak Ridge National Laboratory

and

Matthew Thornton and Shawn Whitacre
National Renewable Energy Laboratory

The Advanced Petroleum-Based Fuels – Diesel Emission Control Activity (APBF-DEC) is a Government/Industry collaborative research study aimed at identifying optimal combinations of fuels, lubricants, diesel engines, and emission control systems to meet projected emission standards through 2010. The research projects are co-funded and supported with in-kind contributions from the U.S. Department of Energy and other Government agencies, engine and vehicle manufacturers, catalyst manufacturers, energy and additive companies, and these industries' respective trade associations. Five separate projects involving light- and heavy-duty engine platforms are being conducted to measure the effects of fuel and lubricant composition on engine-out and tailpipe emissions. Three of these five projects are focused on emissions control systems using NO_x adsorber catalysts in combination with diesel particle filters. Ricardo, Inc., is using a heavy-duty line-haul engine, Southwest Research Institute is conducting a pickup truck/sport utility vehicle project, and FEV is performing a passenger car study. The effects of fuel properties on system performance and unregulated emissions will be investigated, generating comprehensive data on these technologies for the U.S. Environmental Protection Agency's biennial technology assessments. The presentation will provide an overview and current status of the three projects.

THE IMPACT OF LUBRICANT FORMULATION ON EMISSIONS FROM A MEDIUM-DUTY DIESEL ENGINE

Shawn D. Whitacre
National Renewable Energy Laboratory

Increasingly stringent engine emission standards are driving the need for advanced technologies that control nitrogen oxides (NO_x) and particulate matter (PM). To enable the efficient and durable application of these new technologies, a growing body of evidence suggests that diesel fuel quality improvements, specifically reductions in fuel sulfur content, are necessary. Recognizing that this may not be enough, additional research is underway to further examine if new lubricants will also be required in catalyst-equipped engines.

This presentation summarizes the results of the first in a multi-phase research agenda to quantify the effects of lubricant composition on the performance and durability of advanced diesel emission control systems. This first phase examines engine-out (i.e., catalyst-in) emissions from a 1999 International T444E (7.3L, V8) base engine that has been equipped with exhaust gas recirculation (EGR) and closed crankcase ventilation (CCV) systems.

Twelve additive technologies spanning a range of key properties were blended in up to four separate basestocks. Engine emissions, using each of the finished lubricants, were evaluated over a modal steady-state operating cycle. In addition to measuring gaseous emissions, PM was collected in three separate sample trains and analyzed for mass, soluble organic fraction, sulfates, nitrates, metal content, and polycyclic aromatic hydrocarbons.

These results form the basis of follow-on work that is studying how these lubricant-derived emission components impact diesel emission control system performance. This work is being conducted within the U.S. Department of Energy's Advanced Petroleum Based Fuels – Diesel Emission Control Activity, a Government/Industry collaborative research program to study advanced fuel- efficient systems for diesel emission control.

NATURAL OILS – THE NEXT GENERATION OF DIESEL ENGINE LUBRICANTS?

Joe Perez
Pennsylvania State University

and

Shawn Whitacre
National Renewable Energy Laboratory

This presentation focuses on the next generation of diesel engine lubricants. It reviews current lubricant technology, including both petroleum and renewable lubricants. Current technology suggests that diesel engines will require aftertreatment systems to meet the stringent 2007 emission regulations. To meet current regulations, API CI-4 was developed to handle anticipated severe oil conditions, such as increased soot, acids, and higher temperatures resulting from the use of cooled exhaust gas recirculation.

The next generation of diesel engine lubricants faces an even more severe challenge. Changes in lubricant additive packages will be the biggest challenge faced by lubricant manufacturers in the last two decades. Poisoning or plugging of emission control system components by ash, sulfur, and other metals may require elimination or significant reduction of currently preferred additives, such as zinc dithiophosphate. Similar problems exist for passenger car motor oils. Most of the effective antiwear and EP lubricating additives contain either sulfur, phosphorus, chlorine, or combinations.

The question is whether natural renewable oils can be utilized to make the quantum leap transition to the next generation of diesel engine and passenger car engines. The weaknesses of vegetable oils are well known and include poor thermal and oxidative stability and undesirable low-temperature properties. Significant progress is being made in each of these areas. Chemical and genetic modification can be used to change the chemical structure of these oils and thereby improve their oxidative stability. Alkylation and other syntheses are used to modify the low-temperature properties and also to improve thermal and oxidative stability. However, this costly processing makes the oils more similar in price to synthetic esters and hydrocarbons.

One issue is whether there are enough vegetable oils to go around. Competition exists from the demand for food products, hydraulic fluids, and biodiesel fuels. Another issue is whether variations in composition of the oils can be controlled and acceptable specifications developed. Although a number of companies are manufacturing and supplying environmentally friendly lubricants, most of the applications are niche markets or hydraulic oils. This still leaves their unproven performance as engine oils as an issue. This presentation discusses these issues and the technical hurdles yet to be tackled. A research plan to accelerate the use of these natural oils is reviewed.

HYDROGEN AS A CANDIDATE FUEL FOR TRUCKS

Jay Keller
Sandia National Laboratories (Livermore, California)

This presentation discusses the motivation and opportunities for hydrogen use as a fuel for light- and heavy-duty trucks. The production application of fuel cells is now recognized to be decades away. Moreover, it is not clear that the application of fuel cell technologies will ever meet the constraints of the trucking industry. I will discuss the applicability of hydrogen-fueled internal combustion engines as they exists today and as they might develop in the near future to meet the needs of the trucking industry. This discussion will highlight those trucking applications where I believe hydrogen as a fuel may work well and those where it will not work.

CONCENTRATIONS AND SIZE DISTRIBUTIONS OF PARTICULATE MATTER EMISSIONS FROM CATALYZED TRAP-EQUIPPED HEAVY-DUTY DIESEL VEHICLES OPERATING ON ULTRA-LOW SULFUR EC-D FUEL

Mridul Gautam, Sandeep Mehta, Dan Carder, Nigel Clark, and Don Lyons
West Virginia University

Miriam Lev-On and Chuck LeTavec
British Petroleum

Keith Vertin and Teresa Alleman
National Renewable Energy Laboratory

This paper will present particulate matter (PM) concentration and size distribution results from heavy-duty vehicles equipped with catalyzed filters and operating on EC-Diesel (ECD), produced by BP-ARCO. The test vehicles were also operated on EC-D 1 (with and without catalyzed traps), CARB diesel, and natural gas. These vehicles had undergone a year-long investigation in Southern California.
EC-D fuel, produced by BP/ARCO, has less than 15 ppm sulfur.

As part of this comprehensive program, concentrations and size distributions of the PM emissions were measured to determine the effect of catalyzed filters on the number count of PM emissions. It was observed that an order of magnitude reduction of total PM mass emissions with the EC-D fueled vehicles equipped with traps over CARB-certified diesel-fueled vehicles (without any exhaust aftertreatment systems) was accompanied by drastic reductions in concentrations of particulate matter emissions.

The natural gas-fueled vehicles also showed very low concentrations of particulate matter compared to the Cummins L10G vehicles that were tested in Dallas in 1999 by West Virginia University. Nanoparticle emissions from natural gas-fueled heavy-duty vehicles are linked to lube oil control and very likely to the age of the vehicles.

Measurement of PM concentrations and size distributions from the filter-equipped vehicles and natural gas-fueled vehicles is rather challenging. A dedicated mini-dilution system with an accurate dilution ratio control scheme was employed to measure PM-size distributions. Utmost care was taken to ensure that particle losses in the sampling system were minimal.

Abstracts

Session 5 – Environmental Science and Health Impacts

U.S. DEPARTMENT OF ENERGY'S STUDIES OF WEEKDAY/WEEKEND POLLUTION IN SOUTHERN CALIFORNIA

Douglas R. Lawson
National Renewable Energy Laboratory

Over the past 3-year period, the U.S. Department of Energy (DOE) and others have sponsored a series of coordinated studies to investigate the relationships between emissions of hydrocarbons and nitrogen oxides on ambient ozone and particulate nitrate levels. This presentation will summarize those studies and discuss DOE's future projects in increasing our fundamental understanding of the connection between emissions and ambient air quality.

Ambient ozone concentrations in California's South Coast Air Basin (SoCAB) can be as much as 55 percent higher on weekends than they are on weekdays under comparable meteorological conditions. This is paradoxical because emissions of ozone precursors (hydrocarbons, carbon monoxide, and nitrogen oxides) are lower on weekends relative to weekdays. Day-of-week emissions activity data were collected and analyzed to investigate the hypothesized causes of the "weekend ozone effect." Emissions activity data were collected for various mobile, area, and point sources throughout the SoCAB, including on-road vehicles, lawn and garden equipment, barbecues, fireplaces, solvent use, and point sources with continuous emissions monitoring (CEM) data.

Survey results indicate that significant differences exist between weekday and weekend emissions activity patterns and emissions. The combined effect of these differences resulted in a 12-18 percent decrease in reactive organic gases (ROG) and a 35-41 percent decrease in NO_x emissions on Saturdays and Sundays, respectively, relative to weekdays, in the summer of 2000. These changes in emissions resulted in an increase of the ROG to NO_x ratio of more than 30 percent on weekends compared to weekdays, which, along with lower NO_x emissions, increases ozone production on weekends relative to weekdays.

OFFICE OF HEAVY VEHICLE TECHNOLOGIES' WEEKEND/WEEKDAY OZONE STUDY IN THE SOUTH COAST AIR BASIN

Eric M. Fujita, William R. Stockwell, and David E. Campbell
Desert Research Institute

and

Douglas R. Lawson
National Renewable Energy Laboratory

Many urban locations in the United States experience higher ozone on weekends than on weekdays, despite lower ozone precursor emissions of hydrocarbons, carbon monoxide, and nitrogen oxides. This presentation summarizes the results from a study designed to test hypotheses regarding the cause(s) of high weekend ozone levels in the South Coast Air Basin (SoCAB) of Los Angeles, California. In Phase 1 we analyzed existing ambient and meteorological data for the SoCAB to refine our working hypotheses. We performed time-resolved measurements during Phase 2 to test the hypothesized relationship between emissions sources and the weekend ozone effect.

Analysis of the existing ambient data indicates that the intensity and spatial extent of the weekend ozone effect are correlated with day-of-week variations in the extent of ozone inhibition due to titration with nitrous oxide (NO) and rates of ozone accumulation. Lower NO-mixing ratios and higher NO_2/NO_x ratios on weekend mornings allows ozone to begin accumulating about an hour earlier on weekends compared to weekdays. The weekday/weekend differences in the duration of ozone accumulation have remained relatively constant from 1981 to 2000. In contrast, the rate of ozone accumulation decreased by one-third to one-half over the same period with the largest reductions occurring in the central basin on weekdays.

Trends in mixing ratios of ozone precursors show a transition in the SoCAB to lower VOC/NO_x ratios due to greater reductions in VOC emissions. Reductions in VOC/NO_x ratios were greater on weekdays resulting in higher VOC/NO_x ratios on weekends relative to weekdays. Trends in VOC/NO_x ratios parallel the downward trend in peak ozone levels, a shift in the location of peak ozone from the central to eastern portion of the SoCAB, and an increase in the magnitude and spatial extent of the weekend ozone effect in the SoCAB. Lower NO_x emissions from diesel exhaust are the most important factor in weekday-weekend differences in ambient levels of NO_x and VOC/NO_x ratios.

The decrease in weekend ozone precursor emissions of VOC and NO_x provides a natural test case for investigating the response of ozone levels to specific changes in precursor emissions. This study demonstrates that ozone will increase in the urbanized areas of the SoCAB if NO_x emissions are decreased at current levels of VOC until weekend NO_x mixing ratios are decreased by roughly 90 percent. The study also shows

weekend ozone would be even higher were it not for concomitant weekend emission reductions of VOC's.

Because the SoCAB is hydrocarbon limited and mobile sources are the predominant source of hydrocarbons, the most effective means for reducing ozone in the SoCAB is to reduce emissions from the portion of the motor vehicle fleet responsible for the greatest amount of hydrocarbon emissions. The development of accurate weekend emission inventories by government agencies is urgently needed so air quality models can accurately assess the effects of current and future ozone control regulations.

PHYSICAL AND CHEMICAL CHARACTERISTICS OF DIESEL EXHAUST PARTICLES

David Kittelson, Peter McMurry, Kihong Park, and Hiromu Sakurai
University of Minnesota

and

Herbert Tobias and Paul Ziemann
University of California at Riverside

Exhaust particles from modern diesel engines without aftertreatment are found in two distinct, but overlapping size modes: a mainly volatile nuclei mode and a mainly solid accumulation mode in roughly the 3-30 and 30-500 nm diameter ranges, respectively. These particles have been characterized through size-fractionated measurements of volatility, hygroscopicity, density, and chemical composition using a tandem differential mobility analyzer (TDMA), an aerosol particle mass analyzer (APM) and a thermal desorption particle beam mass spectrometer (TDPBMS).

Volatility measurements showed that nuclei and accumulation mode particles are externally mixed across a wide size range, with the chemical components being distributed between two particle types: “less volatile” (probably comprised of an elemental carbon core with a small organic component) and “more volatile.” The volatility experiments showed that, except for the smallest particles, heating could differentiate volatile and solid particles. The fraction of solid particles decreased as particle size decreased, and only a volatile mode was detectable for the smallest particles tested (7 nm). More than 97 percent of the volume of the volatile constituents of 12- and 30-nm particles disappeared on heating to 400°C. The volatility was found to resemble that of C24-C32 normal alkanes, which implies a significant contribution of lubricating oil to the volatile particles.

APM mass and density measurements showed fractal-like behavior with particle mass increasing with approximately the $D_p^{2.4}$ (D_p = mobility diameter) and effective density decreasing from about 1 to 0.3 g/cm^3 in the 50-300 nm diameter range.

TDMA hygroscopicity experiments and TDPBMS analysis suggest the presence of sulfuric acid in diesel nanoparticles when a 350-ppm sulfur fuel was used, but not when a 96-ppm sulfur CA fuel was used. Hygroscopic measurements found that the smallest particles were the most hygroscopic, suggesting enrichment with sulfuric acid. TDPBMS measurements showed that the organic component of total diesel particulate matter and nanoparticles appears to be comprised predominantly of unburned lubricating oil, while the fuel contribution to the total organic component appears to be negligible. The major organic compound classes (alkanes, cycloalkanes, and aromatics) appear to be distributed fairly uniformly across the volatility spectrum. Low-volatility oxidation products (e.g., organic acids) and PAH’s do not appear to be a major portion of the organic mass. The oil that forms particles appears to be derived primarily

from material evaporated from the cylinder walls, although there may also be a significant component from atomization. Nanoparticles formed using 410-ppm sulfur fuel contained small amounts of sulfuric acid, which may enhance nucleation. No sulfuric acid was detected in nanoparticles formed using 96-ppm sulfur or Fischer-Tropsch (< 1 ppm sulfur) fuel. These results are consistent with hygroscopicity measurements.

MEASUREMENT OF ON-ROAD AND LAB DIESEL PARTICLE SIZE

Jason Johnson, David Kittelson, and Winthrop Watts
University of Minnesota

Particle-size distributions measured in the CRC/DOE E-43 project will be described. The project was designed to determine if modern diesel engines produce size distributions with a significant nuclei mode (particles with diameter less than about 30 nm) under real-world, on-road conditions; to establish laboratory dilution conditions that give size distributions similar to those measured on-road; and to compare the tendency to produce nanoparticles (a nuclei mode) of newer and older technology engines. Other objectives included determination of the chemical composition of these particles and their lifetime in the atmosphere. The first three of these goals are discussed in this presentation.

Field studies were carried out using four test trucks powered by Caterpillar and Cummins engines. On-road chase studies were carried out in Minnesota, and CVS performance cell and chassis dynamometer studies were carried out at Caterpillar and Cummins. A wind tunnel study was also carried out at the National Aeronautics and Space Administration's Langley Wind Tunnel. U.S. Environmental Protection Agency certification and a market-basket blend of California fuels were used.

On-road dilution is rapid (1,000:1 in 2 seconds), and the test vehicles produced bimodal distributions with nuclei mode and accumulation mode geometric number mean diameters ranging from 6 to11 nm and 52 to 62 nm, respectively. Number and volume fractions in the nuclei mode ranged from 37 to 87 percent and 0.3 to 2.1 percent, respectively. Nuclei mode particles were found to consist primarily of volatile material. Lower sulfur fuel produced a smaller nuclei mode under most conditions, but the accumulation modes produced by all fuels were similar. Cold temperatures favored nuclei mode formation. Both old and new technology engines produced nuclei modes of similar magnitude, but the older technology engines produced larger accumulation modes. Nuclei mode properties were highly variable due in part to changes in engine, fuel, and environmental conditions and in part due to on-road experimental uncertainties.

Laboratory exhaust samples were obtained using a mini two-stage ejector dilutor, a partial flow CVS system followed by an ejector dilutor, and a Sierra BG-1 dilutor followed by an ejector dilutor. Although it was not possible to duplicate all individual on-road size distributions in the laboratory, composite average on-road size distributions were similar to those obtained using the CVS or BG-1 systems. Our results suggest that rather than attempting to simulate on-road formation of nuclei mode particles, which takes place under highly variable ambient conditions, the best laboratory sampling strategy might be to adjust conditions to evaluate the tendency of an engine/fuel/operating condition to form nanoparticles.

OVERVIEW OF DETAILED CHEMICAL SPECIATION AND PARTICLE SIZING FOR DIESEL EXHAUST, BOTH REAL-TIME AND FILTER-BASED MEASUREMENTS

Chol-Bum Kweon, Shusuke Okada, David E. Foster,
Martin M. Shafer, Charles G. Christensen, James J. Schauer
University of Wisconsin

and

Deborah S. Gross
Carleton College

U.S Environmental Protection Agency ambient air-quality measurement protocols have been incorporated into the exhaust measurement system of a research single-cylinder diesel engine. To allow more detailed assessment of the individual chemical components of the diesel particulate matter (PM), the exhaust dilution system includes a residence time chamber (RTC) to allow for residence times of 30-60 seconds in the second stage of dilution before sampling. Measurements have been performed using the more normal approach of catching the particulate matter on filters and then analyzing the filters and also using an aerosol time of flight mass spectrometer (ATOFMS), which is capable of analyzing individual particles for size and composition at a rate of up to 150 particles per minute for a particle size range from 0.15 to 5 micrometers. Additional data on particle size were obtained using a scanning mobility particle sizer (SMPS).

Samples have been collected on a range of different filters where mass loading, elemental and organic carbon (ECOC), trace metals, sulfate ions (SO_4), volatile organic compounds, and semi-volatile organic compounds have been evaluated. Using the SMPS, particle-size distributions have been measured for the different operating conditions and for different exhaust gas residence times in the RTC.

This paper gives an overview of the results obtained with the different measurement techniques for the range of engine operating conditions covered by the CARB 8 mode test. Results show that the chemical composition and size distribution of the particulate matter are highly dependent on the engine operating conditions. There is a dramatic shift in the ratio of elemental to organic carbon and in the sulfate ions (SO_4) when the engine is traversed across a load and speed range. Similarly, there is a shift in the particle-size range for which there is virtually no impact on the mass loading, and the nanoparticle size distribution, at a fixed dilution ratio and temperature, is a function of the time spent in the RTC. Trace metal concentrations in the particulate vary significantly with load and speed and are treated as indicative of oil consumption.

Results of the filter-based measurements are being compared to those obtained using the ATOFMS, which have been widely used to study atmospheric aerosols, but have only seen limited use for assessing internal combustion engine exhaust emissions.

Using the ATOFMS to make fundamental measurements of chemical composition and particle size in engine exhaust has the potential to offer unique insights into the impact of changes in engine operating conditions on the resultant changes in the exhaust characteristics.

DEVELOPMENT OF REMOTE SENSING INSTRUMENTATION FOR NO_X AND PM EMISSIONS FROM HEAVY-DUTY TRUCKS

Ralph N. McGill
Oak Ridge National Laboratory

Researchers at Oak Ridge National Laboratory (ORNL) are developing prototype instruments to remotely and non-intrusively measure the NO_x and particulate matter (PM) emissions from heavy trucks. An ultraviolet (UV) absorption method and a modified LIDAR method are being employed to measure NO_x and PM concentrations, respectively, in the exhaust plumes of moving trucks.

To couple the concentration measurements to the truck on a gram-per-mile basis, an innovative approach to determining engine operating conditions with remote sensing is being employed. This is accomplished by using sensitive listening equipment to acquire acoustic signatures as the truck passes.
Acoustic signature analysis will devolve data about the truck's operating parameters, such as engine speed, turbine speed, and number of cylinders. The combined results will be used to make estimates of the instantaneous exhaust flow rate, which, when coupled with the emission concentration measurements, vehicle speed, acceleration, and load, lead to emissions data in terms of grams
per mile. These three technologies represent extensions and modifications of existing measurement sciences into this new application, and much of the challenge is the development of algorithms for interpreting data from each.

This effort is part of a larger project concept dealing with truck emissions and their impacts on local air quality. The Watt Road Environmental Laboratory Initiative is a joint effort between ORNL and the University of Tennessee, Knoxville, to develop a field laboratory for comprehensive studies of truck emissions in a 2.5-mile corridor along Interstate 40 in Knox County, Tennessee.

COMPARATIVE TOXICITY OF COMBINED PARTICLE AND SEMI-VOLATILE ORGANIC FRACTIONS OF GASOLINE AND DIESEL ENGINES

Joe Mauderly, JeanClare Seagrave, Jacob McDonald, and Andrew Gigliotti
Lovelace Respiratory Research Institute

Kristen Nikula
Pharmacia

Steven Seilkop
SKS Consulting Services

Michael Gurevich
U.S. Department of Energy (retired)

This study was conducted to: (1) evaluate a range of mutagenicity and lung toxicity parameters for testing collected emission samples and (2) compare the bacterial mutagenicity and non-cancer lung toxicity of combined particulate matter (PM) and semi-volatile organic compound (SVOC) fractions of emissions from normal- and high-emitting gasoline and diesel vehicles.

PM and SVOC samples were collected from in-use, light- and medium-duty vehicles, including: a composite group of five gasoline normal emitters; a composite group of three diesel current technology (1998-2000) normal emitters; and one each black smoker gasoline, white smoker gasoline, and high-emitting diesel. Vehicles were operated with fuel and crankcase oil "as received" on chassis dynamometers on the California Unified Driving Cycle. Both "normal emitter" groups were sampled while operating at either 72^{o}F or 30^{o}F. PM was collected on filters, and SVOC was collected in polyurethane foam/XAD resin traps.

Both fractions were extracted from collection media in solvent, sent to Lovelace Respiratory Research Institute for testing, recombined in their original collection ratios, and administered to the biological test systems in multiple doses. Bacterial (Ames) mutagenicity was tested using Salmonella strains TA98 and TA100 with and without metabolic activation. Rats were instilled intratracheally, and cellular and chemical constituents of lung washings and histopathology were evaluated at multiple doses and times after administration. The potencies of the samples were compared on the basis of the slopes of dose-response curves.

Most biological response parameters gave dose-response slopes that clearly demonstrated a range of potency among the samples. Mutagenic potency differed between the two bacterial strains, although they reflected similar general patterns of samples having greater and lesser potency. There was generally good agreement among the sample rankings indicated by multiple parameters reflecting cytotoxicity, inflammation, and lung tissue changes, allowing the selection of a more limited set of

parameters for future studies. The parameters selected for oxidative injury and macrophage function yielded little useful information.

Some important general conclusions could be drawn from the aggregate lung toxicity results: (1) the toxicity per unit PM+SVOC mass was similar for normal-emitting gasoline and diesel vehicles; (2) operating temperature did not appear to cause systematic differences in toxicity; (3) high-emitters not only emitted more mass, but the toxicity per unit of mass was also greater than that of normal-emitters.

IN VITRO GENOTOXICITY OF GASOLINE AND DIESEL ENGINE VEHICLE EXHAUST PM2.5 PARTICULATE AND SEMI-VOLATILE ORGANIC COMPOUND MATERIALS

W. Wallace, M. Keane, M. Cui, L. Liu, M. Ensell, W. Miller, and M. Kashon, T. Ong
Centers for Disease Control and Prevention

Three categories of *in vitro* genotoxicity were measured for acetone extracts of exhaust materials from a set of gasoline-engine automobiles and from a set of diesel-engine autos or light trucks supplied by a vehicle exhaust studies program sponsored by the U.S. Department of Energy. Acetone-washed filter samples of exhaust particulate matter with equivalent aerodynamic diameter less than 2.5 micrometers and XAD resin-sorbed semi-volatile organic compounds (SVOC) sampled at 72°F from modern, in-tune vehicles operated on the "Unified Driving Cycle" for light-duty vehicles were provided to the National Institute for Occupational Safety and Health (NIOSH) of the Centers for Disease Control and Prevention.

These samples were prepared for assay by filtration, evaporation, and re-suspension in TWEEN-80. National Institute of Standards and Technology Standard Reference Material 1650a was similarly treated and assayed. Mutagenicity testing *in vitro* used the *Salmonella typhimurium* histidine reversion micro-suspension assay with tester strains YG1024 and YG1029, with and without S9 microsomal activation of samples. Each sample preparation was tested at four or more concentrations, with duplicate tests at each concentration, and with a repetition of the entire experiment. Micronucleus induction assay for chromosomal damage used Chinese hamster lung fibroblasts (V79 cells), which were challenged for 24 hours, and 3000 cells from each treatment were scored for micronucleated cells. The single cell, gel-electrophoresis assay (SCGE) for DNA migration was used as a measure of DNA single- and double-strand breaks in V79 cells challenged for 24 hours. Each sample preparation was tested at four or five concentrations.

Results are presented for gasoline vehicle PM2.5, gasoline vehicle SVOC, diesel PM2.5, and diesel SVOC for the three sets of genotoxicity tests with dose expressed in terms of both extracted mass and normalized to equivalent vehicle miles.

PRO-INFLAMMATORY CYTOKINE RESPONSES TO EXPOSURE TO DIESEL SOOT

JeanClare Seagrave, Cindy Knall, and Joe Mauderly
Lovelace Respiratory Research Institute

Inhalation of particulate material (PM) of many types causes inflammation in the lung. The mechanisms by which PM activates the cellular and molecular processes resulting in recruitment of white blood cells (leukocytes) into the air spaces of the lung are not fully understood, but clearly involve stimulation of the production of small proteins called chemokines, which are chemoattractants for leukocytes.

This study was conducted to investigate the role of chemokines in the pro-inflammatory cascade following exposure to diesel soot (DS). Studies were conducted by intratracheal instillation of DS into rat lungs and exposure of a human alveolar epithelial cell line (A549 cells) in cell culture to the same material. In both systems, toxicity was assessed by measuring release of the intracellular enzyme, lactate dehydrogenase (LDH). Lung inflammation following instillation was measured by counting the numbers of leukocytes in the lung washes.

Doses of DS between 0.1 and 1 mg/rat increased the amount of the chemokine Macrophage Inflammatory Protein-2 (MIP-2) measured in the lung washes, but at higher doses, less MIP-2 was detected. In contrast, the number of inflammatory cells continued to increase throughout the dose range. Small increases in LDH were observed, reaching a plateau at doses above 1 mg/rat.

Similar results were observed in cultured A549 cells. Increased Interleukin-8 (IL-8: a human chemokine analogous to rat MIP-2) was measured in cells exposed to DS over the range of 0.03-1 $\mu g/cm^2$, but reduced levels of the chemokine were detected at higher doses. DS had little effect on the release of LDH. This indicates that DS was not acutely toxic to the cells and that the suppressed response at high doses in both systems was unlikely to be due to acute toxicity. Instead, DS may adsorb the chemokines, making them unavailable for assay.

ARB'S STUDY OF EMISSIONS FROM DIESEL AND CNG HEAVY-DUTY TRANSIT BUSES

Alberto Ayala, Norman Y. Kado, Robert A. Okamoto, Michael Gebel, and Paul Rieger
California Environmental Protection Agency

The identification of diesel particulate matter (PM) as a Toxic Air Contaminant (TAC) in California triggered the development of control strategies under the Diesel Risk Reduction Program (DRRP), which was recently approved by the California Air Resources Board (ARB). The DRRP aims to reduce PM emissions from diesel-fueled engines, and it includes numerous control measures to be phased in over the next several years. These measures are meant to substantially curtail emissions from new and existing on-road and off-road sources.

Approaches to reducing the risk of exposure to diesel PM include the use of alternative fuels, like compressed natural gas (CNG), and advanced aftertreatment control for existing and new diesel engines. Buses fueled by CNG or using diesel particulate filters (DPF) are two "green" alternatives to conventional diesels. These alternatives have been demonstrated to reduce PM emissions. However, additional information is needed on their effect on the
emissions profiles of non-regulated species, toxic and otherwise.

For this reason, the ARB embarked on a research effort to collect emissions data from two late-model, heavy-duty transit buses in three different configurations. These were: (1) a CNG bus equipped with a 2000 DDC Series 50G engine, (2) a diesel bus equipped with a 1998 DDC Series 50 engine and a catalyzed muffler, and (3) the same diesel vehicle retrofitted with a Johnson Matthey Continuously Regenerating Technology (CRT™) DPF in place of the muffler. The CNG bus in this study was certified for operation without oxidation catalyst. The diesel bus configurations ran on ARCO's (a BP company) Emission Control Diesel (EC-D 1) fuel with a measured sulfur content of 11 ppm.

The objectives of the study were: (1) to assess driving cycle effects, (2) to characterize the types and amounts of several toxic substances emitted for the various configurations, and (3) to investigate total PM and ultrafine (<100 nm) particle emissions. This study has shown that, in terms of PM mass, CNG and trap-equipped diesel buses are significantly superior to the conventional diesel bus. However, no single "green" technology is clearly superior to the other for every pollutant indicator measured. Measurable levels of toxic compounds in the exhaust suggest that neither the CNG nor the trap-equipped bus may be clearly superior to the other in all aspects. Most importantly, possible technology improvements were identified.

A COMPARISON OF TWO GASOLINE AND TWO DIESEL CARS WITH VARYING EMISSION-CONTROL TECHNOLOGY

Peter Ahlvik
Ecotraffic ERD^3 AB

The transport sector contributes significantly to air pollution and particularly influences local air quality. Besides the question of air quality, the consumption of fossil fuels in the transport sector and the CO_2-emissions from this use are increasingly important issues.

For a long period of time, the emissions from light-duty vehicles have been in focus, and a lot of measures have been taken to reduce the emissions from these vehicles.

The market penetration for light-duty diesel cars has been increasing in most markets in Europe and is now over 30 percent (2001). In Sweden, however, the market share for diesel cars has decreased the last 3 years and is now slightly above 5 percent.

The issue of whether petrol or diesel fuel should be used as fuel in passenger cars has been the subject of lively debates during the last years, particularly in Sweden, especially the particle emissions from diesel cars. This study is an attempt to contribute with some more facts to the subject.

The study presented in this paper is built on new investigations of two petrol and two diesel cars with varying emission-control strategies. Tests have been carried out both in the European driving cycle and in other driving cycles. Besides the regulated substances, analysis has been made on unregulated substances as well. The data have also been compared with data from earlier studies.

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Session 6 – Environmentally Concerned Public Sector Organization Panel

DIESEL AND PUBLIC HEALTH

Diane Bailey
Natural Resources Defense Council

It is clear that uncontrolled diesel exhaust is hazardous to public health, causing or exacerbating asthma and other lung diseases, cancer, and even premature death. New emission controls for diesel show the potential to dramatically cut pollution, but these technologies have yet to demonstrate their effectiveness over the long run.

There have been several preliminary studies evaluating the various toxic and smog-forming emissions from natural gas and diesel transit buses, with and without controls. While these early studies are too limited in scope to make definitive conclusions, they do highlight the potential emissions reductions from diesel vehicles. But these limited studies also present a lopsided view of natural gas and diesel bus emissions, testing today's natural gas technologies against tomorrow's diesel. In addition, the tests do not demonstrate that the diesel emission control technologies will function over the range of real-world driving conditions.

NONROAD DIESEL: THE NEXT PUBLIC HEALTH CHALLENGE

Patricia Monahan
Union of Concerned Scientists

Construction equipment, agricultural vehicles, and other non-road engines and vehicles release more toxic particulates than highway heavy-duty diesel vehicles. Yet these types of vehicles have historically received little regulatory oversight, and there are relatively few emission controls developed specifically for non-road equipment.

A new study by state air pollution officials indicates that 8,500 deaths per year could be avoided if the U.S. Environmental Protection Agency were to adopt a non-road diesel rule consistent with the current highway rule for heavy-duty diesel vehicles. California could avoid 770 premature deaths and over 16,000 asthma attacks per year through the harmonization of the non-road and highway standards. Reducing pollution from non-road diesel vehicles is the next public health priority.

ACHIEVING CLEAN TRANSIT IN CALIFORNIA

Vandana Bali
Coalition for Clean Air

In an effort to clean up California's transit buses, the California Air Resources Board developed the Transit Bus Rule, which gave transit districts the option of selecting two pathways: a diesel path and an alternative fuel path. The diesel pathway required transit operators to retrofit older buses with particulate traps, to purchase low-emission diesel vehicles in the future, and to conduct demonstration programs for zero-emission buses. In addition, diesel engine manufacturers committed to producing demonstration engines that could achieve significant reductions in nitrogen oxide and particulate emissions. Today, almost 3 years after the transit rule's initial adoption, the diesel fuel path has yet to live up to its full expectations in terms of emission benefits, creating numerous setbacks, while alternative fuel applications appear more and more to be the bridge to a zero-emission transit bus future.

BARRIERS TO LIGHT-DUTY DIESEL IN THE UNITED STATES

Jim Kliesch
American Council for an Energy Efficient Economy

Renewed interest in domestic light-duty diesel vehicles has re-sparked the "diesel debate" among industry, energy, and environmental communities. Prior limitations of diesel engines, such as inferior performance and exhaust issues, have seen significant improvements in recent years, while the 2004 introduction of Tier 2 /LEV II emission standards provides new technical and economic challenges to advanced diesel technology. Penetration levels of light-duty diesel in the United States will depend on both the industry's ability to surmount these barriers and renewed consumer acceptance of the technology.

REDUCING PETROLEUM DEPENDENCE: DOUBTS ABOUT LIGHT-DUTY DIESEL

Kathryn Phillips
Center for Energy Efficiency and Renewable Technologies

Two state agencies, the California Air Resources Board and the California Energy Commission, are engaged in a legislatively mandated process to identify and recommend strategies for reducing the transportation sector's petroleum dependence. Diesel proponents have watched the process closely and contend that increasing the light-duty diesel fleet in California is a viable option for reducing petroleum consumption. However, there are enough concerns about light-duty diesel's costs, ability to meet emissions standards, and climate-forcing characteristics to raise questions about whether diesel is a reasonable petroleum reduction strategy.

PERSPECTIVE ON THE FUTURE DEVELOPMENT OF DIESEL EMISSION STANDARDS IN EUROPE

Stefan Rodt
Federal Environmental Agency (Germany)

The European emission standards have been reduced substantially by more than 90 percent during the last 15 years, and achieving the air-quality targets is in reach once EURO 4/5-vehicles will have penetrated the fleet around the year 2010. There are two key remaining tasks. First, diesel cars need to meet the same pollutant emissions as gasoline cars. Second, rather than just limiting the mass of particulate emissions, emissions standards should also account for the health impacts of the particulates.

The share of diesel cars in the fleet has been increasing to over 35 percent in Germany, highlighting the need for action to control diesel emissions. Although particulate traps have successfully been tested and retrofitted in heavy-duty vehicles in large numbers and some car types are in serious production with traps (210,000 sold in Europe until the end of 2002), the introduction of this technology or an equivalent technology with an efficiency well above 90 percent is still uncertain on a broad basis. Based on the boundary conditions given in Europe and in Germany, a proposal for the further development of emission standards for diesel passenger cars (EURO 5) and corresponding amendments for the EURO 5 heavy-duty engine standards is presented.

REDUCING HEAVY-DUTY DIESEL EMISSIONS -- PRACTICAL EXPERIENCE, FUTURE GOALS

David Park
Northeast States for Coordinated Air Use Management

The Northeast States for Coordinated Air Use Management (NESCAUM) have been working on several fronts to study and reduce heavy-duty diesel emissions in the region, from both the highway and non-road sectors. NESCAUM is studying the pervasiveness of the use of diesel engines across non-road applications and the exposure of heavy- equipment operators to diesel exhaust.

On the technology side, NESCAUM is managing diesel emission control programs that involve long-haul trucking, construction vehicles, school buses, and sanitation trucks. Difficulties encountered in these projects range from the practicality of retrofit technology in cold weather applications to the availability of appropriate fuel. As retrofit technology becomes more accepted in on-road applications, the region is beginning to focus on methods to reduce emissions in the non-road sector, including construction equipment, stationary engines, and airport equipment. NESCAUM provides some of the reasons why these controls are necessary and examples of how these controls can be implemented.

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Session 7 – Emissions-Related Technologies and Regulations

HEAVY DUTY DIESEL EMISSION REGULATIONS AND TECHNOLOGY SOLUTIONS

Pranab Das
International Truck & Bus

Emissions regulations for 2007 and beyond are driving diesel engines to have near-zero emissions. Reaching these goals demands rapid development of many new technologies. Fuel injection systems are progressing to provide high injection pressure and multiple injection capability with complete timing and quantity flexibility. New combustion bowl concepts are evolving to match the injection capability and significantly reduce emissions. Air system design has already evolved to VG, and dual turbochargers in production and assisted turbochargers are considered for the future. Camless valve technology is developing, which will offer command and control of not only the air-fuel ratio but also swirl. New exhaust gas recirculation (EGR) mapping and sourcing strategies are being explored along with a differentiation between internal and external EGR. Aftertreatment technologies, such as particulate filters and NO_x adsorbers, are showing much promise. All these technologies also require their own sophisticated control strategies as well as their integration as a system. The task is quite challenging. However, progress to date is impressive and showing the potential feasibility of being solved.

NO_X ADSORBER REGENERATION IN TRANSIENT CYCLES: PARAMETRIC STUDY

Scott Sluder and Brian West
Oak Ridge National Laboratory

A 1999 Mercedes A170 CDI has been equipped with prototype NO_x adsorber devices in order to study the impacts of regeneration conditions on the emissions reduction performance of the devices. This study consisted of a number of laboratory experiments utilizing a bottled-gas injection system to periodically provide fuel-rich exhaust conditions for device regeneration. The NO_x adsorbers were evaluated on the LA4 driving cycle using a fixed regeneration schedule. The rich-pulse duration and minimum air/fuel ratio during the rich pulse were varied, and the impacts upon pollutant emission rates were measured. Results are presented for five prototype NO_x adsorbers.

EVALUATION OF PASSIVE AND ACTIVE PARTICULATE FILTERS FOR REMOVAL OF PARTICULATE EMISSIONS FROM DIESEL ENGINES

K. E. Kelly, D. A. Wagner, J. S. Lighty, and A. S. Sarofim
University of Utah

B. Holden
Naval Facilities Engineering Service Center

B. Bretecher
Cummins, Inc.

K. Sahay
California Air Resources Board

As particulate emission standards for diesel engines are tightened, manufacturers and users are looking toward catalytic filters as one means of meeting the new standards. This study evaluated the effect of passive and active catalytic filters on diesel exhaust in terms of particulate matter concentration and size distribution, black carbon (soot) concentration, and particle-bound polycyclic aromatic hydrocarbon concentration. Passive filters were installed on three military diesel buses, and an active filter was installed on two military diesel generators. Particle concentrations were measured before and after installation of the filter and again after several months of operation. Generally, the passive filter removed at least 90 percent of particulate matter mass, black carbon, and particle-bound polycyclic aromatic hydrocarbons, and the removal efficiency did not deteriorate after several months of operation. The limited gas-phase pollutant measurements showed that the filters also reduced total hydrocarbon and carbon monoxide. In addition to evaluating the catalytic filters, the sampling team also compared the results of several real-time particle measurement instruments to traditional filter measurements.

EMISSIONS FROM IDLING TRUCKS FOR EXTENDED TIME PERIODS

John Storey, Sam Lewis, Dean Edwards, Thang Dam, and John Thomas
Oak Ridge National Laboratory

and

Han Lim
U.S. Environmental Protection Agency

The U.S. Environmental Protection Agency, Oak Ridge National Laboratory, and the U.S. Army Aberdeen Test Center (ATC) collaborated to characterize emissions from heavy trucks idling for extended periods. An environmental chamber at Aberdeen was used to vary the ambient temperature with extremes of 0°F and 90°F while the cab temperature was maintained constant. Emissions sampling and measurement equipment was transported to ATC. Gaseous emissions, including aldehydes plus particulate matter emissions, were recorded for five trucks at three ambient temperatures and two idle speeds. The five trucks covered a range of manufacturers and vintages. A truck auxiliary power unit (APU) was tested and compared to idling the engines for the same duty.

The results show interesting time and temperature dependence of the emissions and fuel use. The APU was found to provide major reductions in NO_x and fuel consumption relative to idling the engine for cab heating/cooling.

SIZE-RESOLVED CHEMICAL COMPOSITION OF AEROSOL VIA SINGLE-PARTICLE, REAL-TIME MASS SPECTROMETRY

Alla Zelenyuk, Dan Imre, and James E. Wegrzyn
Brookhaven National Laboratory

We will present results from measurements of single-particle size and chemical composition using the Brookhaven National Laboratory (BNL) Single Particle Mass Spectrometer (SPMS). We will also demonstrate our data analysis and visualization tools that provide an interactive interface between the user and the statistical analysis package.

SPMS is the ideal tool to address the combustion engine industry needs to characterize particulate emissions. It provides real-time detailed accounting of particle composition and size as a function of time and distance from the point of emission, making it possible to derive correlations between engine and fuel performance and aerosol properties.

The compositions of exhaust aerosol tend to be complex, containing inorganic compounds, elemental carbon, and a large number of organic compounds, many of which are semi-volatile. SPMS can readily distinguish between the three classes and quantify their presence.

Single-particle instruments use an ultraviolet laser to vaporize individual particles and produce ions for time-of-flight mass analysis. The vaporization ionization process, also known as ablation, is highly nonlinear and nonspecific. Organic compounds tend to be the most sensitive to the ablation process, producing a high degree of fragmentation that can vary drastically from one particle to the next. To resolve this problem, we at BNL have recently developed an experimental approach, in which particle evaporation is separated from ionization, thereby eliminating the inconsistent spectra and the nonlinear response. Moreover, we are in the process of introducing modifications that are designed to make possible a molecular-level analysis of the highly complex organic fraction.

DEVELOPMENT OF A SUB-GRID MODEL OF A DIESEL PARTICULATE FILTER

George Muntean, David Rector, Delbert L. Lessor, Darrell R. Herling, and Mohammad A. Khaleel
Pacific Northwest National Laboratory

The U.S. Environmental Protection Agency's (EPA) 2007 heavy- duty diesel engine exhaust emissions standards mandate a 90-percent reduction in particulate matter over current levels. The majority opinion in the diesel industry is that these standards are, by implication, mandating exhaust particulate filtration for diesel engines. Currently there is no commercially viable filtration technology that can be universally applied to all on-highway heavy-duty diesel engines. Several key technical hurdles that must be overcome in order for diesel particulate filters to become practical include: filter plugging, thermal failures, size, cost, filtration performance, and durability.

The resolution of these issues requires a detailed systems-level understanding. This includes the diesel engine's characteristics and the application duty cycle in order to understand the temperature of exhaust gas and its constituents. It also includes a characterization of installation requirements and the individual aftertreatment-device performance to understand filtration effectiveness, durability, and fuel-economy impacts.

In order for the diesel industry to meet the quickly approaching EPA regulations, the industry requires modeling capabilities. These models can be used to optimize the engine-control strategies in order to help determine the physical dimensions of the catalyst system and to simulate numerous real-world applications, which are prohibitively expensive to test in the field. Regardless of the specific question being answered, a critical key component of these models is the representation of the soot oxidation rate. This term directly influences most of the macroscopic phenomena of interest, including filtration efficiency, heat transfer, back pressure, and substrate geometries.

One key technical challenge relates to the fact that particulate filter soot regeneration remains a poorly understood and inadequately characterized phenomenon. Current sub-grid models use gross simplifications to represent the carbonaceous soot oxidation rates. All phenomena that occur on the finest length scales (approximately less than 100 microns) are typically lumped together into a single Arhenius-type equation with curve-fitted, pre-exponential and activation energy terms. Furthermore, intrinsic soot cake properties, such as packing density, permeability, and heat transfer coefficients, are poorly understood. Improvements in these sub-grid model formulations will improve the ability of engineers to model the filter on a device scale and lead to better systems optimization capabilities and improved design tools.

This paper will report on improved sub-grid representations of the local oxidation reactions by employing detailed sub-grid modeling techniques. These techniques involve the use of a lattice Boltzman modeling approach coupled with validation via both

in-situ and ex-situ experiments. This approach resolves length scales, which are orders of magnitude below those typical of a standard computational fluid dynamics (CFD) representation of an aftertreatment device. This improved resolution allows for the characterization of functionality not previously employed in the CFD analysis. Sub-grid modeling results will be presented describing the interactions of the soot-cake layer evolution with the substrate structure and catalyst materials.

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Session 8 – Emerging Diesel Engine Technology

DIESEL EMISSION CONTROL – LAST 12 MONTHS IN REVIEW

Timothy V. Johnson
Corning Incorporated

The presentation aims to bring the audience up-to-date on the state of diesel emissions control in the last year. Topics to be covered include recent studies on: the nature of nanoparticles from internal combustion engines, diesel particulate filter technology developments, selective catalytic reduction, NO_x adsorber progress and issues, and integrating NO_x and particulate material control into feasible systems. Discussion of key issues facing the industry will also be included.

FRENCH PERSPECTIVE ON DIESEL ENGINES AND EMISSIONS

Stéphane Nino
Aaqius & Aaqius

Diesel is a high-stakes market for European engines manufacturers: almost 45 percent of passenger and light commercial (<5 ton) cars are diesel in Europe, even more in France.

The French car manufacturers -- PSA and Renault -- account for a large part of this production; this is why they are very impacted by EURO regulations for emissions reduction. Thus, they were among the first to develop solutions to meet these standards, and Peugeot even took advantage of it to be the first to market a car equipped with a diesel particulate filter with additive: the Peugeot 607.

Today, diesel vehicles have to comply with EURO 3; the next steps (EURO 4 and EURO 5) will enforce even more stringent levels for particulate matter and NO_x in 2005 and 2008. Low-sulfur level in gazole will also have to be reached.

To meet these standards, lots of programs are being conducted throughout Europe by the European Commission. If Sweden, Switzerland, and Germany were usually the first countries to be concerned by environment, today all Europe has taken over. This is especially true in the field of public transportation, which plays a key role in experimenting with available technologies for more than 15,000 buses equipped with depollution systems.

A closer look at the strategies of the bus and truck engine manufacturers shows that the games are still open, and everyone is mixing both known and proprietary technologies to fulfill technical and economical requirements.

EUROPEAN DIESEL ENGINE TECHNOLOGY: AN OVERVIEW

Stephen Brueckner
AVL Powertrain Engineering, Inc.

Modern, high-technology diesel engines have become extremely popular in Europe. What are some of the reasons for this success? Numerous market factors influence customers' buying preferences. But the market share approaching 50 percent would not be possible without the latest diesel engine technology.

Several key market factors will be reviewed, including legislation, cost, and vehicle performance. Reduction of exhaust emissions and fuel consumption of diesel engines is crucial to their continued sales growth. Current diesel engine technology and future trends to reduce engine-out emissions, improve performance and aftertreatment efficiency, and enhance control system capabilities will be discussed.

UPDATE ON DIESEL ENGINE WASTE HEAT RECOVERY UTILIZING ELECTRIC TURBOCOMPOUND TECHNOLOGY

Ulrich Hopmann
Caterpillar, Inc.

A cooperative program between the U.S. Department of Energy Office of Heavy Vehicle Technologies and Caterpillar is aimed at demonstrating electric turbocompound technology on a Class 8 truck engine. The goal is to demonstrate the level of fuel-efficiency improvement attainable with the electric turbocompound system. The system consists of a turbocharger with an incorporated electric motor/generator on the turbo shaft. The generator extracts the surplus power at the turbine and feeds it back to a crankshaft-mounted electrical motor. The electric turbocompound system also provides more control flexibility in that the amount of power extracted can be varied. This allows for control of engine boost and thus air/fuel ratio.

The paper presents the status of development of an electric turbocompound system for a Caterpillar heavy-duty, on-highway truck engine. Layout of the system architecture, the turbocharger design features, and the development of a system control strategy is shown. Furthermore, engine simulation results are presented, and development of electrical machinery is described.

THERMOELECTRIC TECHNOLOGY FOR AUTOMOTIVE APPLICATIONS

Aleksandr S. Kushch, John C. Bass, and Mark Hauerbach
Hi-Z Technology, Inc.

and

Richard A. Bergstrand, Lew Plummer, David Furrow, and Mike Melvin
PACCAR Technical Center

A thermoelectric generator (TEG) waste heat recovery system for Class 8 diesel trucks is under development by Hi-Z Technology and PACCAR. The TEG was assembled and tested at Hi-Z and integrated by PACCAR into the exhaust system of a Kenworth truck, which is equipped with a Caterpillar 550-hp diesel engine. The TEG is mounted on the truck frame under the cab. The shock absorption system developed by PACCAR reduces the mechanical impact of the harsh road environment. The inlet of the TEG is connected with the engine exhaust via an 80-inch insulated pipe. TEG cooling plenums are integrated into engine cooling system by means of flexible hoses. An additional heat exchanger is installed into the coolant line in order to reduce the coolant temperature. The test truck is equipped with the data acquisition system that allows recording of all the engine parameters (speed, load, rpm, temperatures, etc.)

A test truck with a TEG has already completed a test run that is equivalent of about 100,000 miles and is continuing. No TEG mechanical damage or internal resistance change has been recorded yet.

A self-powered cab/space heater needed to minimize cold weather truck idling has also been demonstrated by Hi-Z. The D1LC heater manufactured by Espar has been modified by integration of two HZ14 thermoelectric modules (TEM) and pin-type heat sinks. The heater uses diesel/gasoline as the fuel and uses about 22 W of electric power when operated at a high thermal output mode; it releases 2 kW of thermal energy. The TEM's were sandwiched between two flat sides of the heat exchanger and the heat sinks. The circulation blower conveys the ambient air through the heat sinks ensuring TEM cooling and drives the heated air into the cab.

The TEM's generated about 26 W of electricity, which is more than sufficient to make the unit self powered. The self-powered heater was assembled and tested with a DC/DC converter and a battery. During startup, a battery supplied power for the igniter, blowers, and pump. After 2 minutes, the TEM generated sufficient electric power and also recharged the battery.

A similar unit can be converted into a larger auxiliary power (APU) unit by adding more thermoelectric modules. Diesel-driven APU's can be used as an anti-idling device, saving considerable fuel and reducing pollutant emissions.

ATTAINING TIER 2 EMISSIONS THROUGH DIESEL ENGINE AND AFTERTREATMENT INTEGRATION –

STRATEGY AND EXPERIMENTAL RESULTS

R. Aneja, B. Bolton, N. Hakim, Z. Pavlova-MacKinnon
Detroit Diesel Corporation

The feasibility of diesel engines to meet the stringent emissions regulations of 2007 and beyond is an important consideration for light trucks and other personal transportation vehicles. Integrated engine and aftertreatment systems have been developed at Detroit Diesel Corporation for multiple engine and vehicle platforms. Tier 2 emissions technologies have been demonstrated with significant fuel economy advantage compared to the respective production gasoline engines while maintaining excellent drivability.

The performance and emission results were achieved by integrating advanced combustion strategies with prototype aftertreatment systems. The system development methodology included the integration of experimental and digital tools. Further, the experimental development approach included systematic testing on steady-state dynamometer, transient dynamometer and chassis dynamometer test beds.

CUMMINS/U.S. DEPARTMENT OF ENERGY LIGHT TRUCK DIESEL ENGINE PROGRESS REPORT

John Stang, David Koeberlein, and Michael Ruth
Cummins

Cummins has studied requirements of the light-truck automotive market in the United States and believes that its proposed V-family of engines meets those needs. Design and development of the V-family engine system continues. The engine system is a difficult one, since the combined requirements of a very fuel-efficient commercial diesel with the performance and sociability requirements of a gasoline engine are needed.

Results of testing have shown that the engine can meet requirements for fuel economy and emissions in the Tier 2 interim period from 2004 to 2008. Advanced results show that the full Tier 2 results for 2008 and beyond can be achieved on a laboratory basis.

Various results of ongoing system development are shown, including air-handling system, noise, overhead system dynamics, and overall vehicle performance. General aftertreatment system design direction is discussed.

Abstracts

Session 9 – Combustion and HCCI Development

A MIXED-MODE HCCI/DI ENGINE BASED ON A NOVEL DIESEL FUEL ATOMIZER

Giorgio Rizzoni, Yann Guezennec, and Shawn Midlam-Mohler
Ohio State University

The homogeneous charge compression ignition (HCCI) mode has long been touted as the next engine combustion system to combine the high efficiency of diesel engines with very low tail-pipe emissions; however, it has been demonstrated only in the laboratory under very controlled conditions. It is clear that achieving a robust and controllable HCCI combustion system capable of handling heavy fuels in engines under a realistic and wide range of operating conditions and transients is not feasible today.

Our approach is aimed at developing a compression engine capable of operating with heavy fuels over a wide range of operating (speed, load, temperatures) conditions in a robust and controllable fashion to achieve both high thermal efficiency and low emissions. Furthermore, our approach builds upon the technological recent advances and successes in advanced CIDI engines, married with a novel enabling technology in ultra-fine heavy fuel atomization and advances in modern, model-based engine control systems.

The novel atomizer is a low-pressure system capable of atomizing heavy liquid fuels in a "fog-like" suspension of sub-micron liquid droplets over a very wide range of temperature conditions. The air/fuel mixture so formed has many positive attributes: it behaves in a gas-like manner; is highly resistant to settling and segregation, subsequent film condensation, and wall wetting; and is highly homogeneous and capable of achieving a well-mixed air/fuel vapor mixture very fast due to the extremely high surface-to-volume ratio of the fuel droplets.

Our engine concept is also a mixed-mode, HCCI/CIDI combustion system:
part of the fuel is introduced in the engine to achieve a lean and very homogeneous, premixed phase capable of combusting in an HCCI mode, while part of the fuel is introduced directly by a common rail direct injection (DI) system. The non-condensing, highly mixed nature of the fuel/oxidizer mixture achieved with the novel atomizer enables port injection for the preparation of a very lean and highly homogeneous phase capable of supporting the HCCI combustion mode at low-to-medium loads. The CR-CIDI conventional injection system enables the medium-to-high load operation, which is not feasible with a pure HCCI combustion system. However, both systems are intended to operate *simultaneously* with the emphasis between the two systems shifting as load/speed varies. We foresee that the DI injection at high loads into a lean and homogenous air/oxidizer mixture phase will further extend the PM/NO_x trade-offs and limits facing conventional CIDI engines. At low-to-medium loads, a relatively smaller DI part can act as a "combustion" trigger for the otherwise homogeneous (and possibly lean) phase, hence capable of achieving much greater controllability of the combustion system. This mixed-mode fueling strategy is combined with advanced, model-based control for the VGT/EGR loop to achieve at each cycle a reliable estimate and control of

the thermochemical oxidizer charge, hence achieving the narrow range of intake conditions required for proper HCCI operation.

Finally, the system is to be used with an active, thermochemically managed exhaust aftertreatment system. Again, the novel atomizer plays a significant enabling role to achieve the thermochemical management of a bifurcated lean-NO_x trap system, which does not require an engine-based reductant addition to achieve NO_x trap regeneration.

DIESEL HCCI DEVELOPMENT AT CATERPILLAR

Kevin P. Duffy
Caterpillar, Inc.

Implementation of a practical homogeneous charge compression ignition (HCCI) engine has numerous technical challenges. Among these are proper mixture preparation, controlling combustion phasing and cylinder pressure rise rates, and expanding the operating range to higher loads. Methods to control combustion phasing include managing inlet manifold temperature and pressure, exhaust gas recirculation rate, and injection timing. Recent progress on part-load HCCI operation using diesel fuel will be given.

HCCI COMBUSTION: DETAILED ANALYSIS AND PERFORMANCE EXPERIMENTS

Salvador Aceves and Daniel Flowers
Lawrence Livermore National Laboratory

and

Robert Dibble
University of California at Berkeley

Homogeneous charge compression ignition (HCCI) is a new engine technology that allows both high efficiency and low emissions for cars, trucks, and sport utility vehicles (SUV's). The high efficiency of diesel engines is highly desirable for improving the fuel economy of light-duty trucks and SUV's. However, diesel engines are well known as significant sources of NO_x and particulate matter emissions. The use of HCCI combustion systems represents a promising approach that needs further research and development.

Our research work on HCCI is divided into two major tasks: analysis and experimental work. On analysis, we have developed two powerful HCCI analysis tools: a single-zone HCT model and a multi-zone HCT model. The single-zone model has proven very successful in predicting the start of combustion and providing reasonable estimates for peak cylinder pressure, indicated efficiency, and NO_x emissions, with very little computational cost (5 minutes on an engineering workstation). The multi-zone model is capable of very accurate predictions of the combustion process, including HC and CO emissions, at the cost of substantially longer running times (8 hours on an engineering workstation). The two models complement each other very nicely. Most of the work can be done with the single-zone model, and the multi-zone model can be used for a detailed analysis of important operating points and to learn more about the fundamentals of HCCI combustion.

We are currently conducting detailed analysis of experiments at other institutions, such as University of California at Berkeley, Sandia National Laboratories in Livermore, California, and Lund Institute of Technology. The purpose of the detailed analysis is to determine the fundamentals of HCCI combustion, study the effect of mixing on HCCI combustion, and develop methodologies for controlling the engine. We are also working in collaboration with the chemical kinetics group at Lawrence Livermore National Laboratory (LLNL) to develop surrogate mechanisms for practical HCCI fuels, mainly gasoline.

On experimental work, we are working on validating the application of the modified HCT code and implementing strategies for HCCI engine startability and control. We currently have a 4-cylinder Volkswagen TDI engine and a Caterpillar 3401 engine operating in HCCI mode in the University of California at Berkeley Engine Laboratory. Experiments on the TDI engine are focused on balancing combustion between the cylinders and on

obtaining combustion at the appropriate timing. The experiments on the Caterpillar engine are dedicated to performing fundamental experiments on HCCI combustion in collaboration with the LLNL Accelerated Mass Spectroscopy team.

HCCI Combustion: the Sources of Emissions at Low Loads and the Effects of GDI Fuel Injection

John E. Dec and Magnus Sjöberg
Sandia National Laboratories

Abstract

Homogeneous Charge Compression Ignition (HCCI) engines have been shown to provide both high efficiency and low emissions of NO_X and particulate. However, hydrocarbon (HC) and carbon monoxide (CO) emissions are often high, with amounts depending on operating conditions. To gain a better understanding of the reasons for these emissions and their relative importance over the operating range, a study of HCCI combustion and emissions has been conducted, with particular emphasis on understanding the sources of HC and CO emissions and the associated combustion inefficiencies during low-load operation. This investigation included both experimental measurements and computations for a variety of fuel loads and engine speeds.

The experiments were conducted in a single-cylinder engine (0.98 liters/cyl.) fitted with a custom HCCI piston that minimizes crevice volume, using iso-octane as the fuel. For three engine speeds (600, 1200, and 1800 rpm) the fuel loading was varied from near the knocking limit to loads at or below idle (based on typical diesel-engine fueling). For each condition, cylinder pressure and exhaust-gas data (CO_2, O_2, CO, HC, NO_X, and smoke) were acquired. Comparative computations were made using the Senkin application of the CHEMKIN III kinetic rate code with the full chemistry mechanisms for iso-octane. This single-zone model provides results that are representative of the bulk-gas behavior for an idealized engine with no crevices.

The experimental data show that when the fueling rate is reduced below an equivalence ratio (ϕ) of 0.18, CO emissions begin to increase substantially, reaching levels corresponding to 60% of all fuel carbon at idle loads (ϕ = 0.1 to 0.12). As this occurs, the combustion efficiency falls from 95% to less than 60%. These high CO levels are found to be in very good agreement with those predicted by the model, indicating that the high CO emissions and the associated combustion inefficiencies are due to incomplete bulk-gas reactions. HC emissions also increase, but the effect is less pronounced than that of CO. In addition, the model indicates that high levels of oxygenated hydrocarbons (OHC) should occur as bulk-gas reactions become less complete. Since these emissions are not readily measured, a method of estimating the OHC level from the available data was developed, and is shown to compare well with the modeling results. Finally, partial charge stratification, obtained using a gasoline-type direct fuel injector has been investigated as a means of mitigating the problem of incomplete bulk gas reactions at lower loads, and the results are presented and discussed.

SIMULTANEOUS LOW ENGINE-OUT NOX AND PM WITH HIGHLY DILUTED DIESEL COMBUSTION

Robert M. Wagner, Johney B. Green Jr., Thang Q. Dam, K. Dean Edwards, and John M. Storey
Oak Ridge National Laboratory

We are investigating the simultaneous reduction of nitrogen oxides (NO_x) and particulate matter (PM) in a modern light-duty diesel engine under high exhaust gas recirculation (EGR) levels. This type of behavior was observed under lean conditions at several low-load conditions using two different approaches.

The first approach utilizes a throttle to increase EGR rate beyond the maximum rate possible with only the EGR valve for a particular engine condition. The second approach does not use a throttle but rather uses a combination of EGR and manipulating injection parameters.

A significant reduction in PM size and concentration was observed corresponding to the reduction in particulate mass. This was accompanied by a significant shift in the heat release profile. In addition, there were significant cylinder-to-cylinder variations in PM characteristics, gaseous emissions, and heat release.

A fuel penalty is associated with operating in the low NO_x and low PM regime. Preliminary experiments indicate that the penalty can be reduced to a few percent while still maintaining a significant reduction in NO_x and PM. An improved understanding of this combustion regime could lead to improved EGR utilization for lowering the performance requirements of post-combustion emissions controls.

OPTICAL DIAGNOSIS AND MODELING TOOLS APPLIED TO DIESEL HCCI

Cathy Y. Choi
Caterpillar Inc.

Fundamental investigation of diesel homogeneous charge compression ignition (HCCI) has been performed through the use of optical diagnostic techniques and computational modeling tools. An optically accessible engine and a spray visualization rig have been used to characterize HCCI-type combustion and appropriate spray characteristics for charge homogeneity. In parallel, improvements to computational modeling of multidimensional sprays and combustion have been implemented in order to identify potential HCCI-enabling technologies.

HIGH-ENERGY, PULSED LASER DIAGNOSTICS FOR REAL-TIME MEASUREMENTS OF RECIPROCATING ENGINE PM EMISSIONS

Peter O. Witze
Sandia National Laboratories

With stricter particulate matter (PM) emission regulations looming ahead in 2004 and 2007, there is a need for new instrumentation capable of real-time measurements with high sensitivity. We foresee applications for both extractive sampling and *in situ* measurements, where the former is the simplest approach to implement, and the latter is needed to characterize engine-out/aftertreatment in conditions for design optimization and life-cycle simulation. High-energy, pulsed-laser diagnostics are well suited for these tasks, and offer a wide range of measurement capabilities that include the following: (1) laser-induced incandescence (LII) for soot volume fraction and primary particle size; (2) elastic light scattering (ELS) for total volume fraction; (3) laser-induced desorption (LID) with ELS (LIDELS) for volatile fraction; (4) LII with ELS for aggregate size, number, and structure; and (5) laser-induced breakdown spectroscopy (LIBS) for metallic-ash species and concentration.

The principles behind these diagnostics will be briefly discussed, followed by a description of a compact, mobile instrument for "hands-off" implementation based on PC control. Three demonstrations of the instrument's use will be presented: (1) LII measurements during cold-start of a gasoline engine, comparing open- and closed-valve fuel injection; (2) LII measurements of transient diesel PM emissions for a cranking-start/idle/shutdown sequence and on/off cycling of exhaust gas recirculation (EGR); and (3) real-time LIDELS measurements of the volatile fraction during EGR and load sweeps.

Abstracts

Session 10 – Diesel Engine Exhaust Aftertreatment, Part I

LOW EMISSIONS POTENTIAL OF EGR-SCR-DPF AND ADVANCED FUEL FORMULATIONS: A PROGRESS REPORT

Magdi Khair
Southwest Research Institute

One of the major projects of the Advanced Petroleum-Based Fuels – Diesel Emission Control (APBF-DEC) project is the demonstration of potential for selective catalytic reduction (SCR) and diesel particulate filters (DPF). This project is integrating several diesel emission control technologies for the purpose of demonstrating their capability in achieving the 2007 heavy-duty diesel engine (HDDE) standards. The project also includes the evaluation of several fuels with various sulfur contents.

The work is conducted on a Caterpillar C-12 HDDE. Two emission control systems will be calibrated to meet the 2007 HDDE standards. Each system consists of EGR, CB-DPF, and urea SCR. Once a satisfactory calibration is achieved, both systems will undergo 6,000 hours of durability with emission evaluations conducted at 2,000-hour intervals. Selected unregulated, toxic, and nitrogen compounds will also be sampled at regular intervals for both control systems. This presentation is a progress report on what the project has accomplished to date.

EVALUATION OF A NO_x ADSORBER SYSTEM ON A LIGHT-DUTY DIESEL VEHICLE

R. Mital, J. Li, S. C. Huang, and R. C. Yu
Cummins, Inc.

and

John A. Anderson
Argonne National Laboratory

This paper presents the results of NO_x adsorber testing done under the FreedomCAR Program. A compact exhaust aftertreatment system (EAS) design was developed after various iterations of the catalyst formulation and system configuration. The EAS tested is dual leg and consists of sulfur trap, adsorber, and catalyzed soot filter (CSF). During regeneration, supplementary low-sulfur diesel fuel is injected upstream of the adsorber and CSF in the exhaust. The adsorber catalyst volume is 1.8 times the engine displacement. Steady-state and transient emission test results with and without the EAS are presented. Results of soot filter regeneration by injecting low-sulfur diesel fuel and slip of unregulated emissions, such as NH_3, are discussed. Effects of adsorber size and bypass strategy on NO_x conversion efficiency and fuel economy penalty are also presented in this paper. The results show that if the supplementary fuel injection is optimized, NH_3 slip is negligible. During the FTP cycle, injection of low-sulfur diesel fuel can create temperature exotherms high enough to regenerate a loaded CSF. It was observed that the adsorber size affects the NO_x conversion efficiency significantly, and the right catalyst size will need to be chosen based upon the application.

UREA SELECTIVE CATALYTIC REDUCTION AND DIESEL PARTICULATE FILTER SYSTEM FOR DIESEL SPORT UTILITY VEHICLE MEETING TIER II BIN 5

Brendan Carberry, Robert Hammerle, Paul Laing, Christine Lambert, Cliff Montreuil, Rick Soltis, Devesh Upadhyay and Scott Williams
Ford Motor Company

Ford Motor Company is participating in the U.S. Department of Energy's (DOE) Ultra-Clean Transportation Fuels Program with the goal of developing an innovative emission control system for diesel sport utility vehicles. This program focuses on diesel vehicles because they currently offer 40-percent better volumetric fuel economy and 20-percent lower CO_2 emissions than comparable gasoline vehicles. We chose a selective catalytic reduction (SCR) catalyst that uses aqueous urea as the NO_x reductant and a catalyzed diesel particulate filter (DPF) for this program. We plan to demonstrate more than 90-percent reduction in particulate matter (PM) and NO_x emissions. We use very low sulfur diesel fuel (less than 15 ppm) to enable low PM emissions, to reduce the fuel economy penalty due to the emission control system, and to enhance long-term durability of the system. The end result will allow vehicles with diesel engines to be Tier II - emissions certified at a minimum cost to the consumer.

In the first year of the program, we have scaled up the exhaust system --which has an oxidation catalyst, urea SCR and a catalyzed DPF -- from a passenger car to a light-duty truck. We have achieved excellent mixing of the injected urea with the truck exhaust gas and 85-percent NO_x conversion on the Federal Test Procedure as predicted by modeling. We have also begun exploring rapid-warming procedures to increase NO_x conversion when exhaust temperatures are too low and modeling ammonia storage to maximize NO_x conversion while minimizing ammonia emissions. We have begun improving exhaust gas NO_x and ammonia sensors for more accurate control of reductant injection and on-board diagnostics. Finally, we have tested the on-road durability of the aqueous urea SCR system on a 2.4-liter transit van for 25,000 miles and separately improved the durability of both the urea SCR and DPF systems.

DURABILITY OF NO_x ADSORBERS

Jim Parks, Bill Epling, Aaron Watson, and Greg Campbell
EmeraChem

NO_x adsorber catalysts can obtain NO_x reduction efficiencies greater than 90 percent in lean exhaust. The capability of the NO_x adsorber to perform the NO_x reduction with a diesel-fuel-based reductant coupled with the broad temperature range of operation makes NO_x adsorber catalysts well suited for diesel engine applications. However, durability issues need to be addressed for compliance with upcoming emission regulations.

Specifically, sulfur in diesel fuel is a known masking agent, and over time sulfur accumulation directly on NO_x sorption sites degrades NO_x reduction performance. One method of controlling sulfur masking is by removal of sulfur compounds from the catalyst in a reducing environment; this process is referred to as desulfation and typically occurs at elevated catalyst temperatures. Here the effect of multiple repetitive sulfur loading and desulfation cycles on catalyst performance will be presented, and projections of NO_x performance over time will be made to predict catalyst lifetime.

NO_X ADSORBER DEVELOPMENT

Steve Faulkner
Caterpillar, Inc.

The development of the NO_x adsorber technology is one of the key challenges facing the heavy-duty diesel industry. Caterpillar will review recent progress with this technology and discuss some of the remaining challenges.

LEAN-NO_X CATALYST DEVELOPMENT FOR DIESEL ENGINE APPLICATIONS

Paul Park, Carrie Boyer, Christie Ragle, and M. Lou Balmer
Caterpillar, Inc.

and

Chris Aardahl, Jerry Birnbaum, Ken Rappe, and Diana Tran
Pacific Northwest National Laboratory

Because of the inherently low hydrocarbon concentration in diesel exhaust, any NO_x reduction catalyst requires the addition of supplemental reductant to reduce NO_x. From a diesel engine user's standpoint, the best reductant to use in conjunction with aftertreatment systems is diesel fuel. However, the natural form of diesel fuel is not an ideal reductant to reduce NO_x over various catalysts.

Reformation of diesel fuel to create feasible reductant has been considered to improve NO_x reduction performance. In this study, catalyst materials demonstrated hydrocarbon reformation as well as NO_x reduction on the catalyst surface. The reformation active sites were identified independently from NO_x reduction sites in the catalyst formulation.

The research and development of catalysts suitable for lean-NO_x or non-thermal plasma applications to optimize NO_x reduction will be discussed.

PLASMA-ACTIVATED LEAN NOX CATALYSIS FOR HEAVY-DUTY DIESEL EMISSIONS CONTROL

Chris Aardahl, Jerry Birnbaum, Ken Rappe, Diana Tran
Pacific Northwest National Laboratory

and

Paul Park
Caterpillar, Inc.

NO_x reduction exceeding 90 percent has been demonstrated for a simulated exhaust stream in bench-scale experiments and in engine slip-stream tests using a plasma treatment step followed by catalytic lean-NO_x reduction. The effect of reducing agent on catalysis has been probed in some detail, and results show that a variety of hydrocarbons can be used to reduce NO_x. It is also demonstrated that optimal catalyst formulation, based on silver-doped ?-alumina, is highly dependent on the hydrocarbon species. Fuel-like hydrocarbons, such as iso-octane, can give high activity, but the level of silver in the catalyst must be increased above levels typically used for propene or other light hydrocarbons. Comparison between bench data and steady-state engine testing conducted in 2001 will also be provided.

A NON-THERMAL PLASMA APPLICATION FOR THE ROYAL NAVY

Lt. Cdr. D. E. Hughes (CF – Canadian Forces)

U.K. Ministry of Defence

The worldwide travel of the British Royal Navy provides for a varied environment that naval vessels are accustomed and presents numerous challenges. Environmental legislation has become increasingly stringent for the marine industry and navies worldwide. The NO_x and particulate emissions reduction from diesel engines continues to be of importance to the U.K. Ministry of Defence (MOD). Evaluation of the feasibility of exhaust control technologies suitable for NO_x reduction is constantly being monitored. The Accentus plc proprietary and patented non-thermal plasma (NTP) system is presently in stage 2 development with U.K. MOD and is being applied to the naval environment. A stage 1 feasibility and analysis study has been completed, and a 1/10-scale demonstrator is a deliverable for stage 2. NTP compared to selective catalytic reduction (SCR) has the potential to offer significantly improved low load and shock performance over the conventional SCR without the inconvenience of using an ammonia-based reductant.

The primary objective of the paper is to discuss the Accentus NTP system application to a broad range of operational naval diesels and the recent engine trials conducted at MAN B&W. The secondary objective is to discuss U.K. policy and naval environmental strategy and to monitor, evaluate, develop, and advise future capital projects.

The NO_x reduction through primary means is preferred in U.K. MOD vessels. However, the vast array of engine types and imminent emission level change has focused the Royal Navy on secondary treatment such as NTP and SCR. Investment appraisal in secondary fits will increasingly support new technology engine after-treatment retrofit. The uncertain nature of NO_x and particulate level legislation has reinforced the Royal Navy commitment to remaining an informed customer on “green” issues.

NOXTECH'S PLASMA-ASSISTED CATALYST PROGRAM

Ralph Slone, B. Bhatt, and Victor Puchkarev
Noxtech, Inc.

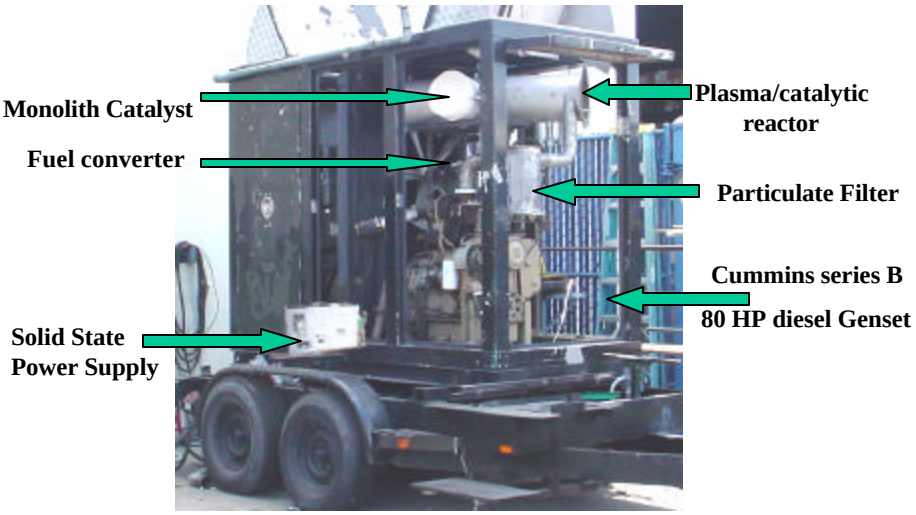
Diesel emissions reduction technology remains a key obstacle in achieving cleaner and healthier environmental standards. It is estimated the diesel emissions will have to be reduced by as much as 90 percent from current levels to meet the 2007 and beyond standards being sought by the U.S. Environmental Protection Agency and the California Air Resources Board.

Non-thermal plasma-assisted catalyst (NTPAC) technology being developed at Noxtech, Inc., continues to focus on achieving the 2007 and beyond standards. Noxtech's NTPAC technology utilizes an efficient non-thermal plasma reactor working in harmony with a solid-state pulsed power supply to efficiently convert NO to NO_2 in the presence of a suitable hydrocarbon generated on-board from diesel fuel. NO_2 is then converted to N_2 in the presence of an A9 monolithic sulfur-tolerant catalyst.

Noxtech has made major progress in the development and enhancement of the NTPAC system under the U.S. Department of Energy-sponsored program. Noxtech has designed, built, and demonstrated an 80-HP NTPAC system with up to 94-percent NO_x reduction from an 80-HP diesel engine genset using a diesel as a source of reductant for the NTPAC system.

Major improvements have been made in the Noxtech's NTPAC system components. Noxtech has successfully designed, built, and tested a diesel fuel converter, which uses the exhaust energy to convert diesel into a suitable gaseous hydrocarbon so it can be used by the NTPAC system as a reductant. The NO_2 conversion catalyst performance has been improved, and the ceramic spheres have been replaced with a monolithic unit. Noxtech continues to screen additional catalysts to find more active and better catalysts than A9. The efficiency of the pulser and reactor has been enhanced, and their size and components have been greatly reduced.

Noxtech plans to demonstrate its advanced 80-HP NTPAC system at the DEER 2002 Conference. The system developed at Noxtech will be integrated with an 80-HP series B diesel engine genset. This system will be operated with a load bank and a NO_x analyzer. Metered diesel fuel will be used as a reductant for the NTPAC system demonstration. The plasma reactor will be powered by a solid-state power conditioner/pulser, and the system will be operated at steady state with manual controls.


Monolith Catalyst
Fuel converter
Solid State
Power Supply
Plasma/catalytic
reactor
Particulate Filter
Cummins series B
80 HP diesel Genset

TEMPERATURE TRANSIENT EFFECTS IN PLASMA CATALYSIS

John Hoard
Ford Motor Company

and

Paul Park
Caterpillar, Inc.

Plasma discharge is used together with a combination of catalysts for simulated diesel exhaust NO_x removal. A transient evaluation is made using a programmed temperature ramp between 100°C and 500°C, and using FTIR to measure the gas composition before and after the treatment. Although the temperature transient is not directly related to any driving cycle, it has provided useful insight on plasma-catalyst system issues.

A controller was made that holds constant plasma-specific energy deposition (J/L) over the temperature range. It is necessary to vary both frequency and amplitude of the AC excitation in the dielectric barrier discharge. Surface conductivity effects on the barrier affect the discharge NO_x at higher temperatures.

Zeolite-based catalysts, such as NaY and BaY, have both steady-state NO_x conversion and significant NO_x storage. The stored NO_x can be released during catalyst heating. By themselves, these catalysts have poor conversion over the temperature cycle.

An alumina-based catalyst provided by Caterpillar has higher temperature operation than the zeolite-based catalysts. When placed downstream of BaY, the cycle average NO_x efficiency is greatly improved. This is partly because the desorption of NO_x from the BaY occurs at a temperature near the lower operating range of the alumina-based catalyst, and partly because the zeolite-based catalyst increases the concentration of formaldehyde, which is a useful NO_x reductant over the alumina-based catalyst.

A platinum-based catalyst is required downstream of the NO_x catalysts to remove remaining HC and aldehydes. At the same time, there is a narrow temperature range of NO_x conversion over the platinum, so that the cycle average NO_x conversion is highest when the three catalysts are used in combination.

ON-BOARD PLASMATRON GENERATION OF HYDROGEN-RICH GAS FOR DIESEL AFTERTREATMENT AND OTHER APPLICATIONS

L. Bromberg, D. R. Cohn, J. Heywood, and A. Rabinovich
Massachusetts Institute of Technology

Plasmatron reformers can provide attractive means for conversion of diesel fuel into hydrogen-rich gas. The hydrogen-rich gas can be used for improved NO_x trap technology and other aftertreatment applications. Plasmatron reformers developed at MIT use a special low-power, low- current electrical discharge to boost partial oxidation conversion of hydrocarbon fuels into hydrogen and carbon monoxide. This reformer technology provides the advantages of:

- Rapid startup and response to transient conditions
- Efficient conversion
- Compact size
- Relaxation or elimination of reformer catalyst requirements
- Capability to process difficult-to-reform fuels.

Diesel plasmatron reformer technology can provide substantial throughputs with homogeneous reforming. The use of the special plasma facilitates robust, non-catalytic conversion of diesel fuel into hydrogen-rich gas with hydrogen yields that are sufficient for NO_x trap regeneration applications. Higher yields can be obtained with the use of a catalyst.

Plasmatron reformers could also be used for manufacturing of ethene, which could be useful as a selective reducing agent. In addition, plasmatron reformer technology can be used for converting a range of biofuels into hydrogen-rich gas. These fuels include various oils. This capability may improve the prospects for use of renewable fuels in a variety of vehicular applications. The status of plasmatron diesel-fuel reformers will be discussed.

PERFORMANCE EVALUATION OF THE DELPHI NON-THERMAL PLASMA SYSTEM UNDER TRANSIENT AND STEADY-STATE CONDITIONS

Joseph V. Bonadies, Joachim Kupe, Galen B. Fisher, Craig L. DiMaggio, David A. Goulette, Thomas W. Silvis, Mark Hemingway, and William J. LaBarge
Delphi Corporation

and

Darrell R. Herling, Monty R. Smith, John G. Frye, and Mark A. Gerber
Pacific Northwest National Laboratory

A non-thermal plasma (NTP) exhaust aftertreatment system, consisting of a diesel particulate filter (DPF), NTP reactor, power supply, controller, catalyst, and NO_x sensor, was developed to reduce the emission of oxides of nitrogen and particulate (PM) matter for diesel engines. The goal of the project was to reduce NO_x by 80 percent and PM by 90 percent with a maximum fuel economy penalty of 3 percent. System development was conducted on a 2.2-liter light-duty, common rail, diesel vehicle using steady-state and transient emission tests. The total NO_x emission reduction on transient testing over the European MVEG cycle averaged 15 percent, with a fuel economy penalty of 8 percent. DPF regeneration using the NTP was demonstrated under steady-state conditions at exhaust temperatures greater than 280°C. A comprehensive analysis of the vehicle emission data will be presented.

A PARAMETRIC STUDY SHOWING THE EFFECT OF TEMPERATURE AND HYDROCARBON SPECIES ON THE PRODUCT DISTRIBUTION FROM A NON-THERMAL PLASMA REACTOR

Galen B. Fisher, Craig L. DiMaggio, Joachim Kupe, Joseph V. Bonadies, Mark Hemingway, and David A. Goulette
Delphi Corporation

and

Delbert L. Lessor, Monty R. Smith, and Darrell R. Herling
Pacific Northwest National Laboratory

In an attempt to better understand how the performance of a plasma reactor varies in actual diesel exhaust, its ability to (1) convert NO-to-NO_2 and (2) create chemically active oxygenates (e.g., acetaldehyde) was evaluated as a function of variables, such as gas temperature, hydrocarbon species, and hydrocarbon concentration. Simulated diesel exhaust conditions including O_2, CO_2, H_2O, CO, NO, and hydrocarbons were employed together with a single-cell plasma reactor in a bench system. The source of reductant species was one of nine lighter weight saturated or unsaturated hydrocarbons ranging in carbon number from 2 to 5. The gas temperature was varied between 125° C and 475° C. The resulting product distribution was then examined with an FTIR and a chemical ionization mass spectrometer (CIMS) to better clarify the role of hydrocarbon speciation in forming NO_2 and oxygenates.

In general, we find that higher hydrocarbon concentrations are essential at all gas temperatures to optimize NO-to-NO_2 formation. Unsaturated straight chain hydrocarbons appear superior at low temperatures, while saturated straight chain hydrocarbons perform better at higher temperatures. Longer chain hydrocarbons outperform shorter chain hydrocarbons at any temperature on a molar basis. A combination of saturated and unsaturated hydrocarbons can provide a broad temperature window for good NO_2 formation.

To maximize formation of oxygenates, like acetaldehyde, higher concentrations of longer chain hydrocarbons are superior. Unsaturated hydrocarbons show little temperature dependence, while saturated hydrocarbons work better at high temperatures. Some additional work was also done to examine the reactor performance as a function of NO concentration, reactor power, and space velocity. Modeling of the gas-phase chemistry in a plasma reactor supports many of these findings. Extensions of this work, using mixtures of gases present in actual exhaust, should allow for the determination of the optimal conditions at which to run a plasma reactor, depending on its application.

Abstracts

Session 11 – Diesel Engine Exhaust Aftertreatment, Part II

USE OF A MOBILE ON-ROAD LABORATORY TO MEASURE HEAVY-DUTY DIESEL "REAL WORLD" EMISSIONS FROM STANDARD AND NON-STANDARD OPERATING CYCLES

Wayne Miller, David Cocker, Kent Johnson, Carlos Gaeta, and Joe Norbeck
University of California at Riverside

Heavy-duty diesel engines are abundant and will remain the workhorse of the commercial sector for years to come. Thus, it is important to understand emissions from heavy-duty diesel (HDD) engines both as certified and while operating under 'real world' conditions. Towards that end, the University of California at Riverside College of Engineering Center for Environmental Research and Technology (CE-CERT) developed a HDD mobile on-road emissions laboratory with the capability of measuring gaseous, semi-volatile, and particulate emissions, while in motion, from heavy-duty tractors operating under actual conditions. The report will detail some of the verification phases that were used to complete the development of the lab and the new secondary dilution tunnel.

Results will be presented to show that the mobile laboratory can achieve similar driving repeatability for a standard cycle while under "real world" conditions as in a stationary laboratory. This driving precision leads to analytical precision for the various emissions. As a result, CE-CERT is able to determine actual operating emissions of HDD emissions over various on-road cycles to compare with existing certification results
and emission inventories. In addition, CE-CERT has developed the capability of assessing the performance of emission reduction technologies in actual operating conditions. The presentation will also discuss the HDD emissions from non-standard cycles, such as a four-mode transient cycle or one developed to represent HDD vehicles that are entering or leaving the Los Angeles Basin. Future plans for the HDD mobile laboratory will be discussed.

NO_X ADSORBERS FOR HEAVY-DUTY TRUCK ENGINES – TESTING AND SIMULATION

N. Hakim, J. Hoelzer, and Y. Liu

Detroit Diesel Corporation

This feasibility study of NO_x adsorbers in heavy-duty diesel engines examined three configurations (dual-leg, single-leg, and single-leg-bypass) in an integrated experimental setup, composed of a Detroit Diesel Class-8 truck engine, a catalyzed diesel particulate filter, and the NO_x absorber system. The setup also employed a reductant injection concept, sensors, and advanced control strategies.

The study included the development of thermal and empirical NO_x absorber characteristic models. These models were further applied to the development of regeneration strategies and were used for a comparative performance analysis of the three NO_x adsorber configurations.

The reported steady-state experimental and simulation results show relatively high NO_x conversion efficiencies, with various levels of fuel economy deterioration. Further, the findings confirm that the development of acceptable regeneration and desulfation control logics is a major technical challenge for practical NO_x absorber system applications. These logics are further complicated by such factors as engine transient operation, drivability, and durability.

UPDATE ON MODELING FOR EFFECTIVE DIESEL ENGINE AFTERTREATMENT IMPLEMENTATION -- MASTER PLAN, STATUS, AND CRITICAL NEEDS

B. Bolton, X. Fan, N. Hakim, K. Sisken, and H. Zhang

Detroit Diesel Corporation

An integrated diesel engine-aftertreatment-vehicle system is extremely complex with numerous interacting variables and an unlimited number of control options. An experimental approach to developing an optimized viable system is tedious, if at all possible. Sophisticated component, subsystem, and integrated simulation tools offer an excellent option of a virtual laboratory approach to the development of such a complex system. A viable and robust diesel engine aftertreatment system can thus be developed within optimum time and resources when this virtual simulation is integrated with selective hardware-based testing.

Detroit Diesel has developed an effective virtual laboratory integrated system package. A multi-level common platform embodies 0-, 1-, and multi-dimensional models of selected components and subsystems. Different models can be coupled or integrated, and simulated tests can be carried out in order to define optimum control parameters or to predict system response. This paper will present the technology development master plan, update technical status of the simulation fidelity, and outline critical needs that impact simulation tool development and serious application.

EXPANDED CAPACITY MICROWAVE-CLEANED DIESEL PARTICULATE FILTER

Dick Nixdorf
Industrial Ceramic Solutions, LLC

Beginning in FY 2000, the DOE Partnership for a New Generation of Vehicles (PNGV) Program has funded the development of a ceramic-fiber, diesel particulate filter system that is cleaned by microwave energy (Mw-DPF). That silicon carbide fiber filter cartridge was a round, corrugated wall-flow configuration. The shape was adequate for the relatively low exhaust flows experienced on a PNGV-type vehicle.

Recently, Industrial Ceramic Solutions (ICS) has developed a flat, pleated, multiple-filter cartridge design, which has demonstrated 1/20th of the back-pressure of the classic wall-flow cartridges. This higher exhaust capacity, multiple-cassette design will allow the use of the Mw-DPF's in Class 8 diesel vehicles or even larger electric cogeneration diesels and locomotives.

The pleated cassettes are inexpensive to fabricate and can be used as catalyst carriers without the microwave unit. The design and operation of the pleated ceramic-fiber filter system is discussed. Data are presented comparing the flat, pleated-media back-pressure to that of a wall-flow DPF.

Emissions testing on the first flat, pleated-filter unit by the National Transportation Research Center shows the particulate removal efficiency. Photographs of a complete microwave filter system, mounted on a 7.3-liter diesel vehicle, will be discussed.

This system is being prepared for a 7,000-mile controlled track test to demonstrate system durability using periodic chassis dynamometer FTP emissions testing. The filter will be microwave cleaned at a variety of engine operating conditions from idle to full load.

“RYPOS TRAP” ACTIVE DIESEL PARTICULATE FILTER SYSTEM: FIELD DEMONSTRATIONS

Frank DePetrillo, Zachary Nardi, Amin Saeid, and Kevin Lubinsky
Rypos, Inc.

Rypos Trap is an actively regenerated diesel particulate filter that has high efficiency and very low electrical power consumption for regeneration. The regeneration is independent of engine exhaust temperature and fuel sulfur content. The filter material is made of sintered metal fibers and has high porosity, high soot-holding capacity, and low thermal mass. The filter material is capable of capturing 85-95 percent of the soot in diesel exhaust.

The operation of the Rypos Trap is controlled by a microprocessor that allows it to function automatically during normal engine operation. Periodically, as required, an electric current is passed through a filter element, which then acts as a heating element.

The Rypos Trap is currently undergoing field demonstrations in several locations in California. In conjunction with Cummins and the Naval Facilities Engineering Service Center, Rypos Traps are used to remediate exhaust from aircraft ground power units. Additional demonstrations have been supported by a grant from the Innovative Clean Air Technologies (ICAT) program of the California Air Resources Board.

These field demonstrations had shown that the Rypos Trap is capable of keeping back-pressure under control while operating with very high efficiency.

INVESTIGATION OF DIESEL SOOT OXIDATION PROCESS AND CATALYSTS DEGRADATION

Alex Yezerets and Neal Currier
Cummins, Inc.

Flow-reactor tools have been successfully employed by Cummins in recent years to study the performance and degradation of aftertreatment devices under well-controlled conditions. In particular, a micro-reactor system has been used to investigate reactivity of diesel soot samples collected from different engines and duty cycles under different simulated exhaust conditions. It was found that the properties and origin of the soot substantially affect its ability to be oxidized.

The discussion will include information obtained using kinetic analysis about the behavior of soot at different temperatures. Also, the reaction systems were used to obtain information about catalysts' degradation using probe reactions. The developed methodology allows us to measure the degradation and, in some cases, determine its cause.

THERMOLYSIS CHARACTERIZATION OF UREA-SELECTIVE CATALYTIC REDUCTION

Howard L. Fang and Herbert M. DaCosta
Cummins, Inc.

Although urea-selective catalytic reduction (SCR) is one leading contender for NO_x control in engine emissions, surface passivation caused by deposit formation and non-stoichiometric balance of urea consumption are critical detriments to catalyst performance. The deposit formation deactivates catalytic performance by not only consuming part of the ammonia produced during urea decomposition but also by degrading the structural and thermal properties of the catalyst surface.

We have characterized urea thermolysis with and without urea-SCR catalyst using both spectroscopic (DRIFTS and Raman) and thermal analysis (TGA and DSC) to identify the deposit components and their corresponding thermal properties. The thermolysis of urea exhibits two stages, involving ammonia generation and consumption, respectively. The second stage involves the formation of melamine complexes, $(HNC=NH)_x(HNCO)_y$, which hinders catalytic performance. The presence of catalyst and a good spray of urea solution help to eliminate the second stage. The concept using additive in urea solution to rejuvenate the catalytic surface will be discussed.

ACTIVE SOOT FILTER REGENERATION

Bruce Bunting, Arvind Suresh, and John Chi
Cummins, Inc.

Passive soot filters can only be successfully applied to part of needed applications due to the need for elevated exhaust temperature to trigger soot regeneration. Some form of active regeneration assist is needed to make a soot filter robust under all duty cycles. This regeneration assistance can take the form of additional heat, active engine management, or increasing the reactivity of the soot or the catalyst. This presentation will discuss the requirements of an active regeneration system and presents results indicating the performance of such a system.

A SYSTEMATIC INVESTIGATION OF PARAMETERS AFFECTING DIESEL NO_x ADSORBER CATALYST PERFORMANCE

Danan Dou, Thomas R. Pauly, Ken Price, and Laurie Salyers
Delphi Corporation

NO_x adsorber catalysts, also called lean NO_x traps (LNT), have proven to be successful in meeting Japanese LEV and European Level IV emission standards for light-duty passenger cars powered by gasoline direct- injection engines. Much interest has been generated in the last several years regarding the use of NO_x adsorber catalysts for both light-duty and heavy-duty diesel engines. However, before successful application of this catalyst technology, it is essential to understand the parameters relevant to these diesel exhaust conditions and their implications for the performance of NO_x adsorber catalysts.

In the current study, we systematically investigated the parameters that could influence the conversion efficiency of NO_x adsorber catalysts. Results showing the effect of catalyst technology, PGM loading, substrate, temperature, flow rate, and exhaust composition will be reported. Results regarding sulfur poisoning and desulfations of NO_x adsorber catalysts will also be presented.

PERFORMANCE OF JOHNSON MATTHEY EGRT ä EMISSION CONTROL SYSTEM FOR NO_X AND PM EMISSION REDUCTION IN RETROFIT APPLICATIONS

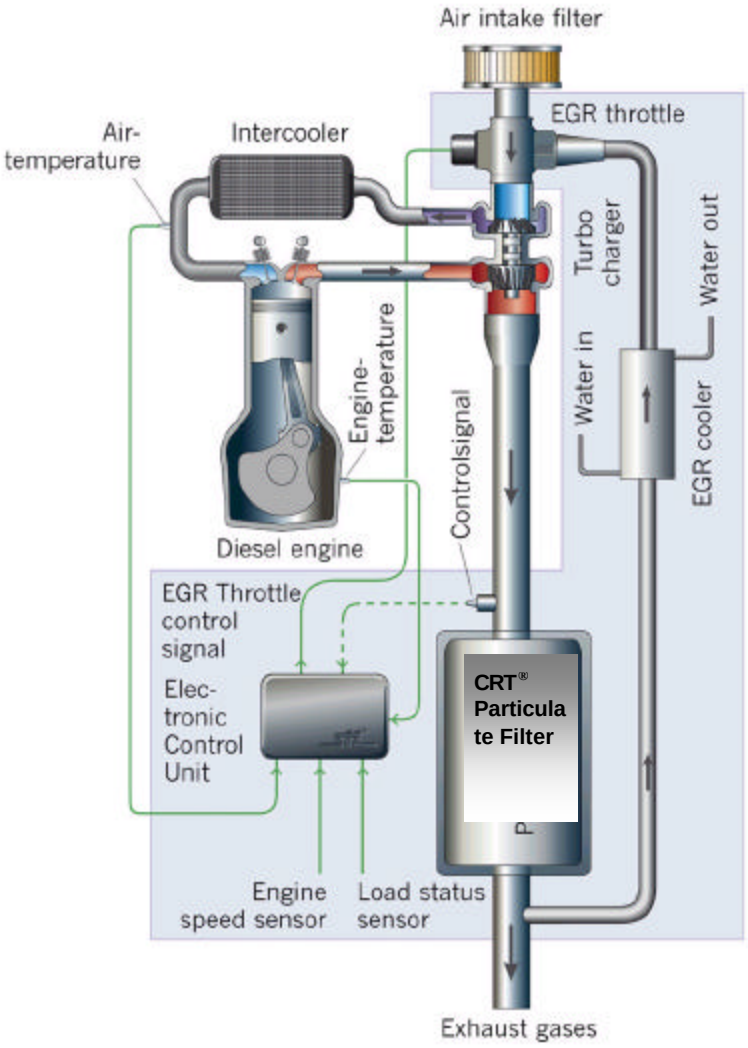
S. Chatterjee, R. Conway, and S. Viswanathan
Johnson Matthey

With growing concerns about NO_x and particulate matter (PM) emissions from diesel engines, stricter emission regulations are being implemented which require advanced emission control technology. In that regard, Johnson Matthey has combined the Continuously Regenerating Technology (CRT®) diesel particulate filter system with a low-pressure exhaust gas recirculation (EGR) system to provide four-way emission control of NO_x, PM, CO, and HC from existing heavy-duty diesel engines. This is known as the EGRT™ system.

The CRT filter is a highly effective technology for diesel PM reduction. The CRT system provides a unique and successful solution to the filter regeneration issue by using NO_2 to combust engine soot under the diesel engine operating temperature without any external heating. The overall system consists of a platinum metal-based oxidation catalyst upstream of the particulate filter. The catalyst oxidizes a portion of the exhaust NO_x into NO_2, which carries out continuous combustion of accumulated soot trapped by the filter, at temperatures above 250^{o}C. In addition, the system also eliminates most of (greater than 90 percent) the CO and HC in the diesel exhaust.

The EGR system used is a low-pressure system which recirculates a portion of the clean exhaust gas from downstream of the CRT filter into the engine intake through an EGR throttle valve. The recirculated exhaust is cooled using an EGR cooler. The EGR flow is controlled by the EGR throttle valve, based on signals from an EGR throttle control unit. The EGR flow is designed based on the engine speed and load conditions as well as exhaust parameters which allow the CRT filter system to operate effectively. The flow is also optimized for NO_x emission reduction.

The EGRT™ system has been used in Europe over the past 4 years, with over 1200 systems installed on urban buses and other on-road applications. This system has shown 40-60 percent NO_x reduction in addition to greater than 90 percent CO, HC, and PM reductions. Recently, several field trial programs have been initiated to evaluate the performance and durability of the EGRT™ system under U.S. operational conditions. These include retrofit applications on urban buses and on a construction truck. FTP tests on an engine dynamometer have demonstrated 48-58 percent NO_x reductions with these systems while chassis dynamometer tests have indicated 50-60 percent NO_x reductions. Simultaneously, the CRT filter has shown greater than 90 percent CO, HC, and PM reductions in these tests. Emissions and on-road performance data of EGRT™-equipped vehicles from these programs will be presented in this paper.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