Abstracts

Laboratory Capabilities

WORKING WITH THE U.S. DEPARTMENT OF ENERGY NATIONAL LABORATORIES

The U.S. Department of Energy (DOE) national laboratories have many types of contractual research and development (R&D) agreements to meet the needs and interests of industry. The following are brief descriptions of the types of agreements most commonly used. For more information on working with a specific laboratory, please call the individual contacts below.

COST-SHARED R&D

Cost-shared R&D is usually conducted under a cooperative research and development agreement (CRADA). Both the partnering organization and the laboratory contribute to the costs of the R&D and share the results. The industry partner may obtain exclusive rights (in a field of use) to inventions created by the laboratory. The results of the CRADA work can be protected from disclosure for a period of up to 5 years after completion of the work.

REIMBURSABLE R&D

"Work for Others" (WFO) is R&D, or technical services, where costs are paid entirely by the sponsoring organization or company, and the work is conducted by the laboratory. Under certain conditions, the company may take title to inventions created by the laboratory under the WFO. Research results are considered proprietary if so designated by the company.

LICENSING

Opportunities to acquire rights in laboratory inventions and copyrights are available. Licenses may be nonexclusive, depending on the nature of the intellectual property and the business fields to be actively pursued by the licensee.

PERSONNEL EXCHANGES

Industry researchers can work at a laboratory site, or vice versa, on research of mutual interest. Each party pays for the cost of its own employees. Appointments range from 3 months to 1 year.

TECHNICAL ASSISTANCE

Laboratory researchers provide short-term technical assistance to companies with technical problems requiring expertise that is not available commercially. Funding arrangements vary.

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LAB CAPABILITY MATRIX

Technology Area	**ANL**	**INEEL**	**LLNL**	**NREL**	**ORNL**	**PNNL**	**Sandia**
Fuels and Lubricants							
Advanced Petroleum-Based Fuels	X	X	X	X	X		X
Alternative Fuels	X	X	X	X	X	X	X
Lubricants (synthetic and petroleum-based)	X			X			
Reduced friction	X		X		X		
Vehicle Systems							
Aerodynamics			X			X	X
Rolling resistance		X	X		X		
Auxiliary systems			X			X	
Heavy hybrids	X	X	X	X	X		
Friction and wear	X				X		
Thermal management	X				X	X	X
Systems modeling and analysis	X	X	X	X	X	X	X
Engines							
Combustion and emissions control modeling	X		X		X	X	X
Light-truck engines	X	X	X		X	X	X
Heavy-truck engines	X	X			X	X	X
Waste heat utilization	X					X	
Lightweight moving parts		X			X	X	
Lightweight engine blocks	X	X			X	X	
Emissions reduction technology	X		X	X	X	X	X
Materials							
High-strength weight reduction	X	X	X		X	X	X
Coatings	X		X		X	X	X
Propulsion system materials		X			X	X	X
Environment and Health							
Emissions Testing	X	X		X	X	X	
Environmental and health impacts	X	X	X			X	
Truck Safety							
Brakes		X			X	X	
Fuel Storage	X	X		X	X	X	
Crash-energy management	X		X		X	X	
Ergonomics		X			X		

ARGONNE NATIONAL LABORATORY

Argonne National Laboratory, one of the U.S. Government's largest research and development laboratories, is committed to research and development leading to high-quality, cost-effective products that meet the Nation's goals for improving energy efficiency and reducing emissions, as well as the transportation industry's goal of manufacturing affordable advanced-technology vehicles.

Argonne's location, in the heart of the Nation's automotive, truck, and engine (gasoline and diesel) manufacturing industry, facilitates frequent, personal, and cost-effective interaction between Argonne researchers and industry representatives. Argonne is easily reached from Chicago's two major airports, O'Hare and Midway.

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CAPABILITIES

Engine Research

Argonne's engine research facilities, skilled staff with extensive industry engine manufacturing experience, and associated engine/vehicle modeling expertise are combined to conduct a wide range of engine experiments and to develop new technologies to improve engine performance, increase fuel economy, and reduce emissions. Argonne has developed novel approaches:

- to improve fuel economy and power density
- to reduce exhaust emissions
  - particulates and smoke in diesel engines
  - carbon monoxide, hydrocarbons, air toxics, and aldehydes in gasoline engines
  - two new patents for nitrogen oxide control (in-cylinder and aftertreatment)
- to use low-grade and non-petroleum fuels

Sensors

Scientists at Argonne are researching an array of rugged, low-cost sensors that record vehicle information instantaneously, so that engine and drivetrain components can be activated or adjusted in response. The result will be constant, seamless adaptation of system components to each other as the vehicle travels, delivering better mileage and fewer emissions.

Argonne-developed near-frictionless carbon coating is produced in a high-vacuum chamber.

Friction and Wear/Lubricants

Argonne is developing advanced friction, wear, and lubrication tech-nologies to improve the reliability and durability of critical engine components deleteriously impacted by low-emission fuels and lubricants and exhaust gas recirculation strategies required to improve engine emissions.

Thermal Management

Argonne researchers are working on improved thermal-management systems that include compact heat exchangers, innovative heat-transfer schemes, and environmentally friendly "nanofluids" with improved heat-transfer properties.

Supercomputing Applications

As a member of the U.S. Car Council on Automotive Research Supercomputer Automotive Applications Partnership (SCAAP), Argonne is helping to bring advanced modeling and massively parallel supercomputing to automotive design engineers. SCAAP's efforts have focused on the development of computer codes that enable massively parallel superconducting to be used in vehicle design: one code "crash-tests" composite frame components without damaging real cars, the other models airflow inside the vehicle passenger compartment. Recent work has included development of new models to calculate and predict underhood thermal management conditions in both conventional and hybrid vehicles.

Technology Assessment

Argonne has developed comprehensive analysis techniques that provide definitive projections of the effects of using advanced transportation technologies and of the Government policies that may stimulate their development and use. Staff members combine expertise in civil and mechanical engineering, economics, environmental science, and transportation planning to perform large-scale, comprehensive assessments of the interactions among engineering, economics, and the environment.

Nondestructive Characterization of Materials

As part of U.S. Department of Energy's (DOE) Office of FreedomCAR and Vehicle Technologies research, Argonne scientists are developing methods for nondestructive characterization of materials in cooperation with two major engine manufactures. Argonne is working on valve trains, insulating materials, and the fuel delivery system.

UNIQUE FACILITIES/EQUIPMENT/CAPABILITIES

Novel Approaches to Emissions Control

In 1999 Argonne's method for controlling diesel and gasoline emissions by selectively modifying intake air received an R&D 100 Award. The technique used a "chemical filter" membrane that separates air into oxygen- and nitrogen-rich streams for use in the engine. Engines using this technology have the potential to meet the U.S. Environmental Projection Agency's NO_x and particulate emissions standards for locomotives, trucks, and cars for the year 2004.

Evaluating Hybrid Vehicles

Argonne's hybrid electric vehicle (HEV) systems activities include modeling using the Powertrain Systems Analysis Toolkit (PSAT), prototyping (PSAT-PRO), and testing at the Advanced Powertrain Test Facility. PSAT modeling simulates over 100 drivetrain configurations; fuel consumption and exhaust emissions for 15 different cycles; performance; and powertrain transient phases. Argonne's hybrid testing experience includes over 100 HEV's (comprising about 70 different hybrid configurations) in DOE-sponsored competitions, extensive Toyota Prius and Honda Insight testing, and the development of HEV procedures and instrumentation.

Advanced Powertrain Research Facility

State-of-the-art equipment in this integrated facility allows the study of HEV powertrain performance, efficiency, and emissions – without installing components in a vehicle. The flexible facility can also be used to test and develop direct-drive, or stand-alone, engine technologies. Integrated exhaust emissions testing equipment allows testing of both spark-ignition and compression-ignition engines using both conventional and alternative fuels.

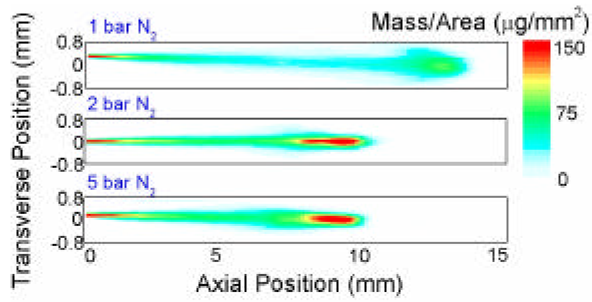
Advanced Powertrain Research Facility

A unique four-wheel chassis dynamometer with top-grade emissions measurement instruments is now operational. This facility is "hydrogen-fuel capable" and can measure emissions from super ultra-low emissions vehicles (SULEV).

Engine Research Facility

At Argonne's Engine Research Facility, researchers are investigating engines ranging in size from automotive through locomotive. This unique world-class facility enables researchers to study high-pressure fuel-injection systems, in-cylinder and aftertreatment of exhaust emissions, and methods to improve power and fuel economy.

Advanced Photon Source



X-ray measurements of Diesel Fuel Sprays

The world's brightest x-ray source, Argonne's Advanced Photon Source (APS), is a unique user facility that is being used to explore the dense core of the fuel spray in the near-nozzle regime where lasers cannot penetrate. Better understanding and control of the fuel spray structure and atomization process are essential for improving engine performance and emissions levels. Argonne researchers, working with the fuel-injector manufacturers, have reported the first quantitative data ever on droplet velocity, local air/fuel ratio, and mass flux from optically dense areas. Argonne researchers were the first to discover the existence of shock waves in diesel fuel sprays. The APS is also being used to probe the chemical bonding and microstructure of near-surface regions of interacting surfaces to understand how lubricant additives behave under high stresses.

Near-Frictionless Carbon Coatings

Ultra-low friction, combined with other unusual mechanical and chemical properties, makes Argonne's near-frictionless carbon (NFC) coatings ideal for many transportation applications. Argonne researchers have determined that NFC aids emissions reduction in compression ignition direct inject engines operating under severe conditions. Investigations are now under way to determine the performance of NFC coatings with engine lubricant additives. NFC coatings should allow oil formulations with low levels of sulfur, phosphorous, and other metallic compounds that poison aftertreatment devices.

Fuel Cell Test Facility

The Fuel Cell Test Facility at Argonne National Laboratory provides an independent resource for testing and evaluating fuel cell stacks and systems up to 50 kW. Through standardized tests and test conditions, Argonne provides its sponsors with comparative data on the performance, operational characteristics, and durability of fuel cells. The test results also help developers and sponsors evaluate technical progress.

Battery Analysis and Diagnostic Laboratory

Argonne's battery laboratory has evaluated more than 4,000 cells and batteries since 1976. It tests 4-Wh cells to 50-kWh batteries and provide versatile test capabilities, which include 120 independent test stations, ability to simulate any driving profile, -75ºC to +200ºC chambers, and up to 500 volts+/-500 amperes. The laboratory has evaluated batteries for DOE, the U.S. Advanced Battery Consortium, and battery developers and users. Advanced cell and battery technologies for both electric vehicle and HEV applications have been tested. A unique four-wheel chassis dynamometer with top-grade emissions measurement instruments is now operational. This facility is "hydrogen-fuel capable" and can measure SULEV emissions.

Rapid Tooling

Argonne researchers are refining a system for rapid tooling of very hard ceramic materials that provides direct, near-net-shape of tools using solid free-form fabrication. The system will help companies inexpensively reduce the time required to go from design to finished part. Specifications can be adjusted and retested before the design is cast into a costly die.

PATENTS AND AWARDS

For its transportation-related research, Argonne National Laboratory has over 200 patents, 11 R&D 100 Awards, 2 Discover Awards, 4 FLC Awards, 2 PNGV Awards, and 2 DOE Awards.

RECENT AND ONGOING EFFORTS

Argonne has forged successful working partnerships with major engine and vehicle manufacturers, as well as with universities recognized for their engine research. These include:

DaimlerChrysler
General Motors Corp.
Ford Motor Company
adapco, Inc.
Caterpillar
Cummins
Delphi
Diesel Technology Company
DuPont
Electro-Motive Division of General Motors
Outboard Marine Corp.
Robert Bosch Corporation
Spawr Industries, Inc.
3M
United Catalysts Corporation
U.S. Advanced Battery Consortium

FOR FURTHER INFORMATION

Visit the Argonne National Laboratory Transportation Technology R&D Center's web site at http://www.transportation.anl.gov.

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CAPABILITIES

Fuels and Lubricants

Alternative Fuels **-** The focus of the Idaho National Engineering and Environmental Laboratory's (INEEL) Alternative Fuels Program is on liquefied natural gas (LNG) and compressed natural gas (CNG) as alternatives to conventional gasoline and diesel fuel for powering heavy and light vehicles within the INEEL fleet. The program continues to convert transit buses, cars, pickup trucks, and vans in the INEEL fleet for operation on LNG or CNG. In addition, the onboard storage capacity of 48 bifuel CNG vehicles is being increased by the addition of second CNG tanks and the use of larger CNG tanks at higher storage and fueling pressures. However, the few replacement vehicles (0.5 percent of the total fleet) being added to the fleet are all ethanol vehicles.

Research is being performed to develop new technologies that strengthen LNG and CNG infrastructures. Projects include a small-scale liquefaction plant, a low-cost refueling station, a cold-tank pressurizing device, and a nozzle standardization effort.

Development is underway at INEEL on processes that produce hydrogen from nuclear, methane, water, biomass, and other abundant sources. INEEL is pursuing development and commercialization of technologies related to production, infrastructure, utilization, and storage of hydrogen and hydrogen/CNG-blended fuels.

INEEL has embarked on a major new lab-wide initiative to support the development and implementation of bioenergy to support the Nation's bioenergy initiative. The focus of the INEEL bioenergy initiative will be "whole crop utilization." Crop residues represent a very significant potential fuel source that is currently greatly underutilized. INEEL brings world-class capabilities in biotechnology, sensors and controls, simulation and modeling, and separations. The laboratory has a long successful history of working collaboratively with industry.

Vehicle Systems

Vehicles - INEEL has over 1,600 vehicles in its fleet. Its trained technicians and mechanics are certified not only to do a variety of specialized tasks but also to do warrantee work on most vehicles. In the heavy-truck category, 150 are truck-type vehicles and 99 are motor coach buses. INEEL is currently using 110 CNG and 50 LNG vehicles (including 7 transit buses) as well as methane, biodiesel, diesel, electric, ethanol, and propane vehicles. (The 7 LNG-equipped transit buses emit 50-percent less nitrous oxide and 98-percent fewer particulates than diesel engines.)

Robotics - The INEEL Robotics and Intelligent Machines department has developed advanced control architectures that support the optimum operation of field equipment. These control architectures range from total autonomous operation of the vehicle with optimal path and decisionmaking capabilities to operator-assisted control, which allows the operator to perform the primary task while the computer monitors and controls secondary tasks. These control architectures have been deployed on actual commercial equipment provided by a heavy-equipment vendor and utilized in field operations. They have demonstrated increased operational capabilities and reduced operator fatigue and training.

Systems Modeling - INEEL is also tasked to develop, extend, refine, and utilize computer models and databases to assist in the assessment of advanced powertrain and battery system concepts and in the interpretation of test data reported to the automobile community. This activity also evaluates and lends meaning to data collected in laboratory and field tests. Dynamometer and battery test data are routinely compared with a simulation model to validate the simulation and to better understand laboratory test results.

Materials

Rapid Tooling and Joining Technology - Nearly all mass-produced items require hollow casts or dies for their formation. Compared to conventional fabrication methods, INEEL-developed rapid-solidification process tooling reduces cost and turn-around time for production of precision tooling by a factor of 5-10. The process involves spraying layers of molten metal onto a three-dimensional pattern and building up the layers into a full-size die. INEEL expertise in joining, casting, and coating technologies encompasses many general areas, including: equipment and processes, automation and mechanization, feedstock materials, manufacturing and processing methods, materials characterization and evaluation, testing and characterization, quality assurance, nondestructive evaluation, applications, and refurbishment.

Environment and Health

Emissions - INEEL has the capability to conduct combustion engine exhaust analysis in accordance with the U.S. Federal Test Procedure. INEEL's exhaust-gas analysis capabilities include the ability to monitor, in real time, up to 25 gaseous species in raw or diluted exhaust via state-of-the-art Fourier Transform Infrared (FTIR) spectroscopy. In addition to the ability to conduct real-time analysis of exhaust emissions provided by the FTIR, the laboratory has acquired an AVL North America, Inc., Constant Volume Sampling bag system. The composition of gases in the bag can then be analyzed using a variety of analytical techniques, including FTIR. A fully equipped analytical laboratory capable of complete gas and particulate analysis for toxic components that impact health and safety supports the emissions capability.

Truck Safety

Human Factors - The Human Factors Engineering discipline at INEEL is the largest among the U.S. Department of Energy (DOE) laboratories and is broadly recognized outside DOE. The core competency in human-machine interaction (including safety, instructional design, and human reliability) is supported through the Center for Human-System Simulation and a cadre of professionals. This center provides enabling knowledge and technologies to support effective designs for current and future systems. INEEL knowledge of the psychology and biology of humans and organizations is leveraged to produce designs that are more efficient and significantly safer than existing systems. A core competency in human reliability has been long established at INEEL, and INEEL is recognized as a world leader in the area.

UNIQUE FACILITIES AND EQUIPMENT

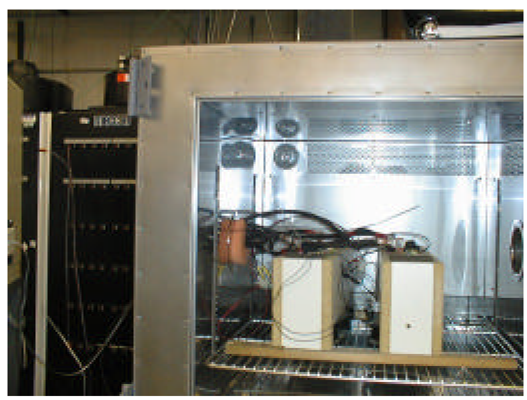
Transportation Center

The INEEL Transportation Center is large enough and suffi-ciently to handle almost any heavy vehicle integration, demonstration, or verification project. The Transpor-tation Center bays are specially designed to handle difficult fuel, engine, battery, or fuel-cell issues with sever-al air exchanges per hour and the necessary lifts and hoists to accom-modate all equipment needs. The center is equipped with a 500-hp engine dynamometer that can sim-ulate driving cycles and is equipped with state-of-the-art emission (inclu-ding particulate) characterization equipment.

Transportation Center capabilities exist to support complex engine or vehicle modifications and conversions, vehicle instrumentation and testing, complex data analysis, cooling and exhaust system modeling/testing, and large systems engineering/integration programs. The Center is supported by well-equipped analytical and research laboratories staffed by scientists and engineers from most technical disciplines. INEEL also possesses considerable economic analysis expertise that is capable of evaluating energy and life-cycle costs on components, vehicles, and transportation systems.

Energy Storage Technologies Laboratory

The Energy Storage Technologies Laboratory at INEEL is the world leader in the testing of advanced battery technologies and ultracapacitors. It is the only national laboratory to document measurement uncertainty procedures for data quality, and it has pioneered the development of analysis procedures for battery scaling, thermal management, capacity fade, and power fade. The Energy Storage Technologies Laboratory offers controlled testing on batteries, fuel cells, ultra-capacitors, and mechanical flywheels under conditions typical of electric and hybrid vehicle applications. Tests can be performed on small storage components as well as large multi-component heavy-vehicle storage systems. The Energy Storage Technologies Laboratory is the lead DOE facility for hybrid vehicle battery performance and life-characterization studies.



RECENT AND ONGOING EFFORTS

Diesel Truck Idle Reduction Demonstration Project

The INEEL is conducting a heavy-truck idle-reduction demonstration project to support the reduction of the 800+ million gallons of diesel fuel annually used during idling periods, such as when loading and unloading loads or when the drivers rest. The project activities include assessing regional and national driver/truck idling needs and practices. Various idling technology options for heating, air-conditioning, and auxiliary loads are being demonstrated with the objective of matching driver and mission needs and technology capabilities. The activities include several fleet and component demonstrations, a data-collection effort, and the analysis and dissemination of the demonstration results.

Oil Bypass Filter Technology Evaluation

The objective of the oil bypass filter evaluation is to demonstrate and quantify engine-oil use reductions possible from oil-bypass filtration systems. Oil-bypass filter systems are currently installed on eight INEEL motor coach diesel buses. The eight buses have accumulated 200,000 evaluation test miles. Additional systems are being installed on six Chevrolet Tahoes. The oil is regularly sampled for 26 additives and contaminants. The evaluation project will include an economic benefits analysis for each vehicle and for the INEEL fleet as a whole. If the demonstration is successful, the analysis will be expanded to identify DOE complex-wide economic and oil reduction benefits.

Advanced Vehicle Testing Activity

The Advanced Vehicle Testing Activity (AVTA) is a DOE activity managed by INEEL that tests advanced technology vehicles and the infrastructure necessary to support the vehicles. In conjunction with private sector testing partners, Electric Transportation Applications and Arizona Public Service, the testing has included the construction and operations of a hydrogen production and fueling pilot plant. The hydrogen, which is produced by operating a PEM fuel cell in reverse, supports the testing of 20 internal combustion engine vehicles operating on 100-percent hydrogen and blends of hydrogen and CNG fuels. The hydrogen vehicles have accumulated 200,000 test miles while operating on hydrogen and hydrogen/CNG-blended fuels. The AVTA is currently testing 16 hybrid electric vehicles; 750,000 miles of maintenance, operations, and fuel economy data have been accumulated on the hybrid-electric vehicles. An additional 400 neighborhood and urban-electric vehicles are also in testing.

INEEL continues to work with heavy-duty diesel engine manufacturer Detroit Diesel to explore concepts of LNG application in the INEEL bus fleet. A cooperative research and development agreement (CRADA) signed with Detroit Diesel in 1995 remains active today. This CRADA has resulted in the conversion of seven diesel buses to LNG and has aided this industry partner in commercializing natural gas technology. INEEL has also performed a 750-hour heavy-duty engine durability test and provided engineering and technical support for Westport Innovations, a Canadian engineering company.

FOR FURTHER INFORMATION

http://www.inel.gov
http://energy.inel.gov/eenr/default.shtml
http://avt.inel.gov

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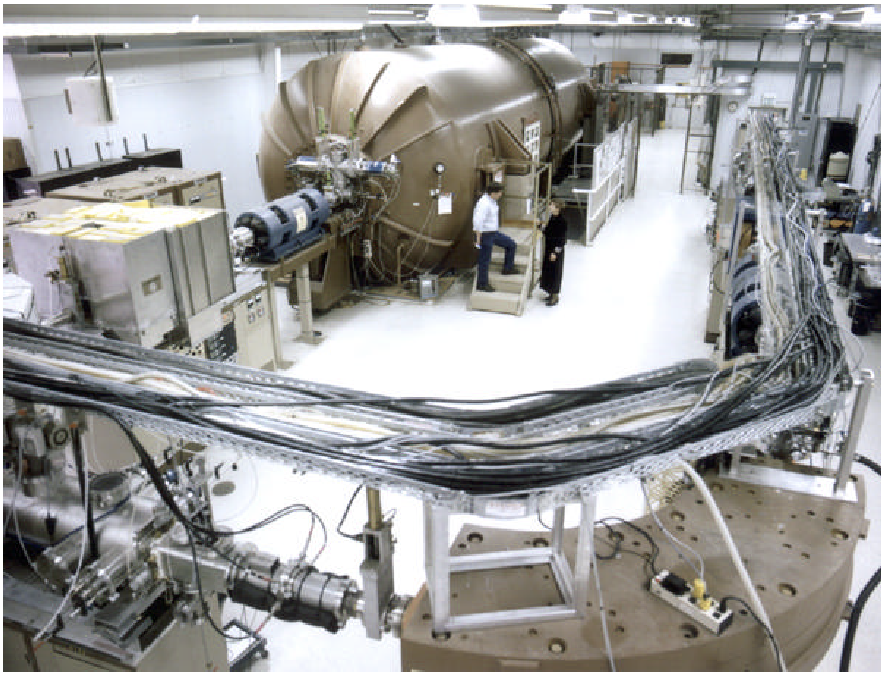
CAPABILITIES

Fuels and Lubricants

***Chemical Kinetics* --** The kinetic modeling effort at Lawrence Livermore National Laboratory (LLNL) is a world-class capability focused on developing detailed chemistry mechanisms for fuel decomposition, ignition, and combustion under homogeneous charge compression ignition (HCCI) and diesel engine conditions for various fuel types, including gasoline, diesel, and alternative fuels. This effort also consists of the development of appropriate fuel surrogates for real distillate fuels that are computationally tractable. Understanding the detailed kinetics is central to predicting compression ignition combustion and the selection of appropriate fuels. Once developed, the kinetic mechanisms are made available to industry and other researchers for application in a variety of engine-simulation models. westbrook1@llnl.gov

Isotopic Tracing of Fuel Components in Engine Emissions Using Accelerator Mass Spectrometry (AMS) -- LLNL is the site of the Center for Accelerated Mass Spectrometry (CAMS). This is the most versatile, precise, and productive AMS facility in the world. We are applying this facility as a unique diagnostic tool for conducting detailed analysis of engine combustion. CAMS allow us to determine exact concentrations of carbon isotopes (^{12}C and ^{14}C) in a gas stream or in solid particles. This capability makes it possible to conduct engine diagnostic experiments that were never before possible. A recent example is determining what fraction of particulate matter (PM) engine emissions originates in the fuel or in the lubricant. This is done by running an engine with a fuel with contemporary concentration of ^{14}C (a renewable fuel) and with a fossil-based lubricant (which contains no ^{14}C isotopes). Under these conditions, any ^{14}C in the PM is known to originate in the fuel, allowing an accurate calculation of the origin of PM emissions. Other applications include detailed validation of chemical kinetic mechanisms and evaluation of oxygenated fuels for diesel engines. bbuchholz@llnl.gov



CAMS facility at LLNL

Fuel and Additive Risk Assessment **--** The Consortium for Fuels Assessment (CFA) is a systems-based framework to prepare scientifically sound assessments of the potential health and environmental impacts of fuel compounds necessary to meet future emissions standards. We use a combination of analytical and experimental techniques to determine the environmental impact of additives used for fuels, lubricants, or aftertreatment systems. The goal is to detect and avoid future MTBE-like problems before they happen.

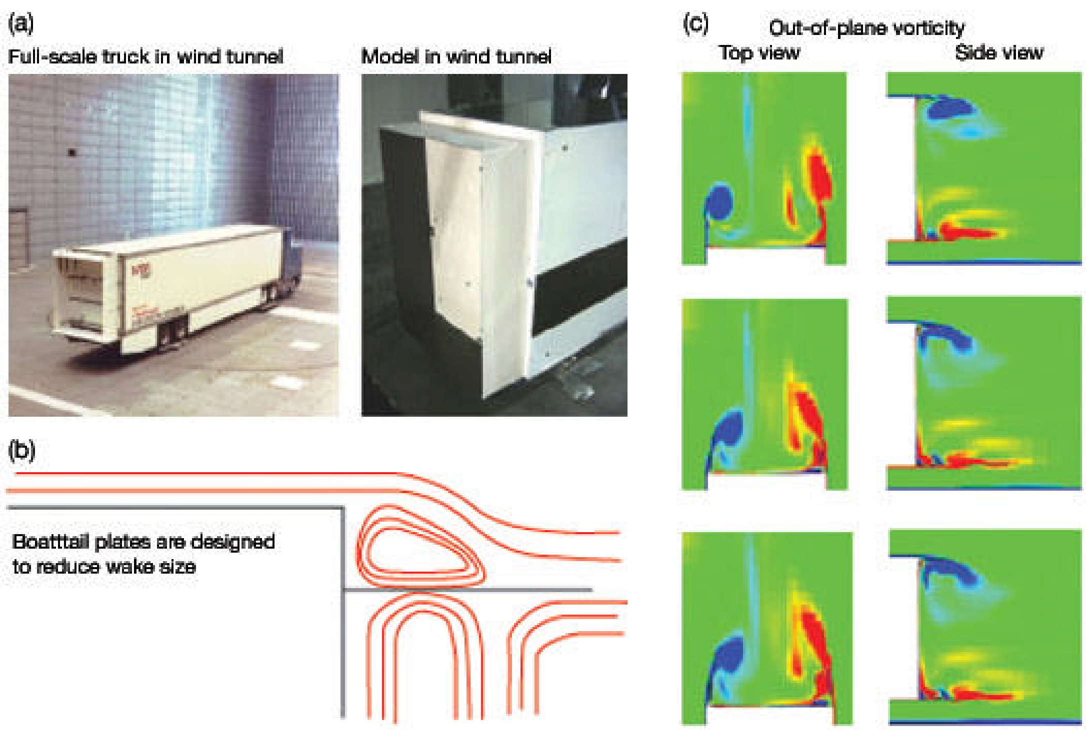
The CFA has completed a major assessment for the California Environmental Protection Agency on the consequences of using ethanol as a gasoline oxygenate. We also conducted an analysis of the environmental chemistry of alkylates, which are high-octane components in gasoline. Future plans focus on selection and analysis of optimum fuels for new combustion regimes (HCCI, smokeless rich combustion, modulated kinetics [MK], etc.). layton1@llnl.gov

Vehicle Systems

Vehicle Aerodynamics **--** LLNL is leading a consortium effort with representatives from U.S. Department of Energy (DOE) national laboratories, the National Aeronautics and Space Administration (NASA), and universities to reduce fuel consumption on heavy vehicles by reducing the aerodynamic drag. Today, a heavy vehicle (Class-8 truck) traveling at 70 miles per hour requires 65 percent of its engine output to overcome the aerodynamic drag. It is conceivable that present-day truck drag coefficients can be reduced by as much as 50 percent. The drag reduction can be achieved through altering the truck shape, integrating the tractor and the trailer, and add-on devices. DOE encourages industry participation and involvement in the consortium from both tractor and trailer manufacturers and fleet operators.

The goal of this effort is to develop and demonstrate the ability to simulate and analyze aerodynamic flow around heavy vehicles using existing and advanced computational fluid dynamics (CFD) tools. Activities include an extensive experimental effort and the development and demonstration of new concepts and technologies for aerodynamic drag-reducing devices. The final products are an experimental database, validated CFD methods, and add-on devices to reduce aerodynamic drag of heavy vehicles and thus improve their fuel efficiency and reduce emissions.

Experiments on models of generic and integrated tractor-trailers are underway at NASA Ames Research Center in Moffett Field, California; the University of Southern California (USC) in Los Angeles, California; and Georgia Tech Research Institute (GTRI), in Atlanta, Georgia. Companion computer simulations are being performed by LLNL in Livermore, California; Sandia National Laboratories (SNL) in Albuquerque, New Mexico; California Institute of Technology (Caltech) in Pasadena, California; and Argonne National Laboratory (ANL), in Argonne, Illinois. USC, LLNL, and GTRI are developing devices for reducing aerodynamic base drag. salari1@llnl.gov



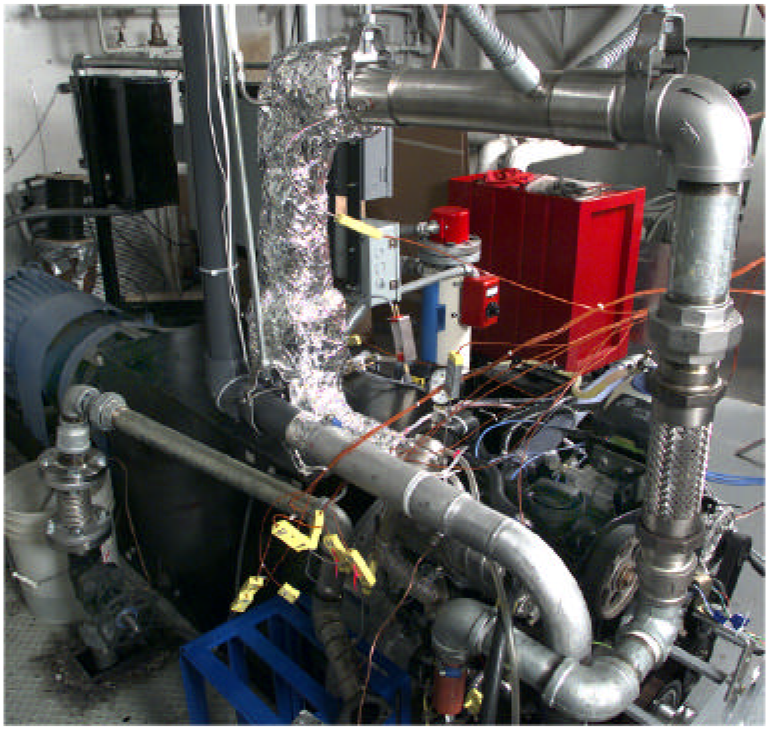
Aerodynamic drag experiments and analysis

Auxiliary Systems

Sensors -- Increasingly stringent emissions regulations will require automobile manufacturers to reduce exhaust gas pollutants in the near future. Compact, inexpensive, on-board diagnostic sensors will be needed for monitoring and control of regulated pollutants including oxides of nitrogen (NO_x), hydrocarbons, and carbon monoxide. Because the need for these sensors is fairly recent, very few sensors of any kind are available. The principal challenges associated with development are sensitivity, response time, and sensor stability. LLNL currently has an experimental effort to develop electrochemical gas sensors for various automotive applications. This effort approaches the problem of sensor performance by the application of novel materials and fabrication processes designed to optimize electrode microstructures. A NO_x sensor with fast response time and high sensitivity has been developed for monitoring compression ignition direct ignition (CIDI) exhaust. This sensor is currently entering the prototype phase. In addition, a rugged, low-cost, solid-state electrochemical sensor for monitoring non-methane hydrocarbons (Mac's) has been developed. That sensor was dynamometer tested in U.S. Council for Automotive Research partner laboratories and appears to be one of the most promising hydrocarbon sensors to undergo such preliminary testing. Similar technology for hydrogen sensors to be used as part of the safety system around hydrogen fuel cells is also being developed. martin89@llnl.gov

Engines and Combustion

HCCI -- HCCI is a new combustion methodology that yields the high efficiency of diesel engines without the high nitrogen oxide (NO_x) and particulate matter (PM) emissions. However, several hurdles stand in the way of successful HCCI engine commercialization. These include robust control of combustion timing, low power output, obtaining consistent combustion timing in different cylinders of a multi-cylinder engine, and engine start ability. We are addressing these challenges through a combination of analytical and experimental techniques. We have developed advanced analysis techniques that allow us to calculate all parameters of HCCI combustion with high accuracy, and we have applied these models to explain the fundamentals of HCCI combustion. We also have an experimental effort aimed at controlling ignition and balancing combustion between the cylinders of a multi-cylinder engine. saceves@llnl.gov



Experimental multi-cylinder HCCI engine, converted from a Volkswagen TDI diesel engine

***Analysis of New Combustion Regimes and Hydrogen Engines* --** Recent years have witnessed the emergence of new combustion regimes that are aimed at improving engine efficiency while reducing emissions. These include MK and smokeless rich combustion (also known as low-temperature combustion). In addition to this, the effort to advance the hydrogen economy has resulted in increased interest in hydrogen engines. We have expertise in chemical kinetics and fluid mechanics that allows us to successfully conduct detailed analysis of these operating regimes and fuels. We are working with industry and other national laboratories in an effort to develop a deep understanding of the processes that control combustion in these regimes. This understanding will facilitate commercialization of these new technologies. dflowers@llnl.gov

Emissions Reduction Technologies

***Fundamental Analysis of NO_x Traps* --** Diesel engines cannot meet future emissions standards without aftertreatment. Currently, aftertreatment systems are impractical because of cost, complexity, durability and efficiency penalty. NO_x traps are the preferred technology for NO_x aftertreatment in lean burn engines. However, very little is known about the fundamental chemical kinetics that dominate the process of NO_x adsorption and desorption on the catalyst surface. Greater scientific understanding of NO_x traps will facilitate breakthrough technological improvements.

We are using advanced analysis techniques (molecular dynamics and kinetic Monte Carlo) to evaluate the basic energetics of adsorption and desorption reactions of NO_x into catalyst substrates. These calculations will allow us to generate the basic chemical kinetics equations that then can be applied in a thermo-fluids model of the NO_x trap. The purpose is to develop analysis methodologies that industry can help to design efficient and durable NO_x traps. pitz1@llnl.gov

Materials

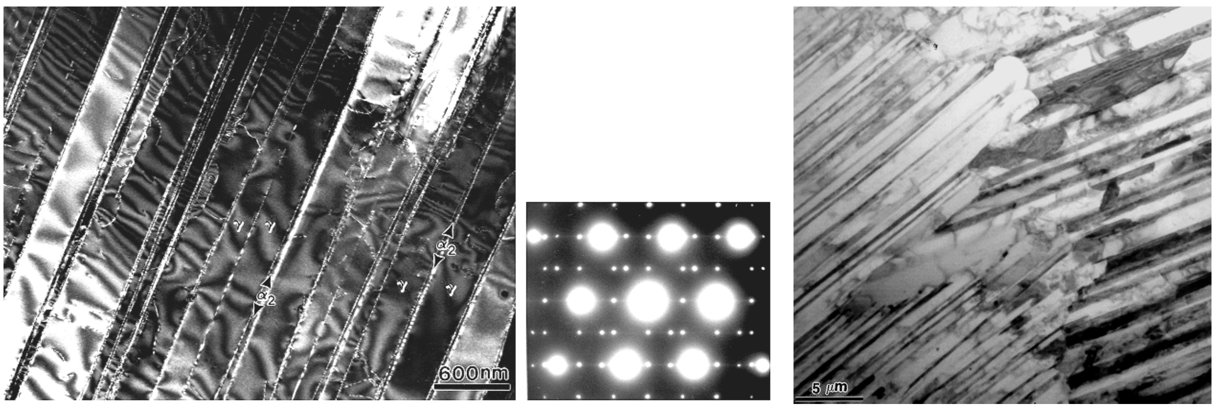
***Composite Materials* --** LLNL has developed analytical and numerical tools that efficiently predict the behavior of carbon-fiber composites in vehicular crashworthiness simulations. We have focused specifically on fabric and braided-fiber architectures molded with a polymeric matrix and consider loading conditions and strain rates that arise in vehicular impacts. **zywicz1@llnl.gov**, deteresa1@llnl.gov

***Magnesium Casting* --** Driven by the need to reduce our consumption of fuel, significant emphasis is placed upon lightening our automobiles. Magnesium offers the potential to provide lighter cars and still maintain the same if not improved structural integrity. LLNL has extensive nondestructive evaluation capabilities and experience that provide a unique resource to support development of new and improved metalcasting techniques. As part of the Structured Cast Magnesium Development cooperative research and development agreement, LLNL is conducting nondestructive evaluations to not only evaluate the structural integrity of magnesium automotive components but also to assist in the selection and optimization of casting parameters. **prindiville1@llnl.gov**

Development of Ultrafine Lamellar Titanium-Aluminum Alloys -- The objective of this effort is to design and fabricate ultrafine lamellar TiAl alloys for advanced diesel engine applications. The primary goals of this project is to exploit advanced thermomechanical processing techniques to fabricate lamellar TiAl alloys with the size of lamella width down to submicron and/or nanometer region. The purpose is to (1) experimentally verify microstructural stability and mechanical properties (room-temperature ductility and strength and elevated-temperature creep resistance) of the ultrafine lamellar alloys and (2) investigate the fundamental interrelationships among processing, microstructures, alloying additions, and mechanical properties of the ultrafine lamellar alloys so as to achieve the desired properties and performance of the alloys for high-temperature structural applications.

Two-phase [TiAl (g-$L1_0$) and Ti_3Al (a_2-DO19)] lamellar TiAl alloys have recently attracted great attention because of their low density (ρ = 3.9 g/cc), high specific strength, adequate oxidation resistance, and good combination of ambient-temperature and elevated-temperature mechanical properties. These characteristics are of interest for engineering applications, such as high-temperature components in diesel engines. Through alloy design and microstructural optimization, significant progress has been made to improve both room-temperature ductility/toughness and high-temperature creep resistance of the alloys.

The result of a preliminary effort has revealed that the alloys fabricated by hot extrusion at 1,400°C can form a refined lamellar microstructure, as shown in the figure below. The hot-extruded lamellar alloys provide a better combination of room-temperature and high-temperature mechanical properties than those of lamellar TiAl alloys fabricated by conventional ingot metallurgy. Accordingly, there is great interest in further refining lamellar spacing of the alloys to submicron- or nanometer- length scales to develop nano-lamellar TiAl alloys for engineering applications. hsiung1@llnl.gov



(a) (b)

(a) A dark-field TEM image showing a typical lamellar microstructure observed from $Ti_{47}Al_2Cr_2Nb$ extruded at 1,400 °C, and an SAD pattern generated from the domain in (a). (b) A bright-field image showing an interwoven colony boundary in the lamellar TiAl alloy.

OAK RIDGE NATIONAL LABORATORY

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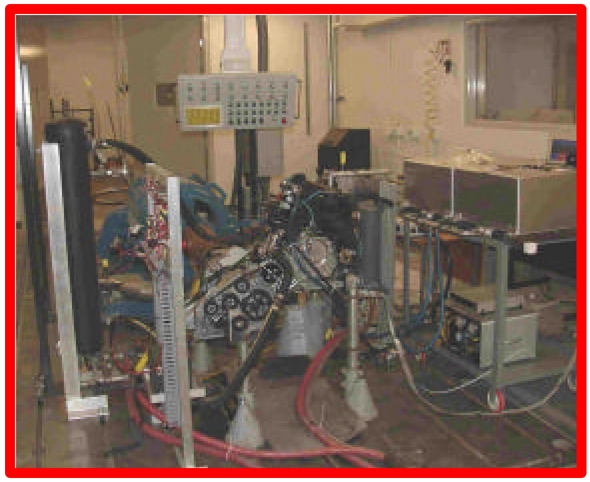
CAPABILITIES

Fuels, Engines, and Emissions Research Center

The Fuels, Engines, and Emissions Research Center (FEERC) specializes in the detailed characterization and studies of internal combustion engine emissions, efficiency, and fuel effects. The facility's comprehensive capabilities include an analytical lab with bench-top engine exhaust simulators, a wide range of engine dynamometers, and a chassis dynamometer for full vehicles. The FEERC boasts several special diagnostic and measurement tools — including many rarely found at other facilities around the country — that aid in development and evaluation of engine and emission control technologies. The FEERC was originally designated a DOE National User Facility in 1999 as the Advanced Propulsion Technology Center.

Key Laboratory Capabilities **--** The analytical laboratory houses the bench flow reactor, mass spectrometry, chemisorption, and laser diagnostics laboratory. Infrared spectroscopy and laser-phosphor thermography are in adjacent labs.



One of five typical engine research cells, this one houses a small direct-injection diesel engine with full-pass control over major engine calibration parameters

The engine dynamometer cells range from 10 to 600 hp, several with motoring capability. Provisions for highly controlled measurements of aftertreatment device performance are available.

Emission control R&D frequently requires use of chassis dynamometers because regulations and "real-world" simulation mandate transient cycles with vehicles. The FEERC chassis dynamometer can handle about 300 hp.

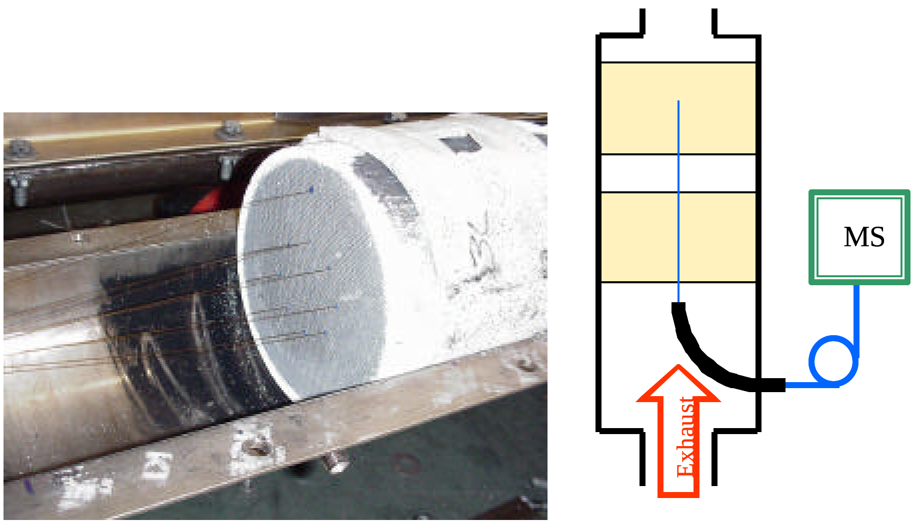
A dSpace-based full-pass engine control system provides capability in integrating engine functions with aftertreatment systems. Emissions measuring equipment is ready for NOx, CO, hydrocarbons, particulates, including FTIR, Fast FID, Fast-NO.

A fast response, direct sampling mass spectrometer for diagnostics of emission control devices (an ORNL innovation) is sufficiently robust for use in the dynamometer cells. Exhaust volatile and semi-volatile constituent speciation can be performed. Exhaust particle characterization is done by the following methods:

- time-integrated mass measurement on filters, near-real-time measurement by tapered element oscillating microbalance (TEOM), particle sizing by micro-orifice uniform deposit impactor (MOUDI) system and scanning mobility particle sizer (SMPS).
- Near-real-time optical particulate measurement via diesel particle scatterometer (a Lawrence Berkeley innovation implemented at ORNL).
- On-site PM composition analysis.
- Transmission electron microscopy, in the High Temperature Materials Laboratory, for morphology.

The vehicle dynamometer has approximately 300-hp absorption capacity and can accommodate the above-mentioned emissions instrumentation. The Center's staff includes specialists in emissions measurements, dynamometer cell operations, and engine controls and control theory.

Current and Recent Research Activities -- Current R&D projects at the Center include determining the effects of fuel sulfur on diesel emissions controls, diesel and gasoline engine-particle emissions, advanced engine control and combustion strategies, such as "low-temperature combustion," and catalyst surface diagnostics. The Center is also active in research projects on diesel emission control via NO_x adsorber catalysts, urea selective catalytic reduction (SCR), exhaust gas recirculation (EGR), particulate filters, and controls with virtual sensing. Fuel- property studies on performance and emissions have included ethanol-diesel fuel blends, ultra-low



An analytical tool developed at ORNL, the "spatially resolved mass capillary input mass spectrometry" (SpaciMS), enables the spatial and temporal resolution of species in functioning catalysts. An electronic valve switches SpaciMS input between sample locations.

sulfur diesel fuels, and biofuels. The direct sampling capillary mass spectrometer is finding use in studies of catalyst functions and EGR. For spark ignition engines, the center has gasoline direct-injection engines and vehicles available for research, as well as natural gas engines. Innovative ignition concepts are being developed. In the analytical lab, NO_x sensors are being studied for time response and sensitivity. Previous work includes *in-situ* engine cylinder-wall oil-film diagnostics, applications of laser phosphor thermography of in-cylinder components, and mapping of vehicle emissions and fuel use in on-road modes.

National Transportation Research Center

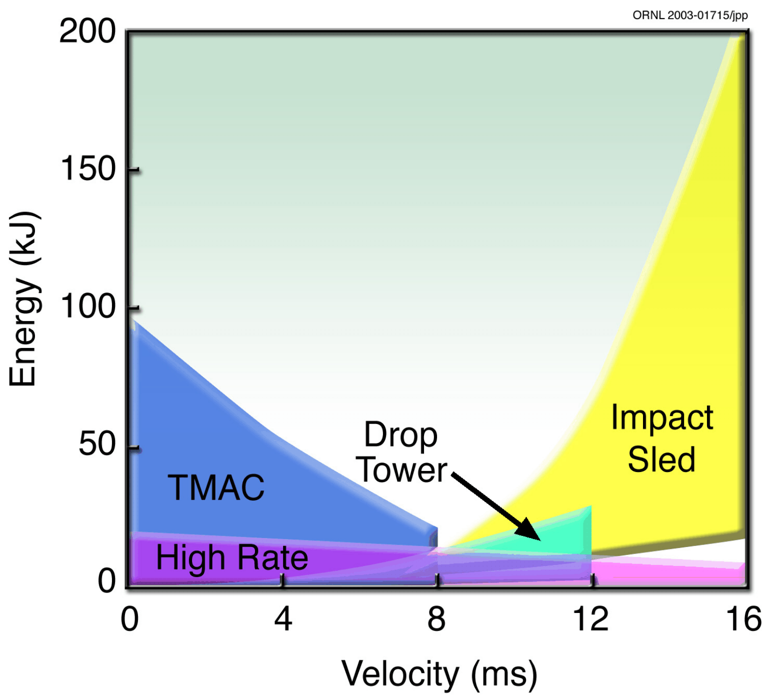
The National Transportation Research Center (NTRC) offers one of the largest multidisciplinary concentrations of transportation researchers in the United States, housing R&D programs and laboratories from Oak Ridge National Laboratory (ORNL) and The University of Tennessee (UT). The NTRC was established to develop and evaluate advanced transportation technologies and systems and to help the transportation industry deal with technology issues. The NTRC seeks to assist industry in utilizing state-of-the-art hardware and computing technologies to address problems of national and international significance, such as declining air quality, dependence on unstable oil supplies, traffic congestion, and highway safety.

The NTRC houses several user centers that focus on different aspects of transportation, including commercial vehicle operations, supply chain management, commercial and military transportation logistics, geographic information systems, infrastructure materials, remote sensing, and heavy vehicle safety. Three user centers funded by the FreedomCAR and Vehicle Technologies Program are:

- Composite Materials Laboratory, which conducts controlled, programmable analysis of the deformation and failure response of lightweight materials in relation to impact velocity
- Fuels, Engines, and Emissions Research Center, which specializes in the detailed characterization of internal combustion engine emissions and efficiency
- Power Electronics and Electric Machinery Research Center, which develops next-generation, cost-effective converters, adjustable-speed drives, motor controls, and efficient, compact electric machines.

***Composite Materials Laboratory* --** Advanced lightweight materials, such as polymer composites and high-strength steels, offer better crash energy absorption per unit of mass than do traditional materials. When those materials are tested to assess their response to crushing, they exhibit different behaviors at different impact velocities. What happens in the transition zone between quasi-static impact rates (for example, 0.058 m/min) and high-velocity impacts (over 16 km/h) is not understood because the capability to conduct impact tests at intermediate velocities has been lacking. The Composite Materials Laboratory operates a unique servo-hydraulic test machine, the Integrated Physical and Virtual Test Machine for Automotive Crashworthiness (TMAC), to fill that gap.

The TMAC is capable of conducting progressive crushing tests on composite automotive components at velocities ranging from 0 to 29 km/h and energy levels up to 50kJ. Using this machine, researchers can study component deformation and failure response in relation to impact velocity in a controlled and programmable manner that is made possible by a unique adaptive control feature of the software. The capability to test across this range of velocities and energy levels is providing the critical data needed for crash simulations that assess the safety of vehicle body structures manufactured from composites and other lightweight materials.



Shaded areas compare the ranges of data collected by the TMAC and by other methods.

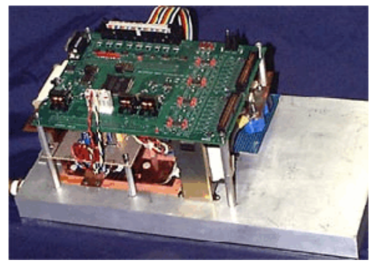
The TMAC was installed in October 2002. It was developed and funded through collaboration between DOE and the U.S. Council on Automotive Research's (USCAR) Automotive Composites Consortium (ACC). The ACC identified the need for this capability; ORNL and the ACC jointly developed the specifications for the machine; and MTS Systems, Inc., designed and built the machine.

Fuels, Engines and Emissions Research Center -- The FEERC specializes in detailed characterization of internal combustion engine emissions and efficiency. The facility's comprehensive capabilities include bench-top engine exhaust simulators, a wide range of dynamometers, and full vehicles. The FEERC boasts several special diagnostic and measurement tools — including many rarely found at other facilities around the country, plus unique instruments developed by Center staff — that aid in development and evaluation of engine and emission control technologies. The FEERC was originally designated a National User Facility in 1999 as the Advanced Propulsion Technology Center.

Full-vehicle research complements bench-scale and engine dynamometer capabilities

Current R&D at the center includes determining the effects of fuel sulfur on diesel emissions controls, gasoline and diesel engine particle emissions, advanced engine control strategies, and catalyst surface diagnostics. The Center is also active in research projects on emission control via NO_x adsorber catalysts, urea selective catalytic reduction (SCR), exhaust gas recirculation (EGR), particulate filters, and controls with virtual sensing. Fuel property studies on performance and emissions have included ethanol diesel fuel blends, new ultra-low sulfur diesel fuels, and biofuels. The direct sampling capillary mass spectrometer is finding use in studies of catalyst functions and EGR. For spark ignition engines, the center has gasoline direct injection engines and vehicles available for research, as well as natural gas engines. Innovative ignition concepts are being developed. In the analytical lab, NO_x sensors are being studied for time response and sensitivity. Previous work includes in-situ engine cylinder-wall oil- film diagnostics, applications of laser phosphor thermography of in-cylinder components, and mapping of vehicle emissions and fuel use in on-road modes.

Power Electronics and Electric Machinery Research Center -- The staff of the Power Electronics and Electric Machinery Research Center (PEEMRC) is recognized worldwide for their expertise in developing and prototyping advanced power converters, adjustable speed drives, and electric machines; power transmission and distribution research and development; and power quality, efficiency, and measurement. The Center provides unique expertise in power converter topologies, thermal management, packaging technologies for minimization of electromagnetic interference and for space and weight reduction, DSP-based control techniques for motor drives, system energy management, flywheel energy storage applications, and ultra-high speed drive applications.



The compact topology of this dc/dc converter for fuel cell systems can power a high-voltage compressor motor expanding unit from a low voltage battery until fuel cell voltage is established.

This expertise is applied to transportation to enable electric and/or hybrid vehicle traction drives, motor-assisted turbochargers, electric air-conditioners, fuel cell converters, and other auxiliary drives. The PEEMRC is working with industrial partners to develop and evaluate automotive electric motor drive units and automotive integrated power modules, and to address system integration issues. PEEMRC researchers use and develop the latest analysis, simulation, and design software to provide proof of principle prior to hardware implementation of their circuit and motor designs.

The PEEMRC also addresses power electronics and electric machinery technology needs, as well as issues in other areas, such as electric power transmission and distribution, distributed energy generation systems, and motors and drives for special applications. Equipment available in the PEEMRC includes a dedicated 600-V, 600A, bi-directional dc power supply; a high-speed rotational equipment safety tank; and a 100-hp, 10,000-rpm, 4-quadrant dynamometer.

High Temperature Materials Laboratory

The Facility -- The High Temperature Materials Laboratory (HTML) is a facility designed to assist American industries, universities, and Governmental agencies develop advanced materials by providing a skilled staff and numerous sophisticated, often one-of-a-kind pieces of materials characterization equipment. It is a nationally designated user facility sponsored by the DOE's FreedomCAR and Vehicle Technologies Program in the Office of Energy Efficiency and Renewable Energy. Physically, it is a 64,500 sq. ft. building on the ORNL site, in which reside six "user centers," which are clusters of specialized equipment revolving around a specific type of properties measurements. Expansion of the HTML User Program since its inception in 1987 has made available new equipment and instrumentation located in other buildings of the Metals and Ceramics Division. HTML users also now have access to the X-14A x-ray beamline at the National Synchrotron Light Source (NSLS) at Brookhaven National Laboratory and a neutron diffraction instrument located at the High Flux Isotope Reactor at ORNL.

The HTML was conceived and built in the mid-1980's to provide a facility that would directly work with American industry, academia, and Government labs to provide advanced high-temperature materials, such as structural ceramics for energy-efficient engines. The scope of the HTML's work has since expanded to include other, non-high-temperature materials of interest to transportation and other industries.

The User Centers

Materials Analysis User Center (MAUC) -- Researchers in this Center employ electron microscopy and surface chemical analysis to determine structure, surface chemistry, and microstructure to the atomic level. Instruments include a Hitachi HF-2000 transmission electron microscope (TEM), a Hitachi HD-2000 scanning transmission electron microscope (STEM), a new JEOL 2010F STEM/TEM, a Phi 680 Scanning Auger nanoprobe, and a Hitachi focused ion beam instrument.

Mechanical Characterization and Analysis User Center -- Researchers in this Center study the fracture toughness, tensile strength, flexure strength, and tensile creep of advanced materials at temperatures to 1,500?C in air or controlled atmospheres. Instruments include nearly a hundred creep frames, several outfitted with atmosphere control, numerous MTS, ATS, and Instron mechanical test frames for tensile, compressive, or bending testing at elevated temperatures. The center also has nanoindentation and fiber-composite characterization capabilities, ranging from individual fibers to complete composite structures.

Residual Stress User Center --This Center has two principal parts: x-ray diffraction and neutron diffraction. The x-ray portion includes x-ray diffractometers to measure residual stress and texture in and near the surface of ceramics and alloys. Users can also access the NSLS at Brookhaven National Laboratory through this user center. The neutron residual stress facility includes a special neutron spectrometer for rapid data collection, plus computer capabilities for data analysis. The spectrometer instrumentation is located at the High Flux Isotope Reactor.

Diffraction User Center -- This Center has both room-temperature and furnace-equipped x-ray and neutron diffractometers. The x-ray furnace is used for studies of materials properties at temperatures up to 2,700?C in vacuum and up to 1,500?C in air. This Center also has access to the NSLS synchrotron mentioned above.

Thermophysical Properties User Center -- Researchers in this Center study thermal stability, expansion, and thermal conductivity of materials to greater than 1,400?C. Instruments include a Netzsch DSC, a Theta dual-pushrod dilatometer, and a laser flash instrument to measure thermal diffusivity to temperatures of 1,900?C. A separate capability is that of thermal mapping, utilizing a high-speed, high-sensitivity infrared camera.

Machining, Inspection, and Tribology Research User Center -- This Center employs instrumented surface and cylindrical grinders to study hard material grinding on ceramics and special alloys. These grinders include high-stiffness surface grinders, a cylindrical grinder, and a creep-feed surface grinder. Other capabilities include instruments for determining the cylindricity and circularity of axially symmetric objects. A coordinate measuring machine is available. Also, this Center contains equipment for the measurement of friction and wear, including fretting, rolling, and sliding.

The HTML Programs -- Within the HTML are programs that function to help outside researchers solve materials problems using state-of-the-art characterization instrumentation. In the "HTML User Program," either non-proprietary or proprietary research can be performed by American industrial and academic researchers. The former is provided free of charge if the user publishes the information produced, while the latter requires payment. Non-proprietary research projects typically last from 1 to 3 weeks at the HTML. The major proviso is that the results must be submitted for publication within 6 months after completion of the research.

For proprietary research, the user and the HTML staff estimate the cost of HTML staff time required to complete the work. The user agrees to pay for this time at an hourly rate specified by the DOE before the start of the research. These projects typically are more extensive than non-proprietary projects, and the user owns the data from the research.

For Further Information

http://www.ntrc.gov/
http://feerc.ornl.gov
http://www.ms.ornl.gov/htmlhome/

NATIONAL RENEWABLE ENERGY LABORATORY

As a world leader in renewable energy and energy efficiency research, the National Renewable Energy Laboratory (NREL) is developing new transportation technologies to benefit both the environment and the economy. Through NREL's Center for Transportation Technologies and Systems, we develop and demonstrate innovative technologies that will allow alternative fuels and advanced vehicle systems to supply a significant portion of the Nation's transportation needs.

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CAPABILITIES

Fuels and Engine Testing

NREL works with Government and industry to research and develop alternative diesel fuels and lubricants, such as biodiesel and E-diesel. The laboratory also leads efforts to improve petroleum-based diesels by researching ultra-low sulfur fuels, advanced engines, and catalysts. We use our facilities to identify, test, and evaluate fuels, lubricants, and engines that will allow manufacturers to meet 2007 emissions requirements while maintaining vehicle performance and fuel efficiency.

Component and Systems Math Modeling and Energy-Efficient Optimization

The laboratory's research into battery performance and auxiliary load reduction allows industry to increase fuel efficiency and reduce emissions. As part of this effort, we work with vehicle manufacturers to improve thermal management systems—from the cell level to the battery pack—for electric, hybrid-electric, and fuel-cell vehicles. NREL also leads efforts to reduce vehicle auxiliary loads, such as air-conditioning, by evaluating advanced window glazings, cooling heat-pipe systems, and parked car ventilation.

Vehicle Simulation—Heavy- and Light-Duty Vehicles

Because energy management strategies depend on accurate vehicle simulation, NREL has developed and commercialized a software package that effectively models vehicle efficiency, performance, and emissions. This package, known as ADVISOR™ (ADvanced VehIcle SimulatOR), allows for virtual testing of vehicle components and systems.

Advanced Heavy-Hybrid Propulsion Systems

Researchers at NREL are working with industry to develop advanced, heavy-vehicle hybrid propulsion components and systems. These systems are expected to significantly improve heavy-vehicle fuel efficiency and reduce emissions. By teaming with industry, we are able to take advantage of the best technologies and skills available from various companies and organizations.

Fleet Evaluations

NREL collaborates with industry and Government fleets to develop fleet test procedures and data-collection plans to evaluate vehicle emissions, maintenance, costs, and performance. We also lead innovative projects designed to demonstrate prototype and production engines and vehicles.

Emissions and Air Quality Research

To better understand the problem of transportation-derived air pollution, researchers examine ambient air samples and exhaust emissions data to determine the effects of pollutants on human health and air quality. Vehicles are tested while operating on traditional and advanced fuels.

Technology Integration

NREL works with the U.S. Department of Energy's Clean Cities Program to help build a sustainable alternative fuels market in participating cities across the Nation. The laboratory also maintains the Alternative Fuels Data Center, which is the most comprehensive resource for information on advanced and alternative transportation technologies and systems in the United States. To access the AFDC on the Web, visit www.afdc.doe.gov.

Fuel Cells and Hydrogen

As worldwide interest in hydrogen and fuel-cell technology increases, NREL continues to work directly with DOE and its subcontractors to develop fuel-cell technologies for vehicle applications.

UNIQUE FACILITIES/EQUIPMENT/CAPABILITIES

ReFUEL Laboratory

The ReFUEL (Renewable Fuels and Lubricants) laboratory is a unique, high-altitude facility for testing alternative and advanced fuels and heavy-duty engines and vehicles. The lab is equipped with a heavy-duty chassis dynamometer, an engine test cell, and emissions measurement equipment compliant with the 2007 Code of Federal Regulations. The laboratory is capable of testing conventional and alternative diesel fuels, heavy-hybrid vehicles, and conventional diesel engines.

Fuel Chemistry Laboratory

The Fuel Chemistry lab is equipped with an Ignition Quality Tester™ (IQT). Researchers use the IQT to characterize the effect of the molecular structure of blending components on ignition properties. The laboratory is also equipped with a gas chromatograph and a high-performance liquid chromatograph for speciating and quantifying unregulated toxic compounds emitted in vehicle exhaust streams. This allows us to compare emissions from engines running on conventional fuels with those using alternative fuels.

Thermal Management Test Facility

The Battery Thermal Management Test Facility houses a unique calorimeter for measuring battery performance and thermal imaging equipment for diagnosing battery behavior. The laboratory also contains a bidirectional battery cycler, which can meet the most demanding driving-cycle profiles, including those of the Federal Urban Driving Schedule and the General Dynamic Stress Test.

Ancillary Loads Reduction Laboratory

The Ancillary Loads Reduction laboratory is focused on improving vehicle fuel economy and reducing emissions by decreasing vehicle auxiliary loads, such as air-conditioning, while maintaining passenger comfort. Engineers at the laboratory conduct vehicle tests and develop integrated models to evaluate the impacts of advanced window glazing, cooling heat-pipe systems, parked car ventilation, ventilated seats, and direct-energy recovery and adsorption-cooling systems. A life-size thermal manikin is also used to evaluate passenger comfort using advanced climate control concepts.

PATENTS AND AWARDS

NREL's Center for Transportation Technologies and Systems has been awarded more than 10 patents and records of invention and 2 R&D 100 awards.

RECENT AND ONGOING EFFORTS

NREL collaborates with fuel, engine, and vehicle manufacturers as well as other Federal laboratories and university research organizations. Some of our recent research partners include:

3M
Allison Transmission
American Chemistry Council
API
ArvinMeritor
BAE Systems
Battelle
Benteler
BP
California Air Resources Board
California Fuel Cell Partnership
Castrol
Caterpillar, Inc.
Chevron Oronite
Chevron Texaco
Ciba
Clean Diesel Technology
Conoco-Phillips
Controls Freightliner
Corning
Crompton
Cummins Engine Company
DaimlerChrysler
Delphi Automotive Systems
Detroit Diesel Company
Donaldson Co.
Eaton
Engelhard
Engine Manufacturers Association
Ergon
Ethyl
ExxonMobil
Ford Motor Company
General Motors
Honeywell International
Infineum
International Truck & Engine
John Deere
Johnson Matthey
Lubrizol
Mack Trucks
Marathon Ashland
MECA
Motiva
NGK
NovaBus
NPRA
OMG
Oshkosh Trucks
PACCAR
Pennzoil-Quaker State
Rhodia
Robert Bosch Corp.
Shell Global Solutions
Siemens
South Coast Air Quality Management District
STT Emtech AB
Tenneco Automotive
Toyota
Truck Manufacturers Association
University of California, Berkeley
University of West Virginia
University of Wisconsin
Valvoline
Volvo Trucks North America

FOR FURTHER INFORMATION

Please visit NREL's Center for Transportation Technologies and Systems on the Web at www.ctts.nrel.gov.

PACIFIC NORTHWEST NATIONAL LABORATORY

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CAPABILITIES

Emissions Science

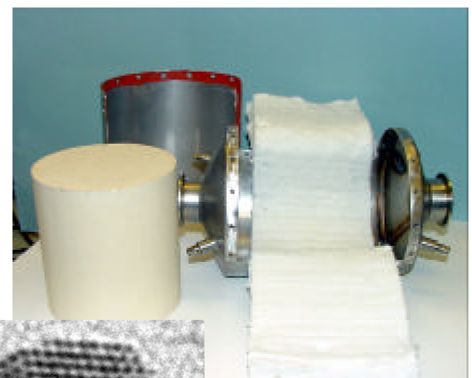
The Exhaust Chemistry & Aerosol Research Laboratory at the U.S. Department of Energy's (DOE) Pacific Northwest National Laboratory (PNNL) offers the necessary resources for the development and testing of emissions-control technologies and catalyst materials under real-life operating conditions. The objective of this laboratory is the application of the chemical and physical sciences to solve engineering problems related to the development of emission control technologies and improving existing devices.

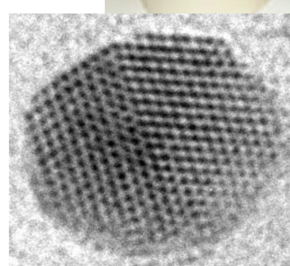
PNNL's research and development activities in the area of emissions-control technologies focus on:

- Emissions Chemistry Characterization
- Particulate Measurement and Characterization
- Catalyst Development and Characterization
- Reaction Mechanism Identification
- Aftertreatment Prototype Development
- Prototypical Device and Systems Testing
- Chemical and Physical Property Sensor Development

PNNL is working with industry and academia to solve many technology hurdles related to emission controls and improving the fundamental understanding of the chemistry involved in aerosol, gas-phase and surface reactions.

Emissions Control





PNNL has broad capabilities in the area of catalyst development and characterization, as well as characterization of chemical and physical processes used for the abatement of pollutants from mobile and stationary internal combustion engines. PNNL works with industry partners on technologies ranging from hydrocarbon (HC) - and urea-selective catalytic reduction (SCR) to NO_x and SO_x traps to particulate filtration and trap regeneration. Much of this work involves developing a detailed understanding of the chemical and physical processes that occur, what the degradation mechanisms are, and how to control the process to achieve a high level of performance and durability.

PNNL and its partners have been successful at developing and improving technologies used for emissions reduction from diesel engines and other reciprocating internal combustions engines.

Sensors and Electronics

Aftertreatment devices require on-board diagnostics to monitor the performance of the aftertreatment devices. PNNL has broad capabilities and experience in the development of innovative sensors, measurement methods, and systems to meet diverse client requirements. PNNL has worked with industrial partners for oxygen and NO_x sensors for automotive applications.

Fuel Reforming

Small and efficient microchannel fuel reformers are being developed by PNNL for use with proton-exchange membrane (PEM) fuel cells. PNNL, together with the National Energy Technology Laboratory as a part of the Strategic Energy Conversion Alliance, is developing low-cost, high-efficiency, solid-oxide fuel cells for auxiliary power on heavy vehicles, military vehicles, and automotive applications. Invention reports have been filed in the area of seals and solid-oxide fuel cell processing.

PNNL is also working with industry partners to develop diesel fuel reformation technologies for applications to improving the performance of lean-NO_x catalysis and other exhaust after-treatment devices for diesel-powered vehicles.

Environmental Molecular Sciences Laboratory

The Environmental Molecular Sciences Laboratory (EMSL) at PNNL is a national scientific user facility and research organization that

- provides advanced resources to scientists engaged in fundamental research on the physical, chemical, and biological processes
- conducts scientific research and advances molecular and computational sciences
- educates scientists in the molecular and computational sciences to meet the demanding environmental challenges of the future.

The EMSL campus offers – at one location – a comprehensive array of leading-edge resources for research in the environmental and molecular sciences, such as

- Gas- and liquid-phase monitoring and detection facility
- High-field magnetic resonance facility
- High-field mass spectrometry facility
- Interfacial structure and compositions facility
- Molecular science computing facility
- Nanoscience and technology facility
- Optical imaging and spectroscopy facility
- Reactions and interfaces facility.

Engineering Simulation and Modeling

The internally funded engineering simulation and modeling activities at PNNL are part of an overall computational science and engineering initiative and are currently focused on thermoplastic composites materials, manufacturing activities, and hydrogen materials. PNNL has state-of-the-art computational facilities and unique software development and application capabilities. Projects are conducted with a broad range of industry, national laboratory, and university partners.

Emission Modeling – NO_x, CO, HC's, Particulates

- Guide future catalyst system development, characterization
- Identity after-treatment bottlenecks (system and component sensitivity analysis)
- Evaluate impact of fuel reformulations, engine changes
- Develop new devices for NO_x reduction and sensing
- Conduct research and development (R&D) on particulates reduction and capture
- Perform system modeling

Advanced Materials and Manufacturing Research and Development

- Materials Science technologies
    - Lightweight metals (aluminum, magnesium, titanium, metal composites)
    - High-strength steel
    - Polymer composites
    - Glazing (glass) materials
    - Ceramics and porous structures (catalysts, membranes, electrical devices)
- Metal casting and forming technology development
- Polymer composite manufacturing
- Ceramics processing
- Coatings and thin-film technologies
- Advanced joining technologies of monolithic, composite and dissimilar materials
- Materials and manufacturing modeling and finite element analysis

PATENTS AND AWARDS

PNNL's activities have led to commercial products and over 35 patents, as well as R&D 100 Awards for innovative technology developments, FLC Awards for Excellence in Technology Transfer, and a Discover Award.

RECENT AND ONGOING EFFORTS

PNNL has forged successful working partnerships with a number of major engine and vehicle manufacturers, as well as universities and other DOE laboratories. These include:

Caterpillar
Cummins
DaimlerChrysler
Delphi Corporation
Detroit Diesel Corporation
Ford Motor
General Electric
General Motors
Lawrence Livermore National Laboratory
Northwestern University
Oak Ridge National Laboratory
Sandia National Laboratories
U.S. Council on Automotive Research - Low Emissions Technologies Research and Development Partnership
University of Maryland

FOR FURTHER INFORMATION

http://www.pnl.gov/auto/
http://www.emsl.pnl.gov.

SANDIA NATIONAL LABORATORIES

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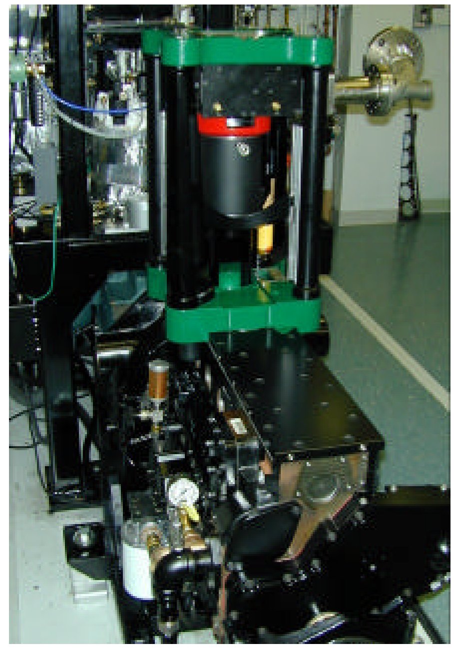
CAPABILITIES

The engine combustion research program at the Combustion Research Facility (CRF), Sandia National Laboratories has closely interacted with U.S. engine manufacturers for more than 25 years to promote the fundamental understanding of in-cylinder processes governing efficiency and emissions. This information is being used by OEMs in their effort to develop more efficient engines that meet stringent new emissions standards for passenger vehicles, light-duty trucks, and heavy-duty transport vehicles. A current emphasis in the program is on developing the science-base for low-temperature combustion (LTC) processes, *e.g.*, homogeneous charge compression ignition (HCCI) and various forms of stratified charge compression ignition (SCCI) combustion. Low-temperature combustion strategies offer the potential for diesel-like efficiencies and extremely low emissions of NO_X and particulates. In our research, we employ advanced, laser-based diagnostics in conjunction with experimental hardware that closely mimics realistic engines while providing optical access. We are also investigating alternative fuel property effects on combustion and emission processes and are developing new diagnostic techniques such as laser-induced incandescence (LII), laser-induced desorption with elastic light scattering (LIDELS), and laser induced breakdown spectroscopy (LIBS) for real-time characterization of particulate matter emissions from engines.

UNIQUE FACILITIES/EQUIPMENT/CAPABILITIES

Homogeneous Charge Compression Ignition/Stratified Charge Compression Ignition Dual-Engine Laboratory

Because of the high-efficiency and low emissions potential of homogeneous charge compression ignition/stratified charge compression ignition (HCCI/SCCI), both automotive and diesel engine manufacturers are actively developing these combustion strategies. Sandia's HCCI/SCCI Dual-Engine Laboratory is supporting this industrial effort by providing understanding of the fundamental processes controlling HCCI/SCCI. The laboratory houses two 6-cylinder Cummins B-series engines converted for balanced, single-cylinder HCCI/SCCI operation: (1) an all-metal engine capable of speeds to 3,600 rpm for determining engine performance in various operating modes, investigating emissions, and developing combustion-control strategies and (2) an optically accessible engine, modified with an extended cylinder and windows into the combustion chamber, capable of speeds to 2,100 rpm, for the application of advanced laser-based diagnostics to the investigation of in-cylinder processes.


Optically Accessible HCCI/SCCI Engine

The two engines are mounted on opposite ends of a 125-hp dynamometer and share a common intake system capable of providing boost pressures up to 4 bars, intake temperatures up to 220°C, and simulated or real exhaust gas recirculation (EGR). These engines displace 0.98 liter/cylinder (a size typical of sport-utility vehicles or medium-duty diesels), have a 4-valve head modified to provide variable swirl ratios from 0.9 to 3.2, and accommodate compression ratios from 12:1 to 21:1. Fueling systems include a centrally mounted direct injector (for either gasoline- or diesel-type fuels), port fuel injectors, or a fully premixed fueling system. The laboratory is equipped with complete exhaust gas analysis instrumentation (HC, O_2, CO, CO_2, NO_X, and smoke), in addition to cylinder-pressure analysis and optical diagnostics. Recent and current research efforts are directed at understanding the sources of HC and CO emissions, investigating the effects of fuel type, determining the role of heat transfer in controlling combustion phasing, studying intake-pressure boosting to extend the load range, and investigating partial charge stratification as a method for improving low-load combustion efficiency, controlling combustion phasing, and extending the operating range.

Automotive HCCI Engine Laboratory

In the near term, the application of HCCI to automotive engines will likely involve a mixed-mode combustion concept in which HCCI is used at low-to-moderate loads and standard spark-ignition (SI) combustion at higher loads. This type of operation using standard gasoline-type fuels requires a moderate compression ratio of 10:1 to 14:1 for SI operation and significant intake heating for HCCI operation (typically provided by retaining a high fraction of residuals). The Automotive HCCI Engine Laboratory houses a versatile light-duty engine designed to allow investigations of a wide variety of issues for this type of HCCI application.

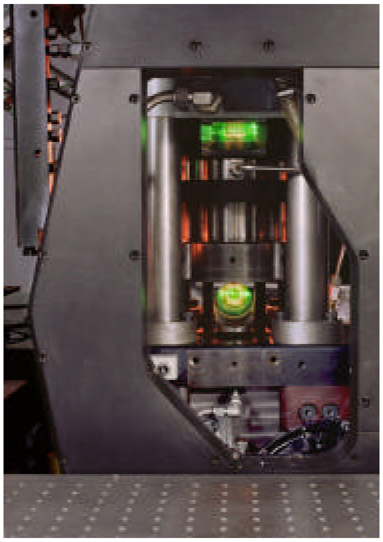
Optically Accessible
Automotive HCCI Engine

This automotive-sized engine (0.63 liter/cylinder) has a 3-valve pent-roof head and is equipped with extensive optical access for the application of advanced laser-based diagnostics, including an extended cylinder with a piston-crown window and a full transparent quartz cylinder liner. The intake air system provides intake pressures up to 2 bars and heating to 250°C. These high intake temperatures allow investigations of HCCI operation with lower compression ratios (10:1 to 12:1). The engine is equipped with a centrally mounted gasoline-type direct injector (GDI), a port-fuel injection capability, and a fully premixed fueling system, allowing investigations of both well-mixed and stratified HCCI operation. In addition, the engine is equipped with spark plugs for investigations of the transition from HCCI to SI operation.

Current experiments are using laser-induced fluorescence (LIF) imaging to understand the relation between the fuel-air-residual mixing process and subsequent emissions. Partial stratification is often proposed as a possible strategy for reducing CO emissions, and these experiments facilitate the development of such strategies. Liquid-phase LIF imaging will be used to judge the extent of wall-wetting and its impact on mixture preparation. Direct luminosity and elastic scattering images recorded during the same cycle as LIF images will allow correlation of charge preparation with combustion and with possible smoke production.

High-Speed, Small-Bore Diesel Engine Laboratory

This laboratory is set up to investigate fluid dynamics and combustion processes in compression-ignition engines for passenger vehicles. The single-cylinder, optical engine mimics the best-in-class high-speed diesel engines being introduced in the European market. This engine has a speed range of 0 to 4,000 rpm, a 4-valve head with variable swirl, a vertical central injector supplied by common rail, and a compression ratio of 19:1. A quartz piston crown machined to match current complex bowls along with cylinder-wall windows provide optical access without compromising geometric similarity. The laboratory is equipped with a full complement of engine support subsystems.

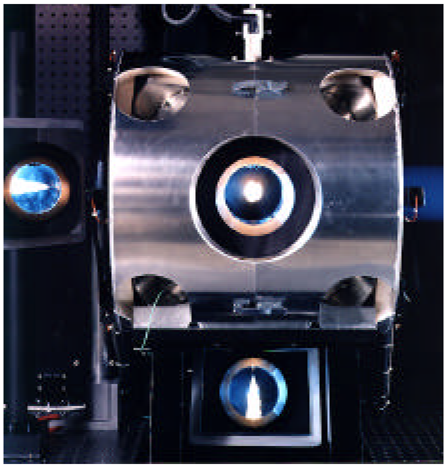


Optically Accessible
Small-Bore Diesel Engine

Researchers at Sandia are using the facility to investigate in-cylinder mixing and combustion processes unique to small-bore diesel engines. The highly swirling flows along with spray-wall and flame-wall interactions found in such engines are considerably different from those in large-bore, quiescent-chamber, heavy-duty diesel engines. The current research emphasis is on developing the physical understanding needed to expand the applicable speed/load range of low-temperature, low-emission diesel combustion regimes.

Diesel Combustion Simulation Facility

The interpretation of data from experiments conducted in diesel engines is challenging because it is difficult to independently vary the many parameters that affect in-cylinder combustion processes. In the Diesel Combustion Simulation Facility (DCSF), injector parameters and the ambient gas temperature, density, and composition can be controlled and varied in a more systematic manner, allowing the effects of these variables to be assessed independently. The capabilities of the DCSF are unique in the world and have provided significant new insights into diesel engine combustion processes. With full optical access, diesel conditions with ambient pressures as high 35 MPa, ambient temperatures between 600 and 1400 K, and ambient densities between 3.5 and 60 kg/m^3 can be simulated.

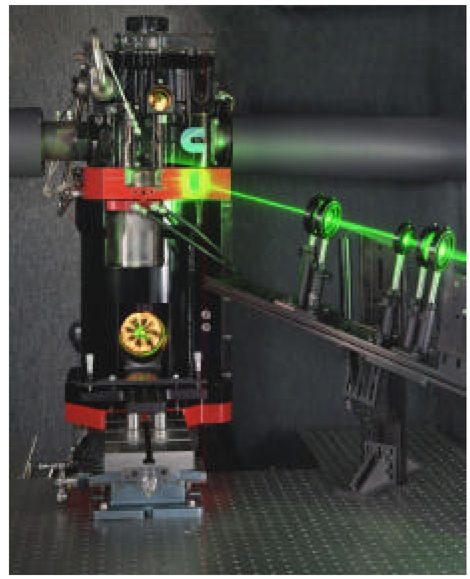


Diesel Combustion Simulation Facility

Researchers at Sandia are currently using the DCSF to study the soot processes in diesel fuel jets. Soot concentration measurements are being performed at diesel operating conditions for a wide range of ambient gas temperatures, ambient gas densities, ambient oxygen concentrations, injection pressures, injector orifice diameters, and fuel types. The data are providing an improved fundamental understanding of diesel soot formation processes. At some injector and ambient conditions, our research has shown that soot formation can be suppressed entirely in a fuel jet, even at low-flame temperature (*i.e.*, low NO_x) conditions when using a #2 diesel fuel. This has lead to a new area of investigation on low-emission, mixing-controlled diesel fuel jet combustion.

Heavy-Duty Diesel Engine Combustion Laboratory

This laboratory employs advanced optical imaging and laser diagnostics to investigate diesel spray combustion and pollutant-formation processes occurring inside an operational diesel engine. The insight gained from these investigations has been shared with U.S. manufacturers of heavy-duty diesel engines (including Detroit Diesel, Caterpillar, and Cummins) and has been used in the development of cleaner, more fuel-efficient engines.

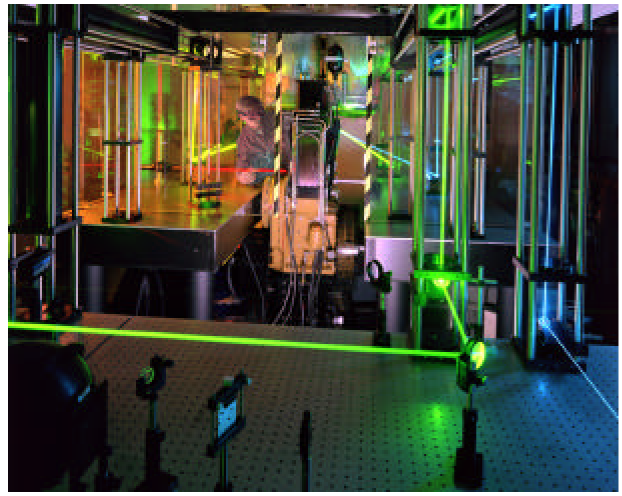


Optically Accessible
Heavy-Duty Diesel Engine

The engine in this laboratory is a 2.3-liter, single-cylinder diesel engine, which was derived from a production highway truck engine. It has been modified for optical access by placing windows in the piston crown, cylinder head, and cylinder walls. These windows provide optical access both for cameras, which record images of in-cylinder combustion, and for laser beams, which are used to probe in-cylinder processes, while the engine is running. Two high-power, pulsed Nd:YAG lasers, an optical parametric oscillator, and a dye laser are used for two-dimensional laser-sheet imaging diagnostics. The lasers and cameras can be tuned to probe and isolate the complex chemical and physical processes occurring inside the engine that eventually lead to pollutant emissions at the tailpipe. The engine hardware has been recently updated with a common-rail fuel injection system, a relatively new fuel-injection technology with advanced fuel injection capabilities. Current research directions include investigation of particulate matter and nitrogen oxides formation when using advanced combustion operating strategies, such as multiple injections and low-temperature combustion.

Non-Traditional Diesel Fuel Engine Combustion Laboratory

Research in this laboratory focuses on the effects of non-traditional diesel fuels and operating modes on diesel engine emissions and performance. State-of-the-art laser/imaging diagnostics are applied in a single-cylinder version of a Caterpillar C-10 engine that has been modified to provide extensive optical access to the combustion chamber. Details of injection, combustion, and emissions-formation processes can be directly observed. Engine-out emissions measurements help show which in-cylinder phenomena contribute most to pollutant reduction and provide a link to results from non-optical engine experiments. The fuel-injection system is capable of multiple injections with user-selected timing and is compatible with a full complement of liquid-phase fuels from bio-diesel, heavy ethers, and Fischer-Tropsch diesel to gasoline and light alcohols. The engine is equipped with a glow plug to assist the ignition of low-cetane fuels. Current research activities include identifying fuel properties and in-cylinder strategies to help achieve non-sooting, low-temperature combustion.



Optically Accessible Diesel
Fuels Research Engine

High-Energy Laser Diagnostics for Particulate Matter Characterization

The CRF has a record of successfully developing practical diagnostic techniques. A current national need is for diagnostic tools that can measure and characterize soot real-time in engine exhaust flows, especially at the very low soot levels characteristic of today's clean engines. In our particulate matter (PM) diagnostics work, we are developing and applying high-energy laser diagnostics for real-time measurement and characterization of PM. Diagnostics being explored include laser-induced incandescence (LII), elastic light scattering, laser-induced desorption with elastic light scattering (LIDEL's), and laser induced-breakdown spectroscopy (LIBS). A research partner, Artium Technologies, is in the final stages of developing a commercial LII instrument for measuring soot concentrations. Their LII instrument is portable, safe, rugged, reliable, and automated and offers push-button simplicity for measuring soot concentration. The LIDEL's technique under development holds promise for providing real-time soot and volatile-organic-fraction measurements. We are currently working with various industry partners, as well as Oak Ridge National Laboratory, to demonstrate and apply the LII and LIDEL's diagnostics.

PATENTS AND AWARDS

The main focus of the Engine Combustion Research Program at the CRF is on developing the science base regarding in-cylinder combustion and emissions processes. The staff's success at this is corroborated by the numbers of technical papers accepted by refereed journals, papers presented at major conferences, and awards received. Over the past 5 years, scientists in the engine combustion group have published more than 120 technical papers. Three of the staff have also been made Society of Automotive Engineers (SAE) Fellows and are recipients of the prestigious SAE Horning Award for significant contributions to the engine and fuels research fields. Two SAE Arch T. Colwell Merit Awards for technical contributions, an American Society of Mechanical Engineers Internal Combustion Engine Division best paper award, two Lloyd L. Withrow Awards for repeated excellence in presentations at SAE conferences, a U.S. Department of Energy 100 Award, as well as many other SAE awards for service and excellence in oral presentation have also recently been received.

RECENT AND ONGOING EFFORTS

The CRF Engine Combustion Research Program continues to be conducted with close interaction and in partnership with many engine manufactures. Partners now include General Motors, Ford, DaimlerChrysler, Caterpillar, Cummins, Detroit Diesel, International, Mack/Volvo, John Deere, and General Electric. Much of the current research focus is shifting toward investigating advanced, low-temperature (*e.g.*, HCCI, SCCI, MK, *etc.*) and advanced diesel combustion regimes. Potential low-temperature combustion applications (LTC) include mixed-mode combustion systems in which diesel or spark-ignited SI combustion will be used at high loads and LTC combustion at light-to-moderate loads. Mixed-mode combustion systems offer the potential for achieving high power density, as well as high efficiency and low emissions.

FOR FURTHER INFORMATION

The CRF website can be reached at http://ww.ca.sandia.gov/CRF

Abstracts

Plenary Session – A View from the Bridge

U.S. ENVIRONMENTAL PROTECTION AGENCY HIGHWAY AND NON-ROAD DIESEL STANDARDS UPDATE

William Charmley

U.S. Environmental Protection Agency

ABSTRACT

This presentation will provide an overview of the U.S. Environmental Protection Agency (EPA) highway heavy-duty diesel 2007 program and an update on recent progress, including both light-duty and heavy-duty vehicles. The pre-sentation will also discuss EPA's recent proposal for a new standards that would dramatically re-duce the fuel sulfur levels in off-highway diesel fuel and at the same time require dramatic re-ductions in particulate matter and oxides of ni-trogen from non-road diesel engines used in farm, construction, and industrial equipment.

GLOBAL CLIMATE CHANGE AND THE TRANSPORTATION SECTOR: AN UPDATE ON ISSUES AND MITIGATION OPTIONS

Charlotte A. Geffen and James J. Dooley

Battelle Pacific Northwest National Laboratory

ABSTRACT

It is clear from numerous modeling exercises that addressing the challenges posed by global climate change will eventually require the active participation of all industrial sectors and consumers on the planet. Yet, these and similar modeling exercises indicate that it is the large stationary CO_2 point sources (e.g., refineries and fossil-fired electric powerplants) that are likely to be the first targets for serious CO_2 emissions mitigation. While focusing on large stationary point sources might be a useful starting point, these efforts ultimately must be expanded to include all other sectors of the global economy. Because of its operating characteristics, price structure, dependence on virtually one energy source (oil), and enormous installed infrastructure, the transportation sector will likely represent a particularly difficult challenge for CO_2 emissions mitigation. Our research shows that climate change induced price signals (i.e., putting a price on carbon that is emitted to the atmosphere) are unlikely to result in fundamental shifts in demand for energy services or to transform the way these services are provided in the transportation sector. We believe that a technological revolution will be necessary to accomplish the significant reduction of greenhouse gas emissions from the transportation sector. This talk will present an update of ongoing research into a variety of technological options that exist for decarbonizing the transportation sector and the various tradeoffs among them.

GLOBAL CLIMATE AND ENERGY PROJECT

Chris F. Edwards

Stanford University

ABSTRACT

Energy is the lifeblood of modern societies. Within 20 years, 7.5 billion humans will occupy this planet, about 25 percent more than do so now. They will want to heat and light their homes, power electrical devices, move from place to place, grow food, and drink clean water. Supplying the energy required to do all this is, by itself, a significant challenge. But that is only part of the challenge. It is now apparent that humans are interacting with the chemistry of the planet on a global scale. The concentration of CO_2 in the atmosphere has increased by a third from its pre-industrial levels. There has been an easily detectable change in the pH of the upper ocean as the CO_2 from the atmosphere dissolves. And, while there is a lively ongoing debate about the magnitude of a global warming response to the presence of greenhouse gases (GHG's) in the atmosphere, there is no question that changes are occurring on a global scale, and there is a significant possibility that the world will need an energy system that adds *much* lower GHG's to the atmosphere in the future. This project aims to make that future possible.

Imagine a global energy system that adds *very* low GHG's to the atmosphere. What would be possible primary sources of energy supply in such a system? How would energy end-users make use of that supply? What technologies and systems would be used in the developing countries in addition to North America and Europe? Would we use wind, solar, nuclear power, hydrogen, fossil fuels, and in what combinations? How would such an energy systems be created? What barriers prevent implementation of such systems today (barriers might include safety, adverse environmental effects, market acceptance, legal and social environments, and cost, for example)? What technologies will have to be developed to eliminate those barriers? How can the creative talents of the world's great universities be harnessed to invent such a future? Who will train the next generation of scientists and engineers who will make all this possible? Those questions are the reasons for this project.

With the support of visionary, international companies, Stanford University will develop and manage a portfolio of pre-commercial research to provide the basis for the low GHG-emission energy technologies of the future. It is unlikely that any one energy source will be able to meet the full range of future energy needs, and hence it is essential that the exploration of energy futures examines the technology development needed across the full spectrum of energy sources and uses. Guesses made now about which energy technologies will dominate in the future are unlikely to foresee accurately how these complex systems will evolve and how markets will respond to them, and hence investigation of a diversified portfolio of research topics is critical to project success. Research conducted as part of the project will be performed at Stanford and at other universities worldwide. Stanford will draw widely from energy expertise around the world to build the portfolio. Results of the research will be openly available, and any technology patents will be widely licensable. A key objective of this initiative is to encourage future commercial application of the technologies that flow from the research results.

ENERGY INDEPENDENCE FOR NORTH AMERICA: TRANSITION TO THE HYDROGEN ECONOMY

James J. Eberhardt

U.S. Department of Energy

ABSTRACT

A strategy will be presented for achieving energy independence for the United States and North America through a pathway that could ultimately transition the United States and the transportation sector into a hydrogen economy. The U.S. transportation sector, because of the unique mobility requirements of cars and trucks, is almost totally dependent on liquid carbon-based fuels, primarily conventional petroleum-based gasoline and diesel fuel. This has resulted in continued reliance on imported oil, mostly from less politically stable countries. Energy security concerns have therefore motivated this focus on the hydrogen economy to replace the oil economy. The *National Energy Policy* has included recommendations for the energy independence, not only of the United States, but for the North American continent as well. The President, in his State of the Union address this year, announced the FreedomCAR and Fuel Initiative for achieving energy independence, which would transition the United States and the transportation sector into a hydrogen economy.

SOUTH COAST AIR QUALITY MANAGEMENT DISTRICT CLEAN TRANSPORTATION PROGRAMS

Mike Bogdanoff

South Coast Air Quality Management District

ABSTRACT

The South Coast Air Quality Management District (SCAQMD) has a number of programs to facilitate the development and deployment of clean transportation. These program elements arise from the SCAQMD's Air-Quality Manage-ment Plan. This plan contains the activities that will be taken by the SCAQMD, the California Air Resources Board, and the U.S. Environ-mental Protection Agency within their respective jurisdictions to achieve ambient air-quality standards in the South Coast Air Basin.

The SCAQMD has seven fleet rules that require the purchase of low-emission and alternative fuel vehicles. These include govern-ment fleets, transit agencies, school districts, and refuse haulers, all with fleets of more than 15 vehicles. State legislation has also enabled the SCAQMD to provide funding to defray the extra cost of the purchase of low-emission and alter-native-fuel vehicles and engines for these and other fleets. Over $57 million was disbursed in 2002. There are seven such programs in the basin.

Finally under the SCAQMD's Clean Fuels Program, new alternative-fuel and low-emission technology is being developed and demonstrated. With an annual budget of about $10 million, there are over 80 contracts in progress at any one time. Currently, the SCAQMD is interested in supporting technologies involving heavy-duty natural gas vehicles, gas-to-liquid fuels, heavy-duty hybrid vehicles, fuel cell technology, and hydrogen production and infrastructure.

GALE BANKS ENGINEERING

M. Ruth, R. Smith, L. Kocher, K. King, M. Meek, W. Harvey, G. Franks, J. Mackey, and J. Stang

Cummins, Inc.

G. Banks, J. Espino, S. Tackett, A. Johnston
Gale Banks Engineering

ABSTRACT

Cummins, Inc., and Gale Banks Engineering have teamed up to build a diesel-powered world record setting vehicle. The objective of the project was to provide a positive showcase to display the virtues of diesel power in a market area where diesel power is not currently available: sport vehicles, mainly trucks. Over a 2-year period, engineers at Gale Banks Engineering, Cummins, Holset, and Robert Bosch worked together to build this showcase. After several hardware exchanges, countless phone calls, and many, many late night thrash sessions, Project Sidewinder hit the road – not the track!

In an unprecedented fashion, the Cummins'-powered, Gale Banks Engineering-built Dodge Dakota made its way to the Bonneville Salt Flats not on a trailer or transporter, but under its own power, pulling a race supply trailer. This amazing vehicle went to the flats in full street-legal dress and capable of achieving over 21 mpg, with only a tire change. It broke four standing records during the driver's qualifying passes at an average speed over 182 mph. That was just the first day.

For 3 days, like-minded racers watched in awe as a diesel-powered pickup truck that looked a lot like what you would see on the street (complete with trailer hitch, air-conditioning, power windows, and stereo) set record after record. Even more amazing, using diesel fuel that anyone could buy at a corner fuel station, this vehicle would set records at speeds in excess of 222 mph without the signature tunnel of black smoke that was typical of diesels on the Salt. Ultimately, this Gale Banks-engineered Dodge Dakota, powered by a Cummins 5.9L turbo-charged diesel engine, succeeded in setting nine records in only seven passes, including two driver licensing runs.

Abstracts

Session 1 – Emerging Diesel Technologies

REDUCTION OF EMISSIONS FROM A HIGH-SPEED FERRY

Gregory Thompson, Nigel Clark, Mridul Gautam, Donald W. Lyons, Daniel Carder, Byron Rapp, Sam George, Ryan Barnett, and Wesley Riddle

West Virginia University

ABSTRACT

Emissions from marine vessels are being scrutinized as a major contributor to total particulate matter (TPM), SO_x, and NO_x environmental loading. Fuel sulfur control is the key to SO_x reduction. Significant reductions in the emissions from on-road vehicles have been achieved in the last decade, and the emissions from these vehicles will be reduced by another order of magnitude in the next 5 years: these improvements have served to emphasize the need to reduce emissions from other mobile sources, including off-road equipment, locomotives, and marine vessels. Diesel-powered vessels of interest include oceangoing vessels with low- and medium-speed engines, as well as ferries with high-speed engines, as discussed below.

A recent study examined the use of intake water injection (WIS) and ultra-low sulfur diesel (ULSD) to reduce the emissions from a high-speed passenger ferry in southern California. One of the four Detroit Diesel 12V92 two-stroke high-speed engines that power the Waverider (operated by SCX, Inc.) was instrumented to collect intake airflow, fuel flow, shaft torque, and shaft speed. Engine speed and shaft torque were uniquely linked for given vessel draft and prevailing wind and sea conditions. A raw exhaust gas sampling system was utilized to measure the concentration of NO_x, CO_2, and O_2, and a mini-dilution tunnel sampling a slipstream from the raw exhaust was used to collect TPM on 70-millimeter filters. The emissions data were processed to yield brake-specific mass results. The system that was employed allowed for redundant data to be collected for quality assurance and quality control. To acquire the data, the Waverider was operated at three different speeds in the open sea off Oceanside, California.

Data have shown that the use of ULSD along with water injection could significantly reduce the emissions of NO_x and PM while not affecting fuel consumption or engine performance, compared to the baseline marine diesel. The results showed that a nominal 40-percent reduction in TPM was realized when switching from the marine diesel to the ULSD. A small reduction in NO_x was also shown between the marine fuel and the ULSD. The implementation of the WIS showed that NO_x was reduced significantly by between 11 and 17 percent, depending upon the operating condition. With the WIS, the TPM was reduced by a few percentage points, which was close to the confidence in measurement.

CATERPILLAR INC., HEAVY TRUCK CLEAN DIESEL PROGRAM

David M. Milam

Caterpillar, Inc.

ABSTRACT

The DOE Heavy Truck Clean Diesel (HTCD) program is a 5-year program aimed at demonstrating 50-percent thermal efficiency while complying with the 2007 and 2010 emissions regulations. The development program includes the evaluation of multiple technical solutions and culminates in the demonstration of the emission-compliant engine system in a truck chassis. This demonstration truck will be used for assessment of drivability, emissions compliance on various driving cycles, noise studies, etc. The other aspect of the demonstration truck is the integration of the various engine subsystems onto the engine and into the truck chassis in a manner that is suitable for multiple original equipment manufacturers.

POWERTRAP ä : ULTRAFINE PARTICULATE MATTER CONTROL WITHOUT PERFORMANCE PENALTIES

Peter Kukla

University of Manchester

ABSTRACT

The PowerTrap™ is a non-exhaust temperature dependent system that cannot become blocked and features a controlled regeneration process independent of the vehicle's drive cycle.

The system has a low direct-current power source requirement available in both 12-volt and 24-volt configurations. The system is fully programmable, fully automated and includes Euro IV requirements of operation verification. The system has gained European component-type approval and has been tested with both on- road and off-road diesel fuel up to 2000 parts per million.

The device is fail-safe: in the event of a device malfunction, it cannot affect the engine's performance. Accumulated mileage testing is in excess of 640,000 miles to date. Vehicles include London-type taxicabs (Euro 1 and 2), emergency service fire engines (Euro 1, 2, and 3), inner city buses, and light-duty locomotives. Independent test results by Shell Global Solutions have consistently demonstrated 85- 99 percent reduction of ultrafines across the 7-35 nanometer size range using a scanning mobility particle sizer with both ultra-low sulfur diesel and off-road high-sulfur fuel.

DEVELOPMENT AND DEPLOYMENT OF ADVANCED EMISSION CONTROLS FOR THE RETROFIT MARKET

Brad Edgar, Marc Rumminger, and Michael Streichsbier

Cleaire Advanced Emission Controls

ABSTRACT

Bringing a diesel retrofit product to market involves two primary phases: development and deployment. Critical product development steps include technology selection, system integration, laboratory and durability testing, and regulatory agency verification work. This initial product development phase is then followed by a deployment phase, which consists of building and managing the infrastructure for installation, distribution, service, sales and warranty support. Building relationships with regulators and air-quality program developers is also a critical aspect of the deployment process. A successful path to market requires close cooperation between developer, distributor, customer, and regulator.

Cleaire Advanced Emission Controls has developed an integrated NO_x and particulate matter (PM) control system called "Longview," which can be applied to a wide variety of engines and applications. In April 2003, Longview became the first broadly applicable, combined NO_x and PM emission control system to be verified by California Air Resources Board. Longview is verified to reduce NO_x by 25 percent and PM by 85 percent. Key elements of Longview include a NO_x reduction catalyst, a catalyzed diesel particulate filter, a reagent injection system, and a combined controller/datalogger called the "MLC®." Key criteria for the end-user are affordability, minimal impact on vehicle operations, and ready access to qualified service and support facilities. Important features for regulators and grant programs are verifiable emission reductions and cost-effectiveness.

Cleaire is a division of Cummins West, Inc., the exclusive distributor of Cummins Incorporated products in central and northern California. While Cleaire has been focused on the development of the system, it has also worked with its parent to develop the criteria to become an "Authorized Cleaire Distributor." Excellent results in the test cell and proven durability in the field are thereby combined with an organization competent to handle sales, installation and service activities to support the product.

The paper will discuss the basic design features of the Longview system, present laboratory and field test results, and discuss the key process steps required for successful launch and support of retrofit emission control systems.

FUEL ADDITIVE STRATEGIES FOR ENHANCING THE PERFORMANCE OF ENGINES AND ENGINE OILS

C. Yvonne Thiel, Thomas E. Hayden and Benjamin J. Kaufman

Chevron Oronite Technology Center

ABSTRACT

Chevron Oronite is developing and has commercialized fuel additives designed to reach the fuel/lubricant interface at the cylinder wall and impart performance improvements to both the engine and the engine oil. One such product is a gasoline-additive friction modifier that provides an immediate fuel economy benefit due to reduced friction between the piston ring and cylinder wall, a further improvement as it accumulates in the oil, as well as assisting wear protection and improving power output. In addition to these more obvious benefits, equal attention was given to avoiding harm issues such as in fuel handling, intake system deposits, combustion chamber deposits, and negative impacts on the engine oil.

We have designed diesel fuel additives that are intended to work similarly in a variety of diesel engines. The program has provided information about additive characteristics needed to reach the cylinder wall, despite engine design efforts to prevent fuel from doing so. As the candidate additives have reached the wall and sump intact, further work has shown that a functionalized molecule can provide the intended benefit upon reaching the cylinder wall and oil in this manner. We are now in the process of modifying the additive chemistry and getting dose/performance responses in a variety of engines.

TRANSIENT, REAL-TIME, PARTICULATE EMISSION MEASUREMENTS IN DIESEL ENGINES

Sreenath Gupta, Gregory Hillman, and Raj Sekar

Argonne National Laboratory

ABSTRACT

An instrument was developed to measure transient particulate mass emissions from diesel engines. This instrument, while based on laser-induced incandescence, allows measurements at 10 Hz. Using such an instrument, measurements were performed in the exhaust of a 1.7L Mercedes-Benz engine coupled to a low-inertia dynamometer. Comparative measurements performed under engine steady-state conditions show the instrument to agree within ±12% of measurements with a scanning mobility particle sizer. Moreover, the instrument showed far better time response to a step change in engine operation when compared with a TEOM 1105. Similar measurements performed over an urban driving cycle revealed that the instrument does not yield negative mass concentrations, unlike a typical TEOM.

Abstracts

Session 2 – Fuels and Lubrication, Part 1

THE NON-PETROLEUM BASED FUEL INITIATIVE

Bruce Bunting and John Storey

Oak Ridge National Laboratory

Wendy Clark

National Renewable Energy Laboratory

Kevin Stork

U.S. Department of Energy

ABSTRACT

The Non-Petroleum Based Fuels Initiative (NPBF) is being undertaken as a multi-year research, development, and testing activity by the Office of FreedomCAR and Vehicle Tech-nologies located in the DOE's Office of Energy Efficiency and Renewable Energy. This activity is being developed in collaboration with in-dustry, academia, and Government agency part-ners. The primary focus of this activity is to produce data that can help lead decisions relative to fuel options that improve fuel economy, reduce petroleum dependence, and ultimately pave the way to a hydrogen-based transportation system.

The multi-year work plan is being developed with input from fuel, automobile, and engine companies in order to identify which fuel options are the most viable and where gaps in knowledge or technology exist that could be addressed with pre-competitive research. The research plan for this work is being developed through a series of meetings and discussions with all interested parties.

This Diesel Engine Emissions Reduction Conference talk will present the work plan in its current, evolving form in order to help dis-seminate information and to gather comments and questions relating to this initiative.

APBF-DEC NO_X ADSORBER/DPF PROJECT: PASSENGER CAR PLATFORM

Dean Tomazic and Marek Tatur

FEV Engine Technology, Inc.

Matthew Thornton

National Renewable Energy Laboratory

ABSTRACT

Due to increased fuel costs and a desire to reduce dependence on foreign oil, the diesel engine is becoming a prime candidate for future medium-duty vehicle applications in the United States. The diesel engine ex-hibits high thermal efficiency and superior durability compared to the gasoline engine. The main obstacle to increased use of diesel engines is the upcoming (extremely strin-gent) EPA Tier 2 emission standards. To succeed, these vehicles must comply with emission standards while maintaining their excellent fuel economy. The availability of technologies, such as common rail fuel injection systems, low-sulfur diesel fuel, NO_x adsorber catalysts, and diesel par-ticulate filters, allow the development of powertrain systems with the potential to comply with targeted requirements. In support of this, the U.S. Department of Energy (DOE) has undertaken several test projects as part of its Advanced Petroleum Based Fuels - Diesel Emission Control (APBF-DEC) activity. Primary questions among those addressed by these projects are sulfur tolerance, durability, and performance of the NO_x adsorber/DPF system for varying fuel sulfur levels. The test bed for one pro-ject in this activity is an Audi A4 Avant equipped with a 1.9L prototype TDI engine with common rail fuel injection.

While NO_x adsorber catalyst (NAC) sys-tems have demonstrated extremely high lev-els of NO_x reduction in steady-state labor-atory evaluations, the application of NAC systems to actual transient engine appli-cations requires development of an integrated engine-emissions management system. This paper discusses the integrated engine-emissions system management and the development of regeneration control strategies. Performance of fresh and aged systems tested over the FTP-75, HFET, and US06 test cycles will also be summarized, including emissions of regulated and presently unregulated species.

APBF-DEC NO_x ADSORBER/DPF PROJECT: SUV/PICKUP PLATFORM

Cynthia Webb and Phil Weber

Southwest Research Institute

Matthew Thornton

National Renewable Energy Laboratory

ABSTRACT

Due to increased fuel costs and a desire to reduce dependence on foreign oil, the diesel engine is becoming a prime candidate for future medium-duty vehicle applications in the United States. The diesel engine exhibits high thermal efficiency and superior durability compared to the gasoline engine. The main obstacle to increased use of diesel engines is the upcoming (extremely strin-gent) EPA Tier 2 emission standards. To succeed, these vehicles must comply with emission standards while maintaining their excellent fuel economy. The availability of technologies, such as common rail fuel injection systems, low-sulfur diesel fuel, NO_x adsorber catalysts, and diesel particulate filters, allow the development of powertrain systems with the potential to comply with targeted requirements. In support of this, the U.S. Department of Energy (DOE) has undertaken several test projects as part of its Advanced Petroleum Based Fuels — Diesel Emission Control (APBF-DEC) activity. Primary questions among those addressed by these projects are sulfur tolerance, durability, and performance of the NO_x adsorber/DPF system for varying fuel sulfur levels. The heavy light-duty (HLDT) and medium-duty passenger vehi-cles (MDPV) will face the greatest tech-nological challenges in meeting the Tier 2 emissions standards. The test bed for one project in this activity is a 2500 series Chevrolet Silverado equipped with a 6.6L Duramax diesel engine certified for 2002 model year Federal heavy-duty and 2002 model year California medium-duty emis-sion standards.

While NO_x adsorber catalyst (NAC) sys-tems have demonstrated extremely high lev-els of NO_x reduction in steady-state labor-atory evaluations, the application of NAC systems to actual transient engine appli-cations requires development of an inte-grated engine-emissions management sys-tem. This paper discusses the integrated engine-emissions system management and the development of regeneration control strategies. Performance of fresh and aged systems tested over the FTP-75, HFET, and USO6 test cycles will also be summarized, including emissions of regulated and presently unregulated species.

APBF-DEC NO_x ADSORBER/DPF PROJECT: HEAVY-DUTY LINEHAUL PLATFORM

Mike May

Ricardo, Inc.

Shawn D. Whitacre

National Renewable Energy Laboratory

ABSTRACT

This presentation outlines the development and integration of an advanced emission control system with a modern heavy-duty diesel engine that is being used for durability testing. The project that is discussed is one of several being conducted under the U.S. Department of Energy's Advanced Petroleum-Based Fuels - Diesel Emission Control (APBF-DEC) activity. This Government/industry collaboration is examining how systems of advanced fuels, engines, and emission control systems can deliver significantly lower emissions while maintaining or improving vehicle fuel economy. A Cummins ISX EGR engine (15 L), with a secondary fuel injection system to enable NO_x adsorber catalyst regeneration, has been developed for use in a series of durability tests with fuels of different sulfur levels. Development of the strategies for NO_x regeneration and sulfur removal as well as integration of the emission control hardware is discussed. Performance of fresh and aged systems tested over transient and steady-state cycles is summarized, including emissions of regulated and presently unregulated species.

DEMONSTRATION OF THE LOW-EMISSION POTENTIAL FOR UREA SELECTIVE CATALYTIC REDUCTION AND DIESEL PARTICULATE FILTER TECHNOLOGIES

Magdi Khair and Chris Sharp

Southwest Research Institute

Ralph McGill

Oak Ridge National Laboratory

ABSTRACT

The demonstration of the potential for urea selective catalytic reduction (SCR) and diesel particulate filter technologies is one of the major projects in the Advanced Petroleum-Based Fuels – Diesel Emission Control (APBF-DEC) activity. The objective of this project is to integrate several diesel emission control technologies to demonstrate their capability to comply with the 2007 heavy-duty diesel engine standards. Once the engine and control system were developed, several fuels having various sulfur content were evaluated to establish the sensitivity of the control system to sulfur.

The work is being conducted on a Caterpillar C-12 heavy-duty diesel engine. Two different emission control systems, employing urea SCR catalysts and diesel particulate filters, were calibrated and showed the potential for controlling NO_x and particulate matter emissions to levels near the 2007 standards. The project will also examine the long-term durability of the control systems and their interaction with the test fuels. This presentation is a summary of this work, which is still in progress.

THE CHEMICAL STATES AND COMPOUNDS OF LUBE OIL PHOSPHOROUS IN DIESEL EXHAUST

Sam Lewis, Bruce Bunting, and John Storey

Oak Ridge National Laboratory

ABSTRACT

Phosphorous in diesel exhaust is derived from the ZDDP additive in lube oil used for wear control. Phosphorous emitted in the engine exhaust can react with an aftertreatment catalyst and cause loss of performance through masking or chemical reaction. It appears that there is a minimum level of ZDDP needed for engine durability. One of the ways of reducing the effects of the resulting phosphorous on catalysts might be to alter the chemical state of the phosphorous to a less damaging form. And, one of the first requirements of altering the chemical state of phosphorous is to be able to measure the chemical state and compounds in diesel exhaust. In this preliminary study, the phosphorous compounds in diesel exhaust were measured by a variety of analytical techniques and correlated to such variables as ZDDP concentration in the oil, exhaust temperature, and fuel doping with ZDDP. These analytical techniques will then be applied to lube oil formulation studies and to catalyst durability studies in order to reduce or eliminate phosphorous poisoning in a catalyst.

Abstracts

Session 3 – Fuels and Lubrication, Part 2

EMISSIONS FROM HEAVY-DUTY DIESEL ENGINE WITH EXHAUST GAS RECIRCULATION USING OIL SANDS DERIVED FUELS

Stuart Neill

National Research Council Canada

ABSTRACT

The oil sands deposits in Alberta contain approximately 1.6 trillion barrels of bitumen, a naturally occurring viscous mixture of hydrocarbons. Approximately 20 percent of these bitumen reserves are recoverable with current technology. In 2002, the Canadian oil sands industry produced approximately 800,000 barrels of bitumen and bitumen-derived crude oil per day, and production is expected to increase to almost 2 million barrels per day by 2011. It is estimated that up to 75 percent of the oil sands production in 2011 will be exported to the U.S. market.

The presentation will discuss the unique characteristics and properties of oil sands derived crude, which reflect the bitumen source and the upgrading processes that the bitumen undergoes, as well as the emissions behavior of diesel fuels containing oil sands components.

In a recent study, the exhaust emissions from a single-cylinder version of a heavy-duty diesel engine with exhaust gas recirculation (EGR) were measured using 12 diesel fuels derived from oil sands and conventional sources. Exhaust emissions were measured using the AVL eight-mode steady-state test procedure. Particulate matter (PM) emissions for all test fuels were accurately modeled by a single regression equation with two predictors: fuel total aromatics and sulfur content. Similarly, NO_x emissions were found to depend on fuel total aromatics and density. In summary, the PM and NO_x emissions were significantly affected by key compositional fuel properties, but the crude oil source did not play a role.

DEVELOPMENT AND DEMONSTRATION OF FISCHER-TROPSCH FUELED HEAVY-DUTY VEHICLES WITH CONTROL TECHNOLOGY FOR REDUCED DIESEL EXHAUST EMISSIONS

Brad Adelman and Mike May

Ricardo

Bernard Treanton

California Energy Commission

Teresa Alleman

National Renewable Energy Laboratory

Greg Barton

Automotive Testing Laboratory

Adewale Oshinuga

South Coast Air Quality Management District

Ralph Cherrillo and Ian Virrels

Shell Global Solutions

ABSTRACT

The objectives of this study are to modify two 2002 Model Year Cummins ISM engines (equipped with exhaust gas recirculation [EGR]) to achieve 1.2 g/hp-h NO_x emissions and 0.01 g/hp-h particulate matter (PM) over the heavy-duty Federal Test Procedure (FTP) cycle using Fischer-Tropsch (F-T) fuel, optimized combustion, lean NO_x catalyst (LNC) with secondary injection, and a diesel particulate filter (DPF). After their performance is proven in a test cell, the plan is to install the modified engines and aftertreatment systems in two vehicles and operate the vehicles in a commercial application. The program is sponsored by the South Coast Air Quality Management District, the California Energy Commission, the U.S. Department of Ener-gy, and the National Renewable Energy Laboratory

This presentation covers the first phase of the work — the optimization of the en-gine and aftertreatment systems to demon-strate the targets in an emissions test cell.

The effect of F-T fuel on the base engine was first evaluated over the heavy-duty diesel FTP cycle. In comparison to a low aromatic California Air Resources Board ultra-low sulfur diesel fuel, a 4.5-percent decrease in NO_x and a 17.6-percent decrease in PM were measured.

To achieve a major reduction in engine out NO_x emissions, the chosen strategy was to increase the EGR rate and employ an LNC. To tolerate higher EGR rates, the combustion bowl was modified to increase the bowl volume (decreased compression ratio is possible due to the superior ignition qualities of F-T fuel) and air motion. Increased EGR rate and combustion modi-fications lead to a further 25-percent de-crease in NO_x but a 30-percent increase in PM.

An exhaust aftertreatment system con-sisting of an LNC and catalyzed DPF was then installed. The efficiency of catalyzed aftertreatment is improved with virtually sulfur-free F-T fuel. Secondary F-T fuel was added to the exhaust to facilitate the LNC performance. The exhaust aftertreatment led to a further 19-percent NO_x reduction and 95-percent PM removal Composite emis-sions of 1.168 g/hp-h NO_x and 0.005 g/hp-h PM were achieved over the heavy-duty FTP cycle.

FUEL FORMULATION EFFECTS ON DIESEL FUEL INJECTION, COMBUSTION, EMISSIONS, AND EMISSION CONTROL

André Boehman, Mahabubul Alam, Juhun Song, Ragini Acharya, Jim Szybist, and Vince Zello

Pennsylvania State University

Kirk Miller

ConocoPhillips

ABSTRACT

This paper describes work under an Ultra Clean Fuels project entitled "Ultra Clean Fuels from Natural Gas," Cooperative Agreement No. DE-FC26-01NT41098. In this study we have examined the incremental benefits of moving from low-sulfur diesel fuel and ultra-low sulfur diesel fuel to an ultra-clean fuel, Fischer-Tropsch diesel fuel produced from natural gas. Blending with biodiesel, B100, was also considered. The impact of fuel formulation on fuel injection timing, bulk modulus of compressibility, in-cylinder combustion processes, gaseous and particulate emissions, diesel particulate filter regeneration temperature, and urea selective catalytic reduction NO_x control has been examined. The primary test engine is a 5.9L Cummins ISB, which has been instrumented for in-cylinder combustion analysis and in-cylinder visualization with an engine video-scope. A single-cylinder engine has also been used to examine in detail the impacts of fuel formulation on injection timing in a pump-line-nozzle engine in order to assist in the interpretation of results from the ISB engine.

A REVIEW OF VEGETABLE OIL RESEARCH AT PENN STATE

Kraipat Cheenkachorn, Kimberly Wain, Waleska Castro, Wallace Lloyd, and Joseph M. Perez

Pennsylvania State University

ABSTRACT

This presentation will review current projects at Pennsylvania State University on the use of vegetable oils as fuels, hydraulic fluids, and engine oils. Research is being conducted on such alternative fuels as B100, B20, and VPO B20. A hydraulic fluid project to convert farm and construction equipment on campus will be described as will efforts to develop high- temperature lubricants and next-generation lubri-cants containing minimal sulfur and phosphorus. Studies of the effect of coatings on friction, wear, and deposits will be discussed.

THE IMPACT OF OIL CONSUMPTION MECHANISMS ON DIESEL EXHAUST PARTICLE-SIZE DISTRIBUTIONS AND DETAILED EXHAUST CHEMICAL COMPOSITION

John Stetter, Nathan Forster, Jaal Ghandhi and David Foster

University of Wisconsin – Madison

ABSTRACT

Detailed exhaust emission data have been taken from a Cummins N-14 single-cylinder research engine in which the oil consumption was varied by different engine modifications. Low-sulfur fuel was used, and oil consumption was varied by modifying the intake valve stem seals, the exhaust valve stem seals, the oil control ring, and combinations of these modi-fications. Detailed measurements of exhaust gas particle-size distributions and chemical compo-sition were made for the various oil consumption configurations for a range of engine loads and speeds.

The data indicate that the particle-size dis-tribution is impacted by oil consumption of the engine. Furthermore, the nature of the change in particle-size distribution depends on the mech-anism of the oil consumption. For example, the diameter of the maximum particle concentration shifts from being smaller than, to being larger than, the base engine case for different oil con-sumption modes and different operating con-ditions.

The particulate mass was measured with TEOM and traditional gravimetric filter me-thods. Filter data for elemental carbon/organic carbon, sulfates, and trace metals have been taken and are being analyzed. The trace metals in the particulate mass serve as the basis for assessing oil consumption at the dif-ferent operating conditions. The results of these analyses will be presented.

IMPACT OF THE FUEL-BORNE CATALYST MMT ON DIESEL PARTICULATE FILTERS AND LEAN NO_X TRAP PERFORMANCE

David Human

Ethyl Petroleum Additives

ABSTRACT

This presentation builds on the work summarized by Ethyl at the DEER 2002 Conference by examining the role that MMT can play in catalyzed diesel particulate filter systems and lean NO_x traps (LNT's) using a contemporary Model Year 2002 medium-duty Cummins 5.9L ISB diesel engine. Balance point and filter loading were investigated at a series of engine speed and load combinations, with soot accumulation and balance point being reduced in all cases. Soot accumulation was affected as MMT lowered the amount of elemental carbon emissions (dry particulate). MMT was also found to protect lean NO_x traps by scavenging the fuel sulfur and engine oil-derived phosphorus and incorporating them into the ash. Improvements in LNT performance and durability were demonstrated using MMT in ultra-low sulfur fuel.

Abstracts

Session 4 – Waste Heat Utilization

THERMOELECTRICAL ENERGY RECOVERY FROM THE EXHAUST OF A LIGHT TRUCK

Eric Thacher, Brian Helenbrook, Madhav Karri, and Marc Compeau

Clarkson University

Aleksandr Kushch and Norbert Elsner

Hi-Z Technology, Inc.

Mohinder Bhatti and John O'Brien,

Delphi Automotive Systems, Inc.

Francis Stabler

General Motors, Inc.

ABSTRACT

A team formed by Clarkson University is engaged in a project to design, build, test, and develop a plan to commercialize a thermoelectric generator (TEG) for recovering some of the energy in the exhaust from light trucks and passenger cars. The team members are Clarkson University (project management, vehicle inter-face design, system modeling, commercialization plan), Hi-Z Technology, Inc. (TEG design and construction, subcontractor to Clarkson), Delphi Automotive Systems (testing services and engi-neering consultation), and General Motors, Inc. (test vehicle).

Funds were supplied by a grant from the Transportation Research Program of the New York State Energy Research and Development Authority (Joseph Wagner, Project Manager). Members of the team and the U.S. Department of Energy's Office of FreedomCAR and Vehicle Technologies (John Fairbanks, Project Manager) supplied cost-sharing and in-kind support. General Motors loaned the test truck (a 1999 Sierra) and supplied information about its sys-tems. Delphi Automotive Systems, Inc., supplies engineering consulting services and will furnish 2 weeks of testing time at its Lockport, New York, facility.

The TEG consists of 16 HZ-20 modules connected in series, clamped between the ex-haust and coolant heat exchangers and elec-trically connected to the DC bus through a power-conditioning unit. It will be capable of generating 330 W of electric power when it op-erates at its design temperature differential. The exhaust from the test truck's 270 hp V8 gasoline engine passes through the two catalytic con-verters located near the left and right sides of the truck frame and then will be routed through the TEG. To provide for reliable thermoelectric module cooling, the TEG will be integrated into the truck engine cooling system.

This presentation will: (1) show some of the results of initial studies using a model that incorporates the TEG system into the National Renewable Energy Laboratory's ADVISOR ve-hicle simulation code, (2) discuss the principal conclusions of a market survey done for the project's draft commercialization plan, and (3) summarize the first portion of the Phase 2 work now underway.

SCALE-UP OF $Si/Si_{0.8}Ge_{0.2}$ AND B_4C/B_9C SUPERLATTICES FOR HARVESTING OF WASTE HEAT IN DIESEL ENGINES

P. M. Martin and L. C. Olsen

Pacific Northwest National Laboratory

ABSTRACT

Thermoelectric devices show significant promise for harvesting and recovery of waste heat from diesel engines, exhaust sys-tems, and industrial heat sources. Con-version efficiencies of bulk thermoelectric systems, however, are still too low for eco-nomical power conversion in diesel-powered vehicles and heavy vehicles.

Thermoelectric superlattice devices have demonstrated the potential for increased efficiencies and utilization of waste heat. Although reported efficiencies are well above 15 percent, fabrication costs are still too high for use in diesel engine systems. To realize this efficiency goal of ~20% and power generation in the kW-MW range, large quantities of superlattice materials are required. Additionally, if the figure of merit (ZT) of these superlattices can be increased to > 2, even less superlattice material will be required to generate electric power from heat in diesel engines.

We report on development of and recent progress in scale-up of $Si/Si_{0.8}Ge_{0.2}$ and B_4C/B_9C superlattices for thermoelectric ap-plications, and particularly for fabrication of large quantities of these materials. We have scaled up the magnetron sputtering process to produce large quantities of $Si/Si_{0.8}Ge_{0.2}$ and B_4C/B_9C superlattices with high ZT at low cost. Superlattices with up to 1,000 layers were deposited onto substrate areas as large as 0.5 m^2 by magnetron sputtering.

Initial studies showed that the power factor of these superlattices was high enough to produce a ZT significantly greater than 1. Both p- and n-type superlattices were fab-ricated to form a complete thermoelectric power-generating device.

ZT measurements will be reported, and based on measured power factor of these materials, should be significantly greater than 1. These results are encouraging for the use of superlattice materials in thermo-electric power generation.

POTENTIAL THERMOELECTRIC APPLICATIONS IN DIESEL VEHICLES

Douglas Crane

BSST, LLC

ABSTRACT

Novel thermodynamic cycles developed by BSST provide improvements by factors of approximately 2 in cooling, heating, and power generation efficiency of solid-state thermo-electric systems. The BSST technology is avai-lable now and is currently being evaluated in automotive development programs for important new applications. New thermoelectric materials are likely to become available that further in-crease performance by a comparable factor. These major advancements should allow the use of thermoelectric systems in new applications that have the prospect of contributing to emis-sions reduction, fuel economy, and improved user comfort.

Potential applications of thermoelectrics in diesel vehicles are identified and discussed. As a case in point, the history and status of the Climate Controlled Seat (CCS™) system from Amerigon, the parent of BSST, is presented. CCS is the most successful and highest production volume thermoelectric system in ve-hicles today. As a second example, the results of recent analyses on electric power generation from vehicle waste power are discussed. Con-clusions are drawn as to the practicality of waste power generation systems that incorporate BSST's thermodynamic cycle and advanced thermoelectric materials.

RECENT PROGRESS IN THE DEVELOPMENT OF HIGH-EFFICIENCY THERMOELECTRICS

J. C. Bass, N. B. Elsner, and S. Ghamaty

Hi-Z Technology, Inc.

ABSTRACT

This paper will discuss the recent de-velopments of high-efficiency quantum well thermoelectrics at Hi-Z Technology, Inc. The performance of the latest P-type B_4C/B_9C – N-type Si/SiGe couple will be presented as well as data for the new N-type Si/SiC that will replace Si/SiGe and improve couple efficiency.

Preliminary calculations regarding the development of actual quantum well mod-ules will be presented for both power pre-diction and cooling applications. These modules can be used in future diesel exhaust energy conversion systems as well as air-conditioning system designs. The design of a family of small quantum well based generator wells being developed for wireless sensor systems will also be presented. These small generators use energy-har-vesting techniques to produce power for the system.

Our current efforts to produce quantum well films more rapidly will be discussed.

DESIGN AND DEVELOPMENT OF E-TURBO™ FOR SPORT UTILITY VEHICLE AND LIGHT-TRUCK APPLICATIONS

Craig Balis, Chris Middlemass, and S. M. Shahed

Garrett Engine Boosting Systems

ABSTRACT

The purpose of the project is to develop an electrically assisted turbocharger, e-Turbo™, for application to the sport utility vehicle (SUV) and light truck class of passenger vehicles. Earlier simulation work had shown the benefits of the e-Turbo™ system on increasing low-end torque and improving fuel economy. This paper will present further data to show that advanced turbocharging can enable diesel engine down-sizing of 10-30 percent with 6-17 percent im-provement in fuel economy. This is in addition to the fuel economy benefit that a turbocharged diesel engine offers over conventional gasoline engines. In this downsizing scenario, e-Turbo™ is necessary to recover acceptable driving char-acteristics with downsized diesel engines.

As a first step towards the development of this technology for SUV/light truck sized diesel engines (4-6 L displacement), design concepts and hardware were evaluated for a smaller engine (2 L displacement). This strategy was chosen to minimize design and development is-sues and then prove the concept in bench testing and small engine testing. Following small en-gine success, the concept could applied to a large V-engine (one on each bank) to prove target performance characteristics. After successful demonstration of concept and performance, large turbomachinery could be designed and built spe-cifically for larger SUV-sized diesel engines. This paper presents the results of development of e-Turbo for a 2 L diesel engine.

A detailed evaluation of motor-generator and turbocharger requirements and designs has been performed, including comparison of different motor-generator technologies and dif-ferent motor-generator/turbocharger integration schemes. Detailed analysis and bench testing have been performed to confirm basic design concepts and will be used to finalize product design for engine testing.

DIESEL ENGINE WASTE HEAT RECOVERY UTILIZING ELECTRIC TURBOCOMPOUND TECHNOLOGY

Ulrich Hopmann

Caterpillar, Inc.

ABSTRACT

Electric turbocompounding (ETC) is a way to recover exhaust heat energy and return it to the driveline. ETC integrates well into a MorElectric™ Initiative vehicle and allows previously unattainable level of con-trol of the engine air system. The primary goal is a 5-percent reduction in fuel con-sumption and/or emissions.

This presentation will report progress to date on a technology demonstration pro-gram. Component design and analysis as well as control system development will be reviewed. The ETC system requires a completely new control strategy and control system. Two electrical motor/generators, one on the turbo shaft and one on the crankshaft, are part of the ETC system; their design and test results on the dynamometer will be shown. Furthermore, design and per-formance test results of a newly developed turbocharger will be presented.

Abstracts

Session 5 – Diesel and CNG Bus Emissions

STATE OF THE ART IN DIESEL EMISSION CONTROL

Timothy V. Johnson

Corning, Inc.

ABSTRACT

The entire field of diesel emission control is developing rapidly. In addition to advances in exhaust emission control technology, regulatory proposals are approaching the U.S. 2010 levels in Japan and Europe, and the engines are getting cleaner.

This presentation will bring the audience up to date with the latest published information on the regulations, estimates of engine-out emissions, filter technology, NO_x technology, and integrating it all into viable systems for use in light- and heavy-duty applications.

In summary, it appears that nominally 80-percent filtration efficiency is needed to hit the Japanese 2005 and U.S. 2007 interim heavy-duty diesel regulations, while employing high levels of exhaust gas recirculation (EGR). In Europe, for both Euro 4 in 2005 and Euro 5 in 2008, 70-80 percent selective catalytic reduction (SCR) will be used in fuel-sensitive applications, while diesel oxidation catalysts (DOC's) and some filters will show up in others. In light-duty, depending on vehicle size and which engine technologies emerge, nominally 50 percent NO_x efficiency will be needed to hit proposed Euro 5 regulation in 2010 and 70-80 percent NO_x efficiency will be needed to hit the Bin 5 U.S. fleet average.

In the filter arena, improvements continue on regeneration strategies and filter performance. For NO_x control, SCR is progressing to commercialization, and the NO_x traps are in a rapid stage of development and improvement, with better materials and strategies for regeneration and desulfation. Integration of NO_x and PM control is entering the heavy-duty vehicle stage with SCR and filter systems on prototype vehicles, and NO_x trap and filter systems showing up on light-duty vehicles and on heavy-duty engine dynamometers.

SUMMARY OF SWEDISH EXPERIENCES ON CNG AND"CLEAN" DIESEL BUSES

Peter Ahlvik

Ecotraffic ERD3 AB

ABSTRACT

In Sweden, emission tests were conducted on compressed natural gas (CNG) and diesel buses in the 1990's as part of several governmental programs in this area. A summary of the evaluation presented at DEER 2001 is provided. In addition, a comparison between the Swedish results and some of the more recent results from the U.S. studies is made.

The analysis of the Swedish results showed considerable improvement on the diesel buses by reformulating the diesel fuel and by fitting aftertreatment devices. Particulate filters (DPF's) can reduce particle emissions from diesel buses to a level similar to that of the CNG buses. The NO_X emissions can be reduced by some 50 percent by using retrofit exhaust gas recirculation (EGR) systems, but the level was still higher than for the best CNG buses.

CNG had a positive impact regarding several of the effects investigated, e.g., acidification and local NO_2 emissions. In other cases (e.g., ozone-forming potential), the difference between the best options was small. The cancer risk index is largely dependent on the unit risk factors, but the overall result in this case did not vary much between the sets of risk factors used. Clean diesel fuel with a particulate trap and CNG/biogas were the options with the lowest cancer risk index. The impact on the greenhouse gas emissions was the most significant advantage for the biofuels.

It is interesting to note that there are both similarities and differences between the engine technology used in Sweden and the United States. First, it should be noted that the U.S. buses are relatively new, i.e., Model Year 2002-2001, while the Swedish tests originate from the 1990's. A large proportion of the diesel buses in Sweden use oxidation catalysts, DPFs or EGR in combination with DPF. Practically all CNG buses in Sweden are equipped with oxidation catalysts, whereas until recently, relatively few have been using oxidation catalysts in the United States. However, it is suspected that the first generation of CNG catalysts has poor durability. Closed loop control was not used on the older Swedish CNG buses but was introduced in 2002.

The "best" test results on CNG in Sweden indicated surprisingly low NO_X emissions in comparison to most U.S. results. A more advanced combustion system on the (newer) U.S. diesel engines yielded lower HC emissions and, thus, also less harmful toxic VOCs, e.g., PAH emissions and formaldehyde. The results for twelve tri+ PAH species analyzed in all studies were compared, indicating a great reduction potential for fuel reformulation and catalytic DPFs. The PAH level for CNG without catalyst was significantly higher, but the impact of a catalyst still has to be assessed. An efficient oxidation catalyst is also essential to achieve low levels of formaldehyde for CNG buses. The results on 1,3-butadiene tended to be somewhat inconclusive.

A valid conclusion from all test results is that aftertreatment devices are crucial to achieve low emissions, regardless of fuel used. It is expected that future development on engines and aftertreatment devices will diminish the advantage of the alternative fuels regarding many of the effects on health and environment. On the contrary, the impact on greenhouse gases from some biofuel options will be more pronounced in the future.

COMPARISON OF EXHAUST EMISSIONS, INCLUDING TOXIC AIR CONTAMINANTS, FROM SCHOOL BUSES IN COMPRESSED NATURAL GAS, LOW-EMITTING DIESEL, AND CONVENTIONAL DIESEL ENGINE CONFIGURATIONS

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ABSTRACT

In the United States, most school buses are powered by diesel engines. Some have advocated replacing diesel school buses with natural gas school buses, but little research has been conducted to understand the emissions from school bus engines. This work provides a detailed characterization of exhaust emissions from school buses using a diesel engine meeting 1998 emission standards, a low-emitting diesel engine with an advanced engine calibration and a catalyzed particulate filter, and a natural gas engine without catalyst. All three bus configurations were tested over the same cycle, test weight, and road load settings. In addition, the quantitative results from this study were used to calculate cancer potency weighted emissions.

Twenty-one of the 41 "toxic air contaminants" (TAC's) listed by the California Air Resources Board as being present in diesel exhaust were not found in the exhaust of any of the three bus configurations, even though special sampling provisions were utilized to detect low levels of TAC's. Although there were no significant differences between the low-emitting diesel and the natural gas bus configurations for 14 TAC's, the low-emitting diesel bus configuration had significantly lower emission levels than the natural gas bus configuration for aldehydes, ketones, and benzene. Overall, the results demonstrate that low-emitting diesel technology had the lowest level of both EPA-regulated emissions and TAC's.

COMPARISON OF CLEAN DIESEL BUSES TO COMPRESSED NATURAL GAS BUSES

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MTA New York City Transit

ABSTRACT

Using previously published data on regulated and unregulated emissions, this paper will compare the environmental performance of current- generation transit buses operated on compressed natural gas (CNG) to current-generation transit buses operated on ultra-low sulfur diesel fuel (ULSD) and incorporating diesel particulate filters (DPF). Unregulated emissions evaluated include toxic compounds associated with adverse health effects (PAH, NPAH, benzene) as well as particulate matter (PM) particle count and size distribution.

For all regulated and unregulated emissions except NO_x, both technologies are shown to be comparable, with virtually identical levels of PM emissions, toxic emissions, and particle number emissions. DPF-equipped buses are shown to have lower HC and CO emissions than CNG buses. CNG buses are shown to have NO_x emissions that average 25 percent less than NO_x emissions from DPF-equipped buses, though CNG bus NO_x emissions are shown to be much more variable.

In addition, this paper will compare the capital and operating costs of CNG and DPF-equipped buses. The cost comparison is primarily based on the experience of MTA New York City Transit in operating CNG buses since 1995 and DPF-equipped buses fueled with ULSD since 2001. Published data on the experience of other large transit agencies in operating CNG buses is used to validate the NYCT experience.

The incremental cost (compared to "baseline" diesel) of operating a typical 200-bus depot is shown to be six times higher for CNG buses than for "clean diesel" buses. The contributors to this increased cost for CNG buses are almost equally split between increased capital costs for purchase of buses and installation of fueling infrastructure, and increased operating costs for purchase of fuel, bus maintenance, and fuel station maintenance.

COMPRESSED NATURAL GAS AND DIESEL TRANSIT BUS EMISSIONS IN REVIEW

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California Air Resources Board

Reiko Kobayashi and Paul Kuzmicky

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ABSTRACT

Over the past 3 years, the California Air Resources Board (CARB), in collaboration with the University of California and other entities, has investigated the tailpipe emissions from three different late-model, in-use heavy-duty transit buses in five different configurations. The study has focused on the measurement of regulated emissions (NO_x, HC, CO, total particulate matter [PM]), other gaseous emissions (CO_2, NO_2, CH_4, NMHC), a number of pollutants of toxic risk significance (aromatics, carbonyls, PAH's, elements), composition (elemental and organic carbon), and the physical characterization (size-segregated number count and mass) of the particles in the exhaust aerosol. The impact of oxidation catalyst control for both diesel and compressed natural gas (CNG) buses and a passive diesel particulate filter (DPF) were evaluated over multiple driving cycles (idle, 55-mph cruise, CBD, UDDS, NYBC) using a chassis dynamometer. The database of results is large, and some findings have been reported already at various forums including last year's DEER Conference. The goal of this paper is to offer an overview of the lessons learned and attempt to draw overall conclusions and interpretations based on key findings to date. To the extent possible, our results are compared to those from other similar studies.

HEAVY-DUTY VEHICLE IN-USE EMISSION PERFORMANCE

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VTT Processes

ABSTRACT

Engines for heavy-duty vehicles are emission certified by running engines according to specified load pattern or duty cycle. In the United States, the U.S. Heavy-Duty Transient cycle has been in use already for a number of years, and Europe is, according to the requirements of the Directive 1999/96/EC, gradually switching to transient-type testing.

Evaluating the in-use emission performance of heavy-duty vehicles presents a problem. Taking engines out of vehicles for engine dynamometer testing is difficult and costly. In addition, engine dynamometer testing does not take into account the properties of the vehicle itself (i.e., mass, transmission, etc.). It is also debatable how well the standardized duty cycles reflect real-life driving patterns.

VTT Processes has recently commissioned a new emissions laboratory for heavy-duty vehicles. The facility comprises both engine test stand and a fully transient heavy-duty chassis dynamometer. The roller diameter of the dynamometer is 2.5 m. Regulated emissions are measured using a full-flow CVS system. The heavy-duty vehicle chassis dynamometer measurements (emissions, fuel consumption) have been granted accreditation by the Centre of Metrology and Accreditation (MIKES, Finland).

A national program to generate emissions data on buses has been set up for the years 2002-2004. The target is to generate emission factors for some 50 different buses representing different degree of sophistication (Euro 1 to Euro5/EEV, with and without exhaust gas aftertreatment), different fuel technologies (diesel, natural gas) and different ages (the effect of aging). The work is funded by the Metropolitan Council of Helsinki, Helsinki City Transport, The Ministry of Transport and Communications Finland, and the national gas company Gasum Oy.

The International Association for Natural Gas Vehicles (IANGV) has opted to buy into the project. For IANGV, VTT will deliver comprehensive emissions data (including particle-size distribution and chemical and biological characterization of particles) for up-to-date diesel and natural gas vehicles.

The paper describes the methodology used for the measurements on buses, the test matrix, and some preliminary emissions data on both regulated and unregulated emissions.

COMPARATIVE STUDY ON EXHAUST EMISSIONS FROM DIESEL AND COMPRESSED NATURAL GAS POWERED URBAN BUSES

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Technologies des Transports

Thierry Seguelong, *presenter*

Aaqius & Aaqius

ABSTRACT

A couple of years ago, ADEME engaged in programs dedicated to emissions studies of the exhaust from urban buses. The measures associated with the reduction of atmospheric and noise pollution have particular importance in the sector of urban buses. In many cases, they illustrate the city's environmental image and contribute to reinforcing the attractiveness of public transport. France's fleet in service, presently put at about 14,000 units, consumes about 2 percent of the total energy of city transport. It causes about 2 percent of the HC emissions and from 4 to 6 percent of the NO_x emissions and particles. These vehicles typically have a long life span (about 15 years) and are relatively expensive to buy, about €150,000 per unit.

Several technical solutions were evaluated to quantify, on a real-condition cycle for buses, pollutant emissions and fuel consumption on one hand and reliability and cost in real existing fleets on the other hand.

This paper presents the main preliminary results on exhaust emissions from urban buses for two different cases:

- existing diesel buses, with fuel modifications (diesel with low-sulfur content, diesel with water emulsion, and biodiesel [30 percent oil ester in standard diesel fuel]) and
- renovated CNG-powered Euro II bus fleet

over representative driving cycles, set up by ADEME and partners. On these cycles, pollutants (regulated and unregulated) were measured as well as fuel consumption at the beginning of a program and 1 year after to quantify reliability and increase/decrease of pollutant emissions.

At the same time, some aftertreatment technologies were tested under real conditions and in several vehicles. Information such as fuel consumption, lubricant analysis, and problems of the technology were followed during a 1-year program.

On the overall level, it is the combination of various action, pollution reduction, and renewal that will make it possible to meet the technological challenge of reducing emissions and fuel consumption by urban bus networks.

STATE-OF-THE-ART AND FUTURE DEVELOPMENTS IN NATURAL GAS ENGINE TECHNOLOGIES

Mark Dunn

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ABSTRACT

Current, state-of-the-art natural gas engines provide the lowest emissions commercial technology for use in medium- to heavy-duty vehicles. NO_x emission levels are 25-50 percent lower than October 2002 diesel engines, and particulate matter (PM) levels are 90 percent lower than non-filter equipped engines. Yet, in common with diesel engines, natural gas engines are challenged to become even cleaner and more efficient to meet environmental and end-user demands. Cummins Westport is developing two streams of technologies to achieve these goals for medium-heavy and heavy-heavy duty applications.

For medium-heavy duty applications, lowest possible emissions are sought on SI engines without significant increase in complexity and with improvements in efficiency and BMEP. The selected path builds on the capabilities of the Cummins Westport, Inc., Plus technology and recent diesel engine advances in NO_x controls, providing the potential to reduce emissions to 2010 values in an accelerated manner and without the use of selective catalytic reduction (SCR) or LNA technology.

For heavy-heavy duty applications where high torque and fuel economy are of prime concern, the Westport-Cycle™ technology is in field trial. This technology incorporates high-pressure direct injection (HPDI) of natural gas with a diesel pilot ignition source. Both fuels are delivered through a single, dual common rail injector. The operating cycle is entirely unthrottled and maintains the high compression ratio of a diesel engine. As a result of burning 95 percent natural gas rather than diesel fuel, NO_x emissions are halved, and PM is reduced by around 70 percent. High levels of exhaust gas recirculation (EGR) can be applied while maintaining high combustion efficiency, resulting in extremely low NO_x potential.

Some recent studies have indicated that diesels equipped with diesel particulate filters (DPF) emit fewer nanoparticles than some natural vehicles. It must be understood that the ultra fine particles emitted from SI natural gas engines are generally accepted to consist predominantly of VOC's and that lubricating oil is a major contributor. Fitting an oxidation catalyst to the natural gas engine leads to a reduction in nanoparticle emissions in comparison to engines without aftertreatment.

In 2001, the Cummins Westport Plus technology was introduced with the C Gas Plus engine, a popular choice for transit bus applications. This incorporates drive by wire; fully integrated, closed loop electronic controls; and a standard oxidation catalyst for all applications. The B Gas Plus and the B Propane Plus engines, with application in shuttle and school buses, were launched in 2002 and 2003. The gas-specific oxidation catalyst operates in concert with an optimized ring-pack and liner combination to reduce total particulate mass below 0.01g/bhp-hr, combat ultra fine particles, and control VOC emissions.

Abstracts

Session 6 – Environmentally Concerned Public Sector Organization Panel

Abstracts

Session 7 – Combustion and HCCI Regimes

DIESEL ENGINE ALTERNATIVES

Tom Ryan

Southwest Research Institute

ABSTRACT

There are basically three different modes of combustion possible for use in reciprocating engines. These include: diffusion burning, as occurs in current diesel engines; flame propagation combustion, such as is used in conventional spark ignition engines; and homogeneous combustion, such as is used in the Southwest Research Institute homogenous charge compression ignition (HCCI) engine.

Diesel engines currently offer significant fuel consumption benefits relative to other powerplants for on- and off-road applications; however, costs and efficiency may become problems as the emissions standards become even more stringent.

This presentation presents a discussion of the potentials of HCCI and flame propagation engines as alternatives to the diesel engines. It is suggested that as the emissions standards become more and more stringent, the advantages of the diesel may disappear.

The potential for HCCI is limited by the availability of the appropriate fuel. The potential of flame propagation engines is limited by several factors, including knock, exhaust gas recirculation tolerance, high BMEP operation, and throttling. These limitations are discussed in the context of the potential for improvement of the efficiency of the flame propagation engine.

EXPLORING LOW NO_X AND LOW PARTICULATE MATTER COMBUSTION REGIMES

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Oak Ridge National Laboratory

ABSTRACT

We are investigating nontraditional combustion regimes for improving engine-system efficiency and reducing the performance requirements of post-combustion emissions controls. Combustion regimes of interest exhibit simultaneous low engine-out NO_x and particulate matter emissions. These regimes are realized through a combination of high EGR rates and/or fuel injection parameters.

In this study, we performed detailed emissions characterization for improved understanding of the combustion process as well as the environmental impact of operating in these regimes. Advanced techniques were applied for speciation of hydrocarbon (HC) emissions and particulate matter (PM).

HC speciation has thus far revealed the presence of many short chain hydrocarbons and partial oxidation products that were not present in the fuel. PM characterization revealed that a significant percentage of the PM in these nontraditional regimes is soluble organic, which may be treated with a simple oxidation catalyst. We are also investigating the possibility of increasing the speed/load envelope of these nontraditional regimes as well as evaluating their applicability to regenerating NO_x adsorbers and diesel particulate filters.

ADVANCED RESEARCH IN DIESEL FUEL SPRAYS USING X-RAYS FROM THE ADVANCED PHOTON SOURCE

Chris Powell

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ABSTRACT

The distribution and degree of atomization of fuel in the combustion chamber is a primary factor in determining the emissions from diesel engines. A number of diagnostics to study sprays have been developed over the last 20 years that are primarily based on visible light measurement techniques. However, visible light scatters strongly from droplets on the periphery of the spray. This prevents quantitative measurements using these techniques, particularly in the dense near-nozzle region.

For this reason we developed the X-ray technique to study the properties of fuel sprays. X-rays have a very low probability of scattering from droplets in the spray, which allows them to be used to make quantitative measurements of the fuel distribution. These measurements are particularly effective in the region near the nozzle where other techniques fail.

We will present the results of our work measuring the mass distribution and density of sprays from heavy- and light-duty common rail diesel injectors, as well as our most recent work studying sprays under higher ambient density conditions.

NEW DIESEL COMBUSTION REGIME: PARTICULATE ANALYSIS WITH THE SINGLE-PARTICLE LASER ABLATION TIME-OF-FLIGHT MASS SPECTROMETER

Dan Imre and Alla Zelenyuk/Imre

Pacific Northwest National Laboratory

John Storey, Shean Huff, Dean Edwards, and Sam Lewis

Oak Ridge National Laboratory

Jian Wang, Gunnar Senum, and James Wegrzyn

Brookhaven National Laboratory

ABSTRACT

To meet the new exhaust gas emission laws, most new diesel engines will be using exhaust gas recirculation (EGR). EGR technology has been shown to be very effective means of reducing NO_x emissions; however, typically any change in engine operating parameters to reduce NO_x emissions results in an increase in particulate matter (PM) emissions, which in the case of diesel emissions is of particularly serious concern because of its known carcinogenic effects. Hence, traditionally the point defined as the ultimate EGR limit was delineated by a sudden increase in HC (hydrocarbons) and PM.

Very recently a few studies have suggested that by further increasing EGR, it might be possible to push the engine into a novel low-temperature combustion regime (NLTC) that, unlike the "classic NO_X-PM tradeoff," simultaneously reduces both PM and NO_x emissions. None of the studies have presented any information about the composition and properties of the particulate mass in this combustion regime.

We will present the results of a recent study investigating this NLTC regime. In this study, diesel exhaust particles generated by the Mercedes A-Class 1.7L diesel engine under the entire range of EGR conditions were sampled and characterized by the Pacific Northwest National Laboratory Single Particle Laser Ablation Time-of-Flight Mass Spectrometer (SPLAT-MS). The instrument's extremely high sensitivity to small particles made it possible to detect and characterize individual particles down to 50 nm, demonstrating SPLAT-MS's utility for studying diesel PM emission.

In this study exhaust particle flow was introduced into the SPLAT-MS after dilution by a factor of 100 to 1,000 through an aerodynamic lens inlet. Each individual particle was then aerodynamically sized, and its chemical composition was characterized by using two-step, two-laser JR evaporation followed by ultraviolet ionization. The separation of the process by which ions are formed into two steps -- particle evaporation and ionization -- greatly improves the analytical capability of the SPLAT-MS and makes spectral assignment significantly more tractable.

Particle-size distributions from 3.5 to 500 nm were measured in parallel using Scanning Mobility Particle Sizer (SMPS). In addition, the NTRC group measured gas phase concentrations of NO_x, CO, CO_2, and HC's; recorded engine performance parameters; collected filter samples for gas chromatograph – mass spectrometer analysis; and measured total aerosol mass with TEOM for all EGR conditions.

Increasing EGR from 0 to 45 percent resulted in an increase (a doubling) in the particle number concentration and a shift in the average particle mobility diameter from 85 nm to 115 nm. At the same time the particle average aerodynamic diameter decreased from 97 to 74 nm, suggesting that increasing EGR from 0 to 45 percent results in a decrease of ~25 percent in particle size.

REAL-TIME SIMULTANEOUS MEASUREMENTS OF SIZE, DENSITY, AND COMPOSITION OF SINGLE ULTRAFINE DIESEL TAILPIPE PARTICLES

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John Storey, Shean Huff, Dean Edwards, and Sam Lewis

Oak Ridge National Laboratory

Jian Wang, Gunnar Senum, and James Wegrzyn

Brookhaven National Laboratory

ABSTRACT

Diesel exhaust particulate has been classified as a carcinogen. To understand its effect on human health, it is important to be able to characterize the composition and size of the emitted particles. We have recently developed a single-particle mass spectrometer for the characterization of size and composition of individual exhaust particles. The instrument was specifically designed to provide high sensitivity for particles in the 150- 5O nm range to cover the bulk of the particle mass that is present in the exhaust. We will present results from a recent deployment of this instrument at the National Transportation Research Center (NTRC) at Oak Ridge National Laboratory.

Our Single Particle Laser Ablation Time-of-Flight Mass Spectrometer (SPLAT-MS) was operated over the period of January 31 through February 13, 2003, and sampled exhaust particles generated by a Mercedes A-Class diesel engine. A total of approximately 0.5 million individual particles were sized and their composition characterized in real-time. The aerodynamic size distribution of the detected particles peaked at 70-100 nm, depending on engine operating conditions. The instrument's extremely high sensitivity to small particles was demonstrated by its ability to detect particles down to 50 nm.

After dilution by a factor of 100 to 1,000, exhaust particles were introduced into the SPLAT-MS through an aerodynamic lens, where each individual particle was sized and its chemical composition was characterized through a synchronous laser heating for particle evaporation followed by ultraviolet ionization. The separation of the process by which ions are formed into two steps -- particle evaporation and ionization -- greatly improves the analytical capability of the instrument and made spectral assignment significantly more tractable.

Initial studies investigated the effects of different load, revolutions per minute (RPM), and exhaust gas recirculation (EGR) conditions on particle-size distributions and composition. When EGR reached 52 percent, the engine operation became "smokeless," and the number concentration of particles dropped by a factor of 20. Studies of the effects of different loads and RPM on particle size and composition were repeated with the diesel fuel containing 15 percent alcohol.

Variation of particle composition with injection timing and sequence, the use of oil recirculation, and the presence or absence of a catalytic converter were also investigated. Very preliminary analysis of the data shows that the vast majority of the exhaust particles were composed of soot, which accounted for over 90 percent of all emitted particulates under many operating conditions. Other types of characterized particles include small amounts of oxygenated organics. Engine wear-and-tear particles containing aluminum, aluminum oxide, and iron were observed under extreme operating conditions of high RPM and low load.

DIESEL HCCI DEVELOPMENT AT CATERPILLAR

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ABSTRACT

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 and idle/light loads. Methods to control combustion phasing include inlet manifold temperature and pressure, injection timing, valve timing and fuel properties. Recent progress on part-load HCCI operation using diesel fuel will be given.

MIXED-MODE DIESEL HOMOGENEOUS CHARGE COMPRESSION IGNITION WITH EXTERNAL MIXTURE FORMATION

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Ohio State University

Simon Haas and Michael Bargende

University of Stuttgart

ABSTRACT

Diesel homogenous charge direct injection (HCCI) is a combustion technology showing great promise for the reduction of oxides of nitrogen and particulate matter from diesel engines. Our implementation is a mixed-mode concept, which relies on the use of an essentially unmodified common-rail compression ignition direct injection (CIDI) engine, coupled with a highly effective atomizer for external mixture formation. With this concept, the engine can operate in HCCI mode, HCCI/DI mixed mode, or DI mode, depending on the load and with seamless, progressive mode transition.

The external mixture preparation for the HCCI mode offers a number of advantages over techniques that utilize only the DI system to perform HCCI mixture preparation. External mixture formation, with the additional residence time and very active mixing through the intake stroke, allows for better HCCI operation due to the very effective mixing and charge homogeneity when compared DI HCCI. The traditional problems of external mixture formation (wall wetting, poor cold start, etc) are largely remedied by a novel fuel atomizer with its ultra-fine atomization. Furthermore, when used in a mixed combustion mode or in pure DI mode at higher loads, the DI injectors can be optimized strictly for DI operation with respect to number, orientation, or size of injector holes.

This mixed-mode operation has been demonstrated on a single-cylinder engine (one-quarter of a recent production 2L engine) in collaboration between Ohio State University and the University of Stuttgart, Germany. The concept has demonstrated extremely low levels of nitrogen oxides (below 10 ppm) and pure HCCI operation up to an IMEP of 4.7 bars. Operation at various conditions (engine speeds, loads, boost pressures, intake temperature, exhaust gas recirculation rates from 0 to 60 percent, etc.) have shown that this technique enables HCCI operation over a wide range of engine conditions with relative insensitivity of the combustion process to operating conditions. This is probably due to the high level of charge homogeneity achieved by this technique. Furthermore, the transition from HCCI to mixed HCCI/DI to DI combustion mode is seamless, significantly enabling the controllability of such a combustion system over the entire engine operating map.

DETAILED MODELING OF HOMOGENEOUS CHARGE COMPRESSION IGNITION AND PRE- MIXED CHARGE COMPRESSION IGNITION COMBUSTION AND MULTI-CYLINDER HOMOGENEOUS CHARGE COMPRESSION IGNITION ENGINE CONTROL

Salvador Aceves, Daniel Flowers, Joel Martinez-Frias, Francisco Espinosa-Loza, and Robert Dibble

Lawrence Livermore National Laboratory

ABSTRACT

This work supports the need to develop a new combustion concept that allows both high efficiency and low emissions for transportation applications. Our work on homogeneous charge compression ignition (HCCI) combustion is a synergistic combination of analysis and experimental work.

On analysis, we have developed advanced methodologies that combine chemical kinetics with fluid mechanics to analyze HCCI engines with accuracy never before achievable for other types of engines. These analysis tools have also been used to guide the experimental effort.

On experimental work we have a multi-cylinder Volkswagen TDI engine that allows us to work on balancing combustion between cylinders. This is a crucial problem with HCCI combustion that has so far precluded commercialization of these engines.

Previously, our analysis capabilities applied only to perfectly homogenized air-fuel mixtures. We have recently extended our methodologies to include mixing between zones. We have used this model to demonstrate that mixing between zones is responsible for most of the production of carbon monoxide in an HCCI engine. In addition to being an important enhancement to our HCCI engine analysis tools, this new model can be used as a framework to analyze engine operating conditions where the charge is not perfectly homogeneous (i.e., PCCI combustion).

We are also developing methodologies for controlling and balancing combustion in a multi-cylinder HCCI engine. We are using an exhaust throttle as a low-cost surrogate for variable valve timing. Our results for using an exhaust throttle in an HCCI engine show some unexpected results. Throttling the exhaust typically advances combustion in a single-cylinder engine, due to the effect of hot combustion gases on HCCI combustion. However, in a multi-cylinder engine, throttling the exhaust of a cylinder *delays* combustion in this cylinder and *advances* combustion in other cylinders. This is due to flow interactions between cylinders, as the exhaust throttle in a cylinder diverts the flow of the fresh charge to the other cylinders. Characterizing these effects is extremely important in obtaining satisfactory combustion in a multi-cylinder HCCI engine.

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

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ABSTRACT

EPA 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 (ATOF-MS), 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 (EC/OC), 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 (SO4) 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 nano-particle-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 ATOF-MS, which has been widely used to study atmospheric aerosols but has only seen limited use for assessing internal combustion engine exhaust emissions. Using the ATOF-MS 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.

NON-SOOTING, LOW-FLAME TEMPERATURE, AND MIXING-CONTROLLED DIRECT INJECTION DIESEL COMBUSTION

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ABSTRACT

Methods of producing non-sooting, low- flame temperature diesel combustion were investigated in an optically accessible, quiescent constant-volume combustion vessel under mixing-controlled diesel combustion conditions. Combustion and soot processes of single, isolated fuel jets were studied after auto-ignition, transient premixed combustion, and while the injector was fully open (i.e., during the mixing-controlled phase of heat release for diesel combustion).

The investigation showed that small injector tip orifices could be used to produce non-sooting, low-flame temperature combustion in two different ways. First, using a 50-micron injector tip and ambient oxygen concentrations as low as 10 percent (simulating the use of extensive exhaust gas recirculation), a fuel jet was non-sooting at typical diesel ambient temperatures (1000 K). Second, using the same injector tip at a reduced ambient gas temperature (850 K), but with 21-percent oxygen, it was shown that non-sooting, mixing-controlled combustion occurred at the lift-off length in a fuel-air mixture with a cross-sectional average equivalence ratio of approximately 0.6—suggesting that the quasi-steady combustion was fuel lean and thereby avoided the formation of a diffusion flame.

The adiabatic flame temperature with reduced ambient oxygen concentration or fuel-lean combustion was approximately 2000 K, compared to typical diesel flame temperatures that exceed 2600 K. The 50-micron injector tip results above were obtained using a #2 diesel fuel. However, using an oxygenated fuel (20 weight percent), the investigation showed that the same low-temperature combustion, either with reduced ambient oxygen concentration or fuel-lean combustion, was realized with a 100-micron injector tip.

Although these single, isolated jets do not have jet-jet interactions that would occur in realistic engines, the results are useful for understanding limiting-case behavior of single-jet mixing and combustion during an injection event. The non-sooting and low-flame temperature, mixing-controlled combustion realized using small orifice tips suggests that the use of small orifices offers the potential for a simultaneous soot and NO_x reduction in an engine, much like diesel homogeneous charge compression ignition combustion.

SHELL GAS-TO-LIQUIDS IN THE CONTEXT OF A FUTURE FUEL STRATEGY – TECHNICAL MARKETING ASPECTS

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Shell Global Solutions (U.S.), Inc.

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Shell Gas and Power

ABSTRACT

Liquid fuels refined from crude oil are likely to continue to dominate the transportation fuels market for the next 20 years. However, fuel properties and specifications will not stand still, with change driven by sustainability challenges of:

- Security and diversification of energy supply
- Reduced greenhouse gas emissions
- Reduced local pollutant emissions
- Affordability, availability, and customer acceptance.

In the long term, hydrogen produced from renewable sources is seen by many as the ultimate solution, combining both local and global environmental advantages. However, in the personal mobility domain, there is still a long way to go on the path to commercialization of hydrogen and fuel cells.

In the interim period, alternative fuels – such as biofuels, liquefied natural gas, compressed natural gas, and gas to liquids (GTL) fuels -- will play, in varying degrees, an increasingly important role in meeting mobility needs. Some may grow beyond niche positions depending on Government transport fuel policy.

GTL fuel offers strategic diversification of energy supply, since it is derived from natural gas, and can provide a bridge to future fuels and technologies. Its compatibility with the existing diesel infrastructure in combination with significant local pollutant emissions benefits (both as pure, 100-percent GTL and as a blend with conventional diesel) results in a more cost effective solution in reducing emissions than other alternative fuels.

This paper discusses various market development activities associated with GTL fuel and how these are often directly related to the technical attributes of the fuel. For example, the ability of GTL fuels to deliver emissions benefits when blended with conventional diesel, has recently allowed the formulation of fuels with reduced black smoke emissions in Thailand and Greece.

EFFECTS OF FUEL TYPE AND ENGINE SPEED ON REQUIRED INTAKE TEMPERATURE AND COMPLETENESS OF COMBUSTION IN A HOMOGENEOUS CHARGE COMPRESSION IGNITION ENGINE

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ABSTRACT

Homogeneous charge compression ignition (HCCI) engines have shown potential for both high efficiency and low emissions of NO_X and particulates. However, as the fuel/air-equivalence ratio is reduced for decreasing engine loads, CO and hydrocarbon (HC) emissions become excessive.

In a previous study, the sources of emissions at low loads were investigated using iso-octane as the fuel. It was found that the peak combustion temperature had a strong influence on the completeness of the bulk-gas combustion reactions, particularly the CO-to-CO_2 reactions. In the engine, this peak temperature is reached by a combination of intake temperature, compression, and combustion heating. However, the intake temperature required to maintain combustion phasing near top dead center (TDC) varies with both the fuel type and engine speed. Therefore, it can be anticipated that the fuel/air-equivalence ratio for onset of incomplete bulk-gas reactions is dependent on both the autoignition characteristics of the fuel and the engine speed.

To gain a better understanding of how the onset of incomplete bulk-gas combustion changes with fuel type and engine speed, a parametric study of HCCI combustion and emissions has been conducted. Four fuels with different ignition characteristics were investigated, including: a research-grade gasoline, pure iso-octane, and two mixtures of the primary reference fuels (*n*-heptane and iso-octane) with octane numbers of 80 and 60. The experiments were conducted at naturally aspirated conditions in a single-cylinder engine (0.98 liters/cylinder) fitted with a custom HCCI piston that minimizes crevice volume. For each fuel, data were acquired at four engine speeds (600, 1200, 1800, and 2400 revolutions per minute), and the fuel loading was varied from near the knocking limit to loads at or below idle (based on typical diesel-engine fueling) at each speed. Cylinder pressure and exhaust-gas data (CO_2, O_2, CO, HC, NO_X, and smoke) were acquired for each condition.

The results show that there is a strong coupling between the ignition quality of the fuel and the intake temperature required to phase combustion at TDC. The intake temperature, in turn, directly affects the completeness of combustion for a given engine speed and fueling rate. The effect of engine speed depends on the ignition characteristics of the fuel. For fuels with little cool-flame activity (i.e., gasoline and pure iso-octane), the equivalence ratio for the onset of incomplete bulk-gas reactions is independent of engine speed. This occurs because the increased compression temperatures required to maintain combustion phasing as the engine speed is increased also increase the rate of CO-to-CO_2 conversion, balancing the shorter time available to complete combustion. However, for fuels with a significant fraction of *n*-heptane (i.e., significant cool-flame chemistry), the onset of incomplete bulk-gas combustion depends strongly on engine speed, with a shift to higher equivalence ratios at lower speeds. This is due to the strong time dependence of the cool-flame chemistry, which necessitates lower intake temperatures at lower engine speeds to maintain combustion phasing. This leads to lower combustion temperatures and a commensurate rise in CO-emissions unless the fueling is increased.

Abstracts

Session 8 – Diesel Engine Development and Durability

STATE-OF-THE-ART AND EMERGING TRUCK ENGINE TECHNOLOGIES FOR OPTIMIZED PERFORMANCE, EMISSIONS, AND LIFE-CYCLE COSTING

Michael Schittler

DaimlerChrysler AG

ABSTRACT

The challenge for truck engine product engineering is and will be not only to fulfill increasingly stringent emission requirements, but also to maintain or improve the engine's economical viability as the powerplant that is the backbone of our economy. As emission limit values are to be reduced in big steps, continuous improvement is not enough but technological quantum leaps are necessary. In the past, the introduction and refinement of electronic control of all major engine functions have been such a quantum leap required to make full use of parameter optimization.

The next big step forward will be exhaust aftertreatment, which is successfully established since many years on Otto-cycle engines. The introduction of exhaust aftertreatment especially for diesel engines for commercial vehicles is a much more demanding task, but the limit values to be met starting in the 2005-2007 timeframe in Europe, the U.S.A., and Japan require this step and the engine industry is able to implement the new technology if all stakeholders support the necessary decisions.

One decision has already been taken: the reduction of sulfur in diesel fuel. This is comparable to the elimination of lead in gasoline as a prerequisite for the three-way catalyst. Now we have the chance to optimize ecology and economy of the diesel engine simultaneously by taking the decision to provide an additional infrastructure for a NO_x reduction agent needed for the introduction of the selective catalytic reduction technology, which is already implemented in electric power generation. This requires some effort, but the costs are significantly below the gains in fuel efficiency in comparison to other technologies. After long discussions, this decision has been taken in Europe and is supported by all truck and engine manufacturers. The necessary logistic support will be in place when it will be needed in 2005.

For the United States, the decision has to be taken this year in order to have the infrastructure available in 2007. It will enable the global engine industry to focus their R & D budgets on one direction not only for 2007 but for the years beyond 2010 with the best benefit for the environment, the customers, and the industry.

RECENT DEVELOPMENTS IN BMW´S DIESEL ENGINE TECHNOLOGY

Fritz Steinparzer

Bayerische Motoren Werke AG

ABSTRACT

In Europe, diesel engines have begun to play a very significant role in the luxury segment of the automotive market. By reengineering the 6- and 8-cylinder engines for the new 7 Series, BMW again succeeded in significantly improving the customer-relevant product characteristics. The advanced engine technology used has also laid the foundation for meeting the more stringent emission requirements of the future.

Improved combustion processes, highly flexible injection systems, and high-performance exhaust aftertreatment are key elements in further reducing emissions. In order to allow manufactures to make a long term commitment to this technology for this market, there must be a holistic approach when considering the environmental benefits of diesel engines vis-à-vis their overall contribution to energy independence and maintaining individual mobility.

DEVELOPMENT OF SIMULTANEOUS REDUCTION SYSTEM FOR NO_X AND PARTICULATE MATTER FROM A DIESEL ENGINE

Tetsu Watanabe

Toyota Motor Corporation

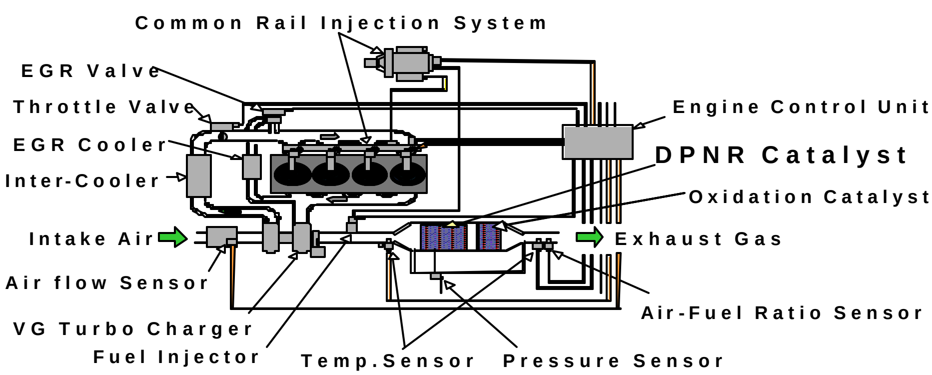
ABSTRACT

Toyota has developed a simultaneous reduction system for NO_x and particulate matter from a diesel engine (DPNR - Diesel Particulate and NO_x Reduction system) and tested it for various applications. We have verified that the DPNR has a high potential for realizing clean diesel engine use for various market segments, such as passenger vehicles in the European market and light-duty trucks in the Japanese market.

The key technologies of the system incorporate the following: the DPNR catalyst; common rail fuel injection system to control catalyst bed temperature and air fuel ratio; an electrically controlled exhaust gas recirculation (EGR) system; and exhaust port-or-pipe injector in order to supply rich gas to the DPNR catalyst for NO_x reduction and sulfur discharging.

For the European market, Toyota has carried out a field trial project in which 60 vehicles with the DPNR system installed in 2L TDI have been tested in order to verify its operation and confirm the reliability of the system. In applying the DPNR to light-duty trucks, we have developed the DPNR for 2-ton payload trucks for the Japanese market. In this application, deterioration of the NO_x storage catalyst was a critical issue because of its long traveling distance. For this issue, we conducted extended durability tests on an engine test bed, using 40-ppm and 7-ppm sulfur content diesel fuel. As a result, the Japanese U-LEV (75-percent reduced emission level from Japanese new short-term regulation in Japan D-13 mode) emissions standard could be achieved when using fuel with sulfur content of 7 ppm even after 1,000,000 km.

When considering applications for the U.S. market, in addition to improving the DPNR performance, the quality and specification of diesel in the market are very important in order to meet severe emission targets (i.e., Tier 2 bin 5). That is, the cetane level and aromatics content need to be at least equivalent to the level required in the European and Japanese fuel standards.



PERFORMANCE AND DURABILITY OF PSA PEUGEOT CITROËN'S DIESEL PARTICULATE FILTER SYSTEM ON TAXIS FLEET IN PARIS AREA

Patrick Coroller and Gabriel Plassat

ADEME Agence De l'Environnement et de la Maîtrise de l'Energie
Technologies des Transports

Thierry Seguelong, *presenter*

Aaqius & Aaqius

ABSTRACT

The use of diesel engines has strongly increased during the last years and now represents 40 percent of the sales in Europe and up to 50 percent of the number of cars in circulation fro some countries. This success is linked not only to the economical aspect of the use of such vehicles, but also to the recent technological improvements of these engines. The new technical solutions (high-pressure direct injection, turbocharger, etc.) have indeed allowed the increase of these engine performances while decreasing their fuel consumption, pollutant emissions, and noise level.

From an environment point of view, diesel engines are nevertheless penalized by their particulates and NO_x emissions. The study and the treatment of the particulates, highly criticized for their potential impact on health, are the subject of numerous works of characterizations and developments.

PSA Peugeot Citroën has recently (2000) launched its diesel particulate filter (DPF) technology in several types of vehicles (500,000 vehicles with DFP have been sold today). In order to evaluate the durability of this technology over a long period of time, a study program has been set up by ADEME (French Environmental Agency), IFP Powertrain, PSA Peugeot Citroën, and Taxis G7 (a Parisian taxi company).

The objective is to study the evolution of five taxis and their aftertreatment-system performance over 80,000 km in hard urban-driving conditions, which correspond to the recommended mileage before the first DPF maintenance, as well over 120,000 km, after the DPF maintenance and remanufacturing. More specifically, the following evaluations are being performed at regular intervals (around 20,000 km): regulated gaseous pollutant emissions on NEDC cycle, particulate emissions, and unregulated pollutant emissions. The results obtained until now have not shown any degradation of the DPF efficiency (more than 90 percent).

This paper presents the methodology set up, and the explanation of the first results obtained. Indeed, a more specific study has shown that most of the aerosols, measured with a scanning mobility particle sizer are composed of liquid fractions, mainly sulfates due to the sulfur coming from the fuel but also from the lubricant. The impact of sulfates stored on the catalyst surface during low-temperature running phases and removed during high-temperature running phases has been also outlined.

COMBINATION OF DIESEL FUEL SYSTEM ARCHITECTURES AND CERIA-BASED FUEL-BORNE CATALYSTS FOR IMPROVEMENT AND SIMPLIFICATION OF THE DIESEL PARTICULATE FILTER SYSTEM IN SERIAL APPLICATIONS

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RHODIA Electronics & Catalysis Inc.

Paul Wouters

INERGY Automotive Systems Research

ABSTRACT

Diesel vehicles have an increasing market share in Europe. To further increase their environmental friendliness, control of particulate emissions is a key topic. Ceria-based fuel-borne catalysts have proven their efficiency to optimize the diesel particulate filter (DPF) efficiency and durability: since the market introduction of the DPF system in serial applications in May 2000 by PSA Peugeot Citröen, more than 500,000 vehicles have been DPF-equipped. Tracking the serial production current situation, several themes for improvement have been identified, including system simplification to limit its total cost as well as an optimized maintenance. The paper presents those upgrades that will be proposed in serial applications, in the near future.

Catalytic activity of ceria-based fuel-borne catalysts has been chemically tuned to meet the compromise between the catalytic activity (reduction in the temperature of soot burn-off and kinetics of DPF regeneration), the temperature peak generated during the DPF regeneration (exotherms of regeneration), and the density of the inorganic ash arising from the fuel-borne catalyst (ash build-up speed). A good compromise is proposed, based on the use of the iron-doped ceria nanoparticles as active catalytic ingredient.

In parallel, dosing strategies of ceria-based fuel-borne catalyst are being developed to match with the proposed evolution in the fuel-borne catalyst for serial applications. New designs of the automatic on-board dosing system are being developed to ensure the global accuracy in the diesel fuel treatment and to limit the maintenance operation for fuel-borne catalyst tank refilling.

Improvement and simplification of the DPF system for serial applications are based on the adaptation and the optimization of several functionalities of the global system. The next step of the "fit for life" target goes necessarily by co-developments between the various functionalities of global DPF system.

DIESEL PARTICULATE FILTER: A SUCCESS FOR FAURECIA EXHAUST SYSTEMS

Robert Parmann

Faurecia Exhaust Systems

ABSTRACT

The presentation is based on more than 3 years experience in mass production of diesel particulate filters (DPF's) for passenger cars in Europe. Faurecia, the technology leader in diesel, has produced over 400,000 DPF's to date – around 70 percent of the present market.

We have developed a number of in-house tests and a wealth of expertise. The function of the DPF system on vehicles is explained, with a focus on the use of the Rhodia's Eolys™ fuel-borne catalyst for DPF regeneration. Several design factors are discussed: substrate and thermal conditions, different operating conditions of the system, linked to the driving profile, and their effect on function and durability. Measurement of thermal stresses on the substrate will be presented along with a method for filter sizing.

Service interval strategies related to filter size and regeneration system are discussed. As a full-system supplier, Faurecia provides a remanufacturing service, and the filter cleaning process used today in Europe is described.

CUMMINS/DOE LIGHT TRUCK DIESEL ENGINE PROGRESS REPORT – 2003

John Stang, David Koeberlein, and Michael Ruth

Cummins, Inc.

ABSTRACT

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

Results show that full EPA Tier 2 Bin 5 emission results are achieved, while also meeting the fuel-economy targets established by DOE. Various results of ongoing system development are shown including air-handling system, noise, and overall vehicle performance. General aftertreatment system design and direction are discussed.

ADVANCED DIESEL ENGINE AND AFTERTREATMENT TECHNOLOGY DEVELOPMENT FOR TIER 2 EMISSIONS

R. Aneja, B. Bolton, B. Oladipo, Z. Pavlova-MacKinnon, and A. Radwan

Detroit Diesel Corporation

ABSTRACT

Advanced diesel engine and aftertreatment technologies have been developed for multiple engine and vehicle platforms. Tier 2 (2007 and beyond) emissions levels have been demonstrated for a light-truck vehicle over a FTP 75 test cycle on a vehicle chassis dynamometer. These low-emissions levels are obtained while retaining the fuel-economy advantage characteristic of diesel engines.

The performance and emissions results were achieved by integrating advanced combustion strategies (CLEAN Combustion©) with prototype aftertreatment systems. CLEAN Combustion© allows partial control of exhaust species for aftertreatment integration in addition to simultaneous NO_x and particulate matter reduction. Analytical tools enabled the engine and aftertreatment subsystems development and system integration. The experimental technology development methodology utilized a range of facilities to streamline development of the eventual solution, including utilization of steady-state and transient dynamometer test-beds to simulate chassis dynamometer test cycles.

THE DEVELOPMENT AND ON-ROAD PERFORMANCE AND DURABILITY OF THE FOUR-WAY EMISSION CONTROL SCRT™ SYSTEM

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Johnson Matthey

Mario Sanchez

Cummins, Inc.

ABSTRACT

The progressive tightening of the heavy-duty diesel emissions legislation worldwide necessitates the development of pollution control systems capable of enabling engines to meet the incoming legislative requirements. It is clear that to maximize the benefit to the environment, as well as to meet the very stringent future standards (especially the U.S. 2010 limits), systems capable of high simultaneous conversions of all four major pollutants -- carbon monoxide (CO), hydrocarbons (HC), oxides of nitrogen (NO_x) and particulate matter (PM) -- are required.

Very high conversions of CO, HC, and PM are achieved using catalyst-based diesel particulate filter (DPF) systems, such as the Continuously Regenerating Technology, (CTR®) system. High NO_x conversions can be obtained using selective catalytic reduction (SCR) systems, in which ammonia (generated from urea) is used to selectively reduce the NO_x. This paper summarizes the key steps in the development of the four-way SCRT™ system, which comprises the CRT system followed by an SCR system. Engine bench results obtained during the development of this system are presented and discussed.

However, the key to real-world emissions benefit is the actual on-road performance of such systems. It is well established that the CRT system provides very high and durable conversions of CO, HC, and PM so the focus of this current work was to demonstrate the NO_x conversion capability and durability of the SCRT™ system.

The SCRT™ unit was installed on a long-haul truck powered by a 15L Cummins engine. On-road NO_x emissions performance was measured using NO_x sensors located upstream and downstream of the SCRT™ unit. Over an 850-km evaluation route, the average on-road NO_x conversion obtained was up to 82 percent, even when the urea injection quantity was set to give a maximum NO_x conversion of around 85 percent. The durability of the system has also been assessed. Over the course of 150,000 km, no reduction in the NO_x conversion efficiency of the system was observed.

The results presented in this paper demonstrate that the SCRT™ system provides very high on-road NO_x conversion and that the system has excellent durability within real-world applications.

VARIABLE CHARGE MOTION FOR 2007- 2010 DIESEL ENGINES

Josef Maier

AVL Powertrain Engineering, Inc.

ABSTRACT

The use of direct-injection diesel engines in U.S. heavy-duty pickup truck applications is becoming increasingly popular, with over 250,000 produced in 2002. The high torque density and greatly improved fuel consumption offer distinct advantages to the end user.

The 2007 and 2010 emissions legislation will present another set of technical and product-cost challenges to this type of powertrain. The introduction of efficient aftertreatment systems is mandatory for the success of these engines, but optimization of engine-out emissions is also a critical element.

Much has been written about the improvements in modern fuel systems, which offer great flexibility for the direct introduction of fuel into the cylinder. This paper presents complementary technologies that allow improved air/fuel mixing processes by the additional flexibility of variable in-cylinder charge motion. This approach is particularly applicable to pickup truck engines, which require high BMEP levels across a wide engine speed range to offer the driveability demanded by the consumer.

Design solutions for 2-valve and 4-valve engines are presented along with the potential emissions and fuel consumption benefits.

DIESEL EXHAUST EMISSIONS CONTROL FOR LIGHT-DUTY VEHICLES

R. Mital, J. Li, S. Popuri, S. C. Huang, B. J. Stroia, and Yul Tarr

Cummins, Inc.

Kenneth Howden

U.S. Department of Energy

ABSTRACT

Results of diesel exhaust aftertreatment testing and analysis being conducted at Cummins, Inc., under the FreedomCAR program are presented. Various NO_x adsorber aftertreatment configurations were tested both in steady state and in transient in an effort to reduce the size and cost of the system while minimizing the fuel economy penalty. Both systems, discrete (adsorber and catalyzed particulate filter) and 4-way (NO_x, HC, CO and particulate matter [PM]), were tested.

After various iterations of the catalyst formulation, regeneration strategy, catalyst configurations etc., the aftertreatment components were integrated and optimized for the light-duty application. The optimized exhaust aftertreatment system was first tested under steady-state conditions in the test cell to evaluate performance and optimize regeneration strategy. The system was then tested in the transient test cell and on the chassis dynamometer. Emission results for FTP-75, US06, HWFET, and UDDS cycles were obtained at different test weights.

Encouraging reduction in both NO_x and PM emissions was observed for all test cycles. Even though the engine-out emissions were high for the aggressive US06 cycle, the system-out results were low, meeting the SFTP Tier II targets. Durability testing was conducted for both the discrete and the 4-way system, the results of which are presented in the paper.

A transient adsorber-modeling tool has been developed to predict and further assist in improving system performance. Results for various other issues including low-temperature light-off, engine-managed regeneration, exhaust sulfur management, system integration, and design trade-off, are also presented and discussed.

ANALYTICAL TOOL DEVELOPMENT FOR AFTERTREATMENT SUB-SYSTEMS INTEGRATION

B. Bolton, A. Fan, K. Goney, Z. Pavlova-MacKinnon, K. Sisken, and H. Zhang

Detroit Diesel Corporation

ABSTRACT

The stringent emissions standards of 2007 and beyond require complex engine, aftertreatment, and vehicle systems with a high degree of subsystem interaction and flexible control solution. This necessitates a system-based approach to technology development, in addition to individual subsystem optimization. Analytical tools can provide an effective means to evaluate and develop such complex technology interaction as well as understand phenomena that are either too expensive or impossible to study with conventional experimental means. The analytical effort can also guide experimental development, and this lead to efficient utilization of available experimental resources.

A suite of analytical models has been developed to represent particulate matter and NO_x aftertreatment subsystems. These models range from computationally inexpensive zero-dimensional models for real-time control applications to computational fluid dynamics (CFD)-based multi-dimen-sional models with detailed temporal and spatial resolution. Such models, in conjunction with well-established engine-modeling tools (such as engine-cycle simulation, engine controls modeling, CFD models of non-combusting and combusting flow, and vehicle models), provide a comprehensive analytical toolbox for complete engine, aftertreatment, and vehicle subsystems development and system integration applications. However, the fidelity of aftertreatment models and application going forward is limited by the lack of fundamental kinetic data.

Abstracts

Session 9 – Environmental Science and Health Impacts

THE WEEKEND OZONE EFFECT - THE WEEKLY AMBIENT EMISSIONS CONTROL EXPERIMENT

Douglas R. Lawson

National Renewable Energy Laboratory

Charles L. Blanchard and Shelley J. Tanenbaum

Envair

Tami H. Funk and Lyle R. Chinkin

Sonoma Technology, Inc.

Eric Fujita, Barbara Zielinska, John Sagebiel, John Bowen, William Stockwell, and Mark McDaniel

Desert Research Institute

Greg Yarwood and Till E. Stoeckenius

ENVIRON

Jeremy G. Heiken

Air Improvement Resource, Inc.

Alan M. Dunker

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ABSTRACT

Since the mid-1970s, ozone concentrations in California's South Coast Air Basin (SoCAB) have been higher on weekends than on weekdays. Despite significantly lower ozone precursor levels on weekends, 20 of all 78 southern California sites show statistically significant higher mean ozone levels on Sundays than on weekdays ($p<0.01$); 49 of the remaining 50 sites show no significant differences between mean weekday and Sunday peak ozone levels. The weekend effect has generated strong interest because of its implications for development of air-quality control strategies.

To investigate the possible causes of higher weekend ozone compared to weekday ozone in the SoCAB, the National Renewable Energy Laboratory (NREL), with support from DOE's Office of FreedomCAR and Vehicle Technologies, and the Coordinating Research Council (CRC) sponsored a multiphase effort beginning in 1999 to collect and analyze weekday and weekend air-quality, emissions, and meteorological data to formulate hypotheses likely to explain the causes of elevated weekend ozone in the SoCAB.

As part of the field study, on-road mobile source emissions activity data were collected in close proximity to each ambient air-quality monitoring site. These emissions-activity data include daily diurnal vehicle count figures for selected surface streets and Caltrans Weigh-in-Motion data collected on major freeways. Surveys also were conducted to acquire data about business and residential activities on weekdays and weekends.

The ambient air-quality field program was conducted during September and October 2000. Measurements were used to attribute weekday/weekend changes in the temporal and spatial patterns of volatile organic compounds (VOC's) and NO_x concentrations to major sources of ozone precursor emissions. While exhaust emissions from on-road gasoline and diesel vehicles are the primary sources of interest, detailed speciation of VOC's also allowed for attribution of other sources of volatile organic compounds.

Air-quality simulation modeling explained the observed weekend ozone effect very well. Changes to the mass of motor vehicle emissions were the main contributor to ozone differences rather than changes to the timing of motor vehicle emissions. Ozone increases on weekends are caused by lower NO_x emissions because ozone formation is strongly VOC-limited throughout most of the Los Angeles area. Carryover of precursors and/or ozone is not an important factor in explaining the relationships between emission changes and ozone effects.

GASOLINE VEHICLE EXHAUST PARTICLE SAMPLING STUDY

David Kittelson, Winthrop Watts, and Jason Johnson

University of Minnesota

ABSTRACT

The University of Minnesota collaborated with the Paul Scherrer Institute, the University of Wisconsin (UWI), and Ricardo, Inc., to physically and chemically characterize the exhaust plume from recruited gasoline spark ignition (SI) vehicles. The project, supported by DOE's Office of FreedomCAR and Vehicle Technologies, had four primary objectives:

- Measure representative particle-size distributions from on-road SI vehicles and distinguish between SI and diesel emissions.
- Compare the information obtained from on-road tests to a small subset of light-duty gasoline vehicles tested on a chassis dynamometer under steady-state cruise conditions and using the Unified Cycle at both room temperature and 0^{o}C.
- Characterize bulk and size-segregated chemical composition of the particulate matter (PM) emitted in the exhaust from the gasoline vehicles.
- If results from objectives 1 and 2 do not agree with regard to PM-size distribution, utilize the latest information on particle formation and dilution to explain the differences.

Particle number concentrations and size distributions are strongly influenced by dilution and sampling conditions. Laboratory methods were evaluated to dilute SI exhaust in a way that would produce size distributions that were similar to those measured during experiments. Size fractionated samples were collected for chemical analysis using a nano-microorifice uniform deposit impactor (nano-MOUDI). In addition, bulk samples using Teflon and quartz fiber filters followed by polyurethane foam were collected and analyzed by the UWI researchers.

Data were also collected during cold, cold start idle tests, laboratory tests to determine the impact of lube oil consumption on particulate matter emissions and during an on-road study to compare weekday with weekend air quality around the Twin Cities area. This portion of the study resulted in the development of a method to apportion the diesel and SI contribution to on-road aerosol.

A mixture of low-, mid-, and high-mileage vehicles was recruited for testing during the study. Under steady highway cruise conditions, a significant particle signature above background was not measured, but during hard accelerations number weighted size distributions for the test fleet were similar to modern heavy-duty diesel vehicles. Number emissions were much higher at high speed and during cold starts, and fuel-specific number emissions range from 10^{12} to 3 x 10^{16} particles/kg fuel. A simple relationship between number and mass emissions was not observed. Other results will be discussed.

DOE'S GASOLINE/DIESEL PARTICULATE MATTER (PM) SPLIT STUDY – CHARACTERIZATIONS OF THE VARIATIONS IN CHEMICAL COMPOSITION OF $PM_{2.5}$ IN THE SOUTH COAST AIR BASIN

Eric M. Fujita, David E. Campbell, William P. Arnott, Barbara Zielinska, and Judith C. Chow

Desert Research Institute

Douglas R. Lawson

National Renewable Energy Laboratory

ABSTRACT

DOE's Gasoline/Diesel Particulate Matter (PM) Split Study is being conducted to quantify the relative contributions of tailpipe emissions from gasoline-powered motor vehicles and diesel-powered motor vehicles to the ambient concentrations of fine particulate matter ($PM_{2.5}$) in the urbanized region of Southern California using an organic compound-based chemical mass balance model (CMB). This study involves several groups working cooperatively on sample collection and quality assurance aspects of the study, but working independently, at least initially, on chemical analysis and data analysis. Groups participating in the study include California's Bureau of Automotive Repair, the South Coast Air Quality Management District, the U.S. Environmental Protection Agency, Ralph's Groceries, the Clean Air Vehicle Technology Center, the West Virginia University, the University of Wisconsin at Madison (UWM), and the Desert Research Institute (DRI).

Source testing of 59 light-duty vehicles (including 2 diesel vehicles) was completed in June 2001; ambient measurements were performed in July; and the testing of 34 heavy-duty vehicles was completed in September. DRI used sample collection and chemical analysis methods consistent with those employed during the Northern Front Range Air Quality Study. Parallel samples were collected by UWM using methods consistent with previous PM studies in Los Angeles. This paper describes the variations in the chemical composition of the ambient samples collected by DRI.

Twenty-four hour samples were collected on Teflon and quartz filters and Teflon-impregnated glass fiber (TIGF) filters followed by polyurethane foam (PUF) plugs and XAD-4 resin cartridges for 28 consecutive days at air-monitoring stations in downtown Los Angeles and Azusa. Teflon filters were analyzed for gravimetric mass, elements, and ions, and quartz filters were analyzed for organic and elemental carbon by thermal optical reflectance (TOR) and thermal optical transmittance (TOT) using both IMPROVE and NIOSH protocols. The TIGF/PUF/XAD samples were combined and extracted together by day of the week, and analyzed for polycyclic aromatic hydrocarbons, hopanes, steranes, alkanes, methoxyphenols, lactones, sterols, and polar organic compounds.

A third set of ambient samples was collected from a mobile sampling van at several regionally representative sites and at locations with expected higher proportions of PM emissions from diesel trucks (e.g., Terminal Island, truck stop, highway truck routes) and from gasoline vehicles (e.g., congested freeways during commuter rush hours, surface streets during weekends, and a parking lot at major sporting events). Black carbon and total PM were monitored continuously by photoacoustic and DustTrak instruments. As a prelude to the CMB analysis, we examined the variations in relative abundances of key marker compounds in the source-dominated ambient samples relative to corresponding variations in the samples from regional air-quality monitoring sites by day of the week. This work was supported by the DOE's Office of FreedomCAR and Vehicle Technologies through the National Renewable Energy Laboratory.

RELATIONSHIP BETWEEN COMPOSITION AND TOXICITY OF ENGINE EMISSION SAMPLES

Joe Mauderly, JeanClare Seagrave, and Jake McDonald

Lovelace Respiratory Research Institute

Ingvar Eide

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Barbara Zielinska

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ABSTRACT

Differences in the lung toxicity and bacterial mutagenicity of samples from gasoline and diesel vehicle emissions were reported previously and have been published (Seagrave *et al*., *Toxicological Sciences* 70:212-226, 2002). Although the toxicity rankings provided important information, the ultimate goal was to determine the physical-chemical species responsible for the differences. The relationships between sample composition and toxicity have now been analyzed.

Filter and semi-volatile organic compound (SVOC) samples were collected from normal and high-emitter gasoline and diesel vehicles operated on chassis dynamometers on the Unified Driving Cycle. Seven vehicle-operating temperature conditions were tested. The composition of extracted filter and SVOC material was measured in detail. The filter and SVOC fractions were combined in their original mass collection ratios, and the toxicity of the seven samples was compared by instillation into rat lungs followed by measures of inflammation and tissue damage and by the Ames bacterial mutagenicity test. There was good coherence among multiple measured variables in ranking the samples and demonstrating a five-fold range in toxicity.

The relationship between chemical composition and toxicity was analyzed by principal component analysis (PCA) and projection to latent surfaces (PLS, also known as partial least squares). The stepwise PCA-PLS analysis revealed the chemical constituents co-varying most strongly with toxicity and gave predictions of relative toxicity with good accuracy. The results, which will be described in detail, suggest that selected, but not all, nitro-aromatic compounds most strongly influenced mutagenicity, and that organic compounds, especially particle-associated organics, most strongly influenced the lung inflammatory response.

THE EFFECT OF CHANGES IN DIESEL EXHAUST COMPOSITION AND AFTERTREATMENT TECHNOLOGY ON LUNG INFLAMMATION AND RESISTANCE TO VIRAL INFECTION

Jacob D. McDonald, Kevin S. Harrod, Matthew D. Reed, JeanClare S. Seagrave, and Joe L. Mauderly

Lovelace Respiratory Research Institute

ABSTRACT

Diesel engine exhaust changes in composition with modification of engine operation/configuration, including the addition of emission reduction technologies, such as low-sulfur fuel and catalyzed ceramic traps. While previous studies have shown that diesel exhaust can cause inflammation in rodents and humans and decreased resistance to respiratory infection in mice (Harrod et al., *Am. J. Resp. Cell Mol. Biol*., vol. 28, pp. 451-463), there is little information on the impact of changes in exhaust composition (resulting from change in engine operation) and aftertreatment technology on these effects.

To address this, identical inflammation and respiratory infection assessments were conducted after exposure of mice to diesel exhaust generated from a single-cylinder diesel engine generator under three steady-state operating conditions: 1) high-load operation, #2 certified fuel, diluted to 200 µg/m^3 particulate matter (PM), 2) low-load operation, #2 certified fuel, diluted to 200 µg/m^3 PM, and 3) high-load operation with ultra-low sulfur fuel and catalyzed ceramic trap, with same dilution rate as condition 1.

Changing the operation (load) of the engine resulted in a twofold change in particle organic content and a fourfold difference in particle size. Comparative results of the compositions of these three exposure atmospheres and the biological effects will be discussed.

IN VITRO GENOTOXICITY OF PARTICULATE AND SEMI-VOLATILE ORGANIC COMPOUND EXHAUST MATERIALS FROM A SET OF GASOLINE AND A SET OF DIESEL ENGINE VEHICLES OPERATED AT 30^0F

M. Ensell, M. Keane, T. Ong, and W. Wallace

Centers for Disease Control and Prevention

ABSTRACT

Extracts of engine exhaust particulate material (PM) or of exhaust semi-volatile organic compound material (SVOC) pooled from a set of gasoline engine automobiles or from a set of diesel engine autos or light trucks, all operated at 30^0 F, were assayed *in vitro* for three measures of genotoxic activity. Materials supplied by the U.S. Department of Energy from modern vehicles operated on the Unified Driving Cycle for light-duty vehicles were acetone extracted and resuspended into TWEEN-80.

Both diesel and gasoline vehicle PM extracts were significantly active for the induction of gene mutation at dose concentrations from 5 to 120 microgram extract/ml, and both displayed a positive dose-response in the *Salmonella typhimurium* histidine reversion micro-suspension assay with tester strains YG1024 and YG1029, with and without S9 microsomal activation of samples. The diesel vehicle PM extract was about twice as active as the gasoline vehicle PM extract on a mass basis.

Chinese hamster lung fibroblasts (V79 cells) were assayed for chromosome damage and for DNA damage at doses from 50 to 125 microgram extract/ml. For chromosome damage determined by the micronucleus induction assay, the maximum activity expressed by gasoline vehicle PM extract was about three times that of the maximum diesel vehicle PM extract. For DNA damage measured by the single cell gel-electrophoresis (comet) assay, the gasoline vehicle PM extract was significantly active at all but the lowest dose. The diesel vehicle PM extract did not express significant activity at any of the doses.

In general, the SVOC extracts were severalfold less active than their PM extract counterparts in all assays. Results are compared with those of a National Institute of Standards and Technology Standard Reference Material diesel exhaust particulate sample, and with those of a similar study of these gasoline and diesel vehicles operated at 70^0F.

COMPARISON OF DIRECT EXPOSURE OF HUMAN LUNG CELLS TO MODERN ENGINE EXHAUST PARTICLES

John Storey, Meng-Dawn Cheng, and Boyd Malone

Oak Ridge National Laboratory

Jean-Clare Seagraves

Lovelace Respiratory Research Institute

ABSTRACT

Cultured human lung cells have been exposed in situ to dilute exhaust from two different vehicles, a gasoline spark-ignited vehicle equipped with a three-way catalyst and a light-duty diesel equipped with a catalyzed diesel particulate filter. Both of these vehicles have extremely low particulate mass emissions, on the order of 5 mg/mile. Particle size and number concentrations are monitored by a scanning mobility particle sizer.

As in previous reports to DEER, the cells are grown in transwell membranes, and dilute exhaust is pumped through the chamber, allowing exhaust nanoparticles to interact individually with the cells. Measurements of cell inflammatory response, including interleukin-8 production and LDH, are reported for time-resolved exposures up to 6.5 hours in duration. A cold start is included in each test sequence.

AN ENGINE EXHAUST PARTICLE SIZER FOR TRANSIENT EMISSION PARTICLE MEASUREMENTS

Tim Johnson, Rob Caldow, and Arndt Pöcher

TSI Incorporated

Aadu Mirme

University of Tartu

David Kittelson

University of Minnesota

ABSTRACT

The measurement of particle emissions from vehicles has been a compromise based on which parameters were most important for the particular measurement. There has been increased interest in obtaining size-distribution data during transient engine operation where total number concentrations can change dramatically. For measuring submicrometer particle sizes, currently the most common technique, scanning mobility particle sizer (SMPS), relies on electrical mobility. The SMPS gives high size resolution but requires an aerosol to be stable with time to make a particle-size distribution measurement.

This paper describes a new instrument, the engine exhaust particle sizer (EEPS), which has high time resolution, uses electrical mobility for classifying the particles, and was designed specifically for measuring engine exhaust. The measurement is based on the particles' electrical mobility similar to what is used in the SMPS system.

Particles entering the instrument are charged to a known charge level. The particles then are repelled outward by the voltage from a central column. When the particles reach an outer cylindrical (a column of rings), they create a current on one of the rings that is measured by an electrometer. The electrometer currents are measured multiple times per second to give high time resolution.

Abstracts

Session 10 – Urea, NOx Adsorber, and Non-Thermal Plasma NOx Reduction

SELECTIVE CATALYTIC REDUCTION SYSTEMS FOR HEAVY-DUTY TRUCKS: PROGRESS TOWARDS MEETING EURO 4 EMISSION STANDARDS IN 2005

Georg Huethwohl

PUREM Abgassysteme GmbH & Co. KG

ABSTRACT

Emissions of diesel engines contain some components that support the generation of smog and are classified as hazardous. Exhaust gas aftertreatment is a powerful tool to reduce NO_x and particulate emissions.

NO_x emissions can be reduced by selective catalytic reduction (SCR) technology. A reduction agent has to be injected into the exhaust upstream of a catalyst. On the catalyst, the NO_x is reduced to N_2 and H_2O. This catalytic process was developed in Japan about 30 years ago to reduce the NO_x emission of coal-fired powerplants. The first reduction agent used was NH_3.

SCR technology was used with diesel engines starting in the mid-1980's. The first applications were stationary operating generator sets. In 1991 a joint development between DaimlerChrysler, MAN, IVECO, and Siemens was started to use SCR technology for the reduction of NO_x in heavy-duty trucks. Several fleet tests demonstrated the durability of the systems. Today, SCR technology is the most promising technology to fulfil the new European Regulations EURO 4 and EURO 5 being effective in October 2005 and October 2008. The efficient NO_x reduction of the catalyst allows an engine calibration for low fuel consumption. DaimlerChrysler decided to use the SCR technology on every heavy-duty truck and bus in Europe, and many other truck manufacturers will introduce SCR technology to fulfil the 2005 emission regulation.

The truck manufacturers in Europe agreed to use aqueous solution of urea as the reducing agent. The product is called "AdBlue," which is a non-toxic, non-smelling liquid. The consumption is about 5 percent of the diesel fuel consumption to reduce the NO_x emissions. A small AdBlue tank has to be installed on the vehicle. With an electronically controlled dosing system, the AdBlue is injected into the exhaust. The dosing system is simple and durable. It has proven its durability during winter and summer testing as well as in fleet tests.

The infrastructure for AdBlue is under evaluation in Europe by urea producers and mineral oil companies to be readily available in time. Urea is one of the most common chemical products in the world, and its production and the distribution are very much known. However, a pure grade is needed for automotive application and requires special attention.

UREA SELECTIVE CATALYTIC REDUCTION AND DIESEL PARTICULATE FILTER SYSTEM FOR DIESEL LIGHT-DUTY TRUCK/SPORT UTILITY VEHICLE MEETING TIER II BIN 5

Robert Hammerle and Christine Lambert

Ford Research & Advanced Engineering

Mike Noorman

ExxonMobil Research & Engineering

ABSTRACT

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 in Europe they currently offer up to 50-percent better volumetric fuel economy and up to 25-percent lower CO_2 emissions than comparable gasoline vehicles. We are using selective catalytic reduction (SCR) with 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 on a light-duty truck/sport utility vehicle application. We are using very low sulfur diesel fuel (~15 ppm) to enable low PM emissions, reducing the fuel economy penalty due to the emission control system, and improving 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 second year of the program, we switched from an ultra low sulfur Swedish-style fuel to a low sulfur fuel developed by ExxonMobil that has properties reflective of those projected for 2007 U.S. diesel fuel. Recalibration of the engine was necessary to compensate for increases in NO_x and hydrocarbon emissions. We continued to separately improve the durability of both the urea SCR and DPF systems. We also have been improving exhaust gas NO_x and ammonia sensors for more accurate control of reductant injection and on-board diagnostics. Finally, we worked with nozzle and dispenser manufacturers to develop durable hardware for delivery of diesel fuel and aqueous urea simultaneously to the vehicle.

ENSURING THE OVERALL SUPPLY OF UREA IN NORTH AMERICA AND THE RELIABILITY OF THE UREA-DOSING UNITS FOR SELECTIVE CATALYTIC REDUCTION SYSTEMS

Glenn Barton

Hilite International

Barry Lonsdale

Terra International

ABSTRACT

Urea is the proven ingredient in the post-combustion treatment of diesel engine exhaust gas for NOx reduction. This paper will discuss the status of urea-dosing units and developments in sensors to insure urea is available and being delivered in the appropriate dose to the post- treatment region and verify that the post-combustion treatment process is effective.

The paper will also address the urea supply infra-structure in North America and how it will insure the proper urea is available for all diesel engine treatment systems, stationary and on-road nationwide.

SELECTIVE REDUCTION OF NO_X IN OXYGEN-RICH ENVIRONMENTS WITH PLASMA-ASSISTED CATALYSIS: CATALYST DEVELOPMENT AND MECHANISTIC STUDIES

C. H. F. Peden, S. E. Barlow, J. H. Kwak, J. Szanyi, and R.G. Tonkyn

Pacific Northwest National Laboratory

M. L. Balmer-Millar and A. G. Panov

Caterpillar, Inc.

J. W. Hoard

Ford Research Laboratory

S. J. Schmieg

General Motors R&D

ABSTRACT

The control of NO_x (NO and NO_2) emissions from so-called 'lean-burn' vehicle en-gines remains a challenge. In recent years, there have been a number of reports that show that a plasma device combined with a catalyst can reduce as high as 90 percent or more of NO_x in simulated diesel and other 'lean-burn' exhaust.

Non-thermal plasma (NTP)-catalysis treatment of a gas stream consists of the sequential (or possibly simultaneous) action of NTP and heterogeneous catalysis. The most common reported strategy for lean NO_x treatment is to separate the plasma from the catalyst, as it is difficult to create robust plasma inside a catalyst bed. In the case of propylene-containing simulated diesel exhaust, the beneficial role of a plasma treatment is now thought to be due to oxidation of NO to NO_2 and the formation of partially oxidized hydrocarbons that are more active for the catalytic reduction of NO_2 than propylene. For plasma-assisted catalysis, both zeolite- and alumina-based materials have shown high activity, albeit in somewhat different temperature ranges, when preceded by an NTP reactor.

This presentation will describe our research efforts aimed at optimizing the catalyst materials for NTP-catalysis devices based, in part, on our continuing studies of the NTP- and catalytic-reaction mechanisms. Various alkali- and alkaline earth-cation-exchanged Y zeolites have been prepared and their material properties characterized. They have been tested as catalytic materials for NO_x reduction in laboratory NTP-catalysis reactors. Interestingly, NO_2 formed in the plasma, and not subsequently removed over these catalysts, will back-convert to NO, albeit to varying extents depending upon the nature of the cation.

Besides this comparative reactivity, we will also discuss selected synthesis strategies for enhancing the performance of these zeolite-based catalyst materials. A particularly important result from our mechanistic studies is the observation that aldehydes, formed during the plasma treatment of simulated diesel exhaust, are the important species for the reduction of NO_x to N_2. Indeed, acetaldehyde has been found to be especially effective in the *thermal* reduction of both NO and NO_2 over Ba- and Na-zeolite-Y catalysts.

Finally, we will discuss experiments aimed at understanding and controlling deactivation of these zeolite-based catalysts due to 'coking.' We believe that this catalyst deactivation mechanism explains a loss of catalyst efficiency with time that is observed in engine dynamometer tests.

HEAVY-DUTY NO_X EMISSIONS CONTROL: REFORMER-ASSISTED VS. PLASMA-FACILITATED LEAN NO_X CATALYSIS

Christopher L. Aardahl

Pacific Northwest National Laboratory

Paul W. Park

Caterpillar, Inc.

ABSTRACT

Recent efforts in plasma-facilitated lean NO_x catalysis and thermal lean NO_x catalysis have shown that hydrocarbon speciation has a dramatic impact on catalyst performance. In particular, use of oxygenated hydrocarbons as reducing agents results in better NO_x efficiency than typical fuel hydrocarbons. In a cooperative research and development agreement between Pacific Northwest National Laboratory and Caterpillar, Inc., reformation of non-oxygenated hydrocarbons to oxygen-containing molecules is being examined as a way to enhance performance in lean NO_x catalyst systems. Recent results for reformer-assisted catalysis are compared to results using traditional plasma-catalysis.

DYNAMOMETER EVALUATION OF PLASMA-CATALYST SYSTEM FOR DIESEL NO_X REDUCTION

John Hoard

Ford Motor Company

Dave Brooks

DaimlerChrysler

Steve Schmieg

General Motors R&D

Charles H. F. Peden, Steve Barlow, and Russ Tonkyn

Pacific Northwest National Laboratory

ABSTRACT

A three-stage plasma-catalyst system was developed and tested on an engine dynamometer. Previous laboratory testing suggested high NO_x efficiency could be obtained. With hexene reductant added to the exhaust, we observed over 90-percent NO_x reduction. However, with diesel or Fischer-Tropsch reductant, the catalyst efficiency rapidly dropped off. Heating the catalyst in air removed brown deposit from the surface and restored conversion efficiency.

Following the engine tests, the used catalysts were evaluated. BET surface area decreased, and temperature-programmed desorption revealed significant storage. This storage appears to be partly unburned diesel fuel that can be removed by heating to around 250-300°C, and partly hydrocarbons bonded to the surface that remain in place until 450-500°C.

Laboratory testing with propene reductant demonstrated that the catalyst regains efficiency slowly even when operating temperature does not exceed 300°C. This suggests that control strategies may be able to regenerate the catalyst by occasional moderate heating.

NOXTECH'S PLASMA-ASSISTED CATALYST SYSTEM DEVELOPMENT AND DEMONSTRATION

Ralph Slone, Victor Puchkarev, and Jeff Marguglio

Noxtech, Inc.

ABSTRACT

The non-thermal plasma-assisted catalyst (NTPAC) technology being developed at Noxtech, Inc., continues to focus on achieving the 2007 and beyond emissions standards for heavy-duty vehicles. Noxtech's NTPAC technology utilizes an efficient non-thermal plasma reactor 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 a sulfur-tolerant catalyst that contains no precious metals.

Noxtech has made significant 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 generator using diesel fuel as a source of reductant.

Noxtech's emphasis for its 2003 program has been to improve and enhance the performance, reliability, and commercial capability of its NTPAC system. It is working with a commercial partner to reduce the size and cost and improve the efficiency of the pulser for its plasma reactor. Noxtech has also redesigned and improved its diesel fuel converter to produce effective hydrocarbons to act as a catalyst and reductant for the NTPAC system. Several new catalysts have been formulated and evaluated to enhance performance (surface efficiency/availability and selectivity) as well as to improve durability and operating temperature range. The goal is to produce a system that is commercially capable in the near future.

Noxtech has conducted a demonstration of its NTPAC system at a third-party test site for assessment by Government and private industry representatives. The result of this test will be presented at the DEER 2003 Conference.

NO_X ADSORBER REGENERATION PHENOMENA IN HEAVY-DUTY APPLICATIONS

Brian West, John Thomas, Mike Kass, John Storey, and Sam Lewis

Oak Ridge National Laboratory

ABSTRACT

Hydrocarbon species are being measured with a gas chromatograph/mass spectrometer and Fourier transform infrared at NO_x adsorber inlet and outlet locations in the exhaust system of a heavy-duty diesel engine. The engine is equipped with electronic throttle and exhaust gas recirculation, in-pipe fuel injection, and various diesel oxidation catalysts upstream of a catalyzed diesel particle filter (CDPF) and a high-temperature NO_x adsorber catalyst. Raw diesel fuel injected into the exhaust system is readily cracked into lighter compounds over catalysts, and the NO_x adsorber more readily utilizes certain compounds during regeneration. Augmenting the CDPF with oxidation catalysts produces preferred species such that comparable NO_x reduction can be achieved with less supplemental fuel.

COMPARISON OF 4-WAY NO_X ADSORBER CATALYST PERFORMANCE ON FIBROUS AND CONVENTIONAL SUBSTRATES

Neil Currier, Matthew Henrichsen, Bill Epling, and Jim Lucas

Cummins, Inc.

ABSTRACT

Performance of a 4-way NO_x adsorber is dependent on a number of non-operating factors. These include catalyst composition, monolith cell size, monolith aspect ratio, substrate thermal properties, substrate material, and substrate wall morphology. The relative significance of these factors was scouted by comparing a standard cordierite monolith to a fibrous monolith. Flexibility in the choice of catalyst loading and differences in heat distribution were found to play a significant role in determining NO_x performance of these devices.

MEASUREMENT AND CHARACTERIZATION OF NO_X ADSORBER REGENERATION AND DESULFATION

Shean Huff, Stuart Daw, John Storey, Brian West, Bill Partridge, Sam Lewis, Dean Edwards, Katey Lenox, and Jae-Soon Choi

Oak Ridge National Laboratory

ABSTRACT

Experiments at Oak Ridge National Laboratory are being conducted to characterize NO_x adsorber catalysts. Full-size samples are being evaluated on a diesel engine stand with full-pass control of electronic throttle and exhaust gas recirculation (EGR), wastegate, number and timing of fuel injection events, etc. Bench-scale work with powders, wafers, and small monolith cores is being conducted in parallel to the engine work.

The presentation will describe recent measurements of hydrogen and other species inside catalyst channels and in the bulk exhaust using spatially resolved, capillary-inlet mass spectrometry (SpaciMS). Gas chromatography is being used in conjunction with SpaciMS to fully characterize the exhaust hydrocarbons and other species that are formed in-cylinder for various regeneration strategies and the usage of various compounds through the oxidation and NO_x adsorber catalysts downstream.

NO_X ADSORBER CATALYST DURABILITY: LIGHT- AND HEAVY-DUTY PERSPECTIVES

Jim Parks, Bill Epling, Greg Campbell, Michele Sanders, and Aaron Watson

EmeraChem

ABSTRACT

NO_x adsorber catalysts can reduce NO_x from diesel engines by over 90 percent, but to be commercially viable, NO_x adsorbers must demonstrate compliance-range durability. Sulfur masking has traditionally limited NO_x adsorber durability, but sulfur management by a combination of catalyst desulfation and fuel-sulfur reduction is an effective method of controlling degradation from sulfur masking.

Since the control of sulfur masking has been demonstrated, thermal degradation is expected to be the primary degradation mechanism. Thermal degradation rates will great-ly depend on the operation temperatures of the catalyst, and the desulfa-tion process typically results in the highest and most severe temperature exposure. A NO_x adsorber catalyst aging experiment testing repetitive thermal exposure during the desulfation process will be presented. Results will be used to predict catalyst lifetime and compare to compliance mileage requirements. Issues relating to the different requirements for light- and heavy-duty applications will be discussed.

COMPLEMENTARY EXPERIMENTAL TOOLS FOR UNDERSTANDING DIESEL PARTICULATE FILTER BEHAVIOR

Aleksey Yezerets, Neal Currier, Arvind Suresh, and William Epling

Cummins, Inc.

ABSTRACT

During the last 3 years, a set of unique laboratory techniques was developed at Cummins to investigate various aspects of diesel particulate filter (DPF) loading and regeneration processes. A novel rapid protocol for measuring particulate matter oxidation rates under various conditions has been developed using a micro-reactor system. Also, a unique system was designed, which allows us to load soot-filter cores in a diesel exhaust and subsequently study their regeneration and back-pressure behavior under well-controlled conditions in a pilot reactor. The results obtained with these techniques show good correlation with the on-engine testing.

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Abstracts

Session 11 – Aftertreatment

USE OF A DIESEL FUEL PROCESSOR FOR RAPID AND EFFICIENT REGENERATION OF SINGLE-LEG NO_x ADSORBER SYSTEMS

R. Dalla Betta, J. Cizeron, D. Sheridan, and T. Davis

Catalytica Energy Systems, Inc.

ABSTRACT

NO_x adsorber or NO_x trap systems must be regenerated frequently to convert the adsorbed NO_x to N_2 and to regenerate the NO_x adsorption capacity of the NO_x trap. This regeneration requires a reducing environment and the presence of a reductant capable of reacting with the NO_x trap components. Recent reports have shown that "reactive" reductants such as H_2, CO, and oxygenated species can regenerate NO_x traps more rapidly and at lower temperatures. While this offers a clear potential advantage, providing a reductant in a cost-effective manner is problematic.

A diesel fuel processor has been developed that can operate from low loads to full loads and can produce periodic, high concentrations of a "reactive" reductant from diesel fuel as required during the regeneration portion of the cycle. Engine tests show that the fuel processor produces a "reactive" reductant over a wide exhaust-temperature range and with good control of reductant mass flux.

The benefits of a reactive reductant were demonstrated by tests in which the NO_x trap was regenerated with reductant pulses as short as 1 second. Steady-state tests have shown fuel penalties in the range of 3 percent for a single-leg system with high NO_x conversion. In addition, the fuel processor is designed to produce a desulfation cycle that includes raising the NO_x trap to the required desulfation temperature and then providing the required reducing environment to regenerate the NO_x adsorber system. The use of a "reactive" reductant should allow the desulfation cycle to occur at lower temperatures, thus increasing NO_x adsorber durability. The operating characteristics and performance of the diesel fuel processor will be presented.

BIFUNCTIONAL CATALYSTS FOR THE SELECTIVE CATALYTIC REDUCTION OF NO BY HYDROCARBONS

Christopher L. Marshall, Michael K. Neylon, Mario J. Castagnola, and A. Jeremy Kropf

Argonne National Laboratory

ABSTRACT

Novel bi-functional catalysts combining two active phases, typically Cu-ZSM-5 and a modifier, were prepared and tested for the selective catalytic reduction of NO_x using propylene in order to overcome the hindering effects of water typically seen for single-phase catalysts, such as Cu-ZSM-5. The catalysts were made by typical preparation techniques, but parameters could be varied to influence the catalyst.

The physical characterization of the materials showed that the modification phase was added strictly to the external surface of the zeolite without hindering any internal surface area. Chemical characterization by temperature programmed reactions, diffuse reflectance infrared Fourier transform spectroscopy, and x-ray absorption spectroscopy indicated strong interaction between the two phases, primarily producing materials that exhibited lower reduction temperatures.

Two improvements in NO_x reduction activity (1000 ppm NO, 1000 ppm C_3H_6, 2% O_2, 30,000 hr^{-1} GHSV) were seen for these catalysts compared with Cu-ZSM-5: (1) a lower temperature of maximum NO_x conversion activity (as low at 250°C) and (2) an enhancement of activity when water was present in the system. The use of a second phase provides a way to further tune the properties of the catalyst in order to achieve mechanistic conditions necessary to maximize NO_x remediation.

LEAN NO_X CATALYSIS DEVELOPMENT FOR DIESEL ENGINES

Dennis L. Endicott, Paul Park, Steve Faulkner, and M. Lou Balmer-Millar

Caterpillar Inc.

ABSTRACT

An attractive NO_x aftertreatment catalyst technology is one based on catalyst materials that utilize hydrocarbons in the diesel fuel to supply the required supplemental reductants, while operating in normal lean-combustion conditions. Thus, lean-NO_x technology still maintains its potential opportunity to reduce NO_x for meeting future NO_x emission regulations as engine technologies advance.

Through catalyst research and development programs with academia and industry (catalyst suppliers), we are able to study various aspects of catalyst technologies from fundamental understanding to applications.

In this presentation the various efforts devoted from Caterpillar on research and development of the lean-NO_x catalyst technology will be discussed.

FUEL-BORNE REDUCTANTS FOR NO_X AFTERTREATMENT

Mike Kass, John Thomas, and Bruce Bunting

Oak Ridge National Laboratory

ABSTRACT

One potential method for meeting stringent NO_x emissions standards involves blending reductants into the bulk fuel, then removing them on board, or perhaps at the pump, for use in selective catalytic reduction (SCR). One family of readily removed reductants is light alcohols.

By using ethanol as the reductant and silver-loaded alumina catalyst bricks, NO_x emissions were reduced by more than 90 percent and 80 percent for space velocities of 21,000/h and 57,000/h, respectively. These results were achieved for catalyst temperatures between 360°C and 400°C and for C1: NO_x ratios of 4-6; at lower temperatures, the NO_x conversion was less efficient.

A concept for utilizing ethanol (distilled from an ethanol-diesel micro-emulsion fuel) as the SCR reductant was included in this initial study to demonstrate fuel-borne reductant feasibility. In contrast to other catalyst technologies, NO_x conversion appeared to be enhanced by the initial catalyst aging, with the presumed mechanism being sulfate accumulation within the catalyst. We anticipate presenting follow-on efforts, which include assessing SCR performance for these catalysts using other reductant (alcohol) types.

HYDROGEN GENERATION FROM PLASMATRON REFORMERS AND USE FOR DIESEL EXHAUST AFTERTREATMENT

Leslie Bromberg

Massachusetts Institute of Technology

Sam Crane

ArvinMeritor

ABSTRACT

The status of plasmatron reformers under development at the Massachusetts Institute of Technology (MIT) and ArvinMeritor will be presented. In these reformers, a special low- power electrical discharge is used to promote partial oxidation conversion of hydrocarbon fuels into hydrogen and CO. This very fuel-rich mixture reaction is hard to initiate, and the plasmatron provides continuous enhanced volume initiation. To minimize electrode erosion and electrical power requirements, a low-current, high- voltage discharge is used, with wide area electrodes. The reformers operate at or slightly above atmospheric pressure.

Plasmatron reformers provide the advantages of rapid startup and transient response; efficient conversion of the fuel to hydrogen-rich gas; compact size; relaxation or elimination of reformer catalyst requirements; and capability to process difficult-to-reform fuels, such as diesel and bio-oils. These advantages facilitate use of hydrogen-manufacturing reformation technology for diesel exhaust aftertreatment. Plasma-enhan-ced reformer technology can provide substantial conversion even without the use of a catalyst.

Recent progress includes substantial decrease in electrical power consumption (to about 200 W), increased flow rate (above 1 g/s of diesel fuel corresponding to approximately 40 kW of chemical energy), soot suppression, and improvements in other operational features.

This technology has been evaluated for use as a regeneration mechanism for NO_x-adsorber aftertreatment systems. At ArvinMeritor, tests were performed on a dual-leg NO_x adsorber system using a Cummins ISC 8.3L diesel engine in a vehicle. A NO_x adsorber system was tested with the plasmatron reformer as a regenerator, and without the reformer (i.e., with straight diesel fuel based regeneration as a baseline case).

The plasmatron reformer was shown to improve NO_x regeneration significantly, compared to the baseline diesel case. The net result was a significant decrease in fuel penalty, roughly 50 percent at moderate catalyst temperatures. This improvement is accompanied by a dramatic drop in slipped hydrocarbon emissions, which decreased by 90 percent or more. Significant advantages are demonstrated across a wide range of engine conditions and temperatures. The study also indicated the potential to regenerate catalytic adsorbers at low temperatures where diesel fuel based regeneration is not effective, such as are typically seen at idle conditions. A vehicle has been equipped for plasmatron reformer exhaust aftertreatment tests.

DIESEL REFORMERS FOR ON-BOARD HYDROGEN APPLICATIONS

Mark Mauss

Hydrogen Source

ABSTRACT

Many solutions to meeting the 2007 and 2010 diesel emissions requirements have been suggested. On-board production of hydrogen for in-cylinder combustion and exhaust aftertreatment provides promising opportunities for meeting those requirements. Other benefits may include using syngas to rapidly heat up exhaust after-treatment catalysts during engine startup.

Hydrogen Source's development of a catalytic partial oxidation reformer for generating hydrogen from ultra-low sulfur diesel fuel will be presented. The system can operate on engine exhaust and diesel fuel with no water tank. Test data for hydrogen regeneration of a lean NO_x trap will be presented showing 90 percent NO_x conversion at temperatures as low as 150°C and 100 percent conversion at 300°C. Finally, additional efforts required to fully understand the benefits and commercial challenges of this technology will be discussed.

MEASUREMENT OF IN-USE EMISSIONS FROM HEAVY-DUTY DIESEL VEHICLES: THE STATE-OF-THE-ART

Mridul Gautam, Greg Thompson, Nigel Clark, Dan Carder, Scott Wayne, Wes Riddle, and Don Lyons

West Virginia University

ABSTRACT

A considerable amount of effort is being devoted toward generating exhaust emissions data from heavy-duty, on-highway diesel engines operating under normal in-use conditions. Engine manufacturers and various regulatory bodies (U.S. Environmental Protection Agency, California Air Resources Board) alike will use this information to ensure that emissions standards are met throughout the useful life of 2007, and later, model year heavy-duty, on-highway diesel engines. Efforts are also being focused on monitoring not-to-exceed emissions compliance. As a result, a fair understanding of in-use and Federal Test Procedures (certification cycle) emission levels from on-highway engines has been afforded. However, there is very sparse information on in-use and steady-state certification cycle emissions from non-road engines. Moreover, the extrapolation of this sparse amount of data to provide estimates of the emissions impact these non-road vehicles have on air quality could lead to large errors (recent work at West Virginia University [WVU] has shown that in-use emissions from non-road engines are severely overestimated by 8-mode steady state certification cycles). An established set of measurement protocols and system design recommendations providing for accurate on-board measurement tools has been the missing link to attaining this information.

In response to such needs, WVU has developed, and continues to evolve, an on-board, in-use emissions measurement system called the Mobile Emissions Measurement System (MEMS) that allows determination of in-use, brake-specific emissions from heavy-duty diesel-powered vehicles. This work is a part of the future trends toward moving out of the certification test cells and into actual in-field emissions measurements. This paper discusses some of the in-use emission results from on-highway engines, marine vessels (from a recently completed study on a high-speed hydrofoil), and non-road engines that were obtained by WVU using the MEMS. Such fieldwork has not only provided WVU with valuable experience related to in-use testing protocols, but also with ideas concerning future on-board emissions measurement system design.

This paper will discuss general in-use test procedures, as well as the essential components of generic, on-board emissions measurement tools. Aspects such as accuracy, precision, "ultra-portability," and system flexibility will be discussed pertaining to in-use testing of emissions from both on-highway and non-road engines. Advanced concepts, such as fuel-specific emissions, and their impact on design of measurement systems used for compliance and development work are discussed.

DIESEL PARTICULATE FILTER OVERVIEW: MATERIAL, GEOMETRY, AND APPLICATION

Martin J. Murtagh and David L. Hickman

Corning, Inc.

ABSTRACT

This presentation is a review of diesel parti-culate filters (DPF's) from the past to the present. It will cover materials choices, filter geometry, and systems integration needs. Included in the presentation will be a discussion of materials properties and their compatibility with diesel fuel and oil compositional make-up and exhaust use temperature, as well as chemo-thermo-mechanical durability limits of selected supports and catalyst options.

NEW CORDIERITE DIESEL PARTICULATE FILTERS FOR CATALYZED AND NON-CATALYZED HEAVY-DUTY APPLICATIONS

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ABSTRACT

Ceramic wall-flow diesel particulate filters (DPF's) are presently being explored for the collection and combustion of carbonaceous soot in heavy-duty vehicle applications. To minimize reduction in vehicle power, it is important for the DPF to have a low pressure drop. The pressure drop of a DPF is known to increase with the accumulation of soot. Furthermore, depending upon the type of engine and the strategy employed to initiate regeneration of the filter, DPF's may be catalyzed to reduce emissions of NO_x, CO, and HC, as well as to lower the temperature required for regeneration. The presence of a catalyst within, or on top of, the filter wall can further contribute to an increase in pressure drop of the filter. To minimize the pressure drop for catalyzed and non-catalyzed filters, it is necessary to optimize the pore microstructure of the ceramic walls as well as the external dimensions and cell geometry of the filter.

Cordierite DPF's provide an economical approach to diesel emission control. However, further reduction in the pressure drop of catalyzed and non-catalyzed cordierite filters is desirable. In an effort to develop new cordierite filters that possess lower pressure drop while maintaining high filtration efficiency and strength, cordierite ceramics have been fabricated spanning an extended range in porosity, pore-size distribution, and pore connectivity. Pressure drops of the clean and soot-loaded filters before and after catalyst impregnation have been measured over a series of flow rates for a wide range of pore microstructures. Analysis of the results has provided explicit equations relating the pressure drop versus soot- loading behavior to the porosity and pore-size distribution of the ceramic wall, and has increased the fundamental understanding of the relationship between filter permeability and pore microstructure.

Optimum values for the percent porosity, median-pore diameter, and breadth of the pore- size distribution for minimizing pressure drop have been identified. These results have been applied to the development of several new, high-porosity, cordierite diesel particulate filters that possess a unique combination of high filtration efficiency, high strength, and very low clean and soot-loaded pressure drop in both the catalyzed and non-catalyzed states. By controlling the microstructure, the impact of the catalyst on pressure drop has been minimized. Soot-loaded pressure drops of these new filters in their catalyzed state are less than 50 percent of other catalyzed commercial filters with the same cell geometry.

NON-THERMAL PLASMA BASED TECHNOLOGIES FOR THE AFTERTREATMENT OF AUTOMOTIVE EXHAUST PARTICULATES AND MARINE DIESEL EXHAUST NO_X

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ABSTRACT

The trend in environmental legislation is such that primary engine modifications will not be sufficient to meet all future emissions requirements, and exhaust aftertreatment technologies will need to be employed. One potential solution that is well placed to meet those requirements is non-thermal plasma technology. This paper will describe our work with some of our partners in the development of a plasma-based diesel particulate filter (DPF) and plasma-assisted catalytic reduction for NO_x removal.

Accentus and Eberspächer have been working to develop non-thermal plasma regenerated DPF technology for diesel passenger car applications. The results from the evaluation of a prototype system on a 3.0L diesel engine with Euro IV engine management will be presented. During the evaluation, filtration efficiencies between 95 and 100 percent were recorded with plasma regeneration demonstrated at powers down to 600 W at a range of exhaust gas temperatures. The evaluation also demonstrates the possibility for a flexible control strategy, which could be based around either continuous or intermittent regeneration.

The U.K. Ministry of Defence (Navy) is evaluating the feasibility of exhaust control technologies suitable for the reduction of NO_x emissions from diesel engines. The plasma - assisted catalysis approach can offer a number of potential advantages over the use of selective catalytic reduction in a warship application, such as low-load performance and the removal of the need for a urea-based reductant. A development program is underway to produce a plasma-assisted catalytic reduction system for NO_x removal. This program has been based on understanding the process at the laboratory scale and then undertaking the design, build, and testing of a system to treat $1/10^{th}$ the flow from a 1.4 MW marine diesel engine. The overall strategy for the program will be described together with results from the programme to date, including the initial testing of the $1/10^{th}$ scale system.

RECENT DIESEL EMISSION MITIGATION ACTIVITIES OF THE U.S. MARITIME ADMINISTRATION ENERGY TECHNOLOGIES PROGRAM

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ABSTRACT

The Santa Barbara County (California) Air Pollution Control District is forecasting that NO_x pollutants generated by coastal ships are on the way to eclipsing all land-based county sources. The Port of New York and New Jersey is developing an innovative strategy whereby emissions reduced from the renown Staten Island ferries could be used to legally offset other sources within the harbor. What technologies can be applied to vessels (which are often foreign owned) to reduce criteria pollutants? What marine unique challenges will have to be accommodated by an emissions-measurement protocol to support the concept of "offsetting" and other technology incentive programs?

At the DEER 2002 Conference, the author gave a presentation providing an overview of the Maritime Administration (MARAD) Energy Technologies Program. The presentation highlighted air-pollution mitigation pressures currently being applied to diesel engines in the maritime industry and program steps taken to address these pressures. This year's presentation will provide an update of the program and respond to the above questions by examining four subject areas:

- Brief review of program, goals, progress, and new regulations.
- Emissions measurement and performance results from ultra-low sulfur diesel fuel and inlet air humidification technology tests aboard a San Diego based ferry.
- Discussion of marine unique emission measurement challenges presented by ships and the maritime environment.
- Developments in a large vessel engine retrofit technology demonstration project.