I. EXECUTIVE SUMMARY.

The USDOE Office of Heavy Vehicle Technologies envisions the development of flexible-fuel, energy-efficient, near-zero emissions, heavy duty U.S. diesel engine technology in all truck classes as a real and viable strategy for reducing energy requirements for commercial transportation services and the rapid growing multipurpose vehicle market. To achieve this vision, R&D goals have been set for three classes of trucks, Heavy (Class 7 & 8), Medium (Class 3 to 6) and Light (Class 1 & 2) Trucks. To achieve these goals necessitates development of future diesel vehicle technology to meet the stringent EPA 2004 emission requirements.

The chronology of the diesel NOx and Particulate emission reductions achieved to date and the target levels for 2004 are found on Figure 1. Meeting the target levels for 2004 is even more difficult for the heavy duty diesel engine manufacturers, who, as a result of the 1998 EPA/DOJ decree, agreed to meet the EPA 2004 regulations by October 1, 2002. Meeting the targets and future regulations may result in a fuel economy penalty for large trucks. To meet the 2002 targets and future regulations will require both new emission control technologies and an improved fuel quality

A significant issue arising from the urgent need to develop post combustion catalyst and particulate trap technology is the potential impact on heavy-duty engine oils on any new technology developed. Removal of the sulfur from diesel fuel raises real issues that include the effect of the sulfur and phosphorus content of the lubricating oils on new technology and how changes in additive chemistry affect engine durability and component compatibility.

A workshop to explore the technological issues involved with the removal of sulfur from lubricants and the development of low emission diesel engine oils was held in Scottsdale, AZ on January 30, 31 and February 1, 2000. A total of 89 attendees from industry, government and academia with extensive expertise in the areas of aftertreatment technology, petroleum and alternate fuels, basestocks, lubricants, additives, tribology, and alternative lubricants participated in the workshop. The group had OEM representatives from both diesel and gasoline engine and vehicle industries.

The primary purpose of this DOE Workshop on Low Emission Diesel Engine Oils was to explore the issues and ***"To craft a shared vision for Industry - Government (DOE) R&D collaboration in diesel engine oils to minimize emissions, while maintaining or enhancing engine performance".***

The format of the workshop was to present an overview of the current technology by means of panel discussions and technical presentations from industry, government and academia and then address the key areas (Basestocks, Additives, Alternative Fuels, Alternative Lubricants and Catalysts) in breakout sessions.

The breakout or working groups were formed on the second day of the workshop. The five groups were asked to address their area in the context of improving energy efficiency and reducing emissions of the vehicle as a system and to establish a list of high priority R&D opportunities related to low emission diesel engine oils for industry and government collaboration. Table 1 is a summary of the priority areas.

FIGURE 1.

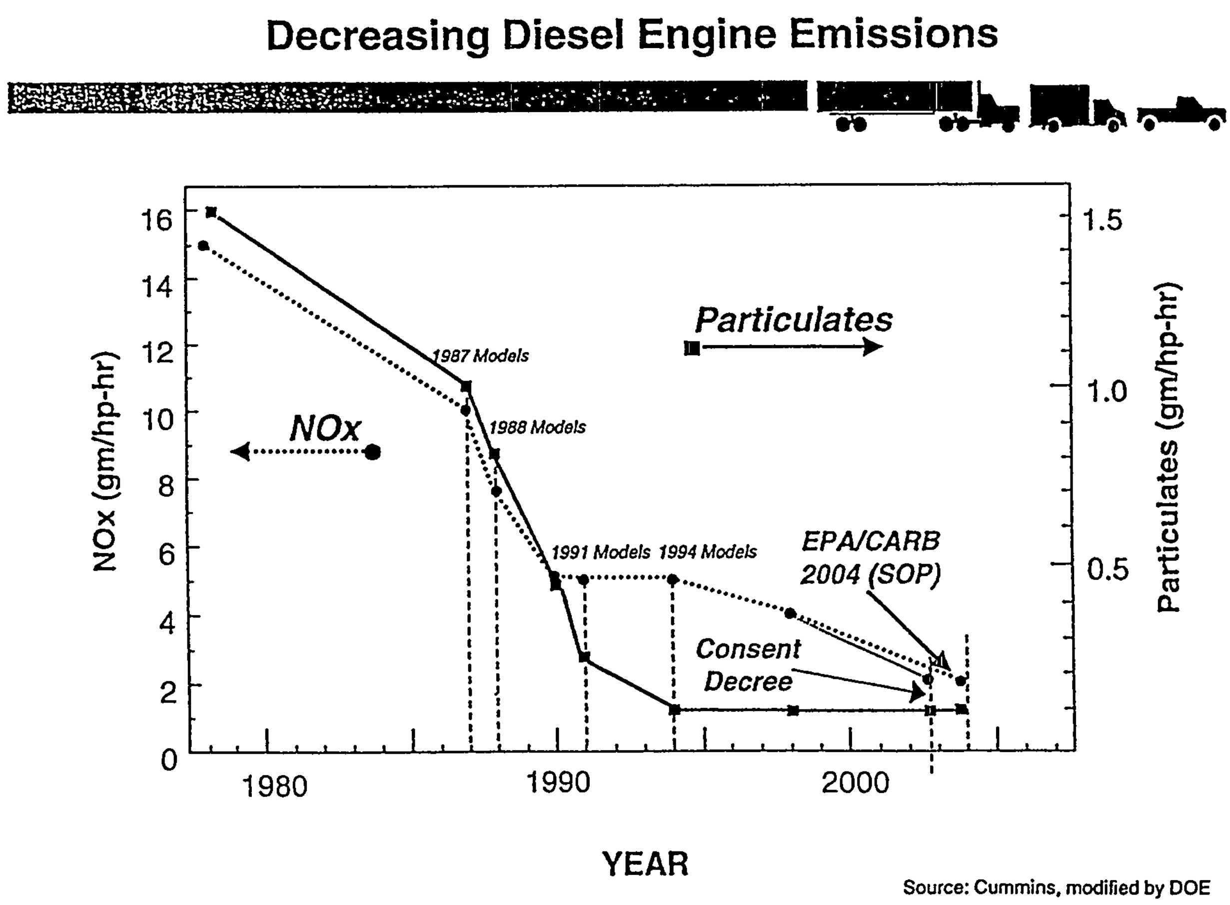

TABLE 1. SUMMARY OF WORKSHOP NEEDS AND STATUS

NEEDS	TECHNICAL TARGET	CURRENT BARRIER	FEASIBILITY OF SUCCESS (Reasons)
MORE TOLERANT CATALYSTS	**Develop sulfur tolerant catalysts**	**Specific knowledge on masking & poisoning**	**Low (Needs revolutionary change in catalyst, Time factor, Investment High.)**
ROLE OF LUBRICANT	**Determine specifics on catalyst masking & poisoning**	**Contribution of additives to problem unknown factor. Reducing ZDP, metals and S may be adequate.**	**High (DECSE program partially addressing need)**
ADDITIVE TYPE AND ROLE	**Determine mechanism of additive involvement**	**Assumes all additive Sulfur, Phosphorus, Metals end up in exhaust. Volatility factors unknown.**	**High (Fundamental data can be determined in laboratory - Bench & Dynomometer tests).**
ADDITIVE - EGR INTERACTIONS	**Knowledge on type of additive & concentration factor needed.**	**Assumes more particulate reduces effectiveness of additives.**	**High (Bench and engine dynamometer tests can yield information needed)**
NEW ADDITIVES	**Additives non-detrimental to catalyst efficiency or durability**	**Extensive knowledge on current additives and how to synthesize new additives.**	**Medium (Time and high cost of research. Also, need to prove in new engines and field)**
EGR FILTER	**Effective way to remove acids and particulate from EGR stream.**	**Application of current filter technology. May have similar trap problems as exhaust.**	**High – Medium (Sizing filter is minor problem, some chemical, mechanical and durability factors)**
ALTERNATIVE LUBRICANTS	**Biodegradable, effective DEO with new additives**	**Current renewable lubricants on test, using minimal sulfur and phosphorus.**	**Medium (Cost, lack of engine & field testing, availability of sufficient base fluids)**
FUELS	**No Sulfur Fuel**	**Current fuels available, limited quantities**	**Medium (Cost of infrastructure, may need special lubricants)**
ALTERNATE FUELS	**Reduction of emissions and expand supplies at reasonable costs.**	**Availability limited, costs high, mixed emission data, efficiency loss, cold flow properties and oxidative stability.**	**Medium (infra-structure, studies on material compatibility, limited advanced engine and vehicle testing)**

RECOMMENDATIONS:

1. The issue coming out of the workshop with the top priority is to solve the exhaust emissions aftertreatment problems resulting from fuel sulfur and possibly lubricant additives affecting the performance of the system. It is known that the level of sulfur in the fuel is a problem and a low sulfur fuel by 2002 will help solve part of the problem. It is not known to what extent the lubricant plays a role. Engine out and catalyst out information using a future engine with exhaust gas recirculation (EGR), an ultra-low or zero sulfur fuel and a test procedure are essential to resolve this issue.

The DOE Diesel Emissions Control – Sulfur Effects (DECSE) Program is addressing this issue and should be expanded if necessary to determine the effect of current lubricants and reduced sulfur and ZDP additive lubricants on the efficiency of the catalyst. (The DECSE Program was recently renamed the Advanced Petroleum-Based Fuels, Diesel Emission Control [APBF-DEC] Program; it is referred to as the DECSE Program throughout this document.) The development of PC-9 DEO involves some 10-12 engine and laboratory tests is costing the industry over $40 million. Therefore, it is not unreasonable to consider increasing the DECSE Lubricant budget an estimated $5 million to solve this issue.

2. The second priority that has an impact on the system is the effect of EGR on the lubricant. To develop the next generation of low emission lubricants requires resolving several issues regarding the particulate loading of the lubricant. Unless the particulate can be effectively removed from the recirculated exhaust, the loading of particulate in the lubricant is expected to more than double. As a result, excessive engine wear may occur. A tribology program to explore the effect of particulate in the lubricant is needed in order to determine the range of options available to make revolutionary changes in the lubricant.

3. The development of environmentally friendly fuels and lubricants is feasible for the 2007 timeframe. To accomplish this 1) alternative fuels, blends with diesel fuels, and selected additives need to be evaluated in the laboratory and the better fuels evaluated in advanced engines to identify the impact on emissions and if long term problems exist, and 2) biodegradable alternative lubricants need to be optimized using selected additives prior to evaluation in advanced engines and vehicles to identify problems or concerns. To accomplish this, prescreening tools to evaluate alternative fuels and lubricants, test methods and required specifications need to be agreed upon and standardized. Non-sulfur and reduced additive requirements of these oils make this approach friendly to the aftertreatment systems.

4. The nature of the particulate emitted from a future EGR engine needs to be determined. The distribution mass and number of the particles and the origin of the nanoparticles is needed. Characterization of particulate is important to the resolution of health effects issues hanging over the diesel.

5. Collaboration with existing fuel and lubricant programs is recommended to expedite completion of the research and development to enable meeting the 2004 emission requirements.

II. INTRODUCTION.

The USDOE Office of Heavy Vehicle Technologies envisions the development of flexible-fuel, energy-efficient, near-zero emissions, heavy duty U.S. diesel engine technology in all truck classes as a real and viable strategy for reducing energy requirements for commercial transportation services and the rapid growing multipurpose vehicle market. To achieve this vision, R&D goals have been set for three classes of trucks, Heavy (Class 7 & 8), Medium (Class 3 to 6) and Light (Class 1 & 2) Trucks:

Class 7 (26,001 - 33,000 lb.) & Class 8 (33,001 lb. and over) Trucks:
To develop by 2004, the enabling technologies needed to achieve a fuel efficiency of at least *10 miles per gallon* (at 65 mph) and *meet* emission standards prevailing in 2004, using petroleum based diesel fuel. __

Class 3 to 6 (10,001 to 26,000 lb.) Trucks :
By 2004, to develop and demonstrate commercially viable vehicles that achieve, on an urban cycle, at least *double the fuel economy* of comparable current (1999) vehicles, and as a research goal, reduce criteria pollutant emissions to *at least 30 percent below* EPA standards prevailing in 2004.

Class 1 (6,000 lb. and less) and Class 2 (6,001 to 10,000 lb.) Trucks:
To develop by 2004 the enabling technologies for clean diesel engines to be competitive with and *at least 35 percent more fuel efficient* than equivalent gasoline engines for light trucks, while meeting Federal and State emission standards prevailing in 2004.

OVHT plans that focus on critical R&D areas for all truck classes can be found in the OHVT Technology Roadmap (October 1997) and the OHVT Multi-year Plan for 1998 - 2002. Both can be found on the internet at http://www.osti.gov/roadmap.pdf and http://www.osti.gov/multiyr.pdf

To achieve these goals requires meeting stringernt EPA regulations by October 1, 2004. The 1988 EPA/DOJ Consent Decree with heavy-duty engine manufacturers requires that they develop the new technologies to enable them to meet the EPA 2004 emission regulations by October 1, 2002. Meeting the decree may result in a fuel economy penalty for large trucks. This fuel penalty would result in a projected ten percent loss in efficiency in heavy duty diesel engines (HDD) which equates to an increase in fuel consumption of over 10 million barrels of fuel per year.

It is anticipated that further reductions in emissions will be required for HDD in 2007. The NOx reduction goal will be approximately 90 % of 2004 standards and beginning in 2007, PM trap based reductions are expected to be 90 % lower than 1994 levels. Light duty diesel trucks and diesel passenger cars will be expected to meet Tier 2 automotive standards of 0.07g/mi. NOx and 0.01 g/mi. of particulate by 2007.

To enable the use of the new control technologies will require improved quality, ultra low sulfur fuel. A significant issue arising from the use of low sulfur fuel is the potential impact on the heavy-duty engine oils. Real questions arise on the effect of sulfur and phosphorus content of the lubricating oils on new technology, and how changes in additive chemistry affect engine durability and component compatibility. These issues were the drivers for the "Low Emissions Diesel Engine Oils" workshop.

The primary purpose of this DOE Workshop on Low Emission Diesel Engine Oils was to explore the issues and ***"To craft a shared vision for Industry - Government (DOE) R&D collaboration in diesel engine oils to minimize emissions, while maintaining or enhancing engine performance".***

The format of the workshop was to present an overview of the current technology by means of panel discussions and technical presentations from industry, government and academia and then address the key areas (Basestocks, Additives, Alternative Fuels, Alternative Lubricants and Catalysts) in breakout sessions. The agenda for the meeting is found in Attachment 1. The attendance list for the meeting is Attachment 2 and includes participants with outstanding expertise in the five breakout areas.

The breakout or working groups were formed on the second day of the workshop. The five groups were asked to address their area in the context of improving energy efficiency and reducing emissions of the vehicle as a system and to establish a list of high priority R&D opportunities related to low emission diesel engine oils for industry and government collaboration.

III. TECHNICAL PROGRAM.

Six sessions are listed on the agenda of the workshop. In some cases, the sessions contained a mix of presentations covering several technical areas related to achieving low emission engine oils. It was obvious from the presentations that the workshop focus on low emission diesel engine oils is only part of a larger R&D problem involving the overall system. The technical issues related to the various components of the diesel engine or vehicle system are intertwined. If the 2004 and 2007 goals are to be met, R&D efforts cannot be polarized by fixing one component of the system at a time. To better understand the needs in the individual areas, this report will first group the technical presentations by system area and then address the interrelationship of the issues in an attempt to better understand the recommendations resulting from the workshop.

A. USDOE OHVT Program Overview.

To give the participants of the workshop a detailed understanding of the DOE OHVT R&D program, its mission, goals and budget:

"Overview of the DOE Heavy Vehicle Technologies R&D Program" by Dr. James J. Eberhardt, Director of Heavy Vehicles Technologies, U.S. Department of Energy.
The OHVT Mission is "To conduct, in collaboration with our heavy duty vehicle industry partners and their suppliers, a customer-focused national program to research and develop

technologies that will enable trucks and other heavy vehicles to be more energy efficient and able to use alternative fuels while simultaneously reducing emissions".

The presentation is Attachment 3.

The outline of the presentation is as follows:

- Organizational Structure
- Rational
- Program Strategy
- Implications of Consent Decree
- Purpose of Workshop
- Summary

B. The Keynote Address.

"The Diesel Challenge" by Rodica Barenescu, Chief Engineer, Navistar International Truck and Engine Corporation and president-elect of the Society of Automotive Engineers (SAE).

Dr. Barenescu reviewed the state of the art of diesel engines, the progress that has been made in reducing emissions, a systems approach to the development of cleaner engines, clean fuels as a technology enabler and the challenges beyond the year 2000. Dr. Barenescu's talk summarized some of the key issues that needed to be addressed at the workshop:

1. Although current heavy duty diesels have made outstanding progress in reducing engine emissions since 1974, future engines must reduce levels by 90% to near-zero levels. Also, light duty diesel trucks and diesel powered passenger cars must achieve Tier 2 type emission standards by 2007. This can only be accomplished through a systems approach.
2. Progress on after-treatment is encouraging and the engine manufacturers and suppliers are working feverishly on a number of systems. The fuel and oil must be included in the studies if we are to achieve the 2004 goals.
3. All after-treatment systems have sensitivity to sulfur and a national fuel with a sulfur level of 30 PPM is needed for the diesel to meet the 2004 standards.
4. Having a national ultra low sulfur fuel (5 PPM) fuel will enable achieving the 90% reduction in emissions from the current level.
5. Catalysts are seen as the ultimate system for reducing emissions and eliminating health effects concerns associated with the diesel engine.
6. The potential exists for a green diesel technology with near-zero emissions and a decrease in green house gases.
7. Future diesel engine advantages include reliability, fuel efficiency, durability, low emissions, and sociability.

The diesel engine supports economic development by providing the most practical and efficient transportation system on water, land and rail. It is highly utilized in agriculture, construction, forestry, mining and industrial applications. The popularity of the diesel has stimulated interest in the field of light duty and passenger cars primarily because of its efficiency and durability. However, the newly proposed EPA emission standards for passenger cars in 2004 and beyond are particularly challenging for the diesel engine.

In passenger cars the competitive fuel economy target of 80 miles per gallon (3 liters per 100 kilometers) is pushing the envelope. The direct injection diesel engine is one of the leading alternatives. Reliability and durability of future cars will be benchmarked at 100,000 miles of operation without tune-up. The norm for commercial heavy-duty diesel trucks is currently 1 million miles. The reputation of superior durability, rugged construction and reliability is driven by competitive commercial forces between manufacturers.

Environmental requirements have made the engines virtually smokeless. Beyond 2000, regulated emissions of diesel engines will be very low in nitric oxides and particulate emissions. Sociability requires low noise, easy start, convenience of service and maintenance. The sociability benchmark comes from the domain of advanced passenger car engines. It is expected that the passenger car technology can be gradually transferred to the diesel vehicles but with some difficulty. Lastly, the cost has to be reduced to be competitive.

What are some of the benefits of the diesel engine? The first is energy savings. About 30-40 % of the energy in a barrel of crude oil can be economically processed to produce distillates that are the starting point for diesel fuels. More of the crude is naturally suited for use as a diesel fuel than gasoline. Refinery processes can be biased to produce more gasoline but it is not practical to go beyond a given point due to increasing process costs and difficulty in cracking the heavier crude components.

Fuel efficiency and carbon dioxide are the next benefits. The diesel achieves the highest thermal efficiency of current engines. A prototype with 55% efficiency has already been demonstrated in the larger engines. Current diesels can achieve 45% efficiency, significantly higher than gasoline engines.

Carbon dioxide is the green house gas associated with global warming. The diesel is the lowest emitter of carbon dioxide, it is proportional to the fuel consumption.

The reliability and durability of the diesel are positive factors for the customer who is looking for longer life.

Diesel fuel is also less flammable and therefore safer in closed spaces like garages and boathouses. The newer diesel engines are low in odor.

The biggest challenges for the diesel are emissions. It is always benchmarked against gasoline engines although from a cycle standpoint, it is a different cycle, the combustion is different, and the ignition profile is different. Gaseous hydrocarbon and carbon monoxide emissions are inherently low in the diesel. Evaporative emissions are also low due to the low volatility of the fuel. The challenges are due to the NOx -Particulate tradeoff. The industry has made significant progress on the reduction of emissions. The progress has been phenomenal and the industry should take some credit.

In the last 25 years of diesel engine emission developments, NOx and Particulates, that started being regulated in 1974, have been drastically reduced. NOx was reduced some 73% from the 1974 base, and will be reduced by 87% by 2000. Current particulate levels are reduced by 90 % from 1974 levels. Considering the fact that this is a trade-off situation, the reduction of both NOx and Particulates achieved to date, is a credit to the advances in diesel engine technology.

In 1991 most diesel engines had mechanically controlled fuel systems. Most of the technological advances that have reduced particulates are the result of engine developments. Some of the advances include transition from the mechanical to electronically controlled fuel systems, exclusive use of direct injection, air-to-air charge cooling, improved combustion chamber designs, injection rate design and control, advanced forms of turbocharging, higher compression ratios, use of pilot injection and controlled multiple injection.

Other approaches such as exhaust gas recirculation (EGR) and aftertreatment of the exhaust with catalysts and particulate traps were investigated but not considered to be of high priority until now. EGR was effective but required good mixing with fresh air and temperature control and also increased engine wear, due to increased soot loading of the oil. . The aftertreatment systems were prone to plugging, made the engine more complex, were expensive, less durable and had poor reliability.

The effect of sulfur on particulates was demonstrated and analyzed in the early 1980's. Sulfur in the form of sulfate with bound water was a component of the total particulate in the transient diesel test method. Numerous engine tests helped to quantify the contribution of sulfur and identified the fuel as the main source of the problem. It was found that the sulfur level of the fuel, and not combustion characteristics, resulted in the higher particulate levels. In 1993, this resulted in the reduction of diesel fuel sulfur for on-road applications from 3000 to 500 PPM.

The impact of air quality goals on diesel engines and the plans of manufacturers to penetrate the light duty vehicle market makes it imperative that breakthrough progress be achieved in diesel engine emission control. We are finding that to reduce emissions in the engine, it must be treated as a system consisting of the fuel, the engine and the aftertreatment system. Methodologies of system engineering can then be applied to optimize the system for lower emissions. The proper combination of engine, exhaust aftertreatment, fuel and oil formulation can be selected, but must be kept in perspective with performance, life, reliability, cost, customer needs and sociability. Concentration of resources on one area alone, fuel, oil, aftertreatment, system, alone will not enable meeting near-zero/Tier 2 emission standards.

The presentation is Attachment 4.

C. FUELS.

The following presentations focus on petroleum and alternative fuel sources and the role of sulfur in the fuel as related to future low emission diesel engines and vehicles. The reduction of sulfur in diesel fuel is necessary for lower emissions via aftertreatment technology. The components of the system are intertwined and the introduction of very low sulfur fuels places increased performance requirements on the lubricant and the necessity to change the lubricant technology.

"Low Sulfur Diesel Fuel an Enabling Technology for Future Low Emitting Diesel Engines". Paul Machiele of the U.S. EPA, Ann Arbor, MI presented an update on fuel-related issues and EPA's concerns on fuel and lubricant sulfur.

The U.S. Environmental Protection Agency is considering setting new quality requirements for fuel used in diesel engines, in order to bring about large environmental benefits through the enabling of a new generation of diesel emission control technologies. The Advanced Notice of Proposed Rule Making (ANPRM) published last July sought comment on the merits of improving the quality of diesel fuel, as an enabler of advanced technologies for diesel emission control. These advanced sulfur-sensitive technologies have the potential to reduce diesel engine NOx and PM emissions by more than 90%. As with past changes in diesel engine technology, these changes are likely to place new demands on the composition and performance of engine lubricants. The presentation reviews these new emission control technologies and discusses the importance of the fuel and engine lubricant composition and their performance on them.

The presentation is Attachment 5.

"Fuel Formulations" Brent Bailey, Coordinating Research Council, Atlanta, GA presented a historical overview of the developments and interdependency of fuels, lubricants and engines.

Diesel engine lubricants have been developed and improved for over 100 years. This development has coincided with developments in fuel and engine technologies as each of the components in the system are interdependent. Fuel composition impacts lubricant formulation because the lubricant is exposed to the unburned fuel and to the fuel combustion products. The extent and conditions of exposure are dependent on the engine technology employed. The presentation includes a short historical review of developments in fuel composition over the last 100 years, a review of new diesel fuel formulations under investigation, and a brief glimpse into what may be expected for future fuel, engine, and lubricant development.

The fuel, engine and lubricant system has shown gradual evolutionary improvements over the years. In view of the rapidly changing requirements of today, future system improvements could experience a step change. The changes will require interdependency of the components. This interdependency is not new. It was also identified in the development of the CLR Oil Test Engine, CRC Report No.301, June 1955, which states "....Satisfactory oil under one set of conditions may be unsatisfactory in the same engine under another set of conditions. This emphasizes the necessity for matching these four factors: oil, fuel, engine design and conditions."

The focus of the workshop is on the lubricant but the fuel composition has to be considered. Based on previous studies, the fuel composition impacts the lubricant formulation. The lubricant is exposed to unburned fuel. Experience with the use of alcohol fuels in diesel engines shows the necessity to design the additive package to be compatible with the unburned fuel and blowby fuel combustion products. One problem at this point in time is that the future fuel composition is uncertain.

The presentation also compares the effects of various fuels on emissions, including NOx and Particulate tradeoffs and the effect of the fuels on particulate size. CRC research studies have shown that the higher the hydrogen/carbon ratio of the fuels the lower the PM. The presence of oxygen in the fuel further reduces the PM. The presentation identifies previous CRC studies that can contribute to the research planning for the development of low emission diesel engine oils

This presentation is Attachment 6.

"Renewable Diesel Fuels" K. Shaine Tyson, Renewable Diesel Project, National Renewable Energy Laboratory, Golden, CO

The U.S. Department of Energy's Renewable Diesel Alternatives Program focuses on expanding supplies of reasonably priced renewable diesel fuels for transportation. The program's focus on alternative diesel fuel production and supply issues compliments the other parts of DOE's Office of Transportation, such as the Office of Heavy Vehicle Technologies where much of the engine emission and design research originates. The program is evaluating :

1. fuels that can be used (neat or in blends with diesel) in existing compression ignition engines with little or no modification,
2. liquid fuels that may require engine modification or new engine technology,
3. gaseous fuels with their own unique engine designs, and
4. fuels for hydrogen reforming.

The goal of the evaluation is to develop a rational strategy for investing in R&D to improve production technology, reduce costs, and expand supplies of promising alternative diesel fuels.

Diesel fuel will be a dominant fuel for the next several decades, and thereafter, will play a strong if not dominant role in heavy-duty transportation. At the same time, the quality of diesel fuel will improve. Some alternative diesel fuels can play a role in that process, as blends of those fuels with diesel provide public benefits at reasonable costs. Therefore, the program is interested in developing alternative diesel fuels that can be blended with petroleum diesel and used in existing compression ignition engines. Some of these fuels may even evolve to the point where they are used in their pure form as costs decline.

As diesel's dominance wanes, some yet unknown fuels will begin to capture large market shares. Are they hydrogen, biogas or natural gas, electric, liquid fuels, or some combination of all of these? No clear answers are available. Most fuels face some type of potential market limitation, but that may not be a good reason for suppressing an otherwise promising fuel, as we may never return to the days of one fuel dominance. The program may need to support the production of a variety of promising alternative diesel fuels, although budget limitations will restrict investment in all but a few promising "winners."

The Renewable Diesel Alternatives Program is under the Office of Fuels Development of the Office of Transportation Technologies of the DOE Office of Energy Efficiency and Renewable Energy. The mission of the Renewable Diesel Alternatives Program is "To invest in R&D to expand supplies of reasonably priced renewable diesel fuels."

This presentation is Attachment 7.

"*PSU Fuel Additive Program*" André L. Boehman, Assistant Professor of Fuel Science and Director of the Combustion Laboratory, The Energy Institute, The Pennsylvania State University, University Park, PA 16802

A number of studies on oxygenated fuel additives for diesel fuels are in progress. One of the more comprehensive current programs is at Penn State University. To supply technical input in this area, Dr. Boehman, Director of the Combustion Laboratory of the Energy Institute at Penn State reviewed the projects. Most of the oxygenated additives, including methyl soyate were beneficial in the diesel and reduced engine out emissions.

Dimethyl ether (DME) and a liquid fuel additive made from dimethyl ether offer the promise of reduced diesel engine emissions without any sacrifice in performance. The liquid fuel additive, CETANER™, offers the additional benefit of a seamless transition to cleaner burning, reformulated diesel fuel. Inclusion of oxygen in diesel fuel is known to reduce particulate emissions. Both, DME and CETANER™ have the additional benefit of a high cetane number. DME has a cetane number of 55 and CETANER™ can be formulated to have a cetane number as high as 125, making CETANER™ both an oxygenating and a cetane boosting fuel additive. Both fuels can lead to cleaner burning Diesel engines and potentially, to greater market acceptance of Diesel powered vehicles.

In the present work, engine combustion and emissions studies are ongoing to determine the optimal treat rates and fueling strategies for DME and CETANER™ across a range of engine platforms. These projects also involve field demonstrations and emissions measurements in on-road vehicles for verification of the laboratory results. These projects involve collaborations between the Penn State Energy Institute, the University of

California-Berkeley, Air Products and Chemicals, Inc., Cummins Engine Company, Navistar International, USA PRO (a consulting company in Southern California), the Pennsylvania Department of Environmental Protection, the Federal Energy Technology Center and the South Coast Air Quality Management District.

The status of five current PSU projects:

"Incorporating Oxygen in Diesel Fuel as a Means of Reducing Engine Emissions",

"Effect of Oxygenated Cetane Improver on Diesel Engine Combustion and Emissions",

"Impact of Molecular Structure",

"Reformulated Clean Burning Diesel Demonstration Program", and

" Development of a Dimethyl Ether (DME) - Fueled Shuttle Bus Demonstration" are briefly described.

This presentation is Attachment 8.

D. CATALYSTS/TRAPS/AFTER-TREATMENT.

"Diesel Emission Catalysts and Filters", Dale McKinnon, MECA , Washington, DC

As emission requirements for diesel engines become stricter and manufacturers move towards cleaner diesel engines, a systems approach will be required including advanced engine technologies, advanced fuels and lubricants, and advanced emission control technologies. This presentation outlines the interactions of lubricant constituents on catalysts and filter technologies and their effects on the performance of the technologies.

This presentation is Attachment 9.

"Post Combustion Devices For Diesel Applications", Magdi Khair, Southwest Research Institute, San Antonio, TX

This paper will review the standards, goals and research targets for diesel engine emissions. Several post combustion emission control systems and their principle of operation will be described. A comparison of the various systems will be made and their advantages and disadvantages reported. Progress in Post Combustion Technology has been made and is discussed. The studies indicate current aftertreatment technology developments do not identify a clear cut winner in the current technology systems.

This presentation is attachment 10.

"Sample Analytical Tools For Diesel Catalyst/Lube Oil Additive Studies", Magdi Khair, Southwest Research Institute, San Antonio, TX

This presentation discusses an ongoing program to address the potential poisoning effect of lubricating oil on diesel catalytic converters. The study utilizes several analytical tools to assess the problem. The effect of aging on catalysts is shown using EDX, SEM and other methods of analysis. Assessments of catalysts using fresh, aged and additized lubricants are described. The impact of sulfur is compared to other elements present in the lube oil package.

This presentation is Attachment 11.

"Diesel Emission Controls : NOx and Particulate", John H. Johnson, Presidential Professor, Michigan Technological University, Hougton, MI

This presentation focuses on emission control research by the Vehicle Engine Cooling System Simulation (VECSS) research group in the Department of Mechanical Engineering and Engineering Mechanics at MTU.

This presentation is Attachment 12.

E. BASESTOCKS.

The development of new lubricants is a complex process involving refinery processes, bench tests and engine laboratory research. The first step in the process is in developing low emission diesel oils is the proper selection of the basestock, or base oil. Synthetic base fluids became available as the result of research efforts in World War II. Research efforts in the 1950's and 1960's led to a number of synthetic polyalphaolefins, currently designated as Type IV API Base Oils, and synthetic ester fluids, designated Type V API Base Oils. Removal of aromatic and sulfur compounds to produce high quality petroleum basestocks, started with the "super-refining" of conventional petroleum basestocks in the late 1950's. Considerable progress has been made in recent years in refining crude oils to produce high quality base oils by eliminating sulfur and aromatic components from the petroleum base oils. The presentations in this section identify some of the high quality petroleum base oils of interest to low emission diesel engine oils and describe some lessons learned from an earlier DOE lubricant study using synthetic base fluids and additives.

In addition, environmental concerns have resulted in renewed interest in biodegradable basestocks from renewable resources. Currently, these renewable base oils are used primarily in hydraulic fluid and niche markets, relatively small markets, such as : cutting oils, two stroke engine oils, chainsaw bar oils, wire-rope oils, bicycle chain oils, railroad oils, pump oils, outboard engine oils, and drilling oils. Demands on the oils in the niche markets are less severe than in diesel engine oils. However, research in progress indicates the potential use of these renewable oils as engine base oils is feasible. Some issues related to the market development of alternative diesel engine oils may also be applicable to any novel low emissions engine oil that is not evolutionary.

"Base Oil Chemistry For Diesel Engine Lubricants" Cliff Mansfield, Equilon Enterprises, Houston, TX

Currently, Group I and II base oils along with synthetic PAO's are used in formulating diesel engine lubricants. The compositions of these base oils, along with additive chemistry, can directly impact the performance of these lubricants. Modern analytical methods are available to determine the compositions of these base oils, and the compositions can be empirically related to the performance properties such as oxidation and fuel economy. As demands on diesel engine lubricants increase through new engine design and environmental regulations, demands on base oils will also increase. Future trends may be less use of Group I base oils and more use of Group II, Group III, PAO's and PAO type base oils. Very little work has been done on the effect of base oil composition on diesel particulate emissions. The same techniques that have been used to examine oxidation and fuel economy could also be applied to this question

This presentation is Attachment 13.

"Synthetic Liquid Lube Oil Development: Lessons Learned". John W. Fairbanks, US Department of Energy, Washington , DC

Early work with the "Adiabatic" or low heat rejection (LHR) diesel engine identified a need for a high temperature synthetic liquid lubricant . Roy Kamo's LHR engine used one liquid for lubrication and cooling , Stauffer's SDL-1. Pre-contract work by Cummins and Stauffer showed possibilities of very high top ring reversal temperatures. Specifically they modified an engine and developed an advanced synthetic liquid lubricant that ran for 275 hours with top ring reversal temperatures of 875 °F and a sump temperature of 300 °F. The approach was to develop a synthetic basestock that would compensate for elimination of certain additives and develop an ashless additive pack. The overbase and detergency were achieved with a chemically active filter that allowed elimination of the conventional TBN metallic salts (Calcium Sulfanate) Materials in the ring/liner interface were important. The only ceramic material that worked was one alloyed with a transition element metal. Tribology support showed a phosphate ester anti-wear additive significantly reduced friction. Recent engine tests show a 3.2% improvement in fuel consumption with a commercially available synthetic lube oil accompanied by a 3 to 4 times increase in the oil drain interval compared to the engine builder's standard recommendation. The challenge is to maintain or enhance the fuel economy and drain interval advantages while reducing the crankcase oil's contribution to particulate emissions.

This presentation is Attachment 14.

"The Use of Vegetable Oils as Renewable Basestocks". Sevim Z. Erhan, National Center for Agricultural Utilization Research (NCAUR), U.S.Department of Agriculture (USDA), Agricultural Research Services (ARS), Peoria, IL 61604

Annual consumption of oil-based lubricants in the U.S. is close to 10 million metric tons valued at more than $8 billion. This is a well-established and highly competitive market growing at an average rate of less than 1% per year. More than 70% of the total lubricant volume is used as motor oils for automotive engines and 10% as hydraulic fluids. Other application areas, mostly industrial lubricants are less significant. Major components in lubricants are base stock (usually 80 % or more) and additives, which are used to enhance the most important properties, depending on application. Most of the basestocks originate from petroleum, including many synthetic esters and polyalphaolefins. Vegetable oil basestocks and other vegetable-based fluids have seen a quite promising increase in use as biodegradable lubricants over the last decade. However, still less than 2% of all basestocks are products of oleochemical and related industries. These basestocks are mostly used for hydraulic fluids and various niche markets.

Vegetable oils have a series of advantages that can be beneficial for a number of lubricant applications. They are readily biodegradable and essentially nontoxic, properties that are not exhibited by lubricants based on mineral oils. Volatility is very low due to high molecular weight triglycerides and viscosity does not change rapidly with varying temperature. Ester linkages deliver inherent lubricity and ability to adhere to metal surfaces. Solubilizing power, miscibility with contaminants and additive acceptability of vegetable oils is better than that of mineral oils, especially in the case of polar materials.

The most serious disadvantage of vegetable oils when used in lubricants is their poor oxidative stability. Bis-allylic hydrogen in methylene-interrupted polyunsaturated fatty acids is very susceptible to free radical attacks, peroxide formation and production of polar oxidation products. Oxidation results in increased acidity, corrosion, viscosity and volatility of the lubricant. Antioxidant additives improve oxidative stability of vegetable oils to only a limited extent and chemical modification is necessary to eliminate bis-allylic hydrogen. Micro-oxidation experiments identified the triglyceride ability to oxypolymerize into branched networks that may result in oxidative gelation and subsequent problems in filterability and flowability. Presence of ester linkages makes vegetable oils susceptible to hydrolysis, therefore, contamination control and demulsifiers must prevent formation of emulsions with water. Extensive low temperature testing shows that formulated vegetable oils solidify at -20 °C upon long term exposure. Therefore, chemical modifications are necessary to suppress or eliminate triglyceride crystallization. Inherently, narrow viscosity range limits the usage in various viscosity grades, especially at lower viscosities.

Currently, our research priority is given to chemical modification of vegetable oils to overcome the performance deficiencies. Criteria are being established to determine the necessary improvements in technical parameters through cooperation with industrial partners and correlating field testing data to laboratory observations. In general three possible avenues for an improved soy basestock are being investigated: 1) genetically modification to produce a more stable oil from seed, 2) chemical changes, and 3) additive technology.

This presentation is Attachment 15.

"Market Development Issues for Alternative Diesel Engine Oils", David B. Smith, Creative Energy Products, L.L.C., Moorestown, NJ 08057

Crop based fluids, produced from renewable sources such as corn, canola, soy and sunflower, have the potential to bring added market value to diesel engine oils. This presentation covers several possible ways these fluids could be interesting to current and alternative marketers. Potential value is derived from use of crop fluids as a renewable resource, from taking advantage of unique physical properties, by exploiting the active molecules of these unique lubricant base stocks or combination of all of these factors.

Crop based fluids can gain market entry by satisfying any future government regulation or mandate calling for the replacement of mineral oils with a renewable resource. Baring such government intervention, these fluids will need to solve performance issues either more economically than modern mineral oils, or provide a performance boost not possible with other known lubricant base stocks or additives. Research areas are suggested to explore and identify this potential.

The historical perspective on crop based fluids recalls poor stability at high and low temperatures. Advances in genetics and additive chemistry show promise in solving these issues. Market acceptance will come only when the stability of diesel engine oils containing these fluids is proven with full scale engine testing. This can be proof-of-performance vehicle runs, or documented sequence engine testing. Large-scale market penetration will require proof in all of the engine testing required for today's mineral diesel engine oils.

This presentation is Attachment 16.

F. ADDITIVES.

Additive concentrations in lubricants can vary from about 1 % to 20 % depending on the purpose of the lubricant. Additive packages in diesel engine oils tend to be near the higher end of the concentration range. Additives are used to slow the oxidation process, prevent wear, lower friction, disperse contaminants, keep surfaces clean and prevent corrosion and rust. The additives must be compatible with the system and each other. Current additive technology has evolved over the years by laboratory testing of thousands of additives and additive combinations. The best technology also has undergone extensive engine testing and accumulated years of field experience. To produce low emission diesel engine oils may take an evolutionary change since the better additives currently in use contain sulfur, phosphorus, zinc and other metals that are suspect in reducing catalyst performance and durability. New low-sulfur, low-ash additives are a major departure from past experience and may pose significant market risks as they are introduced. The following presentations give an overview of current additive technology and some insight into the additive problem and some alternatives.

"Diesel Engine oil Additives for Low Emission Engines: The Challenges and Consequences", Tom Boschert, Ethyl Corporation, Southfield, MI

Diesel engine oils (DEO) garner much of their performance through additives that can comprise as much as 20% by weight of a DEO. Several of the more promising paths being pursued for low emission diesel engines require aftertreatment devices which are 'poisoned' by metallics from these oil additives. If we are to substantially decrease the use of metallics in a DEO additive system, we will be faced with many challenges in the oil formulation as well as in the engine design to be able to accomplish this task in a customer friendly fashion. There are also a number of severe consequences that may occur. These include misapplication of the new low metallic oil in older engines, misapplication of older high metallic oils in low emission engines, and a risk factor of new technology being introduced without an adequate history of field use.

This presentation is Attachment 17.

"Lubricant Additives and Strategies for Low Emission Diesel Oils", Steve Hsu, NIST, US Dept. of Commerce, Gaithersburg, MD

This presentation is a review of basic additive chemistries used in diesel engine oils. From the chemistry point of view, the issues encountered in formulating a 'clean' lubricant are be discussed. Several potential strategies are offered to overcome such difficulties.

This presentation is Attachment 18.

"*Challenges and Opportunities for Future Engine Oils"*, Ewa Bardasz, The Lubrizol Corporation, Wickliffe, OH

In light of technological progress that was made during the last century, it is difficult to predict advances, which might occur in the next decade and beyond. One thing is sure, advances are made in response to forces of change, and a look at the current most