PRESENTATIONS – MDEC 2008

1(a). **Keynote Address on Health**: **Health effects of diesel emissions** by Dr. Joe Mauderly (Lovelace Respiratory Research Institute).

1(b) **Keynote Address on DPM**, **What we expect to find in underground DPM ambient monitoring,** Dr. Stewart Gilles (Missouri University of Science and Technology)

2. **New Session:** Summary of MDEC 2007 Roundtable Forum

3. **Testing SMF diesel particulate filter In underground mining**, Frank Stephan (MANN+HUMMEL)

A new innovative Sintered Metal DPF was tested underground in a mining loader. The filter element is made out of sintered metal which has superior properties compared to regular DPF filter media. For the test a mining loader with a 204kW, 19.11 litre V-engine was selected. Each exhaust line was equipped with a SMF filter element, using a fuel born catalyst for the regeneration.
The filter system was mounted on August 30, 2007 and started out with an average pressure drop of as low as 28 mbar (0.827 inch mercury). After 1000 operating hours the pressure drop rose by just 11 mbar and the filter effiency was 99.21 % on EC and 97.91 % on OC.

4. **Effects of biodiesel on aerosols in underground mine**, Aleksandar D. Bugarski, Emanuele Cauda, Samuel J. Janisko, Larry D. Patts, Jon A Hummer, Steven E. Mischler (NIOSH)

This paper provides the analysis of the results of the study conducted in an effort to compare the effects of 20 and 50 percent biodiesel blends (B20 and B50), neat biodiesel (B100) with the effects of ultra-low sulfur diesel fuel (ULSF, <15 ppm sulfur) on properties of diesel aerosols emitted by a mechanically controlled naturally aspirated engine in mine environment. The physical and chemical properties of aerosols were characterized through a series of engine/dynamometer tests in the NIOSH Diesel Laboratory at the Lake Lynn Laboratory experimental mine. The effects on the aerosol and gaseous emissions were determined for four steady-state engine operating conditions (EOCs). In addition, the combined effects of biodiesel and diesel oxidation catalyst (DOC) were examined for two of those EOCs. The size distributions and concentrations of aerosol were assessed from the results of measurements performed using a Scanning Mobility Particle Sizer, a Fast Mobility Particle Sizer, an Electrical Low Pressure Impactor, and a Tapered Element Oscillating Micro Balance. The effects of B20, B50, B100, and ULSF on mass and number concentrations and size distributions of nano and ultrafine aerosols were found to be strongly dependent on EOCs. The significant reductions from baseline case (ULSF) in mass concentrations were observed for B50 and B100 when engine was operated at high-load EOCs. The moderate decreases or in some cases significant increases in mass concentrations over baseline case were observed when engine was operated at light-load EOCs. These increases can be potentially attributed to significant presence of organic aerosols observed for biodiesel fuels when evaluated at light-load EOCs. In general, B20, B50, and B100 were found to produce the aerosol size distributions that were characterized with smaller geometric media diameters (D_{50}) the those observed for ULSF. The significant increases in total number concentrations were observed for B20, B50, and B100 when engine was operated at light loads. The DOC was found in general to have positive effect on total mass and number concentrations for all fuels. The knowledge obtained from this study should strengthen the understanding of health effects that are related to exposure to diesel particulate matter and aid in assessing the potential for biodiesel to reduce this exposure.

5. **Evaluation of an electrically regenerated sintered metal diesel particulate filter system in underground mine laboratory**, Aleksandar D. Bugarski, Emanuele Cauda, Samuel J. Janisko, Larry D. Patts, Jon A Hummer, and Steven E Mischler (NIOSH)

This study was conducted to establish the effects of a diesel particulate filter (DPF) system with sintered metal substrate on the concentrations and size distributions of nano and ultrafine aerosols and concentrations of nitric oxides in underground mine air. Experimental work was conducted in the NIOSH Diesel Laboratory at the Lake Lynn Laboratory experimental mine, a facility developed to allow evaluation of control technologies directly in underground conditions. The DPF system supplied by Rypos was examined in passive and active configuration for four repeatable steady-state engine operating conditions. A naturally aspirated mechanically controlled Isuzu C240 diesel engine coupled to an eddy-current dynamometer was operated in the underground drift with tightly controlled ventilation. The engine was fueled with ultralow sulfur fuel. Measurements upwind and downwind of the exhaust system discharge were used to quantify the effects of the DPF system on the mine air. A baseline was established using a standard muffler. The size distributions and concentrations of aerosol were assessed from the results of measurements performed using a Scanning Mobility Particle Sizer, a Fast Mobility Particle Sizer, an Electrical Low Pressure Impactor, and a Tapered Element Oscillating Micro Balance.

The study showed that sintered metal DPF systems in passive configuration reduced the total mass of aerosols in the mine air by more than ten-fold when compared to a muffler. When evaluated in the active mode the system showed significantly lower average efficiency. The nucleation mode aerosols ($_{50}d_{em}$<40 nm) in mine air were found to be strongly influenced by engine operating mode. The concentration of nucleation mode aerosols was found to be significantly higher for high-load modes than for low-load modes. The muffler and DPF system resulted in comparable total nitrogen oxides (NO_x) and nitrogen dioxide (NO_2) concentrations. However, the nitrogen dioxide (NO_2) fraction of the total NO_x was found to be substantially higher for both exhaust systems for low-load modes than for high-load modes.

The knowledge obtained from this study should strengthen the understanding of the potential of evaluated DPF system to reduce exposure of underground miners to diesel aerosols and gases.

6. **NO_2 emissions from a diesel engine vehicle in underground mines**, Emanuele Cauda,, Aleksandar D. Bugarski, and Steven E. Mischler (NIOSH)

The concentration of NO_2 in US underground mining environments cannot exceed a ceiling value of 5 parts per million (ppm) as established in MSHA standards for Metal/Nonmetal mine and Coal mine. In an underground mine the presence of NO_2 is strictly related to the use of diesel equipments. The concentration of NO_2 at the manifold depends on engine design, engine operation mode and fuel used.

Great concern about the NO_2 concentration has caused the increased use of DPF, Diesel Particulate Filter, for the abatement of particulate matter (DPM). While the filtration process itself should not affect the gasses concentration in the diesel exhaust, the mandatory regeneration of the trapped soot is a critical phase for possible NO_2 variation.

Economical issues, acted to optimize the energy consumption during this phase, force the aftertreatment companies to add catalytic assistance at the regeneration. The catalyst, that can introduced in the system in different way, can affect the NO_2 concentration: some well established systems exploit the NO_2 increase to improve the regeneration efficiency.

In this paper we provide a review of commercialized diesel aftertreatment strategies used in underground mines, both for NOx and DPM abatement, and their possible effect on NO_2 concentration.

7. **An overview of Henderson Mine's DPM program and the conversion to biodiesel,** *David Loring and Chris Rizzardi,(Henserson Mine)*

The Climax Molybdenum Company's Henderson Mine, owned by Freeport McMoRan Corporation, is a 30,000 tonne per day molybdenum mine located 70 km west of Denver, Colorado. Like

other metal/nonmental mines, Henderson has been challenged with reducing diesel emissions in order to meet the 160 □g/m^3 limit that went into effect in May, 2008. In 2006, a minewide DPM survey was performed and from this a comprehensive strategy was developed to meet the 160 □g/m^3 limit. This paper describes the elements of the DPM plan, with particular attention to the conversion of the underground diesel fleet to biodiesel fuel.

8. **Mine Real-time DPM ambient monitoring**, Stewart Gillies (Missouri University of Science and Technology)

A real time DPM monitor has been developed on the base of the successful NIOSH Personal Dust Monitor (PDM) unit. The objectives of recently completed Australian Coal Association Research Program (ACARP) study has been to finalize the design of a DPM unit, to undertake comprehensive and internationally recognized laboratory testing to evaluate the new design and to undertake an underground series of tests to establish the robustness and reliability of the new approach. Under the project Thermo Fisher Scientific has undertaken structural changes to the PDM to convert it to a DPM real time monitoring underground instrument, the D-PDM. The Pennsylvania Pittsburgh Research Laboratories of NIOSH has undertaken laboratory "calibration or verification" testing. A phase of Australian mine robustness and engineering testing has been undertaken to ensure the instrument can effectively assist mine management to handle this health issue. Tests have been undertaken at points of expected high atmospheric DPM such as during Longwall face moves, Development RAM car, Eimco and personnel transport vehicle usages.

The paper discusses how the monitors have performed within the underground mine environment in evaluating DPM during the various phases of the production cycle. They have closely examined the influence of aspects of the mine ventilation system. Results have been compared to alternative industry pollutant measuring approaches.

9. **The search to identify reliable and rugged DPF system at Vale Inco**, Joe Stachulak (Vale Inco)

The Diesel Emissions Evaluation Program (DEEP), a research consortium formed in 1997 by Canadian mining companies, labour unions, and provincial and federal government departments, completed its work by mid-2006. This program, in which Vale Inco participated with both direct funding and in-kind contributions, investigated the ability of currently available technology to significantly reduce underground concentrations of diesel particulate matter (DPM) with high efficiency and low maintenance over a long-term period (years of life).

While DEEP's testing showed that engine maintenance is a critical component for lowering DPM, it was clear that reduction of DPM to the very low target levels of ~0.05 mg/m3 was not possible with maintenance alone. The best candidate technology for achieving low DPM levels was particulate filter systems. Furthermore, successful deployment of such systems was highly dependent on removing them from having to rely on human intervention for their regeneration. The search continues within Vale Inco to identify a reliable and rugged system.

10. **The application of biodiesel in two heavy duty haul trucks in a large Canadian mine**, Adam Levine (Canadian Bioenergy Corporation)

The use of biodiesel in Canadian mining is currently limited, however the potential exists for significant volumes to make its way into the mining sector as requirements to meet the BC 5% biodiesel mandate in 2010, and the federal 2% mandate in 2012 are satisfied. While all major engine manufacturers have approved the use of biodiesel, and millions of road miles in on-road applications have proven its performance, there are still operational questions that fleet managers have regarding the heavy duty equipment used in mining. This paper will provide a report summary of findings associated with the use of biodiesel in two heavy duty haul trucks used in a large Canadian mine.

In sum, biodiesel is a proven fuel and an affordable solution available to help meet HSE objectives for the mining industry. This paper will demonstrate that it can also perform as needed to meet the demanding duty cycles of the Canadian industry's heaviest equipment.

11. **An innovative and integrated safe DPF cleaning process**, Shun Hong Long (ECS)

2007 Heavy Duty Highway emission standards have resulted in the first wave of OEM fitted diesel particulate filters. According to OEM targets, these DPFs will require a first cleaning or ash removal process by the end of 2008 or early 2009. Ash accumulation and removal was a key issue during the development of DPF technologies to determine a reasonable DPF reserve volume that should be dedicated for particulate matter and ash accumulation. A DPF cleaning process for either passive or hybrid regenerated type DPF's will be periodically required, however, the process has to safeguard the DPF integrity for second and even further rounds of application. In this presentation, a comprehensive DPF cleaning process is described while experimental issues such as; methods to quantify cleaning efficiency & mechanical integrity, thermal gradient control and protection are discussed. A prototype apparatus is developed and integrated based on the developed concept to achieve a safe, straightforward and fully-automatic cleaning process.

A newly developed DPF Cleaning process and apparatus shall provide easy, practical, consistent yet, safe maintenance method to clean DPF products from either retrofit or original equipment installations. The new maintenance tool will help end users and service providers the ability to track the physical condition of their filters in support to their operation, warranty disposition and avoid unexplained premature plugging.

12. **Hybrid Passive Active Diesel Particulate Filters**, Kevin Brown (ECS)

This paper will describe the combining of passive and active diesel particulate filter technologies for retrofit applications. In addition, examples of various field installations and durability information will be presented describing the implementation of this retrofit technology in highway and non-road fleets California demonstration programs.

Many diesel engine applications can be characterized as having variable duty cycles or periodic duty cycles where exhaust temperatures are insufficient to support passive regeneration. This need to incorporate an active regeneration component is highlighted by 2007 and newer highway vehicles which typically combine passive and active regeneration strategies.

By installing an inlet section containing electrical resistive elements with a passive filter, it is possible to employ periodic (i.e. weekly, bi-weekly, monthly) active regeneration to maintain passive DPF cleanliness, low exhaust backpressure characteristics and reduce the need to remove DPF's for off-board service. This combination also maximizes equipment up-time and reduces the potential for high backpressure episodes which can result in unplanned maintenance.

13. **Tail –pipe measurements of particulate emissions from LD vehicles with diesel engines: A direct comparison of five different measurement methods**, Hans-Georg Horn and Robert C Anderson (TSI)

Continuing the work conducted at SWRI in 2006, where we evaluate the Electrical Aerosol Detector (EAD) as an alternative method for regulatory particulate measurements for heavy duty diesel engines, we take the next step in applying the technique to the upcoming regulations for the type approval of Light Duty diesel engine powered vehicles which will exhibit a similar reduction of emission limits for particulate matter. A test program of tail-pipe measurements within the project "Emission Check 2010" by VDTÜV and DEKRA was run to investigate whether measurement techniques – both already available and under development – are applicable for regular vehicle inspections, especially with regard to the lower limits defined by the new regulations. All tests were run on the DEKRA chassis dynamometer in Klettwitz, Germany. Three different vehicles (all Euro 4, one without DPF) were tested during a one

week campaign. European drive cycle tests, steady state tests and a test sequence with 10 subsequent engine starts were run. In some of the 31 tests, DPF malfunction was simulated by means of a valve-controlled DPF bypass. In order to maintain confidentiality, only data from a CPC 3010D, an Electrical Aerosol Detector EAD 3070A, a light scattering photometer Dust-Trak 8520 and an Engine Exhaust Particle Sizer EEPS 3090 (all by TSI Inc.), which were measured by the authors themselves, are discussed in this paper. In addition, data from a Micro Soot Sensor (by AVL), which was used as a reference instrument, are included. The particle number distribution measured by the EEPS was transferred to a mass distribution by means of a fractal density function. Data analysis was made for single tests as well as for the whole campaign. In general, good correlations were found for particle number measurements with the CPC, the EAD and the EEPS. Overall, an R^2 of 0.97 was found. The overall particle mass correlation between the EAD and the EEPS was good as well (R^2 approximately 0.99). Mass concentrations measured with the light scattering photometer were much more biased by changes in the particle size distribution, which lead to a weaker correlation with the other methods.

14. **Double wall exhaust systems to reduce surface temperatures**, John Botelho (Pipe in Pipe Exhaust Co.)

A mine fire can occur at anytime and often results in a partial or total evacuation of the mine. Today's safety practices draw attention to all fire hazards and demand practices and measures of reducing fire risks. Diesel powered equipment have the potential to produce exhaust temperatures in excess of 500° Celsius (1000° Fahrenheit) and when combined with systems that include flammable fluids and combustible materials can present a real threat. The risk of a fire on diesel powered equipment can be reduced though design controls such as isolating the ignition source (i.e. "hot side – cold side" configuration of components), however this is not always practical and measures to shield or insulate exhaust systems must be implemented. To be effective, the shield or insulation must reduce surface temperatures below the flash point of materials capable of coming in contact with the hot exhaust system. Over the years many types of solutions have been tried. In most part these do work when they are newly installed but require a high level of maintenance. One form of protection that is more maintenance friendly is the use of double wall exhaust components.

15. **Emissions results from 2008 On-Highway Pickups**, Steve 'Skinner' Forbush (Arch Coal)

During late in 2007 and early in 2008 we ran some chassis dynamometer test on 4 different 2008 pickups. The reason for these test were to determine if this type of vehicle could be used in underground mining. We were aware of the use of catalyzed diesel particulate filters on these vehicles but because of requirements by EPA for lowering total NOX we needed to find out for sure. For the first round we tested a 2008 Dodge ¾ ton with a manual 6-speed transmission and a Ford ¾ ton with an automatic transmission. Snow College South has a diesel program with a shop, class rooms and a chassis dynamometer. We tried to simulate the ISO 8178 test scheme but because of the automatic transmission on the Ford it was very difficult. It should be noted that all of the test vehicles were new and borrowed from the local dealerships so we had to be somewhat careful not to damage or change any of the vehicles. During this round of testing we used an Enerac 500 EMS emissions analyzer. The results indicated a very large increase in Nitrogen Dioxide with reductions in Carbon Monoxide and Nitric Oxide. On the Dodge truck we were able to collect emissions data from before and after the DPF. With the increase in NO2 it was decided future testing would be needed.

For the second round of testing we used a 2008 Chevy ¾ ton with an automatic, a 2008 Ford ¾ ton with an automatic, a 2008 Dodge ¾ ton with a manual, and a 2008 Dodge 1 ton with a manual. Both the Enerac and an Ecom analyzer were used to verify the emissions results and these tests were again taken at the Snow College South diesel lab.

Both trucks using an automatic transmission were difficult to get all data points to try to simulate the ISO 8178 test cycle but we did get enough points to see a trend. All 4 trucks showed an increase in

NO2 over older model vehicles. For example the ventilation rate for a 2006 Dodge is 13,000 cfm and the 2008 appears to require 57,000 cfm. At this point Arch Coal is not going to consider the use of late model on-highway vehicles in our underground mines any time soon.

16. **Technology for a cleaner and safer mining environment**, Terry McDonald and Toney Arbaney (Dry Systems Technologies)

17. **Diesel emissions: Future regulations and control technologies**, Addy Majewski (Ecopoint)

Future diesel emission regulations for new diesel engines and vehicles have been designed to force the use of exhaust aftertreatment technologies, such as diesel particulate filters. While particulate filters have been widely adopted in some applications, for instance in 2007 highway truck engines in North America, they will not necessarily be used in future nonroad engines. This presentation will review the regulatory trends in worldwide diesel emission regulations, and the status of emission control technology to meet future emission standards.

18. **Real-time DPM Monitoring in Underground Mines**, Michel Grenier , Kevin Butler, & Stephen Hardcastle)NRCan), Cheryl Allen & Colin McAnulty (Vale Inco) and Ron Pilon (USWA)

Compliance with Diesel Particulate Matter (DPM) exposure regulation is currently performed using time-weighted average (TWA) sampling on underground mine workers. These samples are collected in the span of an entire shift and the resulting concentrations are compared to a legislated exposure limit. While this is very useful to determine the exposure level of an individual to DPM, it fails to clearly identify causes of exposure and highlight opportunities that could help reduce the exposure of workers in the course of the work shift.

Real-time DPM monitoring would measure the worker's exposure as a function of time and identify circumstances where corrective actions or design changes can be taken by the individual or the employer to reduce the overall exposure of the worker and peers in the same occupational group. Measuring DPM directly from TWA samples using adopted or conventional methods (Respirable Combustible Dust or NIOSH 5040) is still the topic of some debate. Real-time DPM sampling is likely just as controversial a topic.

This work used the EcoChem Analytics PAS 2000 Real-Time PAH Monitor in conjunction with concurrent TWA DPM samples collected on personnel during various underground mining processes. The aim was to demonstrate that the PAS 2000, while not a direct DPM analyzer, was able to provide a concentration profile that could be easily linearly correlated to TC measurements; and in addition demonstrate several instances of improvements that could be implemented to reduce the exposure of underground miners to DPM