MDEC 2008 – ROUNDTABLE FORUM
DPM AND NO_2 ISSUES IN MINES

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Integrated approach is needed to effectively reduce exposures of underground miners to diesel particulate matter and gases

- Controlling diesel emissions at their source:
  - Engine-out emissions;
  - Exhaust aftertreatment technologies;
  - Crankcase emissions.
- Controlling airborne pollutants:
  - Ventilation;
  - Environmental cabs;
  - Personal protective equipment.
- Institutionalizing administrative controls:
  - Better utilization and management of available resources;
  - No idling policy…

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The effective approach is controlling diesel emissions at their source using best available technology.

- Reduction of engine-out emissions through:
  - Replacement of older high-emitting engines with contemporary low-emitting diesel engines;
  - Implementation of emissions assisted maintenance programs;
  - Utilization of clean and alternative fuels.
- Implementation of exhaust aftertreatment technologies to control:
  - Particulate, and
  - Gaseous emissions.
- Reduction of crankcase emissions using:
  - Filtered open crankcase ventilation;
  - Close crankcase ventilation.

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Limited survey between attendees of 2008 MDEC DPM and NO_2 forum revealed following facts and issues (1):

- Controlling airborne pollutants:
  - Canadian underground metal mine operators believe that they do not have major problem with over exposure to diesel contaminants;
  - It is believed that with currently provided quantities of ventilation air (~100 ft^3/hp) only minor corrections are needed;
  - DPM regulations resulted in improved ventilation of the U.S. underground metal and nonmetal mines.

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Limited survey between attendees of 2008 MDEC DPM and NO_2 forum revealed following facts and issues (2):

- Reduction of engine-out emissions:
  - Replacement of older high-emitting engines with contemporary low-emitting diesel engines at accelerated rate is relatively popular approach;
  - Several larger operations implemented emissions assisted maintenance programs;
  - In the U.S., the biodiesel is relatively popular in areas where it is readily available and affordable;
  - In Canada, adjustment of engines for operation in deep mines and high-altitude mines is expected to produce positive effects.

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Limited survey between attendees of 2008 MDEC DPM and NO_2 forum revealed following facts and issues (3):

- Implementation of exhaust aftertreatment technologies:
  - DOCs are currently installed on majority of the UG mining vehicles in Ontario;
  - Small advancements were made in implementation of DPF technology in UG mines;
  - Ontario mine operators need guidance, those would implement DPFs if those are needed to meet future law requirements.
- The implementation of best available technology is hampered by economics, technical issues, lack of regulations (Canada) etc.

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Implementation of retrofit aftertreatment technologies is perceived as a ultimate approach, but not necessarily critical to achieving DPM exposure limits for underground metal and nonmetal miners.

- **Current Trends (DOC OEM and DPFs retrofit)**
  - Diesel oxidation catalytic converters (DOCs) for CO and HC;
  - Flow trough filter (FTF) systems;
  - Diesel particulate filter (DPF) systems;
  - Filtration systems (FS) with disposable filter elements (DFE).

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DPF and DFE Systems in Underground Coal Mining

(Source: MSHA)
https://lakegovprod2.msha.gov/DieselInventory/ViewDieselInventoryExternal.aspx

- DPF and DFE technology is silently inching its way into underground coal mines in the U.S.
- Inventory of DPF and DFE systems shows:
  - ~1320 vehicles equipped with filtration systems;
  - ~ 800 filtration systems with DFEs (heavy-duty permissible and non-permissible);
  - ~ 520 DPF systems (heavy- and light-duty non-permissible);
  - 1 FTF.

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Some of the underground metal and nonmetal mines are proactive in using DPF technology.

- Stillwater Mining Company (Nye Mine, platinum & palladium UG mine, Montana):
  - Total of ~ 330 diesel-powered units;
  - ~ 85 DPF systems;
  - ~ 160 FTF systems;
  - ~ 60 DOC.
- Aftertreatment systems on heavy-duty fleet units:
  - 20 precious metal catalyzed passive systems on 10-ton haulage trucks
  - 4 precious metal catalyzed passive systems on locomotives
  - 4 base metal catalyzed passive DPF systems on CAT AD30 haulage trucks
  - 44 passive precious metal catalyzed systems on 2 yd^3 LHD vehicles
  - 2 active systems with on-board electrical regeneration partially regenerated using fuel borne catalyst on 1½ yd^3 LHD vehicles;
  - 36 FTFs
- Aftertreatment systems on light-duty fleet units:
  - 5 active systems with off-board electrical regeneration
  - 3 passive systems with NO_2 suppressing catalyst
  - 124 FTFs

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DPF systems in Canadian underground metal and nonmetal mining are relatively sparse.

- Total of ~5000 diesel-powered units.
- ~20 vehicles are retrofitted with DPF systems:
  - 18 systems at Xstrata Zink Brunswick Mine, New Brunswick:
    - passive systems with wash-coated base metal catalyst;
  - 2 systems at Vale Inco Creighton Mine, Sudbury:
    - active systems with on-board electrical regeneration fully or partially regenerated using fuel borne catalyst.

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Contemporary and Future Diesel Engine Technology in Underground Mining

- Tier 4i engines (emphasis on PM control):
  - High pressure common rail fuel system with multiple injection;
  - Variable geometry turbocharger;
  - Advance engine management systems;
  - Exhaust aftertreatment system:
    - Diesel oxidation catalyst (DOC);
    - Catalyzed passive diesel particulate filter (DPF) system;
    - NO_X controls: Cooled EGR and Selective catalyst reduction (SCR).
- Tier 4 engines (PM and NO_X control):
  - integrated advanced exhaust aftertreatment systems:
    - DOC for CO and HC control,
    - DPF for DPM control, and
    - SCR and/or Lean NO_X Catalyst (LNC) for NO_X control.

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Future of diesel engine and exhaust aftertreatment technology looks bright, but optimization is needed for underground mining application.

- Future (OEM and retrofit, pending engine and aftertreatment technology development) are integrated systems using
  - DOC;
  - DPF or FTF systems;
  - Selective catalyst reduction (SCR).

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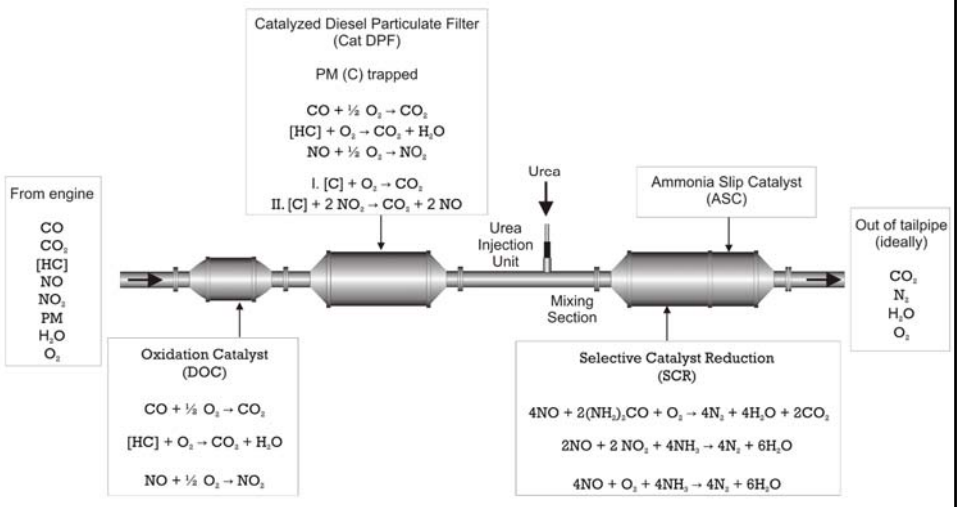
Tier 4: Integrated Systems for DPM and NO_X Control



- DOC + Cat DPF + SCR (heavy-duty).
- DOC + SCR + Cat DPF (light-duty).

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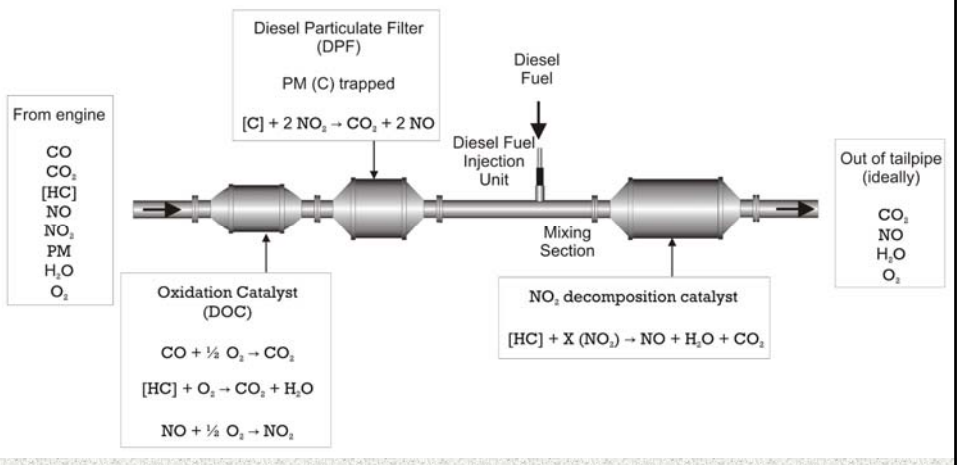
Integrated Systems for DPM and NO_2 Slip Control



- DOC + Cat DPF + NO_2 decomposition catalyst.
- NO_X neutral.
- Control of NO_2 slip from CRT system.

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Tier 4i and Tier 4 engines in Underground Mining

- Are Tier 4 engines going to provide all answers?
  - NO_2 slip;
  - Urea
  - NH_3 slip…

- Engines that meet EPA 2007 on-highway standards (using DPM and NO_x controls) are already available for on-highway applications.

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Secondary emissions of NO_2 are major road block for implementation of passive DPF systems in underground mines.

- Effects of the aftertreatment system on NO_2 emissions is function of:
  - catalyst formulation;
  - exhaust temperatures;
  - NO_x to PM ratio in the engine-out exhaust;
  - amount of soot in DPF system;
  - fuel sulfur content…
- Several studies showed that the systems with platinum based wash-coated catalysts promote NO to NO_2 conversion at the temperatures needed for DPF regeneration.

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The concern over NO_2 "slip" influenced selection of regeneration strategy for DPF systems for coal mining applications:

- MSHA advises against using platinum catalyzed passive DPF system in underground coal mines due to potential for increase in NO_2 emissions (PIB02-04).
- The popular choices of DPF systems in coal mining:
  - Passive systems regenerated with help of platinum/cerium fuel born catalyst;
  - Passive systems with wash-coated base metal catalyst;
  - Passive systems with wash-coated NO_2 suppressing catalyst;
  - Active systems with on-board electrical regeneration;
  - Active systems with off-board electrical regeneration.

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Not all DPF systems promote NO to NO_2 conversion.

- The reaction between NO_2 and DPM in uncatalyzed filters may result is slight reduction in overall NO_2 concentrations.
- Base metal wash-coated catalysts did not exhibit tendency to increase NO_2 emissions.
- The systems using fuel borne catalysts, even those that are based on platinum, were not found to increase significantly NO_2 emissions.
- New formulations with NO_2 suppressant are marketed for underground mining industry.

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Emission-Assisted Maintenance (EAM) Program for Engines and Exhaust Aftertreatment Systems

- Gas analyzers
  - electrochemical cells for measurement of CO, O_2 (calculated CO_2), NO, NO_2 :
    - accuracy within ±5%.
    - portable
    - relatively slow response time:
      - T_{90} for NO ~ 5 sec;
      - T_{90} for NO_2 and CO ~ 30-40 sec;
      - Avoid inserting probe during turbocharger lug period and flooding probes with high concentrations.
- Shelf life of electrochemical cells is relatively short.
- Check and calibration.
  - Shelf life of NO_2 calibration gas is short.

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Instrumentation for Emissions Assisted Maintenance of Engines and Exhaust Aftertreatment Systems

- Temperature dependence of processes guiding oxidation of NO to NO_2 and reduction of NO_2 to NO makes quantification of issue difficult.
- Personal exposure monitoring should provide answer.
- Quantitative measurement of DPM emissions in field conditions is challenging:
  - NIOSH 5040 (EC):
    - Time delay,
    - Elaborate sampling apparatus and procedure.
  - Gravimetric analysis.
  - Photo acoustic sensor;
- Qualitative measurements (Bacharach Number, opacity) should be adequate for "go/no go" tests.

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DISCUSSION!!!
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