

DPM Reduction at the Stillwater Mine





Stillwater's DPM History

- The Stillwater Mine tested many technologies during the Isozone Studies (2003 & 2004).
 - DPF's
 - Active,
 - Passive,
 - Disposable Filter Elements
 - Alternative fuels (bio-diesel, ULS, and fuel emulsions)
 - Results found in the NIOSH Isozone Publications
- Integrated Approach to reduce DPM exposure.
 - Ventilation Upgrades
 - Engine Upgrades
 - Emissions-based Maintenance
 - Exhaust Treatments
 - Bio-Diesel Blends
 - Administrative Controls
 - Reduce/Replace diesel-powered mining techniques



Improved Ventilation

Ventilation design to increase dilution

- Replaced series ventilation paths with series/parallel ventilation paths
 - 600k to 1.1M SCFM – Completed by Q2-02
 - 1.1M to 1.4M SCFM – Completed March 2008
 - Auxiliary fan standard to provide engineered duct-to-fan fit for better efficiencies
- Improvements in main drifts (Footwall Laterals)

Did not get us where we wanted to be in production areas



Electronic Engine Controls

The Stillwater Mine has 330+ pieces of diesel equipment

- Currently, the Stillwater Mine has the following electronic controls (about 1/3 of entire diesel equipment):
 - 85 Electronic Engines (32 are Tier 3)
 - 39 Electronic Governors
- Electronic engines are not available for the complete underground fleet and total replacement cost prohibitive
- Replace properly running Tier 1 or 2 engines with Tier 3 only as part of normal replacement at end of life or if they have high vent rate requirements.
- Electronic controls improve emissions, but don't solve DPM.
 - Will Tier 4 engines will cure DPM?



Emissions-Based Maintenance

- Emissions-based maintenance keeps engines operating in best tune to keep emissions at their best.
 - Emissions testing during each Planned Maintenance
 - EECOM for gas analysis
 - Smoke Dot for PM indicator
 - Train mechanics, Six System Engine Maintenance
- Electronic controls & emissions-based maintenance enhance DPM reduction techniques.
 - All Cummins & Deutz engines
 - Properly maintained engine systems reduce DPM and keep other gaseous emissions in check,
 - Allow other treatments to work to reduce DPM



Exhaust Treatments

Ventilation & electronic controls did not reduce DPM to desired levels.

- Stillwater placed greater emphasis on exhaust treatments as a means to reduce DPM
- Properly tuned engines will better support exhaust treatments.



Exhaust Treatment Strategy

What Strategy for exhaust treatment application?

- Horsepower & Utilization determines big vs. small DPM producers
 - Group 1 (Muckhaul) – Larger Hp, medium to high utilization and small quantity.
 - Group 2 (LHD's) – Medium to large Hp with medium utilization and unknown duty cycles.
 - Group 3 (Utility Fleets) – Low to medium Hp & low to high utilization and unknown duty cycles.
- Duty Cycles from thermal profiles determine exhaust treatment application.
 - Fit & forget is easiest (& best) to use.
 - Stay conservative - good surprises.
 - Haulage equipment probably easiest to apply.
 - Medium duty cycle equipment may accept passive DPF's
 - Hydrostatic drives – pleasant surprise.
 - Low duty cycle – Flow Through Filters or active DPF's.



Exhaust Treatments

First Group Attacked

Muckhaul Fleet - Trucks & Locomotives

- Larger Hp, high duty cycle & low quantity
- Largest percentage of electronic controls (for Stillwater)
- The “perfect” application for passive DPF’s
 - Catalyzed DPF
 - Twenty-three 10-ton haul trucks with catalyzed DPF’s
 - Four 20-ton Brookville Loci’s with catalyzed DPF’s.
 - DCL Mine-X BM Plus[®] DPF
 - 2-Stage unit Base-Metal with Palladium catalyst in front
 - Installed on four Caterpillar/Elphinstone AD30’s
 - Excellent Duty Cycle with EGT’s >900°F
 - Low NO₂ production as well as DPM regeneration.
Field measurements show no detectable NO₂ behind two operating trucks at 400 Hp each.

Examples of Exhaust Treatments on 10-ton Haul Trucks





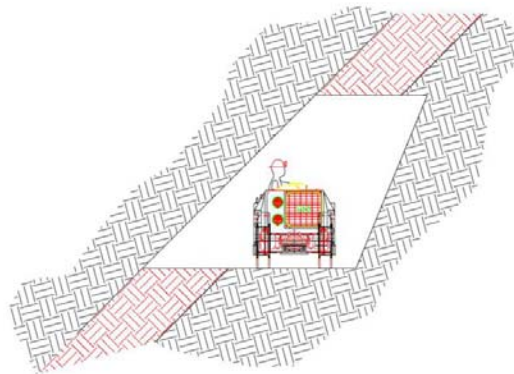
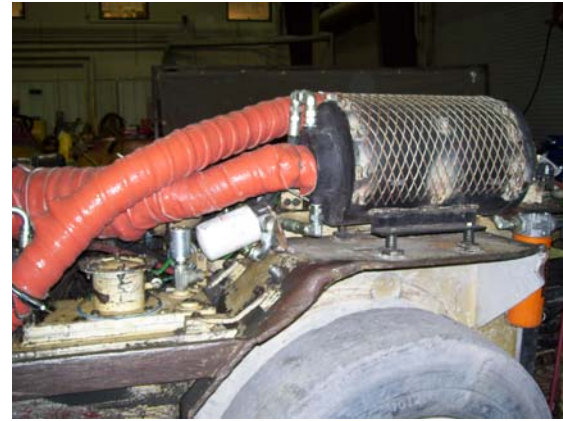
Exhaust Treatments

Second Group Attacked – LHD's

LHD Fleet – 73 LHD's

- Active Exhaust Treatments – 2 Units
- Passive Exhaust Treatments – 59 units,
 - 46 DPF's
 - 13 Flow Through Filters – On small LHD's with Deutz 1012 engine - rapid plugging of DPF's
- Disposable filters 21 units (Historical)
 - Removed all 21 units in Q3-06 due to potential fire hazard.
 - Installed 1 cool can with DFE on an LT-270 in Q1-08 – Removed in Q2-08 for leaking coolant.
 - Not cost effective due to logistics and do not fit narrow vein mining (see following diagrams & photos) and
 - We will find a fit & forget solution.
- One 1-½ yd³ still under testing for conversion to battery power.

Stope Design Considerations for Smaller LHD's



Passive Exhaust Treatments on LHD's



- Passive DPF on a 2 yd³
 - Passives work well on this size LHD.
 - Remotes not so good – Engine control
- FTF on the 1-½yd³.
 - Passive DPF's do not work on SMC's 1-½ yd³ fleet (Deutz 1012).
 - Cool Can/DFE Experiment Failed due to coolant leaks
 - Mann & Hummel Active
 - New Electronic Engine



Active On-Board DPF's

Stillwater tested two different active on-board DPF's

- Rypos - Elphinstone R1300
 - '07 MSHA & Environment Canada testing suggests +90% DPM reduction with NO₂ reduction
 - Excellent emissions results – DPM, CO, & NO₂ reduction.
 - Requires a larger alternator for electric load.
 - Removed from service in Q2-08.
- Caterpillar Emissions Solutions/Mann & Hummel
 - Good emissions – DPM & NO₂ reduction, but no CO conversion
 - Requires additive tank for catalyst to “dose” fuel in fuel tank to assist regeneration.
 - Enerteck's Enerburn Catalyst is MSHA / EPA-approved
 - Currently on an Elphinstone R1300 and an MTI LT-270.
 - Committed to a number for MTI LT-270's.

Caterpillar Emissions Solutions

with Mann & Hummel on Elphinstone R1300



Caterpillar Emissions Solutions

with Mann & Hummel on MTI LT-270





Exhaust Treatments

Third Group Attacked – Utility Fleet & Drill Jumbos

~196 units with wide range of duty cycles and lower hp.

- Eight “medium” duty cycle equipment
 - Five delivery vehicles with dedicated number of operators have DCL Titan™ – active, off-board, catalyzed DPF’s that operate in passive mode
 - Three motor graders have Nett passive DPF’s (Cat 120G’s with 3126B engines).
- Majority of the remaining fleets have FTF’s “Flow Through Filters” utilizing metal substrates (124 Units).
- Next Step (if required) is active, on-board DPF’s.

Electric over hydraulic jumbo drills & bolters (27 Units).

- All air-cooled & initially deemed as having infrequent engine operation
- However, they were in production areas w/o exhaust treatment.
- Currently all have DCL Mine-X Ultra FTF’s



NO₂ Concerns

- Application of catalyzed treatments should increase NO₂.
 - Early – no apparent increase. Stillwater had DOC's on majority of equipment.
- Mid-2007 NO₂ started to “rear its ugly head.”
 - Increased number of catalyzed exhaust treatments.
- “Base-metal” DPF's
 - No NO₂, but require VERY high duty cycle ($T_{30} = 400^{\circ}\text{C}$, or greater)
- Active filters seemed to be the only solution and not yet proven in underground mining.
 - Rypos removed measureable NO₂, and had great smoke dot numbers.
 - Mann & Hummel reduced NO₂, and also had great smoke dot numbers.
- Late 2007 – DPF's with NO₂ suppressing catalyst
 - Reduce NO₂ by 50% to 80% instead of increasing it by 200% to 500%
 - Requires slightly higher T_{30} **and** ULS fuel
 - DCL Mine-X BM Plus – Base Metal Plus palladium for catalyst. ($T_{30} \leq 400^{\circ}\text{C}$)

NO₂ Reducing DPF's



Six System Engine Preventive Maintenance (EPM) Form

Site 3800 Shop
 Date 8/17/07 (m/d/yy)
 Vehicle # MU432 Model 1300 STONE Hourmeter 20,064.00
 Engine Make & Model 3306 CAT

Pre PM Cleaning

- Steam clean engine and surrounding compartments
- Clean radiator and coolers with degreaser and high volume-pressure water hose
- Air Cooled: Remove inspection covers – degreaser and steam clean cylinders and cooler

Perform Emissions Test

- Warm up engine to 180°F oil temperature
- Engine Speed @ hi-idle no load 2300 RPM
- Engine Speed @ hi-idle transmission stall 1800 RPM
- Engine Speed @ hi-idle transmission & hydraulic stall 1600 RPM
- Measure emissions @ transmission & hydraulic stall

Emissions Testing Performed at:

Full Throttle Transmission Only Stall - Steady State

	Inlet Side	Outlet Side
Smoke Index	5.00	0.00
O ₂ %	11.50	13.50
CO ppm	182.10	3.40
NO ppm	302.80	217.10
NO ₂ ppm	10.90	33.50
CO ₂ %	7.00	5.50
T. Gas °F	840.60	759.90
MEQI Cert Index	23.00	20.00
NO _x ppm	313.70	250.60

- DOC Conversion Efficiency
 - $[1 - \text{CO Out} / \text{CO In}] \times 100 = 98.13 \%$
 - Action required if less than 75% OR greater than 75 ppm CO @ tailpipe after DOC



Six System Engine Preventive Maintenance (EPM)

Date 8/17/2007 9:55:42 PM
 Vehicle #: MU432 Model: ELPHINSTONE R1300 Hourmeter: 21089
 Engine Make & Model: CATERPILLAR CAT 3306
 Pre PM Cleaning

- Steam clean engine and surrounding compartments
- Clean radiator and coolers with degreaser and high volume-pressure water hose
- Air Cooled: Remove inspection covers - degreaser and steam clean cylinders and cooler

Pre Testing

- Warm up engine to 180°F oil temperature
- Engine Speed @ hi-idle no load 2300 RPM
- Engine Speed @ hi-idle transmission stall 1800 RPM
- Engine Speed @ hi-idle transmission & hydraulic stall 1350 RPM
- Measure emissions @ transmission & hydraulic stall

Emissions Testing Performed at:

Transmission Stall Steady State

	Inlet DPF	Outlet DPF	TV
SMOKE	4.0	0.0	1.0
O ₂ %	12.0	12.0	
CO PPM	187.7	30.7	
NO PPM	305.9	346.9	
NO ₂ PPM	28.3	6.0	
CO ₂ %	6.6	6.6	
T.GAS F	821.7	753.7	
MEQI	29.2	17.1	
NO _x PPM	334.1	352.9	

- DOC Conversion Efficiency
 - $[1 - \text{CO Out} / \text{CO In}] \times 100 = 83.64 \%$
 - Action required if less than 75% OR greater than 75 ppm CO @ tailpipe after DOC



Flow Through Particulate Filters

- For many of Stillwater's smaller engines, ceramic, wall flow filters resulted in blown engines or plugged filters, or both.
 - Needed a filter with lower backpressure and less chance of plugging
 - Flow Through Filters appeared to be the answer.
- Newer generation FTF's DCL Mine-X Ultra
 - DPM reduction improvement over older generations according to Smoke Dot Numbers
 - Could increase NO₂
- Industry needs FTF's with NO₂ reducing technology.



Six System Engine Preventive Maintenance (EPM) Form

Site Select One
 Date 11/22/06 (m/d/yy)
 Vehicle # mu116 Model MTI Hourmeter 1,692.00
 Engine Make & Model DUETZ 4M 1013 C

Pre PM Cleaning

- Steam clean engine and surrounding compartments
- Clean radiator and coolers with degreaser and high volume-pressure water hose
- Air Cooled: Remove inspection covers – degreaser and steam clean cylinders and cooler

Perform Emissions Test

- > Warm up engine to 180°F oil temperature
- > Engine Speed @ hi-idle no load 2125 RPM
- > Engine Speed @ hi-idle transmission stall 2090 RPM
- > Engine Speed @ hi-idle transmission & hydraulic stall 2090 RPM
- > Measure emissions @ transmission & hydraulic stall

Emissions Testing Performed at:

Full Throttle Transmission + Hyd Stall - Steady State

	Inlet Side	Outlet Side
Smoke Index	7.00	3.00
O ₂ %	11.70	12.40
CO ppm	176.20	60.00
NO ppm	806.40	847.10
NO ₂ ppm	46.60	22.30
CO ₂ %	6.80	6.30
T. Gas °F	447.40	553.30
MEQI Cert Index	54.90	43.70
NO _x ppm	853.00	869.40

- > DOC Conversion Efficiency
 - o $[1 - \text{CO Out} / \text{CO In}] \times 100 = 65.95\%$
 - o Action required if less than 75% OR greater than 75 ppm CO @ tailpipe after DOC

Six System Engine Preventive Maintenance (EPM) Form

Site 6100 Shop
 Date 9/28/06 (m/d/yy)
 Vehicle # AV021 Model Mule Hourmeter 985.00
 Engine Make & Model Kawasaki 1DHXL

Pre PM Cleaning

- Steam clean engine and surrounding compartments
- Clean radiator and coolers with degreaser and high volume-pressure water hose
- Air Cooled: Remove inspection covers – degreaser and steam clean cylinders and cooler

Perform Emissions Test

- > Warm up engine to 180°F oil temperature
- > Engine Speed @ hi-idle no load 3813 RPM
- > Engine Speed @ hi-idle transmission stall RPM
- > Engine Speed @ hi-idle transmission & hydraulic stall RPM
- > Measure emissions @ transmission & hydraulic stall

Emissions Testing Performed at:

Free Snap Acceleration X 3 - Transient

	Inlet Side	Outlet Side
Smoke Index	9.00	7.00
O ₂ %	15.90	16.30
CO ppm	1194.30	917.00
NO ppm	102.50	141.70
NO ₂ ppm	15.50	2.40
CO ₂ %	3.80	3.50
T. Gas °F	388.40	233.40
MEQI Cert Index	57.00	43.10
NO _x ppm	118.00	144.10

- > DOC Conversion Efficiency
 - o $[1 - \text{CO Out} / \text{CO In}] \times 100 = 23.22\%$
 - o Action required if less than 75% OR greater than 75 ppm CO @ tailpipe after DOC



Bio-Diesel Blends

Isozone Studies & Stillwater Experience – Bio-Diesel is the only alternative fuel providing a DPM reduction.

- PuriNOx cold & warm weather emulsions, Soy-based bio, WVO bio, Synthetic Diesel fuel, etc.
- Summer '05 – B5, B10 & B20 showed measurable reductions in discrete area of mine with no operational issues.
- Summer '06 –
 - B20 blended with #2 ULSD in complete underground
 - B50 & B99 in one captive LHD stope
 - Miners noticed improvement in their work environment
 - Noticeable change from B20 to B50 in Area & Personal samples
- Spring '07 – Spring '08
 - Completed two UG storage facilities to support winter use of B50
 - B50 showed improvement in DPM samples.
- Late Spring '08 –
 - Increased blend to B70.
 - Currently winter testing with additive to determine CFP, etc.

UG Bio-Diesel Storage

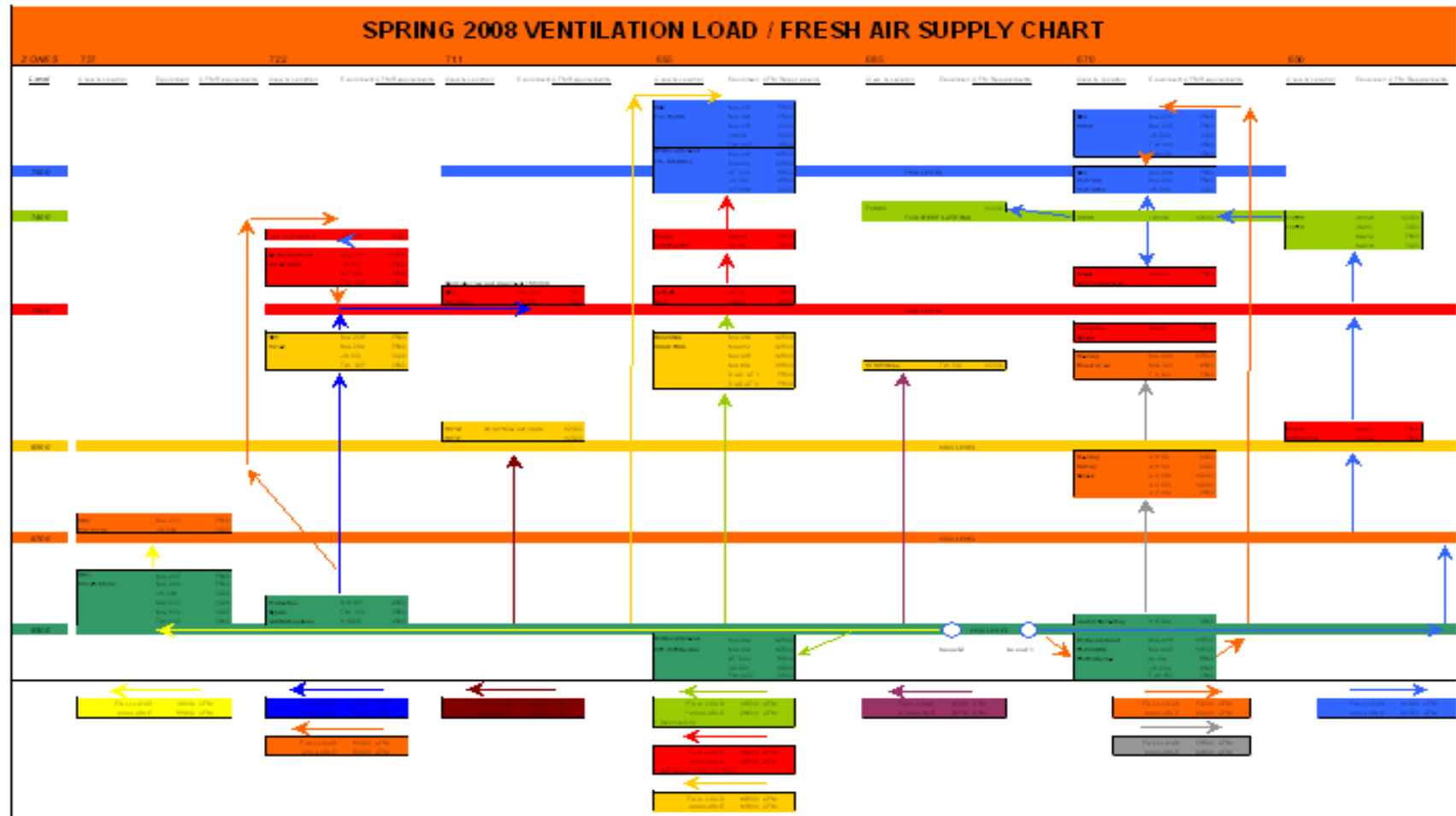




Bio-Diesel Blends

- Successful with B50 bio-diesel blend in winter
 - Additives available that bring cold weather properties of B50 to -10°F.
- Summer use of B70 successful
- Research indicates bio-diesel reduces Balance Point Temperature for DPM regeneration, widening potential DPF applications:
 - B20 => 45°C
 - B100 => 112°C
- Current Issues
 - Local Bio-Diesel producers exporting product
 - Fuel Quality – plugging DPF's (Magnesium, Calcium, & Phosphorus)

Administrative Controls





Reduce Diesel-Powered Mining Techniques

- Electric powered haulage to reduce diesel
 - 3500 Rail Haulage
 - Resurrected Greensburg 8-ton battery locomotives.
 - Removed five 10-ton haul trucks @ 215hp each from area.
 - Future 2000 Level with battery or trolley locomotive haulage
 - ABB Kiruna trolley-powered electric haul trucks to move muck between 2000 Rail and Hoist.
 - 535 Hp, 38-ton payload
 - Battery-powered 1-1/2yd³ LHD.
 - Final testing completed
 - Delivery in Fourth Quarter '08.
- Convert 25% of production mining to captive slusher, replacing diesel LHD's

Electric Powered Equipment



Kiruna Electric Haul Truck

- Electric Trolley Powered
- All AC power
 - Three VFD's
 - Two Traction motors & one service motor
- 38 Tons
- 10+ mph
- 100 Hp diesel engine for off-trolley operation





Results

- By Q3-08 the Stillwater Mine installed 247 exhaust treatments
 - 5 active, off-board DPF's operating passively (DCL Titan TM)
 - 2 active, on-board DPF (Mann & Hummel)
 - 80 Passive units
 - 160 Flow Through Filters
 - Successful implementation of NO₂ reducing technologies.
- Few passive wall flow DPF applications left for the Stillwater Mine
 - Remaining applications will mostly be flow through filters with lower DPM efficiencies, or active on-board DPF's.
- Bio-diesel contributed additional DPM reduction.
 - We assume ~50% for B50.
 - Currently, we do not yet have enough samples post B70, to estimate DPM reduction.



Final Comments

- Has Stillwater had success? **YES!**
 - Mine Ventilation upgrade projects,
 - Emissions-based maintenance,
 - NO₂ Suppressing, Passive & Active DPF's,
 - Successful transition to B50 Bio-D blend with increase to B70,
 - Electric-powered haulage & captive slusher stopes to replace diesel power, and
 - Preliminary acceptance of battery-powered LHD.
 - Extension Letter from MSHA
- Are Stillwater's efforts complete? **NO!**
 - New technology is available and needs to be tested
 - We will continue to seek and share information
- What prevents achievement of final goal? **TIME!**
 - Time for manufacturers to address low duty cycle equipment
 - DPF's **MUST** have NO₂ reducing technologies and should be "fit & forget"