Diesel Exhaust Emissions

Where are we?

Presentation to Queensland Resources Council – November 2012

Dr Brian Davies AM

Look to the past to see the present!

"It is of particular importance that the fuel entering at the mouth should be thoroughly consumed and without the formation of soot"

Rudolf Diesel – US Patent application
8 August 1898

Topics for discussion

- **Composition of diesel exhaust**
- **Health effects of diesel particulate**
- **Monitoring strategies**
- **Control strategies**
- **Global trends and the future**

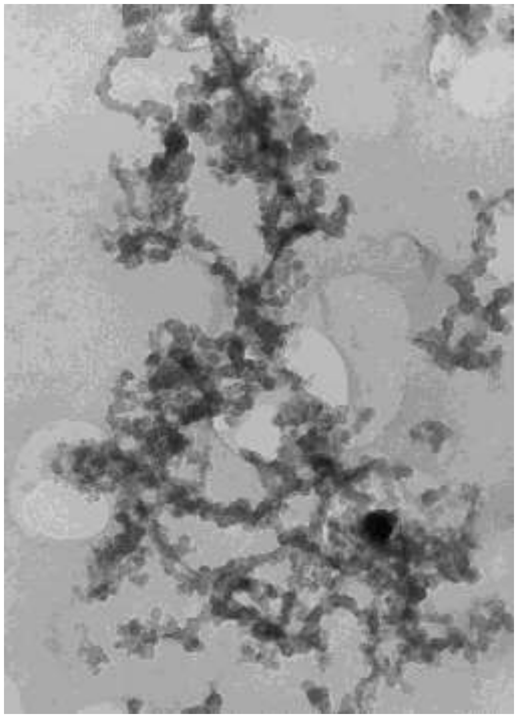
Composition of Diesel Exhaust

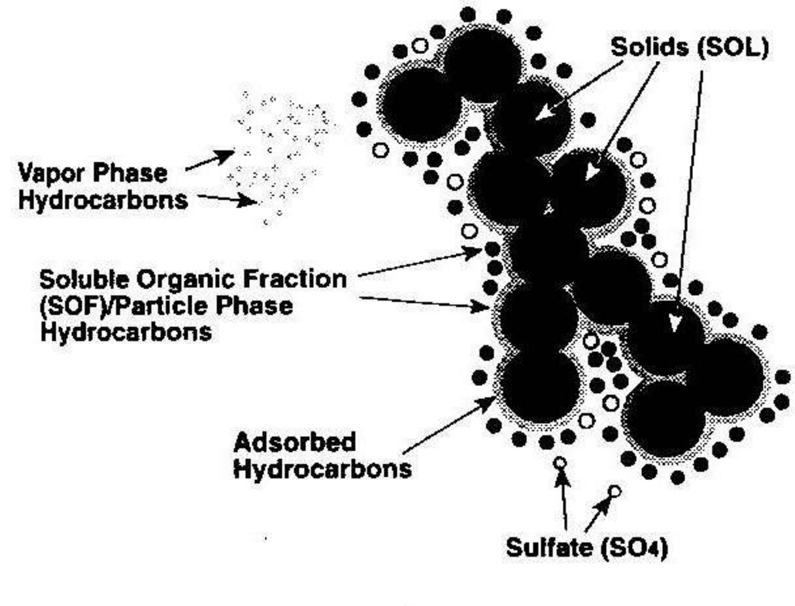
- **Two fractions:**
  - **Gaseous**
    - **Major components (99%)**
      - **N_2, O_2, Ar, CO_2 & H_2O vapour**
    - **Minor components (1%)**
      - **CO, NO_x, SO_2 & Hydrocarbons**
  - **Particulate**

What is Diesel Particulate?

- **Small particles (15-30 nm) called spherules**
- **Agglomerate to form larger particles (<1 μm in diameter)**
- **Absorb significant quantities of hydrocarbons and other organic compounds**
- **Have traces of inorganic compounds**
- **Respirable**

Diesel Particulate - Composition





Electron micrograph – mine diesel particulates showing spherules, chains and agglomerates

Schematic – mine diesel particulate showing spherules, chains and agglomerates

Source: A Rogers

DPM (DP) vs EC vs TC

DPM = Organic C + Elemental C + Mineral Fraction

Total C = Organic C + Elemental C

EC/TC ratio can vary dramatically depending on engine type, load and tuning etc. No absolute ratio

Health Effects of Diesel Particulate (DP)

- **1953 Diesel exhaust extracts cause skin tumors in mice**
- **1957 First epidemiological study**
- **1971 First monitoring method for diesel particulate (Canada)**
- **1978 Mutagenicity of diesel exhaust in bacteria**

Health Effects of Diesel Particulate (DP)

- **NIOSH – Current Intelligence Bulletin 50 (1988)**
  - **Numerous animal studies involving mice, rats & hamsters exposed to whole diesel exhaust indicated increased levels of lung tumors in mice & rats and respiratory tract irregularities in hamsters (but no tumors)**
  - **Human studies (US rail road workers) published in 1987 & 1988 showed a significant elevated relative risk for lung cancer (some confounding issues)**

Health Effects of Diesel Particulate (DP)

- **IARC in 1989 declared whole diesel exhaust category 2A (Probably Carcinogenic to Humans) based on limited evidence of carcinogenicity in humans coupled with sufficient evidence of carcinogenicity in experimental animals**
- **Studies by J L Mauderly & co-workers established the particulate component of whole diesel particulate to be biologically active in rats**

Health Effects of Diesel Particulate (DP)

- **Major epidemiological studies 1990 – 1999**
  - **Long haul truck drivers – increased risk of lung cancer but study limited due to lack of exposure data**
  - **German potash miners study – non significant positive trend with increasing exposure but some confounders**
  - **Swedish bus garage workers – increased risk but study limited by confounders (smoking)**

Health Effects of Diesel Particulate (DP)

- **Heath Effects Institute (HEI) in 1995 reviewed 30 epidemiological studies and concluded that the data was consistent in showing weak associations between exposure to diesel exhaust and lung cancer**
- **Two independent meta-analysis of published epidemiological studies (1998 & 1999) concluded significant elevated risk of lung cancer from exposure to diesel exhaust**

Health Effects of Diesel Particulate (DP)

- **MSHA (2001) suggested that at a mean concentration of 0.64 mg/m^3 DP (approximately 0.32mg/m^3 EC) for a period of 45 years exposure would result in a doubling of the risk of cancer compared to that of unexposed miners**
- **Issues of irritation (eyes, nasal & bronchial) identified**

Health Effects of Diesel Particulate (DP)

- **In May 2002 the US Environmental Protection Agency (EPA) concluded that lung cancer was evident in occupationally exposed groups but was unable to determine a degree of potency**
- **Regulatory response in many countries especially in “over the road’ diesel vehicles**

Health Effects of Diesel Particulate (DP)

- **From 2002 – 2012 carcinogenicity not forgotten but focus clearly on non malignant health effects due to newer engine designs producing more & smaller particles**
- **Cardio vascular effects seen as major issue by major research bodies around world (especially for asthmatics)**
- **Recent evidence (June 2011) has shown that DP may induce inflammation effects in airways of rats and this could be very significant if reproduced in humans**

Health Effects of Diesel Particulate (DP)

- 2010 – US National Cancer Institute – Diesel Exhaust in Miners Study
- 2012 – IARC Working group concluded that there was "sufficient evidence" in humans and animals for the carcinogenicity of whole engine exhaust, of diesel-engine exhaust particles and of extracts of diesel-engine exhaust particles

International Agency for Research on Cancer

- Established in May 1965
- Extension of World Health Organisation
- Has a membership of 22 countries including Australia
- Funded by member countries
- 300 staff from 50 countries

International Agency for Research on Cancer

- Main focus is public health cancer research
- Since 1971 has evaluated 900 agents of which 400 have been identified as carcinogenic, probably carcinogenic or possibly carcinogenic
- Diesel working group consisted of 24 experts from 7 countries (11 from USA)
- Basis of decision will be published in the IARC monograms Volume 105 (late 2013)

My Opinion

- DP is a carcinogen however its potency is not quantified beyond reasonable doubt (probably never will be)
- Non malignant health effects probably the major issue of the future
- Very strong irritant (largely overlooked)
- Significant litigation possible in future

Research Update

- April 2012 – HEI reported no major effects in rats exposed to exhaust from a 2007 compliant engine. Final report 2013
- November 2012 – HEI announced major epidemiological study to review exposure data, explore exposure response relationships and look at non occupational exposures
- Note– HEI jointly funded by US EPA & industry

Exposure Limits

- USA – metal/non-metal
  - 160ug/m^3 TC (123ug/m^3 EC)
  - Coal 2.5gm/hr engine exhaust output
- Canada – All mines
  - Ontario 400ug/m^3 TC & Quebec 600ug/m^3 TC
  - Other provinces still using RCD but moving to TC/EC
  - Also incorporated in EQI (as RCD)

Exposure Limits (Cont)

- Germany – 0.3mg/m3 (non u/g coal mines) and 0.1mg/m3 DP for all other activities
- Other Europe – 0.05mg/m^3 EC (Tunnelling)
- NSW (MDG 29) – 0.1mg/m^3 EC (best practice)
- AIOH– 0.1mg/m^3 EC (irritation & best practice)

Engine Ventilation (Canada & USA)

- Canada
  - Sufficient dilution air to reduce EQI to a value of 3 (with varying minimums based on engine kWs across provinces)
- USA
  - Gases: quantity to reduce CO2, CO, NO & NO_2 to exposure standards
  - Particulate: Amount of dilution air to reduce average exhaust level to 1mg/m^3 (Particulate Index)

Canadian Exhaust Quality Index

$$\frac{CO}{50}+\frac{NO}{25}+\frac{DPM}{2}+1.5\left[\frac{SO_2}{3}+\frac{DPM}{2}\right]+1.2\left[\frac{NO_2}{3}+\frac{DPM}{2}\right]$$

Where, DPM (mg/m^3) and gas concentrations (ppm) are measured in raw exhaust gas

Source: Mahe Gangal 2012

Monitoring Strategies

- Ambient
  - Gaseous
  - Particulate

- Raw exhaust
  - Gaseous
  - Particulate

Ambient Monitoring – Gaseous

- Numbers portable direct reading instruments available
- All require regular calibration
- Some interferences possible

Ambient Monitoring– Particulate

- Respirable combustible dust (RCD) – still used in Canada
- Elemental Carbon (NIOSH Method 5040) – most common method
- Direct reading instrumentation – a number of instruments on the market but validation limited

Raw Exhaust – Gaseous

- Portable instrumentation available
  - Some instruments can give inaccurate results if detector cell pressurised during analysis

- Mobile laboratories
  - High degree of accuracy
  - Can get real time readings and use CO_2 levels to load engine
  - NATA registered

Mobile Laboratory

Source: CMTS website

Raw Exhaust – Particulate

- Gravimetric – accurate but requires laboratory analysis
- Light scattering – numerous devices but calibration an issue. Expensive & requires technician if accurate results required
- Surface area – testing to date has shown good results. Very expensive & requires technician if accurate results required

Research on Calibration of Raw Exhaust Instruments

- Coal Services Health & Safety Trust – University of Wollongong Project
- Development of DP generator with dial up EC concentrations
- Will enable all raw exhaust analysers to be calibrated to NIOSH 5040
- Prototype currently being validated
- Field testing of instruments February 2013

Facts on Raw Exhaust Monitoring

- There is no known relationship between carbon monoxide (CO) & DP
- CO great indicator of over-fueling or blocked intake etc
- There is an inverse relationship between DP and NOx
- Carbon dioxide directly related to engine load
- Controlling emissions at their source reduces worker exposure

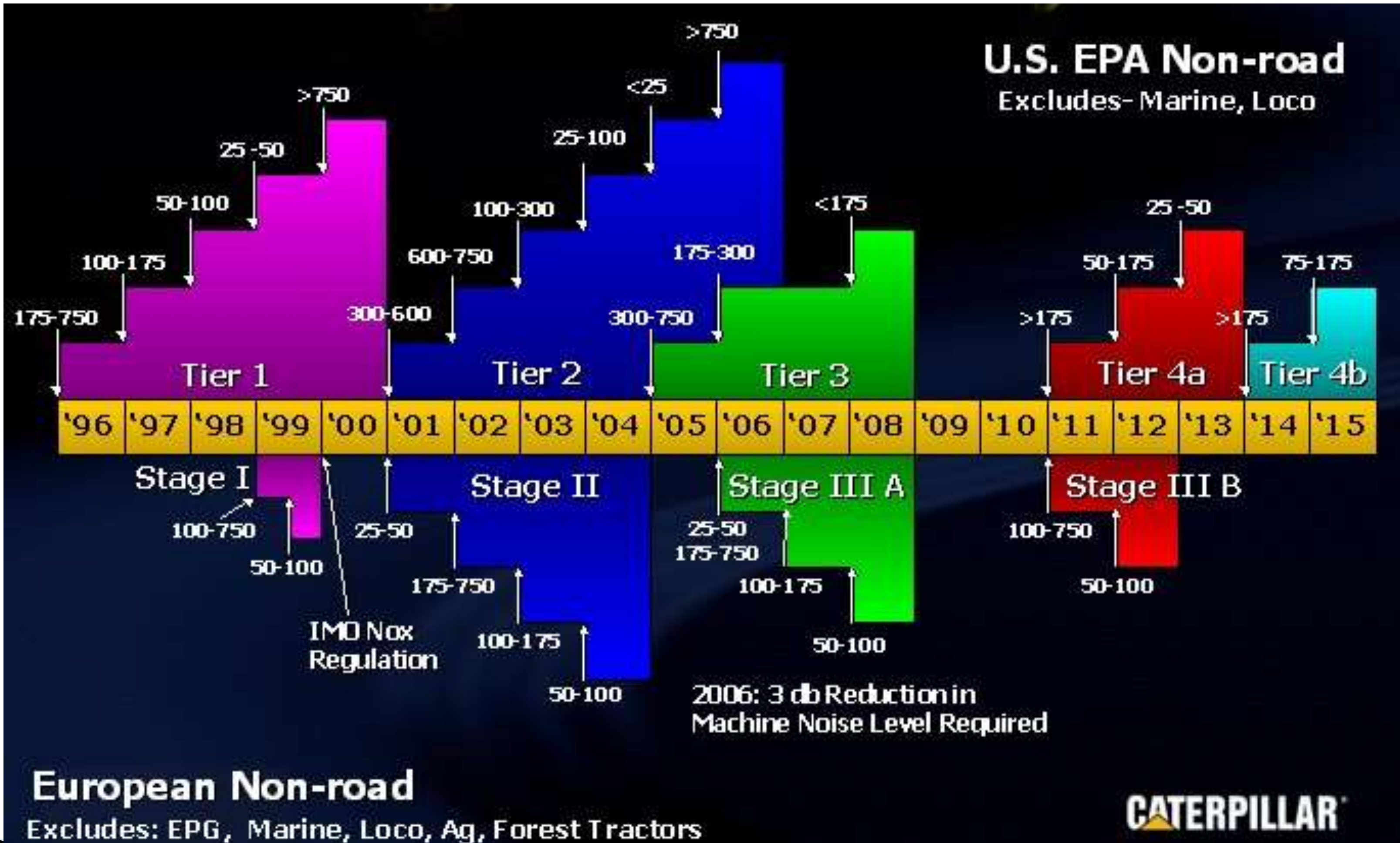
Control Technologies

- Engine design
- Fuel quality
- Ventilation
- Maintenance
- Exhaust treatment devices
- Allied emission controls
- Production & operator practices
- Education
- Respiratory protective equipment

Engine Design

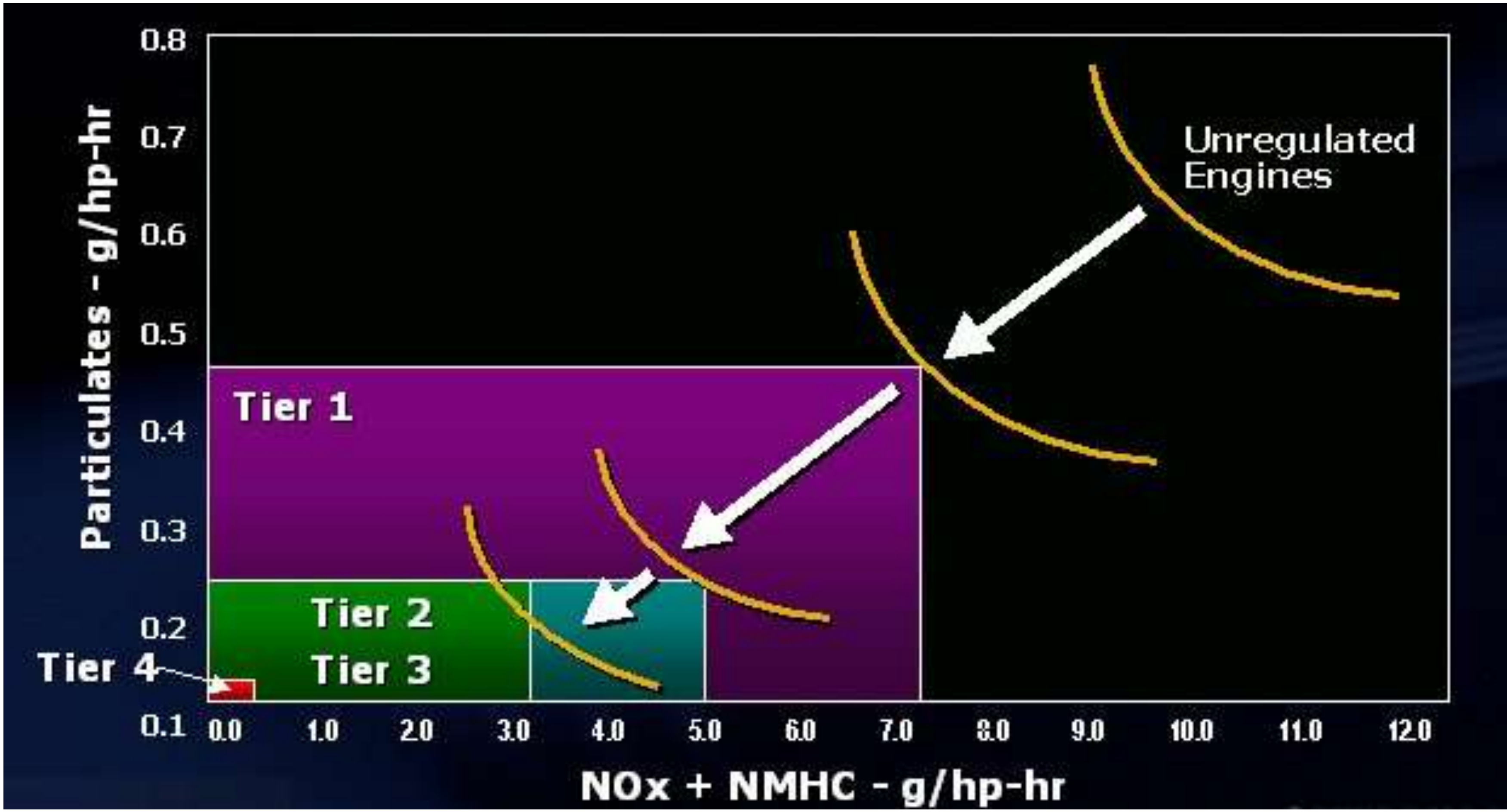
- Focus on combustion process (in-cylinder emission control)
- Electronically controlled
- Exhaust gas recirculation (EGR)
- Waste gated turbochargers
- Selective catalytic reduction (SCR) for NOx (need to add urea to exhaust)
- New fuel & lubricant formulations

US EPA and EU Non-road Emissions Evolution



Source: Caterpillar 2002

US EPA Off-Road Tier 1-4 Emissions



Source: Caterpillar 2002

Caterpillar ACERT Engine

Source: Caterpillar 2006

Fuel Quality

- Main components
  - Cetane number
  - Viscosity
  - Flash point
  - Lubricity
  - Sulphur
  - Aromatics
  - Additives

Typical Parameters

	LSD	ULSD
Density (kg/L)	0.82 – 0.86	0.82 – 0.86
T95 Distillation (°C)	180 – 370	180 – 370
Sulphur (ppm)	<500	<50
Viscosity (cSt)	2.0 – 4.5	2.0 – 4.5
Cetane Number	51	53
Aromatics (%)	15 – 30	10 – 30

Eromanga Diesel Fuel

Parameter	Specification	Typical Value
Density (kg/L)	0.79 – 0.84	0.795
T95 Distillation (°C)	371 (max)	348
Sulphur (ppm)	200 (max)	100
Aromatics (%)	<10	2
Flash Point (°C)	61.6 (min)	64
Viscosity @ 40°C (cSt)	2.0 – 4.7	–
Cetane Index	50 (min)	66

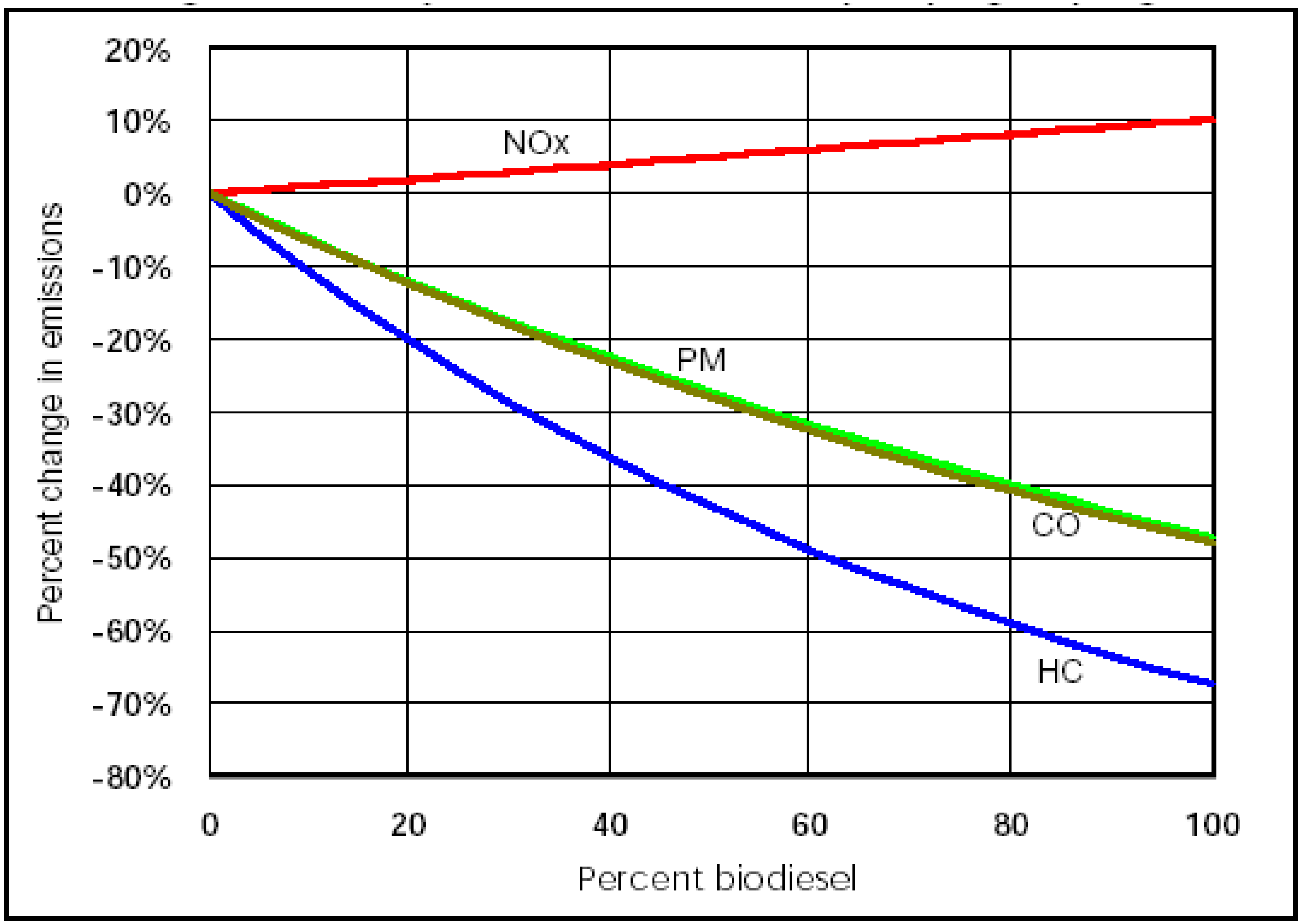
Biofuels

- Advantages
  - Reduced DP, CO & HC emissions
  - No aromatics & PAHs
  - No sulphur
  - Higher cetane value than diesel

Biofuels

- Disadvantages
  - Increased NOx emissions (high O_2 content)
  - Poor low temperature flow
  - High cost
  - Odour an issue with some biofuels

Biofuels



Source: BOM

Impact of Biofuels

- **Vegetable oils first used by Rudolf Diesel in late 1800's**
- **While biodiesels decrease DP they can increase NO_X**
- **Rape seed oil & rape seed oil methyl ester have shown a strong increase in mutagenicity (10 to 60 fold) over established diesel fuels**
- **Calls for research on the potential carcinogenicity of biodiesel**

Fuel Related Issues

- Storage and handling a priority
- Low aromatic content can cause leaking fuel pump seals when changing to some LSFs
- Loss of power can occur–need to tune engine to fuel used onsite
- Off-site repair companies need to use same LSF

Ventilation

- Historically prime method of controlling emissions
- Some authorities require a set amount of air (typically 0.06 $m^3/s/kW$) irrespective of engine type or condition
- Engine certification data used by some countries to develop ventilation plans
- Some authorities base ventilation plans on exposure data alone

Ventilation

- Some authorities give dispensations for low sulphur fuel and low emission engines (0.03 $m^3/s/kW$)
- Thermal stratification has been shown to occur in a narrow heading with large engines (175kW)
- Considerably more air is required to ventilate for particulates than for gases

MSHA Cat 3176C Certification

Engines for Underground Non-Gassy Mines and Tunnels and in Areas of Underground Coal Mines Where "Non-Permissible" Equipment is Allowed (MSHA, Part 7, Category B)

Model Type	bkW	bhp	rpm	Vent Rate cfm	Vent Rate cfm/hp	Particulate Index cfm	Particulate Index cfm/hp	MSHA Cert. No.
3176C ATAAC[1,3]	201	270	2100	11 500	42.6	7500	27.8	7E-B012-0
3176C ATAAC[1,3]	231	310	2100	13 500	43.5	7500	24.2	7E-B012-0
3176C ATAAC[1,3]	250	335	2100	15 000	44.8	8000	23.9	7E-B012-0
3406E ATAAC[1]	269	360	2100	17 000	47.2	14 000	36.9	7E-B018-0
3406E ATAAC[1]	298	400	2100	18 500	46.3	13 000	32.5	7E-B018-0
3406E ATAAC[1]	317	425	2100	20 000	47.1	12 000	28.2	7E-B018-0
3406E ATAAC[1]	336	450	2100	21 000	46.7	12 000	26.7	7E-B018-0
3406E ATAAC[1]	354	476	2100	22 000	46.3	13 000	27.4	7E-B018-0
3406E ATAAC[1]	366	490	2100	22 000	44.9	10 500	21.4	7E-B012-0
3406E ATAAC[1]	373	500	2100	24 000	48.0	12 500	25.0	7E-B012-0

[1] Electronically controlled/governed
[2] Mechanically governed
[3] Also approved to CANMET/CSA (Cert. No. 1099)

Nomenclature:

ATAAC ....Turbocharged and Air-to-Air Aftercooled

Source: MSHA

CANMET Cat 3176C Certification

Engine Manufacturer: **Caterpillar**
Engine Model: **3176C**
Governing Standard: **CSA M424.2-90 (Non-Gassy Mines)**

Certificate Number	Engine Rating and Measured Maximum Fuel Rate at Sea Level	Sulphur in Fuel - %wt.	Ventilation Prescription*	
			CFM	m^3/min
1099	335 HP @ 2100 RPM 122.3 lb/hr	0.05 0.10 0.20 0.25 0.50	17300 19400 23600 25700 36700 44300+	489.9 549.3 668.3 727.7 1039.3 1254.4+
1099	310 HP @ 2100 RPM 112.3 lb/hr	0.05 0.10 0.20 0.25 0.50	16300 17700 20600 22100 32000 38500+	461.6 501.2 583.3 625.8 906.2 1090.2+
1099	270 HP @ 2100 RPM 98.3 lb/hr	0.05 0.10 0.20 0.25 0.50	16200 17400 20600 22300 30700 33600+	458.7 492.7 583.3 631.5 869.4 951.4+

Source: Canmet

Key Maintenance Items

- Intake system
  - Intake turbo-charging
  - Intake air cooling
- Exhaust system
  - Exhaust monitoring
- Emissions control technology
  - Exhaust backpressure
  - Seals, pipes ,connections etc

Key Maintenance Items (Cont)

- Fuel injection system
  - Contamination
  - Fuel overheating
  - Tampering
- Cooling system
- Fuel handling system
- Lubrication system

Effect of Maintenance on DP

- BOM (1985) Engines >4000-5000 Hours
  - Hydrocarbons increase
  - Carbon Monoxide increases
  - Oxides of Nitrogen decreases
  - Particulates increase

- DEEP (2002)
  - Poor fuel handling
  - Recycled oil
  - Lack of diagnostic tests for engines
  - CO reduced by 65% particulates by 55%

US Bureau of Mines – 1985

- Hydrocarbons :
  - Timing adjustment – up 306%
- Carbon monoxide:
  - Intake restriction & excess fuel – up 445%
- Oxides of Nitrogen:
  - Timing adjustment – up 50%
- Particulates:
  - Intake restriction & excess fuel – up 1038%

VUT/Illawarra Coal Maintenance Project

- **Tested raw exhaust of 66 engines at four mines using R&P 5100 and mobile gas laboratory**

- **Engines loaded as per MDG 29**

- **Identified 7 abnormal engines**

Number of Engines Tested

Engine Type	No. of Units Tested
Caterpillar 3304	26
Caterpillar 3306	5
KIA 6-247	12
Perkins 1006.6	14
MWM D916.4	6
MWM D916.6	3

Source: B Davies

Abnormal Engines

Mine	Vehicle	Engine	EC mg/m^3 (UCL)
A	SMV 5073	Perkins	93 (42)
A	SMV 5100	Perkins	60 (42)
A	MPV 98	Cat 3304	71 (37)
B	PJB 103	KIA 6-247	102 (85)
C	PJB 114	KIA 6-247	131 (85)
C	PJB 132	KIA 6-247	139 (85)
C	Ram Car	MWM 916	159 (70+)

Source: B Davies

Particulate Results Vs Maintenance

Vehicle	Pre Mtce. EC mg/m^3	Post Mtce. EC mg/m^3	EC g/hr	Maintenance Performed
PJB 132	139	46	9.5	New fuel pump and cleaned scrubber tank
PJB 114	131	40	8.5	New scrubber tank, New injectors, adjusted fuel
Ram Car	159	71	11.3	Replaced injectors
PJB 103	102	61	14.5	Replaced injectors, cleaned scrubber tank and intake air system

Source: B Davies

Blocked Scrubber Tank

Source: B Davies

Gaseous Results Vs Maintenance

Vehicle	Date Tested	CO_2 %	CO ppm	NOx ppm	Maintenance Performed
PJB 132	30.9.03	11	690	400	New fuel pump and cleaned scrubber tank
PJB 114	30.9.03	11	>2500	280	New scrubber tank
PJB 114	30.9.03	10	690	350	Reduced fuel
PJB 114	9.10.03	9	310	350	New injectors
Ram Car 194	6.1.04	10	620	230	Replaced injectors
PJB 103	13.1.04	10.5	720	320	Replaced injectors, cleaned scrubber tank and air intake system

Source: B Davies

Comparison To Previous Data

		OC mg/m^3		TC mg/m^3		EC mg/m^3	
Vehicle No.	Engine	XYZ Colliery 1999	XYZ Colliery 2003	XYZ Colliery 1999	XYZ Colliery 2003	XYZ Colliery 1999	XYZ Colliery 2003
PJB 108	KIA 6-247	3.4 – 70	12	66 – 245	29	56 – 224	17
PJB 115	KIA 6-247	7 – 33	7.2	160 – 242	58	146 – 209	51
PJB 116	KIA 6-247	8.8 – 26	8.5	141 – 191	51	116 – 177	43
PJB 132	KIA 6-247	9.3 – 34	8.6	202 – 241	55	178 – 223	46

Source: B Davies

Further Data (Raw Exhaust)

Vehicle	Initial Result (mg/m3 EC)	Post Maintenance (mg/m3 EC)	Maintenance Performed
Eimco 9	166	54	New Injectors
SMV 5076	75	44	Retarded timing, cleaned intake system and reduced fuel
PJB 107	206	80	Cleaned intake system, reduced fuel
PJB 15	150	75	Changed air cleaner

Source: B Davies

Raw Exhaust Limits

- MSHA use 2.5g/hr DP in coal mines
- No known health basis for this limit
- MSHA also use "Particulate Index" at engine certification stage – useful for identifying high emission engines

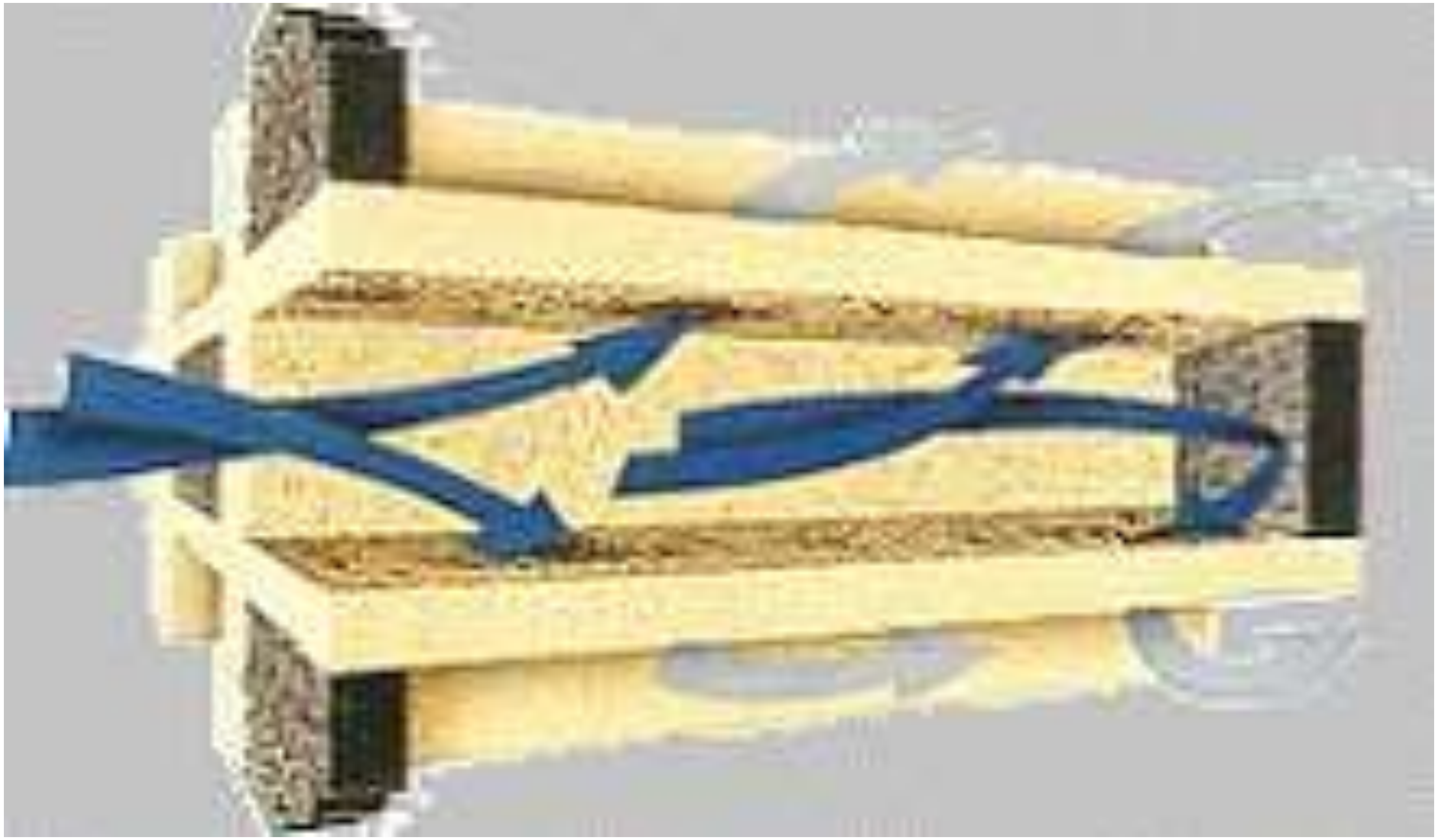
What if There are no Statutory Raw Exhaust Limits?

- Best practice is to use process of continual improvement based on 95% UCL of engine type average
- Link between raw exhaust concentration and atmospheric concentration still needs to be established (not the same as gases)

Exhaust Treatment Devices

- Diesel Particulate Filters (DPF)
- Disposable Diesel Exhaust Filters (DDEF)
  - High temperature
  - Low temperature

DPF Design



Source: BOM

Regeneration

- Passive
  - Uses exhaust temperature as initiator
  - Catalysts
  - Precious metal coatings
- Active
  - Requires external heating system

DPF Selection

- Critical to match DPF to engine, vehicle and duty cycle
- Duty cycle and exhaust temperature profile required to aid selection

Operating Considerations

- Keep idling to a minimum
- Keep engine working as hard and as hot as possible
- Monitor exhaust backpressure
- Ensure active systems get plugged in and are working

Maintenance Considerations

- Engine performance critical to make DPF work efficiently
- Check for leaks and damage regularly
- Measure and check DPF performance routinely

Disposable Diesel Exhaust Filters

- Disposable exhaust filters first developed by US Bureau of Mines in 1991
- Based on Donaldson truck air filter element
- Initial trials on a Jeffrey Ram Car at Skyline Mine in Utah (90% reduction)

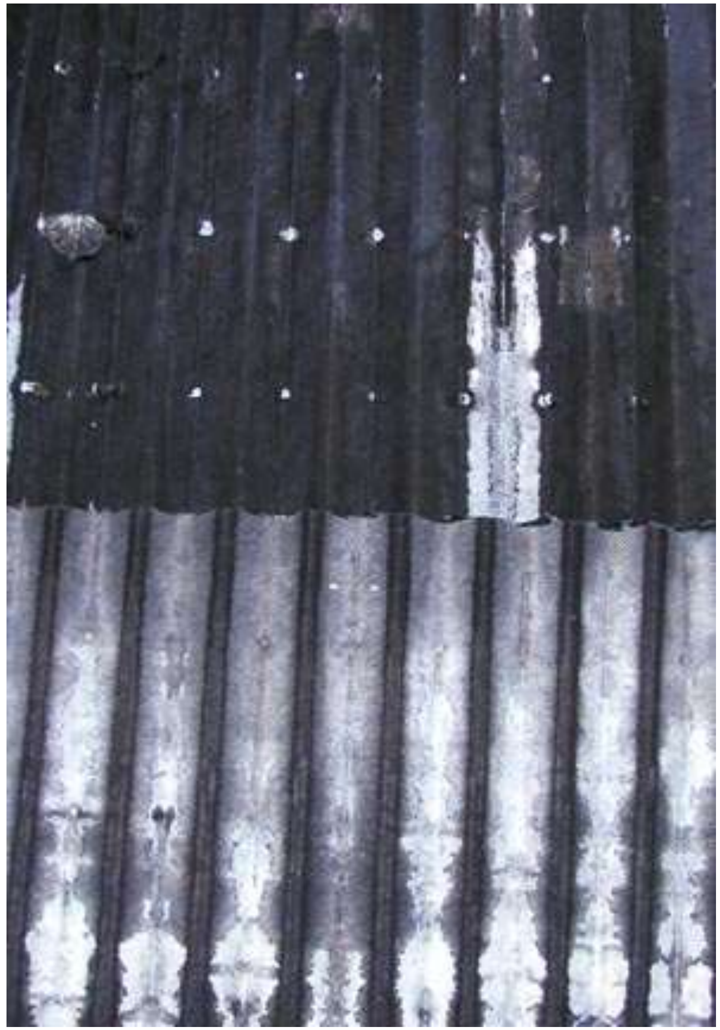
Disposable Exhaust Filters

- Microfresh Filters system (developed with Illawarra Coal)
  - Non flammable material
  - Reduction in DP levels of about 85%
  - Introduced in NSW underground mines in 1995

New & Used DDEF

Source: B Davies

Filter Media After 44 Hours Use (160)



Source: B Davies

DDEF Issues

- In USA a built up of DP lead to a fire in several vehicles (paper filters) due to loss of scrubber water (cause identified as scrubber tank operated when empty)
- Maintenance of seals and canisters important
- Change out needs to be on performance not operator perceptions
- Significant ongoing cost but very effective in controlling DP

Allied Control Devices

- Catalytic Converters
- Scrubber tanks
- Exhaust fume diluters
- Re-direction of exhausts
- Air conditioned operator cabins
- Workshop extraction systems

Catalytic Converters

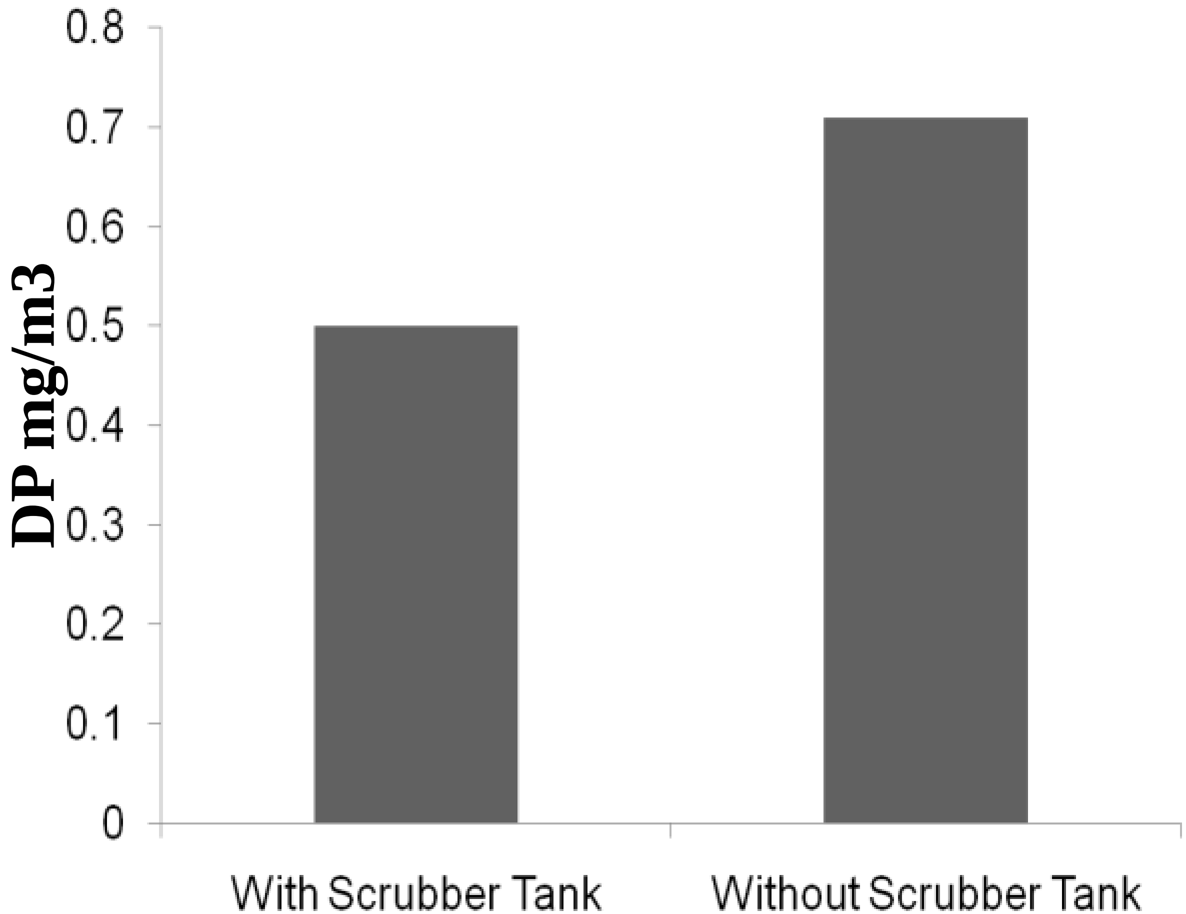
- Remove carbon monoxide & hydrocarbons
- Reductions of >70% for CO & HC
- Reduces total DPM by 35% but it is only the organic fraction not EC
- Requires an exhaust temperature of >250 C
- NO converted to NO_2 at temperatures between 300-400 C
- Requires low sulphur fuel

Effect Of Catalytic Converter

Parameter	Units	DOC Inlet	DOC Outlet
O_2	%	11.2	11.2
CO	ppm	59	22
NO	ppm	627	591
NO_2	ppm	25	44
CO2	%	7.2	7.2
Exhaust Temperature	Degrees C	419	354

Source: B Davies

Scrubber Tanks



Source: B Davies

Exhaust Fume Diluters

- Do not reduce the level of DP in the ambient atmosphere
- Can place backpressure on exhaust system increasing CO and particulate emissions
- Use quickly diminishing in industry as a control measure

Re-direction of exhausts

- Can be very effective in reducing emissions
- Direct exhaust so it is on opposite side of vehicle to operator
- Direct exhaust to minimise agitation of dust etc from roadways
- Ensure extended exhaust piping does not increase back pressure on engine
- Directing exhaust vertically on forklifts can be very effective in controlling operator exposures

Air Conditioned Operator Cabs

- Can reduce operator exposures by up to 80%
- Maintenance of filtration system and door/window seals a key issue
- Operator must keep window closed
- Has negative effect on workers in adjacent area due to aggressive driving practices of vehicle operators

Workshop Extraction Systems

- May be necessary when
  - Running up engines for diagnostic testing
  - Continuous idling of engines is occurring
  - Workshop doors are shut due weather conditions
- Need to be designed such that they have
  - Sufficient fan volume for number of engines and extraction outlets in workshop
  - Have adaptors to fit all types of exhaust pipes
  - Sufficient flexibility to cover whole workshop
  - Appropriate disposal of extracted exhausts

Production & Operator Practices

- Training and attitudes of operators key to a successful emission reduction programme
- Need for standard operating procedures which incorporate best practices
- Roadway design and maintenance in underground mines can influence emission levels

Education

- Need for an integrated site education approach
- Workforce general awareness
- Operator specific training
- Maintenance personnel specific training

Respiratory Protective Equipment

- Respirators used in mines are generally used to protect against mechanically generated dusts
- Few RPEs have been specifically tested with EC as the challenge contaminant
- 3M 9913v has been tested against EC and has a filtration efficiency of >95% (may be others but most suppliers rely on other challenge products)

Site Management Plans – Initial

- Need to be based on risk of employee exposure and have a clear implementation timetable
- Should include:
  - Low emission fuel (if available)
  - Emissions based maintenance programme
  - Workforce & driver education programme
  - Ventilation strategies consistent with the control of DP
  - Low emission engine purchasing policy
  - Controls on contractor or hire vehicles

Site Management Plan – Secondary

- If the initial plan isn't successful in lowering exposures
  - Low emission engines
  - Diesel exhaust filters
  - Air-conditioned & filtered operator cabins
  - Alternative power systems (electric)

Does All This Work?

Personal Monitoring for EC Pre & Post Control Strategy

	1994	2005
No. Samples	13	36
MVUE (mg/m^3 EC)	0.12	0.05
GSD	1.91	1.75
Lands (mg/m^3 EC) (95% LCL & UCL)	0.09–0.18	0.04–0.06

Source: B Davies

Global trends & the future

- Clear global focus on emissions from diesel engines which isn't likely to abate soon
- Technology improvements being constantly rolled out by OEMs
- Regulatory pressure will increase
- Litigation highly likely especially in compensation cases

Summary

- DP isn't an issue that will disappear quickly
- No one single simple control technology currently exists. Operations need to determine the best package for their activities
- Effective control technologies do exist and can be made to work but it takes effort and attention to detail
- Maintenance is a key issue which has the potential for quick emission reduction gains with productivity returns as a bonus

Useful Websites

- Health Effects Institute
  - www.healtheffects.org
- DieselNet (subscription)
  - www.dieselnet.com
- Mining Diesel Emissions Council
  - www.mdec.ca