EIMCO

COAL INDUSTRY SAFETY CONFERENCE

DIESEL ENGINE PROJECT

IMPROVING THE SAFETY AND EFFICIENCY OF DIESEL ENGINES IN UNDERGROUND COAL MINING

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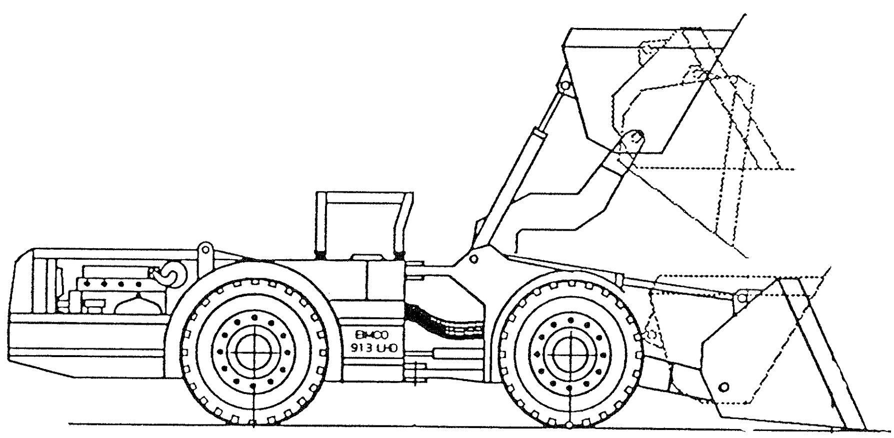
1. ABSTRACT

Diesel engines power much of the personnel and materials transport, road way maintenance and development equipment used in underground Australian coal mines. The operation of these mines depends almost entirely upon the efficiency and mobility that diesel powered free steered vehicles offer. Unfortunately, the release of the chemical energy in the diesel engine combustion process produces many potentially hazardous substances such as Carbon Dioxide, Carbon Monoxide, Nitrous oxide, PAHs (Polycyclic Aromatic Hydrocarbons) and Aldehydes. The control of the exposure to mining personnel from these substances, is the responsibility of the mining equipment manufacturers, mine management and government regulatory bodies.

Current legislation and Australian standards are limiting the application of new technology diesel engines and exhaust treatments thereby minimising the ability of mines to improve the efficiency and safety of its diesel engine operations. Following a discussion paper produced by the Queensland Department of Resource Industries in 1992, entitled " Diesel engines in underground coal mines, a strategy for the future", a research and development project was applied for and granted to the ACIRL organisation (Australian Coal Industry Research Laboratories) under the ACARP program. (Australian Coal Association Research Program). EIMCO Australia is working closely with ACIRL, the Oakey Creek mine and the Queensland Department of Resource Industries to develop and apply new technology in engine design and emission control into an EIMCO 913 Load Haul Dump vehicle.

The project is titled "The improvement of the productivity of underground diesel vehicles by optimising the engine exhaust system and exhaust gas monitoring process whilst maintaining or increasing worker safety.". This short paper will briefly describe the features of the new engine and monitoring system and will also comment on possible efficiency and safety improvements which will be derived from the project.



1.1 Illustration of standard EIMCO 913 LHD (Load HaulDump)

2. INTRODUCTION

The project is directed to improving the productivity and safety of underground diesel vehicles and to make recommendations on the altering of legislation from a raw engine exhaust gas limit to a system which is based upon continuous atmospheric monitoring. It is important to monitor what the mining personnel are breathing rather than what the engine is producing. When the cleanest engine available is placed into a poorly ventilated area, toxic gas levels will exceeded recommended maximums.

This however does not preclude manufacturers and suppliers of diesel powered equipment from offering clean engines nor does it wave the need for continuous testing and maintenance of existing equipment. As ventilation is expensive and mining personnel will know exactly what they are breathing, pressure will be placed upon the equipment to perform to the best of its ability. This will force suppliers to constantly better engine technology and emissions so that they remain competitive. Mine maintenance personneland systems would also need to be refined to keep diesel engines in top condition. This process will result in improved occupational health and increased mine efficiency beyond the limits of existing test and monitoring systems and regulations.

	CO ppm (mg/m^3)	CO_2 ppm (mg/m^3)	NO_2 ppm (mg/m^3)	NO ppm (mg/m^3)	NO_x ppm (mg/m^3)
Australia					
New South Wales	50	12,500	NS	NS	5
Queensland	50	5,000	5	NS	NS
South Australia	50	5,000	5	NS	NS
Victoria	50	5,000	5	NS	NS
Western Australia	50	5,000	5	NS	NS
United Kingdom	50	12,500	NS	NS	NS
United States	100	5,000	2.5	NS	NS
Australia worksafe standard					
TWA*	50 (57)	5000 (9000)	3 (5.6)	25 (45)	NS
TWA* in coal mines	NS	12500(22500)	NS	NS	NS
STEL*	400 (458)	30000(54000)	5 (9.4)	NS	NS

TWA: Time Weighted Average over a standard 8 hour day, 5 days a week.
STEL: Short Term Exposure Limit. Peak or maximum limit.

2.1 Current general air body maximum pollutant limits

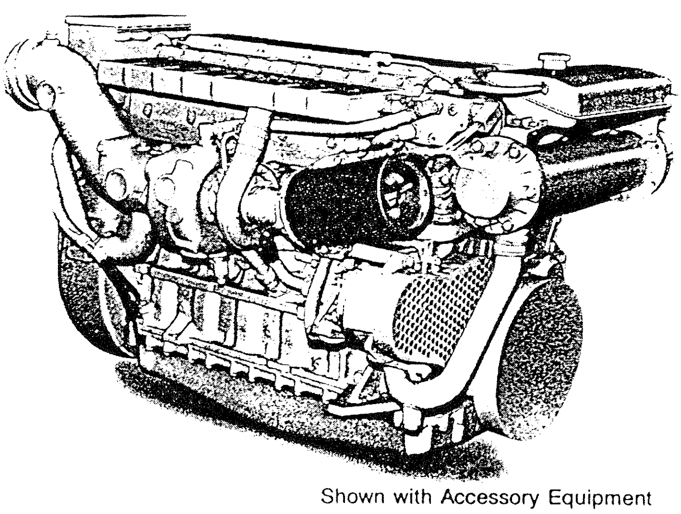
To achieve the necessary data to recommend alterations to underground emission legislation and procedures, the following program will be followed.

ORGANISATION	FUNCTION
EIMCO	Develop, manufacture and test a caterpillar 3116 engine package (150 hp) complete with a dry scrubber and particulate filter.
EIMCO	Develop, manufacture and test an electronic engine management system to suit the 3116 engine.
EIMCO & ACIRL	Assemble a standard 3304 PCNA 100 hp 913 engine package. This engine will be run and tested on a dynamometer to compare exhaust and emission data.
OAKEY CREEK	Supply standard 913 for re fit with 3116 engine
EIMCO	Fit complete engine package into 913.
ACIRL	Test the vehicle on site at the Oakey Creek mine, measuring and recording TWA and STEL levels for CO, NO2, PAH & Aldehydes. Both on board and strategically placed monitors within the mine,
ACIRL	Combine the results and define the best method of emission monitoring to ensure worker's safety.

2.2 Basic project work plan

3. CATERPILLAR 3116 ENGINE

Within the Australian underground coal mining industry, the Caterpillar 3300 series diesel engine in 4 and 6 cylinder configurations is without doubt the most popular work horse. Caterpillar specially manufacture the 3300 series PCNA (Pre Combustion Naturally Aspirated), engine solely for the underground mining market. In its specified "clean burning" form, the engine is no longer used in any other surface equipment as it very fuel inefficient and outdated.



Shown with Accessory Equipment

3.1 Illustration Marine 3116 engine

Conversely, the project 3116 engine is a modern diesel engine that has not been used in underground coal in Australia. The following table is a comparison between the conventional 3306 PCNA engine at 150 hp as currently used in many vehicles and the new 3116 DITJWA (Direct Injection, Turbo charged, Jacket Water After cooled) engine at 155 hp. Table 3.2 adequately shows the sizes, fuel consumption, and cost disadvantages of the 3300 series engine compared to the 3116. As testing is continuing, table 3.2 is derived from interpolated information and therefore there will be variations between this table and the final 3116 engine.

	3306	3116	Percent change %	Improvement Yes/No
Aspiration	PCNA	DITJWA	N/A	N/A
Power (kW)	112	119	+6.25	Yes
Rated speed (rpm)	2200	2200	0	N/A
Air flow at full power (m^3/min)	9.5	10.00	+5.26	Yes
Exhaust flow full power (m^3/min)	29.0	23.3	-19.7	Yes
Fuel flow At full power (l/Hour)	35.2	23.9	-32.1	Yes
Engine mass (kg)	930	493	-47.0	Yes
Overall length (mm)	1236	970	-21.5	Yes
Overall Height (mm)	1007	790	-21.5	Yes
Overall width (mm)	755	580	-23.1	Yes
Cost ($)	26,500	20,000	-24.5	Yes

3.2 Table of relative advantages of new engine

The real improvement with this engine is that for less than the cost of the original engine a standard 913 with a 3304PCNA at 76 kW can be refitted with a 3116 DITJWA unit running at 112 kW. The two engines are approximately the same length but the 3116 is 21.5% lower, 34% lighter and 23% narrower. These dimensional and power improvements will allow EIMCO to design the following benefits into a standard 913

3.3.1 50% increase in speed on any grade due to extra power and less weight.

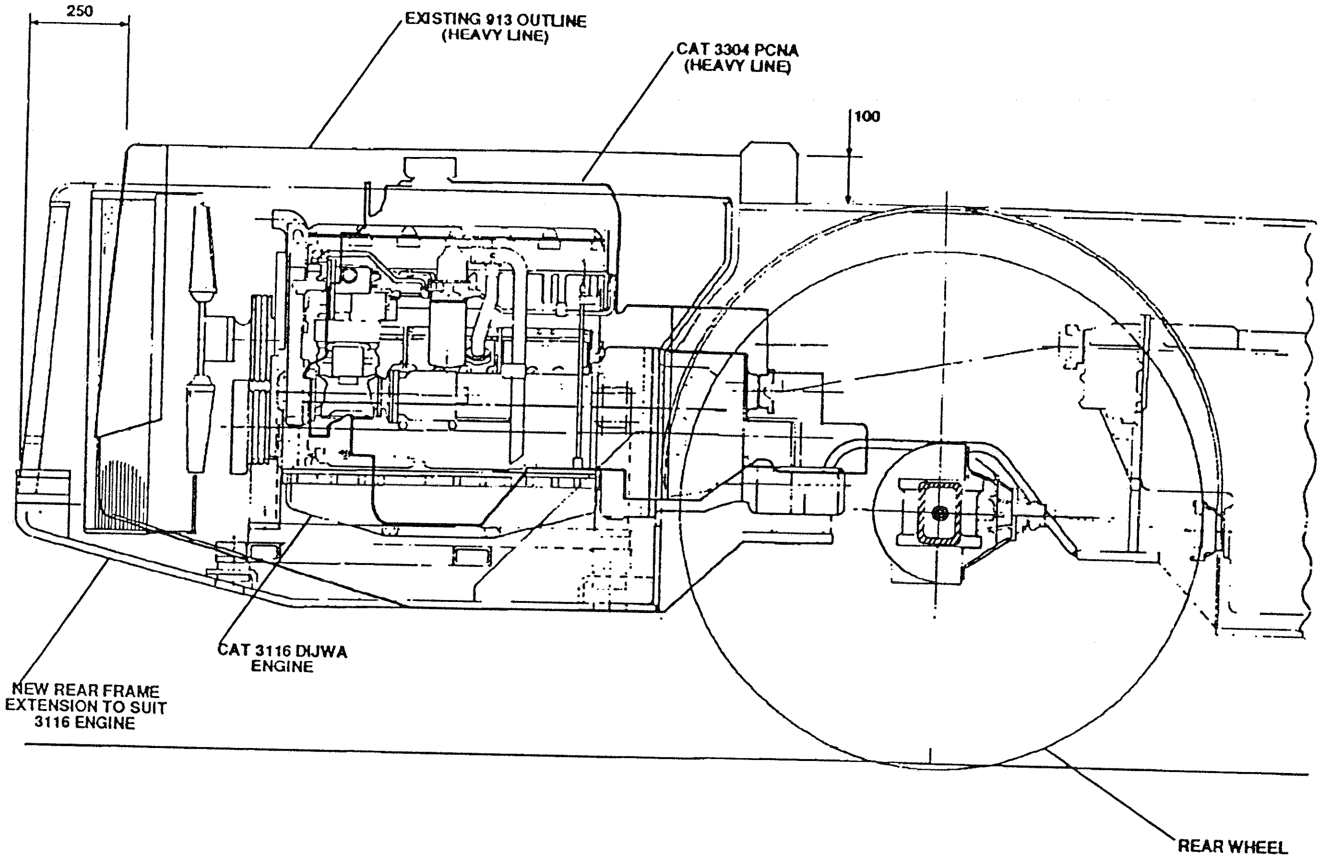
3.3.2 Visibility over the rear end of the vehicle will be improved as the lower height of the engine allows for the lowering of the rear engine covers by 100 mm.

3.3.3 Improved fuel consumption. The 76 kW 3304 uses approximately 2 litres an hour more than the 112 kW 3116 at full power.

3.3.4 Better access to parts and service as the 3116 powers much of the current small Caterpillar surface equipment.

3.3.5 Lower noise and vibration.

3.3.6 The 3116 is a current engine and is constantly being upgraded to meet new EPA regulations world wide. Therefore unlike the 3304, improvements will continue to be made and passed onto the end user.



3.4 Illustration side elevation 913 with 3116 engine

With increased demands from EPAs for applications in trucks and buses, engine manufacturers have been forced to develop new technologies that meet more stringent emission requirements without sacrificing fuel economy or power. Typically these engines in the past used indirect injection, but improvements in direct injection technology have removed this advantage. Modern direct injection diesel engines are cleaner burning because of refinements in combustion chamber design, piston ring design, higher fuel injection pressures, higher combustion chamber pressures, turbo chargers, after cooling and electronic engine control.

Over the next 10 years it will become increasingly difficult to obtain engines that are not turbo charged and electronically controlled as these are the major tools the manufacturers use to improve emission quality. We are seeing today, the price of the 3300 series engines rise dramatically as they are being produced on a special basis and therefore do not enjoy the economies of scale of the newer higher volume 3116 unit.

There are some issues which need to be addressed in the current Australian standard AS3584 which are impeding the application of modern engines into underground Australian coal. Each of these will be addressed in the development of the engine and risk assessments will be carried out before changes are accepted on the project vehicle.

3.5.1 Restrictive NOx levels are limiting the application of engines which have very good emmissionlevels for other gases. . Higher combustion temperatures, leaner air fuel ratios and efficiency has lead to lower CO, PAH and particulate emissions with an increase in NOx levels. In an effort to achieve 750 ppm NOx, engine mechanical controls such as timing and air fuel ratios are altered and the other emissions are worsened. A better balance is required which optimises what is lost with what is gained.

3.5.2 PPM (Parts Per Million) measurements for exhaust contaminants is not sufficient to access the true pollution effect of an engine. The internationally recognised standard is g/kW-hr. The emission data should be recorded in g/kW-hr and exhaust gas total mass flow rates in kg/hr should also be recorded. With this information accurate comparisons can be made between engines.

	Engine A	Engine B
Power (kW)	112	112
Speed (rpm)	2200	2200
Total Exhaust gas mass flow rate (kg/hr)	650	500
CO (PPM)	200	200
CO (g/hr)	125	96
CO (g/kW-hr)	1.116	0.857

3.5.2.1 Table PPM versus g/kW-hr for similar diesel engines

Under the current method of testing and emissionassessment, the above two engines with the same power, speed and CO emissions in PPM would be regarded as equal in emission quality. However engine B produces less overall exhaust gas, therefore in reality, it is a far cleaner engine. Under the current system this factor is not considered and therefore limits the selection of available engines. Typically DI engines produce less exhaust gases than PC engines.

3.5.3 The standard does not address the application and testing of dry scrubbers.

3.5.4 Exhaust outlet temperatures are too low at 77 ^{0} C for dry scrubbers as they are cooled by the engine cooling water which is typically thermostatically controlledbetween 85-95^0 Celcius. This should be altered to 150 ^{0} Celsius which is the same as for the engine surface temperature. However a clause must also be added to protect personnel from exhaust burns. Air dilution methods such as allowing the exhaust to be mixed with the engine cooling air flow may achieve this.

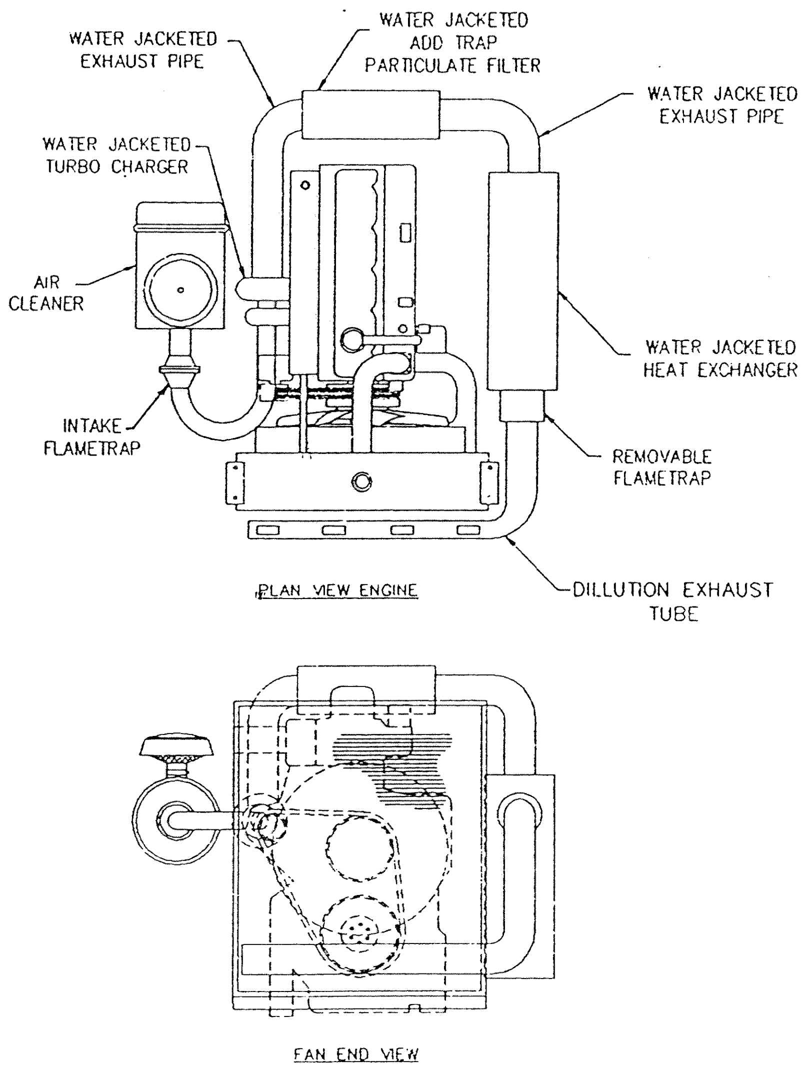
3.5.5 The application and testing of turbo chargers.

3.5.6 The application and testing of electronic engine management systems.

3.5.7 Air quality indexes should be calculated for each engine and supplied to mines so that they can access the relative "cleanness" of engines and the ventilation required to run the engine underground.

3.5.8 An adequate standard for fuel quality. Resent tests have indicated that fuel has an enormous effect on emission quality, especially particulates.

3.5.9 The number of engines required for the underground Australian coal market is extremely limited and therefore not considered as a large enough market to allocate development funds when engine manufacturers design new engines. We cannot stand alone with an emission standard that varies wildly from that of every other EPAs. It would be to the advantage of the personnel in underground mining if we were allowed to access the wealth of engine developments and emission quality improvements by linking in with some internationally recognised standard. When we compare the millions of dollars that are being spent internationally every day by the large EPAs and engine manufacturers, to the limited resources of the Australian coal mining industry, it is impossible to see how we can derive a better system by developing our own standard. We must lock into a standard which is dynamic and improves with technology.



3.6 Illustration Cat 3116 engine system with ADDTRAP and dry scrubber.

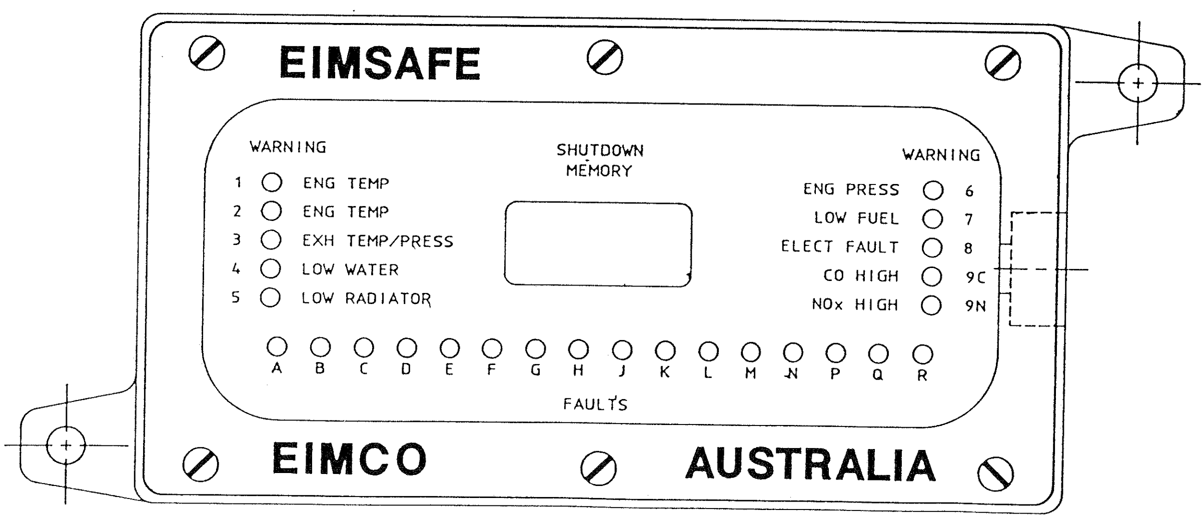
4. ELECTRONIC SHUTDOWN SYSTEM

A significant part of the project is to develop an effective electronic shutdown and machine monitoring system. The new system is know as EIMSAFE (Electronic Intergrated Machine Safety Supervisory Equipment) and is completely designed to comply with the safety requirements of AS2380, "Electrical equipment for underground coal mines". It consists of an intrinsically safe electronic logic package, various sensors and an associated power supply in a flameproof enclosure. The system is designed to run either from the standard machine's flameproof 12 volt alternator or an in built intrinsically safe back up battery.

The new system entirely replaces the existing air/oil systems found on standard EIMCO vehicles. In addition to controlling the start up and shutdown of the engine, the system displays a red LED which identifies the cause of the shutdown. In total, nine shutdown conditions are recognised.

CODE Number	Cause of shutdown
0	Manual shutdown
1	Exhaust temperature over 85°C (wet scrubber) or 140°C (Dry scrubber)
2	Coolant temperature No 1 over 100°C
3	Coolant temperature No 2 over 100°C
4	Low engine coolant level
5	Low water level in scrubber (wet scrubber) or Excess back pressure over 710 mm H_2O (Dry scrubber)
6	Low engine oil pressure Less than 40 kPa
7	Low fuel level
8	Electrical fault in wiring or power supply
9a	Optional CO monitor
9b	Optional NO_2 monitor

4.1 Table shutdown conditions



4.2 Illustration of main display board

In addition to the monitoring sensors and shutting down the engine, the system also has the following features.

4.3 Self diagnosis of wiring faults

The entire external wiring system is continually being monitored for broken wires, broken sensors and short circuit between wires and to earth. Should the system sense a fault in the wiring the machine will shut down and a code number 8 will be indicated. To aid in fault finding and the avoidance of costly down time, an additional row of LEDs have been added to indicate which sensor is at fault. All external connections are via quick push together plugs which will only engage in one way, making repairs quick and easy. All replacement plyug in cables looms for the entire system are the same and vary only in standard 1, 2, 3 or 4 metre lengths. Cables can be combined to make longer lengths. With very little training, machine operators and mechanical fitters can be trained to under take diagnostic tests and make the appropriate simple repairs to the system.

4.4 Solid state liquid level switch

A solid state (No moving parts) level switch has been developed which can be used in either, diesel fuel, hot scrubber water or engine cooling water. The sensor switches when ever the probe is removed from the measured liquid. A smoothing circuit has been added to compensate for the sloshing motion of large tanks.

4.5 Low fuel switch

Should the solid state switch sense a low fuel condition, the LED code Number 7 will light up. From this moment the operator has 10 minutes to obtain fuel or the engine will shutdown, This feature was added to minimise the down time caused by machines running out of fuel and then requiring maintenance fitters to bleed the engine fuel systems. If the machine cuts out on low fuel, the operator may restart the engine by filling the tank above the sensor.

4.6 CO and NO_2 monitors

An option for the system is to have continuous CO and NO_2 monitoring. These monitors are designed to light up their LED Code numbers 9a and 9b on the display panel should the gas reading exceed the regulation TWA. If the gas monitor senses STEL levels of a gas for more than 10 seconds, it will shut down the machine. To overcome emergency situations which require the vehicle to be driven in the case of a fire. An emergency over ride button has been added to allow the driver to drive through areas which would have CO concentrations above STEL levels.

4.7 Intrinsically safe battery back-up

Should the alternator power supply malfunction, a 6 hour back-up battery has been installed in the main control enclosure. This battery is used also during start up when the alternator is not operating. The battery is charged from the alternator whilst the engine is running and should be good under normal operation for 2-4 years. The battery is fully Intrinsically safe and can be replaced underground into the main control box which is also fully intrinsically safe..

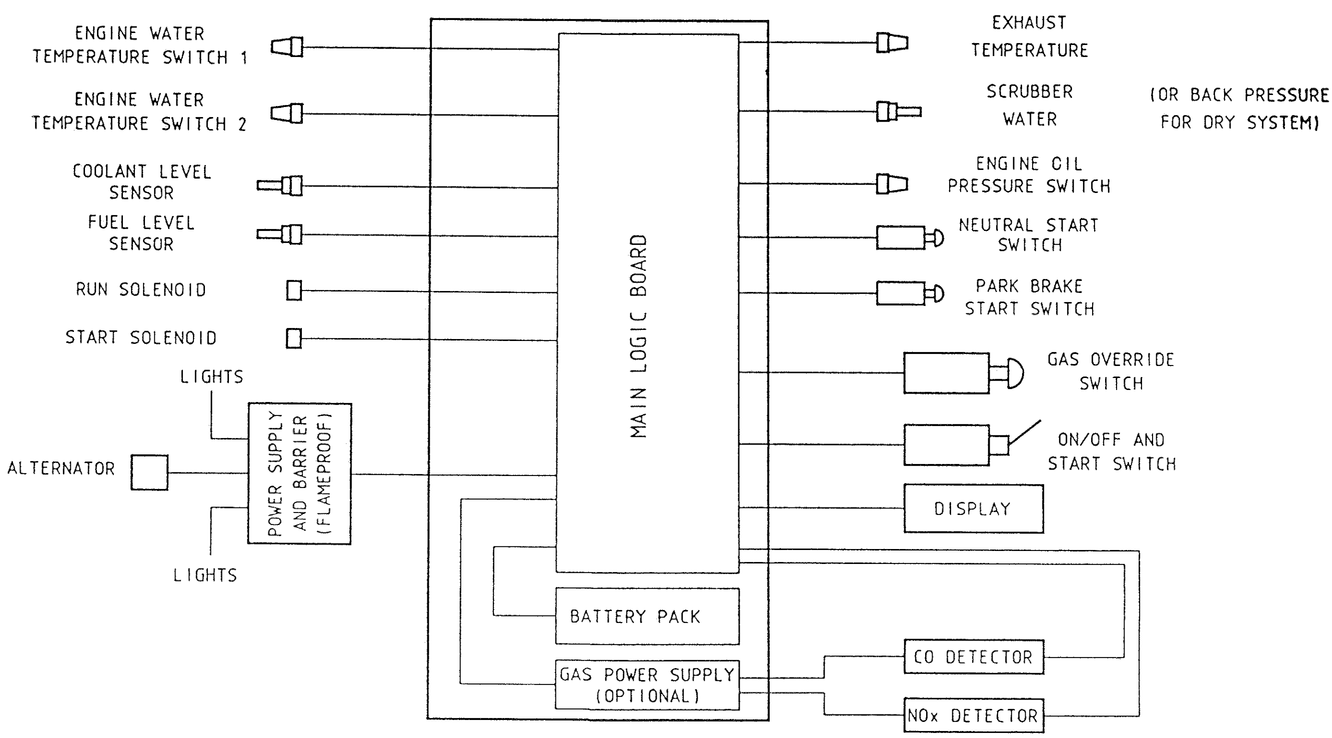
4.8 Start up logic

The starter system has been arranged such that the starter motor can not be activated unless all of the following conditions are satisfied

*All temperature sensors are below their trip points.
*There are no faults in the wiring.
*Scrubber water level is high.
*Park brake is engaged.
*Neutral is selected on the transmission.
*The manual start switch is ON.
*Fuel tank is high.
*COand NOx levels are above STEL.

4.9 Shutdown history

To aid in fault finding, a four digit liquid crystal display shows the last four shutdown codes. The display has a "first in First out (FIFO) display which at any new shutdown pushes the leftmost shutdown off the display and moves the other three to the left allowing the most recent shutdown to be displayed on the right.



4.10 Illustration of electronic EIMSAFE system

5. EXHAUST TREATMENT AND MONITORING

Diesel particulate emissions have been linked in the United States as a carcinogen. This issue will eventually put extreme pressure on the application of diesel engines in Australian under ground coal mines. Internationally, agencies such as California EPA (Environmental Protection Authority) and the USBM (United States Bureau of Mines) have legislated very restrictive limits for particulate emissions by 1994.

California:	0.075 g/kW-hr (0.1 g/bhp-hr)
USBM	0.15 mg/m^3

As yet there is no general air body requirements for particulates in Australia though testing and investigation is currently being conducted by statutory authorities and mining companies. Initial tests have indicated that the USBM limit is regularly exceeded in Australian coal mines.

Filtration techniques are being perfected overseas which will have an important impact on Australian underground mining. In many hard rock mines in Australia especially in Western Australia, it is now mandatary for vehicles to have regenerative particulate filters fitted.

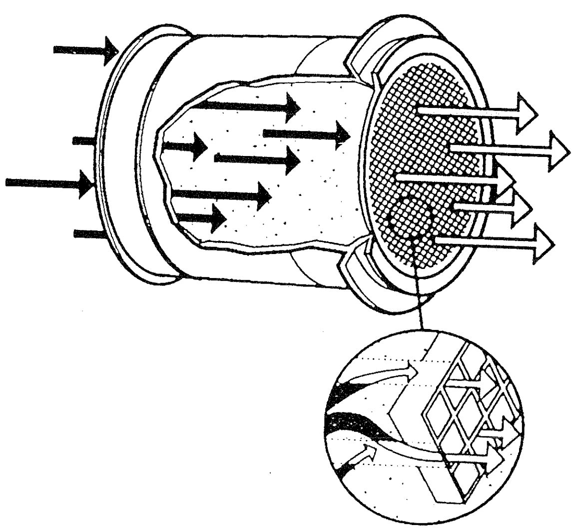
Conventional regenerative particulate filters as seen in hard rock mines are typically a ceramic lattice impregnated with a catalyst which catches and burns off up to 95% of the particulate entering the filter. These filters have to date not found an application in coal mines because they need a regeneration temperature in the exhaust of 400 ^{0} Celsius for 25 % of their operating cycle. These temperatures are impossible to achieve in a coal mining engine as the exhaust system water jacketing lowers the maximum temperature to approximately 350 ^{0} Celsius.

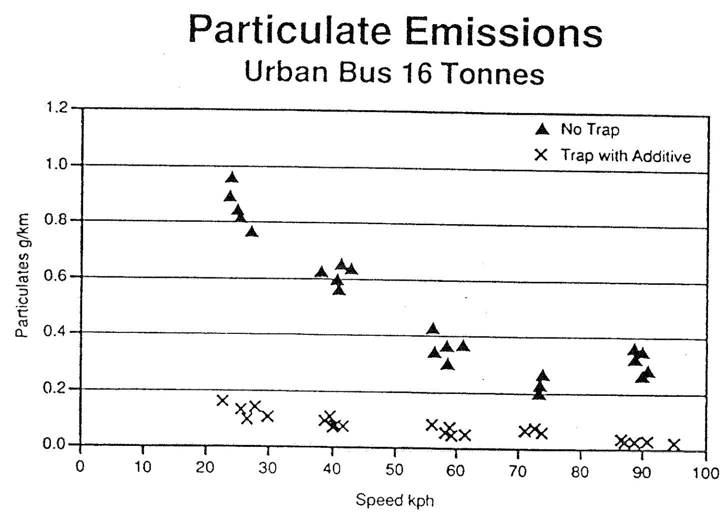
A recent innovation developed for surface buses and trucks that currently has approval for use in the US coal industry is the ADDTRAP system. This filter is again a ceramic lattice through which the exhaust passes but in this instance, the catalyst is mixed with the fuel. This filter regenerates at 250 ^{0} Celsius and therefore can find direct application in the underground coal mining arena.

The attached table 5.1 shows the results of testing on a 3306 Caterpillar engine:

	Standard fuel no trap (g/kW-hr)	Standard fuel with additive and trap (g/kW-hr)	Percentage change (%)	Significant change Yes/No
HC Hydrocarbon	1.18	0.87	-26.1	Yes
CO Carbon Monoxide	4.22	6.05	+43.2	Yes
NOx Oxides of Nitrogen	9.02	8.69	-3.7	No
Particulates	0.56	0.07	-88.1	Yes

5.1 Table of 3306 engine test results ADDTRAP system





5.2 Illustration of non water jacketed ADDTRAP

A spin off advantage of the ADDTRAP and the removal of up to 95% of the particulates is that the clean particulate free exhaust can be put through a dry scrubber system. In the past dry scrubbers have been developed but failed due to the build up of particulate on the heat exchanger fins and in the flame trap element. This created the need to remove the flame trap and heat exchanger periodically for cleaning.

EIMCO Australia is developing the flame proof dry scrubber system which incorporates the ADDTRAP filter. This package will be coupled to the Caterpillar 3116 engine running at 112 kW and the electronic shutdown system. The final package will be fitted to a standard 913 LHD and tested at the Oakey Creek mine in Queensland.

The project is using a basic 225 kW at 2700 rpm marine 3116 because it has water cooled manifolds and exhaust. As such, extensive emission and engine setting tests are being undertaken to reset the engine to 112 kW at 2200 rpm. Testing for the 3116 engine is in early stages but some trends are becoming evident. When compared to a 3306 of equivalent horsepower, CO, aldehydes and DPM is expected to be up to 50 % less and NO_2 is expected to increase, possibly even double.

6. CONCLUSIONS

An opportunity now exists to alter or modify existing diesel engine regulations to the advantage of the underground coal mining industry in Australia. Like so many risk assessments and hazard analysis, it is often found that improved safety also has financial benefits.

By directly measuring what mining personnel are breathing and indicating to them that conditions are either suitable or not, the traditional qualitative estimation process will be eliminated. This information will allow personnel to operate longer in minimal ventilation areas as the ADDTRAP will remove the tell tale smoky haze and irritating Hydrocarbons that personnel have in the past associate with bad air. Long term injury and compensation claims relating to toxic gas poisoning and the carcinogenic effects of DPM (Dry Particulate Mater) may also be avoided.

From the operational side, we will have reduced engine monitoring and operational costs. The exhaust after treatment via the ADDTRAP will extend engine life as oil related blue smoke will be converted into CO_2 by the filter. Engine gas analysis times could be extended if sufficient ventilation exists. Internal pressure from the mine management will be placed upon the maintenance people if machines are continually cutting out on high gas readings. Manufacturers will be forced to continually supply cleaner engines to remain competitive.

There are also the obvious physical advantages of the new engines. Current technology is smaller, lighter, quieter ,and more cost effective which will allow vehicle manufactures to improve on safety and operability problems such as visibility, noise, component access, vehicle performance, fuel consumption and emissions.