Diesel Emissions Evaluation for the Surface Mining Industry

David R. Leslie, P. Eng.
Senior Engineer, Fording Coal Ltd., Calgary, Alberta

Abstract

An evaluation of diesel emissions in open-pit mines was undertaken by the Surface Mining Association for Research and Technology (SMART), a group formed through the co-operation of most of the large open-pit mining companies in Canada. The impetus for the study was to address some of the issues related to diesel emissions before they become business issues with the potential to increase operating costs. One of the main issues that needed addressing was the commitment by our federal government to limit the production of "greenhouse" gases in support of the theory of "global warming". As an industry, it was important to understand and quantify the levels and trends of emissions created by diesel mining equipment. We needed to show that we use energy wisely to minimize costs and environmental effects, and it is in the mining industry's overall best interest to be as energy efficient as current technology and business economics allow.

This study has shown that, in the absence of government imposed regulations, mining equipment in open-pit mines continues to show increasing efficiency in its use of fuel, and that emissions, on a per unit moved basis, have continued to fall over time. Larger, more productive mining equipment and continued advancements in diesel engine technology will ensure that the trends of increasing energy efficiency and decreasing emission levels will continue into the future, as long as the economics of improvement are not lost due to over-regulation.

INTRODUCTION

An evaluation of diesel emissions in large open-pit mines was undertaken by the Surface Mining Association for Research and Technology (SMART), a group formed through the co-operation of most of the large open-pit mining companies in Canada. With the increasing concerns, whether real or perceived, regarding "global warming", and the commitment by our federal government to limit the production of "greenhouse" gases, it is time the mining industry understands and can quantify the levels and trends of emissions created by mining equipment. Comprehensive facts regarding emissions were needed in order to combat any potential moves by government to impose regulatory costs and constraints, which would increase mining costs. We needed to prove that as an industry we use energy wisely, and that it is in our own overall best interest to be as energy efficient as current technology and business economics allows. The goal of this study was to prove with real data that, in the absence of government imposed regulations, the mining industry as a whole continues to show more efficient use of fuel in open-pit mines, and emission levels, on a per unit moved basis, have fallen over time. The mining industry refers to not only the users of the equipment at actual mine sites, but the entire industry including all the manufacturers and suppliers that work together to accomplish the goal of increasing efficiency. The alternative to this pro-active approach is to wait for anti-development interests to convince the government that the mining industry wastes energy and emits dangerous levels of emissions, and that the only way to protect the environment is by imposing strict emission controls and increased energy costs. With larger, more productive mining equipment and continued advancements in diesel engine technology, the trend of increasing energy efficiency while decreasing emission levels will continue into the future.

<u>Purpose and Scope of Study</u>

The first phase of the study into diesel emissions from mining equipment was to gather data from the major manufacturers of diesel engines used in open-pit mining equipment in order to create an historic technical evaluation of the evolution of diesel equipment up to current technology. A comprehensive database of equipment with engine types, horsepower ratings, fuel consumption, and emission levels including Carbon Monoxide (CO), Oxides of Nitrogen (NOx), Oxides of Sulphur (SOx), Hydrocarbons (HC), other Organic Compounds (OOC), and Particulate Matter (PM) was to be created. In addition, new or emerging engine technologies would be evaluated to understand what the future holds. Underground diesel engine technology would be assessed for its application in the surface environment in collaboration with the Diesel Emissions Evaluation Program (DEEP) being carried out by eastern Canadian underground operators.

The second phase was the compilation of all the data to analyze trends in efficiency and emission levels. Technological improvements in equipment design would be summarized and evaluated on their contribution to higher efficiencies on diesel powered equipment, and reduced emissions on a per unit of material moved basis. The health and safety or irritant aspects pertaining to various emission types and levels in relation to equipment operators would be addressed in the study. With the historic and current data available, and some insight into the near future, some realistic future projections of engine efficiency and emission levels would be made. With the assistance of consultants that specialize in the field, an evaluation document would be produced that would be used as a reference for the environmental, health, and safety aspects of the mine permitting process.

BACKGROUND

Combustion Reaction Components

The diesel combustion reaction consists of hydrocarbon chains (C_xH_y) being oxidized in an explosive reaction to form carbon dioxide (CO_2) and water (H_2O). However, the reaction is not 100% efficient and the constituents are not pure. The air used to supply the oxygen (O_2) contains about 80% nitrogen (N_2) and the diesel fuel contains a small percentage of sulphur (S). The result is that trace amounts of other chemicals are formed in the reaction. The generalized reaction equation (Equation 1) shows the constituents formed from the combustion of diesel fuel and air. All of the trace constituents are of concern to the environment or can pose a health risk in higher concentrations.

1) $$C_xH_y(S_z) + (O_2 + N_2) \Rightarrow CO_2 + H_2O + (O_2 + N_2) + \{NOx + HC + OOC + C + CO + SOx\}$$
Combustion Reaction $\Rightarrow$ Major Constituents + { Trace Constituents }

Of the major constituents of the reaction, CO_2 is a concern as a potential "greenhouse" gas and a theoretical contributor to "global warming". Since it is an integral part of the reaction, the way to reduce output is to increase the efficiency of the engine and reduce fuel consumption. CO_2 is produced at rate of approximately 2.73 kg/litre of fuel (JAQUES, 1992). There are no health risks or direct environmental risks from the production of CO_2. The trace constituents are of more concern to the environment and health. The production of SOx is directly related to the amount of sulphur in the diesel fuel. In certain regions, SOx emissions are significant and can contribute to environmental concerns related to the formation of acidic compounds in the atmosphere. NOx is produced in the high temperature, high-pressure diesel fuel combustion chamber since there is excess oxygen available to combine with nitrogen during the reaction. Oxides of nitrogen can react in the atmosphere to form acidic compounds as well as low level ozone, a major component of smog. Ozone is a lung irritant and can cause serious health effects and breathing difficulty in higher concentrations. CO is not formed in large quantities due to the excess amount of oxygen available during combustion, and is generally not the concern it is in gasoline powered engines. The other trace constituents are the result of incomplete combustion. Unburned hydrocarbons or the products of partial combustion account for the HC, OOC, and free carbon (C) components of the trace constituents. These compounds contribute to the formation of smog after further reactions in the presence of sunlight, and can pose health risks as concentrations rise. Hundreds of separate OOC can be formed when the combustion reaction is not complete. These OOC are reported as the soluble organic fraction (SOF), and the volatile organic fraction (VOF). The trace constituent products also account for the majority of the particulate matter (PM) in diesel exhaust. The visible portion of PM, the black smoke, is larger carbon particles that are formed under acceleration and heavy load due to insufficient air or low combustion temperatures. Electronic engine controls can minimize the formation of black smoke such that it is rarely visible. The majority of the PM is too small to be seen, and is composed of very fine carbon particles, often less than 1 micron in diameter. These carbon particles can have many other exhaust compounds, formed from HC, OOC, and SOx, adsorbed on their surfaces (NAUSS, 1997). There are also secondary transformations of NOx and SOx into nitrate and sulphate particulate in the atmosphere. When PM are less than 10 microns in diameter, they are respirable and a lung irritant. As the particles decrease in size to less than a 2.5 microns, they can be deposited deep in the lungs where there is potential to impair function and cause damage, or increase the risk of future serious illness.

Diesel Engine Development

Engine manufacturers have been driven over the years by the need to reduce the operating costs of the engines they produce. This has been accomplished by producing engines that require less maintenance time and burn less fuel. In an unregulated environment, the drive to reduce emissions was not an issue except for the visible components of particulate matter, or black smoke. Even without a focussed effort, most emission component levels were reduced with this strategy. By producing engines that are more efficient, the manufacturers reduced products of incomplete combustion including CO, HC, and OOC, as well as CO_2 since less fuel was consumed. The only component of the emissions that did show any potential for increase was NOx, since its formation occurs as temperatures rise in a combustion chamber.

In the United States, the Environmental Protection Agency (EPA) has used legislation to force diesel engine manufacturers to limit emissions with a primary focus on the reduction of NOx. This has been accomplished through a phased approach that started with smaller horsepower engines for highway applications. The volume of engines produced for those applications was sufficient to bear the research and development costs without huge increases in the cost of the engines. The engines used in off-highway applications, and in particular the large horsepower engines for mining application, have benefited from this strategy of having a phased approach to implementation. Sufficient time is required to implement changes to engine technology, especially where engine volumes are low. The economics of upgrading equipment would be seriously jeopardized if the cost of new engine technology pushed the price of emission regulated engines to unrealistic levels. The benefits of purchasing new larger equipment are that they are more cost effective in mining operations, and the new engines use fuel more efficiently and produce fewer emissions.

Upgrading to larger, more efficient and productive equipment has played a major role in the continued reduction of emissions from mining operations. Increased size and efficiency produce lower fuel consumption and fewer emissions for the same amount of work performed. Even before the EPA regulations were introduced, more efficient diesel engines were being produced for the larger equipment, and overall emissions on a unit moved basis were falling. The EPA regulations for typical large mining equipment sized engines (> 560 kW or 750 hp), which Canada intends to follow under a memorandum of understanding, are shown in Table 1.

TABLE 1: <u>EPA Emission Standards for Non-Road Engines Greater than 560 kW</u> (LEVELTON, 1999)

Tier	Model Years	Emission Standards g/kW-hr (g/bhp-hr)										Emissions Warranty Period**
		NOx		HC		NMHC+NOx		CO		PM		
		g/kW-hr	g/bhp-hr	g/kW-hr	g/bhp-hr	g/kW-hr	g/bhp-hr	g/kW-hr	g/bhp-hr	g/kW-hr	g/bhp-hr	
Actual Unregulated*	Pre-1996	14.3	10.7	0.4	0.3	14.8	11.0	1.7	1.3	0.17	0.13	
Actual Pre-Tier 1*	1996-2000	11.3	8.5	0.3	0.3	11.7	8.7	0.8	0.6	0.15	0.11	
Tier 1	2000+	9.2	6.9	1.3	1.0			11.4	8.5	0.54	0.40	5yrs/3000 hr.
Tier 2	2006+					6.4	4.8	3.5	2.6	0.20	0.15	5yrs/3000 hr.
SOP Long-term goal		2.0	1.5							0.07	0.05	

* Approximate values based on averaged manufacturers (CAT) data

** Tier 1 and Tier 2 engines must comply over "Useful Life" of 10yrs/8000 hr.

Diesel engines greater than 450 kW (600 hp) have a wide range of applications in large open-pit mining operations. Three manufacturers, Caterpillar (46%), Detroit Diesel (27%), and Cummins (26%), supply 99% of the U.S. market, which constitutes only 3% of the total non-road market (EPA, 1998). Large haul trucks, dozers, loaders, and diesel hydraulic shovels typically are in the greater than 560 kW (750 hp) category which constitutes only 0.7% of the total non-road market. During the years from 1991 to 1995, Generator Sets accounted for over 70% of the average annual sales in the greater than 560 kW (750 hp) category, where off-highway trucks accounted for 13%, loaders accounted for 0.7%, and crawlers accounted for 8% (EPA, 1998). The fraction of these total engine sales used in surface mining operations would be considerably smaller. The Canadian breakdown of engine sales is expected to be similar in that there is a very small percentage of the total non-road diesel engines involved in surface mining activities. As well, surface mining operations generally are in sparsely populated areas of the country where the production of NOx and the formation of smog is not the environmental issue that it is in urban centres.

Emission Reducing Strategies

From the time all large diesel engines were naturally aspirated and mechanically injected, numerous improvements have been made to increase horsepower and reduce fuel consumption. At rated power, about 30% of the energy from a diesel engine is lost through the exhaust (EPA, 1998). Turbocharging utilizes some of that lost energy to boost air intake pressure, which increases engine efficiency. Aftercoolers, both air-to-air and air-to-water, were then added to increase the air density going back to the engine, which further increased power ratings. Aftercoolers have the added benefit of reducing NOx production by reducing air intake temperature (EPA, 1998). Constant improvements in combustion optimization, including injection timing, combustion chamber geometry, and increasing air intake turbulence or swirl, have all contributed to reduced output of HC, PM, and lowering fuel consumption. Full authority engine electronic management combined with very high-pressure fuel injection can allow shaped or multiple injections at optimized timing to reduce NOx production without increasing PM. Exhaust gas recirculation is a recent strategy designed to reduce NOx production but some problems still need to be addressed. Introducing exhaust and PM back into the air intake system and combustion chamber can lead to increased turbocharger and engine wear. Deposits on the air intake system can also reduce the efficiency of aftercoolers (EPA, 1998).

At this point, exhaust gas after-treatment technologies to remove HC and PM are not deemed necessary to meet EPA regulations. Oxidation catalysts in conjunction with low sulphur diesel (< 0.05% S) to remove HC and CO, which are already in very low concentrations, can have the unwanted reactions of creating SO_3 from SO_2, and NO_2 from NO (EPA, 1998). Particulate traps definitely show some promise for diesel equipment operating in confined spaces such as underground mines. These technologies are currently not economically viable for the large horsepower engines used in surface mining operations, nor are they necessary for air quality.

STUDY RESULTS

Data Gathering

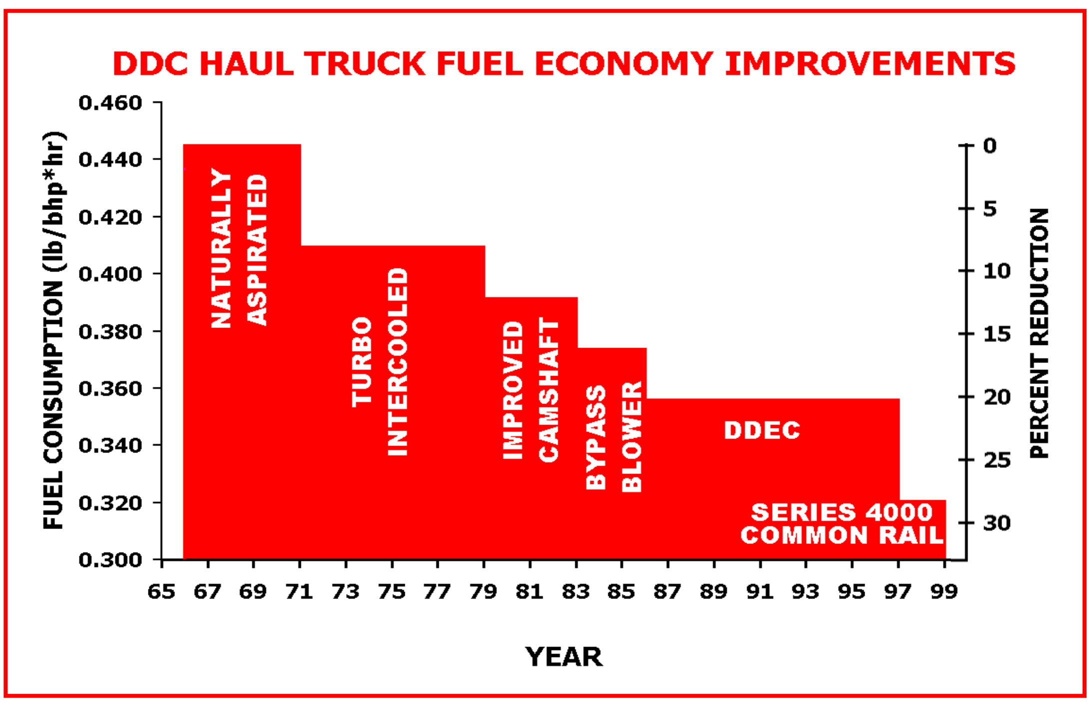
Visits were made to the manufacturing facilities of Detroit Diesel Corp. (DDC), Caterpillar Inc. (CAT), and Cummins Engine Company Inc. (Cummins) in June 1998. CAT is a vertically integrated company; it is the only manufacturer of large non-road diesel engines that also builds the equipment they power. Cummins and DDC only manufacture engines, which they then supply to many different original equipment manufacturers. Information on horsepower growth, fuel consumption and exhaust emissions was requested to detail the evolution of engine product lines used in large surface mining equipment. All of the companies responded with some information, but the amount of information available seemed limited. Aside from some historical fuel efficiency and smoke index numbers, and current technology emission data, there seemed to be little to share. In an unregulated environment, there was no apparent need to perform the complicated and expensive testing required to collect emissions data, and there was no agreement on standard testing procedures. The Tier 1 EPA legislation (59 FR 31306) for non-road diesel engines greater than 37 kW (50 hp) was set in 1994 with compliance required starting in 1996 (NERA, 1997). Similar emission levels were required from heavy-duty highway engines in 1990. With this lead-time before the larger horsepower engines had to comply, it was evident that new technology would have to be employed to meet the standards, and there was no need to conduct rigorous emissions testing. In some cases, new test cells had to be constructed before these large engines could physically be accommodated for testing. DDC and Cummins decided that technology dictated totally new engine designs utilizing new technology proven with their heavy-duty highway engines. DDC has dropped its two-cycle line for equipment to be certified, and introduced the S4000 series. Cummins has introduced the QSK60 series. CAT has made changes to their existing 3500 series engines with advances to the electronic controls and injection. All the manufacturers are confident that these current engine series can be modified to comply with the Tier 1 EPA regulations that come into effect in the year 2000.

The information gathered was reviewed by Levelton Engineering Ltd. to ensure that any conclusions derived from the data were done in an appropriate manner.

<u>Engine Manufacturers Data</u>

Historical data from DDC on fuel consumption for the two-stroke 16V-149 engine, from 1966 through to the introduction of the four-stroke 16V-S4000 engine, is shown in Figure 1. The 16V-149 engine has been a workhorse in the mining industry, especially in powering haulage trucks. The major engine modifications responsible for the drop in fuel consumption are noted. For clarification, DDEC is full authority electronic control and Common Rail is a very high-pressure electronically controlled fuel injection system. Fuel consumption on a per horsepower basis dropped over 20% from 1966 to 1986 in this series of engine, and with the introduction of the S4000 series of engines a further drop of more than 9% was achieved. From 1966 to 1998, a drop in fuel consumption per horsepower of over 27% was achieved in unregulated engines. Emissions of CO_2 are directly related to fuel consumption, so there has been a corresponding reduction on a per horsepower basis. The 16V-149 at 2200 hp is one of the engines currently used to power mine haulage trucks with a capacity of up to 218 tonnes (240 ton).

FIGURE 1: <u>Fuel Consumption Improvements with the DDC 16V-149 Engine Series</u> (DDC, 1998)



As can be seen in Figure 2, maximum rated horsepower doubled from 1966 through to 1989. The introduction of the S4000 series saw another jump of 22% in maximum rated horsepower in a similar sized engine. The horsepower increases correspond with the fuel consumption improvements due to technological improvements in the engines. The series S4000 with a maximum of 2700 horsepower is now available to power the next generation of haul trucks in the 290 + tonne range (320 + ton).

FIGURE 2: <u>Horsepower Growth with the 16V-149 Engine Series</u> (DDC, 1998)

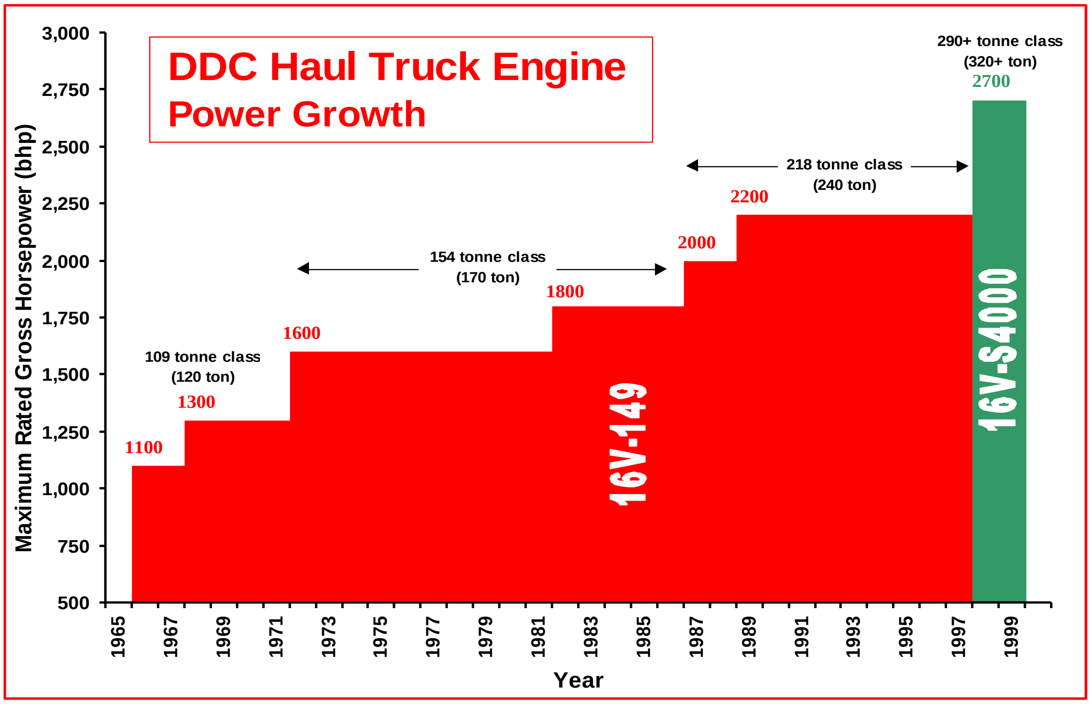


FIGURE 3: <u>Fuel Consumption Improvements per tonne of Truck Capacity</u>

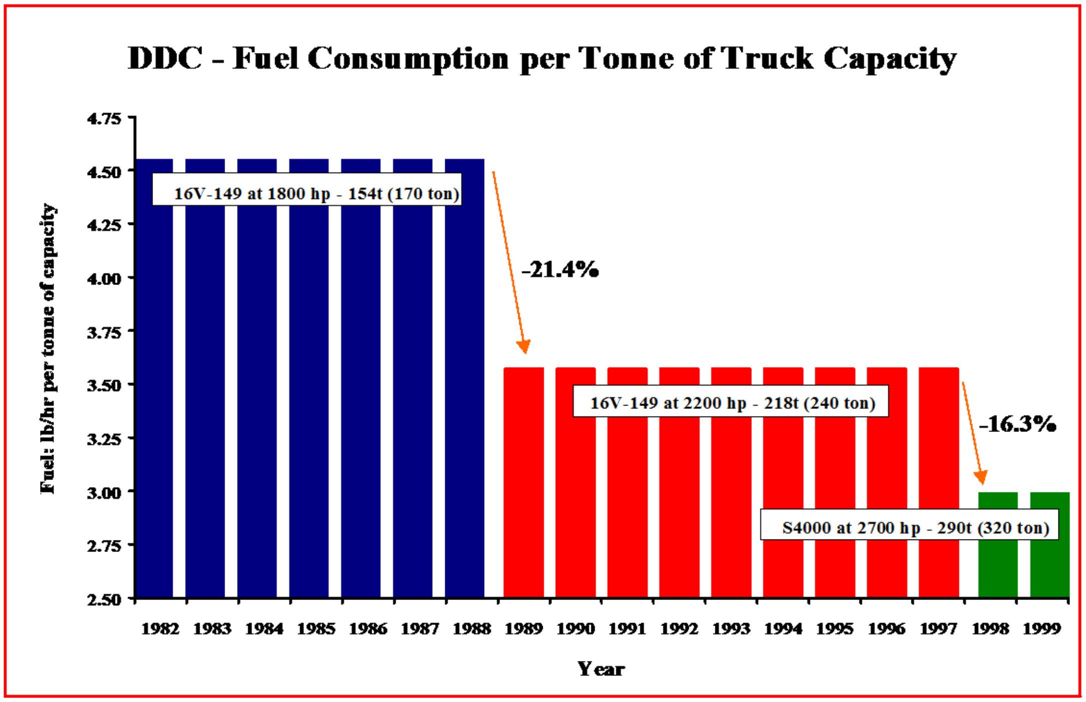


Figure 3 shows the dramatic decrease in fuel consumption by moving to larger more productive equipment, and taking advantage of more efficient engines. Since the production of CO_2 is directly proportional to fuel consumption, the amount of CO_2 released into the atmosphere decreases by 21.4% when moving to a 218 tonne (240 ton) capacity haul truck, and another 16.3% to the 290 tonne (320 ton) truck. The total decrease per tonne of truck capacity could amount to over 34% with upgrades to equipment, in a totally unregulated environment. These decreases were driven by the economics of larger, more productive equipment coupled with more efficient and cost-effective engines. In addition, improved engine efficiency is responsible for reductions in HC, CO, and OOC emissions.

Data supplied from CAT was tailored to focus on haul trucks since it could show not only the engine evolution in terms of emissions and fuel efficiency, but also the equipment evolution in terms of size and productivity. Table 2 shows CAT data from four different sized haul trucks that all use 3500 series engines in varying configurations. The technology covered is from the previous generation Electronic Unit Injection (EUI) engines to the current B-series engines that will, after final modifications, meet and exceed Tier 1 regulations in the year 2000. Tier 2 regulations are shown as the next goalpost for the year 2006. CAT believed it could meet Tier 1 regulations using the existing 3500 series engines with some modifications to electronics and injection timing. The EUI engines were then tested to establish base levels for comparing different emission reducing strategies. CAT will aim at being 15 to 20% lower than Tier 1 NOx emission levels in order to account for any variance from engine to engine. Emissions of HC, CO, and PM are already well below Tier 1 regulated levels, so the effort will focus on keeping the current emission levels from rising significantly.

TABLE 2: <u>CAT Haul Truck Emission Data</u> (CAT, 1998)

Caterpillar Data (98/10/30) ISO 8178; Type C1 8-Mode cycle data (weighted average)

CAT Machine: 777 (100 ton)
Engine: 3508 at a SCAC temp. of 56 degrees C.

Machine Model:	**777C**	**777D**	**777D**	**777X**
Engine Model:	EUI	B-Series	Tier I Reg.*	Tier II Reg.**
Rated Power (HP):	920	1000	1000	TBA
NOx (gram/HP-Hr):	10.06	7.48	6.90	4.80
CO (gram/HP-Hr):	1.65	0.53	8.50	2.60
HC (gram/HP-Hr):	0.28	0.24	1.00	N/A
PM (gram/HP-Hr):	0.13	0.14	0.40	0.15
*****BSFC (gram/HP-Hr):**	164.6	156.2	TBA	TBA
Maximum Payload (t):	86.2	91.0	91.0	91.0

CAT Machine: 785 (150 ton)
Engine: 3512 at a SCAC temp. of 56 degrees C.

Machine Model:	**785B**	**785C**	**785C**	**785X**
Engine Model:	EUI	B-Series	Tier I Reg.*	Tier II Reg.**
Rated Power (HP):	1380	1447	1447	TBA
NOx (gram/HP-Hr):	10.81	8.70	6.90	4.80
CO (gram/HP-Hr):	1.70	0.63	8.50	2.60
HC (gram/HP-Hr):	0.26	0.23	1.00	N/A
PM (gram/HP-Hr):	0.12	0.10	0.40	0.15
*****BSFC (gram/HP-Hr):**	155.9	151.8	TBA	TBA
Maximum Payload (t):	136.0	136.0	136.0	136.0

CAT Machine: 789 (195 ton)
Engine: 3516 at a SCAC temp. of 56 degrees C.

Machine Model:	**789B**	**789C**	**789C**	**789X**
Engine Model:	EUI	B-Series	Tier I Reg.*	Tier II Reg.**
Rated Power (HP):	1800	1904	1904	TBA
NOx (gram/HP-Hr):	10.85	9.61	6.90	4.80
CO (gram/HP-Hr):	1.04	0.55	8.50	2.60
HC (gram/HP-Hr):	0.28	0.25	1.00	N/A
PM (gram/HP-Hr):	0.14	0.08	0.40	0.15
*****BSFC (gram/HP-Hr):**	161.2	151.2	TBA	TBA
Maximum Payload (t):	177.0	177.0	177.0	177.0

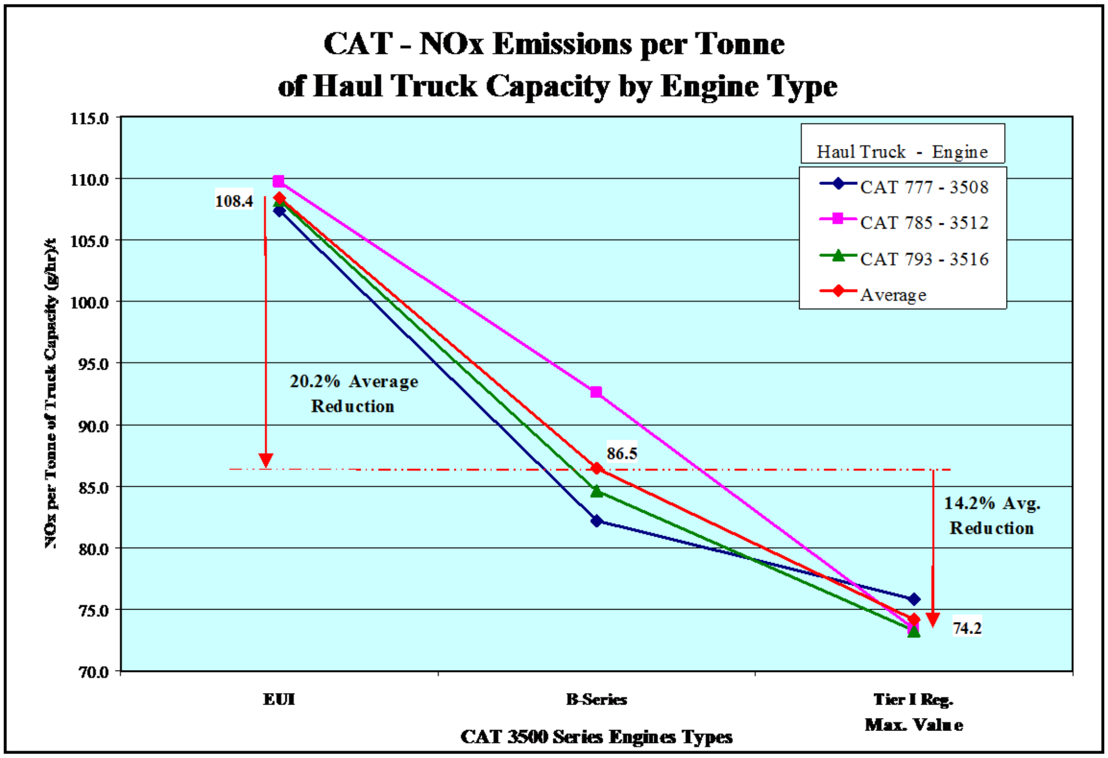
CAT Machine: 793 (240 ton)
Engine: 3516 at a SCAC temp. of 65 degrees C.

Machine Model:	**793B**	**793C**	**793C**	**793X**
Engine Model:	EUI	B-Series	Tier I Reg.*	Tier II Reg.**
Rated Power (HP):	2160	2300	2315	TBA
NOx (gram/HP-Hr):	10.92	8.02	6.90	4.80
CO (gram/HP-Hr):	0.81	0.69	8.50	2.60
HC (gram/HP-Hr):	0.48	0.27	1.00	N/A
PM (gram/HP-Hr):	0.14	0.12	0.40	0.15
*****BSFC (gram/HP-Hr):**	160.6	160.9	TBA	TBA
Maximum Payload (t):	218.0	218.0	218.0	218.0

***** Tier I and Tier II Regulation emission numbers are maximum permissible values. Actual CO, HC, PM values will be similar to B-series values.
****** Tier II changes the convention by combining NOx and HC, therefore the Tier II value will represent NOx + HC.
******* BSFC is associated with rated point.

Figure 4 shows the reduction in NOx emissions per tonne of truck capacity with the advances to engine design. The economics of acquiring new larger, more productive equipment, with improved engines that produce fewer emissions, is good for business as well as the environment. When the emissions data is tied to a truckload in the units of tonnes of material capacity, it is evident that emissions of NOx are reduced dramatically when equipment is upgraded.

FIGURE 4: CAT NOx Emission Data per Tonne of Truck Capacity by Engine Type



CONCLUSIONS

The surface mining industry has done a good job over the years in using energy wisely. The operating cost savings when moving to larger, more productive equipment produce the added benefits of reduced fuel consumption and fewer diesel emissions on a unit moved basis. Fuel efficiency and CO_2 emissions have been reduced nearly 30% on a per horsepower basis over the last 30 years in a totally unregulated market. The marketplace drove the manufacturers to produce more fuel efficient and reliable diesel engines to power larger, more productive equipment. With efficiency comes reduced fuel consumption and reduced emissions of CO_2, CO, HC, and OOC.

Emission reductions of PM and NOx are also of concern, and engine manufacturers have met the challenge to reduce these components of diesel emissions while not allowing the other components to increase. Further reductions are regulated by the EPA with the high horsepower engines meeting Tier 1 targets in 2000. These non-road regulations have been phased in over several years starting with the higher volume engines having highway heavy-duty truck engine counterparts. Canada, through a memorandum of understanding, intends to follow the EPA regulations by requiring new engines for new equipment to be EPA certified before being imported. The concern is that the push to reduce NOx and PM will be at the expense of diesel engine efficiency, and that regulations will not allow time for technological advancements in engine design. Compliance may be accomplished through additional air cooling fans and other parasitics that will drive up fuel consumption and operating costs.

New capital is only employed when the economics are positive on a time-value basis. If the cost of new diesel engines is too high due to onerous emission standards, then upgrades to become more efficient will not occur. The economic incentive must remain for companies to strive for increased productivity, and fewer emissions per tonne of material moved in surface mining.

REFERENCES

CAT, 1998
Personal Communication and Statistical Data. Caterpillar Inc., Peoria, IL.

CUMMINS, 1998
Personal Communication. Cummins Engine Company Inc., Columbus, IN.

DDC, 1998
Personal Communication and Statistical Data. Detroit Diesel Corp., Detroit, MI.

EPA, 1998.
Final Regulatory Impact Analysis: Control of Emissions from Non-road Diesel Engines.
U.S. Environmental Protection Agency, Office of Mobile Sources. Report: EPA420-R-98-016, August. 127p.

JAQUES, A., 1992
Canada's Greenhouse Gas Emissions: Estimates for 1990. Environment Canada, Report EPS 5/AP/4

LEVELTON, 1999
Personal Communication: Review of Emission and other Characteristics for Heavy Duty Diesel Engines. Levelton Engineering Ltd., Calgary, AB

NAUSS, K., 1997
Diesel Exhaust: A Critical Analysis of Emissions, Exposure, and Health Effects.
Summary of HEI Diesel Working Group Special Report, Health Effects Institute, Cambridge, MA.

NERA, 1997.
Economic Evaluation of Regulations on Exhaust Emissions from Large Non-road, Compression Ignition Engines. National Economic Research Associates. Cambridge, MA. 38p.