Curtailment of Contribution of Light-Duty and Medium-Duty Diesel-Powered Vehicles to Exposure of Underground Miners to DPM: Burden, Challenges, and Opportunities

by

Aleksandar D. Bugarski

National Institute for Occupational Safety and Health (NIOSH)

Pittsburgh Mining Research Division (PMRD)

The Mine Safety and Health Administration (MSHA)/

National Institute for Occupational Safety and Health (NIOSH)

Diesel Health Effects Partnership Meeting

Washington D.C.

January 23, 2019

Ever since introduction of the DPM regulations [30 CFR Part 72, 30 CFR Part 57], the focus was on reducing contributions from heavy-duty (HD) vehicles.

- The priority was given to HD vehicles for the following reasons:
  - high output engine operated over HD cycles;
  - high utilization factors;
  - role in the development and production process…

- The medium-duty (MD) and light-duty (LD) vehicles were traditionally considered as a secondary contributors:
  - less powerful engines operated over MD and LD cycles;
  - operated in better ventilated areas…

- Over time, relative contribution from MD and LD vehicles became more substantial:
  - efforts to control contribution of HD vehicles were productive;
  - travel distances in the mines grew over the time;
  - utilization of MD and LD vehicles is high as ever…

Several working definitions of HD and LD vehicles are currently used in underground mining industries.

- In the case of underground coal mining fleets, the MSHA clearly differentiate between HD and LD equipment [30 CRF 75.1908]:
  - HD diesel-powered equipment is:
    - equipment that cuts or moves rock or coal;
    - equipment that performs drilling or bolting functions;
    - equipment that moves longwall components;
    - self-propelled diesel fuel transportation units and self-propelled lube units; or
    - machines used to transport portable diesel fuel transportation units or portable lube units.
  - LD diesel-powered equipment is any other equipment that does not meet the aforementioned criteria.

- In the case of underground metal/nonmetal mining, the delineation between HD and LD vehicles is fuzzy:
  - engine output;
  - vehicle categories; and less frequently
  - duty-cycle…

For underground coal mining, the diesel particulate matter (DPM) emission standards [30 CFR Part 72] for the HD diesel-powered equipment are more stringent than those that apply to LD equipment.

- The MSHA regulations [30 CFR Part 7, Subpart E] require use of MSHA-approved diesel engines in underground coal mines in the U.S.A.

- The contribution of diesel-powered vehicles to personal exposures of underground coal miners to DPM is indirectly limited by limiting particulate matter emissions to:
  - 2.5 grams per hour of DPM for permissible diesel-powered equipment [30 CFR 72.500];
  - 2.5 grams per hour of DPM for non-permissible diesel-powered HD equipment [30 CFR 72.501];
  - 5.0 grams per hour of DPM for non-permissible diesel-powered LD equipment [30 CFR 72.502].

- Since the regulations do not require monitoring personal exposure of underground coal miners to DPM, the data is not available to verify the hypothetical impact of those prescribed control strategies.

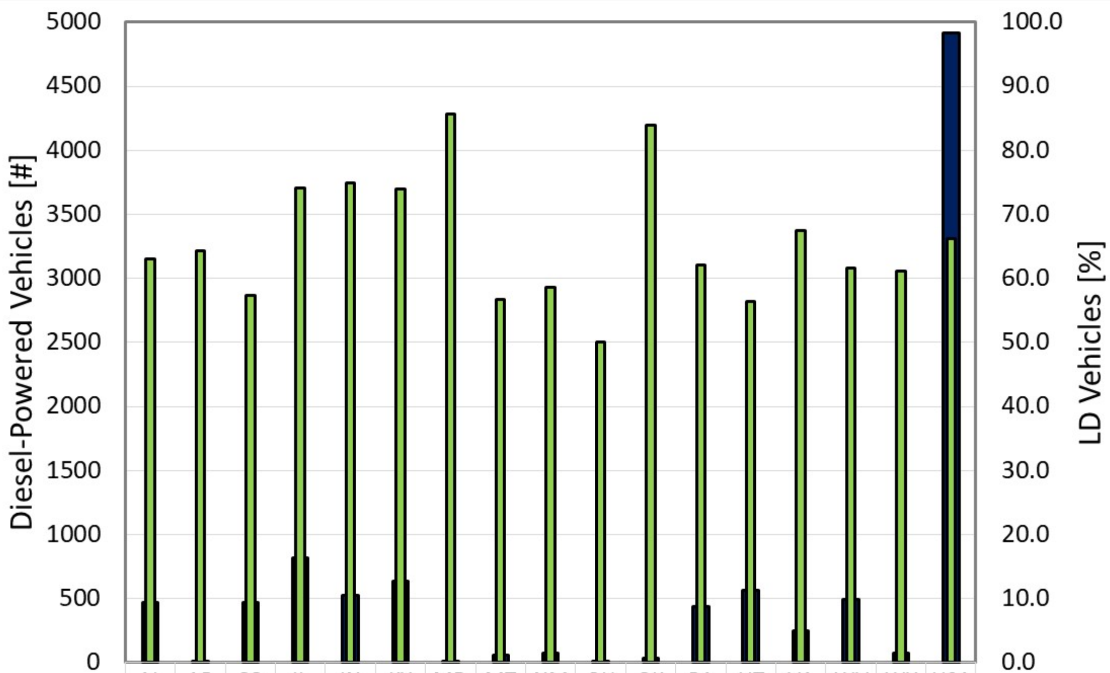
The DPM standards for underground metal/nonmetal mining diesel-powered equipment are more stringent for engines [30 CFR 57.5067] with power outputs between 37 kW (50 hp) and 560 kW (700 hp) than for sub-37 kW (50 hp) output engines.

- The MSHA regulations [30 CFR 57.5067] require use of diesel engines that are:
  - approved by MSHA under 30 CFR Part 7 subpart E or 30 CFR Part 36; or
  - approved by EPA - listed in Table 57.5067-1.
- Those emission standards are dated and trailing behind current Environmental Protection Administration (EPA) emission standards [EPA 2016].

	EPA category	PM limit
40 CFR 86.094-8(a)(1)(i)(A)(2)	light duty vehicle	0.1 g/mile
40 CFR 86.094-9(a)(1)(i)(A)(2)	light duty truck	0.1 g/mile
40 CFR 86.094-11(a)(1)(iv)(B)	heavy duty highway engine	0.1 g/bhp-hr
40 CFR 89.112(a)	nonroad (tier, power range)	varies by power range:
	tier 1 kW<8 (hp<11)	1.0 g/kW-hr (0.75 g/bhp-hr)
	tier 1 8<kW<19 (11<hp<25)	0.80 g/kW-hr (0.60 g/bhp-hr)
	tier 1 19<kW<37 (25<hp<50)	0.80 g/kW-hr (0.60 g/bhp-hr)
	tier 2 37<kW<75 (50<hp<100)	0.40 g/kW-hr (0.30 g/bhp-hr)
	tier 2 75<kW<130 (100<hp<175)	0.30 g/kW-hr (0.22 g/bhp-hr)
	tier 1 130<kW<225 (175<hp<300)	0.54 g/kW-hr (0.40 g/bhp-hr)
	tier 1 225<kW<450 (300<hp<600)	0.54 g/kW-hr (0.40 g/bhp-hr)
	tier 1 450<kW<560 (600<hp<750)	0.54 g/kW-hr (0.40 g/bhp-hr)
	tier 1 kW>560 (hp>750)	0.54 g/kW-hr (0.40 g/bhp-hr)

The analysis of the inventory of diesel-powered vehicles [30 CFR 72.520, MSHA 2018a] in underground coal mines indicate that the LD vehicles dominate those fleets.

- Total of 4918 diesel-powered vehicles are operated in 157 mines:
  - Permissible HD: 318 (6.5%);
  - Non-permissible HD: 1270 (25.8%);
  - **Non-permissible LD: 3261 (66.3%);**
  - Fire fighting and ambulance equipment: 17 (0.3%);
  - Unknown: 52 (1.1 %).



	AL	AR	CO	IL	IN	KY	MD	MT	NM	OH	OK	PA	UT	VA	WV	WY	USA
Total	466	14	467	815	523	638	14	60	70	6	31	440	562	246	494	72	4918
LD [%]	63.1	64.3	57.4	74.1	75.0	74.0	85.7	56.7	58.6	50.0	83.9	62.0	56.4	67.5	61.5	61.1	66.3

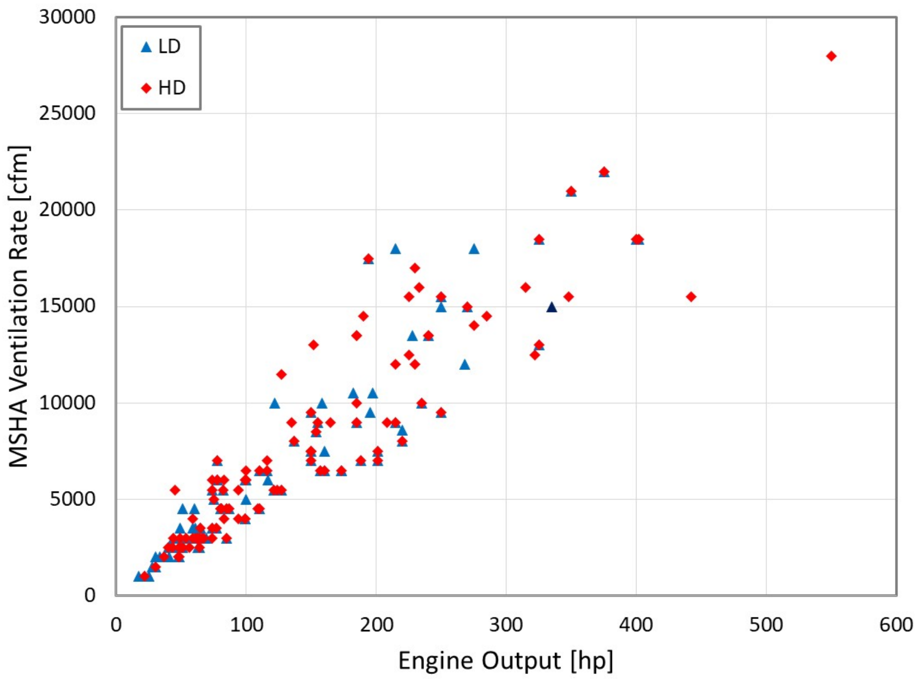
State/Nationwide (USA)

Underground coal mines are using wide variety of engines in LD diesel-powered equipment [MSHA 2018a].

- 103 different models of MSHA-approved engines (07-ENAXXXXXX and 7E-BXXX) power 3261 LD vehicles .

- A broad spectrum of power outputs:
  - kW < 19 (hp < 25) (4.9 %),
  - 19 ≤ kW < 56 (25 ≤ hp < 75) (34.0 %),
  - 56 ≤ kW < 130 (75 ≤ hp < 175) (34.0 %),
  - 130 ≤ kW < 225 (175 ≤ hp < 302) (20.4 %), and
  - 225 ≤ kW < 450 (302 ≤ hp < 603) (6.8 %).

- Apparently, the LD vehicles in underground coal mines in the U.S. are not necessarily powered by low output engines, but might be operated over LD duty-cycle.



The LD vehicles represent large fractions of underground metal and nonmetal diesel fleets.

- The inventories of diesel-powered vehicles used in underground metal and nonmetal operations are not publically available.

- The limited survey that we performed at several mines across the spectrum of the commodities (metal, nonmetal, stone) revealed that the differentiation between HD and LD vehicles is fuzzy and subject of personal interpretation:
  - HD: Haulage trucks, LHD vehicles, drills, fuel/lube truck…
  - MD: (treated sometimes as HD or sometimes as LD): shotcrete truck, ENFO loader, scissor truck, grader, scaler, welding truck…
  - LD: personnel carriers, side-by-sides, utility vehicles, tractors, 400 hp pickup trucks…

- The LD and MD vehicles appear to make 60 or more percent of the examined fleets.

Several pathways are available to underground mining industry to address contribution of diesel-powered vehicles to exposure of underground miners to DPM:

- Acquisition of new or re-powering existing vehicles with advanced engine and exhaust aftertreatment technologies;
- Retrofitting existing (EPA Tier 2 and Tier 3) engines with viable DPF systems;
- Substituting petroleum based fuels with cleaner burning fuels;
- Improving quality of existing and acquisition of new environmental enclosures and filtration/pressurization systems for MD and LD vehicles;
- Substitution of selected vehicles with electric-powered vehicles…

Acquisition of New or Re-powering Existing LD and MD Vehicles with Advanced Engines

It appears that there is plenty of potential to reduce engine emissions from aging coal diesel-powered fleets [MSHA 2018a].

#	MSHA Approval Number	Make and Model, kW (hp) @ rpm	DPM [g/kW-hr / g/hp-hr]	EPA Standards [g/kW-hr / g/hp-hr]	DPM [g/h]	Number [#]
1	07-ENA040004	Deutz BF4L2011, 58 (78) @ 2800	0.11 / 0.08	0.40 / 0.30	3.7	388
2	07-ENA040002	Deutz BF4M2012, 75 (100) @ 2500	0.11 / 0.08	0.40 / 0.30	4.51	314
3	07-ENA040015-1	ISB-215, 160 (215) @ 2900	0.20 / 0.15	0.20 / 0.15	15.56	263
4	07-ENA050001	Mitsubishi S4S-DT, 57 (77) @ 2500	0.24 / 0.18	0.40 / 0.30	6.91	244
5	07-ENA030001	Mitsubishi s4s, 47 (63) @ 2500	0.35 / 0.26	0.40 / 0.30	7.65	171
6	07-ENA040012	Deutz F4L2011, 48 (64) @ 2800	0.27 / 0.20	0.40 / 0.30	6.52	155
7	07-ENA040011	Deutz F3L 2011 (D 2011L03i), 36 (48) @ 2800	0.27 / 0.20	0.60 / 0.45	4.89	130
8	07-ENA070006	Cummins QSB4.5, 82 (110) @ 2500	0.24 / 0.18	0.30 / 0.22	11.1	125
9	07-ENA100009	Cummins ISB 6.7, 164 (220) @ 2900	0.12 / 0.09	0.20 / 0.15	9.22	115
10	07-ENA040004-1	Deutz BF4L2011, 58 (78) @ 2800	0.11 / 0.08	0.40 / 0.30	3.7	75
19	07-ENA140005	Kubota D902-E4, 16 (22) @ 3200	0.54 / 0.40	0.40 / 0.30	4.25	40
24	07-ENA140006	Kubota D1105-E4, 19 (25) @ 3000	0.15 / 0.11	0.40 / 0.30	1.42	33

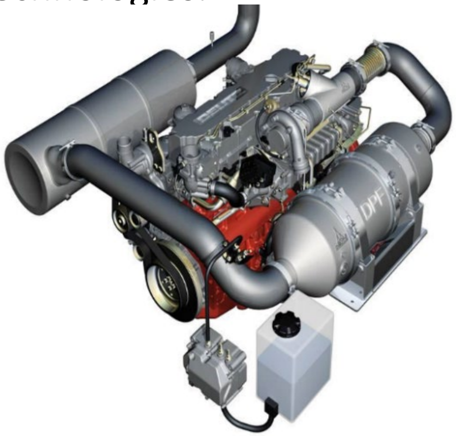
EPA Tier 2/Tier 3

EPA Tier 4 final

- The most ubiquitous engines in the LD vehicles are those that meet U.S. EPA Tier 2 and Tier 3 DPM standard and few meet U.S. EPA Tier 4 final standard.
- Approximately 49.3% (1,608 out of 3,261) pieces of non-permissible LD diesel-powered equipment emit less than 5.0 g/hr of DPM.
- Approximately 23.6 % (771 out of 3,261) pieces of non-permissible LD diesel-powered equipment emit less than 2.5 g/hr of DPM.
- The majority of engines in the LD vehicles that meet 5.0 g/hr standard without filtration systems have outputs under 37 kW (50 hp).

Attrition of older vehicles and engines should play important role in the process of reducing contributions of HD and LD diesel-powered vehicles to DPM burden.

- In the case of metal and nonmetal mines in the U.S., the typical life expectancy of diesel engines varies with type of equipment:
  - haulage truck life expectancy is approximately 15,000 hours;
  - LHD vehicle life expectancy is approximately 12,000 hours;
  - shotcrete vehicle or ANFO loader life expectancy is anywhere between 8,000-15,000 hours;
  - LD vehicles last between several months and several years.
- Therefore, depending on utilization factor, the spontaneous attrition might take some time:
  - the haulage trucks and LHD vehicles are repowered every 3-5 years.
  - the LD and MD vehicles might be repowered every 5-10 years.
- When replacing engines, operators might opt for alternative contemporary low-emitting engines rather than the rebuilt engines of the same kind.
- In the case of smaller LD vehicles, the relatively fast vehicle attrition might help implementation of advanced engine and exhaust aftertreatment technologies.



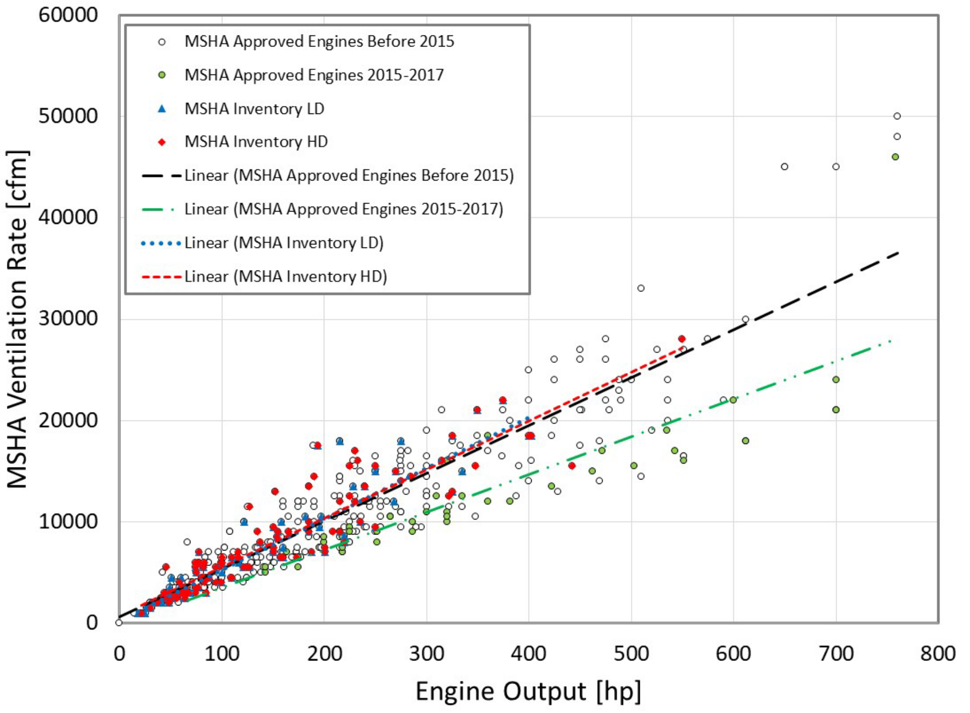
However, it appears that the attrition of the LD vehicles in the underground coal [MSHA 2018] and other mines is happening rather slow and that the industry still did not fully benefit from the recent technological advancements in engine and exhaust aftertreatment technologies.

- Over past two decades the U.S. EPA [EPA 2016] emissions standards gradually became more stringent.
  - PM standards for engines with outputs between 75 and 130 kW (100 and 175 hp), evolved as follows:
    - 1997 (EPA Tier 1): no standard
    - 2003 (EPA Tier 2): 0.30 g/kW-hr (0.22 g/hp-hr);
    - 2007 (EPA Tier 3, never adopted): 0.30 g/kW-hr (0.22 g/hp-hr);
    - 2011 - 2014 (EPA Tier 4i and Tier 4f): 0.02 g/kW-hr (0.01 g/hp-hr).
- Lately, EU introduced the more stringent particulate mass and particulate number emission standard [EU 2016]: the Euro Stage V engines with power output between 19 and 560 kW should not emit more than 0.015 g/kWh of PM and $1x10^{12}$ #/kWh of PN.

Tier 3 → > 90% reduction in PM; > 90% reduction in NO_X → **Tier 4f**

MSHA engine certification data [MSHA 2018b] indicate that replacing older engines with adequate engines certified after January 2015 could result in lower ventilation rate requirements.

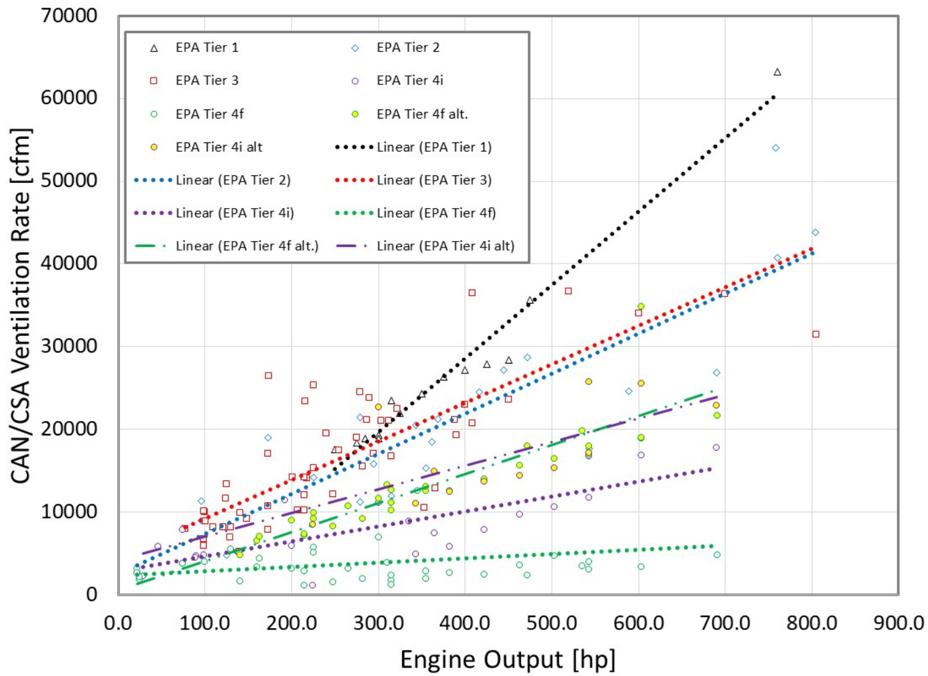
- MSHA approves diesel engines for use in underground mines under 30 CFR Part 7, Subpart E.
- Emissions are determined using ISO 8178-C1 test protocol (Non-Road Steady Cycle, NRSC)
- Ventilation rate is determined for each engine as an amount of air necessary to dilute the gaseous emissions from the engine to 1972 ACGIH TLVs for:
  - Carbon Dioxide (CO_2) - 5000 ppm
  - Carbon Monoxide (CO) - 50 ppm
  - Nitric Oxide (NO) - 25 ppm
  - Nitrogen Dioxide (NO_2) - 5 ppm



CANMET engine certification data also indicate that replacing EPA Tier 1,2, and 3 engines with selected EPA Tier 4i and 4f engines would result in lower ventilation rate requirements.

- CANMET approves diesel engines for use in underground mines [CANMET 2018] under CAN/CSA-M424.2-M90 [2011] or under CAN/CSA-M424.1-88 [2011].

- The emissions data determined for 18-mode test are used to calculate exhaust quality index (EQI):
  - $(EQI) = \frac{CO}{50} + \frac{NO}{25} + \frac{DPM}{2} + 1.5\left(\frac{SO_2}{3} +\right.$



Re-powering low output engines might not necessarily produce desired effects.

- Out of the engines that meet EPA Tier 4 final standards [EPA 2016], the low output engines that are not fitted with DPF systems might contribute more to DPM concentrations than high output engines fitted with DPF systems.
- The emission standards are specific to the engine output:
  - < 19 kW (< 25 hp) is 0.40 g/kW-hr (0.30 g/hp-hr);
  - 19 ≤ kW < 56 (25 ≤ hp < 75) is 0.03 g/kW-hr (0.02 g/hp-hr);
  - 56 ≤ hp < 560 (75 ≤ hp < 750) is 0.02 g/kW-hr (0.01 g/hp-hr);
  - ≥ 560 kW (≥ 750 hp) is 0.04 g/kW-hr (0.075 g/hp-hr).
- The LD vehicles powered with engines with outputs below 19 kW (25 hp) might be prime candidates for replacement with similar battery-powered vehicles.

Viable Retrofit-Type DPF Systems for Existing (EPA Tier 2 and Tier 3) LD and MD Engines

Application of various advanced in-cylinder emissions strategies might produce +90% reductions in the mass of particulates emitted, but +90% reductions in the solid particulate number emissions can only be achieved through use of diesel particulate filter (DPF) systems and filtration systems with disposable filter elements (DFEs).

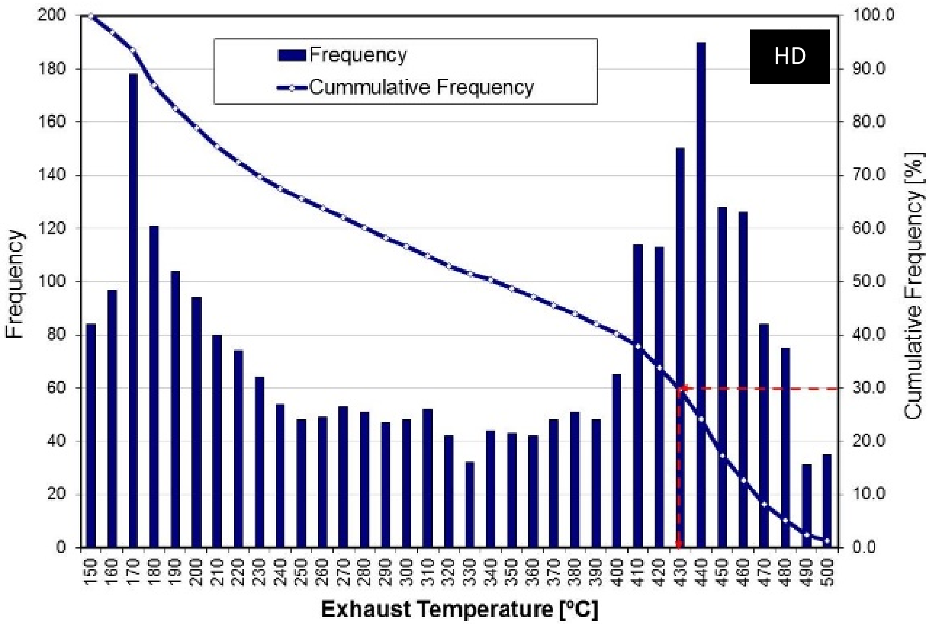
- Promulgation of DPM regulations resulted in gradual increase in number of the engines retrofitted with exhaust aftertreatment systems such as DPF systems and filtration systems with DFEs.

- According to the coal mining inventory [MSHA 2018a]:
  - over 97% of permissible HD vehicles are equipped with filtration systems with DFEs;
  - over 90% of non-permissible HD vehicles are equipped with DPFs and filtration systems with DFEs; and

- Apparently, the filtration systems play very pivotal role in curtailing DPM emissions from LD underground coal mining equipment:
  - Nationwide, the engines in 672 out of 3,261 LD vehicles in underground coal mines, approximately 21% of non-permissible fleet, are retrofitted with DPFs or DFE systems.
  - All diesel-powered LD vehicles in Pennsylvania and West Virginia underground coal mines are retrofitted DPF or DFE systems.

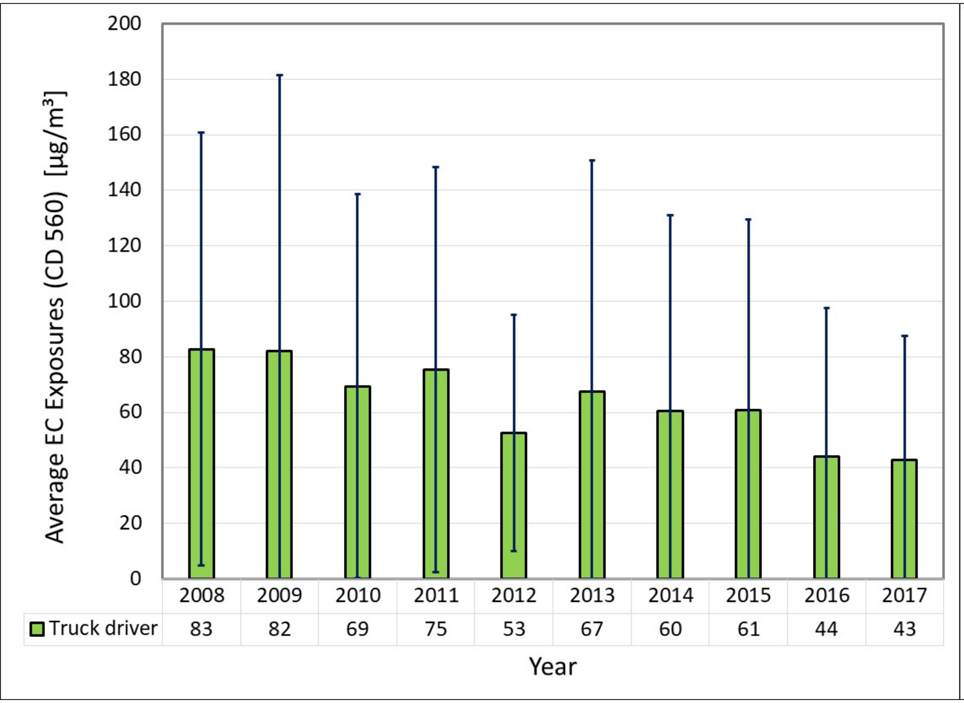
The major focus of the efforts to retrofit diesel-powered vehicles with DPFs in underground metal/nonmetal mining fleets were on haulage trucks and LHD vehicles [Demeres 2017, Deayton 2018, Lessard et al. 2018].

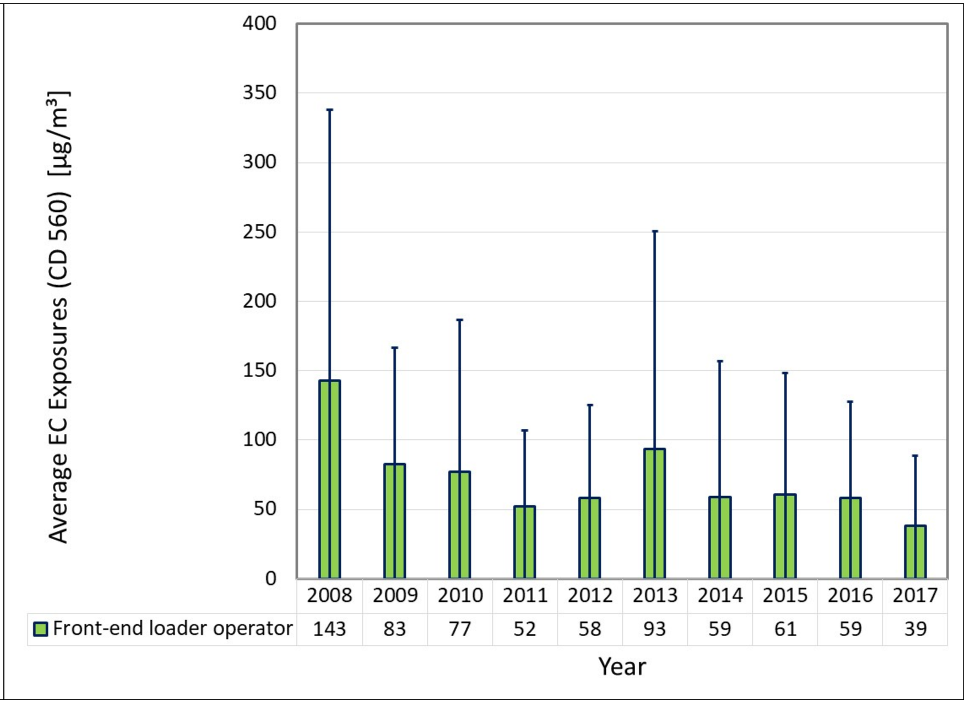
- Operators primarily retrofit haulage trucks and LHD vehicles with DPF systems:
  - perceived as the major contributors to the exposures of underground miners to diesel aerosols and gases;
  - operated over duty cycles that are characterized by higher DPM emissions;
  - operated over duty cycles that favor passive regeneration of DPF systems;
  - several manufacturers offer viable products…



The efforts to reduce particulate emissions from haulage trucks and LHD vehicles operated in underground metal and nonmetal mines coincided with gradual reductions in exposures of the operators of those vehicles to elemental carbon (EC).

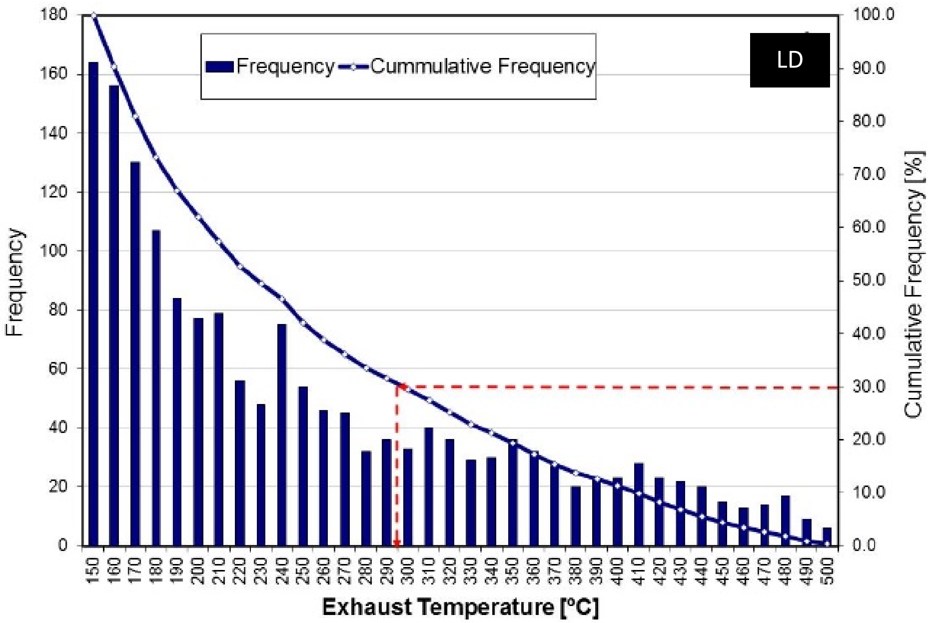
- The average EC exposures of truck drivers and LHD operators gradually decreased [MSHA 2018c, Bugarski and Potts 2018]:
  - truck drivers: 83 μg/m³ to 43 μg/m³ and
  - LHD operators: 143 μg/m³ to 39 μg/m³.





Retrofitting LD or MD diesel-powered vehicles from underground metal/nonmetal mining fleets with DPFs proved to be much more challenging.

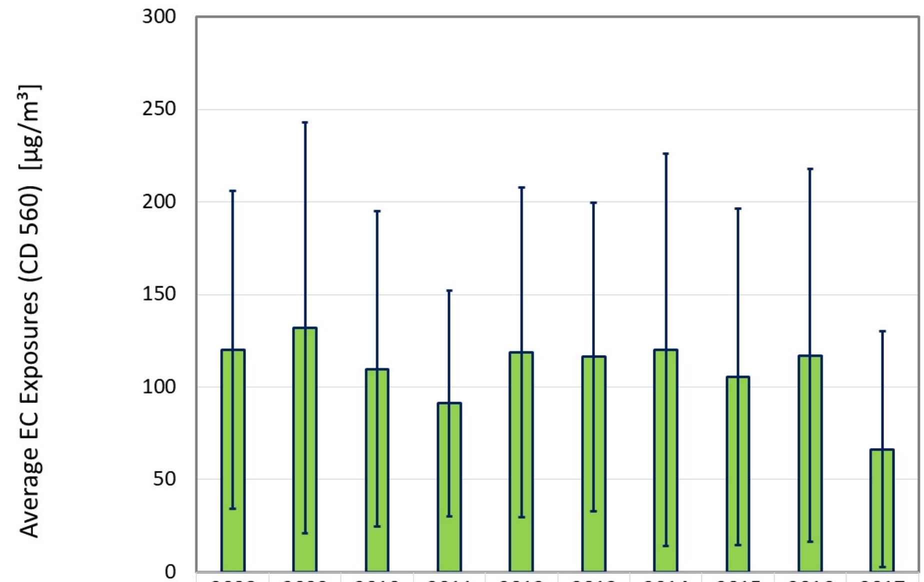
- Operators infrequently report retrofitting DPF systems to LD vehicles [Stachulak 2017]
  - perceived as minor contributors to the exposures of underground miners to diesel aerosols and gases;
  - operated over duty cycles that are characterized by low DPM emissions;
  - operated over duty cycles that do not favor passive regeneration of DPF systems;
  - few manufacturers offer viable products…



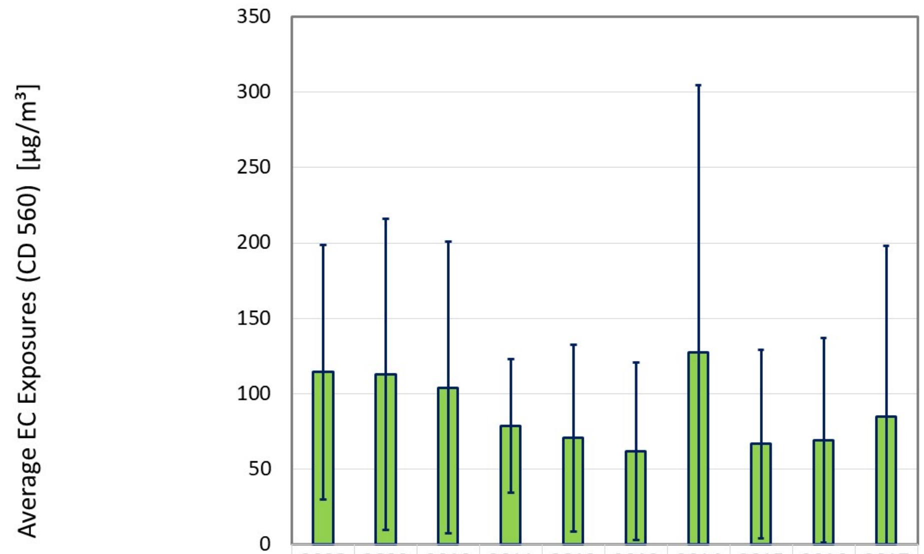
- More work is needed to develop retrofit-type DPF systems viable for LD applications.

The average EC exposures for powder men/shotfirers/shooters/blasters and rotary electric/hydraulic drill operators did not exhibit noticeable decline over the period between 2008 and 2017 [MSHA 2018c].

- Emissions reduction efforts should be diversified to address emissions from equipment other than haulage trucks and LHD vehicles and to reduce exposures of all occupations in underground mines.



	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Powder man (807)	120	132	110	91	119	116	120	105	117	66



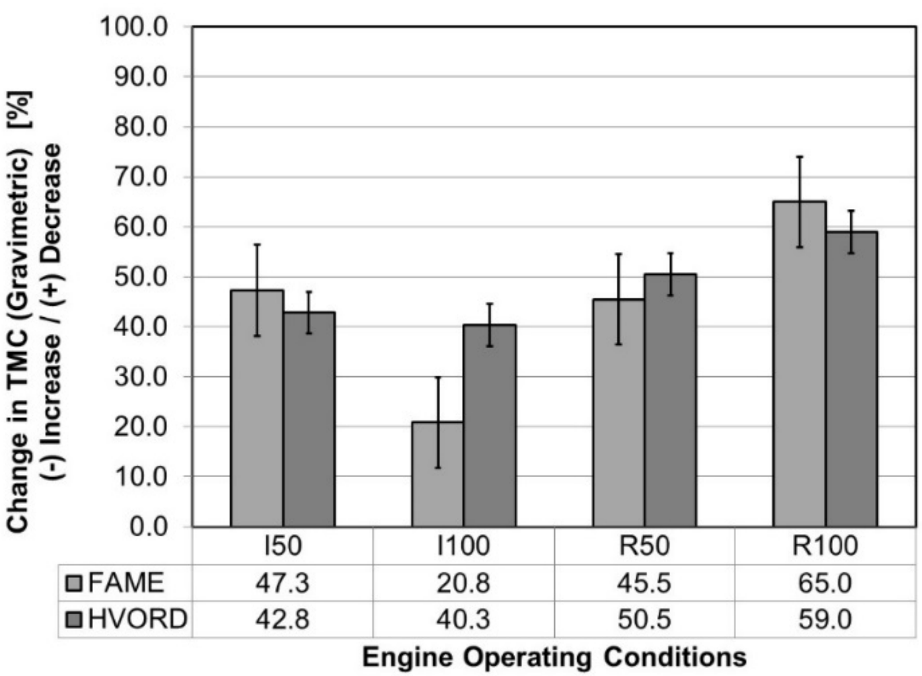
	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Rotary electric/hydraulic drill (634)	115	113	104	79	71	62	128	67	69	85

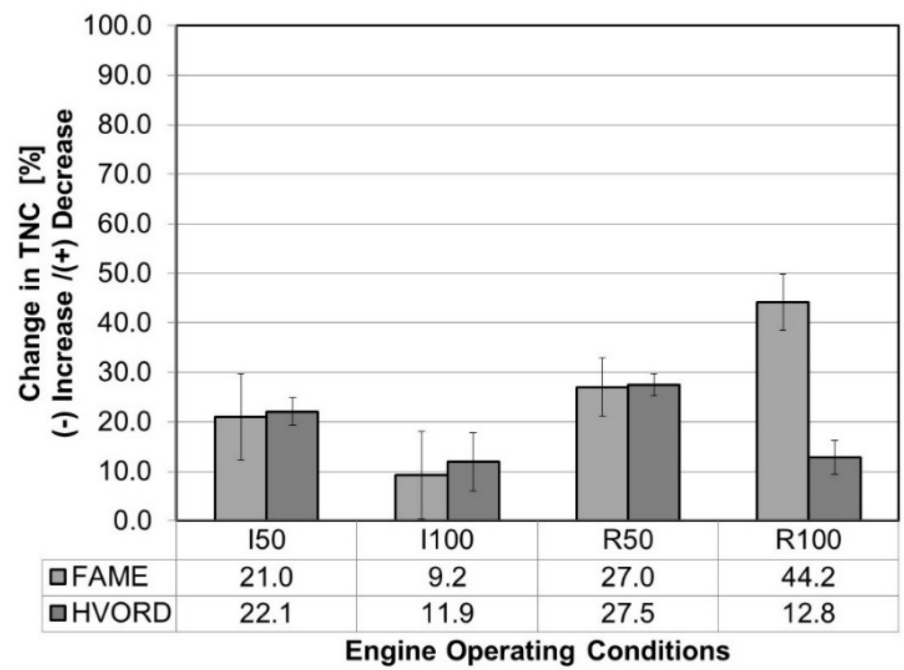
Substitution of Petroleum Based Fuels with Cleaner Burning Fuels

Substitution of petroleum-based diesel fuels with fatty acid methyl ester (FAME) biodiesel and hydrotreated vegetable oil renewable diesel (HVORD) are used as a viable strategies to reduce particulate matter emissions.

- When compared with ULSD, both FAME biodiesel and HVORD reduced emissions of total mass concentration (TMC) and total number concentrations (TNC) of aerosols [Bugarski et al. 2017].

- Substituting fuels might address emissions from HD, MD, and LD fleets.





Improving Quality of Existing and Acquisition of New Environmental Enclosures and Filtration/Pressurization Systems for MD and LD Vehicles

In some operations, environmental enclosures with adequate filtration/pressurization systems are used to reduce exposures of HD equipment operators to DPM [Noll et al. 2014].

- Only few LD and MD vehicles are equipped with environmental enclosures with adequate filtration/pressurization systems that provide desired reductions in DPM exposures.

- When available on LD and MD vehicles, the environmental enclosures and filtration/pressurization systems typically do not meet the same quality standards as those on HD equipment.

Substitution of Selected Vehicles with Electric-Powered Vehicles

Substitution of diesel-powered vehicles with electric-powered vehicles could be ultimate solution for practical elimination of exposures to diesel aerosols and some other pollutants.

- Electric-powered vehicles of various types have been workhorses of the underground coal mining industry.

- On the contrary, use of electric-powered vehicles of various types in the metal and nonmetal underground mining industry is rather limited.

- Underground mining industry could potentially benefit from replacement of diesel-powered vehicles with electric-powered vehicles:
  - Battery-powered;
  - tethered (cable) operated;
  - trolley operated; and
  - hydrogen fuel cell powered.

Rapid development of battery technology greatly improved the viability of battery-powered underground vehicles.

- Substitution of diesel-powered vehicles with battery-powered vehicles potentially could result in [GMG 2018]:
  - improved working environment (no DPM, less noise…),
  - better energy efficiency,
  - lower ventilation requirements;
  - lower heat generation;
  - lower maintenance requirements;
  - better equipment performance.

- However, electrification of mines might require major changes in mine design, mining methodology, and management [Schinkel, 2015; Mullally, 2017; Huff, 2018; GMG, 2018].

- Legal framework needs to be developed to facilitate implementation of these technologies in underground mines.

- If implemented, electrical underground vehicles might improve sustainability of mining industry.

We at NIOSH PMRD would like to assist the industry in addressing some of the aforementioned issues.

- We are currently working on:
  - Developing and evaluating technologies and strategies to prevent overexposures to DPM of critically affected occupations in underground metal and nonmetal mining operations;
  - Implementing and evaluating novel and emerging advanced engine technologies for HD, MD, and LD underground mining applications:
    - DPF retrofits for Tier 2 and Tier 3 engines; vs. Tier 4 final engines vs. Euro Stage V engines; vs. battery power;
  - Developing and evaluating canopy air curtains for mobile underground mining equipment such as ANFO loaders;
  - Developing and evaluating filtration and pressurization systems for environmental enclosures for mobile underground mining equipment;
  - Developing and evaluating advanced disposable filter elements for use in filtration systems for permissible diesel-powered equipment;
  - Improving DPM monitoring methodologies;
  - Improving ventilation strategies…

- We are actively searching to partner with industry to address some of the aforementioned and other related issues.

All aforementioned activities might fit well within the International Council on Mining and Metals (ICMM) Initiative for Cleaner Safer Vehicles (ICSV).

- ICMM brings 27 of the world's leading mining companies and over 30 associations together to address the various challenges associated with sustainable development of mining industry:
  - African Rainbow Minerals, Anglo American, Anglo Gold Ashanti, Antofagasta Minerals, Barrick, BHP, Codelco, Freeport-McMoRan, Glencore, Gold Fields, Goldcorp, Hydro, JX Nippon, Lonmin, Minera San Cristóbal, Minsur, Mitsubishi Materials, MMG, Newcrest Mining, Newmont, Orano, Polyus, Rio Tinto, South32, Sumitomo Metal Mining Co., Teck, and Vale.

- ICMM members joined forces with 13 major suppliers of mining equipment to develop innovation roadmap for making mining vehicles cleaner and safer:
  - Caterpillar, Cummins, Epiroc, GE, Hexagon Mining, Hitachi Construction Machinery, Komatsu, Liebherr, MacLean Engineering, PBE Group, Sandvik Mining, and Rock Technology.

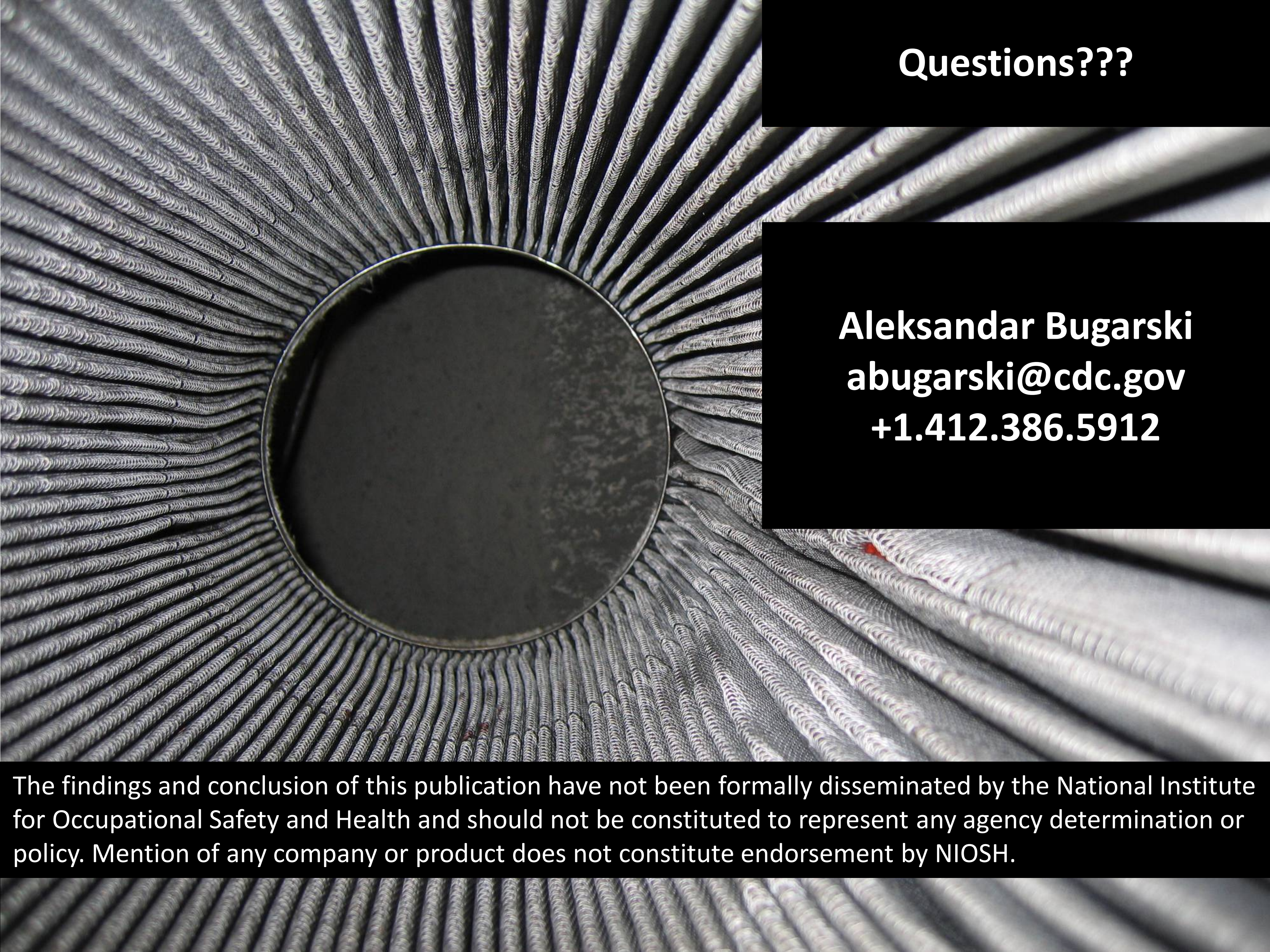
ICMM
International Council on Mining & Metals

- On October 30th 2018, during the International Mining and Resources Conference (IMARC) in Melbourne, Australia, the CEOs of ICMM member companies and leading equipment suppliers announced ICSV to the public.

- The plan is to minimize the operational impact of diesel exhaust by 2025.

- The project is open to everyone.

CDC Workplace Safety and Health NIOSH



Questions???

Aleksandar Bugarski
abugarski@cdc.gov
+1.412.386.5912

References

- 30 CFR 57.5060. Limit on Exposure to Diesel Particulate Matter. Safety and Health Standards—Underground Metal And Nonmetal Mines. Mine Safety and Health Administration. Code of Federal Regulations. Washington, DC: U.S. Government Printing Office, Office of the Federal Register.
- 30 CFR 57.5067. Engines. Mine Safety and Health Administration. Code of Federal Regulations. Washington, DC: U.S. Government Printing Office, Office of the Federal Register.
- 30 CFR 72.500. Emission Limits for permissible diesel-powered equipment. Mine Safety and Health Administration. Code of Federal Regulations. Washington, DC: U.S. Government Printing Office, Office of the Federal Register.
- 30 CFR 72.501. Emission limits for nonpermissible heavy-duty diesel-powered equipment, generators and compressors. Mine Safety and Health Administration. Code of Federal Regulations. Washington, DC: U.S. Government Printing Office, Office of the Federal Register.
- 30 CFR 72.502. Requirements for nonpermissible light-duty diesel-powered equipment other than generators and compressors. Mine Safety and Health Administration. Code of Federal Regulations. Washington, DC: U.S. Government Printing Office, Office of the Federal Register.
- 30 CFR 72.520. Diesel equipment inventory. Mine Safety and Health Administration. Code of Federal Regulations. Washington, DC: U.S. Government Printing Office, Office of the Federal Register.
- 30 CFR Part 7 Subpart E. Diesel engines intended for use in underground coal mines. Mine Safety and Health Administration. Code of Federal Regulations. Washington, DC: U.S. Government Printing Office, Office of the Federal Register.
- 30 CRF 75.1908 Nonpermissible diesel-powered equipment; categories. Mine Safety and Health Administration. Code of Federal Regulations. Washington, DC: U.S. Government Printing Office, Office of the Federal Register.
- 30 CRF Part 72. Subpart D—Diesel Particulate Matter—Underground Areas of Underground Coal. Health Standards for Coal Mines. Mine Safety and Health Administration. Code of Federal Regulations. Washington, DC: U.S. Government Printing Office, Office of the Federal Register.
- Bugarski A, Potts JD [2018]. Exposures of Underground Miners to Diesel Particulate Matter in the United States. Proceedings of 24th Annual MDEC Conference, Toronto, Ontario, Canada, October 2-4.
- Bugarski, A.D., Hummer, J.A., Vanderslice, S.E. [2017]. Effects of FAME biodiesel and HVORD on emissions from an older technology diesel engine. Mining Engineering 69(12): 43-49.
- CAN/CSA-M424.1-88 [2011]. Flameproof Non-rail-bound Diesel-Powered Machines for Use in Gassy Underground Coal Mines. Standards Councils of Canada.
- CAN/CSA-M424.2-M90 [2011]. Non-Rail-Bound Diesel-Powered Machines for Use in Non-Gassy Underground Mines. Standards Councils of Canada.
- CANMET [2018]. Approved Diesel Engines. Natural Resources Canada’s (NRCan), CANMET-MMSL. [https://www.nrcan.gc.ca/mining-materials/green-mining/approved-diesel-engines/8180].

References (2)

- Deayton, R [2018]. Controlling diesel particulate matter through filtration. Proceedings of 24th Mining Diesel Emissions Council (MDEC) Conference, Toronto, Canada, October 2-4.
- Demeres, H [2017]. DPM management strategies and results. Proceedings of 23rd Mining Diesel Emissions Council (MDEC) Conference, Toronto, Canada, October 3-5.
- EPA [2016]. Nonroad Compression-Ignition Engines: Exhaust Emission Standards. United States Environmental Protection Agency. Office of Transportation and Air Quality. EPA-420-B-16-02240.
- EU [2016]. Regulation (EU) 2016/1628 of the European Parliament and of The Council. Official Journal of the European Union, L252/3, September 16, 2016.
- GMG [2018]. GMG recommended practices for battery electric vehicles in underground mining. 2nd Edition. Global Mining Guidance Group (GMG). 20180621_UG_Mining_BEV-GMG-WG-v02-r01.
- Huff, B [2018]. Heat regeneration I battery electric underground haul truck. Proceedings of 24th Mining Diesel Emissions Council (MDEC) Conference, Toronto, Canada, October 2-4.
- Lessard P, Levesque S, Harvey L [2018]. Retrofit DPF implementation at Goldcorp. Proceedings of 24th Mining Diesel Emissions Council (MDEC) Conference, Toronto, Canada, October 2-4.
- MSHA [2018a]. National coal diesel inventory. Mine Safety and Health Administration. [https://lakmshaegov01.msha.gov/DieselInventory/ViewDieselInventoryExternal.aspx]. (downloaded on November 16, 2018)
- MSHA [2018b]. MSHA Approved Diesel Engines. United State Department of Labor. Mine Safety and Health Administration. [https://lakmshaegov01.msha.gov/ReportView.aspx?ReportCategory=EngineAppNumbers].
- MSHA [2018c]. The DPM personal sampling compliance data. [https://arlweb.msha.gov/OpenGovernmentData/OGIMSHA.asp].
- Mullally, J. [2018]. Borden Gold: Mine of the Future: Update. 24st Annual Mining Diesel Emissions Council (MDEC) Conference. Toronto, Canada, October 2-4.
- Noll, J.D.; Cecala, A.B.; Organiscak, J.A.; Rider, J.P. [2014]. Effects of MERV 16 filters and routine work practices on enclosed cabs for reducing respirable dust and DPM exposures in an underground limestone mine. Mining Eng. 66(2), pp. 45-52.
- Schinkel, A. [2015]. Kirkland Lake Gold's experience adding battery powered equipment to the mine. 21st Annual Mining Diesel Emissions Council (MDEC) Conference. Toronto, Canada, October 6-8.
- Stachulak J [2017]. Strategies and technologies to curtail diesel emissions. 16th North American Ventilation Symposium. Colorado School of Mines, June 18.