# The Concerns about Diesel Engine Exhaust

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**Operations Division**
811 SW 6th Avenue
Portland, OR 97204
Phone: (503) 229-6549
(800) 452-4011
Fax: (503) 229-6762
Contact: Kevin Downing
www.oregon.gov/DEQ

DEQ is a leader in restoring, maintaining and enhancing the quality of Oregon's air, land and water.

State of Oregon
**Department of Environmental Quality**

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This report prepared by:

Oregon Department of Environmental Quality
811 SW 6th Avenue
Portland, OR 97204
1-800-452-4011
www.oregon.gov/deq

Contact:
Kevin Downing
503-229-6549

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## Health Effects from Diesel Exhaust Exposure

The exhaust from diesel engines is a mixture of gases and particles. A number of health and environmental impacts can occur from short and long term exposures including cardiovascular, respiratory and nervous system effects, and even cancer.

Although diesel powered vehicles are a small portion of the vehicles on the road (6 % in Oregon), their air pollution impacts are large (60-70% of particulate emissions from all vehicles). One study found that diesel exhaust is 100 times more toxic than gasoline exhaust[1]. After reviewing scientific research, the International Association for Research on Cancer reclassified diesel exhaust to be a *known* human carcinogen while keeping the classification of gasoline exhaust as a *possible* human carcinogen[2]. A carcinogen is a substance or agent that is capable of causing cancer.

A diesel engine releases gaseous pollutant emissions that include carbon monoxide, sulfur oxides, nitrogen oxides, alkenes, aromatic hydrocarbons, volatile organics , aldehydes and low molecular weight polycyclic aromatic hydrocarbons (PAH) and PAH-derivatives. These pollutants occur as a result of incomplete combustion. At least one of the aromatic hydrocarbons (benzene) is a known carcinogen along with other PAHs. Other chemicals found in diesel exhaust and classified as *possible* or *probable* human carcinogens include formaldehyde, acetaldehyde and 1,3-butadiene.

The majority (80-95%) of a diesel engine's pollutants are released as ultrafine (nanoscale) particulates with a diameter of about 0.2 ųm. A human hair is about 80 ųm in diameter. These very small particles have a large surface area compared to their mass which allows organic compounds with toxic and carcinogenic properties to hold on to the surface[3,4]. Because of their size, the particulates can be easily inhaled and left in the lower area of the lungs. They are also capable of entering the bloodstream, allowing them to be circulated to all parts of the body[5].

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[1] Zielinski, B., Sagebiel, J., McDonald, J. D., Whitney, K., & Lawson, D. R. (2004). Emission rates and comparative chemical composition from selected in-use diesel and gasoline-fueled vehicles. *Journal of Air and Waste Management, 54*, 1138-1150.
[2] International Association for Research on Cancer. (2012). *Diesel and gasoline engine exhausts and some nitroarenes.* Lyon, France: IARC.
[3] Oberdörster, G. (2001). Pulmonary effects of inhaled ultrafine particles. *International Archives of Occupational and Environmental Health, 74*, 1-8.
[4] Krivoshto, I., Richards, J., Albertson, T., & Derlet, R. (2008). The Toxicity of Diesel Exhaust: Implications for Primary Care. *Journal of the American Board of Familiy Medicine, 21*(1), 55-62.
[5] Nemmar, A., Hoet, B., Vanquickenborne, D., Dinsdale, M., Thomeer, M., Hoylaerts, H., . . . Nemery, B. (2002). Passage of inhaled particles into the blood circulation in humans. *Circulation, 105*, 411-414.

## Cancer

Whole diesel exhaust is classified as a known human carcinogen by the World Health Organization (WHO) based on its links to lung and bladder cancer. The Environmental Protection Agency (EPA) has concluded that diesel engine exhaust is a likely human carcinogen[6] and the U.S. Department of Health and Human Services' National Toxicology Program lists diesel particulates as 'reasonably anticipated to be a human carcinogen'[7]. At the Oregon state level, the Environmental Quality Commission recognized that diesel particulate matter is a human carcinogen. A health benchmark was adopted in 2006 as part of Oregon's Air Toxics Program.

A number of studies have identified an increased risk of cancer from both occupational and environmental exposures to diesel engine exhaust. These exposures may account for six percent of lung cancer deaths in the United States and England[8]. Pediatric cancer cases are of particular concern. Harmful, or malignant, brain tumors are the leading cause of death among children and the second most common type of pediatric cancer. One study observed an increased risk for childhood brain tumors from the parents' exposure in work settings to diesel exhaust. Maternal (mother) exposure can also occur during pregnancy while paternal (father) exposure around conception was found to be enough to increase the risk[9].

## Cardiovascular Effects

Acute coronary syndrome (i.e.: heart attacks) and other blood clotting effects have been tied to diesel exhaust exposure[10]. After controlling for smoking, another study has reported higher incidence of ischemic heart disease (Coronary Artery Disease) in heavy equipment operators exposed to diesel particulates[11].

## Pulmonary Effects

Acute effects of diesel exhaust exposure include nose and eye irritation, swollen airway, headache, fatigue and nausea[12]. Poor lung function can be seen in children living near roadways with heavy truck traffic[13]. Diesel exhaust causes an increase in allergic reactions and asthma. The increased risk for asthma prompted the state of California Office of Environmental Health Hazard Assessment to list diesel particulate among the five toxic air contaminants with the greatest harm to children[14].

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[6] U. S. Environmental Protection Agency. (2002). *Health Assessment Document for Diesel Engine Exhaust.* Washington, DC: National Center for Environmental Assessment, Office of Research and Development.

[7] National Toxicology Program. (2011). *Report on Carcinogens, Twelfth Edition.* Research Triangle Park, NC: U. S. Department of Health and Human Services, Public Health Service.

[8] Vermeulen, R., Silverman, D., Garshick, E., Vlaanderen, J., Portengen, L., & Steenland, K. (2014). Exposure-response estimates for diesel engine exhaust and lung cancer mortality based on data from three occupational cohorts. *Environmental Health Perspectives, 122*, 172-177.

[9] Peters, S., Glass, D., Reid, A., de Klerk, N., Armstrong, B., Kellie, S., . . . Fritschi, L. (2013). Parental occupational exposure to engine exhausts and childhood brain tumors. *International Journal of Cancer, 132*(12), 2975-2979.

[10] Mills, N., Törnqvist, H., Gonzalez, M., Vink, E., Robinson, S., Söderberg, S., . . . Newby, D. (2007). Ischemic and thrombotic effects of dilute diesel-exhaust inhalation in men with coronary heart disease. *The New England Journal of Medicine, 357*(11), 1075-1082.

[11] Finkelstein, M., Verna, D., Sahai, D., & Stefov, E. (2004). Ischemic heart disease mortality among heavy equipment operators. *American Journal of Industrial Medicine, 46*, 16-22.

[12] Sydborn, A., Blomberg, A., Parnia, S., Stenfors, N., Sandström, T., & Dahlen, S.-E. (2001). Health effects of diesel exhaust emissions. *European Respiratory Journal, 17*, 733-746.

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[14] CA EPA, OEHHA. (2001, October). *Prioritization of toxic air contaminants under the Children's Health Protection Act.* Retrieved March 31, 2014, from http://oehha.ca.gov/air/toxic_contaminants/pdf_zip/SB25%20TAC%20prioritization.pdf

## Nervous System Impacts

Diesel exhaust exposure in occupational settings has also been linked to brain function, behavior, and visual deficits[15]. Higher levels of black carbon exposure, the major component of diesel exhaust, can lower cognitive functioning (speech and memory) in children[16]. Traffic caused air pollution, focusing on black carbon, is associated with lower cognitive functioning in older men[17]. Researchers have also identified an increased risk factor for autism spectrum disorder for children of women exposed to environmental pollutants during pregnancy[18] and the first year of life[19]. While the causes of autism spectrum disorder are not well understood, diesel exhaust appears to be a higher risk factor for nervous system impacts than other pollutants.

## Oregon Air Toxics Benchmark

Oregon has adopted ambient benchmark concentrations that serve as health based clean air goals for 52 air toxics present in the state. An ambient benchmark concentration is based on the average levels of a toxic chemical in the air that would cause a cancer risk of one-in-a-million additional cancers through a lifetime of exposure. For non-cancer-causing air toxics, the benchmarks are levels that could be breathed in for a lifetime without any non-cancer health effects. Each air toxic of concern has a benchmark set based on its non-cancer or cancer causing effects, whichever level would be more protective. These benchmarks have been established based on the protection and sensitivity of vulnerable populations, including children and the elderly.

The Environmental Quality Commission adopted Oregon's air toxics program ambient benchmark concentration for diesel particulate in 2006. Periodically DEQ updates Oregon's air toxics benchmarks based on the latest public health research for each pollutant. DEQ's Air Toxics Science Advisory Committee will meet in 2014-2015 to consider updates to several air toxics benchmark concentrations, including Oregon's diesel benchmark value.

## Health Impacts from Diesel Exhaust in Oregon

EPA has estimated, on a national basis, the expected health and welfare benefits that will come from reduced diesel emissions as a result of federal rules requiring lower emitting engines. It has estimated that by 2030 if most of the heavy duty trucks are operating with lower emitting engines, 8,300 premature deaths, 9,500+ hospitalizations and 1.5 million work days lost per year would be avoided. Similar estimations were made for non-road, train and marine engine analyses.

EPA did not complete estimates of impacts and benefits for individual states. However, the Clean Air Task Force (CATF), a nonprofit organization dedicated to reducing air pollution, did complete a state by state analysis based on 2005 National Air Toxics Assessments[20]. The annual health impacts for Oregon are shown in Table 1.

[15] Kilburn, K. (2000). Effects of diesel exhaust on neurobehavioral and pulmonary functions. *Archives of Environemntal Health, 55*(1), 11-7.
[16] Suglia, S., Gryparis, A., Wright, R. O., Schwartz, J., & Wright, R. J. (2008). Association of black carbon with cognition among children in propsective birth cohort study. *American Journal of Epidemiology, 167*, 280-286.
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[19] Volk, H., Lurmann, F., Penfold, B., Hertz-Picciotto, I., & McConnell, R. (2013). Traffic-related air pollution, particulate matter and autism. *Journal of the American Medical Association-Psychiatry, 70*(1), 71-77.
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**Table 1 Diesel Fine Particle Annual Health Impacts - Oregon 2005**

| | |
|---|---|
| **Adults** | |
| 176 | Premature Deaths |
| 145 | Non-Fatal Heart Attacks |
| 25,910 | Work Loss Days |
| 151,520 | Minor Restricted Activity Days |
| **Children** | |
| 119 | Asthma Emergency Room Visits |
| 250 | Acute Bronchitis |
| 3,203 | Lower Respiratory Symptoms |
| 2,449 | Upper Respiratory Symptoms |
| 5,376 | Asthma Exacerbation |

This analysis likely underestimates the impact because it relied on an earlier version of an EPA modeling tool. EPA emission factors have been revised since then showing higher levels of emissions than previously estimated. If another health impacts analysis was done with the most recent emissions estimates and not those of 2005, the health impacts would be adjusted and expected to increase proportionally.

### Context for Understanding Health Benefits of Lower Emitting Diesel Engines

The exhaust from diesel engines is connected to a wide range of harmful human health effects. It can affect respiratory, cardiovascular and nervous systems from exposures in different settings. Some of the studies reported here demonstrate cause and effect while others show strong relationships and the need for further research. The described health effects may have multiple pathways and diesel exhaust may not be the major or only cause. However, with the broad range of health effects found to be associated with exposure to diesel exhaust, it is clear that any action to manage and reduce diesel emissions will have many benefits.

## Black Carbon as a Climate Forcing Agent

Diesel engines are the largest source of black carbon in North America. The rate of climate change can be slowed by reducing the black carbon emissions released by diesel engines.

### Black Carbon Basics

Black carbon is an extremely small particle that is emitted into the air as a result of incomplete combustion of fossil fuels, bio fuels and biomass. Diesel engines, wood and coal combustion are examples of black carbon pollution. Because of their size, black carbon particles have the ability to cause negative effects on human health. The human health impacts range from cardiovascular, respiratory and nervous system disorders with both acute and chronic symptoms[21, 22].

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[21] Janssen, N., Gerlofs-Nijland, M., Lanki, T., Salonen, R., Cassee, F., Hoek, G., . . . Kryzanowski, M. (2012). *Health effects of black carbon.* Copenhagen, Denmark: World Health Organization.

[22] Smith, K., Jerrett, M., Anderson, H., Burnett, R., Stone, V., Derwent, R., . . . Thurston, G. (2009). Public health benefits of strategies to reduce greenhouse-gas emissions: health implications of short-lived greenhouse pollutants. *The Lancet, 374*(9707), 2091-2103.

## Black Carbon Impact on Climate

Black carbon has been evaluated as a contributor to climate change over the past fifteen years. In 2013, it was confirmed as the second largest human influence on climate change[23] next to carbon dioxide.
Black carbon has the ability to warm the atmosphere differently than greenhouse gases. It contributes to climate change by:

- Warming the atmosphere directly by absorbing solar radiation and emitting it as heat;
- Darkening snow and ice, causing them to warm and melt much faster;
- Affecting the properties of clouds, including their reflectivity and lifetime, stability and precipitation.

## Focus on Black Carbon for Near Term Mitigation

Black carbon has a lifetime in the atmosphere of days to weeks, compared to 50 to 100 years for carbon dioxide. Reductions in black carbon, and other short lived climate forcers like methane, can result in significant near term climate benefits. Action on black carbon now can provide climate change relief worth one to two decades of action on carbon dioxide[24].

## Sources of Black Carbon

Globally the largest sources of black carbon are in developing countries. Asia, Latin America and Africa account for 75% of total black carbon emissions, mostly from the residential sector (cookstoves) and open biomass burning. Black carbon emissions in developed countries in Europe and North America have been declining since the early 1900s due to pollution controls and the use of cleaner fuels. Even so, in North America diesel engines remain the largest source of black carbon, accounting for about six percent of the total global inventory.
Any combustion process emits a complex mixture of pollutants with different effects on climate change. Black carbon is emitted with other pollutants, or co-pollutants, that have different properties. Some of them have cooling properties and put solar radiation back into the atmosphere. The type and quantity of co-pollutants depends on the combustion source. Combustion sources with a high ratio of warming to cooling aerosols are the most effective to target for climate change mitigation. Diesel engines have the highest ratio of warming to cooling aerosols of any black carbon source[25], making emission reduction from this category very effective for climate change mitigation.

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[23] Bond, T., Doherty, S., Fahey, D., Forster, P., Berntsen, T., DeAngelo, B., . . . Zender, C. (2013). Bounding the role of black carbon in the climate system: A scientific assessment. *Journal of Geophysical Research: Atmospheres, 118*(11), 5380-5552.
[24] Bice, K., Eil, A., Habib, B., Heijmans, P., Kopp, R., Nogues, J., . . . Whitworth, A. (2009). *Black carbon: A review and policy recommendations.* Princeton University. Princeton, NJ: Woodrow Wilson School of Public and International Affairs.
[25] Bond, T., Op Cit., 2013.

## Black Carbon Impacts Specifically in Oregon

Unlike carbon dioxide and other greenhouse gases that can spread further, black carbon is not evenly mixed in the air and concentrations can be different from region to region. This uneven distribution means that geographic specific climate impacts tend to occur. In the Arctic, black carbon can accelerate snow melt[26], exposing the darker land mass and ocean to solar radiation. Black carbon emissions from as far south as the $40^{th}$ parallel ($40^{o}$ N latitude) are contributing to Arctic snow melt[27] with all of Oregon being above this latitude.
Researchers have theorized the Arctic effect could also occur on snow fields and glaciers in the western United States[28]. Researchers since have confirmed the effect in the Cascades[29] and Sierra Nevada mountains[30]. Early snow melt affects water storage and availability impacting salmon, irrigators and other water users. Researchers have reported changes in streamflow and temperature in streams throughout the western states, Oregon included, from the 1950s to the present that are the result of these types of climate change impacts[31].

## Black Carbon Reduction Efforts

Tackling black carbon emissions alone will not solve the effects of climate change caused by the long term accumulation of greenhouse gases. Reducing black carbon, with co-benefits for human health, is a complementary strategy alongside needed reductions in greenhouse gases like carbon dioxide.
The most significant source of black carbon in North America is the diesel engine. Diesel particle filters reduce black carbon by 95 percent. Since 2001, through grants and tax incentives, the state of Oregon has been encouraging diesel engine owners to upgrade to newer engines, retrofit exhaust controls, reduce idling or considering switching to lower emitting alternative fuels. Federal regulations have required high efficiency particle filters since 2007 and 2010 for new heavy duty and light duty vehicles, respectively, however the projected full benefit of this technology will not be realized until sometime after 2030.
The state of California adopted a comprehensive regulatory program moving operators to clean diesel and other low emitting engines emphasizing the use of diesel particulate filters. A recent study documented the black carbon climate change benefits of the California program[32] and the California Air Resources Board reports the reduction as the equivalent of 21 million metric tons of carbon dioxide reduced every year. This translates to removing four million cars off California roads every year[33].

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[26] Sand, M., Bernsten, T., Seland, Ø., & Kristjánsson, J. (2013). Arctic surface temperature change to emissions of black carbon within Arctic or mid-latitudes. *Journal of Geophysical Research: Atmospheres, 118*(14), 7788-7798.
[27] Bice, K., Op Cit, 2009.
[28] Qian, Y., Gustafson Jr., W., Leung, L., & Ghan, S. (2009). Effects of soot-induced snow albedo change on snowpack and hydrological cycle in western United States based on weather research and forecasting chemistry and regional climate simulations. *Journal of Geophysical Research: Atmospheres, 114*(D3, 16), 1984-2012.
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[32] Ramanathan, V., Bahadur, R., Prather, K., Hadley, O., Cazorla, A., Leung, R., . . . Zhao, C. (2013). *Black carbon and the regional climate of California.* San Diego: University of California, San Diego/Lawrence Berkeley National Laboratories/Pacific Northwest National Laboratories.
[33] CA EPA Air Resources Board. (2013, June 13). *Air Resources news room.* Retrieved March 31, 2014, from http://www.arb.ca.gov/newsrel/newsrelease.php?id=444

# Economic Valuation of the Benefits of Reducing Diesel Emissions

> Emissions from diesel engines result in a variety of health effects, many of which have corresponding economic effects. Relying on EPA health effects methodology DEQ estimated that over $1.6 billion could be saved in Oregon every year in avoidable public health impacts including treatment for illness, hospitalizations, lost work days and premature death. In addition, black carbon emissions from diesel engines in Oregon have a separate estimated annual climate impact of about $274 million. Upgrading exhaust controls on existing vehicles and equipment or moving to late model engines will both save money and reduce negative health impacts.

EPA has relied upon peer-reviewed methods for estimating health and welfare benefits of diesel particulate reductions over the last twenty years. Atmospheric modeling is used to incorporate the proposed emission reductions and translate the changes in concentrations and exposure along with health and welfare benefits. Table 2 lists health and welfare endpoints identified by EPA as associated with diesel particulate exposure, including those monetized and those discussed only qualitatively.

**Table 2 $PM_{2.5}$ Health and Welfare Endpoints Included in EPA's Regulatory Impact Analyses for Diesel Engine Emission Standards**

| Pollutant/Effect | Primary Quantified and Monetized Effects | Unquantified Effects |
|---|---|---|
| **PM/Health** | Premature mortality<br>Bronchitis - chronic and acute<br>Hospital admissions - respiratory and cardiovascular<br>Emergency room visits for asthma<br>Asthma attacks<br>Lower and upper respiratory illness<br>Minor restricted activity days<br>Work loss days<br>Non-fatal heart attacks (myocardial infarction)<br>Asthma exacerbations (asthmatic population)<br>Respiratory symptoms (asthmatic population) | Infant mortality[34]<br>Low birth weight<br>Pre-term birth and other reproductive outcomes<br>Changes in pulmonary function<br>Chronic respiratory diseases other than chronic bronchitis<br>Morphological changes<br>Altered host defense mechanisms<br>Cancer<br>Non-asthma respiratory emergency room visits |
| **PM/Welfare** | Visibility in California, Southwestern,<br>and Southeastern Class I areas | Visibility in Northeastern, Northwestern, and Midwestern Class I areas<br>Visibility in residential and non-Class I areas<br>Household soiling<br>Sulfate PM reductions associated with reductions in sulfur in home heating oil |

The EPA's estimation of avoided health and welfare impacts can be characterized on a per ton of pollution reduced basis from each regulatory impact analysis completed for diesel engine certification standards[35].

[34] Quantified in non-road rule

Estimates on a per ton basis are useful for evaluating incremental air quality improvements as well as for characterizing the scale of impact in Oregon. Applying the results from a county by county analysis of the 2011 emission inventory using the Benefits Module, based on outputs from the Environmental Benefits Mapping and Analysis Program (BenMAP), reveals an estimated annual impact of $1.6 billion annually in Oregon. This analysis may represent a lower range of costs as EPA recently estimated implementation of federal engine standards in 2030 would result in a total of 39,000 annual avoided deaths, representing savings of over $296 billion per year[36]. If this were scaled to Oregon based on population, this would suggest as many as 460 premature deaths per year with annual costs from exposure at $3.5 billion.

Regulations affecting climate change at the federal level are also subject to a cost/benefit analysis. A multi agency workgroup has developed the Social Cost of Carbon (SCC) as the financial metric for this analysis[37]. The SCC is an estimate of some of the economic damages associated with an increase in carbon dioxide emissions, typically per metric ton in a year, and also represents the value of avoided damages from emission reductions. Based on the 2011 emission inventory for diesel particulate and using the central value of $37 per metric ton, the annual impact from emissions of diesel engine black carbon in Oregon alone is $274 million.

When considering the economic impacts of diesel engines it is particularly helpful to consider the costs and benefits per vehicle. This allows for better context in evaluating mitigation strategies. Table 3 provides the results of this analysis for an over-the-road truck and an excavator.

**Table 3 Health and Climate Costs Associated with Representative Highway and Non-road Vehicle Usage**

| | $PM_{2.5}$ Tons per year | BC Metric tons | $CO_2$ equivalent Metric tons | Annual Climate cost | Climate Impact per gallon | Annual Health cost | Health Impact per gallon |
|---|---|---|---|---|---|---|---|
| Truck | 0.067 | 0.046 | 146 | $ 5,404 | $ 0.32 | $ 31,787 | $ 1.91 |
| Excavator | 0.031 | 0.022 | 69 | $ 2,553 | $ 0.42 | $ 15,017 | $ 2.46 |

It is estimated that a vehicle owner will spend $16,000 to install and maintain a diesel particle filter with emission reduction efficiencies of 85-95 percent. Although this is a high cost to the owner, the savings from avoided health costs alone for the example truck is returned in about six months. The excavator shows positive returns in less than twelve months and both examples continue positive returns from avoided health costs through the remaining life of the devices. This compares favorably to traditional return on investment considerations by businesses. The cost is reasonable and warranted, given the scale of the impacts to both human health and the environment.

[35] U.S. Environmental Protection Agency. (2000). *Regulatory Impact Analysis: Heavy-Duty Engine and Vehicle Standards and Highway Diesel Fuel Sulfur Control Requirements.* Washington DC: US EPA.

[36] Bailey, C. *Update on Diesel Health Issues and EPA Actions.* PowerPoint presentation, May 21, 2014, accessed July 15, 2014, http://www.epa.gov/cleandiesel/documents/diesel-health-issues-5-21-14.pdf.

[37] Interagency Working Group on Social Cost of Carbon, US Government. (2013). *Technical Support Document - Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis.* Washington, DC: Office of Management and Budget.