

**To learn more about our investigation of truck drivers' exposure to diesel pollution inside their cabs and recommendations for reducing pollution and minimizing the health threats to drivers working at or near California's ports, please read the full issue paper at [www.nrdc.org/policy](http://www.nrdc.org/policy).**

**Online Appendix to the NRDC Issue Paper  
*Driving on Fumes:  
Truck Drivers Face Elevated Health Risks from Diesel Pollution***

**Literature Review on the Topic of Truck Driver In-Vehicle Diesel Exhaust Exposure**

**I. Research on Truck Driver Exposure to Diesel Exhaust**

There are a series of articles addressing lung cancer deaths among Teamsters and the association between those deaths and diesel exhaust (DE) exposure. However, the determination of diesel exposure was not initially based on in-vehicle measurements. In the initial study, Steenland et al. (1990, 1992) looked at 994 lung cancer cases and 1,085 controls among former members of the Teamsters Union who died in 1982 or 1983. Subjects were divided into job categories based on the job held the longest. The job categories included short-haul driver and long-haul driver, among others. The researchers used a yes/no (ever/never) variable based on job category in order to determine DE exposure. Since dieselization of trucks didn't take place until the early 1960's, determination of use of gasoline and diesel powered trucks was based on next-of-kin recollections. Steenland et al., while noting limitations to their methodology, concluded that their results "suggest that diesel truck drivers have an excess risk of lung cancer compared to other Teamsters in jobs outside the trucking industry."

In 1991, an industrial hygiene survey of elemental carbon exposures in the trucking industry (Zaebst et al.) was used to estimate diesel particulate matter (DPM) exposure for the DE-exposed jobs (from the Steenland et al. study). Steenland et al. later completed exposure-response analyses using the Zaebst et al. study to estimate historical exposures (Steenland et al., 1998). The authors assumed that historical DE exposures were a function of the number of heavy-duty trucks on the road, the particulate emissions (grams/mile) of diesel engines over time, and leaks from trucks' exhaust systems for long-haul drivers. To estimate worker exposures, they multiplied miles traveled by heavy duty trucks from 1949 to 1990 by estimated emissions per mile. They assumed that long-haul drivers received at least 50% of their exposure from their own trucks based on research done in the 1970's.<sup>1</sup> Steenland et. al. found that long-haul and short-haul drivers had DE exposure levels that were slightly above roadway levels and 3-4 times background residential levels. They also estimated yearly exposure levels for each job category. While noting that their exposure estimates are based on broad assumptions rather than on actual measurements, they concluded that their data suggests "a positive and significant increase in lung cancer risk with increasing estimated cumulative exposure to diesel exhaust among workers in the trucking industry."

This analysis was later criticized in a 1999 review by the Health Effects Institute (HEI).<sup>2,3</sup> Refined estimates of exposure, and a response to the HEI critique, were presented by Bailey et al. in 2003.<sup>4</sup> Bailey et al. employed a probabilistic model for historical exposure assessment by calculating DPM exposures as a function of the fleet emission rate and diesel truck vehicle miles traveled (VMT). They excluded nondiesel sources of elemental carbon (EC) from exposure estimates by using ambient particulate source apportionment studies. They found lower DPM exposures than Steenland et al. (1998). The difference in the two methods' predictions resulted from differing assumptions about emissions and dieselization.<sup>5</sup>

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## II. In-Vehicle Measurements of Truck Driver Diesel Exposure

### A. Zaebst et al. (1991)<sup>6</sup>

Zaebst et al. measured EC in samples that corresponded to the major job categories described in the Steenland et al. (1990, 1992) study as well as in ambient roadway and nonroadway samples. Surveys were conducted at seven large “breakbulks” and one smaller terminal. NIOSH Method 5040 was used to obtain three mass measures for each air sample [EC, organic carbon (OC), and total carbon], and from those results they concluded that EC was a useful surrogate for DPM. Personal EC exposures were measured among road drivers, local drivers, mechanics, dock workers, and other occupations. They found that long- and short-haul truck drivers were exposed to EC levels equivalent to highway background levels and significantly elevated over residential levels.

### B. Lee et al (2005)

Lee et al. (2005) sampled in-vehicle areas for  $PM_{2.5}$ , EC, and organic carbon (OC) for pick-up and delivery (P&D) truck drivers (18 drivers) and long haul truck drivers (11 drivers) by mounting the sampler in the vehicle next to the driver. They also obtained personal exposure concentrations at breathing zones of workers (including dockworkers who were usually drivers) by having them wear air sampling vests. They found that P&D areas were responsible for the second highest area concentrations of EC and OC followed by long haul drivers. They believed this difference to be due to differences in environment (i.e. the tendency for P&D drivers to spend a larger percentage of their time in traffic jams in city areas). They calculated the EC ratio of total carbon (EC/EC+OC) and were surprised to find the highest EC ratio in the shop areas and that the EC ratio was similar among dock, yard, and P&D areas.

Lee et al. (2005) also measured personal exposure concentrations of workers to EC and OC (8 hour TWA). However, while the dockworkers were noted to usually be drivers, no distinction was made between measurements from drivers and other dockworkers, and no relationship was drawn between EC or OC concentrations and amount of time spent driving. They did calculate EC fraction to total carbon exposure based on personal exposure measurements. The authors’ conclusions incorporated observations from the data regarding  $PM_{2.5}$  exposure; they interpreted the low EC to total carbon ratios to mean that non-DE particulates dominated the exposures.

The personal exposure concentrations to particulate matter were much greater than those of the area concentrations. The personal TWA EC and OC exposure concentrations were approximately 6.9% and 62.4% of the personal TWA  $PM_{2.5}$  exposure concentrations, respectively, in the whole areas. The area concentrations of  $PM_{2.5}$ , EC, and OC at a large terminal, which has busier activity levels, were higher than those at a small one. The area concentrations and personal exposure to  $PM_{2.5}$ , EC, and OC in the shop and P&D areas, which are highly affected by diesel engine exhaust emissions, were much higher than those in the docks, which are significantly affected by liquefied petroleum gas (LPG) engine exhaust emissions. Smoking significantly contributed to the worsening of the indoor air quality in the workplaces and the break rooms and thus increased the personal exposure to  $PM_{2.5}$  and OC. However, smoking may not significantly contribute to the personal exposure to EC. There were significant correlations between the  $PM_{2.5}$  and OC concentrations in both the area and personal exposure concentrations.<sup>7</sup>

### C. Smith et al. (2006)

A 2006 study (Smith et al.) attempted to determine how much of a truck terminal worker’s personal exposure to DE was derived from background versus personal work activities. They measured exposures at 36 randomly sited large truck freight terminals in the US for  $PM_{2.5}$ , EC, and OC. Measurements were made upwind of the terminal (for background levels), in work areas, and by personal samples. Unlike the Lee et al. study in which area sampling was done in the truck cab, in this study area sampling was done in the offices, freight dock, or shop and it was the personal sampling that involved truck cab measurements. Terminal workers were invited to volunteer for personal sampling; for drivers who volunteered, a sampling box was mounted in the cab. This study produced summary statistics for EC, OC, and  $PM_{2.5}$  as well as percentage of total carbon in EC by location. The authors found that:

[t]he nonsmoking pickup and delivery (P&D) and long haul (LH) drivers had very similar  $PM_{2.5}$ , EC, and OC exposures. They had an EC/TC ratio of 6–7%, which was similar to the dockworkers and hostlers, but very low relative to both car and heavy duty truck emissions. Geometric mean (GM[GSD]) measurement of in-vehicle

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concentrations of black carbon (BC) were 1.3[4.5]  $\mu\text{g}/\text{m}^3$  in Los Angeles on urban arterial roads and 4.4[2.6] on freeways, and in Sacramento BC was 0.56[3.5]  $\mu\text{g}/\text{m}^3$  on urban arterial roads and 3.8[2.4] on freeways. P&D drivers had a small but significantly higher EC exposure than other drivers, which was overall comparable with the BC exposures on Sacramento freeways.

*D. Ziskend et al. 1978*

Access was not available to this 1978 study of exhaust systems contaminating driver compartments of older, poorly maintained diesel trucks.

### III. Study Criticisms

Criticisms about the results from these studies have been made. In a study by Sirianni et al. (2003), measurements of EC and OC were made in areas with DE and without DE. They concluded that non-diesel organics “overwhelm and obscure levels of OC expected from diesel engines.” Hesterberg et al. (2006)<sup>8</sup> suggest that non-diesel sources (such as tobacco smoke, gasoline exhaust, solvents, and fuel) dominate particulate exposure among truck drivers. They also note that truck drivers are unlikely to be exposed to their own-truck exhaust emissions (because of where the exhaust pipe is located on a diesel truck). And they conclude that the “low” elevations in lung cancer reported in transportation studies are likely due to “an unidentified occupational agent or lifestyle factor” as “a causal relationship between [DE] exposure and lung cancer has not been conclusively demonstrated.”

### Abstracts<sup>9</sup>

#### 1. Davis ME, Smith TJ, Laden F, Hart JE, Ryan LM, Garshick E. Modeling particle exposure in the U.S. trucking terminals. *Environ Sci Technol.* 2006 Jul 1;40(13):4226-32

Multi-tiered sampling approaches are common in environmental and occupational exposure assessment, where exposures for a given individual are often modeled based on simultaneous measurements taken at multiple indoor and outdoor sites. The monitoring data from such studies is hierarchical by design, imposing a complex covariance structure that must be accounted for in order to obtain unbiased estimates of exposure. Statistical methods such as structural equation modeling (SEM) represent a useful alternative to simple linear regression in these cases, providing simultaneous and unbiased predictions of each level of exposure based on a set of covariates specific to the exposure setting. We test the SEM approach using data from a large exposure assessment of diesel and combustion particles in the U.S. trucking industry. The exposure assessment includes data from 36 different trucking terminals across the United States sampled between 2001 and 2005, measuring  $\text{PM}_{2.5}$  and its elemental carbon (EC), organic carbon (OC) components, by personal monitoring, and sampling at two indoor work locations and an outdoor “background” location. Using the SEM method, we predict the following: (1) personal exposures as a function of work-related exposure and smoking status; (2) work-related exposure as a function of terminal characteristics, indoor ventilation, job location, and background exposure conditions; and (3) background exposure conditions as a function of weather, nearby source pollution, and other regional differences across terminal sites. The primary advantage of SEMs in this setting is the ability to simultaneously predict exposures at each of the sampling locations, while accounting for the complex covariance structure among the measurements and descriptive variables. The statistically significant results and high  $R^2$  values observed from the trucking industry application supports the broader use of this approach in exposure assessment modeling.

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**2. Steenland K., Silverman D, Zaubst D. Exposure to diesel exhaust in the trucking industry and possible relationships with lung cancer. *Am J Ind Med.* 1992;21(6):887-90**

We previously reported that long-term truck drivers and mechanics in the Teamsters Union had higher lung cancer risks than Teamsters outside the trucking industry. We now summarize results from an industrial hygiene survey of current exposures to diesel exhaust in the trucking industry, and relate these to our prior results pertaining to lung cancer risk.

**3. Steenland K. Lung cancer and diesel exhaust: a review. *Am J Ind Med.* 1986;10(2):177-89.**

The evidence from animal studies indicates that organic extracts of diesel particulate are mutagenic and carcinogenic. Of four animal inhalation studies, two have been positive and two have been largely negative. The most recent data indicate that inhalation studies may be positive only with high doses of exhaust. Human studies of diesel-exposed occupations have been inconclusive. These studies have focused on truck drivers, bus drivers and garage workers, railroad workers, and heavy equipment operators. Most human studies have not been able to estimate exposure to diesel exhaust. Negative studies have frequently suffered from insufficient potential latency. Positive studies have often failed to control for smoking, and have sometimes involved confounding occupational exposures. In general, the occupational epidemiology of diesel-exposed workers is made difficult by the fact that many of the suspected toxic components of diesel-exhaust are also present in cigarette smoke and in ambient air. There are two ongoing epidemiologic studies in the United States, focusing on railway workers and truck drivers, which attempt to overcome prior difficulties. Preliminary data from the study of truck drivers indicates an excess of lung cancer among workers in the trucking industry compared to the U.S. population, but these data need to be controlled for smoking and analyzed according to diesel exposure.

**4. Zaubst DD, Clapp DE, Blade LM, Marlow DA, Steenland K, Hornung RW, Scheutzle D, Butler J. Quantitative determination of trucking industry workers' exposures to diesel exhaust particles. *Am Ind Hyg Assoc J.* 1991 Dec;52(12):529-41.**

As part of a case-control mortality study of trucking industry workers, exposures to diesel aerosol were measured among the four major presumably exposed job groups (road drivers, local drivers, dock workers, and mechanics) in the industry. Eight industrial hygiene surveys were conducted during both warm and cold weather at eight U.S. terminals and truck repair shops. A single-stage personal impactor was used to sample submicrometer-sized diesel particles on quartz fiber filters. Laboratory and field studies demonstrated that the elemental carbon content of the particles is a useful and practical marker of exposure to vehicular diesel exhaust. A thermal-optical analysis technique was used to determine the concentration of elemental carbon in the filter samples. Overall geometric mean exposures to submicrometer-sized elemental carbon ranged from 3.8 micrograms/m<sup>3</sup> in road (long distance) drivers (N = 72) to 13.8 micrograms/m<sup>3</sup> in dock workers (N = 75). Geometric mean background area concentrations, measured in the same cities where workers were sampled, were 2.5 micrograms/m<sup>3</sup> on major highways (N = 21) and 1.1 micrograms/m<sup>3</sup> in residential areas (N = 23). A factorial analysis of variance indicated that exposures in two job groups, dock workers (particularly those exposed primarily via diesel forklift trucks, introduced relatively recently) and mechanics (working in poorly ventilated shops during cold weather), were significantly higher than background concentrations and were significantly higher than the exposures in the local and road drivers. The exposures of the truck drivers could not be distinguished from background highway concentrations but were significantly higher than background concentrations in residential areas.

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## Endnotes

- 1 According to Steenland et al. (1998), Ziskend et al. (1978) demonstrated that at least part of the in-vehicle exposure to DE was due to the engine's own emissions. "Engine exhaust entered the truck cab either through holes in the truck cab floor where the pedals were located or through the window. Ziskend et al. estimated that in-cab concentrations approximately doubled when leaks were present and that 40% of the 88 trucks tested had such leaks."
- 2 According to their website (<http://www.healtheffects.org/about.htm> accessed 8/30/07), HEI is a "nonprofit corporation chartered in 1980 as an independent research organization to provide high-quality, impartial, and relevant science on the health effects of air pollution. Typically, HEI receives half of its core funds from the US Environmental Protection Agency and half from the worldwide motor vehicle industry."
- 3 Health Effects Institute (HEI): Diesel emissions and lung cancer: epidemiology and quantitative risk assessment. Special report of the Institute's diesel epidemiology expert panel. Boston: HEI, 1999.
- 4 Bailey CR, Somers JH, Steenland K. Exposures to diesel exhaust in the International Brotherhood of Teamsters, 1950-1990. *AIHA Journal*. July/August 2003;64(4):472-479.
- 5 "First, in-use emissions data are used and fleet average emissions characterized. Second, dieselization of the trucking fleet is estimated, reflecting a phase-in over time. Third, mechanic exposures were calculated as a function of dieselization of the trucking industry, rather than of diesel truck VMT. Fourth, fleet turnover is simulated using truck-use surveys. Fifth, EC from nondiesel sources is removed from exposure estimates. Finally, exposure distributions, rather than point estimates, are used in each year, which reflects the potential for overlap in exposure among job categories and ambient background exposures."
- 6 The abstract of the article is included at the end of this appendix. The results are consistent with results that were published in the article by Bailey et. al. (2003), which was also referencing the Zaebst study.
- 7 Lee BK, Smith TJ, Garshick E, Natkin J, Reaser P, Lane K, Lee HK. Exposure of trucking company workers to particulate matter during the winter. *Chemosphere*. 2005 December;61(11):1677-1690.
- 8 Note that when this article was written, Hesterberg et al. were employed by, or working as consultants for, the International Truck and Engine Corporation.
- 9 This section contains abstracts for original articles that were not available (Steenland et al., Zaebst et al.) or were not directly on point (Davis et al.).