Appendix D

Health Impacts from On-Road Diesel Vehicles

Assessment of Health Impacts from On-Road Diesel Vehicles

A. Methodology

Details on the methodology used to calculate these estimates can be found in Appendix A of the Emission Reduction Plan for Ports and Goods Movement in California (CARB, 2006).

1. Primary Diesel PM

As part of the development of emission reduction plans and control measures for particulate matter, including that for ports and goods movement, the California Air Resources Board quantifies some of the health impacts of exposure to current and future levels of ambient PM. The estimation of premature death and other health impacts from PM exposure used by CARB staff is based on a peer-reviewed methodology developed by the U.S. Environmental Protection Agency for their risk assessments (US EPA, 1999, 2004, 2005). This methodology is regularly updated by CARB staff as new epidemiological studies and other related studies are published that are relevant to California's health impacts analysis. The methodology uses concentration-response functions which describe the relation between exposure to ambient PM2.5 concentration and premature death and illness. The selection of the concentration-response functions was based on the latest epidemiologic literature, as described in Emission Reduction Plan for Ports and Goods Movement in California (CARB, 2006) and Methodology for Estimating the Premature Deaths Associated with Long-term Exposure to Fine Airborne Particulate Matter in California (CARB, 2008). The central estimate of the relative risk of premature death used in this assessment is a 10% per 10 $\mu g/m^3$ increase in PM2.5 exposures, with a confidence interval of 3% - 20% (CARB, 2008).

For this analysis, staff used a "tons per incident" approach to estimate the health impacts associated with emissions from the on-road trucks and buses. Using the estimated diesel PM concentration for year 2005 (1.6 $\mu g/m^3$), the diesel PM2.5 emissions for year 2005 (37,800 tons), and the concentration-response functions for mortality and morbidity (CARB 2006, 2008), we estimated the number of tons per year of primary diesel PM that can be associated with each case of health endpoint for the year 2005 in California.

For example, using this information for premature mortality, we estimate that for a reduction of 10.8 tons diesel PM2.5 emissions per year, one fewer premature death would result. This factor is derived by first determining the total number of premature deaths from exposure to 1.6 $\mu g/m^3$ of diesel PM2.5, which was estimated to be 3,500 per year. Then the total annual diesel PM2.5 inventory (37,800 tons) is divided by 3,500 premature deaths to calculate the factor of tons per premature death. Although a single statewide factor (tons per case of health endpoint) is discussed in this example, staff actually developed basin-specific factors for the health impacts assessment of emissions from on-road trucks and buses. These basin-specific factors were developed

using basin-specific diesel PM concentrations and emissions for the year 2005. The basin-specific factors were applied to each air basin to estimate health impacts.

a. *Health Impacts of Diesel PM Baseline Emissions*

After adjusting for population changes, staff estimates that baseline PM emissions from in-use on-road diesel vehicles in the years 2010 to 2025 are associated with approximately 1100 annual premature deaths (330 – 2000, 95% CI). Estimates of other health impacts, such as hospitalizations and asthma symptoms, were calculated using basin-specific factors developed from other health studies, basin-specific diesel PM concentrations, and emissions. Details for these estimates can be found in Appendix A of the Emission Reduction Plan for Ports and Goods Movement in California (ARB, 2006).

b. *Benefits of Diesel PM Emissions Reductions*

After adjusting for population changes between each future year and 2005, staff estimates that the cumulative total of approximately 34,600 tons of PM2.5 emissions from on-road trucks reduced through implementation of this regulation in years 2010 – 2025 are associated with a reduction of approximately 3,300 deaths (990 – 6,000, 95% CI). Estimates of other health benefits, such as hospitalizations and asthma symptoms, were calculated using basin-specific factors developed from other health studies.

2. Secondary Diesel PM

In addition to directly emitted PM, diesel exhaust contains NOx, which is a precursor to nitrates, a secondary diesel-related PM formed in the atmosphere that can lead to additional health impacts beyond those associated with directly emitted diesel PM2.5. To quantify such impacts, staff developed population-weighted nitrate concentrations for each air basin using data not only from the statewide routine monitoring network, which was used in Lloyd and Cackette (2001), but also from special monitoring programs such as IMPROVE and Children's Health Study (CHS) in years 2004, 2005 and 2006. The IMPROVE network provided additional information in the rural areas, while the CHS added more data to southern California. Staff calculated the health impacts resulting from the three-year average exposure to these concentrations of PM2.5 and then associated the impacts with the basin-specific NOx emissions from diesel sources to develop basin-specific factors (tons per incident). The basin-specific factors and emissions were applied to each air basin to estimate health impacts. Other health effects were also estimated as outlined above.

Using an approach similar to that used for primary diesel PM and adjusting for population changes between each future year and 2005, staff estimates that the cumulative reduction of approximately 480,000 tons of NOx emissions from the implementation of the on-road truck rule from 2010 to 2025 are associated with the reduction of an estimated 6,100 premature deaths (1,800 – 11,000, 95% CI). Other health effects were also estimated as outlined above.

3. Assumptions and Limitations of Health Impacts Assessment

There are a number of uncertainties involved in quantitatively estimating the health impacts associated with exposure to outdoor air pollution. They include the selection and applicability of the concentration-response functions, the exposure assessment, and the baseline incidence rates. These are briefly described below.

- A primary uncertainty is the choice of the specific studies and the associated concentration-response (C-R) functions used for quantification. Epidemiological studies used in this report have undergone extensive peer review and include sophisticated statistical models that account for the confounding effects of other pollutants, meteorology, and other factors. While there may be questions on whether C-R functions from the epidemiological studies are applicable to California, it should be noted that some of the cities in the ACS cohort are in California. Also, studies have shown that the mortality effects of PM in California are fairly consistent with those found in other locations in the United States (Dominici et al. 2005, Franklin et al. 2007, Jerrett et al. 2005; Pope et al. 2002). The C-R function for PM2.5-related mortality used in this report was based on a careful review of all relevant scientific literature and a thorough consideration of each study's strengths and limitations. In addition, it was approved by our advisors and independent peer reviewers.

- In this assessment, staff assumed diesel PM is as toxic as ambient PM2.5. However, this approach may underestimate the true effects of diesel PM exposure on adverse health outcomes. Indirect evidence for this possibility comes from a number of studies that link motor vehicle-related PM exposure to premature death including: Elderly people living near major roads had almost twice the risk of dying from cardiopulmonary causes (Hoek et al., 2000); PM from motor vehicles was linked to increased mortality (Tsai et al., 2000); PM2.5 from mobile sources accounted for three times the mortality as did PM2.5 from coal combustion sources (Laden et al., 2000).

- This report estimated health impacts due to emissions. The methodology applies a "tons per incident" factor to estimate the number of health effects associated with PM2.5 emissions and assumes the emissions are evenly distributed within the air basin.

- CARB staff assumed the baseline incidence rate for each health endpoint was uniform across each county. This assumption is consistent with methods used by the U.S. EPA for its regulatory impact assessment, and the incidence rates match those used by U.S. EPA.

- Although the analysis illustrates that diesel PM exposure would be associated with health effects to people living in California, we did not provide estimates for all endpoints for which there are C-R functions available. Health effects such as myocardial infarction (heart attack), chronic bronchitis, and onset of asthma were unquantified due to the potential overlap with the quantified effects such as lower

respiratory symptoms and hospitalizations. In addition, estimates of the effects of PM on low birth weight and reduced lung function growth in children are not presented. While these endpoints are significant in an assessment of the public health impacts of diesel exhaust emissions, there are currently few published investigations on these topics, and the results of the available studies are not entirely consistent (CARB, 2006). In summary, because only a subset of the total number of health outcomes is considered here, the estimates should be considered an underestimate of the total public health impact of diesel PM exposure.

B. Health Impacts Associated with Baseline Diesel PM Emissions

Staff estimates that approximately 4,500 premature deaths (1,400 – 8,000, 95 percent confidence interval (95% CI)) are associated with the baseline uncontrolled emissions from on-road trucks and buses in the year 2008. Other health impacts are listed in the Table 1. The methodology for estimating these health impacts is outlined below. Details can be found in Appendix A of the Emission Reduction Plan for Ports and Goods Movement in California (CARB, 2006).

Compared to the estimate for truck emissions presented in the CARB 2006 report, the health impacts presented here differ due to the following reasons:

1) The concentration-response function relating changes in long-term PM2.5 exposure to risk for premature death was updated from Pope et al. 2002 to CARB (2008);

2) The category of "trucks" was expanded to include medium heavy duty trucks or buses;

3) Emissions were estimated based on EMFAC2007;

4) Spatial allocation was updated to reflect real-world variation in emissions throughout California.

In short, the current estimated emissions and the associated health impacts presented in this report are the most up-to-date and reflect the most current understanding on the subject matter.

Table 1: Baseline Health Impacts Associated With Emission from On-Road Trucks and Buses for year 2008*

Endpoint	Pollutant	# of Cases 95% C.I. (Lower Bound)	# of Cases (Mean)	# of Cases 95% C.I. (Upper Bound)
Premature Death	PM	330	1,100	2,000
	NOx	1,000	3,400	6,000
	Total	1,400	4,500	8,000
Hospital admissions (Respiratory)	PM	8	21	35
	NOx	320	560	830
	Total	330	590	860
Hospital admissions (Cardiovascular)	PM	47	90	130
	NOx	330	530	780
	Total	380	620	910
Asthma & Lower Respiratory Symptoms	PM	6,900	18,000	28,000
	NOx	21,000	53,000	83,000
	Total	28,000	71,000	110,000
Acute Bronchitis	PM	0	1,500	3,200
	NOx	0	4,200	8,700
	Total	0	5,700	12,000
Work Loss Days	PM	93,000	110,000	130,000
	NOx	290,000	340,000	390,000
	Total	380,000	450,000	520,000
Minor Restricted Activity Days	PM	520,000	640,000	760,000
	NOx	1,600,000	2,000,000	2,300,000
	Total	2,100,000	2,600,000	3,100,000

* Health effects from primary and secondary PM are labeled PM and NOx, respectively. The sum of PM and NOx impacts may not equal the total given due to rounding. Estimates for premature deaths are based on an updated relative risk of 10% per 10 μg/m^3 change in long-term PM2.5 exposure, with a confidence interval of 3% - 20% (CARB, 2008).

C. Health Benefits of Reduction in Emissions from In-Use Off-Road Vehicles

A substantial number of epidemiologic studies have found a strong association between exposure to ambient PM2.5 and a number of adverse health effects (CARB, 2002). For this report, ARB staff quantified seven noncancer health impacts associated with the change in exposures to the diesel PM emissions. This analysis shows the statewide cumulative health impacts of the emissions reduced through this regulation from year 2010 through 2025. Staff estimates that the cumulative emissions reductions would result in approximately 9,400 fewer premature deaths. Other health impacts are listed below in Table 2.

The impacts associated with primary PM and secondary PM diesel emissions are listed separately. The methodology for estimating these health impacts is outlined above and details can be found in Appendix A of the Emission Reduction Plan for Ports and Goods Movement in California (CARB, 2006).

Table 2: Total Health Benefits Associated with Reductions in Emissions from the Implementation of the On-Road Truck and Bus Regulation (2010-2025)*

Endpoint	Pollutant	# of Cases 95% C.I. (Lower Bound)	# of Cases (Mean)	# of Cases 95% C.I. (Upper Bound)
Premature Death	PM	990	3,300	6,000
	NOx	1,800	6,100	11,000
	Total	2,800	9,400	17,000
Hospital admissions (Respiratory)	PM	23	64	110
	NOx	580	1,000	1,500
	Total	600	1,100	1,600
Hospital admissions (Cardiovascular)	PM	140	270	400
	NOx	590	960	1,400
	Total	730	1,200	1,800
Asthma & Lower Respiratory Symptoms	PM	20,000	53,000	85,000
	NOx	39,000	96,000	150,000
	Total	59,000	150,000	230,000
Acute Bronchitis	PM	0	4,400	9,600
	NOx	0	7,600	16,000
	Total	0	12,000	25,000
Work Loss Days	PM	280,000	330,000	380,000
	NOx	520,000	620,000	710,000
	Total	800,000	950,000	1,100,000
Minor Restricted Activity Days	PM	1,600,000	1,900,000	2,300,000
	NOx	2,900,000	3,600,000	4,200,000
	Total	4,500,000	5,500,000	6,500,000

* Health effects from primary and secondary PM are labeled PM and NOx, respectively. The sum of PM and NOx impacts may not equal the total given due to rounding. Estimates for premature deaths are based on an updated relative risk of 10% per 10 µg/m^3 change in long-term PM2.5 exposure, with a confidence interval of 3% - 20% (CARB, 2008).

D. Economic Valuation of Health Effects

This section describes the methodology for monetizing the value of avoiding adverse health impacts.

The U.S. EPA has established $4.8 million in 1990 dollars at the 1990 income level as the mean value of avoiding one premature death (U.S. EPA, 1999). This value is the mean estimate from five contingent valuation studies and 17 wage-risk studies. Contingent valuation and wage-risk studies examine the willingness to pay (or accept payment) for a minor decrease (or increase) in the risk of premature death. For example, if individuals are willing to pay $800 to reduce their risk of mortality by 1/10,000, then collectively they are willing to pay $8 million to avoid one death. This is also known as the "value of a statistical life" or VSL.[1]

As real income increases, people are willing to pay more to prevent premature death. U.S. EPA adjusts the 1990 value of avoiding a premature death by a factor of 1.201[2] to account for real income growth from 1990 through 2020, (U.S. EPA, 2004). Assuming that real income grows at a constant rate from 1990 until 2030, we adjusted VSL for real income growth, increasing it at a rate of approximately 0.6% per year. We also updated the value to 2007 dollars. After these adjustments, the value of avoiding one premature death is $8.9 million in 2007, $9.2 million in 2010 and $10 million in 2025, all expressed in 2007 dollars.

The U.S. EPA also uses the willingness-to-pay (WTP) methodology for some non-fatal health endpoints, including lower respiratory symptoms, acute bronchitis and minor restricted activity days. WTP values for these minor illnesses are also adjusted for anticipated income growth through 2025, although at a lower rate (about 0.2% per year in lieu of 0.6% per year).

For work-loss days, the U.S. EPA uses an estimate of an individual's lost wages, (U.S. EPA, 2004), which CARB adjusts for projected real income growth, at a rate of approximately 1.5% per year.

"The Economic Value of Respiratory and Cardiovascular Hospitalizations," (CARB, 2003), calculated the cost of both respiratory and cardiovascular hospital admissions in California as the cost of illness (COI) plus associated costs such as loss of time for work, recreation and household production. When adjusting these COI values for inflation, CARB uses the Consumer Price Index (CPI) for medical care rather than the CPI for all items.

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[1] U.S. EPA's most recent regulatory impact analyses, (U.S. EPA 2004, 2005), apply a different VSL estimate ($5.5 million in 1999 dollars, with a 95 percent confidence interval between $1 million and $10 million). This revised value is based on more recent meta-analytical literature, and has not been endorsed by the Environmental Economics Advisory Committee (EEAC) of U.S. EPA's Science Advisory Board (SAB). Until U.S. EPA's SAB endorses a revised estimate, CARB staff continues to use the last VSL estimate endorsed by the SAB, i.e., $4.8 million in 1990 dollars.

[2] U.S. EPA's real income growth adjustment factor for premature death incorporates an elasticity estimate of 0.4.

Table 3 lists the valuation of avoiding various health effects, compiled from CARB and U.S. EPA publications, updated to 2007 dollars. The valuations based on WTP, as well as those based on wages, are adjusted for anticipated growth in real income.

Benefits from the proposed rule for on-road trucks are substantial. CARB staff estimates cumulative benefits over the period from 2010 to 2025 to be $69 billion using a 3% discount rate or $48 billion using a 7% discount rate[3]. A large proportion of the monetized benefits results from avoiding premature death. The estimated benefits from avoided morbidity are approximately $510 million with a 3% discount rate and nearly $350 million with a 7% discount rate. Approximately 68% of the benefits are associated with reduced PM from NOx emissions, and the remaining 32% from direct PM emissions.

Table 3: Undiscounted Unit Values for Health Effects
(at various income levels in 2007 dollars) [1]

Health Endpoint	2007	2010	2025	References
Mortality				
Premature death ($ million)	8.9	9.2	10	U.S. EPA (1999, p. 70-72, 2000, 2004, p. 9-121)
Hospital Admissions				
Cardiovascular ($ thousands)	36	37	54	CARB (2003), p. 63
Respiratory ($ thousands)	44	45	44	CARB (2003), p. 63
Minor Illnesses				
Acute Bronchitis	452	455	471	U.S. EPA (2004), 9-158
Lower Respiratory Symptoms	20	20	21	U.S. EPA (2004), 9-158
Work loss day	191	201	260	2002 California wage data, U.S. Department of Labor
Minor restricted activity day (MRAD)	64	64	67	U.S. EPA (2004), 9-159

[1]The value for premature death is adjusted for projected real income growth, net of 0.4 elasticity. Wage-based values (Work Loss Days) are adjusted for projected real income growth, as are WTP-derived values (Lower Respiratory Symptoms, Acute Bronchitis, and MRADs). Health endpoint values based on cost-of-illness (Cardiovascular and Respiratory Hospitalizations) are adjusted for the amount by which projected CPI for Medical Care (hospitalization) exceeds all-item CPI.

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[3] CARB follows U.S. EPA practice in reporting results using both 3% and 7% discount rates.

E. Conclusion

The health benefits of implementing the proposed regulation are substantial. Staff estimates that the cumulative emissions reductions over the lifetime of the rule can be associated with approximately 9,400 fewer premature deaths, 1,100 fewer hospital admissions due to respiratory causes, 1,200 fewer hospital admissions due to cardiovascular causes, 150,000 fewer cases of asthma-related and other lower respiratory symptoms, 12,000 fewer cases of acute bronchitis, 950,000 fewer work loss days, and 5,500,000 fewer minor restricted activity days. The uncertainty behind each estimated benefit ranges from about 15% to 75% for most endpoints. The estimated statewide benefits over 2010 to 2025 from these reductions in adverse health effects is $48 billion using a 7% discount rate or about $69 billion using a 3% discount rate.

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