Los Angeles County
Metropolitan Transportation Authority

CLEAN TRUCK TECHNOLOGY COMPARATIVE REPORT 5

Air Quality, Climate, and Public Health Implications

METRO GOODS MOVEMENT PLANNING

Metro

MAY 2022

Table of Contents

Nomenclature

EJ	Environmental Justice
CAA	Clean Air Act
CARB	California Air Resources Board
CERP	Community Emissions Reduction Plan
DPM	Diesel Particulate Matter
EMFAC	EMission FACtor Model
EPA	Environmental Protection Agency
GHG	Greenhouse Gas
HD I&M	Heavy-Duty Inspection and Maintenance
ISOR	Initial Statement of Reasons
MATES	Multiple Air Toxics Exposure Study
NAAQS	National Air Ambient Air Quality Standards
NOx	Nitrogen Oxides
PPB	Parts per Billion
PPM	Parts per Million
SCAB	South Coast Air Basin
SCAQMD	South Coast Air Quality Management District
SIP	State Implementation Plan
VMT	Vehicle Miles Traveled
PM	Particulate Matter
LCFS	Low Carbon Fuel Standard
WTW	Well to Wheel
RPS	Renewable Portfolio Standard
RESOLVE	Renewable Energy Solutions Model
bhp-hr	Brake Horsepower Hour
MATES	Multiple Air Toxics Exposure Study
TWC	Three-Way Catalyst
SCR	Selective Catalytic Reduction
H2	Hydrogen
ZEV	Zero Emissions Vehicles
DGE	Diesel Gallons Equivalent
GGE	Gasoline Gallon Equivalent
SLCP	Short-Lived Climate Pollutants
GWP	Global Warming Potential
CPUC	California Public Utilities Commission
CEC	California Energy Commission
EER	Energy Economy Ratio
MJ	Mega Joules
um	Micrometer (10^{-6} m)

1 Background and Overview

The intent of report 5 is to quantify the air quality, and climate change impacts of each of the studied technologies (i.e., diesel, natural gas, battery electric, and hydrogen) over the immediate, short, mid, and long term. This report also provides a discussion on the public health implications of the studied technologies and will use that information to estimate the public health impacts of the technology mix scenario presented in Report 3. We also use the EMFAC2021 model to quantify the NOx, PM2.5 (both exhaust as well as tire and brake wear), as well as diesel PM (DPM) emissions in units of grams per miles to draw a comparison on the air quality impacts of these four technologies. For the purpose of discussing criteria pollutants impacts, we will keep the focus on the vehicle emissions (i.e., downstream emissions). While there are emissions associated with fuel and electricity production and delivery (e.g., emissions from refineries or power plants), those emissions may not necessarily occur within the LA county, and therefore, may or may not have impacts on air quality within the county. For example, currently 30 percent of California electricity is imported from out of state[1] which means that the emissions associated with the production of imported electricity is occurring outside of California.

With respect to climate impacts, this report will provide a comparison of life cycle (i.e., well to wheel or WTW) greenhouse gas (GHG) emissions associated with these four technologies. These WTW GHG emissions are consisted of a) upstream (or well-to-tank) emissions such as crude extraction, fuel transportation, feedstock, fuel production, refinery, power generation, power transmission, and system loss; and b) downstream (or tank-to-wheel) which include the GHG emissions associated with the combustion of the fuel. For the purpose of this study, the scope of the upstream emissions analysis is consistent with California's Low Carbon Fuel Standard (LCFS) which considers GHG emissions for the entire life cycle of fuels regardless of where emission activities occur. To calculate life cycle GHG emissions (WTW) associated with the four fuel technologies considered in this study, we used multiple sources of data, including CARB's 2018 LCFS compliance scenarios as well as 2020 Mobile Source Strategy as follow:

- **Diesel**: Used similar assumption as CARB's 2018 Low Carbon Fuel Standard (LCFS) compliance scenario which assumes that by 2030, almost 50 percent of California's transportation diesel will be renewable and bio diesel (500 million gallons of biodiesel, and 1.1 billion gallons of renewable diesel).
- **Natural Gas**: Similar to diesel, CARB's 2018 LCFS compliance scenario is used to calculate average carbon intensity of natural gas consumed in California's transportation system. According to CARB's low demand/low ZEV compliance scenario, post 2019, 100 percent of natural gas consumed for transportation in California is considered to be renewable natural gas[2] (dairy and landfill). Considering that dairy gas has significantly lower carbon intensity (-255 g per MJ) as compared to landfill gas (+40 g per MJ), we used the similar mix as CARB's LCFS program to calculate a weighted average carbon intensity for renewable natural gas. CARB's 2018 LCFS assumed that by 2030, 24 percent of renewable natural gas will be consisted of dairy gas, and the rest are associated with landfill gas.
- **Electricity**: Similar to 2020 Mobile Source Strategy, and to be consistent with California's Renewable Portfolio Standard (RPS) and SB 100, carbon intensity of electricity is estimated using the electricity generation mix (including contracted imports) and unspecified import information from the 2019 Renewable Energy Solutions (RESOLVE) model outputs. Since this

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[1] California Energy Commission https://www.energy.ca.gov/data-reports/energy-almanac/california-electricity-data/2020-total-system-electric-generation

[2] According to LCFS Quarterly data, in 2021, of more than 178 million DGE of natural gas reported through LCFS, 98% were Bio-CNG and Bio-LNG. This percentage has been reducing rapidly from 2019 levels of 23% and therefore it validates the assumption that in future all of the natural gas consumed by the transportation sector will be of renewable sources.

analysis has been completed by CARB staff as part of the 2020 Mobile Source Strategy, we directly extracted data from that report.

- **Hydrogen:** Similar to electricity, we used the carbon intensity embedded in the 2020 mobile source strategy for hydrogen. CARB's 2020 mobile source strategy assumed that 60 percent of transportation hydrogen will be renewable by 2030, and this fraction will increase to 100 percent by 2045 consistent with SB 662[3]. CARB assumed that California's renewable hydrogen (i.e., green hydrogen) will be produced using curtailed[4] renewable electricity as utilities procure more zero GHG generation to meet the Renewable Portfolio Standard (RPS). In other words, CARB used a carbon intensity of zero for renewable hydrogen.

Aside from the criteria pollutants, toxics (i.e., diesel PM) and GHG emissions associated with these technologies, this report will also discuss some of the unregulated pollutants such as ammonia as well as brake and tire wear emissions.

[3] Archuleta, SB-662 Energy: transportation sector: hydrogen. (2019-2020). http://leginfo.legislature.ca.gov/faces/billTextClient.xhtml?bill_id=201920200SB662

[4] Curtailment refers to intentional reduction in power output below what could have been produced in order to balance energy supply and demand or due to transmission constraints.

2 Public Health Impacts

As discussed in Report 1, air pollution from sources of emissions including Class 8 trucks contribute to a wide variety of adverse health effects. This is why EPA has established national ambient air quality standards (NAAQS) for six of the most common air pollutants namely carbon monoxide (CO), lead, ground-level ozone, particulate matter (PM), nitrogen dioxide (NO2), and sulfur dioxide (SO2) also known as criteria air pollutants (or simply criteria pollutants). Under Clean Air Act, EPA conducts comprehensive review of the scientific literature on health and welfare effects associated with exposure to the criteria air pollutants. The resulting assessments serve as the basis for making regulatory decisions about whether to retain or revise the NAAQS that specify the allowable concentrations of each of these pollutants in the ambient air. Typically, the NAAQS are set at a level intended to protect public health, including the health of at-risk populations, with an adequate margin of safety. The Clean Air Act does not require EPA to establish NAAQS at a zero-risk level, but rather at a level that reduces risk sufficiently so as to protect public health with an adequate margin of safety. This is one of the main reasons that attainment with NAAQS is often used as a mean to improve and protect public health in various regions of the country.

According to the latest Ozone NAAQS established by U.S. EPA in 2015[5], the South Coast Air Basin where LA County is residing is one of the only two areas in the country that is designated as an "extreme" ozone nonattainment area. As an "extreme" ozone nonattainment area, SCAQMD has until August 3, 2038 to attain the 2015 Ozone NAAQS for the Basin, which is 20 years from the designation as an "extreme" nonattainment area. Aside from the 2015 Ozone NAAQS, the South Coast Air Basin is still in non-attainment with both 1997 and 2008 Ozone NAAQS of 80 and 75 ppb, respectively.

Aside from the regional air quality issues (e.g., non-attainment with NAAQS), there are many communities in LA County, often disadvantaged communities neighboring major freight facilities, that are suffering from high exposure to toxic air contaminants and elevated levels of local air pollution. For example, communities adjacent to Ports, rail yards and warehouses are exposed to higher levels of DPM, a carcinogen in California,[6] that is associated with emissions from diesel ships, locomotives, and trucks. Scientific studies have linked elevated long-term air concentrations of DPM to health effects for communities surrounding the Ports. These health effects include exacerbation of asthma, increased hospitalizations, premature birth, and premature deaths from heart and/or lung diseases[7].

To further elaborate the environmental justice issues in the LA County, Figure 1 shows a side-by-side comparison of asthma, cardiovascular disease cases (from CalEnviroScreen 4.0), and air toxics cancer risk (from MATES V study) to poverty levels (from CalEnviroScreen 4.0) in LA County. As shown, regions with higher levels of poverty, especially those surrounding the ports, are the ones suffering from elevated levels of asthma and cardiovascular disease cases as well as high levels of air toxics cancer risk. This clearly shows the significant role of emissions mobile sources, especially heavy-duty trucks, in creating adverse health impacts and environmental justice issues in LA County.

Here in this section, we will first describe the specific health outcomes of exposure to criteria pollutants considered in this study and will quantify the public health benefits of reducing air pollution by transitioning Class 8 trucks to zero and near-zero emission technologies. As part of this report, we will also monetize the health benefits resulting from such transition. In quantifying the impacts, we will leverage the scenario modeling conducted under Report 3.

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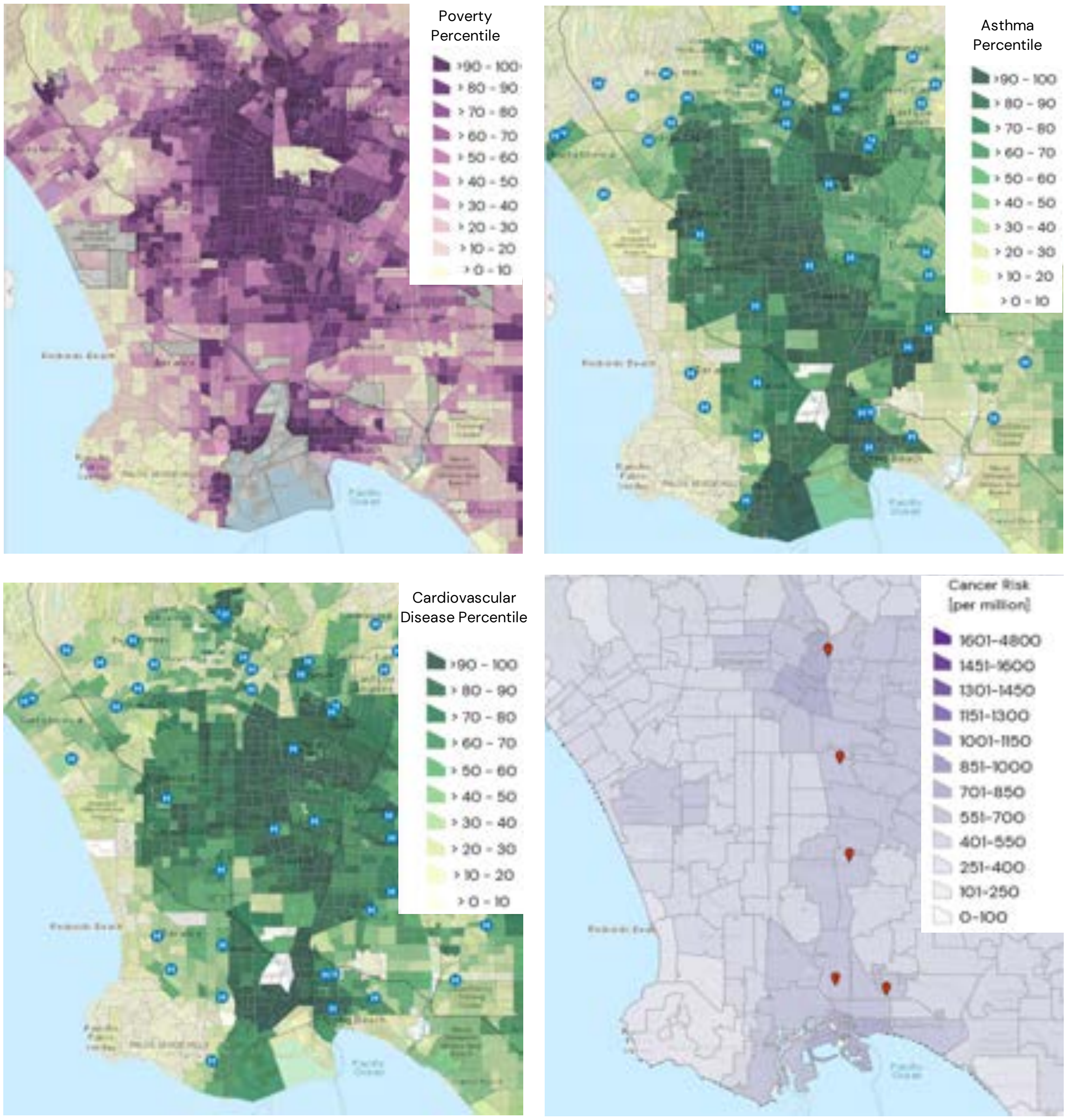
[5] In 2015, the U.S. EPA established a new ozone standard of 70 ppb. The design value of an air basin for the 2015 8-hour ozone standard is determined by the highest ozone value of all stations, based on a 3-year average.

[6] Note that while diesel PM is considered as a carcinogen in California, U.S. EPA does not identify it as a carcinogen

[7] Pope et al. 1995, 2002; Jerrett et al. 2005, Krewski et al, 2001

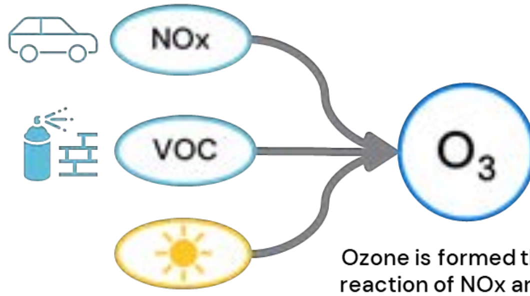
Figure 1. Poverty (top left), asthma cases (top right), cardiovascular disease (bottom left), and air toxics cancer risk (bottom right) in LA County[8]



[8] Based on CalEnviroScreen 4.0 at: https://oehha.ca.gov/calenviroscreen/report/calenviroscreen-40 and MATES V Multiple Air Toxics Exposure Study at: http://www.aqmd.gov/home/air-quality/air-quality-studies/health-studies/mates-v

2.1 Ozone

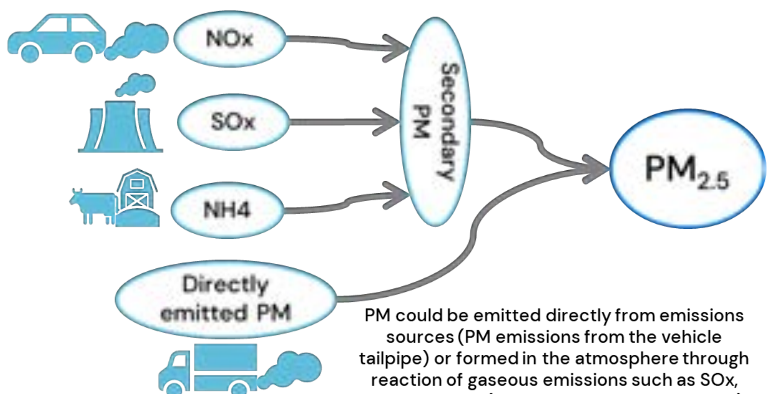
As described in Report 1, ground level ozone is mainly formed through the reaction of NOx and VOC emissions – pollutants that are known as ozone precursors. According to U.S. EPA, short-term exposure to ground-level ozone can cause a variety of respiratory health effects, including inflammation of the lining of the lungs, reduced lung function, and respiratory symptoms such as cough, wheezing, chest pain, burning in the chest, and shortness of breath. Exposure to ambient concentrations of ozone has been associated with the aggravation of respiratory illnesses such as asthma, emphysema, and bronchitis, leading to increased use of medication, absences from school, doctor and emergency department visits, and hospital admissions. Short-term exposure to ozone is associated with premature mortality.



Ozone is formed through reaction of NOx and VOC in the presence of sunlight

2.2 Particulate Matter (PM)

Particulate matters or PM is a generic term that is used to describe a broad class of chemically and physically diverse substances that exist as discrete particles (liquid droplets or solids) over a wide range of sizes. PM could be emitted directly from emissions sources (PM emissions from the vehicle tailpipe) or formed in the atmosphere through reaction of gaseous emissions such as SOx, NOx, and NH4 (also known as secondary PM). In general particulate matters are grouped by their size into PM10 and PM2.5. PM2.5 refers to particles with diameter less than 2.5 micrometer (um), whereas PM10 refers to particles of diameter between 2.5 um and 10 um. Studies have demonstrated that short or long-term exposure to both PM2.5 and PM10 could result in adverse health effects such as premature mortality, aggravation of respiratory and cardiovascular disease (e.g., increased hospital admissions and emergency visits), and changes in sub-clinical indicators of respiratory and cardiac function.



PM could be emitted directly from emissions sources (PM emissions from the vehicle tailpipe) or formed in the atmosphere through reaction of gaseous emissions such as SOx, NOx, and NH4 (also known as secondary PM)

2.3 Diesel Particulate Matter (DPM)

Diesel PM is a type of generic PM (that was described in section 2.2) that is generated through combustion of diesel fuel in an internal combustion engine. In 1998, CARB identified DPM as a toxic air contaminant[9] based on published evidence of a relationship between diesel exhaust exposure and lung cancer and other adverse health effects. These health impacts are of particular concern for communities surrounding the goods movement facilities. These health effects include exacerbation of asthma, increased hospitalizations, premature birth, and premature deaths from heart and/or lung diseases (Pope et al. 1995, 2002; Jerrett et al. 2005, Krewski et al, 2001). More than 90% of DPM is less

[9] According to section 39655 of the California Health and Safety Code, a toxic air contaminant (TAC) is "an air pollutant which may cause or contribute to an increase in mortality or an increase in serious illness, or which may pose a present or potential hazard to human health.". A complete list of TACs can be found at: https://oehha.ca.gov/air/general-info/toxic-air-contaminant-list-staff-reportsexecutive-summaries

than 1 μm in diameter (about 1/70th the diameter of a human hair) which is small enough to be inhaled into the lungs and be deposited on the surface of the lungs. DPM is typically composed of carbon particles also called black carbon, and numerous organic compounds, including over 40 known cancer-causing organic substances[10]. Examples of these chemicals include polycyclic aromatic hydrocarbons, benzene, formaldehyde, acetaldehyde, acrolein, and 1,3-butadiene. According to CARB's analysis, it is estimated that about 70% of total known cancer risk related to air toxics[9] in California is attributable to DPM. Based on 2012 estimates of statewide exposure, DPM is estimated to increase statewide cancer risk by 520 cancers per million residents exposed over a lifetime. Non-cancer health effects associated with exposure to DPM (based on 2014 - 2016 air quality data) are shown in **Error! Reference source not found.**.

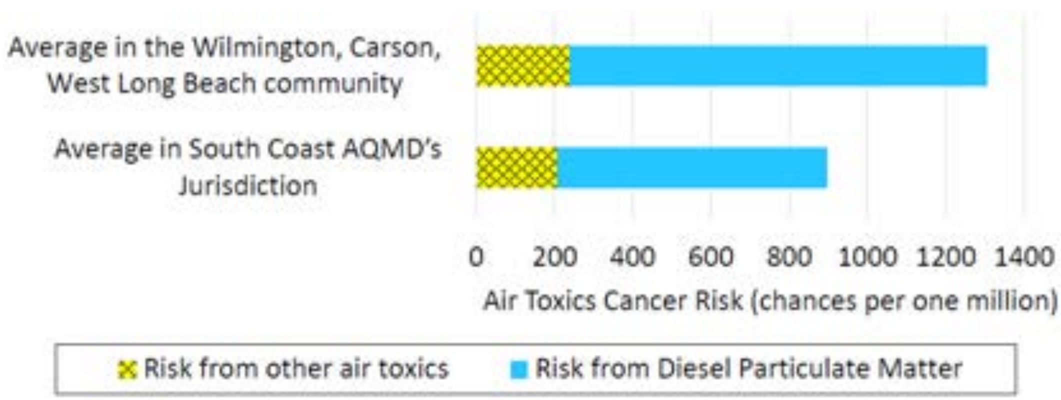
Table 1. Non-cancer health effects associated with exposure to DPM at Statewide Level

Health Effect	Estimated Annual Number of Cases*
Cardiopulmonary Death	730 (570 – 890)
Hospitalizations (Cardiovascular and Respiratory)	160 (20 – 290)
Emergency Room Visits for Asthma	370 (240 – 510)

*Values in parenthesis indicate 95% confidence interval.

Note that DPM is unique to diesel technology. While other fuel technologies such as natural gas emit PM2.5 emissions, their emissions are not considered as DPM. Although, other pollutants result in negative public health impacts, DPM is still considered as the major contributor to air toxics cancer risk in both disadvantaged communities as well as the whole South Coast Air Basin. Figure 2 extracted from South Coast AQMD CERP for Wilmington, Carson, and West Long Beach communities, illustrate the air toxics cancer risk both in these communities as well as the whole South Coast AQMD's jurisdiction. This graph shows how mitigating diesel PM emissions could significantly enhance public health especially in low income and disadvantaged communities near major freight facilities and corridors, and why DPM reduction should be at forefront EJ policies in California.

Figure 2. Air toxics cancer risk in South Coast, based on MATES IV modeled data[11]



2.4 Nitrogen Dioxide (NO2)

Mobile sources especially diesel vehicles and equipment are major sources of nitrogen oxides emissions such as NO and NO2 emissions. NO emissions when released from vehicle tailpipes quickly convert to NO2 in the atmosphere. Exposure to NO2 is known to create various health related issues

[10] https://ww2.arb.ca.gov/resources/overview-diesel-exhaust-and-health
[11] https://www.aqmd.gov/nav/about/initiatives/environmental-justice/ab617-134/wilm/cerp

such as respiratory related hospital admission and emergency visits especially among children and older adults.

2.5 Public Health Benefits of Transition to Zero and Near-Zero Emissions Technologies

As discussed thoroughly in Report 1, meeting the U.S. EPA health-based ozone NAAQS in the South Coast region requires significant reduction of NOx emissions. As illustrated in Report 3, the adoption and implementation of regulations such as HD Omnibus, Advanced Clean Truck (ACT), Heavy Duty Inspection and Maintenance (HD I/M), and Advanced Clean Fleet (ACF) regulations will result in significant reductions of NOx, PM2.5, as well as GHG emissions in LA County. Table 2 below shows the level of emissions reductions that the project team quantified for Class 8 trucks in LA county. More details can be found in Report 3.

Table 2. Criteria emissions reductions associated with the proposed technology mix under Report 3

Year	NOx Benefit (tpd)	PM2.5 Benefit (tpd)
2024	5	0.05
2025	8.6	0.09
2026	9.9	0.1
2027	11.4	0.12
2028	12.6	0.13
2029	13	0.13
2030	13.4	0.14
2031	14	0.15
2032	14.5	0.16
2033	14.8	0.16
2034	15.2	0.17
2035	15.7	0.18
2036	15.8	0.18
2037	16.1	0.18
2038	16.3	0.19
2039	16.5	0.19
2040	16.7	0.19

To quantify the health benefits associated with these emissions reduction, the project team used the incidence-per-ton (IPT) methodology developed by U.S. EPA[12]. Under this methodology, changes in emissions are assumed to be proportional to changes in health outcomes. U.S. EPA calculated the IPT factors by estimating the number of health outcomes associated with exposure to PM2.5 as well as ozone. These health outcomes are estimated using the Benefits Mapping and Analysis Program (BenMAP) software developed by U.S. EPA which calculates the number and economic value of air pollution-related deaths and illnesses. The software incorporates a database that includes many of the concentration-response relationships, population files, and health and economic data needed to quantify these impacts. While EPA's most recent published IPT include values for both ozone and

[12] https://www.epa.gov/benmap/estimating-benefit-ton-reducing-directly-emitted-pm25-pm25-precursors-and-ozone-precursors

PM2.5, here in this report, we focused our assessment on health benefits from reduced exposure to ambient PM2.5 through reductions of directly emitted PM2.5, and PM2.5 precursors (i.e., NOx). This is mainly because the health outcomes of exposure to ambient PM2.5 are much more significant than ozone. According to a study conducted by MIT researchers (Caiazzo et al., 2013[13]), the mortality effects of PM2.5 are likely to be much larger than those of ozone, 10 times as large for all road transportation in 2005. Also as illustrated in Appendix I (Health Effects)[14] of the draft 2022 South Coast Air Quality Management Plan (AQMP), of the $173 billion monetized health benefits resulting from the emission reductions in South Coast air basin between 2017 – 2031, almost 95 percent of those are associated with health benefits from reduced exposure to PM2.5 and only 5 percent associated with those from reduced exposure to ozone. Aside from the significantly higher health benefits associated with reduced exposure to PM2.5, the complex, non-linear photochemical processes that govern ozone formation is also another factor that makes IPT method relatively uncertain when quantifying ozone health benefits. As described in Report 1, under "VOC limited" regime, reducing NOx emissions could sometimes lead to increased ozone. Quantifying health benefits through reduced exposure to PM2.5 is also a common practice that CARB has been using throughout its regulatory development.

For the purpose of this report, we quantified values associated with four health outcomes of:

- Mortality
- Emergency Room (ER) Visits Respiratory
- Hospital Admissions Respiratory
- Work Loss Days.

For each of these health outcomes, the project team extracted the IPT factors from the 2022 U.S. EPA Technical Support Document titled "Estimating the Benefit per Ton of Reducing Directly-Emitted PM2.5, PM2.5 Precursors and Ozone Precursors from 21 Sectors". Considering that all the emissions reductions presented in Table 2 are from mobile sources, the project team used the IPT factors for the Internal Combustion Engine estimated for California. Details on IPT factors used can be found in Appendix A. Combining the IPT factors and the estimated emissions reductions for NOx and PM2.5, the project team estimated the PM2.5 related health benefits resulting from the adoption of zero and near-zero emission technologies as described in Report 3. These health benefits are illustrated in

[13] Caiazzo, Fabio, et al. "Air pollution and early deaths in the United States. Part I: Quantifying the impact of major sectors in 2005." Atmospheric Environment 79 (2013): 198-208.

[14] http://www.aqmd.gov/docs/default-source/clean-air-plans/air-quality-management-plans/2022-air-quality-management-plan/combined-appendix-i.pdf?sfvrsn=8

Table 3. Please note that these health benefits are only associated from Class 8 trucks in LA County.

Table 3. Health benefits associated with emissions reductions from Class 8 trucks in LA County

Year	Mortality All Cause	ER visits respiratory	Hospital Admissions Respiratory	Work Loss Days
2024	10 – 10	6	1	1,613
2025	16 – 15	10	2	2,744
2026	19 – 18	11	2	3,154
2027	22 – 22	13	3	3,666
2028	25 – 25	15	3	4,054
2029	26 – 26	15	3	4,179
2030	27 – 27	16	3	4,341
2031	29 – 29	17	3	4,570
2032	31 – 31	18	4	4,772
2033	32 – 33	18	4	4,874
2034	34 – 35	19	4	5,051
2035	36 – 37	20	4	5,212
2036	37 – 39	20	4	5,269
2037	39 – 40	21	4	5,383
2038	40 – 42	21	4	5,515
2039	42 – 44	22	4	5,602
2040	48 – 52	23	5	5,844
Cumulative 2024 - 2040	**511 - 524**	**285**	**57**	**75,843**

As shown, between 2024 and 2040, the technology mix presented in Report 3 combined with the reduction in emissions resulting from the HD I/M and ACF regulations will results in approximately 511 – 524 reduced mortality, 285 less respiratory related ER visits, 57 less respiratory related hospital admission, and almost 75,000 less work loss days in LA County. Please note that for mortality rates, U.S. EPA IPT factors provide a low and a high range. This is why we are presenting a range for reduction in mortality under

Table 3.

In addition to quantifying the health benefits, the project team also quantified the economic value of avoided health impacts. In addition to IPT values, U.S. EPA also provide the benefit per ton (BPT) values which are the monetized value of avoided health outcomes associated with reduced exposure to PM2.5. These values are reported in 2016$. Considering that economic value of health benefits is accumulated over time, U.S. EPA uses two sets of discount rates, 3 and 7 percent[15], to adjust future costs and outcomes of health-care interventions to present value.

[15] The 3 percent discount rate reflects society's valuation of differences in timing of benefit while the 7 percent discount rate reflects the opportunity cost of capital to society.

Table 4 shows the monetized health outcomes resulting from the technology mix scenario presented in Report 3. Considering that EPA uses a range for mortality rates, the monetized health benefit is also presented as a range.

Table 4. Monetized health outcomes associated with emissions reductions from Class 8 trucks in LA County

Year	3 Percent Discount ate		7 Percent	
	Low	High	Low	High
2024	$104,348,400	$93,740,400	$105,331,200	$94,707,600
2025	$180,588,720	$162,230,640	$182,295,360	$163,909,200
2026	$206,887,200	$185,855,280	$208,837,200	$187,774,080
2027	$239,578,560	$215,223,840	$241,843,680	$217,451,520
2028	$264,067,440	$237,222,960	$266,560,320	$239,675,280
2029	$271,305,840	$243,725,040	$273,861,120	$246,239,760
2030	$286,980,096	$257,876,736	$291,441,696	$262,070,016
2031	$306,823,920	$275,779,920	$313,391,520	$281,832,720
2032	$325,299,936	$292,458,816	$334,088,976	$300,473,472
2033	$337,339,392	$303,356,352	$348,284,352	$313,262,976
2034	$354,650,400	$318,995,040	$367,991,520	$331,019,520
2035	$378,426,048	$340,368,288	$394,969,536	$355,321,824
2036	$391,292,928	$351,931,008	$410,668,128	$369,472,896
2037	$408,610,176	$367,494,816	$431,087,904	$387,872,160
2038	$427,462,464	$384,443,904	$453,185,616	$407,784,000
2039	$443,227,200	$398,611,200	$472,087,200	$424,819,200
2040	$459,681,456	$413,324,496	$492,024,624	$442,678,080
Cumulative 2024- 2040	**$5,386,570,176**	**$4,842,638,736**	**$5,587,949,952**	**$5,026,364,304**

As shown, the project team estimated that the technology mix presented in Report 3 could results in avoided health cost of approximately $5 billion in LA County. This illustrates that despite the cost associated with the transition to zero and near-zero technology (e.g., higher upfront cost of zero emission trucks as well as cost of zero emission infrastructure buildout), such transition could result in significant health benefits often exceeding the cost of transition.

In the rest of this report, we will focus on a comparison of criteria and GHG emission on vehicle basis across the four technology types (i.e., diesel, natural gas, electric, and hydrogen).

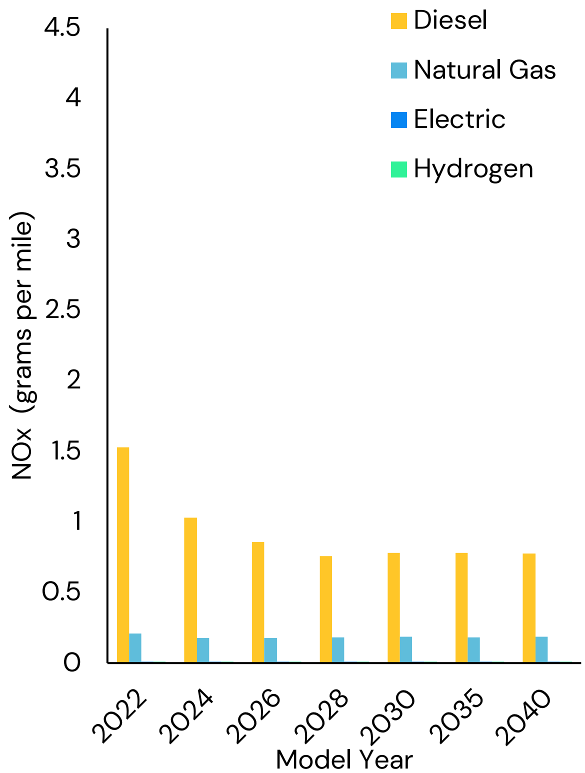
3 Criteria Pollutants

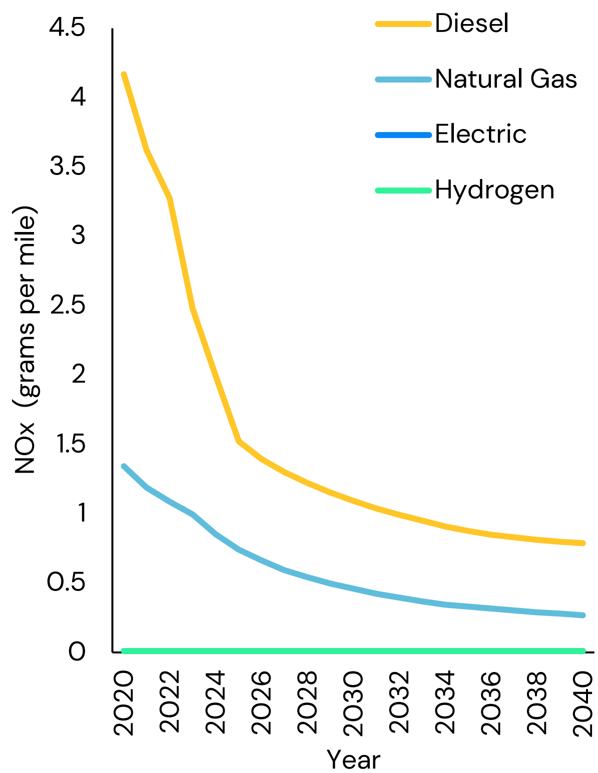
This section provides a comparison of NOx, exhaust PM2.5 and diesel PM emissions across the four different technologies. As described in Section 1, these emissions are only reflective of the downstream emissions and do not account for the criteria emissions related to production and delivery of the fuel/electricity.

3.1 NOx

Starting with NOx, Figure 3 shows a comparison of NOx emissions in units of grams per mile for both new and average in-use vehicles[16].

Figure 3. Comparison of in-use NOx emissions for a) new vehicles (left panel) and b) an average in-use vehicle (right panel) in LA County





As shown in Figure 3, a brand new 2022 model year Class 8 diesel engine is expected to emit around 1.5 grams per mile of NOx emissions whereas emissions for an equivalent Class 8 natural gas truck is assumed to be 86 percent lower than that at 0.2 g/mile. For electric and hydrogen vehicles the tailpipe NOx emissions are assumed to be zero and therefore, they do not show up in this graph. With the adoption of the CARB's Heavy Duty Low NOx Omnibus (HD Omnibus) Regulation[17], the emission rates for diesel engines sold in California are expected to be significantly reduced between 2024 through 2031. As described in Report 2, the HD Omnibus Regulation requires all heavy-duty engines of model year 2024-2026 to meet 0.05 g/bhp-hr NOx standard, with more stringent standards (0.02 g/bhp-hr) for the subsequent model years. This is compared to 0.2 g/bhp-hr standards for 2010 through 2023 model year engines. However, these standards only apply to engines sold in California and does

[16] An average in-use vehicle refers to all model years within a certain calendar year. The emission factor for an average in-use vehicle is calculated as VMT weighted average of emission factors for all model year within a specific calendar year.
[17] https://ww2.arb.ca.gov/rulemaking/2020/hdomnibuslownox

not impact engines that are originally sold in other states and brought into California as used truck. Additionally, these standards do not apply to out of state trucks that travel within California but are registered in other states. Currently, California considers any vehicle with more than 7,500 miles on their odometer at the time of purchase or trade by a California resident or business, to be a used vehicle. According to CARB's staff analysis[18], a significant fraction of Class 8 trucks registered in California were originally purchased outside of California. Considering that Class 8 long haul trucks travel more than 100,000 miles per year, 7,500 miles is less than one month worth of driving on a Class 8 truck. This is why despite the HD Omnibus regulation reducing NOx emissions from diesel engines by more than 90 percent (for model years 2027 and onward), in reality, NOx emissions from an average brand-new diesel Class 8 trucks operating in LA County will only drop by 50 percent over the next 10 years. As described, this is mainly due to the high fraction of trucks operating in LA county that are not subject to HD Omnibus Regulation. However, if U.S. EPA follows California's footsteps and adopt stringent NOx standards for heavy duty engines to be applied nationwide, then a much more significant reduction in NOx emissions from Class 8 diesel trucks will be expected. Considering the uncertainties with federal actions on HD Low NOx engine standards, this report does not quantify the potential emission reductions from the EPA Clean Truck Plan[19].

With respect to natural gas, currently CARB's EMFAC2021 model assumes that natural gas engines of model year 2018 and newer are all certified to 0.02 g/bhp-hr standards (also known as the optional low NOx standards prior to the adoption of HD Omnibus regulation). In EMFAC2021, CARB staff used data from a comprehensive emission testing program conducted by the University of California, Riverside in collaboration with West Virginial University to quantify real world emissions associated with Low NOx natural gas engines (i.e., 0.02 g/bhp-hr certified engines). According to this study, these engines emit approximately, 0.2 grams per mile of NOx when operating in LA County which is 85 percent cleaner that 2022 model year diesel engines, and 75 percent cleaner than an average brand-new diesel engine operating in LA County in 2030.

In addition to NOx emissions from brand new vehicles, this report also quantifies NOx emissions from an average in-use Class 8 truck[20] operating in LA County (right panel of Figure 3). As shown, NOx emissions from both natural gas and diesel engines will be substantially reduced over the next two decades. For diesel engines, this reduction is mainly driven by a) the full implementation of the truck and bus regulation in California which will require all heavy duty diesel trucks operating in California to transition to 2010 or newer technology by 2023, b) the adoption of the HD Omnibus regulation which will require new diesel engines sold in California to meet lower emission standards, and c) the adoption of the Heavy Duty Inspection and Maintenance (HD I/M) program which will require heavy duty diesel engines in California to undergo semi-annual inspection and repair any malfunctioning emission control system. As a result of these three major policies, NOx emissions from an average in-use diesel truck will be reduced by more than 80% from 2022 through 2040. With respect to natural gas-powered vehicles, average in-use NOx emissions are expected to drop by almost 80 percent from 2022 through 2040 as new engines are emitting at much lower levels (i.e., 0.02 g/bhp-hr) than older natural gas engines deployed prior to 2018 in California.

3.2 Particulate Matter

As described earlier, particulate matters or PM is a generic term that is used to describe a broad class of chemically and physically diverse substances that exist as discrete particles (liquid droplets or solids) over a wide range of sizes. For vehicles, PM emissions are generated through a) the combustion of fuel in an internal combustion engine also known as "Exhaust PM2.5", b) the friction between tires

[18] https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2019/act2019/appf.pdf

[19] https://www.epa.gov/regulations-emissions-vehicles-and-engines/proposed-rule-and-related-materials-control-air-1

[20] An average in-use vehicle refers to all model years within a certain calendar year. The emission factor for an average in-use vehicle is calculated as VMT weighted average of emission factors for all model year within a specific calendar year.

and the road surface also known as "tire wear PM", and c) the friction of the brake pads and the brake disc also known as "brake wear PM". The exhaust PM emissions are also referred to as diesel PM if they are generated through the combustion of diesel fuel in an internal combustion engine. Here in this section, we will describe different types of PM emissions associated with Class 8 trucks.

3.2.1 Exhaust PM2.5

To compare PM2.5 emissions from the four studied technologies, we will first discuss the exhaust PM2.5 (i.e., tailpipe emissions) and then provide insights on PM2.5 associated with tires and brakes in a separate subsection. Similar to NOx emissions, Figure 4 illustrate a comparison of PM2.5 exhaust emissions for both brand-new trucks as well as an average in-use truck. As shown on the left panel of Figure 4, currently, a brand-new diesel engine emits approximately 0.013 grams per miler (13 mg per mile) of exhaust PM2.5 emissions and those emissions are expected to slightly drop to 0.011 grams per mile for 2024 and newer model years. Note that the small deviations for post 2024 model years could be attributed to changes in fleet mix and duty cycles (e.g., EMFAC assumes different speed profiles for future years which could lead to slightly different emissions profiles for future model years). While HD Omnibus regulation set 50 percent lower emission standards for heavy duty diesel engines (i.e., 0.005 g/bhp-hr), considering that most current diesel engines (e.g., model year 2016 and newer) have PM certification levels around 0.001 g/bhp-hr (10 times lower than 2007 EPA HD engine PM standard of 0.01 g/bhp-hr), the regulation is not expected to significantly impact PM2.5 emissions from the Class 8 diesel trucks. The very low PM emissions from current diesel trucks is mainly due to the use of diesel particulate filters which in certain cases have the ability to capture more than 99 percent of the diesel PM produced during combustion. This is one of the main reasons that properly functioning diesel particulate filters is critical to keep PM emissions from these trucks at low levels. In case these filters fail, emissions from these trucks can increase by a factor of 10 – 100.

The reduction in PM emissions from 2022 through 2024 is mainly attributed to the impact of HD I/M program which can reduce PM emissions by up to 15 percent even during the first year of the vehicle operation[21]. With respect to natural gas vehicles, PM2.5 emissions for 2022 through 2040 model years are 85 percent lower than their diesel counterparts. Considering that most of these engines are stoichiometric[22], the low level of PM emissions are expected in these engines. Similar to NOx discussion, we do not anticipate any exhaust PM2.5 emissions from battery electric and hydrogen powered vehicles.

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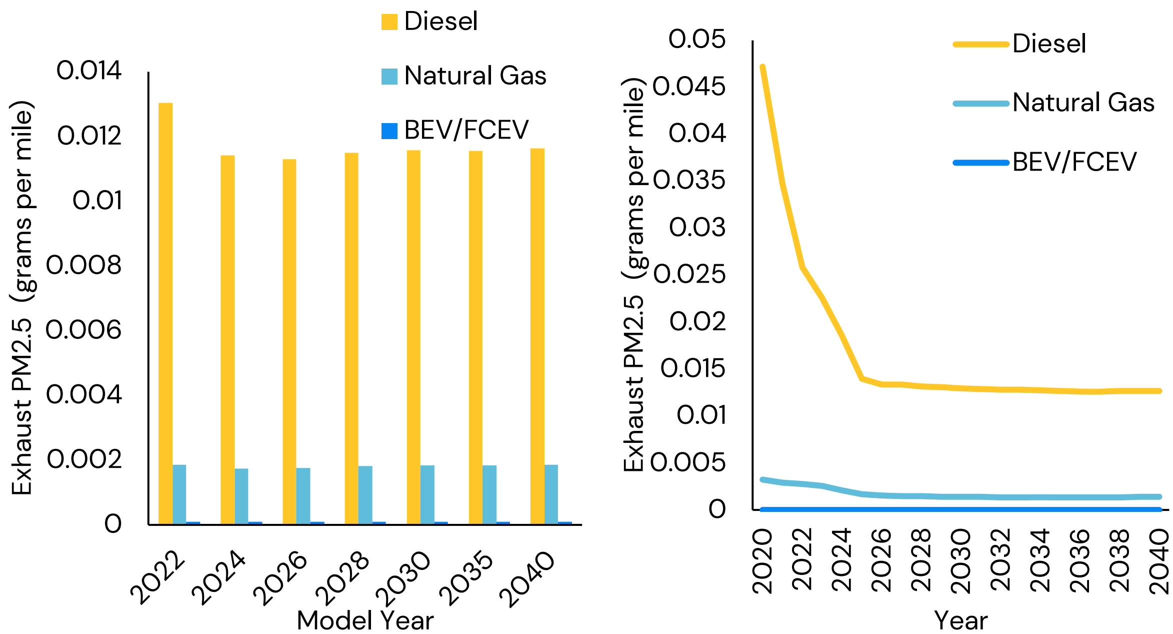
[21] This is based on CARB's assessment of the HD I/M regulation which showed 15 percent reduction in PM emissions from class 8 line haul trucks during their first year of operation.

[22] In an internal combustion engine, the air–fuel ratio is an important measure for anti-pollution and performance-tuning reasons. If exactly enough air is provided to completely burn all of the fuel, the ratio is known as the stoichiometric mixture. Gasoline and most of today's natural gas engines are burn fuel under stoichiometric condition.

Figure 4. Comparison of in-use exhaust PM2.5 emissions f for a) new vehicles (left panel) and b) an average in-use vehicle (right panel) in LA County



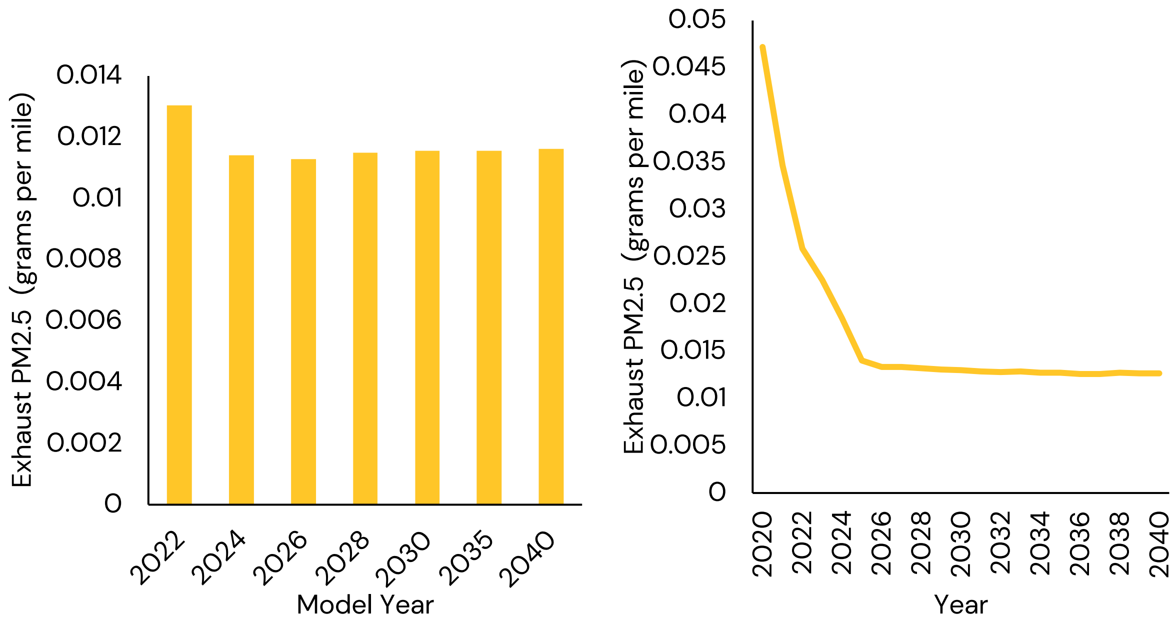
The right panel of Figure 4 illustrates the in-use PM2.5 emissions from an average Class 8 trucks operating in LA County (i.e., weighted average across all model years). Similar to NOx graphs, emissions from diesel engines are expected to significantly drop as a result of a) the full implementation of the truck and bus regulation in California which will require all heavy duty diesel trucks operating in California to transition to 2010 or newer technology by 2023 where all diesel trucks will be equipped with diesel particulate filters, and b) the implementation of HD I/M program which, starting in 2023, will require heavy duty diesel engines in California to undergo semi-annual inspection and repair any malfunctioning emission control system.

With respect to natural gas-powered trucks, exhaust PM2.5 emissions drop by more than 57 percent from 2022 through 2040 as legacy compression ignition natural gas trucks are being replaced with stoichiometric Low NOx natural gas trucks that have significantly lower PM and NOx emissions.

3.2.2 Diesel PM (DPM)

Figure 5 shows the diesel emissions associated with both brand-new Class 8 diesel trucks as well as an average in-use diesel truck. Considering that only diesel trucks have DPM emissions, the emissions of DPM for all other technologies are assumed to be zero. Similar to PM2.5, DPM emissions from brand new diesel trucks drop slightly between 2022 to 2024 as a result of HD I/M, but no further reduction is expected either due to the HD Omnibus regulation or any other policies that CARB has adopted so far. With respect to in-use emissions from an average Class 8 diesel truck operating in LA county, DPM emissions from diesel trucks are expected to drop by more than 73 percent from 2020 through 2040 as a result of both the full implementation of the Truck and Bus rule as well as the implementation of HD I/M program.

Figure 5. Comparison of in-use DPM emissions for a) new vehicles (left panel) and b) an average in-use vehicle (right panel) in LA County



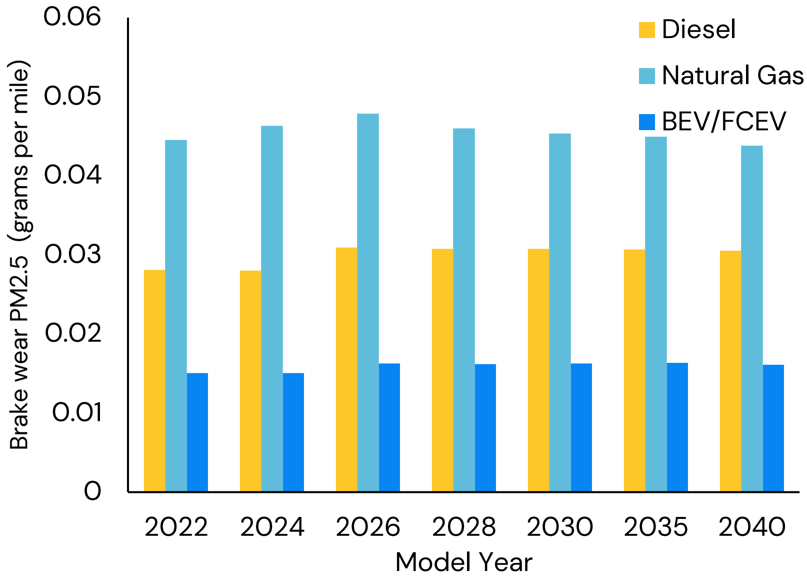
3.2.3 Tire and Brake Wear PM2.5

Tire and brake wear PM refer to airborne particle that are released from on-road vehicles as they drive on the roadways. The tire wear is resulting from the friction between the asphalt and the tire (including tire sliding on the road), and brake wear refer to brake materials released in the form of airborne particles as the vehicle brakes. Currently due to lack of data, EMFAC2021 model assumes similar tire wear emissions for all technologies of trucks Of course, the weight of the truck could impact the amount of tire wear emissions[23]; however, due to lack of testing data, we cannot confidently speak to the impact of electrification and heavier batteries on the tire wear emissions from battery electric trucks. Currently the EMFAC2021 model assumes a tire wear emission of 0.009 grams per mile of PM2.5 (9 mg per mile) for Class 8 trucks. It is noteworthy to mention, that total PM emissions from tire wear are higher than this number, as most of the airborne particles released as a result of tire wear are larger than 2.5 um.

While tire wear emissions do not vary across different technologies, this is not the case for brake wear emissions. Brake wear emissions are sensitive to duty cycles and operation of the truck. For example, trucks with stop-n-go type operations (e.g., refuse trucks) are expected to have much higher brake wear emissions as compared to trucks that are mostly cruising on highways (e.g., line hauls). Additionally, battery and fuel cell electric technologies are equipped with regenerative braking systems which uses the electric motor to reduce the speed of the vehicle and recoup the kinetic energy, as opposed to using the actual brakes. As a result, these vehicles are expected to have significantly lower brake wear emissions than their counterpart diesel or natural gas. Figure 6 compare the brake wear PM2.5 emissions across the four technologies.

[23] Note that as compared to passenger vehicles, the excess weight of battery to total weight of the class 8 tractor-trailer combination truck could be relatively smaller. Therefore, it is expected that the potential increase in tire wear emissions in battery electric trucks (in percent over baseline) to be relatively smaller than passenger vehicles.

Figure 6. Brake wear PM2.5 emissions from Class 8 trucks extracted from CARB's EMFAC2021 model in LA County



As shown, natural gas trucks in LA County exhibit the highest brake wear emissions mainly due to their current duty cycles. Today most of the natural gas-powered Class 8 trucks operating in LA county are either refuse or public trucks which often operate within urban areas and make frequent stops and therefore emit higher levels of brake wear emissions. Under a scenario where natural gas technology adoption expands into other truck categories and duty cycles, their brake wear emissions are expected to be reduced and line up with their diesel counterparts. With respect to battery and fuel cell electric vehicles, as described, these vehicles utilize regenerative braking technology which reduces their brake wear emissions significantly.

3.3 Ammonia

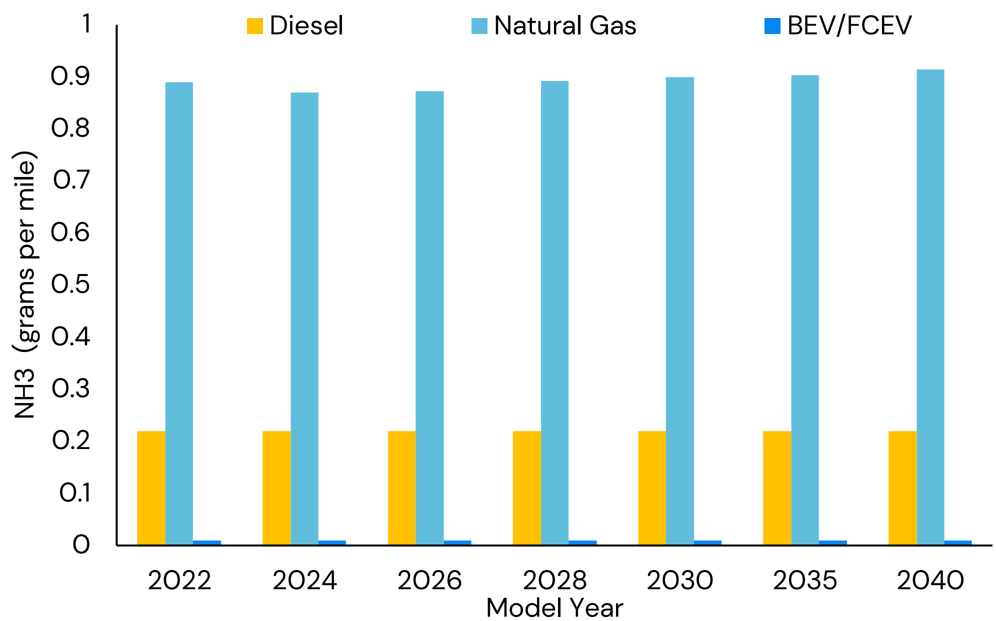
Ammonia (NH3) emissions contribute significantly to the formation of PM2.5 in the atmosphere and nitrogen deposition in ecosystems[24]. In addition to the role of Ammonia in formation of secondary PM2.5, exposure to high concentrations of ammonia can cause immediate burning of the eyes, nose, throat and respiratory issues[25]. This means that ammonia plays a critical role in air quality, public health, and environment. Currently ammonia emissions for on-road vehicles are not regulated at the state and federal level, although for heavy duty vehicles U.S. EPA recommends that ammonia slip from SCR systems should be below 10 ppm average over the applicable test cycle. Gaseous ammonia is relatively short-lived in the atmosphere; and it is either deposited back to ground by dry deposition or it reacts rapidly with nitric acid or sulfuric acid to form compounds such as ammonium nitrate and ammonium sulfate. These are the secondary PM2.5 that are currently one of the major causes of air quality issues in San Joaquin Valley region of California.

[24] Sulfuric and nitric acids can react with ammonia to form PM2.5 ammonium nitrate, and ammonium sulfate.

[25] https://www.health.ny.gov/environmental/emergency/chemical_terrorism/ammonia_general.htm#:~:text=Exposure%20to%20high%20concentrations%20of,and%20nose%20and%20throat%20irritation.

While the majority of anthropogenic ammonia emissions in California are associated with agricultural activities (pesticides and fertilizers)[26], it is important to understand the ammonia emissions from various truck technologies. Unlike, NOx and PM emissions that are formed during combustion, in on-road vehicles, ammonia is mainly formed within the after-treatment systems (e.g., Selective Catalytic Reduction system or SCR as well as Three-Way Catalyst or TWC). EMFAC2021 is the first version of the EMFAC model that provides estimates of ammonia emissions for light, medium and heavy-duty vehicles based on years of test data across various technologies. While the methodology is still in infancy, the outputs from the model are helpful to shed light on the magnitude of ammonia emissions from various technologies.

Figure 7. Ammonia (NH3) emissions from Class 8 trucks extracted from EMFAC2021 model in LA County[27]



As illustrated in Figure 7, natural gas-powered vehicles have the highest ammonia emissions, almost four times higher than their diesel counterparts. While ammonia emissions from diesel powered vehicles stay around 0.2 grams per mile, natural gas-powered vehicles show ammonia emissions on the order of 1 gram per mile (5 times higher than diesel engines). The high ammonia emissions from natural gas trucks are mainly attributed to the use of TWCs to reduce the NOx and hydrocarbon emissions from natural gas engines. According to Farren et. al. (2020)[28], ammonia is formed in TWCs as a result of the reduction of nitric oxide (NO) by hydrogen (H2), which is generated from CO and H_2O via the water-gas shift reaction or from hydrocarbons via steam reforming. In diesels engines that are equipped with SCR system, ammonia comes from the injection of urea, into the SCR catalyst to reduce NOx emission. Injection of excessive quantities of urea, low temperatures in the system, and catalyst degradation are often the main factors that may lead to excess ammonia emissions, commonly referred to as “ammonia slip”.

[26] According to CARB’s emission inventory, in 2022, of 745 tpd of ammonia emissions at the statewide level (including natural sources), 50 tpd is associated with mobile sources, whereas 416 tpd is associated with pesticides/fertilizers and farming operations.

[27] There are no ammonia emissions associated with zero emission vehicles

[28] Farren, N.J., Davison, J., Rose, R.A., Wagner, R.L. and Carslaw, D.C., 2020. Underestimated ammonia emissions from road vehicles. Environmental Science & Technology, 54(24), pp.15689-15697.

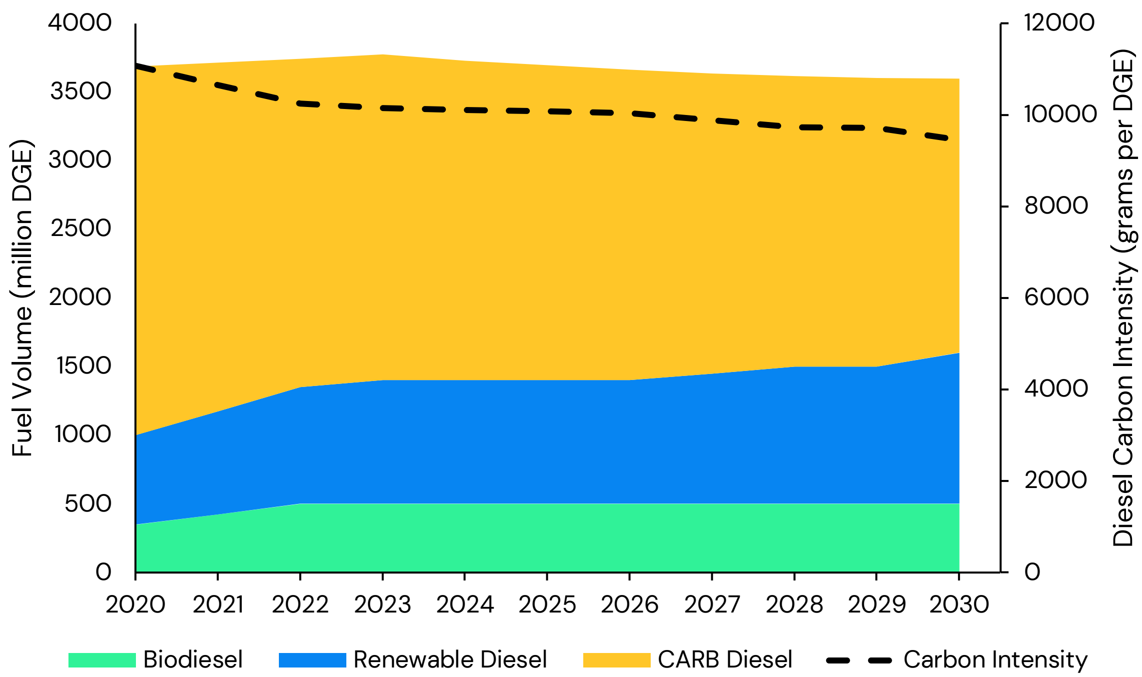
4 GHG Emissions

As described earlier, while this report only focused on the downstream emissions of criteria pollutants (i.e., vehicle emissions), for GHG emissions, the report intends to cover the full life cycle emissions for each of the four technologies. Here in this section, we describe the underlying assumptions used for the calculation of the life cycle GHG emissions (also referred to as carbon intensity) associated with each technology.

4.1 Diesel

For diesel, ICF used similar assumption as CARB's 2018 Low Carbon Fuel Standard (LCFS) compliance scenario (Low Demand/Low ZEV) which assumes that by 2030, almost 50 percent of California's transportation diesel will be renewable and bio diesel (500 million gallons of biodiesel, and 1.1 billion gallons of renewable diesel) as illustrated in Figure 8.

Figure 8. California's diesel blend mix and resulting carbon intensity extracted from CARB's LCFS Compliance Scenario[29]



While LCFS compliance scenario only extends out to 2030, as part of the 2020 Mobile Source Strategy, we assumed that in the absence of post-2030 LCFS standards, carbon intensity of diesel will remain the same as in 2030.

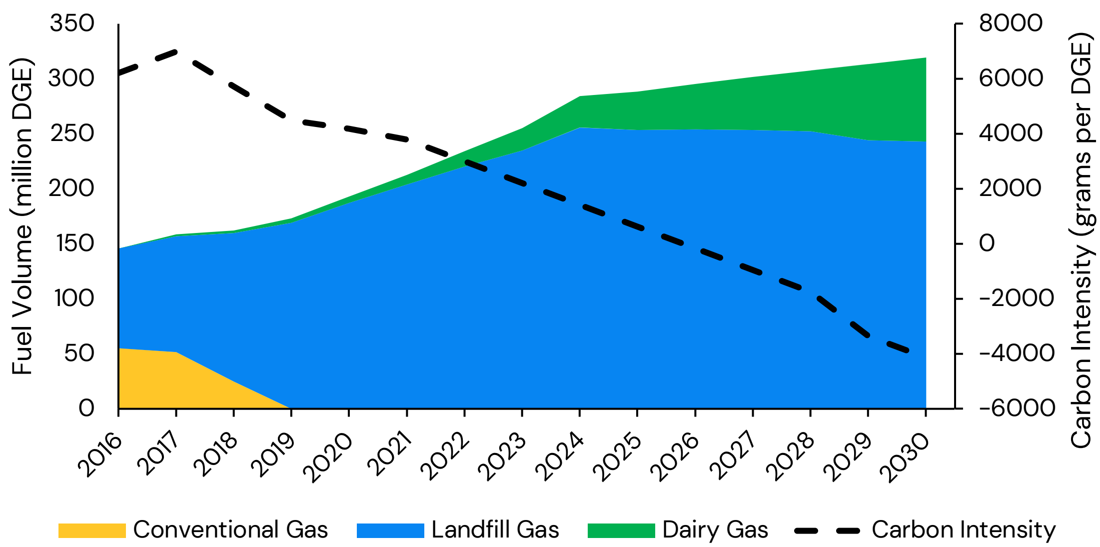
4.2 Natural Gas

Similar to diesel, CARB's 2018 LCFS compliance scenario is used to calculate average carbon intensity of transportation natural gas in California. According to CARB's analysis, post 2019, 100 percent of natural gas consumed for transportation in California is considered to be renewable natural gas (dairy and landfill). According to LCFS Quarterly data[30], in 2021, of more than 178 million DGE of natural gas

[29] CARB diesel refers to diesel fuel that meet the requirements of California diesel fuel regulation
[30] https://ww2.arb.ca.gov/resources/documents/low-carbon-fuel-standard-reporting-tool-quarterly-summaries

reported through LCFS, 98% were Bio-CNG and Bio-LNG. This percentage has been reducing rapidly from 2019 levels of 23% and therefore it validates the assumption that in future all of the natural gas consumed by the transportation sector could be of renewable sources. Considering that dairy gas has significantly lower carbon intensity (-255 g per MJ) as compared to landfill gas (+40 g per MJ), we used the similar mix as CARB's LCFS compliance scenario to calculate a weighted average carbon intensity for renewable natural gas. The significantly low carbon intensity associated with dairy gas is mainly due to the avoided methane emissions in dairies. In other words, through the production of renewable natural gas from dairy manure, the methane emissions that would have been released into the atmosphere is now captured and converted to renewable natural gas. Once this fuel is combusted in natural gas vehicles, the methane will be converted to CO_2 which has much lower global warming potential (GWP) than methane. This is why dairy gas has negative carbon intensity. However, according to CARB's revised draft of 2020 Mobile Source Strategy[31], the avoided methane emissions can only be counted toward dairy gas carbon intensity until 2033. Post 2033, when dairy methane can no longer be used to comply with LCFS because of the SB 1383 Short-Lived Climate Pollutants (SLCP): Organic Waste Methane Emissions Reductions Rulemaking, the emission rate will increase to above zero. For the purpose of this analysis, we assume that post-2033, the carbon intensity of dairy gas will be similar to carbon intensity of landfill gas. CARB's 2018 LCFS assumed that by 2030, 24 percent of renewable natural gas will be consisted of dairy gas, and the rest are associated with landfill gas. Figure 9 shows the assumed fuel volume (in unit of diesel gallons equivalent or DGE) as well as the resulting carbon intensity (in unit of grams CO_2 per DGE) from 2016 through 2030.

Figure 9. California's transportation natural gas blend mix and resulting carbon intensity extracted from CARB's LCFS Compliance Scenario



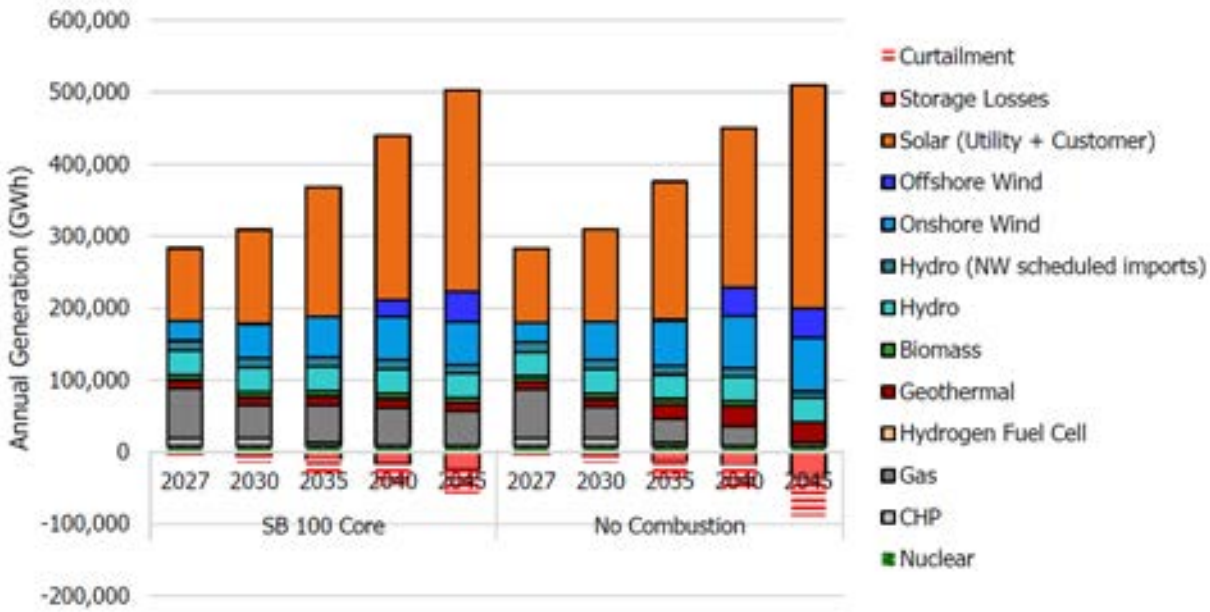
4.3 Electricity

California has ambitious plans to decarbonize its electricity targets. In 2018, California legislatures passed a landmark policy, Senate Bill 100 (SB 100, De León), requiring renewable energy and zero-carbon resources supply 100 percent of electric retail sales to end-use customers by 2045. The statute also set an interim target of 60 percent renewable electricity by 2030. The statute also requires the California Energy Commission (CEC), California Public Utilities Commission (CPUC), and CARB to prepare a report to evaluate the challenges and opportunities in implementing SB 100. In 2021,

[31] https://ww2.arb.ca.gov/sites/default/files/2021-04/Revised_Draft_2020_Mobile_Source_Strategy.pdf

CEC released the 2021 SB 100 Joint Agency Report which lays out an initial assessment of the additional energy resources and the resource building rates needed to achieve 100 percent clean electricity, along with the associated costs. This report used the 2019 Renewable Energy Solutions (RESOLVE) model to analyze these factors under various conditions and technologies. Figure 10 illustrate the generation mix assumed under the SB 100 scenario (SB 100 Core) as well as an additional scenario presented by CEC in which combustion resources are expressly retired to significantly reduce the contribution to criteria pollutants and toxic air contaminants in California from supply-side electricity generation.

Figure 10. California's electricity generation mix under SB 100 Scenario[32]



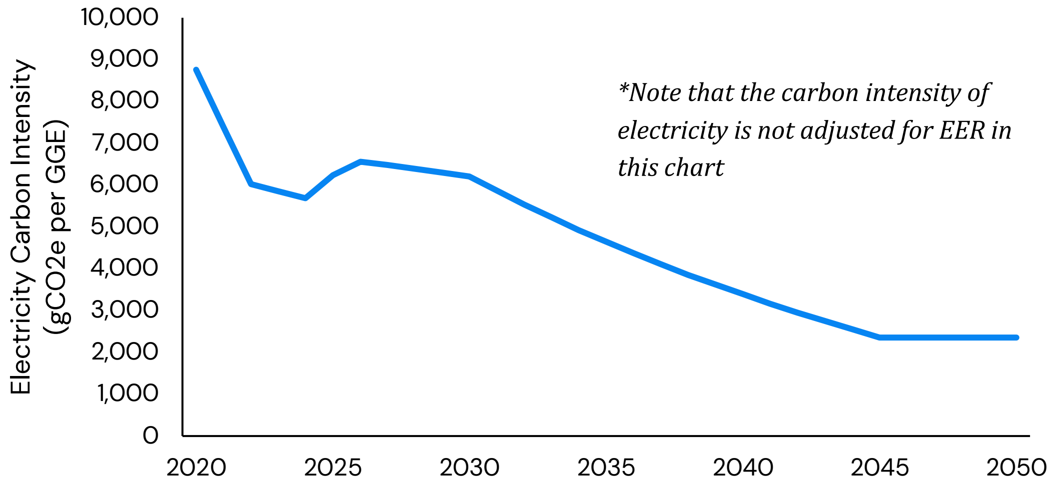
Using the modeled generation mix under SB 100 Core scenario, CARB staff calculated the annual average emission factors, including emissions at power plants, natural gas extraction, processing, and delivery as shown in Figure 11. Note that while the carbon intensity of electricity in California is similar to that of diesel or natural gas, electric Class 8 trucks are assumed to be 5 times more efficient than their diesel counterparts. In other words, with the same amount of energy, an electric Class 8 truck is assumed to drive 5 times higher distance than a diesel truck. This factor of 5 is also known as Energy Economy Ratio (EER) which is a value that represents the efficiency of a fuel as used in a powertrain as compared to a reference fuel. For example, for heavy duty vehicles, CARB's LCFS assumes an EER ration of 5. Later in this report, we will compare the EER adjusted electricity carbon intensity to carbon intensity of other fuels in order to draw an apple-to-apple comparison. It is also noteworthy to mention that the increase in electricity carbon intensity from 2024 through 2026 is due to the assumed decommissioning of Diablo Canyon nuclear power plant.[33,34]. It is assumed that added capacity to replace Diablo Canyon nuclear power plant will slightly increase the carbon intensity of California's electricity.

[32] Curtailment refers to intentional reduction in power output below what could have been produced in order to balance energy supply and demand or due to transmission constraints.

[33] Located at Avila Beach in San Luis Obispo County

[34] Note that PG&E has recently submitted application for federal funds to keep the plants operational post 2025. While the current analysis assumes that plants will be shut down between 2024 and 2026, it is possible that these plants may continue their operation post 2025.

Figure 11. California's Electricity Carbon Intensity from CARB's 2020 Mobile Source Strategy



4.4 Hydrogen

Similar to electricity, we also used the carbon intensity embedded in the 2020 Mobile Source Strategy for hydrogen. CARB's 2020 Mobile Source Strategy assumed that 60 percent of transportation hydrogen will be renewable by 2030, and this fraction will increase to 100 percent by 2045 consistent with SB 662[35]. CARB also assumed that this renewable hydrogen will be produced mainly using curtailed renewable electricity[36] as utilities procure more renewable electricity generation capacity to meet the Renewable Portfolio Standard (RPS). In other words, CARB used a carbon intensity of zero for renewable hydrogen. While this assumption may hold true for the renewable hydrogen produced in California, it may not be valid for the imported renewable hydrogen. Of course, in 2020 Mobile Source Strategy, CARB only accounted for GHG emissions associated with activities occurring within California territory (consistent with AB 32 inventory). As a result, their assessment is not impacted by the carbon intensity of renewable hydrogen imported into California, however, certain amount of hydrogen is imported from outside of California, indicating a potential non-applicability of zero carbon intensity for the imported hydrogen.

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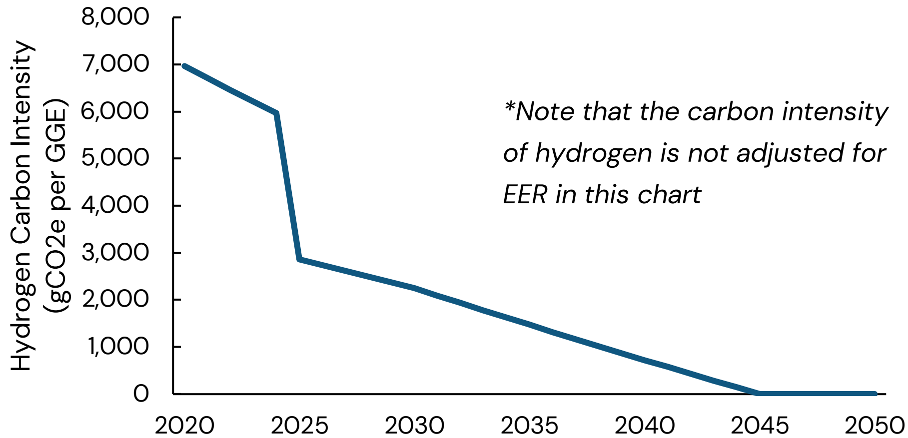
[35] Archuleta, SB-662 Energy: transportation sector: hydrogen (2019-2020). http://leginfo.legislature.ca.gov/faces/billTextClient.xhtml?bill_id=201920200SB662

[36] Curtailment refers to intentional reduction in power output below what could have been produced in order to balance energy supply and demand or due to transmission constraints.

Figure 12. California's Hydrogen Carbon Intensity from CARB's 2020 Mobile Source Strategy

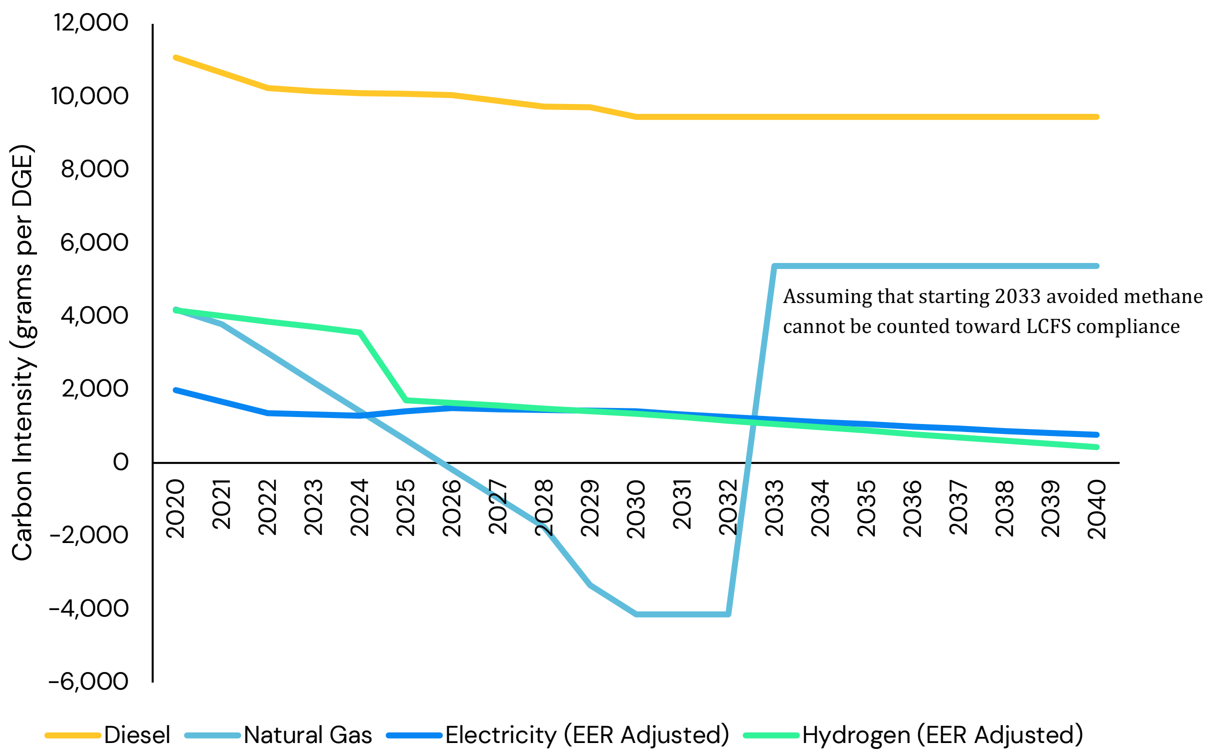


Since it is not crystal clear on what fraction of hydrogen used in California will be imported, for the purpose of this study, we assumed that renewable hydrogen (whether produced in California or outside of California) is using curtailed renewable electricity, and hence have a carbon intensity of zero. The carbon intensity for hydrogen extracted from CARB's 2020 Mobile Source Strategy is shown in Figure 12. Similar to electricity, the carbon intensity of hydrogen shown in this figure is not adjusted for hydrogen powered vehicles EER. According to CARB's LCFS program, hydrogen powered heavy duty vehicles are assumed to have an EER of 1.9.

4.5 All Fuels Comparison

Figure 13 shows a comparison of WTW GHG emissions associated with the four technologies considered for this study. Please note that the carbon intensity of hydrogen and electricity are adjusted for their EER assuming an EER of 5 for electricity and 1.9 for hydrogen. Also, all carbon intensities are converted to gCO2 per diesel gallons equivalent (DGE). As shown, in early years, electricity seems to have the lowest carbon intensity, whereas in 2025 RNG becomes the lowest carbon intensity fuel as dairy gas constitute 14 percent of the RNG production. Post 2033, when avoided methane emissions from dairies cannot be counted toward LCFS compliance (to avoid double counting), the carbon intensity of RNG increase. ICF assumed that post 2033, RNG carbon intensity is similar to landfill gas. Also post 2030, as the fraction of renewable hydrogen (produced from renewable electricity) increases, the carbon intensity of hydrogen becomes smaller than electricity even though it has a lower EER as compared to electricity.

Figure 13. Comparison of WTW GHG emissions (grams per diesel gallons equivalent) across the four fuel technologies in California



To further demonstrate the overall climate impacts of the zero and near zero emission technologies, the project team estimated the social benefits of reducing CO2 using the Social Cost of Carbon (SCC) estimates provided by CARB. The SCC is a dollar valuation of the damages caused by carbon pollution and represents the monetary benefit today of reducing carbon emissions in the future and it is calculated using complicated models (called integrated assessment models) that assess and monetize the impact of one ton of extra CO2 on agricultural productivity, changes in health outcomes, sea level rise and coastal property damage, changes in energy consumption and declines in labor productivity at the global level. The project team estimated that avoided GHG emissions associated with the proposed technology mix under Report 3 will results in approximately $788 million to $3.4 billion of avoided social cost of carbon through 2040, depending on the chosen discount rate. Please note that these avoided costs are likely to be underestimated as they do not account for the physical, ecological, and economic impacts of the GHG reductions. For example, transition to green economy has significant workforce development implications. According to research conducted by Environmental Defense Fund in 2021[37], shows that the transition to zero emission trucks is generating jobs across the country and bringing in significant economic benefits at local and regional level.

5 Summary

We used a combination of the EMFAC2021 as well as CARB's LCFS and Mobile Source Strategy data to compare the air quality, climate, and toxics risk associated with the four studies technologies. Here are some key takeaways associated with this report:

[37] https://www.edf.org/sites/default/files/documents/National%20MHD-ZEV-Supply-Chain-Analysis%2010.27.21_0.pdf

- ZE technologies such as battery electric and hydrogen trucks are shown to provide the significant air quality benefits (i.e., NOx and PM2.5).
- With California's electricity grid and hydrogen becoming 100 percent carbon free over the next two decades, zero emission trucks powered by renewable electricity and hydrogen will also provide significant climate benefits.
- Project team has estimated that between 2024 and 2040, the technology mix presented in Report 3 combined with the reduction in emissions resulting from the HD I/M and ACF regulations will results in approximately 511 – 524 reduced mortality, 285 less respiratory related ER visits, 57 less respiratory related hospital admission, and almost 75,000 less work loss days in LA County.
- These health impacts are equivalent to avoided health cost of approximately $5 billion in LA County.
- As discussed in Report 3, project team also estimated that avoided GHG emissions will results in approximately $788 million to $3.4 billion of avoided social cost of carbon through 2040, depending on the chosen discount rate.
- While NOx and PM emissions from Low NOx NG trucks are higher than their zero emission counterparts, today emissions from these trucks are still significantly lower than their diesel counterparts.
- When powered by RNG, Low NOx NG trucks can offer significant climate benefits especially in the near term when dairy gas has significantly lower carbon intensity than EER adjusted electricity due to avoided methane emissions.
- With respect to diesel trucks, while the technology has become significantly cleaner over time and CARB's recent HD Omnibus and HD I/M regulations are going to further reduce their in-use emissions, these trucks will continue to have higher emissions than their counterpart natural gas and zero emission options.
- Considering the public health impacts of DPM discussed earlier in this report, especially in low income and disadvantaged communities, eliminating emissions from these trucks should be at the forefront of environmental justice policies of California.