Appendix C-3

Further Detail on Costs and Economic Analysis

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LIST OF ACRONYMS AND ABBREVIATIONS USED IN APPENDIX C-3

Acronym or Abbreviation	Description
3B-MAW	Three-Bin Moving Average Window
ABT	Averaging, Banking, and Trading
ACT	Advanced Clean Trucks
APU	Auxiliary Power Units
CA	California
CARB	California Air Resources Board
CE-CERT	College of Engineering – Center for Environmental Research and Technology
CFR	Code of Federal Regulations
DAAAC	Diesel Aftertreatment Accelerated Aging Cycle
DDP	Durability Demonstration Program
DEF	Diesel Exhaust Fluid
DMV	Department of Motor Vehicles
DOC	Diesel Oxidation Catalyst
DPF	Diesel Particulate Filter
ECU	Engine Control Unit
EGR	Exhaust Gas Recirculation
EMA	Truck and Engine Manufacturers Association
EMFAC	Emission Factors Inventory Model
EWIR	Emissions Warranty Information and Reporting
FIR	Field Information Report
FTP	Federal Test Procedure
GHG	Greenhouse Gas
GVWR	Gross Vehicle Weight Rating
HDIUT	Heavy-Duty In-Use Testing
HDO	Heavy-Duty Otto-Cycle
HDOV	Heavy-Duty Otto-Cycle Engine Vehicle
HHDD	Heavy Heavy-Duty Diesel
HHDV	Heavy Heavy-Duty Vehicle
ISR	Sacramento Institute for Social Research
LHDD	Light Heavy-Duty Diesel
LHDV	Light Heavy-Duty Vehicle
LLC	Low Load Cycle
MAW	Moving Average Window
MD	Medium-Duty
MDDE	Medium-Duty Diesel Engine
MDOE	Medium-Duty Otto-Cycle Engine
MHDD	Medium Heavy-Duty Diesel
MHDV	Medium Heavy-Duty Vehicle
MY	Model Year

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Acronym or Abbreviation	Description
NAICS	North American Industrial Classification System
NOx	Oxides of Nitrogen
NREL	National Renewable Energy Laboratory
NTE	Not-to-Exceed
OBD	On-Board Diagnostics
OEM	Original Equipment Manufacturer
PM	Particulate Matter
PM2.5	Fine Particulate Matter
REMI	Regional Economic Models, Inc.
RMC	Ramped Modal Cycle
RMC-SET	Ramped Modal Cycle Version of the Supplemental Emission Test
SCR	Selective Catalytic Reduction
SRIA	Standardized Regulatory Impact Assessment
SwRI	Southwest Research Institute
TWC	Three-Way Catalyst
UL	Useful Life
U.S. EPA	United States Environmental Protection Agency
ZEV	Zero-Emission Vehicle

APPENDIX C-3: FURTHER DETAIL ON COSTS AND ECONOMIC ANALYSIS

This appendix provides further details on the cost and economic analysis for the Proposed Amendments. The calculations conducted for these analyses are contained in the Heavy-Duty Omnibus Regulation Cost Spreadsheets (CARB, 2020b), the Heavy-Duty Omnibus Regulation Emission Benefit Files (CARB, 2020c), and the Heavy-Duty Omnibus Regulation Health Benefit Spreadsheets (CARB, 2020d).

I. DIRECT COST IMPACTS

The Proposed Amendments would require medium- and heavy-duty engine manufacturers to produce lower-emitting engines, which would increase upfront production and operational costs, compared to preexisting engines. These increased costs are assumed to be passed on to the engine/vehicle operators, i.e., fleets. Elements contributing to increased costs include reduction of emission standards over existing regulatory cycles, addition of the low-load cycle (LLC) certification test cycle, amendments to in-use test procedures, modifications to the durability demonstration for certification, lengthened warranty periods, lengthened useful life periods, amendments to Emissions Warranty Information and Reporting (EWIR) and corrective action procedures, and Oxides of Nitrogen (NOx) data collection and reporting. There are also proposed elements that are not expected to have a cost impact, such as powertrain test procedures, heavy-duty vehicle Greenhouse Gas (GHG) tractor Auxiliary Power Units (APU) certification amendments, Phase 2 GHG cleanup amendments, and On-Board Diagnostics (OBD) requirement.

Table I.1 summarizes the total statewide costs of the Proposed Amendments by each proposed element from 2022 to 2050. All costs are evaluated relative to the business as usual scenario in 2018 dollars. Table I.1 shows the total costs to the manufacturers that are expected to be passed on to the fleet owners as well as the additional cost for Diesel Exhaust Fluid (DEF) consumption purchased by fleet owners. For consistency with the Emission Factors Inventory Model (EMFAC), the model years (MYs) for heavy-duty diesel engines (i.e., Heavy Heavy-Duty Diesel [HHDD], Medium Heavy-Duty Diesel [MHDD], and Light Heavy-Duty Diesel [LHDD]) are offset by one year in relation to the calendar year. For example, the 2024 MY HHDD engine sales population would be accounted for in calendar year 2025. A detailed discussion on cost estimates for each element is provided in subsections 1 to 14 below.

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Table I.1. Estimated Proposed Amendments Statewide Incremental Costs from 2022 through 2050 (2018$)

Calendar Year	Standards, Certification, and New Technology	In-Use Amendments	Lengthened Warranty	Durability Demonstration	EWIR and Corrective Action Amendments	ABT	Total Costs on Manufacturers	Annual DEF Consumption	Total Costs Passed to Vehicle Buyers
2022	$0	$0	$0	$0	$0	$217,000	**$217,000**	$0	**$217,000**
2023	$0	$0	$0	$8,612,420	$0	$43,400	**$8,655,820**	$0	**$8,655,820**
2024	$1,825,884	$132,657	$0	$850,000	$328,320	$43,400	**$3,180,260**	$4,635	**$3,184,895**
2025	$45,200,392	$59,481	$0	$140,810	$10,237,296	$43,400	**$55,681,378**	$1,260,430	**$56,941,807**
2026	$45,745,702	$60,198	$0	$11,511,176	$10,336,778	$43,400	**$67,697,255**	$2,535,391	**$70,232,645**
2027	$40,982,758	$61,678	$1,069,205	$869,431	$10,641,299	$43,400	**$53,667,772**	$3,841,377	**$57,509,149**
2028	$109,539,586	$62,336	$13,611,269	$754,981	$21,017,003	$43,400	**$145,028,575**	$5,427,646	**$150,456,221**
2029	$111,797,840	$63,714	$13,904,492	$1,137,957	$21,502,340	$43,400	**$148,449,742**	$7,049,592	**$155,499,335**
2030	$96,736,169	$64,657	$14,068,992	$13,545,139	$21,825,015	$43,400	**$146,283,371**	$8,698,381	**$154,981,752**
2031	$96,282,989	$65,544	$15,163,761	$1,707,090	$21,921,155	$43,400	**$135,183,940**	$10,370,476	**$145,554,416**
2032	$134,783,615	$67,378	$41,448,718	$2,001,917	$7,445,446	$43,400	**$185,790,474**	$12,090,101	**$197,880,575**
2033	$137,481,896	$68,759	$42,228,382	$2,041,017	$7,596,388	$43,400	**$189,459,842**	$13,848,578	**$203,308,420**
2034	$121,521,857	$71,025	$43,577,031	$2,085,403	$7,841,967	$43,400	**$175,140,684**	$15,661,540	**$190,802,224**
2035	$121,265,142	$72,362	$44,373,973	$2,131,965	$7,983,740	$43,400	**$175,870,582**	$16,257,271	**$192,127,853**
2036	$119,537,729	$72,778	$44,638,032	$2,175,676	$8,035,462	$43,400	**$174,503,078**	$16,845,154	**$191,348,232**
2037	$118,057,423	$73,351	$45,005,620	$2,211,745	$8,098,670	$43,400	**$173,490,209**	$17,415,968	**$190,906,177**
2038	$116,470,502	$73,792	$45,244,815	$2,242,112	$8,152,780	$43,400	**$172,227,402**	$19,300,350	**$191,527,752**
2039	$115,117,319	$74,373	$45,595,209	$2,262,263	$8,212,366	$43,400	**$171,304,929**	$19,920,738	**$191,225,667**
2040	$114,501,103	$74,900	$45,882,018	$2,277,510	$8,268,410	$43,400	**$171,047,341**	$20,226,153	**$191,273,494**
2041	$113,726,998	$75,347	$46,139,454	$2,292,944	$8,322,800	$43,400	**$170,600,943**	$20,516,054	**$191,116,997**
2042	$113,194,894	$75,954	$46,505,442	$2,308,595	$8,390,443	$43,400	**$170,518,728**	$20,797,440	**$191,316,168**
2043	$112,594,172	$76,498	$46,819,567	$2,324,872	$8,452,813	$43,400	**$170,311,322**	$22,756,630	**$193,067,953**
2044	$112,202,975	$77,180	$47,223,532	$2,341,762	$8,526,676	$43,400	**$170,415,525**	$23,028,468	**$193,443,993**
2045	$112,437,873	$77,817	$47,605,191	$2,359,323	$8,596,601	$43,400	**$171,120,205**	$23,601,250	**$194,721,455**
2046	$112,674,805	$78,451	$47,977,842	$2,378,024	$8,666,507	$43,400	**$171,819,028**	$24,142,753	**$195,961,781**
2047	$112,834,056	$79,048	$48,336,754	$2,396,662	$8,733,137	$43,400	**$172,423,058**	$24,348,447	**$196,771,505**
2048	$113,036,856	$79,688	$48,730,929	$2,415,887	$8,803,268	$43,400	**$173,110,029**	$24,554,099	**$197,664,128**
2049	$113,193,816	$80,268	$49,065,347	$2,434,502	$8,863,687	$43,400	**$173,681,021**	$24,753,806	**$198,434,827**
2050	$113,193,816	$80,268	$49,065,347	$2,449,278	$8,863,687	$43,400	**$173,695,797**	$24,936,098	**$198,631,895**
Total	**$2,775,938,169**	**$1,999,501**	**$933,280,923**	**$82,260,462**	**$275,664,054**	**$1,432,200**	**$4,070,575,309**	**$424,188,827**	**$4,494,764,136**

Note: ABT= Averaging, Banking, and Trading, DEF= Diesel Exhaust Fluid, EWIR= Emissions Warranty Information and Reporting

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Low NOx Standards Technology Costs

The incremental low NOx technology cost includes the cost of:

1) New and/or improved engine and aftertreatment technologies to meet the more stringent NOx standards, and

2) Research and development investment for the new technologies.

California Air Resources Board (CARB) staff contracted with National Renewable Energy Laboratory (NREL) to conduct a cost analysis to estimate costs associated with new engine technologies and hardware upgrades, aftertreatment system upgrades, as well as research and development as compared to the 2018 technology baseline. NREL conducted a survey in 2019 of the engine, aftertreatment, and other suppliers on the cost to make technology packages to fulfill the proposed low NOx emission standards, considering California-only sales volume and the extension of useful life. NREL published their cost survey and analysis results in May 2020 (NREL, 2020).

The technology package associated with meeting the 2024 Proposed Amendments for diesel engines included exhaust gas recirculation (EGR) cooler bypass, changes and upgrades to current aftertreatment technologies (such as diesel oxidation catalyst [DOC], Diesel Particulate Filter [DPF], ammonia slip catalysts, DEF dosing, OBD sensors and controllers), and others. The technology package associated with meeting the 2027 Proposed Amendments for diesel engines included cylinder deactivation, light-off Selective Catalytic Reduction (SCR), changes and upgrades to current aftertreatment technologies (DOC, DPF, ammonia slip catalysts, DEF dosing, OBD sensors and controllers), and others. The technology package for Otto-cycle (gasoline) engines to meet the more stringent NOx standards included upgrades to current three-way catalyst (TWC) technology.

For the Proposed Amendments' low NOx technology cost assessment, CARB staff adjusted NREL's technology cost values to reflect the different useful life and warranty periods used for the NREL surveys and those periods contained in the Proposed Amendments.

Comments from industry have suggested there would be a GHG emission penalty to meet the more stringent NOx standards. However, Southwest Research Institute (SwRI) Low NOx testing program results have shown no GHG emission penalty to meet the proposed 0.02 g/bhp-hr NOx standard for 2027 and later model year engines. Although CARB staff also does not expect any GHG emission penalty to meet the proposed 0.05 g/bhp-hr NOx standards for 2024-2026 model year engines, because meeting the 0.05 g/bhp-hr NOx standard may make it more difficult to simultaneously meet the 2024 Phase 2 GHG standards, CARB staff has conservatively included the cost of GHG technology to reduce GHG emissions as an additional one percent CARB Staff used United States Environmental Protection Agency's (U.S EPA's) technology cost estimates in the federal Phase 2 GHG Regulation to estimate incremental costs per vehicle per one percent GHG emission reduction (U.S. EPA, 2016). The resulting additional GHG technology costs for

2024-2026 model year engines are $501 for HHDD engines and $100 for medium-duty (MD), LHDD, and MHDD engines.

Table I.2 below presents a summary of technologies and their adjusted incremental cost for a 6/7-liter diesel and 12/13-liter diesel engine to meet the 2024, 2027, and 2031 amendments based on NREL's May 2020 findings. For Heavy-Duty Otto-Cycle (HDO) engines (not shown in Table I.2), the total integrated cost for both hardware and research and development, based on the NREL survey, is $411 per engine on average.

Table I.2. Summary of Technologies and Adjusted Incremental Costs for Meeting the 2024 and 2027 Low NOx Standards Based on NREL Survey

		6/7-Liter Diesel			12/13-Liter Diesel		
Applicable Model Years		**2024-2026**	**2027-2030**	**2031+**	**2024-2026**	**2027-2031**	**2031+**
Engine Technology[a]	EGR Cooler Bypass	$243	NA	NA	$302	NA	NA
	Cylinder Deactivation	NA	$811	$831	NA	$1,017	$1,097
	Other	NA	$588	$665	NA	$764	$932
Aftertreatment Technology[a]	Light-off SCR	NA	$988	$1,030	NA	$1,181	$1,256
	DOC (subtotal)	$10	$31	$50	$89	$105	$125
	DPF (2018 baseline system only)[b]	($17)	$9	$34	($44)	($7)	$38
	SCR + Ammonia Slip Catalyst + DEF Dosing (subtotal)	$621	$747	$865	$784	$917	$1,079
	OBD sensors and controllers (NOx, Ammonia, temp sensors)	$333	$452	$564	$330	$457	$611
	Other*	$175	$204	$232	$150	$384	$667
Total Incremental Hardware Cost to Manufacturer		**$1,365**	**$3,830**	**$4,271**	**$1,611**	**$4,818**	**$5,803**
Incremental Research and Development Costs to Manufacturer[c]		**$85**	**$82**	**$78**	**$354**	**$355**	**$356**
Incremental Costs to Simultaneously Meet Phase 2 GHG Standards[d]		$100	NA	NA	$501	NA	NA
Total Incremental Cost		**$1,550**	**$3,912**	**$4,350**	**$2,466**	**$5,173**	**$6,159**

[a] Values are only shown for technologies applicable to that application.
[b] Values in parentheses represent savings compared to the baseline 2018 technology and costs.
[c] Note that the costs in Table I.2 were estimated by NREL based on Original Equipment Manufacturer (OEM) shareholder reports and adjusted by CARB staff to fit the Proposed Amendments. They are intended to represent fixed research and development costs distributed on a per engine basis, based on the population of engines expected to be subject to the Proposed Amendments.
[d] Incremental cost to meet Phase 2 GHG emission standards was derived using U.S. EPA's cost estimate for the federal Phase 2 GHG Regulation.
NA- not applicable

In addition to the useful life and warranty period adjustments, CARB staff applied a steep learning curve adjustment (U.S. EPA, 2016), as used in previous U.S. EPA analyses, to reflect improvements and cost reductions in the manufacturing processes of engine and aftertreatment system technologies over time. The steep portion learning algorithm was applied for those technologies considered to be newer technologies that would likely have rapid cost reductions through manufacturer learning. The steep portion learning algorithm results in 20 percent lower costs after two full years of implementation. Once the steep-portion learning steps have occurred, flat portion learning at 3 percent per year is applied for 5 years, then 2 percent per year is applied for the next 5 years, and lastly 1 percent per year is applied for the next 5 years. The cost would remain the same beyond the 17-year span of the steep learning curve. Table I.3 summarizes the total incremental cost of engine and aftertreatment system technologies as well as research and development, for each engine type once the steep learning curve was applied, from 2022 to 2050 model year engines. For technologies not considered to be newer, such as TWC improvements for Otto-cycle (gasoline) engines, no learning curve was applied and hence per-engine incremental costs are assumed to be steady over time (e.g., constant at $411 per engine as shown in the right-hand column of Table I.3).

Table I.3. Total Incremental Costs of Engine Technologies, Aftertreatment System Technologies, and Research and Development Based on Engine Size and Fuel Type to Meet the Proposed Heavy-Duty Low NOx FTP, RMC-SET, LLC, and Idle Standards for Model Year 2022 through 2050 Engines (2018$ per engine)

MY Engine	6/7-liter Diesel	12/13-liter Diesel	6/7-liter Gasoline
2022	$0	$0	$0
2023	$0	$0	$0
2024	$1,550	$2,466	$411
2025	$1,550	$2,466	$411
2026	$1,309	$2,165	$411
2027	$3,912	$5,173	$411
2028	$3,912	$5,173	$411
2029	$3,306	$4,438	$411
2030	$3,233	$4,349	$411
2031	$4,350	$6,159	$411
2032	$4,350	$6,159	$411
2033	$3,681	$5,326	$411
2034	$3,601	$5,226	$411
2035	$3,524	$5,129	$411
2036	$3,448	$5,035	$411
2037	$3,375	$4,944	$411
2038	$3,304	$4,855	$411
2039	$3,258	$4,798	$411
2040	$3,213	$4,742	$411
2041	$3,169	$4,687	$411
2042	$3,126	$4,633	$411
2043	$3,083	$4,580	$411
2044	$3,063	$4,554	$411
2045	$3,042	$4,528	$411
2046	$3,022	$4,503	$411
2047	$3,002	$4,478	$411
2048	$2,982	$4,453	$411
2049	$2,982	$4,453	$411
2050	$2,982	$4,453	$411

CARB staff estimated the number of projected new engine sales from 2022 to 2050 calendar years using CARB's EMFAC 2017 emission inventory model. Table I.4 below summarizes CARB staff's projected statewide new medium- and heavy-duty engine sale volumes. Note that the MYs for heavy-duty diesel engines (i.e., HHDD, MHDD, and LHDD) are offset by one year in relation to the calendar year. For example, the 2024 MY HHDD engine sales population would be accounted for in calendar year 2025.

Table I.4. Projected Statewide New Medium- and Heavy-Duty Engine Sales from 2022 to 2050

Calendar Year	Medium-Duty Diesel	Light Heavy-Duty Diesel	Medium Heavy-Duty Diesel	Heavy Heavy-Duty Diesel	Medium-Duty Otto	Heavy-Duty Otto
2022	223	5,793	8,966	6,803	68	3,452
2023	217	6,213	9,396	7,202	61	3,556
2024	236	6,358	9,780	6,703	54	3,501
2025	232	6,473	10,291	7,054	62	3,512
2026	217	6,605	10,307	7,209	31	3,556
2027	225	6,731	10,616	7,365	30	3,529
2028	234	6,848	10,620	7,500	39	3,600
2029	230	6,975	10,884	7,672	29	3,611
2030	218	7,093	11,005	7,825	13	3,585
2031	221	7,186	11,150	7,943	13	3,624
2032	223	7,380	11,463	8,176	13	3,635
2033	225	7,538	11,637	8,400	13	3,670
2034	227	7,777	12,019	8,693	13	3,705
2035	229	7,937	12,238	8,852	13	3,740
2036	231	7,987	12,294	8,913	13	3,801
2037	233	8,042	12,408	8,972	13	3,834
2038	235	8,104	12,440	9,055	13	3,867
2039	237	8,164	12,531	9,138	14	3,898
2040	239	8,226	12,575	9,242	14	3,928
2041	241	8,289	12,627	9,306	14	3,958
2042	243	8,357	12,723	9,386	14	3,988
2043	244	8,422	12,792	9,471	14	4,017
2044	246	8,493	12,894	9,572	14	4,045
2045	248	8,560	12,995	9,660	14	4,072
2046	249	8,629	13,086	9,754	14	4,099
2047	251	8,697	13,181	9,831	14	4,125
2048	253	8,766	13,296	9,904	14	4,150
2049	254	8,834	13,371	9,994	15	4,175
2050	254	8,834	13,371	9,994	15	4,175

CARB staff multiplied the incremental costs on a per vehicle basis listed in Table I.3 by the projected new engine sale volumes listed in Table I.4 to estimate the statewide annual incremental costs associated with the low-NOx technology, as shown in Table I.5 below.

Table I.5. Statewide Incremental Costs Associated with Low-NOx Technology including Hardware and Research and Development

Calendar Year	Technology Cost
2022	$0
2023	$0
2024	$1,825,884
2025	$45,200,392
2026	$45,745,702
2027	$40,982,758
2028	$109,539,586
2029	$111,797,840
2030	$96,736,169
2031	$96,282,989
2032	$134,783,615
2033	$137,481,896
2034	$121,521,857
2035	$121,265,142
2036	$119,537,729
2037	$118,057,423
2038	$116,470,502
2039	$115,117,319
2040	$114,501,103
2041	$113,726,998
2042	$113,194,894
2043	$112,594,172
2044	$112,202,975
2045	$112,437,873
2046	$112,674,805
2047	$112,834,056
2048	$113,036,856
2049	$113,193,816
2050	$113,193,816
Total	**$2,775,938,169**

Diesel Exhaust Fluid Consumption Costs

Because the Proposed Amendments would require SCR systems to operate during more of the vehicles' actual operating hours, even during low load conditions for example, the Proposed Amendments would lead to the consumption of more DEF. The annual total incremental changes in operational costs due to DEF consumption for 2024-2026 and 2027+ model year engines are summarized by year in Table I.6.

Table I.6. Incremental Annual DEF Consumption Costs by Engine Class (2018$ per engine)

Engine Class	Model Year 2024-2026	Model Year 2027+
HHDD	$89.84	$107.81
MHDD	$36.97	$44.37
LHDD	$36.63	$43.96
MDDE-3	$19.61	$23.53
MDOE-3	$0.00	$0.00
HDO	$0.00	$0.00

Note: MDDE= Medium-Duty Diesel Engine , MDOE= Medium-Duty Otto-Cycle Engine

CARB staff used the incremental DEF consumption cost on a per vehicle basis listed in Table I.6 and the EMFAC future vehicle sales projections listed in Table I.4 to estimate the statewide annual incremental costs associated with the anticipated increased DEF consumption, as shown in Table I.7.

Table I.7. Statewide Incremental Increased Cost for DEF Consumption with the Proposed Regulation

Calendar Year	Annual DEF Consumption
2022	$0
2023	$0
2024	$4,635
2025	$1,260,430
2026	$2,535,391
2027	$3,841,377
2028	$5,427,646
2029	$7,049,592
2030	$8,698,381
2031	$10,370,476
2032	$12,090,101
2033	$13,848,578
2034	$15,661,540
2035	$16,257,271
2036	$16,845,154
2037	$17,415,968
2038	$19,300,350
2039	$19,920,738
2040	$20,226,153
2041	$20,516,054
2042	$20,797,440
2043	$22,756,630
2044	$23,028,468
2045	$23,601,250
2046	$24,142,753
2047	$24,348,447
2048	$24,554,099
2049	$24,753,806
2050	$24,936,098
Total	**$424,188,827**

Low Particulate Matter Standards Technology Costs

Analysis of 2018 model year heavy-duty diesel engine Particulate Matter (PM) certification levels show that 93 percent of the engines have emission certification levels below the proposed PM standard of 0.005 g/bhp-hr. These engines can continue to use their existing filters to meet the proposed standard and thus no additional cost would be imposed to meet this standard. The remaining 7 percent of the certified engines have PM certification levels above the 0.005 g/bhp-hr but below the current 0.01 g/bhp-hr. These engines would need some additional calibration work to reduce PM emissions and meet the proposed PM standard.

NOx and PM emissions in diesel engines are closely tied together, and calibration to optimize NOx emissions would also involve calibration to optimize PM emissions. CARB staff assumes that the cost for reducing PM emissions would be absorbed by the engineering cost required to optimize NOx emissions (included in Table I.5) and that there would be no additional cost to meet the proposed PM standard. As a result, CARB staff estimates that there would be no additional cost to meet the proposed PM standard.

Amended Heavy-Duty In-Use test Procedure Costs

CARB staff estimated administrative costs for manufacturers to implement the Heavy-Duty In-Use Testing (HDIUT) amendments, including the new Three-Bin Moving Average Window (3B-MAW) method. CARB staff does not assume any additional hardware or DEF costs are needed to comply with the HDIUT amendments because the costs discussed in subsection i above include design and calibration costs to meet HDIUT requirements. Costs attributed to the proposed amendments include cost for initial learning to be able to analyze the in-use testing with the proposed 3B-MAW test procedure and OBD data collection capability, cost for testing CA certified engine families, and cost for coordinating test plan pre-approval and OBD data reporting. Further details for each cost component are as followed:

- Initial implementation of the 3B-MAW and the OBD data reporting amendments – It was estimated that 160 hours and 40 hours would be necessary for a junior engineer at salary of $70 per hour (U.S. BLS, 2019) to set up the 3B-MAW and the OBD data reporting requirements respectively. An additional hardware cost of $2,509 was attributed to a HEM data logger or similar device to record OBD parameters. The labor and hardware costs were attributed to the eight heavy-duty engine manufacturers subject to the HDIUT program. In total, an initial cost of $132,072 was estimated in the first year of implementing the amendments.

- In-use testing on the CA only certified engine families outside of the federal HDIUT program – The number of engine families required for testing by a manufacturer for any year is 25 percent of qualifying engine families per year as described in 40 CFR 86.1905. Qualifying engine families are those that sell a minimum of 1,500 units in a calendar year. The number of engine families required for testing was therefore estimated to be 25 percent of the total number of diesel engines divided by 1,500 units. An engine family test would require between 5 to 10 vehicles. CARB staff assumed manufacturers would test 10 percent of their qualifying engine families with 10 vehicles and 90 percent of their qualifying engine families with 5 vehicles. It would cost manufacturers approximately $1,680 per tested vehicle; hence the weighted average testing cost per each qualifying engine family would be $9,240. The total cost to manufacturers in a given year is the testing cost per qualifying engine family multiplied by the number of qualifying engine families produced in a year.

- Coordination for test plan pre-approval and OBD reporting – CARB staff estimated 80 hours for a junior engineer would be required for both the test plan approval coordination and OBD reporting amendments for each tested engine family. The additional labor cost is the labor cost for each tested engine family multiplied by the estimated number of engine families to be tested each year.

A summary of the HDIUT procedure amendment costs is presented in Table I.8.

Table I.8. Summary of heavy duty in use test procedure amendment costs

Calendar Year	Initial Costs	CA Engine Family Testing	Test plan coordination and OBD Reporting	Total HDIUT costs
2024	$132,072	$364	$221	$132,657
2025	$0	$37,035	$22,446	$59,481
2026	$0	$37,482	$22,716	$60,198
2027	$0	$38,403	$23,275	$61,678
2028	$0	$38,813	$23,523	$62,336
2029	$0	$39,671	$24,043	$63,714
2030	$0	$40,258	$24,399	$64,657
2031	$0	$40,811	$24,734	$65,544
2032	$0	$41,952	$25,426	$67,378
2033	$0	$42,812	$25,947	$68,759
2034	$0	$44,223	$26,802	$71,025
2035	$0	$45,055	$27,306	$72,362
2036	$0	$45,315	$27,463	$72,778
2037	$0	$45,671	$27,680	$73,351
2038	$0	$45,946	$27,846	$73,792
2039	$0	$46,308	$28,065	$74,373
2040	$0	$46,636	$28,264	$74,900
2041	$0	$46,914	$28,433	$75,347
2042	$0	$47,292	$28,662	$75,954
2043	$0	$47,631	$28,867	$76,498
2044	$0	$48,055	$29,124	$77,180
2045	$0	$48,452	$29,365	$77,817
2046	$0	$48,847	$29,604	$78,451
2047	$0	$49,219	$29,829	$79,048
2048	$0	$49,617	$30,071	$79,688
2049	$0	$49,978	$30,290	$80,268
2050	$0	$49,978	$30,290	$80,268

Lengthening Warranty Costs

In order to estimate the incremental costs due to CARB staff's proposed lengthened warranty, CARB staff first examined the baseline warranty practices and coverages. Generally, warranty costs are either included in the original purchase price of the vehicle or are included at an additional cost at the time of purchase through available extended warranty coverages. Next, CARB staff determined the average miles driven while under the baseline warranty, and the proposed warranty. From there, CARB staff estimated the baseline costs and the costs under the proposed warranty, and the difference between the two gives the overall incremental costs under the proposed Step 2 warranty amendments.

5.1. Baseline Information

To estimate the cost impacts of the proposed warranty amendments, a baseline characterization was developed. The cost impact of the proposed warranty amendments is then evaluated against the baseline scenario. As explained below, beginning with the 2022 model year, the warranty coverage market for heavy-duty vehicles is expected to be comprised of CARB-required emission control system warranties, manufacturer-provided warranties, and customer-purchased extended warranties.

5.1.1. Baseline Warranty Purchasing Business Practice

The projection for warranty coverages beginning in model year 2022 is expected to have a profile as shown in Table I.9 for heavy-duty diesel vehicles. These values come from estimates based on a survey conducted by the Sacramento Institute for Social Research (ISR), and discussions with manufacturers and third-party warranty providers, all obtained during the development of CARB's June 2018 Step 1 warranty amendment rulemaking effort (CARB, 2018c). The baseline used in this analysis accounts for real-world purchasing behavior and focuses on the out-of-pocket expenses that would be covered under the Proposed Amendments. Table I.9 also shows the expected baseline for the heavy-duty vehicles that use an HDO engine. Because heavy-duty vehicles with Otto-cycle engines were not included in the June 2018 Step 1 warranty amendments, a similar breakdown based on the Sacramento ISR survey was not developed for that category. As Table I.9 shows, for the heavy heavy-duty vehicle (HHDV) and medium heavy-duty vehicle (MHDV) purchases, CARB staff expects 40 percent of the vehicles to have warranty beyond the minimum required emissions warranty, and 60 percent of the vehicles to have just the minimum warranty coverage required by the June 2018 Step 1 warranty amendments. As Table I.9 indicates, for light heavy-duty vehicle (LHDV) purchases, it is estimated that 100 percent of the vehicles will have a warranty coverage of 110,000 miles, the minimum required by the June 2018 Step 1 warranty amendments. Similarly, for the HDO engine vehicles (HDOV), as a conservative approach (which will overestimate cost), CARB staff assumed that 100 percent of these vehicles rely on the CARB-regulatory specified warranty periods and do not currently purchase extended warranties.

Table I.9. Projected Baseline Warranty Purchasing Business Practices Due to the June 2018 Heavy-Duty Warranty Amendments (MY 2022)

Vehicle Category	Miles Warranted	Percent of Vehicle Population
HHDV	500,000	40%
	350,000	60%
MHDV	185,000	40%
	150,000	60%
LHDV	110,000	100%
HDOV	50,000	100%

5.1.2. Mileage Covered Under Baseline Warranty

Warranty periods under the baseline beginning in model year 2022 will be given as a mileage threshold and a year threshold. Warranty coverage ends based on whichever threshold occurs first. The warranty year threshold is currently 5 years for all the considered categories, and the mileage threshold can be either the regulatory mileage period, or the customer-purchased extended warranty period.

The EMFAC2017 on-road vehicle emissions model categorizes the heavy-duty market by their vehicle subcategories as shown in Table I.10. These subcategories are grouped by Gross Vehicle Weight Rating (GVWR), and CARB staff assumed a matching combination for each heavy-duty engine and heavy-duty vehicle, e.g., a HHDD engine installed in a Class 8 heavy-duty vehicle greater than 33,000 pounds GVWR. The 2022 model year populations from EMFAC were used in the baseline analysis, and their population percentages are shown in Table I.10

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Table I.10. EMFAC Vehicle Service Application Population Percentages for Model Year 2022

HHDV EMFAC T7: > 33,000 lbs. GVWR		MHDV EMFAC T6: 19,501 – 33,000 lbs. GVWR		LHDV EMFAC T6: 14,001 – 19,500 lbs. GVWR		HDOV GVWR > 14,000 lbs.	
Vehicle Subcategory	Population%	Vehicle Subcategory	Population%	Vehicle Subcategory	Population%	Vehicle Subcategory	Population%
Motor Coach	1.31%	T6 CAIRP Heavy	1.16%	T6 CAIRP Heavy	1.38%	OBUS	16.18%
T7 CAIRP	13.15%	T6 CAIRP Small	0.63%	T6 CAIRP Small	0.75%	SBUS	8.29%
T7 CAIRP Construction	1.19%	T6 Instate Construction Heavy	3.32%	T6 Instate Construction Heavy	3.94%	T6TS	68.15%
T7 Other Port	0.70%	T6 Instate Construction Small	10.17%	T6 Instate Construction Small	12.08%	T7IS	0.17%
T7 POAK	2.57%	T6 Instate Heavy	14.31%	T6 Instate Heavy	16.99%	UBUS-GAS	7.22%
T7 POLA	7.74%	T6 Instate Small	45.59%	T6 Instate Small	54.12%		
T7 Public	11.01%	T6 Public	7.51%	T6 Public	8.91%		
T7 Single	11.79%	T6 Utility	1.55%	T6 Utility	1.84%		
T7 Single Construction	8.29%	All Other Buses[a]	3.68%				
T7 SWCV	7.18%	SBUS[a]	5.87%				
T7 Tractor	21.75%	UBUS[a]	6.21%				
T7 Tractor Construction	5.54%						
T7 Utility	0.27%						
UBUS	7.50%						
TOTAL	**100%**	**TOTAL**	**100%**	**TOTAL**	**100%**	**TOTAL**	**100%**

[a] EMFAC bus categories for T6 grouped into GVWR range from 19,501- 33,000 lbs.

EMFAC2017 also models the annual vehicle miles traveled for each of the vehicle subcategories. Using the 2022 model year populations for EMFAC's vehicle service applications, the mileage accumulated during the first five years per vehicle application was examined to estimate which vehicle types sold in California typically exhaust their warranties due to the mileage threshold (i.e., either by regulatory or customer-purchased extended warranties), and which do so due to the year threshold. The warranty purchasing business practices were applied for all the vehicle subcategories because CARB staff is not able to determine which of them would purchase the extended coverage and which would rely on the regulatory warranty. So, for example, with the HHDV category, the miles covered under warranty at 350,000 miles versus 5 years were weighted at 60 percent, and the miles covered under warranty at 500,000 miles versus 5 years were weighted at 40 percent, and combining them, the overall weighted average miles that are covered under warranty would be 288,710 miles. This approach is shown in Table I.11 for HHDV. CARB staff performed a similar analysis for MHDV, LHDV, and HDOV, as shown in Table I.12, Table I.13, and Table I.14, respectively.

Table I.11. Table Showing the Calculations for the Mileage Covered Under Warranty for the HHDV Category under Baseline (MY 2022)

HHDV Warranty Mileage Estimates				
60% covered to 350,000 miles				
Vehicle Subcategory	**Population %**	**5 Year Mileage**	**Warranty Mileage**	**Miles Covered Under Warranty**
Motor Coach	1.31%	352,917	350,000	350,000
T7 CAIRP	13.15%	584,953	350,000	350,000
T7 CAIRP Construction	1.19%	584,953	350,000	350,000
T7 Other port	0.70%	488,987	350,000	350,000
T7 POAK	2.57%	488,987	350,000	350,000
T7 POLA	7.74%	488,987	350,000	350,000
T7 Public	11.01%	49,896	350,000	49,896
T7 Single	11.79%	211,768	350,000	211,768
T7 Single Construction	8.29%	211,768	350,000	211,768
T7 SWCV	7.18%	100,325	350,000	100,325
T7 Tractor	21.75%	488,987	350,000	350,000
T7 Tractor Construction	5.54%	488,987	350,000	350,000
T7 Utility	0.27%	46,656	350,000	46,656
UBUS	7.50%	194,564	350,000	194,564
			Weighted Average Miles Covered for 60%	**258,793**
40% covered to 500,000 miles				
Vehicle Subcategory	**Population %**	**5 Year Mileage**	**Warranty Mileage**	**Miles Covered Under Warranty**
Motor Coach	1.31%	352,917	500,000	352,917
T7 CAIRP	13.15%	584,953	500,000	500,000
T7 CAIRP Construction	1.19%	584,953	500,000	500,000
T7 Other Port	0.70%	488,987	500,000	488,987
T7 POAK	2.57%	488,987	500,000	488,987
T7 POLA	7.74%	488,987	500,000	488,987
T7 Public	11.01%	49,896	500,000	49,896
T7 Single	11.79%	211,768	500,000	211,768
T7 Single Construction	8.29%	211,768	500,000	211,768
T7 SWCV	7.18%	100,325	500,000	100,325
T7 Tractor	21.75%	488,987	500,000	488,987
T7 Tractor Construction	5.54%	488,987	500,000	488,987
T7 Utility	0.27%	46,656	500,000	46,656
UBUS	7.50%	194,564	500,000	194,564
			Weighted Average Miles Covered for 40%	**333,586**
Overall Weighted Average Mileage Covered for HHDV: 288,710 miles				

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Table I.12. Table Showing the Calculations for the Mileage Covered Under Warranty for the MHDV Category under Baseline (MY 2022)

MHDV Warranty Mileage Estimates				
60% covered to 150,000 miles				
Vehicle Subcategory	**Population %**	**5 Year Mileage**	**Warranty Mileage**	**Miles Covered Under Warranty**
T6 CAIRP Heavy	1.16%	152,742	150,000	150,000
T6 CAIRP Small	0.63%	152,742	150,000	150,000
T6 Instate Construction Heavy	3.32%	152,742	150,000	150,000
T6 Instate Construction Small	10.17%	152,742	150,000	150,000
T6 Instate Heavy	14.31%	152,742	150,000	150,000
T6 Instate Small	45.59%	152,742	150,000	150,000
T6 Public	7.51%	43,876	150,000	43,876
T6 Utility	1.55%	40,908	150,000	40,908
All Other Buses	3.68%	168,252	150,000	150,000
SBUS	5.87%	89,469	150,000	89,469
UBUS	6.21%	194,564	150,000	150,000
			Weighted Average Miles Covered for 60%	**136,793**
40% covered to 185,000 miles				
Vehicle Subcategory	**Population %**	**5 Year Mileage**	**Warranty Mileage**	**Miles Covered Under Warranty**
T6 CAIRP Heavy	1.16%	152,742	185,000	152,742
T6 CAIRP Small	0.63%	152,742	185,000	152,742
T6 Instate Construction Heavy	3.32%	152,742	185,000	152,742
T6 Instate Construction Small	10.17%	152,742	185,000	152,742
T6 Instate Heavy	14.31%	152,742	185,000	152,742
T6 Instate Small	45.59%	152,742	185,000	152,742
T6 Public	7.51%	43,876	185,000	43,876
T6 Utility	1.55%	40,908	185,000	40,908
All Other Buses	3.68%	168,252	185,000	168,252
SBUS	5.87%	89,469	185,000	89,469
UBUS	6.21%	194,564	185,000	185,000
			Weighted Average Miles Covered for 40%	**141,700**
Overall Weighted Average Mileage Covered for MHDV: 138,756 miles				

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Table I.13. Table Showing the Calculations for the Mileage Covered Under Warranty for the LHDV Category under Baseline (MY 2022)

LHDV Warranty Mileage Estimates				
100% covered to 110,000 miles				
Vehicle Subcategory	**Population %**	**5 Year Mileage**	**Warranty Mileage**	**Miles Covered Under Warranty**
T6 CAIRP Heavy	1.38%	152,742	110,000	110,000
T6 CAIRP Small	0.75%	152,742	110,000	110,000
T6 Instate Construction Heavy	3.94%	152,742	110,000	110,000
T6 Instate Construction Small	12.08%	152,742	110,000	110,000
T6 Instate Heavy	16.99%	152,742	110,000	110,000
T6 Instate Small	54.12%	152,742	110,000	110,000
T6 Public	8.91%	43,876	110,000	43,876
T6 Utility	1.84%	40,908	110,000	40,908
Weighted Average Miles Covered for 100%				**102,838**
Overall Weighted Average Mileage Covered for LHDV: 102,838 miles				

Table I.14. Table Showing the Calculations for the Mileage Covered Under Warranty for the HDOV Category under Baseline (MY 2022)

HDOV Warranty Mileage Estimates				
100% covered to 50,000 miles				
Vehicle Subcategory	**Population %**	**5 Year Mileage**	**Warranty Mileage**	**Miles Covered Under Warranty**
OBUS	16.18%	105,564	50,000	50,000
SBUS	8.29%	89,469	50,000	50,000
T6TS	68.15%	112,091	50,000	50,000
T7IS	0.17%	337,468	50,000	50,000
UBUS	7.22%	212,149	50,000	50,000
Weighted Average Miles Covered for 100%				**50,000**
Overall Weighted Average Mileage Covered for HDOV: 50,000 miles				

Overall, the baseline average miles traveled under warranty, are shown in Table I.15.

Table I.15. Projected Baseline Warranty Average Miles Traveled Under the June 2018 Warranty Amendments for Each Vehicle Category (MY2022+)

Vehicle Category	Baseline Average Miles Traveled Under Warranty
HHDV	288,710
MHDV	138,756
LHDV	102,838
HDOV	50,000

5.1.3. Cost of Repairs Under the Baseline Warranty

To establish the baseline costs, CARB staff determined the cost of repairs under the June 2018 Step 1 warranty amendments, which, as noted above, will be in effect beginning with the 2022 model year. CARB staff did the analysis using information from the warranty claims-related data and sales data from the engine certification applications. Table I.16, below, shows the certification sales data for 2013 MY heavy-duty engines sold in California.

Table I.16. 2013 Model Year California Certified Engine Sales by Vehicle Category

Vehicle Category	Sales
HHDV	11,022
MHDV	4,967
LHDV	5,025
HDOV	8,522

The total number of warranty claims for each emissions-related engine component over the 5-year reporting period were added up and divided by the number of certified engines sold for each vehicle class to calculate the rate of repair under warranty, referred to as the warranty claims rate. The most recent EWIR complete 5-year warranty claims data set is based on the 2013 model year, and so, CARB staff used the 2013 model year engine certification reported sales to calculate the warranty claims rate.

CARB staff estimated the average repair costs, including both parts and labor, for each component through analysis of service station repair order records, online searches for component costs, and an estimated labor rate of $100 per hour, and costs utilized in the June 2018 Step 1 warranty rulemaking (CARB, 2018d). Multiplying these average repair costs by the claims rate for each emissions-related engine component provides an estimate for the weighted average repair costs per component. Adding up all the weighted average repair costs for the components gives the total expected warranty repair costs that a typical heavy-duty vehicle would experience while still under warranty.

This approach is shown in Table I.17 for the HHDV category, which had 11,022 engines sold for the 2013 model year, and a total of 17,933 warranty claims over the five year reporting period which gives a total warranty claims rate of 162.7 percent. A warranty claims rate that exceeds 100 percent means that, on average, the vehicle category received more than one claim per vehicle. The table also shows a total of $2,400 for the weighted average repair costs which is the expected warranty repair costs that a typical HHDV would experience while under warranty.

Using this approach, the total weighted average repair costs can be found for all the vehicle categories that are considered under this proposal. Tables I.18 through I.20 break down the estimated repair rates and costs for MHDV, LHDV, and HDOV.

Table I.17. 2013 Model Year Warranty Claims Rates and Costs for the HHDV Category (2018$)

Component	Total Claims[a]	Warranty Claims Rate	Average Repair Cost	Weighted Average Repair Cost
CATALYST	0	0.0%	$2,500	$0.00
DOC	893	8.1%	$3,800	$307.88
DPF	118	1.1%	$2,600	$27.84
ECU	653	5.9%	$1,725	$102.20
SCR	138	1.3%	$5,371	$67.25
DEF DOSER	1,010	9.2%	$1,178	$107.95
DPF DOSER	778	7.1%	$1,178	$83.15
EGR COOLER	1,059	9.6%	$3,100	$297.85
EGR VALVE	358	3.2%	$1,200	$38.98
FUEL INJECTOR	659	6.0%	$2,208	$132.02
TURBOCHARGER	1,082	9.8%	$5,100	$500.65
BLOWBY FILTER	0	0.0%	$150	$0.00
BOOST CONTROL VALVE	12	0.1%	$450	$0.49
CHARGE AIR COOLER	2	0.0%	$3,000	$0.54
CHARGE AIR DUCT	28	0.3%	$300	$0.76
CLAMP	8	0.1%	$50	$0.04
CRANKCASE SEPARATOR	22	0.2%	$1,029	$2.05
CYLINDER HEAD	26	0.2%	$5,000	$11.79
DEF PUMP	454	4.1%	$1,445	$59.52
DEF TANK	27	0.2%	$1,000	$2.45
ECU REPROGRAM	3,246	29.5%	$400	$117.80
ELECTRICAL HARNESS	122	1.1%	$277	$3.07
EXHAUST MANIFOLD	369	3.3%	$2,500	$83.70
EXHAUST VALVE	81	0.7%	$3,500	$25.72
FUEL LINE	6	0.1%	$1,362	$0.74
FUEL PUMP	370	3.4%	$1,624	$54.52
FUEL TANK	0	0.0%	$2,000	$0.00
GASKET	111	1.0%	$100	$1.01
IGNITION CONTROL MODULE	282	2.6%	$550	$14.07
INTAKE MANIFOLD	2	0.0%	$2,500	$0.45
NOx SENSOR	1,677	15.2%	$670	$101.94
OIL PUMP	35	0.3%	$1,293	$4.11
OIL RAIL	16	0.1%	$1,638	$2.38
OIL SEPARATOR	879	8.0%	$500	$39.87
OTHER SENSORS	3,206	29.1%	$670	$194.88
PRESS CONTROL VALVE	41	0.4%	$500	$1.86
RUBBER HOSE	25	0.2%	$250	$0.57
THROTTLE VALVE	138	1.3%	$805	$10.08
VACUUM PUMP	0	0.0%	$550	$0.00
TOTAL	**17,933**	**162.7%**	**--**	**$2,400**

[a] Note that the total claims values shown are for HHDV and urban buses. This was done in order to remain consistent with CARB's certification requirements that define an urban bus as a bus that is normally powered by a heavy heavy-duty engine and weighs greater than 33,000 pounds GVWR

Table I.18. 2013 Model Year Warranty Claims Rates and Costs for the MHDV Category (2018$)

Component	Total Claims	Warranty Claims Rate	Average Repair Cost	Weighted Average Repair Cost
CATALYST	0	0.0%	$2,500	$0.00
DOC	246	5.0%	$3,800	$188.20
DPF	72	1.4%	$2,600	$37.69
ECU	641	12.9%	$1,725	$222.61
SCR	548	11.0%	$5,371	$592.57
DEF DOSER	324	6.5%	$1,178	$76.84
DPF DOSER	108	2.2%	$1,178	$25.61
EGR COOLER	882	17.8%	$3,100	$550.47
EGR VALVE	334	6.7%	$1,200	$80.69
FUEL INJECTOR	264	5.3%	$2,208	$117.36
TURBOCHARGER	599	12.1%	$5,100	$615.04
BLOWBY FILTER	0	0.0%	$150	$0.00
BOOST CONTROL VALVE	24	0.5%	$450	$2.17
CHARGE AIR COOLER	8	0.2%	$3,000	$4.83
CHARGE AIR DUCT	45	0.9%	$300	$2.72
CLAMP	16	0.3%	$50	$0.16
CRANKCASE SEPARATOR	0	0.0%	$1,029	$0.00
CYLINDER HEAD	0	0.0%	$5,000	$0.00
DEF PUMP	0	0.0%	$1,445	$0.00
DEF TANK	0	0.0%	$1,000	$0.00
ECU REPROGRAM	32	0.6%	$400	$2.58
ELECTRICAL HARNESS	63	1.3%	$277	$3.51
EXHAUST MANIFOLD	128	2.6%	$2,500	$64.43
EXHAUST VALVE	0	0.0%	$3,500	$0.00
FUEL LINE	0	0.0%	$1,362	$0.00
FUEL PUMP	68	1.4%	$1,624	$22.23
FUEL TANK	0	0.0%	$2,000	$0.00
GASKET	68	1.4%	$100	$1.37
IGNITION CONTROL MODULE	39	0.8%	$550	$4.32
INTAKE MANIFOLD	0	0.0%	$2,500	$0.00
NOx SENSOR	391	7.9%	$670	$52.74
OIL PUMP	0	0.0%	$1,293	$0.00
OIL RAIL	53	1.1%	$1,638	$17.48
OIL SEPARATOR	0	0.0%	$500	$0.00
OTHER SENSORS	556	11.2%	$670	$75.00
PRESS CONTROL VALVE	0	0.0%	$500	$0.00
RUBBER HOSE	58	1.2%	$250	$2.92
THROTTLE VALVE	35	0.7%	$805	$5.67
VACUUM PUMP	0	0.0%	$550	$0.00
TOTAL	**5,602**	**112.8%**	**--**	**$2,769**

Table I.19. 2013 Model Year Warranty Claims Rates and Costs for the LHDV Category (2018$)

Component	Total Claims	Warranty Claims Rate	Average Repair Cost	Weighted Average Repair Cost
CATALYST	0	0.0%	$2,500	$0.00
DOC	9	0.2%	$3,800	$6.81
DPF	170	3.4%	$2,600	$87.96
ECU	13	0.3%	$1,725	$4.46
SCR	0	0.0%	$5,371	$0.00
DEF DOSER	43	0.9%	$1,178	$10.08
DPF DOSER	150	3.0%	$1,178	$35.16
EGR COOLER	36	0.7%	$3,100	$22.21
EGR VALVE	256	5.1%	$1,200	$61.13
FUEL INJECTOR	67	1.3%	$2,208	$29.44
TURBOCHARGER	272	5.4%	$5,100	$276.06
BLOWBY FILTER	95	1.9%	$150	$2.84
BOOST CONTROL VALVE	14	0.3%	$450	$1.25
CHARGE AIR COOLER	0	0.0%	$3,000	$0.00
CHARGE AIR DUCT	22	0.4%	$300	$1.31
CLAMP	14	0.3%	$50	$0.14
CRANKCASE SEPARATOR	0	0.0%	$1,029	$0.00
CYLINDER HEAD	0	0.0%	$5,000	$0.00
DEF PUMP	1	0.0%	$1,445	$0.29
DEF TANK	197	3.9%	$1,000	$39.20
ECU REPROGRAM	309	6.1%	$400	$24.60
ELECTRICAL HARNESS	64	1.3%	$277	$3.53
EXHAUST MANIFOLD	225	4.5%	$2,500	$111.94
EXHAUST VALVE	0	0.0%	$3,500	$0.00
FUEL LINE	3	0.1%	$1,362	$0.81
FUEL PUMP	0	0.0%	$1,624	$0.00
FUEL TANK	0	0.0%	$2,000	$0.00
GASKET	13	0.3%	$100	$0.26
IGNITION CONTROL MODULE	0	0.0%	$550	$0.00
INTAKE MANIFOLD	0	0.0%	$2,500	$0.00
NOx SENSOR	172	3.4%	$670	$22.93
OIL PUMP	103	2.0%	$1,293	$26.50
OIL RAIL	5	0.1%	$1,638	$1.63
OIL SEPARATOR	79	1.6%	$500	$7.86
OTHER SENSORS	2106	41.9%	$670	$280.80
PRESS CONTROL VALVE	0	0.0%	$500	$0.00
RUBBER HOSE	47	0.9%	$250	$2.34
THROTTLE VALVE	3	0.1%	$805	$0.48
VACUUM PUMP	104	2.1%	$550	$11.38
TOTAL	**4,592**	**91.4%**	**--**	**$1,073**

Table I.20. 2013 Model Year Warranty Claims Rates and Costs for the HDOV Category (2018$)

Component	Total Claims	Warranty Claims Rate	Average Repair Cost	Weighted Average Repair Cost
CATALYST	701	8.2%	$2,500	$205.64
DOC	0	0.0%	$3,800	$0.00
DPF	0	0.0%	$2,600	$0.00
ECU	0	0.0%	$1,725	$0.00
SCR	0	0.0%	$5,371	$0.00
DEF DOSER	0	0.0%	$1,178	$0.00
DPF DOSER	0	0.0%	$1,178	$0.00
EGR COOLER	0	0.0%	$3,100	$0.00
EGR VALVE	0	0.0%	$1,200	$0.00
FUEL INJECTOR	0	0.0%	$2,208	$0.00
TURBOCHARGER	0	0.0%	$5,100	$0.00
BLOWBY FILTER	0	0.0%	$150	$0.00
BOOST CONTROL VALVE	0	0.0%	$450	$0.00
CHARGE AIR COOLER	11	0.1%	$3,000	$3.87
CHARGE AIR DUCT	0	0.0%	$300	$0.00
CLAMP	0	0.0%	$50	$0.00
CRANKCASE SEPARATOR	0	0.0%	$1,029	$0.00
CYLINDER HEAD	0	0.0%	$5,000	$0.00
DEF PUMP	0	0.0%	$1,445	$0.00
DEF TANK	0	0.0%	$1,000	$0.00
ECU REPROGRAM	0	0.0%	$400	$0.00
ELECTRICAL HARNESS	0	0.0%	$277	$0.00
EXHAUST MANIFOLD	0	0.0%	$2,500	$0.00
EXHAUST VALVE	0	0.0%	$3,500	$0.00
FUEL LINE	0	0.0%	$1,362	$0.00
FUEL PUMP	9	0.1%	$1,624	$1.72
FUEL TANK	0	0.0%	$2,000	$0.00
GASKET	0	0.0%	$100	$0.00
IGNITION CONTROL MODULE	0	0.0%	$550	$0.00
INTAKE MANIFOLD	16	0.2%	$2,500	$4.69
NOx SENSOR	0	0.0%	$670	$0.00
OIL PUMP	0	0.0%	$1,293	$0.00
OIL RAIL	0	0.0%	$1,638	$0.00
OIL SEPARATOR	0	0.0%	$500	$0.00
OTHER SENSORS	286	3.4%	$670	$22.49
PRESS CONTROL VALVE	0	0.0%	$500	$0.00
RUBBER HOSE	0	0.0%	$250	$0.00
THROTTLE VALVE	0	0.0%	$805	$0.00
VACUUM PUMP	0	0.0%	$550	$0.00
TOTAL	**1,023**	**12.0%**	**--**	**$238**

Additionally, beginning with the 2022 model year for HHDV, MHDV, and LHDV, the warranty coverage will also include emissions components that cause the OBD system's malfunction indicator light to illuminate. The total average repair costs, taking into account both the costs associated with the indirect OBD components[1] and the traditionally reported components, are shown in Table I.21.

Table I.21. Total Average Baseline Warranty Repair Costs Per Vehicle Expected Under the June 2018 Step 1 Warranty Amendments (MY 2022) for Each Vehicle Category (2018$/vehicle)

Vehicle Category	Average Repair Costs from 2013 Model Year EWIR Data	Expected Indirect Emissions Components Repair Costs Beginning in Model Year 2022 under Step 1 Warranty	Expected Total Average Baseline Repair Costs Beginning in Model Year 2022
HHDV	$2,400	$16	$2,416
MHDV	$2,769	$6	$2,775
LHDV	$1,073	$23	$1,096
HDOV	$238	N/A	$238

5.1.4 Summary of Baseline Estimates

CARB staff used the warranty purchase practices, the warranty claim rates, and average repair costs to establish the minimum cost that the manufacturer would need to recoup when providing warranties. Table I.22 below provides a summary of the average miles driven under warranty and the associated costs for each vehicle category

Table I.22. Summary of the Baseline Estimates (MY 2022) for Each Vehicle Category (2018$)

Vehicle Category	Baseline Average Miles Traveled Under Warranty	Expected Total Average Baseline Repair Costs Beginning in Model Year 2022
HHDV	288,710	$2,416
MHDV	138,756	$2,775
LHDV	102,838	$1,096
HDOV	50,000	$238

[1] Indirect OBD components do not have a direct impact on the emissions, but are monitored by the OBD system because a malfunction of one of these input or output sensors, if undetected, could lead to incorrect diagnosis of emission malfunctions or even prevent the OBD system from checking for malfunctions.

5.2 Proposal Information

CARB Staff is proposing to lengthen the warranty periods for diesel and HDOVs greater than 14,000 pounds GVWR based on the certified primary intended service class of the engines used in these vehicles. Table I.23 below provides the proposed warranties for HHDVs, MHDVs, LHDVs, and HDOVs.

Table I.23. Proposed Heavy-Duty Warranty Periods

Vehicle Category	Proposed Phase-in for Step 2 Warranty Effective MY 2027-2030 (Miles)	Proposed Phase-in for Step 2 Warranty Effective MY 2031 and later (Miles)
HHDV	450,000 7 years 22,000 hours	600,000 10 years 30,000 hours
MHDV	220,000 7 years 11,000 hours	280,000 10 years 14,000 hours
LHDV	150,000 7 years 7,000 hours	210,000 10 years 10,000 hours
HDOV	110,000 7 years 6,000 hours	160,000 10 years 8,000 hours

5.2.1 Estimated Warranty Purchasing Business Practices under the Proposed Warranty

Table I.24 and Table I.25 below show expected warranty purchasing practices for model year 2027 and 2031 under the Proposed Amendments. As Table I.24 shows, CARB staff expects that for the 2027 model year, 40 percent of HHDV vehicles would still have warranties beyond the required minimum emissions warranty, while 60 percent of them would have the minimum warranty required by the Proposed Amendments. In the 2027 model year, all MHDVs, LHDVs, and HDOVs would rely on the regulatory warranty rather than buying an extended warranty. By the 2031 model year, all affected vehicles would rely on the proposed regulatory warranty. In other words, beginning in model year 2031, CARB staff assumes no heavy-duty vehicle purchasers would buy emission warranties extending beyond those required by the Proposed Amendments.

Table I.24. Estimated Warranty Purchasing Business Practices Due to the Proposed 2027 Phase-In Warranty Amendments (MY 2027-2030)

Vehicle Category	Miles Warranted	Percent of Vehicle Population
HHDV	500,000	40%
	450,000	60%
MHDV	220,000	100%
LHDV	150,000	100%
HDOV	110,000	100%

Table I.25. Estimated Warranty Purchasing Business Practices Due to the Proposed 2031 Phase-In Warranty Amendments (MY 2031+)

Vehicle Category	Miles Warranted	Percent of Vehicle Population
HHDV	600,000	100%
MHDV	280,000	100%
LHDV	210,000	100%
HDOV	160,000	100%

5.2.2 Average Mileage Driven under the Proposed Warranty

CARB staff estimated the average miles traveled while under warranty for model years 2027 to 2030, and model years 2031 and subsequent with the proposed warranty amendments. The estimates were based on the warranty coverage practices, the mileage accumulated at the proposed years obtained from EMFAC, and equivalent mileage for the proposed hours periods derived from the College of Engineering – Center for Environmental Research and Technology (CE-CERT) vocational truck study (CE-CERT, 2017).

Using the same approach as was done for the baseline, CARB staff determined whether each vehicle subcategory would exhaust their projected warranty via either the mileage threshold, the year threshold, or the hours threshold. So, for example, with the HHDV category, the miles covered under the proposed warranty in model year 2027 at 450,000 miles versus 7 years, versus the equivalent miles at 22,000 hours were weighted at 60 percent, and the miles covered under warranty at 500,000 miles versus 7 years, versus the equivalent miles at 22,000 hours were weighted at 40 percent. Combining them, the overall weighted average miles that are covered under warranty would be 307,763 miles. The results for the projected mileage driven under the proposed warranties are shown in Tables I.26 to I.33 for each of the vehicle categories beginning in MY 2027 and MY 2031.

Table I.26. Calculations for the Mileage Covered Under Warranty for the HHDV Category under the Proposal (MY 2027- 2030)

HHDV Warranty Mileage Estimates in MY 2027- 2030					
60% covered to 450,000 miles					
Vehicle Subcategory	**Population %**	**7-year mileage**	**22,000 hours equivalent miles**	**Warranty Mileage**	**Miles Covered Under Warranty**
Motor Coach	1.31%	462,917	903,665	450,000	450,000
T7 CAIRP	13.15%	731,451	903,665	450,000	450,000
T7 CAIRP Construction	1.19%	731,451	378,880	450,000	378,880
T7 Other port	0.70%	615,841	232,056	450,000	232,056
T7 POAK	2.57%	615,841	232,056	450,000	232,056
T7 POLA	7.74%	615,841	232,056	450,000	232,056
T7 Public	11.01%	65,448	443,133	450,000	65,448
T7 Single	11.79%	265,329	603,795	450,000	265,329
T7 Single Construction	8.29%	265,329	378,880	450,000	265,329
T7 SWCV	7.18%	131,595	240,933	450,000	131,595
T7 Tractor	21.75%	615,841	710,426	450,000	450,000
T7 Tractor Construction	5.54%	615,841	378,880	450,000	378,880
T7 Utility	0.27%	62,208	278,715	450,000	62,208
UBUS	7.50%	270,358	221,255	450,000	221,255
				Weighted Average Miles Covered for 60%	**300,715**
40% covered to 500,000 miles					
Vehicle Subcategory	**Population %**	**7-year mileage**	**22,000 hours equivalent miles**	**Warranty Mileage**	**Miles Covered Under Warranty**
Motor Coach	1.31%	462,917	903,665	500,000	462,917
T7 CAIRP	13.15%	731,451	903,665	500,000	500,000
T7 CAIRP Construction	1.19%	731,451	378,880	500,000	378,880
T7 Other Port	0.70%	615,841	232,056	500,000	232,056
T7 POAK	2.57%	615,841	232,056	500,000	232,056
T7 POLA	7.74%	615,841	232,056	500,000	232,056
T7 Public	11.01%	65,448	443,133	500,000	65,448
T7 Single	11.79%	265,329	603,795	500,000	265,329
T7 Single Construction	8.29%	265,329	378,880	500,000	265,329
T7 SWCV	7.18%	131,595	240,933	500,000	131,595
T7 Tractor	21.75%	615,841	710,426	500,000	500,000
T7 Tractor Construction	5.54%	615,841	378,880	500,000	378,880
T7 Utility	0.27%	62,208	278,715	500,000	62,208
UBUS	7.50%	270,358	221,255	500,000	221,255
				Weighted Average Miles Covered for 40%	**318,336**
Overall Weighted Average Mileage Covered for HHDV MY 2027- 2030: 307,763 miles					

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Table I.27. Calculations for the Mileage Covered Under Warranty for the HHDV Category under the Proposal (MY 2031 and subsequent)

HHDV Warranty Mileage Estimates in MY 2031 and subsequent					
100% covered to 600,000 miles					
Vehicle Subcategory	**Population %**	**10-year mileage**	**30,000 hours equivalent miles**	**Warranty Mileage**	**Miles Covered Under Warranty**
Motor Coach	1.31%	611,967	1,232,271	600,000	600,000
T7 CAIRP	13.15%	800,000	1,232,271	600,000	600,000
T7 CAIRP Construction	1.19%	800,000	516,654	600,000	516,654
T7 Other port	0.70%	765,588	316,440	600,000	316,440
T7 POAK	2.57%	765,588	316,440	600,000	316,440
T7 POLA	7.74%	765,588	316,440	600,000	316,440
T7 Public	11.01%	88,776	604,272	600,000	88,776
T7 Single	11.79%	336,079	823,356	600,000	336,079
T7 Single Construction	8.29%	336,079	516,654	600,000	336,079
T7 SWCV	7.18%	178,500	328,544	600,000	178,500
T7 Tractor	21.75%	765,588	968,762	600,000	600,000
T7 Tractor Construction	5.54%	765,588	516,654	600,000	516,654
T7 Utility	0.27%	85,536	380,066	600,000	85,536
UBUS	7.50%	393,363	301,712	600,000	301,712
			Weighted Average Miles Covered for 100%		**399,843**
Overall Weighted Average Mileage Covered for HHDV MY 2031 and subsequent: 399,843 miles					

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Table I.28. Calculations for the Mileage Covered Under Warranty for the MHDV Category under the Proposal (MY 2027- 2030)

MHDV Warranty Mileage Estimates in MY 2027- 2030					
100% covered to 220,000 miles					
Vehicle Subcategory	**Population %**	**7-year mileage**	**11,000 hours equivalent miles**	**Warranty Mileage**	**Miles Covered Under Warranty**
T6 CAIRP Heavy	1.16%	196,337	451,833	220,000	196,337
T6 CAIRP Small	0.63%	196,337	451,833	220,000	196,337
T6 Instate Construction Heavy	3.32%	196,337	189,440	220,000	189,440
T6 Instate Construction Small	10.17%	196,337	189,440	220,000	189,440
T6 Instate Heavy	14.31%	196,337	301,897	220,000	196,337
T6 Instate Small	45.59%	196,337	301,897	220,000	196,337
T6 Public	7.51%	56,539	221,566	220,000	56,539
T6 Utility	1.55%	53,571	139,358	220,000	53,571
All Other Buses	3.68%	215,078	168,935	220,000	168,935
SBUS	5.87%	116,195	301,897	220,000	116,195
UBUS	6.21%	270,358	110,628	220,000	110,628
				Weighted Average Miles Covered for 100%	**171,667**
Overall Weighted Average Mileage Covered for MHDV MY 2027- 2030: 171,667 miles					

Table I.29. Calculations for the Mileage Covered Under Warranty for the MHDV Category under the Proposal (MY 2031)

MHDV Warranty Mileage Estimates in MY 2031 and subsequent					
100% covered to 280,000 miles					
Vehicle Subcategory	**Population %**	**10-year mileage**	**14,000 hours equivalent miles**	**Warranty Mileage**	**Miles Covered Under Warranty**
T6 CAIRP Heavy	1.16%	252,551	575,060	280,000	252,551
T6 CAIRP Small	0.63%	252,551	575,060	280,000	252,551
T6 Instate Construction Heavy	3.32%	252,551	241,105	280,000	241,105
T6 Instate Construction Small	10.17%	252,551	241,105	280,000	241,105
T6 Instate Heavy	14.31%	252,551	384,233	280,000	252,551
T6 Instate Small	45.59%	252,551	384,233	280,000	252,551
T6 Public	7.51%	74,622	281,994	280,000	74,622
T6 Utility	1.55%	71,654	177,364	280,000	71,654
All Other Buses	3.68%	277,383	215,008	280,000	215,008
SBUS	5.87%	155,239	384,233	280,000	155,239
UBUS	6.21%	393,363	140,799	280,000	140,799
				Weighted Average Miles Covered for 100%	**220,816**
Overall Weighted Average Mileage Covered for MHDV MY 2031 and subsequent: 220,816 miles					

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Table I.30. Calculations for the Mileage Covered Under Warranty for the LHDV Category under the Proposal (MY 2027- 2030)

LHDV Warranty Mileage Estimates in MY 2027- 2030					
100% covered to 150,000 miles					
Vehicle Subcategory	**Population %**	**7-year mileage**	**7,000 hours equivalent miles**	**Warranty Mileage**	**Miles Covered Under Warranty**
T6 CAIRP Heavy	1.38%	196,337	287,530	150,000	150,000
T6 CAIRP Small	0.75%	196,337	287,530	150,000	150,000
T6 Instate Construction Heavy	3.94%	196,337	120,553	150,000	120,553
T6 Instate Construction Small	12.08%	196,337	120,553	150,000	120,553
T6 Instate Heavy	16.99%	196,337	192,117	150,000	150,000
T6 Instate Small	54.12%	196,337	192,117	150,000	150,000
T6 Public	8.91%	56,539	140,997	150,000	56,539
T6 Utility	1.84%	53,571	88,682	150,000	53,571
Weighted Average Miles Covered for 100%					**135,184**
Overall Weighted Average Mileage Covered for LHDV MY 2027- 2030: 135,184 miles					

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Table I.31. Calculations for the Mileage Covered Under Warranty for the LHDV Category under the Proposal (MY 2031 and subsequent)

LHDV Warranty Mileage Estimates in MY 2031 and subsequent					
100% covered to 210,000 miles					
Vehicle Subcategory	**Population %**	**10-year mileage**	**10,000 hours equivalent miles**	**Warranty Mileage**	**Miles Covered Under Warranty**
T6 CAIRP Heavy	1.38%	252,551	410,757	210,000	210,000
T6 CAIRP Small	0.75%	252,551	410,757	210,000	210,000
T6 Instate Construction Heavy	3.94%	252,551	172,218	210,000	172,218
T6 Instate Construction Small	12.08%	252,551	172,218	210,000	172,218
T6 Instate Heavy	16.99%	252,551	274,452	210,000	210,000
T6 Instate Small	54.12%	252,551	274,452	210,000	210,000
T6 Public	8.91%	74,622	201,424	210,000	74,622
T6 Utility	1.84%	71,654	126,689	210,000	71,654
Weighted Average Miles Covered for 100%					**189,343**
Overall Weighted Average Mileage Covered for LHDV MY 2031 and subsequent: 189,343 miles					

Table I.32. Calculations for the Mileage Covered Under Warranty for the HDOV Category under the Proposal (MY 2027- 2030)

HDOV Warranty Mileage Estimates in MY 2027- 2030					
100% covered to 110,000 miles					
Vehicle Subcategory	**Population %**	**7-year mileage**	**6,000 hours equivalent miles**	**Warranty Mileage**	**Miles Covered Under Warranty**
OBUS	16.18%	140,195	92,146	110,000	92,146
SBUS	8.29%	116,195	164,671	110,000	110,000
T6TS	68.15%	153,009	164,671	110,000	110,000
T7IS	0.17%	424,368	164,671	110,000	110,000
UBUS	7.22%	274,009	60,342	110,000	60,342
Weighted Average Miles Covered for 100%					**103,526**
Overall Weighted Average Mileage Covered for HDOV MY 2027- 2030: 103,526 miles					

Table I.33. Calculations for the Mileage Covered Under Warranty for the HDOV Category under the Proposal (MY 2031 and subsequent)

HDOV Warranty Mileage Estimates in MY 2031 and subsequent					
100% covered to 110,000 miles					
Vehicle Subcategory	**Population %**	**10-year mileage**	**8,000 hours equivalent miles**	**Warranty Mileage**	**Miles Covered Under Warranty**
OBUS	16.18%	186,974	122,862	160,000	122,862
SBUS	8.29%	155,239	219,562	160,000	155,239
T6TS	68.15%	198,317	219,562	160,000	160,000
T7IS	0.17%	539,311	219,562	160,000	160,000
UBUS	7.22%	365,858	80,456	160,000	80,456
Weighted Average Miles Covered for 100%					**147,854**
Overall Weighted Average Mileage Covered for HDOV MY 2031 and subsequent: 147,854 miles					

A summary of the average mileages traveled while under the proposed warranty are shown in Table I.34 for each vehicle category.

Table I.34. Estimated Average Miles Travelled Under the Proposed Step 2 Warranty Amendments in Model Years 2027- 2030 and Model Years 2031 and Subsequent

Vehicle Category	Average Miles Traveled Under Proposed Warranty Period for Model Years 2027- 2030	Average Miles Traveled Under Proposed Warranty Period for Model Years 2031 and subsequent
HHDV	307,763	399,843
MHDV	171,667	220,816
LHDV	135,184	189,343
HDOV	103,526	147,854

As shown in Table I.34, the miles traveled under warranty are less than the warranty mileage period because some vehicles either are lost through attrition before they reach the new warranty mileage periods or they exhaust their warranty coverage via years or hours instead of miles.

5.2.3 Cost of Repairs under the Proposed Warranty

In order to calculate the incremental repair costs under the proposed lengthened warranty periods, the repair costs associated with the baseline are needed, along with the projected repair costs out to the proposed phased-in periods in model year 2027 and model year 2031. Adding the difference between the model year 2027 and the baseline costs, as well as the difference between the model years 2031 and 2027 costs, represents the total incremental repair costs associated with the lengthened warranty proposal. These total incremental repair costs represent the increase in warranty claims payments for repairs that are expected to be done during the proposed lengthened warranty periods.

The projected repair costs in model years 2027 and 2031 were determined by calculating a mileage ratio for each vehicle category for both parts of the phase-in. This ratio was obtained from dividing the average mileage traveled under the proposed warranty periods by the average miles traveled under the baseline warranty analysis done earlier. The resulting quotient yields a mileage ratio for each vehicle category that was applied to the baseline costs to determine the cost of repairs for the proposed lengthened warranty periods. Inherently this assumes a linear relationship between the vehicle odometer mileage and the warranty repair costs derived from the claims rate. An underlying aspect of this assumption is that components would continue to fail at the same rate for the duration of the lengthened warranty period. CARB staff understands that for mechanical systems there is often a non-linear “bathtub” curve (NIST, 2013) that generally characterizes the failure rates for such systems as being high initially due to manufacturing defects, then leveling off, and finally ramping up again as the system approaches the end of its life. However, the non-linear trend could only be quantified with data for different stages over the life cycle of each part, which CARB staff does not have. Therefore, the conservative approach that is used here assumes a linear relationship that gives a higher

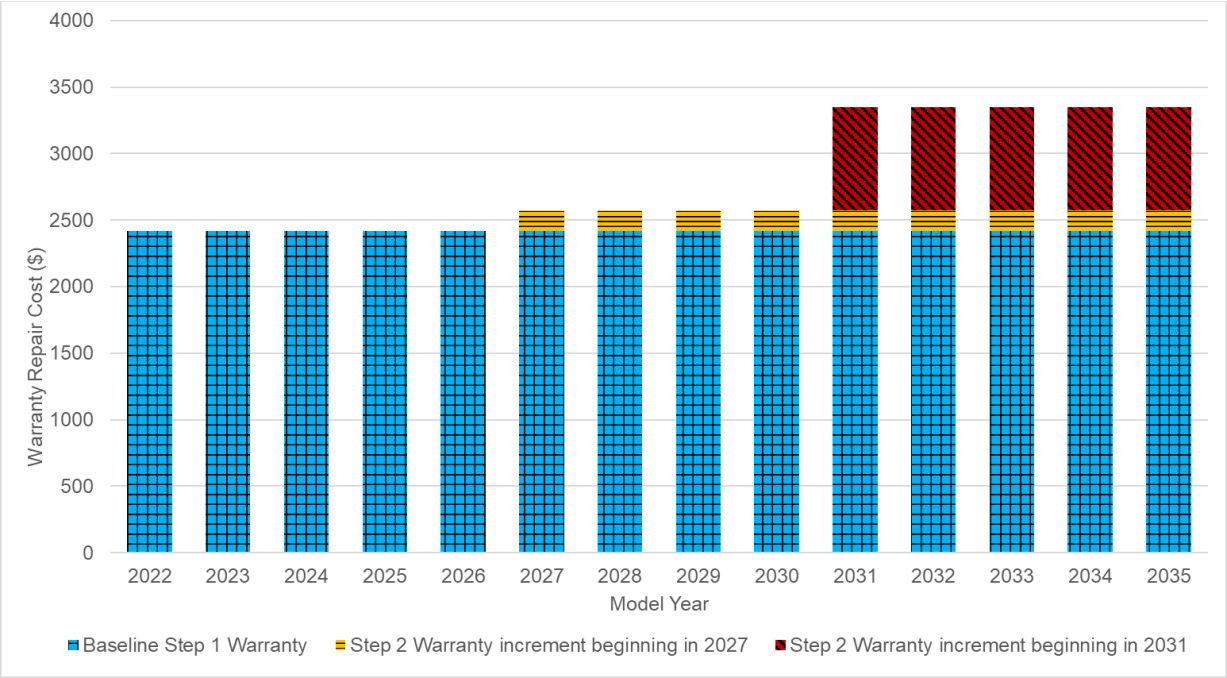
estimate of the costs and represents the most suitable approach for the projected estimates. The resulting values for the projected warranty costs are shown in Table I.35 below. These costs are on a per vehicle basis for a heavy-duty vehicle.

Table I.35. Estimated Per Vehicle Repair Costs and Incremental Repair Costs Associated with the Proposed Lengthened Step 2 Warranty Period Amendments (2018$)

Vehicle Category	Baseline Repair Costs	2027 Phase-in Repair Costs	2031 Phase-in Repair Costs	Incremental Repair Cost Beginning MY 2027	Additional Incremental Repair Cost Beginning MY 2031	Total Incremental Repair Costs
HHDV	$2,416	$2,576	$3,346	$159	$771	$930
MHDV	$2,775	$3,434	$4,417	$658	$983	$1,641
LHDV	$1,096	$1,441	$2,019	$345	$577	$922
HDOV	$238	$494	$705	$255	$211	$467

Figure I.1 shows a visual representation of the incremental costs due to warranty, using a HHDV as an example. Figure I.1 shows a two-step increase from the baseline, with the first step of $159 beginning in model year 2027 and the second step increase of $771 beginning in model year 2031. As shown, beginning in model year 2031, there would be a total of $930 incremental repair costs due to the warranty amendments.

Figure I.1. Example Showing the Estimated Per Vehicle Baseline Repair Costs for a HHDV and the Incremental Repair Costs Associated with the Proposed Lengthened Step 2 Warranty Period Amendments (2018$)



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5.2.4 Costs to the Vehicle Purchaser under the Proposed Warranty

The incremental repair costs occurring in model years 2027 and 2031 due to the proposal represent the projected increases in costs that are expected to be passed on to the vehicle purchaser through an increase in the vehicle purchase price. Assuming vehicle purchases are made using a 5-year loan financed at a 6 percent interest rate, CARB staff calculated the total "capital" for each part of the phase-in as shown in Table I.36. Therefore, the increase in "capital" costs to the vehicle purchaser is slightly higher than the costs passed through by the manufacturer because of loan interest costs.

Table I.36. Estimated Per Vehicle Capital Costs Associated with the Proposed Lengthened Step 2 Warranty Period Amendments (2018$)

Vehicle Category	Capital Cost Increase Per Vehicle Beginning MY 2027	Additional Capital Cost Increase Per Vehicle Beginning MY 2031
HHDV	$189	$915
MHDV	$781	$1,167
LHDV	$409	$685
HDOV	$303	$251

5.3 Total Statewide Costs under the Proposed Warranty

CARB staff used the capital cost increases that occur in model years 2027 and 2031 on a per vehicle basis listed in Table I.36 and the EMFAC's projected new engine/vehicle sales listed in Table I.4 to estimate the statewide annual increase in costs associated with the proposed Step 2 warranty amendments. The values are shown in Table I.37 and represent the repair costs for all new vehicle sales from 2027 to 2050.

Table I.37. Total Annual Increase in Costs Per Year for Proposed Lengthened Step 2 Warranty Periods for Each Vehicle Class (2018$)

Calendar Year	HHDV	MHDV	LHDV	HDOV	Total
2027	$0	$0	$0	$1,069,205	$1,069,205
2028	$1,419,454	$8,297,974	$2,803,201	$1,090,640	$13,611,269
2029	$1,451,996	$8,503,710	$2,854,968	$1,093,817	$13,904,492
2030	$1,481,023	$8,598,437	$2,903,447	$1,086,085	$14,068,992
2031	$1,503,340	$8,712,100	$2,941,505	$2,006,817	$15,163,761
2032	$9,025,695	$22,331,185	$8,078,852	$2,012,986	$41,448,718
2033	$9,272,426	$22,671,578	$8,252,061	$2,032,316	$42,228,382
2034	$9,596,311	$23,415,016	$8,513,756	$2,051,948	$43,577,031
2035	$9,771,564	$23,842,490	$8,688,844	$2,071,074	$44,373,973
2036	$9,839,592	$23,950,094	$8,743,017	$2,105,329	$44,638,032
2037	$9,904,854	$24,173,681	$8,803,885	$2,123,200	$45,005,620
2038	$9,996,276	$24,235,668	$8,871,413	$2,141,459	$45,244,815
2039	$10,087,758	$24,412,150	$8,936,619	$2,158,682	$45,595,209
2040	$10,202,968	$24,498,206	$9,005,245	$2,175,598	$45,882,018
2041	$10,273,594	$24,599,397	$9,074,140	$2,192,323	$46,139,454
2042	$10,361,913	$24,786,359	$9,148,489	$2,208,680	$46,505,442
2043	$10,454,979	$24,920,219	$9,219,739	$2,224,630	$46,819,567
2044	$10,566,337	$25,120,490	$9,296,582	$2,240,124	$47,223,532
2045	$10,663,445	$25,315,750	$9,370,719	$2,255,277	$47,605,191
2046	$10,768,056	$25,493,839	$9,445,955	$2,269,992	$47,977,842
2047	$10,852,534	$25,679,558	$9,520,220	$2,284,441	$48,336,754
2048	$10,933,176	$25,902,786	$9,596,374	$2,298,594	$48,730,929
2049	$11,032,698	$26,050,036	$9,670,242	$2,312,371	$49,065,347
2050	$11,032,698	$26,050,036	$9,670,242	$2,312,371	$49,065,347
Total	**$200,492,689**	**$501,560,758**	**$183,409,516**	**$47,817,959**	**$933,280,923**

Lengthened Useful Life Costs

The lengthened useful life costs are intrinsically linked with the durability and costs of the technologies used to meet the proposed emission standards for certification of California heavy-duty engines and vehicles. Manufacturers would be required to certify that the emission standards would continue to be met throughout the useful life of the engine/vehicle. The described low NOx technology costs in subsection 1. above already included costs to meet the proposed lengthened useful life as part of the estimated hardware and research and development costs. Overall, therefore, CARB staff did not project any additional cost as a result of the lengthened useful life proposal.

Amended Emissions Warranty Information and Reporting (EWIR) and Corrective Action Costs

To estimate the cost impact of the proposed EWIR and corrective action amendments, a baseline scenario was first developed. The cost impact of the proposed amendments was

then evaluated against the baseline scenario. The baseline scenario accounts for the current California required emission control system warranty, manufacturer provided warranties, and real-world purchasing behavior. Manufacturers are currently required to provide an emissions warranty for heavy-duty diesel vehicles with a GVWR over 14,000 pounds, submit reports based on warranty claims, and take corrective action if the failure rate of an emission control component has exceeded the corrective action threshold. The Proposed Amendments adjust the thresholds for submitting reports to match the lengthened warranty periods included in the Proposed Amendments and provide specificity when corrective action is required.

The estimated direct costs from the proposed EWIR and corrective action amendments and the baseline scenario include upfront capital costs due to changes of corrective action thresholds, corrective action procedures, and reporting procedures. In general, costs for corrective action were obtained by determining the number of components subject to corrective action at the end of the warranty periods and useful life periods. This was done by using the most current and complete warranty data set for the 2013 model year and extrapolating those rates from the current warranty period of 5 years to the proposed lengthened warranty period. The difference between extrapolated warranty rates at the end of the proposed useful life period and the proposed warranty periods was used to determine how many components would need corrective action.

7.1 Cost for Baseline Scenario

7.1.1 Repair Costs for Aftertreatment Components, Computers, and Non-Aftertreatment Components Subject to Recall

Manufacturers are required to recall aftertreatment and critical components that exceed the applicable corrective action threshold. Repair costs were obtained through analysis of service station repair records and costs utilized in the 2018 heavy-duty warranty lengthening process (CARB, 2018d). CARB staff broke down costs into two categories: aftertreatment components and computers, and non-aftertreatment components that would be subject to recall, shown in Table I.38.[2] The average repair cost was determined by averaging the cost of repairs for components from all classes that potentially could be subject to recall and for which EWIR data was submitted. Most manufacturers remedied the majority of in-use problems and component failures through software calibration reflashes. Through analysis of historic data regarding recalls, CARB staff determined that over 83 percent of recalls resolve issues through software reflashes (CARB, 2019e). Based on this, to provide a conservative estimate, 70 percent of repairs were assumed to be software reflashes, at a cost of $400 per reflash, rather than part replacements.[3]

[2] Aftertreatment claims consist of claims for DPFs, SCR, and DOCs. The non-aftertreatment claims consist of other critical emission control components that would be subject to recall.

[3] The average replacement cost for aftertreatment components and computers is $3,374. The average replacement cost for non-aftertreatment components is $2,327. These replacement costs account for 30% of recall repair costs while the other 70% of repairs are assumed to be the cost of a reflash, which is $400 because it has been observed that 70% of recall repairs are reflashes. The weighted average of these costs provides the average repair costs for repairs made under recall that can be seen in Table B-37. For example, ($400 x 0.7) + ($3,374 x 0.3) = $1292.

Table I.38. Average Repair Costs for Components Subject to Recall (2018$)

	Aftertreatment Components and Computers	Non-Aftertreatment Components
Average Repair Cost	$1,292	$978

7.1.2 Recall Methodology

Table I.39 provides a summary for the 2013 model year of the population of vehicles and engines for each class and the number of unscreened warranty claims[4] per class separated by aftertreatment component and computer claims, and non-aftertreatment component claims that would be subject to recall. The 2013 model year was used because it is the most current data for which the five years of EWIR reporting has been completed. The average recall rate per engine may exceed 100 percent as some engines had multiple issues remedied through multiple recalls. The HDO class did not have claims for other components that exceeded the corrective action threshold.

Table I.39. Components Subject to Recall for the 2013 Model Year

Class	2013 Calendar Year Sales	Total Claims for Aftertreatment and Critical Components, and Computers	Total Claims for Other Components	Average Recall Rate Per Engine for Aftertreatment and Critical Components, and Computers	Average Recall Rate Per Engine for Other Components
HHDD	11,022	5,662	13,731	51.4%	124.6%
MHDD	4,967	5,270	4,405	106.1%	88.7%
LHDD	5,025	146	5,253	2.9%	104.5%
HDO	8,522	3405	0	40.0%	0.0%

Table I.40 provides the baseline costs of recalls estimated for the 2022 through 2050 calendar years for each vehicle class. The costs were obtained by applying the percentage of the population subject to recall in Table I.39 to the projected 2022 through 2050 calendar year sales volume in Table I.4 and then multiplying by the corresponding repair cost in Table I.38. The costs were then multiplied by 93 percent which is the typical capture rate that is achieved by manufacturers when conducting recalls with a California Department of Motor Vehicles (DMV) tie-in. Not all vehicles are captured by a recall due to several factors

[4] Unscreened warranty claims refer to the number of parts replaced during the warranty period for any reason, regardless of whether the replaced or repaired part actually experienced a failure. CARB staff considered examining screened failure data as an alternative approach, but manufacturers are not required to submit screened failure rate data unless the unscreened rate exceeds 4 percent. Therefore, it was determined that unscreened data should be used for cost estimates as it contains information on a larger number of engine families and parts and is more representative of the in-use population.

such as vehicles moving out-of-state or no longer being in service. CARB staff assumed that the percentage of the population subject to recall would remain similar to the 2013 model year for later model years.

Table I.40. Baseline Recall Costs (2018$)

Calendar Year	HHDD	MHDD	LHDD	HDO	Total
2022	$0	$0	$0	$0	$0
2023	$0	$0	$0	$0	$0
2024	$0	$0	$0	$1,681,126	$1,681,126
2025	$12,348,360	$21,423,357	$6,381,804	$1,686,422	$41,839,942
2026	$12,621,073	$21,457,604	$6,512,227	$1,707,446	$42,298,350
2027	$12,892,871	$22,101,060	$6,636,449	$1,694,667	$43,325,047
2028	$13,129,784	$22,109,576	$6,751,995	$1,728,639	$43,719,994
2029	$13,430,792	$22,657,749	$6,876,687	$1,733,676	$44,698,903
2030	$13,699,284	$22,910,144	$6,993,456	$1,721,420	$45,324,304
2031	$13,905,713	$23,212,994	$7,085,125	$1,739,878	$45,943,710
2032	$14,313,349	$23,863,274	$7,276,145	$1,745,227	$47,197,995
2033	$14,704,625	$24,227,022	$7,432,145	$1,761,985	$48,125,777
2034	$15,218,256	$25,021,465	$7,667,838	$1,779,006	$49,686,564
2035	$15,496,181	$25,478,267	$7,825,529	$1,795,587	$50,595,565
2036	$15,604,062	$25,593,253	$7,874,320	$1,825,286	$50,896,921
2037	$15,707,558	$25,832,180	$7,929,139	$1,840,780	$51,309,658
2038	$15,852,538	$25,898,420	$7,989,958	$1,856,610	$51,597,526
2039	$15,997,614	$26,087,010	$8,048,686	$1,871,543	$52,004,852
2040	$16,180,320	$26,178,970	$8,110,493	$1,886,208	$52,355,992
2041	$16,292,322	$26,287,104	$8,172,542	$1,900,708	$52,652,677
2042	$16,432,383	$26,486,893	$8,239,504	$1,914,890	$53,073,669
2043	$16,579,971	$26,629,936	$8,303,675	$1,928,718	$53,442,300
2044	$16,756,566	$26,843,947	$8,372,882	$1,942,151	$53,915,547
2045	$16,910,565	$27,052,604	$8,439,654	$1,955,289	$54,358,111
2046	$17,076,461	$27,242,911	$8,507,414	$1,968,046	$54,794,833
2047	$17,210,431	$27,441,372	$8,574,301	$1,980,573	$55,206,677
2048	$17,338,316	$27,679,915	$8,642,888	$1,992,844	$55,653,962
2049	$17,496,143	$27,837,268	$8,709,416	$2,004,788	$56,047,615
2050	$17,496,143	$27,837,268	$8,709,416	$2,004,788	$56,047,615
Total	**$400,691,680**	**$655,391,561**	**$202,063,689**	**$49,648,302**	**$1,307,795,232**

7.1.3 Repair Costs for Components Subject to Extended Warranty

Manufacturers often provide extended warranties for emissions control components that exceed applicable corrective action thresholds in lieu of recalling those components. In addition, parts that are replaced through recall often also have extended warranties. Repair costs were obtained through analysis of service station repair records and costs utilized in the 2018 heavy-duty warranty lengthening rulemaking (CARB, 2018d). The average repair costs, shown in Table I.41, were determined by averaging the cost of repairs for components from all classes that potentially could be subject to extended warranty where EWIR data were submitted. The average extended warranty repair cost for all components is $1,587.

Table I.41. Average Repair Costs for Components Subject to Extended Warranty (2018$)

Components Subject to Extended Warranty	Average Repair Cost
Average Extended Warranty Repair Cost for All Components	$1,587

7.1.4 Extended Warranty Methodology

Table I.42 provides a summary for the 2013 model year population of vehicles/engines for each class, the number of unscreened warranty claims per class, and the average rate per engine class for extended warranty under EWIR and corrective action amendments. The 2013 model year data was used for a baseline because this EWIR reporting is the most current and complete data set for which the five years of reporting has been completed. The average rate per engine subject to extended warranty is derived by linearly extrapolating the number of components that reach the corrective action threshold at the end of the warranty period and at the end of the useful life period. The difference between the extrapolated values from the most complete warranty data set for five years to the end of the proposed useful life and warranty periods is used to determine the number of components subject to extended warranty, which is divided by the sales volume to determine the average rate per engine subject to extended warranty. All failures that occur within the warranty period would be covered under warranty and therefore are not included as part of the extended warranty cost.

Table I.42. Components Subject to Extended Warranty for the 2013 Model Year

Class	2013 Model Year Sales	Total Claims for Components	Average Rate Per Engine Subject to Extended Warranty
HHDD	11,022	4,115	37.3%
MHDD	4,967	301	6.1%
LHDD	5,025	1,109	22.1%
HDO	8,522	273	3.2%

The costs of extended warranties for the 2022 through 2050 calendar years are shown in Table I.43. The costs were obtained by applying the percentage of the population subject to extended warranty in Table I.41 to the projected sales volume for the 2022 through 2050 calendar years in Table I.4 and then multiplying by the corresponding repair cost in Table I.41.

Table I.43. Baseline Extended Warranty Costs (2018$)

Calendar Year	HHDD	MHDD	LHDD	HDO	Total
2022	$0	$0	$0	$0	$0
2023	$0	$0	$0	$0	$0
2024	$0	$0	$0	$177,996	$177,996
2025	$4,179,243	$989,667	$2,267,142	$178,557	$7,614,609
2026	$4,271,542	$991,249	$2,313,475	$180,783	$7,757,048
2027	$4,363,530	$1,020,974	$2,357,605	$179,430	$7,921,539
2028	$4,443,712	$1,021,368	$2,398,652	$183,027	$8,046,759
2029	$4,545,587	$1,046,691	$2,442,949	$183,560	$8,218,787
2030	$4,636,457	$1,058,351	$2,484,432	$182,262	$8,361,501
2031	$4,706,322	$1,072,341	$2,516,997	$184,216	$8,479,876
2032	$4,844,284	$1,102,381	$2,584,857	$184,783	$8,716,305
2033	$4,976,710	$1,119,185	$2,640,276	$186,557	$8,922,728
2034	$5,150,546	$1,155,885	$2,724,007	$188,359	$9,218,796
2035	$5,244,608	$1,176,987	$2,780,027	$190,115	$9,391,736
2036	$5,281,120	$1,182,299	$2,797,359	$193,259	$9,454,037
2037	$5,316,147	$1,193,336	$2,816,834	$194,900	$9,521,218
2038	$5,365,215	$1,196,396	$2,838,440	$196,576	$9,596,627
2039	$5,414,316	$1,205,108	$2,859,303	$198,157	$9,676,884
2040	$5,476,152	$1,209,356	$2,881,260	$199,710	$9,766,478
2041	$5,514,058	$1,214,352	$2,903,303	$201,245	$9,832,958
2042	$5,561,461	$1,223,581	$2,927,091	$202,747	$9,914,880
2043	$5,611,411	$1,230,189	$2,949,888	$204,211	$9,995,699
2044	$5,671,179	$1,240,075	$2,974,474	$205,633	$10,091,362
2045	$5,723,300	$1,249,714	$2,998,195	$207,024	$10,178,233
2046	$5,779,446	$1,258,506	$3,022,267	$208,375	$10,268,594
2047	$5,824,788	$1,267,674	$3,046,028	$209,701	$10,348,191
2048	$5,868,070	$1,278,694	$3,070,394	$211,000	$10,428,157
2049	$5,921,486	$1,285,963	$3,094,028	$212,265	$10,513,741
2050	$5,921,486	$1,285,963	$3,094,028	$212,265	$10,513,741
Total	**$135,612,172**	**$30,276,285**	**$71,783,313**	**$5,256,712**	**$242,928,482**

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7.1.7 Summary of Baseline Costs

The costs of the baseline scenario for the 2022 through 2050 calendar years, which is the summation of the costs from Table I.40 and Table I.43 above, are shown in Table I.44.

Table I.44. Summary of Baseline Total Recall and Extended Warranty and Corrective Action Costs (2018$)

Calendar Year	HHDD	MHDD	LHDD	HDO	Total
2022	$0	$0	$0	$0	$0
2023	$0	$0	$0	$0	$0
2024	$0	$0	$0	$1,859,122	$1,859,122
2025	$16,527,602	$22,413,024	$8,648,945	$1,864,979	$49,454,551
2026	$16,892,615	$22,448,853	$8,825,701	$1,888,229	$50,055,398
2027	$17,256,401	$23,122,035	$8,994,054	$1,874,096	$51,246,586
2028	$17,573,496	$23,130,944	$9,150,647	$1,911,666	$51,766,753
2029	$17,976,378	$23,704,440	$9,319,636	$1,917,235	$52,917,690
2030	$18,335,740	$23,968,495	$9,477,888	$1,903,683	$53,685,806
2031	$18,612,034	$24,285,335	$9,602,122	$1,924,094	$54,423,586
2032	$19,157,633	$24,965,655	$9,861,002	$1,930,009	$55,914,300
2033	$19,681,335	$25,346,206	$10,072,421	$1,948,543	$57,048,505
2034	$20,368,802	$26,177,349	$10,391,845	$1,967,365	$58,905,360
2035	$20,740,789	$26,655,254	$10,605,556	$1,985,702	$59,987,301
2036	$20,885,182	$26,775,552	$10,671,679	$2,018,546	$60,350,958
2037	$21,023,706	$27,025,516	$10,745,973	$2,035,680	$60,830,875
2038	$21,217,753	$27,094,816	$10,828,398	$2,053,186	$61,194,153
2039	$21,411,930	$27,292,118	$10,907,989	$2,069,700	$61,681,736
2040	$21,656,472	$27,388,327	$10,991,753	$2,085,918	$62,122,470
2041	$21,806,380	$27,501,455	$11,075,846	$2,101,953	$62,485,635
2042	$21,993,843	$27,710,474	$11,166,595	$2,117,637	$62,988,549
2043	$22,191,382	$27,860,125	$11,253,563	$2,132,929	$63,437,999
2044	$22,427,745	$28,084,023	$11,347,357	$2,147,784	$64,006,909
2045	$22,633,865	$28,302,318	$11,437,849	$2,162,313	$64,536,344
2046	$22,855,907	$28,501,417	$11,529,681	$2,176,421	$65,063,426
2047	$23,035,219	$28,709,046	$11,620,329	$2,190,274	$65,554,868
2048	$23,206,385	$28,958,609	$11,713,281	$2,203,844	$66,082,119
2049	$23,417,629	$29,123,230	$11,803,445	$2,217,053	$66,561,357
2050	$23,417,629	$29,123,230	$11,803,445	$2,217,053	$66,561,357
Total	**$536,303,852**	**$685,667,846**	**$273,847,002**	**$54,905,013**	**$1,550,723,714**

7.2 Costs for New EWIR and Corrective Action Amendments

7.2.1 Costs Associated with Corrective Action Amendments

The corrective action amendments would require manufacturers to conduct mandatory recalls for components that have a failure rate greater than or equal to 25 percent within 5 years. CARB staff estimates the repair cost for such components to be $756, which is lower than the $1,587 repair cost assumed for components that are subject to extended warranties today. For components that would today typically be subject to extended warranty, but that, under the Proposed Amendments would have to be recalled because they have a failure rate greater than or equal to 25 percent within 5 years, it was assumed that 70 percent of repairs would be resolved through software reflashes as this is how manufacturers typically handle hardware warranty issues for recalls, at a cost of $400 per reflash.[5]

Corrective Action Threshold and Procedures

There would be three incremental increases in costs due to the proposed three corrective action thresholds for the 2024, 2027, and 2031 model years. Specifically, effective in 2024, the corrective action threshold would be modified from 4 percent or 50 failures, whichever is greater, to 4 percent or 25 failures, whichever is greater. This would result in a cost increase due to the increased amount of corrective actions that small volume engine families would be subject to. Next, effective in 2027, the corrective action threshold would remain at 4 percent or 25 failures, whichever is greater, for the first five years of the reporting period, and increase to 5 percent or 35 failures, whichever is greater, for years 6-7. Finally, effective 2031, the corrective action threshold would remain at 4 percent or 25 failures, whichever is greater, for the first five years of the reporting period, remain at 5 percent or 35 failures, whichever is greater, for years 6-7, and increase to 7 percent of 50 failures, whichever is greater, for years 8-10. This is to account for the lengthened warranty and useful life periods being proposed.

Also, if corrective action for a component that would normally be subject to only extended warranty also exhibited early failure rates (indicating that the majority of the population would fail within the useful life period), it would be subject to recall. This is based on a projection that if a component reaches a 25 percent failure rate within five years it is very likely that the majority of the parts would fail within the useful life period.

The costs associated with the proposed corrective action thresholds and procedures are shown in Table I.45. Costs were calculated using the same methodology as was used to calculate the cost of the baseline scenario, except that the proposed amendment criteria was used. Failure rates for future model years were obtained by linearly extrapolating data

[5] The average repair cost for repairs made under extended warranties is $1,587, which does not average in the cost of a reflash because repairs made under extended warranties are typically part replacements. The average repair cost for components that need to be recalled because they have a failure rate greater than or equal to 25% within 5 years is $756, which was determined by assuming that 30% of the cost for the recall repair would be that of a part replacement that is $1,587, while the other 70% of repairs would be the cost of a reflash that is $400 (i.e., ($400 x 0.7) + ($1,587 x 0.3) = $756. This is because it has been observed that 70% of recall repairs are reflashes.

from the 2013 model year. The cost of the corrective action and useful life lengthening are conservatively estimated as certain repairs were accounted for in both programs. This was due to both programs requiring manufacturers to address similar in-use durability issues.

Table I.45. Corrective Action Threshold and Procedures Cost Summary (2018$)

Calendar Year	HHDD	MHDD	LHDD	HDO	Total
2022	$0	$0	$0	$0	$0
2023	$0	$0	$0	$0	$0
2024	$0	$0	$0	$2,176,752	$2,176,752
2025	$19,665,127	$28,218,968	$7,831,736	$2,183,610	$57,899,442
2026	$20,099,432	$28,264,079	$7,991,791	$2,210,833	$58,566,135
2027	$20,532,277	$29,111,643	$8,144,237	$2,231,322	$60,019,480
2028	$25,569,028	$33,230,004	$10,387,702	$2,276,053	$71,462,787
2029	$26,155,213	$34,053,890	$10,579,536	$2,282,684	$73,071,323
2030	$26,678,076	$34,433,233	$10,759,182	$2,266,548	$74,137,039
2031	$27,080,078	$34,888,407	$10,900,211	$2,087,075	$74,955,771
2032	$20,696,888	$26,920,641	$12,118,522	$2,093,491	$61,829,543
2033	$21,262,668	$27,330,992	$12,378,342	$2,113,594	$63,085,596
2034	$22,005,370	$28,227,219	$12,770,893	$2,134,011	$65,137,493
2035	$22,407,246	$28,742,547	$13,033,530	$2,153,902	$66,337,224
2036	$22,563,240	$28,872,265	$13,114,791	$2,189,527	$66,739,823
2037	$22,712,894	$29,141,803	$13,206,094	$2,208,113	$67,268,904
2038	$22,922,533	$29,216,529	$13,307,388	$2,227,102	$67,673,552
2039	$23,132,311	$29,429,282	$13,405,200	$2,245,014	$68,211,806
2040	$23,396,501	$29,533,024	$13,508,141	$2,262,607	$68,700,273
2041	$23,558,454	$29,655,012	$13,611,485	$2,280,000	$69,104,951
2042	$23,760,979	$29,880,398	$13,723,010	$2,297,012	$69,661,399
2043	$23,974,390	$30,041,768	$13,829,888	$2,313,599	$70,159,645
2044	$24,229,744	$30,283,198	$13,945,154	$2,329,713	$70,787,809
2045	$24,452,425	$30,518,588	$14,056,363	$2,345,472	$71,372,847
2046	$24,692,307	$30,733,277	$14,169,219	$2,360,776	$71,955,578
2047	$24,886,026	$30,957,165	$14,280,619	$2,375,802	$72,499,613
2048	$25,070,945	$31,226,270	$14,394,851	$2,390,521	$73,082,588
2049	$25,299,162	$31,403,783	$14,505,656	$2,404,849	$73,613,449
2050	$25,299,162	$31,403,783	$14,505,656	$2,404,849	$73,613,449
Total	**$612,102,476**	**$785,717,769**	**$324,459,197**	**$60,844,830**	**$1,783,124,271**

Parts Storage

CARB staff is proposing that manufacturers be required to store parts that are used for failure mode and failure rate analysis for the Field Information Report (FIR) for a period of two years after submitting the FIR. Manufacturers would face costs based on the number of parts that are stored, how long they are stored, and the amount of space (per square foot) that the parts take up. For the purposes of this subsection, component refers to the entire set of individual parts that make up a component. For example, if 100 percent of turbochargers failed for an engine family with a sales volume of 50 engines, there would

be one component failure and 50 parts failures. Table I.46 summarizes the information used to determine the costs for storing parts.

Table I.46. Storage Cost Summary

Component Storage Information	
Retention Length in Years	2
Cost per Square Foot per Year	$18.00
No. of Parts per Report to be Retained	70
Average Square Feet per Part	2

Through an online survey of California storage facilities (CARB, 2020a), it was determined that the cost to store parts would be approximately $9.80 per square foot per part. For a conservative estimate, CARB staff approximately doubled this cost ($18 per square foot), and also assumed that each part would require approximately two square feet of space as certain parts may be stacked upon each other during storage. Thus, the storage cost is estimated to be $36 per part.

CARB staff estimated number of stored components based on 2013 warranty claim and failure rate and projected 2022-2050 sales volumes. Table I.47 summarized CARB staff's estimated number of stored components[6] and their associated storage costs for the required two-year period. In order to provide a conservative estimate, it was assumed that each component would require storage for 70 parts, or 140 square feet of storage space on average.

[6] Components include categories of hardware such as turbocharger, DPF, fuel injector, etc.

Table I.47. Number of Components Needed to be Stored by Year (2018$)

Calendar Year	Number of Components that Need to be Stored	Storage Cost
2022	0	$0
2023	0	$0
2024	2	$10,080
2025	174	$876,960
2026	178	$897,120
2027	182	$917,280
2028	197	$992,880
2029	201	$1,013,040
2030	205	$1,033,200
2031	207	$1,043,280
2032	214	$1,078,560
2033	218	$1,098,720
2034	225	$1,134,000
2035	228	$1,149,120
2036	230	$1,159,200
2037	232	$1,169,280
2038	234	$1,179,360
2039	235	$1,184,400
2040	236	$1,189,440
2041	238	$1,199,520
2042	240	$1,209,600
2043	242	$1,219,680
2044	244	$1,229,760
2045	246	$1,239,840
2046	248	$1,249,920
2047	250	$1,260,000
2048	252	$1,270,080
2049	253	$1,275,120
2050	253	$1,275,120
Total	5,864	$29,554,560

Administrative Costs for Additional Warranty Reporting and Corrective Action

It is assumed that manufacturers are already tracking, gathering, and analyzing data and information that would be required to submit the additional warranty reports, corrective action documents, and quarterly progress reports. There are already systems in place to perform the task of gathering the data and information necessary to generate the reports. Therefore, the cost of submitting this information to CARB would be the cost of generating the anticipated increased number of reports to summarize the information collected by manufacturers and developing corrective action documents. CARB staff assumes that a junior engineer position would be sufficient to perform the duties of generating additional warranty reports and corrective action documents (the hourly rate for a junior engineer is

$70, (U.S. BLS, 2019). Table I.48 summarizes the information used to determine the administrative costs.

Table I.48. Additional Warranty Reporting Summary

Additional Warranty Reporting Information	
Junior Engineer Salary ($/hour)	70
Time Required for 1 EWIR Report Submitted Quarterly for 4 years 2024-2026, 6 years for 2027-2030, and 9 years for 2031 and subsequent model years (hours)	0.5
Time Required for 1 FIR/EIR Report Submitted once (hours)	1
Time Required to Generate Corrective Action Documents (hours)	16
Additional EWIR Reports Submitted due to Lower Thresholds	30% Increase in Number of Reports

EIR = Emissions Information Report; EWIR= Emissions Warranty Information and Reporting; FIR= Field Information Report

Due to the longer proposed warranty periods, manufacturers would be required to report for longer than the current 5-year reporting period. Starting with the 2027-2030 model years it is proposed that manufacturers would be required to report warranty and failure rate information throughout the 7-year warranty period. For 2031 and subsequent model years it is proposed that manufacturers would be required to report warranty and failure rate information throughout the 10-year warranty period. Warranty reporting is not required for the first year, therefore, for model years 2027-2030 manufacturers would only be required to submit reports for six years, and for 2031 and subsequent model years manufacturers would only be required to submit reports for nine years.

Costs were determined by estimating the increase in the number of reports and documents that need to be submitted and the time required to generate them. Table I.49 shows the estimated increase in percentage for the number of each type of report or document that would need to be submitted. The increase in percentage of reports and documents was estimated by analyzing warranty data for the 2013 model year and determining how many additional reports would be submitted under the new thresholds of the Proposed Amendments.

Table I.49. Percent Increase in Number of Reports or Documents to be Submitted Relative to Population

EWIR Reports		
Class	2024-2050	
HHDD	0.7%	
MHDD	1.1%	
LHDD	0.6%	
HDO	0.0%	
FIR Reports		
Class	2024-2026	2027-2050
HHDD	0.2%	0.3%
MHDD	0.3%	0.3%
LHDD	0.2%	0.3%
HDO	0.0%	0.0%
EIR Reports		
Class	2024-2026	2027-2050
HHDD	0.5%	0.6%
MHDD	0.5%	0.6%
LHDD	0.2%	0.2%
HDO	0.0%	0.0%
Corrective Action Documents		
Class	2024-2026	2027-2050
HHDD	0.5%	0.6%
MHDD	0.5%	0.6%
LHDD	0.2%	0.2%
HDO	0.0%	0.0%

EIR = Emissions Information Report; EWIR= Emissions Warranty Information and Reporting; FIR= Field Information Report

The percentage increases listed in Table I.49 were applied to the projected population for each year to determine how many additional reports and documents would need to be submitted for each year. Once the additional number of reports and documents is established, the number of hours needed to generate a warranty report or document and hourly rate for a junior engineer were applied to the number of reports to determine the cost. The cost for the amended reporting thresholds and procedures can be seen in Table I.50.

Table I.50. Cost of Generating Additional Warranty Reports and Corrective Action Documents (2018$)

Calendar Year	HHDD	MHDD	LHDD	HDO	Total
2022	$0	$0	$0	$0	$0
2023	$0	$0	$0	$0	$0
2024	$0	$0	$0	$610	$610
2025	$72,419	$131,045	$36,357	$612	$240,432
2026	$74,018	$131,254	$37,100	$619	$242,992
2027	$75,612	$135,190	$37,808	$1,386	$249,996
2028	$96,950	$175,175	$54,551	$1,414	$328,089
2029	$99,172	$179,518	$55,558	$1,418	$335,666
2030	$101,155	$181,517	$56,502	$1,408	$340,582
2031	$102,679	$183,917	$57,242	$1,851	$345,690
2032	$129,897	$241,118	$78,771	$1,857	$451,643
2033	$133,448	$244,793	$80,460	$1,875	$460,576
2034	$138,109	$252,821	$83,012	$1,893	$475,835
2035	$140,631	$257,436	$84,719	$1,911	$484,697
2036	$141,610	$258,598	$85,247	$1,942	$487,398
2037	$142,550	$261,012	$85,841	$1,959	$491,361
2038	$143,865	$261,682	$86,499	$1,976	$494,021
2039	$145,182	$263,587	$87,135	$1,991	$497,895
2040	$146,840	$264,516	$87,804	$2,007	$501,167
2041	$147,857	$265,609	$88,476	$2,022	$503,964
2042	$149,128	$267,628	$89,201	$2,038	$507,993
2043	$150,467	$269,073	$89,895	$2,052	$511,487
2044	$152,070	$271,235	$90,645	$2,067	$516,016
2045	$153,467	$273,344	$91,367	$2,081	$520,259
2046	$154,973	$275,266	$92,101	$2,094	$524,434
2047	$156,189	$277,272	$92,825	$2,107	$528,393
2048	$157,349	$279,682	$93,568	$2,120	$532,719
2049	$158,781	$281,272	$94,288	$2,133	$536,474
2050	$158,781	$281,272	$94,288	$2,133	$536,474
Total	**$3,423,200**	**$6,164,832**	**$2,011,259**	**$47,574**	$11,646,865

7.2.2 Costs of Proposed EWIR and Corrective Action Amendments

The total costs of the EWIR program under the proposed EWIR and corrective action amendments are shown in Table I.51. The costs were obtained by calculating the sum of the cost of the amended corrective action requirements from Table I.45, storage costs from Table I.47, and warranty reporting costs from Table I.50. Note that the costs shown in Table I.51 are the costs of the EWIR program and corrective action procedures that would exist under the Proposed Amendments instead of the baseline costs shown in Table I.44, i.e., they are not the incremental costs due to the EWIR and corrective action amendments.

Table I.51. Summary of Costs of the EWIR Program Under Proposed EWIR and Corrective Action Amendments (2018$)

Calendar Year	HHDD	MHDD	LHDD	HDO	Total
2022	$0	$0	$0	$0	$0
2023	$0	$0	$0	$0	$0
2024	$0	$0	$0	$2,187,442	$2,187,442
2025	$20,080,266	$28,768,333	$7,973,933	$2,194,302	$59,016,835
2026	$20,526,250	$28,818,693	$8,139,771	$2,221,532	$59,706,246
2027	$20,965,730	$29,680,274	$8,292,925	$2,247,828	$61,186,756
2028	$26,054,058	$33,868,859	$10,568,253	$2,292,586	$72,783,756
2029	$26,647,505	$34,712,208	$10,761,094	$2,299,221	$74,420,029
2030	$27,182,431	$35,098,591	$10,946,723	$2,283,075	$75,510,820
2031	$27,590,997	$35,561,204	$11,088,493	$2,104,046	$76,344,741
2032	$21,250,145	$27,665,759	$12,333,373	$2,110,468	$63,359,746
2033	$21,829,556	$28,084,825	$12,599,922	$2,130,589	$64,644,892
2034	$22,592,040	$29,009,240	$12,995,024	$2,151,024	$66,747,328
2035	$23,001,477	$29,534,223	$13,264,409	$2,170,932	$67,971,041
2036	$23,163,491	$29,670,143	$13,346,198	$2,206,589	$68,386,420
2037	$23,319,124	$29,947,135	$13,438,094	$2,225,192	$68,929,545
2038	$23,535,118	$30,022,531	$13,545,088	$2,244,197	$69,346,934
2039	$23,746,213	$30,242,229	$13,643,535	$2,262,126	$69,894,102
2040	$24,017,101	$30,346,901	$13,747,145	$2,279,734	$70,390,880
2041	$24,185,111	$30,475,020	$13,851,160	$2,297,143	$70,808,434
2042	$24,393,947	$30,707,465	$13,963,411	$2,314,169	$71,378,992
2043	$24,613,737	$30,870,281	$14,076,023	$2,330,771	$71,890,812
2044	$24,875,733	$31,118,914	$14,192,039	$2,346,900	$72,533,585
2045	$25,104,852	$31,361,451	$14,303,970	$2,362,672	$73,132,945
2046	$25,351,280	$31,583,104	$14,417,560	$2,377,990	$73,729,933
2047	$25,546,215	$31,814,037	$14,534,724	$2,393,030	$74,288,006
2048	$25,737,334	$32,090,592	$14,649,699	$2,407,762	$74,885,387
2049	$25,972,023	$32,269,695	$14,761,224	$2,422,102	$75,425,044
2050	$25,972,023	$32,269,695	$14,761,224	$2,422,102	$75,425,044
Total	**$627,253,755**	**$805,591,401**	**$330,195,016**	**$61,285,524**	**$1,824,325,697**

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Date of Hearing: August 27, 2020

7.3 Incremental Costs under the Proposed EWIR and Corrective Action Amendments

The incremental upfront cost due to the proposed EWIR and corrective action amendments is the cost difference between the proposed EWIR and corrective action amendments scenario and baseline scenario, as shown in Table I.52. The incremental cost is determined by subtracting the costs from the baseline scenario in Table I.44 from the costs of the proposed scenario in Table I.51.

Table I.52. Incremental Cost of the Proposed EWIR and Corrective Action Amendments (2018$)

Calendar Year	HHDD	MHDD	LHDD	HDO	Total
2022	$0	$0	$0	$0	$0
2023	$0	$0	$0	$0	$0
2024	$0	$0	$0	$328,320	$328,320
2025	$3,552,664	$6,355,309	$0	$329,323	$10,237,296
2026	$3,633,635	$6,369,840	$0	$333,303	$10,336,778
2027	$3,709,329	$6,558,239	$0	$373,731	$10,641,299
2028	$8,480,562	$10,737,915	$1,417,606	$380,920	$21,017,003
2029	$8,671,127	$11,007,769	$1,441,458	$381,986	$21,502,340
2030	$8,846,691	$11,130,096	$1,468,835	$379,393	$21,825,015
2031	$8,978,962	$11,275,869	$1,486,371	$179,952	$21,921,155
2032	$2,092,512	$2,700,104	$2,472,371	$180,459	$7,445,446
2033	$2,148,221	$2,738,619	$2,527,501	$182,047	$7,596,388
2034	$2,223,238	$2,831,890	$2,603,180	$183,659	$7,841,967
2035	$2,260,688	$2,878,969	$2,658,853	$185,230	$7,983,740
2036	$2,278,309	$2,894,591	$2,674,519	$188,044	$8,035,462
2037	$2,295,418	$2,921,619	$2,692,121	$189,512	$8,098,670
2038	$2,317,365	$2,927,715	$2,716,689	$191,011	$8,152,780
2039	$2,334,283	$2,950,111	$2,735,546	$192,426	$8,212,366
2040	$2,360,629	$2,958,574	$2,755,392	$193,815	$8,268,410
2041	$2,378,730	$2,973,565	$2,775,315	$195,189	$8,322,800
2042	$2,400,104	$2,996,991	$2,796,816	$196,533	$8,390,443
2043	$2,422,355	$3,010,156	$2,822,460	$197,843	$8,452,813
2044	$2,447,988	$3,034,891	$2,844,682	$199,115	$8,526,676
2045	$2,470,987	$3,059,133	$2,866,121	$200,360	$8,596,601
2046	$2,495,373	$3,081,687	$2,887,879	$201,569	$8,666,507
2047	$2,510,996	$3,104,991	$2,914,395	$202,755	$8,733,137
2048	$2,530,949	$3,131,984	$2,936,418	$203,918	$8,803,268
2049	$2,554,394	$3,146,465	$2,957,779	$205,049	$8,863,687
2050	$2,554,394	$3,146,465	$2,957,779	$205,049	$8,863,687
Total	**$90,949,903**	**$119,923,555**	**$58,410,085**	**$6,380,511**	**$275,664,054**

The costs in Table I.51 and incremental costs in Table I.52 could be avoided by the manufacturers if they made more durable components and did not trigger the need for recalls.

Amended Averaging, Banking, and Trading Program Costs

The proposed Averaging, Banking, and Trading (ABT) amendments would lead to the creation of a California-Averaging Banking, and Trading (CA-ABT) program. Under this program, on-road heavy-duty engine manufacturers would be required to implement a two-track system for ABT (i.e., a federal-ABT program and a CA-ABT program).

Based on CARB's 2018 model year certification data, there are 14 heavy-duty engine manufacturers certifying their engines with CARB and 17 Class 4-8 Zero-Emission Vehicle (ZEV) manufacturers certifying their vehicles with CARB. CARB staff assumed all of these 31 manufacturers, as presented in Table I.53, would participate in the CA-ABT program. CARB staff does not expect the number of certified manufacturers would increase over the 2022-2050 period.

Table I.53. California Certified Heavy-Duty Engine and Class 4 to 8 Zero-Emission Vehicle Manufacturers List (Baseline 2018 Model Year)

Manufacturer	Heavy-Duty Diesel Engine Manufacturer	Heavy-Duty Otto-cycle Engine Manufacturer	Class 4 to 8 Zero-emission Vehicle Manufacturer
Advanced Vehicle Manufacturing, Inc.			X
Agility Power Systems, LLC		X	
Blue Bird Body Co.			X
BYD Motors, Inc.			X
Chanje Energy, Inc.			X
Cummins Inc.	X		
Detroit Diesel Corporation	X		
Eldorado National-California Inc.			X
Encore Tec LLC		X	
FCA US LLC		X	
Ford Motor Company	X	X	
General Motors LLC		X	
Gillig LLC			X
GreenPower Motor Company Inc.			X
Hino Motors, LTD	X		
Isuzu Motors LTD	X		
Lion Bus Inc.			X
Mitsubishi Fuso Truck and Bus Corp.			X
Motiv Power Systems, Inc.			X
Navistar, Inc.	X		
New Flyer of America Inc.			X
Orange EV LLC			X
Paccar Inc.	X		
Phoenix Cars LLC, DBA Phoenix Motorcars			X

Power Solutions International Inc.		X	
Proterra Inc.			X
Roush Industries, Inc.		X	
Thor Trucks, Inc.			X
Volvo Group Trucks Technology	X		
Workhorse Group Inc.			X
Zenith Motors, LLC			X

Implementation of a CA-ABT program would lead to additional bookkeeping/labor costs. There would be no material costs for implementation of the CA-ABT program. CARB staff believes that there would be a one-time, upfront labor cost of approximately 3,100 hours (100 hours per manufacturer) for a junior engineer (at $70/hour) (U.S. BLS, 2019) in the 2022 calendar year to establish the CA-ABT program on an industry-wide basis. The required hours would be needed to calculate the portion of the existing banked federal-credits which will be transferred to the CA-ABT program, and to set up the accounting system for the future CA-ABT program. CARB staff also estimates that each manufacturer would need to allocate approximately 20 hours of labor (junior engineer) per year to track the CA-ABT credits for the 2023 to 2050 period.

Based on these assumptions, the additional labor costs for tracking the CA-ABT program for the 2022 through 2050 calendar years were calculated and are shown in Table I.54.

Table I.54. Estimated Incremental Costs for the Proposed ABT Amendments (2018$)

Calendar Year	Incremental costs for CA-ABT program
2022	$217,000
2023	$43,400
2024	$43,400
2025	$43,400
2026	$43,400
2027	$43,400
2028	$43,400
2029	$43,400
2030	$43,400
2031	$43,400
2032	$43,400
2033	$43,400
2034	$43,400
2035	$43,400
2036	$43,400
2037	$43,400
2038	$43,400
2039	$43,400
2040	$43,400
2041	$43,400
2042	$43,400
2043	$43,400
2044	$43,400
2045	$43,400
2046	$43,400
2047	$43,400
2048	$43,400
2049	$43,400
2050	$43,400
Total 2022 - 2050	$1,432,200

Amended Durability Demonstration and In-Use NOx Emissions Data Reporting Costs

For heavy-duty diesel engines, the Proposed Amendments include a new standardized methodology for demonstrating durability that includes the following elements:

- Longer break-in period for medium-duty and heavy-duty diesel engines;
- Required use of standardized aging cycles;
- Increasing the required laboratory aging hours to full useful life, with the option for HHDD in all years and the remaining heavy-duty diesel engines in 2027 and subsequent model years to use an approved accelerated aftertreatment aging protocol for a portion of useful life in order to reduce the overall aging period; and
- For manufacturers that opt to use accelerated aftertreatment aging, the requirement to submit periodic in-use vehicle NOx emissions reports to CARB.

The proposed lengthened useful life would have direct impacts on the required hours of service accumulation for the durability demonstration program, which is intended to demonstrate emissions compliance at the end of useful life. Additionally, manufacturers would need to conduct three separate durability programs to cover 2024-2026, 2027-2030, and 2031 and later model year products. Overall, the proposed durability demonstration program would impose costs for performing the additional laboratory service accumulation for durability testing and costs for reporting in-use NOx emissions to CARB.

The durability testing costs include:

- Program planning costs – Because of the testing time required to age an engine and aftertreatment system to its full useful life, CARB staff anticipates that all HHDD engine manufacturers would use an accelerated aging protocol called the Diesel Aftertreatment Accelerated Aging Cycle (DAAAC) process in the 2024 through 2026 model year timeframe and the remaining heavy-duty diesel manufacturers would use the DAAAC process for the 2027 and subsequent model years. In order to use DAAAC, engineering calculations must be performed to determine the required temperature profiles, and the required level of chemical aging. Manufacturers that use DAAAC would also be required to submit in-use NOx emissions data to CARB during those model years. CARB staff estimates an additional (incremental) 40 hours of program planning labor for a junior engineer (at $70/hour**Error! Bookmark not defined.**) for each manufacturer using the DAAAC process. This covers the labor costs for Durability Demonstration Program (DDP) planning and scheduling.

- Emissions testing costs – On-road heavy-duty engine manufacturers are required to conduct at least three emissions tests (one test at the beginning of the DDP, one test at the DDP midpoint, one test at the DDP endpoint) using the Federal Test Procedure (FTP) and Ramped Modal Cycle Version of the Supplemental Emission Test (RMC-SET) cycles for each durability parent engine[7]. The FTP and RMC-SET cycles are the current baseline emissions testing cycles for the 2018 model year. The LLC cycle is a new emissions testing cycle that would be required under the Proposed Amendments starting with the 2024 model year.

    - The addition of the LLC cycle would increase the emissions testing cost by $69,000 for each durability parent engine ($23,000 multiplied by three emissions tests for each durability parent engine). The estimated cost for performing the LLC emissions test was derived from a survey of previous CARB contracts with emissions testing facilities (CARB, 2016).

    - Under the current baseline DDP, manufacturers only age the durability engine to a portion of the useful life. The Proposed Amendments would

[7] Typically, the durability testing is conducted on a durability parent engine and the emission deterioration factors from the durability parent engine are carried across to other applicable engine families.

increase the DDP period to the full useful life of the engine and aftertreatment system. Due to the increase in the length of the DDP, the engine's DPF may require ash cleaning during the DDP, which would require manufacturers to perform emissions tests before and after this ash cleaning interval. This would lead to the requirement of additional sets of emissions tests. Based on a survey of previous CARB contracts with emissions test facilities, CARB staff used an estimate of $68,000 for any additional set of emissions tests including FTP, Ramped Modal Cycle (RMC) and LLC. As noted earlier, CARB staff believes that this is a conservative overestimation of the actual emissions testing costs because most manufacturers conduct the required emissions testing at their own facilities.

- Aging costs – Based on a survey of information from previous CARB contracts with emissions testing facilities, CARB staff used an estimated cost of $160/hour**Error! Bookmark not defined.** for service accumulation. This cost would cover both labor and material (fuel, power, water, maintenance, etc.) costs for aging the engine to the extra number of hours needed under the Proposed Amendments. The required service accumulation period is a function of the engine and aftertreatment system primary intended service class. On average, the increase in the number of hours for DDP range from 900 to 3,800 hours depending on the primary intended service class.

- Break-in hours – The required break-in hours would be increased from 125 hours for the 2018 model year baseline to 300 hours for 2024 and subsequent model years. For service accumulation, CARB staff used an estimate of $160/hour**Error! Bookmark not defined.** for additional break-in requirements.

- Mule engine – In order to accelerate the chemical aging process, DAAAC usually relies on the use of a mule engine with high oil consumption rates. This is typically either an older engine or an engine with modified piston rings. Based on an internet survey of used on-road heavy-duty diesel engine prices (Adelman, 2019), CARB staff used an average fixed cost of $15,000 for a mule engine. This number is a conservative estimate because all on-road heavy-duty diesel engine manufacturers have access to a large supply of used engines through their engine rebuild divisions.

- Ash cleaning – The Proposed Amendments would require manufacturers to age the engine to full useful life. As such, as previously mentioned, some manufacturers would likely need to add an ash cleaning interval as part of their DDP. Based on the survey of data from repair facilities, CARB staff used an average fixed cost of $500 for each ash cleaning.

The in-use NOx emission reporting costs include:

- Labor Costs – The labor costs for in-use NOx emissions data reporting can be further separated into two components:

  - Upfront programming and database development costs – This is a one-time expense to set up the data collection system that would automatically transfer the required data set from each on-road heavy-duty diesel truck via telematics and store it in a centralized database. The Proposed Amendments would require the manufacturers to provide the required data set for each on-road heavy-duty diesel engine that was originally sold in the California market once per calendar year until the end of useful life is reached.

    CARB staff estimates that a total of 1,000 hours of programming costs for a junior engineer ($70/hour**Error! Bookmark not defined.**) for each of the eight on-road heavy-duty diesel engine manufacturers would be required. The hours will be required to set up the database to store the collected in-use NOx emissions data, and to set up the program which would collect the in-use NOx emissions data every year until the vehicle reaches its useful life period. This is a one-time expense that is included in the 2024 calendar year costs for HHDD engines (5 manufacturers), and the 2027 calendar year for all other manufacturers (3 additional manufacturers).

  - Annual reporting costs – Once the programming for collection and reporting of the in-use NOx emissions data is completed, additional labor would be required each calendar year to prepare and submit the reports electronically to CARB. CARB staff estimates a total of 100 hours for a junior engineer ($70/hour **Error! Bookmark not defined.**) would be required for each report starting with the 2025 calendar year. After collecting the data each calendar year, manufacturers would be required to compile all vehicle data into an annual report and submit annual reports to CARB. The required hours cover the cost of annual reporting.

- Data Transfer Costs Via Telematics – In order to prepare the annual in-use NOx emissions data reports for individual on-road heavy-duty diesel trucks originally sold in California, the required data would first need to be transferred from the truck to a centralized database. CARB staff used an average cost (GPS Insight, 2019) of $30 per truck for each time the data are submitted via telematics (one telematic transaction fee of $30 per calendar year for each on-road heavy-duty diesel truck that needs to submit a report).

  CARB staff believes that the $30 estimate is a conservative overestimation of the actual costs for telematics services. This cost corresponds to one full month of telematics subscription. A one-time per calendar year transaction fee would most likely be an order of magnitude less costly, but at this time, CARB staff does not have access to more detailed telematics pricing for a one-time per calendar year transaction.

- Database Licensing Costs – In order to prepare the in-use NOx emissions data reports, the data set submitted via telematics must be stored in a centralized database for each heavy-duty diesel manufacturer. CARB staff used a one-time upfront cost of $100,000 for procurement of the database license (Oracle, 2019) per manufacturer which includes software update and support. The database must be set up prior to the reporting period so that it would be ready for data collection in the subsequent calendar year.

  CARB staff assumed that each on-road heavy-duty diesel manufacturer would procure one database license exclusively for in-use NOx emissions data reporting. This is an overestimation, as CARB staff believes that on-road heavy-duty diesel engine manufacturers already procure database licenses for other internal applications. Under the Proposed Amendments, HHDD manufacturers would need to procure the database in the 2024 calendar year for 2024 model year engine reporting, while the remaining LHDD and MHDD manufacturers would have to procure the database in the 2027 calendar year for 2027 model year engine reporting.

- Data Storage Costs – The data submitted through telematics from each operating truck must also be stored in a centralized data storage facility. Based on the number of parameters required, CARB staff believes that one data set from one truck should be less than 5 kilobytes in size (this is a conservative estimate in that the actual data set is more likely less than 2 kilobytes in size).

  The cost of data storage varies widely depending on whether it is stored in a localized data storage facility or in cloud services. For this cost analysis, CARB staff used an average cost of $0.026 per gigabyte per month (Google, 2019) to estimate the data storage costs. CARB staff also assumed that after a NOx emissions data report is submitted for each truck, the manufacturer only needs to keep the data set in cloud storage temporarily, and the data set can be either deleted or overwritten by a new data set for the next report. The annual data storage costs per truck were calculated using the following equation:

$$Data\ storage\ costs\ for\ each\ truck\ per\ calendar\ year = \frac{5\ kilobytes}{truck} \times \frac{1\ gigabyte}{1 \times 10^{6}\ kilobyte} \times \frac{\$0.026}{gigabyte.month} \times \frac{12\ months}{1\ year}$$

TableI.55 summarizes the estimated total incremental cost for the proposed durability amendments, which is the sum of the discussed durability testing cost and the in-use NOx emission reporting cost.

Table I.55. Estimated Incremental Costs Relative to the 2018 Model Year Baseline for the Proposed DDP Amendments (2018$ for all Manufacturers)

Calendar Year	Incremental costs for Laboratory Service Accumulation/Aging	Incremental Costs for In-use Emissions Data Reporting	Total Incremental Costs for Durability Demonstration Program
2022	$0	$0	$0
2023	$8,612,420	$0	$8,612,420
2024	$0	$850,000	$850,000
2025	$0	$140,810	$140,810
2026	$11,262,220	$248,956	$11,511,176
2027	$0	$869,431	$869,431
2028	$0	$754,981	$754,981
2029	$0	$1,137,957	$1,137,957
2030	$12,124,120	$1,421,019	$13,545,139
2031	$0	$1,707,090	$1,707,090
2032	$0	$2,001,917	$2,001,917
2033	$0	$2,041,017	$2,041,017
2034	$0	$2,085,403	$2,085,403
2035	$0	$2,131,965	$2,131,965
2036	$0	$2,175,676	$2,175,676
2037	$0	$2,211,745	$2,211,745
2038	$0	$2,242,112	$2,242,112
2039	$0	$2,262,263	$2,262,263
2040	$0	$2,277,510	$2,277,510
2041	$0	$2,292,944	$2,292,944
2042	$0	$2,308,595	$2,308,595
2043	$0	$2,324,872	$2,324,872
2044	$0	$2,341,762	$2,341,762
2045	$0	$2,359,323	$2,359,323
2046	$0	$2,378,024	$2,378,024
2047	$0	$2,396,662	$2,396,662
2048	$0	$2,415,887	$2,415,887
2049	$0	$2,434,502	$2,434,502
2050	$0	$2,449,278	$2,449,278
Total 2022-2050 Calendar Years	**$31,998,760**	**$50,261,702**	**$82,260,462**

Note: For medium-duty engines, there are no additional costs due to the DDP amendments because currently manufacturers of all medium-duty engines do not conduct a separate DDP for these engines. All California-certified medium-duty engines are sister families of either LHDD or MHDD engines. Therefore, manufacturers use the deterioration factors from the LHDD and MHDD engines and carry across the deterioration factors to the corresponding sister family medium-duty engines.

Powertrain Certification Test Procedure for Heavy-Duty Hybrid Vehicles

The Proposed Amendments would amend the existing powertrain testing procedure for certifying heavy-duty vehicles to GHG emission standards to allow it to also be used as an optional procedure to certify hybrid powertrains to criteria pollutants emission standards. The Proposed Amendments would give manufacturers of heavy-duty vehicles an added, voluntary option to certify their vehicles.

Currently, U.S. EPA offers a similar option to test for GHG emissions standards among the federal certification choices. As part of the Proposed Amendments, CARB is adding this certification option, which utilizes essentially the same test, equipment software, and facilities as the federal option, however the CARB option includes criteria pollution emission standards testing. Manufacturers may need to add instrumentation specific for criteria pollution testing, although our estimates show that the costs of extra instrumentation are negligible. This powertrain certification option could in some cases be more convenient and more effective for manufacturers, as it would be more comprehensively harmonized with its federal counterpart optional procedures.

Overall, CARB staff anticipates that the powertrain test procedure amendments would not increase costs or savings to manufacturers or the cost of vehicles certified for sale in California. This is because CARB staff assumes a manufacturer would only choose to use the powertrain certification procedures if this option supports the logistics and flow of the production chain and does not impose more than negligible costs. CARB staff also assumes any savings due to use of the powertrain test procedures would be negligible.

Heavy-Duty Vehicle GHG Tractor APU Certification Amendments

CARB staff expects that the proposed APU certification amendments would not result in a cost increase to APUs that would be used in 2024 and subsequent model year tractors. Existing California APU certification requirements, reporting, and processes remain unchanged. The addition of 40 CFR §1039.699 in the California APU certification test procedures would allow harmonization with the federal certification requirements. Thus, no additional cost to APUs is projected.

California Phase 2 GHG Regulation Clean-up Items

All of the proposed Phase 2 amendments are either minor clean-up items to ensure the functionality of the regulation or alignment with already proposed or adopted national standards. The California-specific Proposed Amendments would not affect the stringency of the emission standards or the testing standards of the already adopted California Phase 2 program. Because of this, CARB staff considers all of these Phase 2 amendments as no-cost changes.

Medium-Duty Engine Clarifications and Amendments

There would be no costs associated with the clarifications and amendments to medium-duty engines. The alteration to change the useful life to align with Low-Emission Vehicle III would not change the technology and durability of current medium-duty vehicles. There would not be additional costs associated with the prohibition of the use of medium-duty engines in vehicles greater than 14,000 pounds GVWR. Engines in vehicles greater than 14,000 pounds GVWR would need to certify to the appropriate available standards for their vehicle class. Finally, the limitation to 2023 and earlier model years for the provision of allowing heavy-duty vehicles in medium-duty test groups would not result in additional costs because these heavy-duty vehicles would be grouped with a similar heavy-duty engine family for certification.

On-Board Diagnostic Requirement

Regarding the proposed changes to the OBD malfunction criteria to effectively extend the use of higher (easier to meet) NOx and PM emission thresholds, there would be no costs associated with the changes. Engine manufacturers are already calibrating and certifying Heavy-Duty (HD) OBD systems to this emission level and certification to the proposed lower NOx emission standards would only provide further separation between properly operating and malfunctioning emission control components making calibration efforts easier, not harder.

II. COST IMPACTS ON BUSINESSES

i. Total Number of Businesses

Medium- and heavy-duty engine/vehicle manufacturers would be the regulated entities under the Proposed Amendments. Since these manufacturers are located outside of California, CARB staff assumes the direct cost impact on these manufacturers would be passed onto California fleets that purchase the California-certified vehicles.[8] CARB staff estimated the number of impacted California fleets using 2017 Department of Motor Vehicles (DMV) registration data, which suggests about 290,775 medium- and heavy-duty fleets (GVWR>10,000 lbs., including owner operators) are registered in California. CARB staff estimated the number of impacted engine/vehicle manufacturers using CARB's certification data, which suggests about 31 medium- and heavy-duty vehicle and engine manufacturers certify their new engines and vehicles with CARB. Therefore, the Proposed Amendments would directly impact approximately a total of 290,806 businesses.

[8] All the affected engine manufacturers are located outside California. However, a number of heavy-duty ZEV manufacturers who could generate credits under the Proposed Amendments are located in California.

Types of Businesses

The impacted businesses were evaluated under a few different systems including the North American Industrial Classification System (NAICS) and its assigned industry codes. The Proposed Amendments would directly impact medium- and heavy-duty Truck Transportation (NAICS 484) and engine and vehicle manufacturers (NAICS 3363 and 3361, respectively). The Proposed Amendments would also have an impact on medium- and heavy-duty fleets in California who purchase the California-certified vehicles, as CARB staff assumes medium- and heavy-duty manufacturers would immediately pass on the increased upfront cost due to the Proposed Amendments to the truck and engine buyers and end users.

In addition, the Proposed Amendments would cause vehicle owners to be more likely to maintain and repair their vehicles during the longer warranty periods that are part of the Proposed Amendments. CARB staff expects more vehicle and engine repairs would occur due to the Proposed Amendments. Hence, secondary industries such as heavy-duty repair shops (both dealerships and independent repair facilities, NAICS 8111) would also be impacted due to the warranty-related Proposed Amendments.

New engine and aftertreatment technologies would be needed to comply with the proposed more stringent emission standards. Increased demand for these new technologies will impact other industries such as vehicle manufacturing (NAICS 3361), motor vehicle parts manufacturing (NAICS 3363), basic chemical manufacturing (NAICS 3259), and other measuring and controlling devices manufacturing (NAICS 3345) industries.

Impacts on Business Creation/Elimination

Regional Economic Models, Inc. (REMI) Policy Insight Plus Version 2.2.8 was used to estimate the macroeconomic impacts of the Proposed Amendments on the California economy. REMI is a structural economic forecasting and policy analysis model that integrates input-output, computable general equilibrium, econometric and economic geography methodologies.[9] More details on the methodology can be found in the original Standardized Regulatory Impact Assessment (SRIA) submitted to Department of Finance in Appendix C-1.

Gross output is used as a measure for business impacts because it represents industries' sales or receipts and tracks the quantity of goods or services produced in a given time period. Gross output is the sum of goods or services in each private industry (including state and local governments) whether for final consumption or for further production. Gross output is affected by production cost and demand changes. If production cost increases or demand decreases, output is expected to contract; conversely, if production costs decline or demand increases, industry will likely experience output growth.

[9] For further information and model documentation see: https://www.remi.com/model/pi/

The Proposed Amendments are modeled to decrease output by $201 million in 2028 and by $535 million in 2050, the year of maximum impact, as shown in Table II.1. Annual impacts on total California output are predicted to never exceed 0.01 percent. There are also small negative impacts on major sectors of the California economy, but the overall predicted trend is still for output growth each year. Due to the small overall impact of 0.01 percent decrease in state output, CARB staff has determined the creation or elimination of the number of businesses impact to be negligible. Tables II.2a and II.2b display the output impact by major sector. The decreases of output in the transportation, retail & wholesale trade sectors, construction sectors and others would be due to increased production costs due to the increased heavy-duty truck prices driven by the Proposed Amendments. The sector most significantly impacted would be the transportation sector and the years of maximum impact would be 2030 and 2034, when output would be 0.11 percent lower than it otherwise would be. It is important to note that for no sector is the impact of the Proposed Amendments expected to be enough to actually make the output decrease from year to year, with the exception of the construction sector from 2025 to 2027. Instead, CARB staff predicts the impact would be a small decrease in the output growth that would otherwise occur.

Table II.1. California Output Impacts of Proposed Amendments

Calendar Year	Change in Total Output (2018M$)	Percent Change	California Output (2018M$)
2022	0.06	0.00%	4,124,016.67
2023	-27.34	0.00%	4,188,289.34
2024	-3.60	0.00%	4,256,615.78
2025	-33.29	0.00%	4,328,114.35
2026	-76.25	0.00%	4,396,032.11
2027	-181.41	0.00%	4,471,622.31
2028	-200.66	0.00%	4,549,224.99
2029	-197.20	0.00%	4,630,802.78
2030	-449.90	-0.01%	4,715,893.11
2031	-431.64	-0.01%	4,805,765.78
2032	-309.26	-0.01%	4,900,403.82
2033	-308.98	-0.01%	4,999,911.87
2034	-414.88	-0.01%	5,104,572.35
2035	-389.06	-0.01%	5,215,717.60
2036	-345.77	-0.01%	5,332,629.05
2037	-344.58	-0.01%	5,452,763.77
2038	-339.65	-0.01%	5,575,782.87
2039	-372.63	-0.01%	5,701,868.44
2040	-371.79	-0.01%	5,830,768.09
2041	-371.21	-0.01%	5,962,542.58
2042	-371.14	-0.01%	6,097,442.79
2043	-371.97	-0.01%	6,235,226.28
2044	-372.32	-0.01%	6,375,337.42
2045	-370.51	-0.01%	6,518,454.95
2046	-504.11	-0.01%	6,664,542.28
2047	-512.21	-0.01%	6,813,630.59
2048	-523.31	-0.01%	6,965,803.69
2049	-531.58	-0.01%	7,121,125.15
2050	-534.69	-0.01%	7,278,970.36

Table II.2a. California Output Impacts of Proposed Amendments by Major Sector (2018$M): Government, Retail & Wholesale, Services, and Construction

Sector:	Government		Retail & Wholesale		Services		Construction	
Calendar Year	Agg. Value	%Change	Agg. Value	%Change	Agg. Value	%Change	Agg. Value	%Change
2022	333,702.38	0.00%	446,813.91	0.00%	337,356.38	0.00%	168,992.00	0.00%
2023	337,178.92	0.00%	455,995.21	0.00%	343,387.66	0.00%	169,914.37	0.00%
2024	340,323.05	0.00%	465,168.75	0.00%	350,140.28	0.00%	169,987.50	0.00%
2025	343,770.48	0.00%	474,165.98	0.00%	357,525.81	0.00%	169,581.06	0.00%
2026	347,421.95	0.00%	481,827.37	0.00%	365,132.69	0.00%	168,895.14	0.00%
2027	350,915.89	0.00%	490,499.85	-0.01%	373,376.70	0.00%	168,254.99	-0.01%
2028	354,236.57	0.00%	499,602.75	-0.01%	381,871.19	0.00%	168,405.38	-0.01%
2029	357,370.71	0.00%	509,146.89	-0.01%	390,346.32	0.00%	169,663.22	-0.01%
2030	360,614.37	0.00%	519,130.31	-0.03%	398,997.78	0.00%	171,736.79	-0.03%
2031	363,994.62	0.00%	529,758.12	-0.02%	407,922.69	0.00%	174,411.91	-0.03%
2032	367,426.36	0.00%	541,156.37	-0.02%	417,068.56	0.00%	177,594.73	-0.02%
2033	370,884.54	0.00%	553,308.60	-0.02%	426,450.40	0.00%	181,232.74	-0.01%
2034	374,339.68	0.00%	566,306.79	-0.02%	436,042.89	0.00%	185,324.63	-0.02%
2035	377,945.84	0.00%	580,263.25	-0.02%	445,971.84	0.00%	189,838.13	-0.01%
2036	381,655.25	0.00%	595,160.48	-0.02%	456,263.71	0.00%	194,586.47	-0.01%
2037	385,567.30	0.00%	610,406.03	-0.02%	466,824.15	0.00%	199,307.57	-0.01%
2038	389,542.65	0.00%	626,051.23	-0.02%	477,561.07	0.00%	204,028.08	-0.01%
2039	393,597.95	0.00%	642,086.41	-0.02%	488,496.09	0.00%	208,773.20	-0.01%
2040	397,706.71	0.00%	658,505.53	-0.02%	499,601.54	0.00%	213,569.62	-0.01%
2041	401,883.74	0.00%	675,283.00	-0.02%	510,904.45	0.00%	218,382.13	-0.01%
2042	406,120.01	0.00%	692,463.16	-0.02%	522,406.91	0.00%	223,237.10	-0.01%
2043	410,393.49	0.00%	709,990.42	-0.02%	534,087.87	0.00%	228,148.11	-0.01%
2044	414,644.39	0.00%	727,830.71	-0.02%	545,866.46	0.00%	233,141.15	0.00%
2045	418,921.41	0.00%	746,078.80	-0.02%	557,798.04	0.00%	238,315.17	0.00%
2046	423,227.08	0.00%	764,701.52	-0.02%	569,902.17	0.00%	243,622.26	-0.01%
2047	427,575.88	0.00%	783,686.51	-0.02%	582,191.38	0.00%	249,041.26	-0.01%
2048	431,949.54	0.00%	803,023.13	-0.02%	594,669.88	0.00%	254,574.34	-0.01%
2049	436,340.58	0.00%	822,739.24	-0.02%	607,330.63	0.00%	260,249.47	-0.01%
2050	440,705.60	0.00%	842,755.90	-0.02%	620,109.84	0.00%	266,061.35	-0.01%

Table II.2b. California Output Impacts of Proposed Amendments by Major Sector (2018$M): Transportation, Manufacturing, Financial Services, and Information Services

Sector:	Transportation		Manufacturing		Financial Services		Information Services	
Calendar Year	Agg. Value	%Change	Agg. Value	%Change	Agg. Value	%Change	Agg. Value	%Change
2022	115,735.86	0.00%	673,610.65	0.00%	179,250.68	0.00%	385,035.39	0.00%
2023	117,497.48	-0.01%	681,224.65	0.00%	182,959.94	0.00%	395,670.67	0.00%
2024	119,349.96	0.00%	691,358.43	0.00%	186,819.45	0.00%	406,051.46	0.00%
2025	121,254.96	-0.01%	701,203.31	0.00%	190,813.24	0.00%	416,459.98	0.00%
2026	123,023.14	-0.02%	709,850.23	0.00%	194,520.54	0.00%	426,177.27	0.00%
2027	125,049.18	-0.05%	719,368.09	0.00%	198,757.08	0.00%	437,323.19	0.00%
2028	127,121.88	-0.06%	727,919.16	0.00%	203,134.10	0.00%	449,188.39	0.00%
2029	129,223.04	-0.05%	738,276.89	0.00%	207,619.99	0.00%	461,434.41	0.00%
2030	131,328.20	-0.11%	749,192.28	0.00%	212,197.19	-0.01%	474,484.81	0.00%
2031	133,633.06	-0.10%	761,013.09	-0.01%	216,886.29	-0.01%	488,562.37	0.00%
2032	136,072.22	-0.08%	773,778.04	0.00%	221,716.81	0.00%	503,706.44	0.00%
2033	138,609.32	-0.08%	787,602.08	0.00%	226,710.71	0.00%	520,007.33	0.00%
2034	141,231.93	-0.11%	802,551.00	-0.01%	231,888.70	-0.01%	537,517.87	0.00%
2035	144,047.99	-0.10%	819,163.41	0.00%	237,220.61	-0.01%	556,458.13	0.00%
2036	147,029.10	-0.09%	836,960.43	0.00%	242,664.53	0.00%	576,941.13	0.00%
2037	150,050.19	-0.09%	855,377.64	0.00%	248,194.02	0.00%	598,253.67	0.00%
2038	153,119.52	-0.08%	874,267.84	0.00%	253,851.37	0.00%	620,339.08	0.00%
2039	156,226.34	-0.09%	893,781.02	-0.01%	259,622.83	0.00%	643,227.06	0.00%
2040	159,384.77	-0.09%	913,705.02	-0.01%	265,507.89	0.00%	666,910.62	0.00%
2041	162,584.42	-0.08%	934,089.33	0.00%	271,485.13	0.00%	691,442.39	0.00%
2042	165,831.01	-0.08%	954,926.11	-0.01%	277,576.96	0.00%	716,858.49	0.00%
2043	169,116.55	-0.08%	976,179.97	0.00%	283,779.16	0.00%	743,154.43	0.00%
2044	172,427.83	-0.08%	997,742.58	0.00%	290,083.16	0.00%	770,250.13	0.00%
2045	175,777.33	-0.07%	1,019,657.24	0.00%	296,523.86	0.00%	798,241.64	0.00%
2046	179,128.15	-0.09%	1,041,948.72	-0.01%	303,083.09	-0.01%	827,171.20	0.00%
2047	182,545.87	-0.09%	1,064,665.79	-0.01%	309,722.82	-0.01%	857,098.95	0.00%
2048	185,997.27	-0.09%	1,087,807.08	-0.01%	316,465.72	-0.01%	888,063.38	0.00%
2049	189,483.02	-0.09%	1,111,376.52	-0.01%	323,316.20	-0.01%	920,097.52	0.00%
2050	192,984.20	-0.09%	1,135,262.22	-0.01%	330,248.09	-0.01%	953,132.25	0.00%

Although the REMI model cannot directly estimate the creation or elimination of businesses, it can be used to understand some potential impacts. The decreased output due to the Proposed Amendments for the transportation industry has the potential to result in a small decrease in business creation in this industry if sustained over time. Increased production costs may marginally increase the risk of business elimination, however the macroeconomic analysis results only show impacts up to 0.11 percent for the transportation sector.

Impacts on Employment Creation/Elimination

Table II.3 presents the impact of the Proposed Amendments on total employment in California across all industries. As Table II.3 shows, the Proposed Amendments would result in a slightly negative employment impact from about 2022 to 2050. CARB staff expects the change in employment due to the Proposed Amendments would represent no more than 0.01 percent of baseline California employment in any year.

Tables II.4a and II.4b display the employment impact down by major sector such as retail and wholesale, transportation, manufacturing and construction, all of which are sectors that would be impacted by the Proposed Amendments. CARB staff's analysis predicts that as the requirements of the Proposed Amendments would go into effect, affected sectors would likely experience increases in production costs and hence slightly slower employment than they otherwise would experience under baseline conditions. The largest decrease in employment would manifest in the manufacturing, construction, transportation, and retail & wholesale trade sectors, which are estimated to realize an increase in production costs due to the increased heavy-duty truck prices driven by the Proposed Amendments.

Table II.3. California Employment Impacts of Proposed Amendments

Calendar Year	Change in Total Jobs	Percent Change	California Employment
2022	0	0.00%	24,692,675
2023	-185	0.00%	24,885,355
2024	-20	0.00%	25,076,789
2025	-215	0.00%	25,266,932
2026	-491	0.00%	25,455,691
2027	-1,161	0.00%	25,644,170
2028	-1,207	0.00%	25,832,756
2029	-1,154	0.00%	26,019,386
2030	-2,707	-0.01%	26,203,839
2031	-2,523	-0.01%	26,389,035
2032	-1,627	-0.01%	26,572,763
2033	-1,592	-0.01%	26,752,682
2034	-2,179	-0.01%	26,928,730
2035	-1,985	-0.01%	27,103,814
2036	-1,693	-0.01%	27,272,990
2037	-1,648	-0.01%	27,439,642
2038	-1,583	-0.01%	27,603,039
2039	-1,714	-0.01%	27,763,011
2040	-1,674	-0.01%	27,918,975
2041	-1,632	-0.01%	28,070,856
2042	-1,590	-0.01%	28,220,305
2043	-1,557	-0.01%	28,366,180
2044	-1,523	-0.01%	28,506,702
2045	-1,483	-0.01%	28,644,601
2046	-2,050	-0.01%	28,779,582
2047	-2,036	-0.01%	28,911,206
2048	-2,037	-0.01%	29,039,779
2049	-2,035	-0.01%	29,165,880
2050	-2,003	-0.01%	29,287,128

Table II.4a. California Employment Impacts of Proposed Amendments by Major Sector: Government, Retail & Wholesale, Services, and Construction

Sector:	Government		Retail & Wholesale		Services		Construction	
Calendar Year	Total Jobs	%Change	Total Jobs	%Change	Total Jobs	%Change	Total Jobs	%Change
2022	2,352,826	0.00%	3,181,461	0.00%	2,188,297	0.00%	1,190,459	0.00%
2023	2,370,742	0.00%	3,195,620	0.00%	2,212,947	0.00%	1,185,452	0.00%
2024	2,385,213	0.00%	3,206,661	0.00%	2,240,453	0.00%	1,174,153	0.00%
2025	2,400,160	0.00%	3,212,633	0.00%	2,269,744	0.00%	1,159,033	0.00%
2026	2,419,025	0.00%	3,210,894	0.00%	2,302,030	0.00%	1,143,552	0.00%
2027	2,433,065	0.00%	3,210,423	-0.01%	2,334,447	0.00%	1,126,987	-0.01%
2028	2,444,986	0.00%	3,211,246	-0.01%	2,366,702	0.00%	1,115,583	-0.01%
2029	2,454,108	0.00%	3,212,480	-0.01%	2,397,085	0.00%	1,110,927	-0.01%
2030	2,462,736	0.00%	3,213,887	-0.03%	2,426,852	0.00%	1,110,987	-0.02%
2031	2,470,849	0.00%	3,216,316	-0.02%	2,456,344	0.00%	1,114,108	-0.02%
2032	2,477,720	0.00%	3,220,330	-0.02%	2,485,075	0.00%	1,119,495	-0.02%
2033	2,483,063	0.00%	3,225,463	-0.02%	2,512,976	0.00%	1,126,641	-0.01%
2034	2,486,610	0.00%	3,232,011	-0.02%	2,539,790	0.00%	1,135,389	-0.02%
2035	2,489,386	0.00%	3,240,232	-0.02%	2,566,110	0.00%	1,145,423	-0.01%
2036	2,490,999	0.00%	3,249,625	-0.02%	2,591,946	0.00%	1,155,498	-0.01%
2037	2,493,301	0.00%	3,258,251	-0.02%	2,617,852	0.00%	1,164,600	-0.01%
2038	2,495,378	0.00%	3,266,510	-0.02%	2,643,318	0.00%	1,172,922	-0.01%
2039	2,497,329	0.00%	3,274,239	-0.02%	2,668,435	0.00%	1,180,624	-0.01%
2040	2,498,998	0.00%	3,281,432	-0.02%	2,693,050	0.00%	1,187,878	-0.01%
2041	2,500,477	0.00%	3,287,875	-0.02%	2,717,280	0.00%	1,194,496	-0.01%
2042	2,501,708	0.00%	3,293,800	-0.02%	2,741,132	0.00%	1,200,640	0.00%
2043	2,502,609	0.00%	3,298,962	-0.02%	2,764,524	0.00%	1,206,410	0.00%
2044	2,502,838	0.00%	3,303,271	-0.02%	2,787,057	0.00%	1,211,955	0.00%
2045	2,502,734	0.00%	3,307,190	-0.02%	2,809,058	0.00%	1,217,786	0.00%
2046	2,502,339	0.00%	3,310,541	-0.02%	2,830,640	0.00%	1,223,644	-0.01%
2047	2,501,765	0.00%	3,313,243	-0.02%	2,851,872	0.00%	1,229,420	-0.01%
2048	2,500,912	0.00%	3,315,246	-0.02%	2,872,764	0.00%	1,235,116	-0.01%
2049	2,499,782	0.00%	3,316,736	-0.02%	2,893,328	0.00%	1,240,876	-0.01%
2050	2,498,146	0.00%	3,317,413	-0.02%	2,913,273	0.00%	1,246,664	-0.01%

Table II.4b. California Employment Impacts of Proposed Amendments by Major Sector: Transportation, Manufacturing, Financial Services, and Information Services

Sector:	Transportation		Manufacturing		Financial Services		Information Services	
Calendar Year	Total Jobs	% Change	Total Jobs	% Change	Total Jobs	% Change	Total Jobs	% Change
2022	930,781	0.00%	1,402,001	0.00%	1,099,151	0.00%	670,638	0.00%
2023	938,108	-0.01%	1,393,118	0.00%	1,110,135	0.00%	677,086	0.00%
2024	945,481	0.00%	1,388,659	0.00%	1,121,170	0.00%	682,443	0.00%
2025	952,469	-0.01%	1,381,345	0.00%	1,131,941	0.00%	687,220	0.00%
2026	959,082	-0.02%	1,371,469	0.00%	1,141,961	0.00%	691,536	0.00%
2027	965,853	-0.04%	1,361,438	0.00%	1,153,203	0.00%	696,673	0.00%
2028	972,603	-0.04%	1,348,871	0.00%	1,164,501	0.00%	702,575	0.00%
2029	978,992	-0.04%	1,339,984	0.00%	1,175,271	0.00%	708,406	0.00%
2030	984,886	-0.09%	1,331,486	-0.01%	1,185,583	-0.01%	715,008	0.00%
2031	991,381	-0.08%	1,323,847	-0.01%	1,195,433	-0.01%	722,604	0.00%
2032	998,028	-0.07%	1,316,905	-0.01%	1,204,872	0.00%	730,946	0.00%
2033	1,004,539	-0.06%	1,310,713	-0.01%	1,213,933	0.00%	740,045	0.00%
2034	1,010,811	-0.08%	1,305,263	-0.01%	1,222,639	-0.01%	749,845	0.00%
2035	1,017,412	-0.08%	1,301,182	-0.01%	1,230,792	0.00%	760,616	0.00%
2036	1,024,106	-0.07%	1,297,461	-0.01%	1,238,131	0.00%	772,409	0.00%
2037	1,030,563	-0.06%	1,293,777	-0.01%	1,245,131	0.00%	784,479	0.00%
2038	1,036,862	-0.06%	1,289,951	-0.01%	1,251,986	0.00%	796,664	0.00%
2039	1,042,935	-0.07%	1,286,249	-0.01%	1,258,618	0.00%	808,980	0.00%
2040	1,048,852	-0.06%	1,282,304	-0.01%	1,265,016	0.00%	821,380	0.00%
2041	1,054,541	-0.06%	1,278,171	-0.01%	1,271,074	0.00%	833,916	0.00%
2042	1,060,054	-0.06%	1,273,842	-0.01%	1,276,892	0.00%	846,587	0.00%
2043	1,065,372	-0.06%	1,269,289	-0.01%	1,282,461	0.00%	859,374	0.00%
2044	1,070,444	-0.05%	1,264,515	-0.01%	1,287,738	0.00%	872,146	0.00%
2045	1,075,348	-0.05%	1,259,474	-0.01%	1,292,895	0.00%	884,981	0.00%
2046	1,079,926	-0.07%	1,254,220	-0.01%	1,297,859	-0.01%	897,919	0.00%
2047	1,084,449	-0.07%	1,248,803	-0.01%	1,302,483	-0.01%	911,017	0.00%
2048	1,088,783	-0.06%	1,243,212	-0.01%	1,306,861	-0.01%	924,280	0.00%
2049	1,092,956	-0.06%	1,237,489	-0.01%	1,311,035	-0.01%	937,719	0.00%
2050	1,096,874	-0.06%	1,231,516	-0.01%	1,314,902	-0.01%	951,232	0.00%

Impacts on California Business Competitiveness

CARB staff considered whether some California state fleets would be competitively advantaged or disadvantaged compared to out-of-state fleets that transport goods on an interstate scale. Because California emission standards would be stricter beginning in 2024 than federally and hence California-certified trucks slightly more expensive than federally-certified trucks (about 0.5 to 10.4 percent increase in purchase price and about 0.4 to 9.5 percent increase in net lifetime cost compared to federally-certified trucks, as discussed further below in Tables II.5, II.6, and II.7), it is possible that California fleets involved in interstate transport may be competitively disadvantaged compared to out-of-state fleets for whom it is easier to purchase cheaper, higher emitting new trucks outside California. However, the likelihood of competitive disadvantage is reduced due to the existence of the 50-state-directed engine standard option under which manufacturers could choose to meet one standard nationwide. In addition, because the cost increase is expected to be small compared to the purchase price of a truck, on average, and because California and out-of-state fleets operating in California have the option of holding onto their existing vehicles slightly longer or purchasing used vehicles in-state or out-of-state in lieu of new vehicles in California, CARB staff is not certain whether such a competitive impact would occur.

Overall, although the REMI analysis above gives CARB staff a general understanding of the expected impacts of the Proposed Amendments on California competitiveness, CARB staff concluded it is not possible to precisely quantify impacts on California competitiveness. CARB staff was unable to obtain complete information on business level responses to regulatory costs due to the highly competitive nature of the truck transportation industry. In addition, CARB staff searched the literature and concluded that empirical research focused on the impact of regulatory costs on heavy-duty vehicle and engine prices does not exist. A number of studies have explored the relationship between general cost increases and the likelihood of out-of-state or used truck and engine purchases. These studies found that there is a very wide range of estimates for how increased costs may impact purchasing behavior (Askin et al., 2015; Greene, 2001) , the estimates are highly uncertain, and that these estimates may change markedly in the span of only several years due to the dynamics of industry, and modern global economics.

Impacts on Small Business

For the impacted California fleets, there are about 267,718 small fleets,[10] which is about 92 percent of the total impacted fleets in California. These small business fleets own about 52 percent of the total medium- and heavy-duty vehicles in California. For the impacted engine/vehicle manufacturers, there are about 10 small businesses,[11] which are about 32 percent of the total impacted manufacturers. In total, therefore, there would be about 267,728 small businesses impacted

[10] For the purposes of this analysis, CARB staff assumed fleets that own 3 or less vehicles are small businesses.

[11] As defined in 40 CFR 1068.30 and 40 CFR 1037.150 (c) and federal Phase 2 GHG regulation: https://www.govinfo.gov/content/pkg/FR-2016-10-25/pdf/2016-21203.pdf

Medium- and heavy-duty engine/vehicle manufacturers would be the regulated entities under the Proposed Amendments. Because all these manufacturers are located outside of California, CARB staff assumed the direct costs imposed on these manufacturers would be passed on from manufacturers to California vehicle fleets that purchase the California-certified vehicles and engines. Based on California DMV 2017 registration data, small businesses, identified as fleets of three or fewer medium- and heavy-duty vehicles, represent 52 percent of the affected vehicle population due to the Proposed Amendments.

The final compliance date for the Truck and Bus Regulation (CARB, 2019c) is January 1st, 2023. As of this date, heavy-duty vehicle owners are required to fully turn over their fleet to 2010 standard compliant engines. Small business fleets throughout California will, in 2023, likely to have recently come into full compliance with the Truck and Bus Regulation via accelerated turnover (i.e., by purchasing new trucks or newer used trucks). Because such small business fleets would have just recently purchased trucks to meet the Truck and Bus Regulation, they are expected to be unlikely to turn over their engines to the proposed 2024 or 2027 and subsequent model year compliant engines soon after the Proposed Amendments takes effect. However, such purchases would be more likely to occur later in the 29-year economic analysis.

The actual cost impact on each fleet would depend on the number of new California-certified vehicles that the fleet would purchase during the lifetime of this cost analysis. An analysis of the cost impacts of the Proposed Amendments, including initial purchase price increase and percent increase, annual additional DEF cost, lifetime additional DEF cost due to the Proposed Amendments, lifetime savings from warranty and EWIR and corrective action amendments, net lifetime cost impact, and net cost as a percent increase of the baseline purchase price is presented in Tables II.5, II.6, and II.7 for purchases of 2024, 2027, and 2031 MY engines respectively, for each vehicle class. As the tables show, the Proposed Amendments overall are expected to increase the initial purchase price 0.5 to 10.4 percent and, over a vehicle's lifetime, impose costs equivalent to 0.4 percent to 9.5 percent of the initial purchase price, depending on the class of vehicle and model year purchased.

Because small businesses are assumed to own three or fewer vehicles, it seems reasonable to assume each would buy no more than one new vehicle. For a small fleet that would buy one new vehicle over the lifetime of the Proposed Amendments, the initial cost due to the amendments (i.e., the increase in purchase price) would range from $412 to $8,478, depending on vehicle class and year of purchase. Annual costs would be due to the increased cost of DEF and would range from $0 to $108/year.

Table II.5. Lifetime analysis for Vehicles with 2024 to 2026 MY Engine

	Increase in Purchase Price	Annual DEF Cost	Lifetime DEF Cost	Lifetime Savings	Lifetime Net Impact	Assumed Baseline Purchase Price	Net Costs as % of Purchase Price
HHDD	$3,761	$90	$898	$60	$4,599	$169,637	2.7%
MHDD	$2,469	$37	$370	$0	$2,839	$103,165	2.8%
LHDD	$1,687	$37	$366	$0	$2,053	$57,694	3.6%
HDO	$506	$0	$0	$143	$363	$94,089	0.4%
MDDE-3	$1,554	$20	$196	$0	$1,751	$52,040	3.4%
MDOE-3	$412	$0	$0	$0	$412	$44,459	0.9%
Population Average	**$2,355**	**$45**	**$455**	**$34**	**$2,776**	**$107,782**	**2.6%**

Table II.6. Lifetime analysis for Vehicles with 2027 to 2030 MY Engine

	Increase in Purchase Price	Annual DEF Cost	Lifetime DEF Cost	Lifetime Savings	Lifetime Net Impact	Assumed Baseline Purchase Price	Net Costs as % of Purchase Price
HHDD	$7,423	$108	$1,186	$791	$7,819	$171,107	4.6%
MHDD	$6,063	$44	$488	$1,234	$5,317	$104,217	5.1%
LHDD	$4,741	$44	$527	$345	$4,923	$58,258	8.5%
HDO	$821	$0	$0	$368	$453	$98,583	0.5%
MDDE-3	$3,916	$24	$235	$0	$4,151	$52,424	7.9%
MDOE-3	$412	$0	$0	$0	$412	$44,843	0.9%
Population Average	**$5,437**	**$55**	**$617**	**$789**	**$5,264**	**$109,559**	**5.2%**

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Table II.7. Lifetime analysis for vehicles with 2031 or later MY Engine

	Increase in Purchase Price	Annual DEF Cost	Lifetime DEF Cost	Lifetime Savings	Lifetime Net Impact	Assumed Baseline Purchase Price	Net Costs as % of Purchase Price
HHDD	$8,478	$108	$1,294	$930	$8,841	$171,107	5.2%
MHDD	$6,923	$44	$532	$1,641	$5,814	$104,217	5.6%
LHDD	$6,041	$44	$659	$1,143	$5,557	$58,258	9.5%
HDO	$1,015	$0	$0	$582	$433	$98,583	0.4%
MDDE-3	$4,354	$24	$235	$0	$4,589	$52,424	8.8%
MDOE-3	$412	$0	$0	$0	$412	$44,843	0.9%
Population Average	**$6,410**	**$56**	**$700**	**$1,197**	**$5,912**	**$109,889**	**5.8%**

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Impacts on Typical Business

Typical businesses are defined here to be California fleets with four or more medium- and heavy-duty vehicles (GVWR > 10,000lbs).

The actual cost impact on a typical fleet would depend mostly on the number of new California-certified vehicles that the fleet would purchase. As an example, CARB staff analyzed a typical business that would buy 20 new vehicles with 2024, 2027, and 2031 MY engines in Tables II.8, II.9, and II.10 respectively. The initial cost due to the amendments (i.e., the increase in purchase price) for the typical business purchasing 20 new vehicles would ranges from $8,243 to $169,556. Annual costs would be due to the increased cost of DEF, which is based on how much would be used per driven mile, and would range from $0 to $2,156/year.

Table II.8. Initial and Ongoing Cost Analysis for Twenty 2024 MY Engines

	Increase Purchase Price	Annual DEF cost	Baseline purchase price	Percent Increase in Purchase Price
HHDD	$75,219	$1,797	$3,392,731	2.2%
MHDD	$49,379	$739	$2,063,292	2.4%
LHDD	$33,737	$733	$1,153,884	2.9%
HDO	$10,122	$0	$1,881,772	0.5%
MDDE-3	$31,089	$392	$1,040,790	3.0%
MDOE-3	$8,246	$0	$889,179	0.9%
Weighted Average	$47,097	**$910**	$2,155,640	2.24%

Table II.9. Lifetime Analysis for Twenty 2027 MY Engines

	Increase Purchase Price	Annual DEF cost	Baseline purchase price	Percent Increase in Purchase Price
HHDD	$148,464	$2,156	$3,422,131	4.3%
MHDD	$121,253	$887	$2,084,347	5.8%
LHDD	$94,813	$879	$1,165,153	8.1%
HDO	$16,421	$0	$1,971,663	0.8%
MDDE-3	$78,319	$471	$1,048,473	7.5%
MDOE-3	$8,245	$0	$896,862	0.9%
Weighted Average	$108,732	$1,103	$2,191,186	5.38%

Table II.10. Lifetime Analysis for Twenty 2031 MY Engines

	Increase Purchase Price	Annual DEF cost	Baseline purchase price	Percent Increase in Purchase Price
HHDD	$169,556	$2,156	$3,422,131	5.0%
MHDD	$138,460	$887	$2,084,347	6.6%
LHDD	$120,826	$879	$1,165,153	10.4%
HDO	$20,307	$0	$1,971,663	1.0%
MDDE-3	$87,079	$471	$1,048,473	8.3%
MDOE-3	$8,243	$0	$896,862	0.9%
Weighted Average	$128,192	$1,114	$2,197,773	6.44%

Impacts on Individual

There are no direct costs to individuals as a result of the Proposed Amendments. Individuals may see health benefits due to the statewide, regional, and local emission benefits of the Proposed Amendments. CARB staff estimates that manufacturers and fleets would see increased costs as a result of this rule and would likely pass the costs through to businesses that buy vehicles with affected engines in the state, as discussed in earlier sections.

Impacts on Investment

REMI's Investment variable is used as a measure for business investment because it represents the propensity of entities to purchase capital goods (including replacements) and other investment vehicles in a given time period. If production cost increases or demand decreases, investment is expected to contract. Conversely, if production costs decline or demand increases, industry will likely experience investment growth.

The Proposed Amendments are modeled to decrease investment by $38.2 million in 2028 and by $48.2 million in 2050, as shown in Table II.11. There are small negative impacts across the California economy, but never an impact in any year of more than 0.02 percent. The decreased statewide investment activity would be due to increased production costs due to the increased heavy-duty truck prices driven by the Proposed Amendments.

Table II.11. Impact of Proposed Amendments on California Investment

Calendar Year	Change in Total Investment (2018$M)	Percent Change	California Investment (2018$M)
2022	-0.03	0.00%	370,890.58
2023	-4.44	0.00%	376,073.09
2024	-1.90	0.00%	380,466.63
2025	-5.66	0.00%	384,647.31
2026	-12.98	0.00%	388,944.60
2027	-30.53	-0.01%	392,880.04
2028	-38.21	-0.01%	398,309.98
2029	-38.31	-0.01%	404,642.72
2030	-72.34	-0.02%	411,658.37
2031	-76.31	-0.02%	419,200.20
2032	-58.45	-0.01%	426,859.50
2033	-49.06	-0.01%	434,653.07
2034	-56.82	-0.01%	442,645.42
2035	-52.74	-0.01%	450,955.60
2036	-43.06	-0.01%	459,168.68
2037	-37.47	-0.01%	467,353.34
2038	-33.15	-0.01%	475,509.22
2039	-34.37	-0.01%	483,740.84
2040	-33.66	-0.01%	491,945.84
2041	-32.62	-0.01%	500,110.59
2042	-31.53	-0.01%	508,123.62
2043	-30.70	-0.01%	516,085.22
2044	-29.98	-0.01%	524,000.59
2045	-29.26	-0.01%	531,975.24
2046	-42.91	-0.01%	540,005.16
2047	-47.37	-0.01%	548,086.38
2048	-49.24	-0.01%	556,226.50
2049	-49.30	-0.01%	564,427.95
2050	-48.23	-0.01%	572,536.08

III. BENEFITS

i. Benefits to Typical Businesses

Typical businesses that may benefit from the proposed requirements include Original Equipment Manufacturer (OEM) component suppliers, manufacturers of innovative technologies, and individual truck and bus owners, including fleets (trucking or bus operations). No OEM component suppliers are located in California, but truck and bus owners and some innovative technology suppliers are. Section a. below discusses benefits for OEM component suppliers, and section c. below discusses benefits for truck and bus owners.

a. Original Equipment Manufacturer Component Suppliers

OEM component suppliers include engine component (e.g., cylinder deactivation, telematics, engine management software, etc.) and emission control system manufacturers. These businesses would benefit from increased business opportunities created by the need to develop, sell, and support new technology solutions to further reduce NOx emissions.

b. Manufacturers of Innovative Technologies

Manufacturers of innovative technologies have the opportunity for increased business as a result of the proposed amendments. For example, one opposed piston manufacturer headquartered in San Diego, California, Achates Power, is currently developing an engine potentially capable of achieving the proposed low NOx standards. The Achates opposed piston technology is one strategy that manufacturers could consider using to meet the 2027 and subsequent model year proposed emission standards.

In addition, as shown in Figure III.1, there are several heavy-duty ZEV manufacturers located within California that may benefit from the proposed amendments. The Proposed Amendments would create a new heavy-duty zero-emission averaging set as a way to incentivize heavy-duty ZEVs. Hence, some manufacturers may choose to make more heavy-duty ZEVs as part of their compliance strategy for Proposed Amendments, and the market share of the heavy-duty ZEV technologies may increase.

Figure III.1. MHDD and HHDD ZEV Manufacturers Located in California

c. Truck and Bus Owners

Although as discussed above, overall, the Proposed Amendments would increase truck prices and DEF consumption and thereby impose costs on truck and bus owners, the Proposed Amendments would provide benefits and savings to truck and bus owners as well. Two parts of the proposed amendments would provide savings to truck and bus owners: the lengthened warranty provisions and the EWIR and corrective action amendments. Under the Proposed Amendments, the manufacturer's warranty period would be significantly lengthened, and owners would not have to pay out-of-pocket for vehicle repairs during that time. In addition, the proposed longer useful life and proposed durability demonstration protocol for the longer useful life would encourage manufacturers to produce more durable components, resulting in fewer failures and less downtime for truck and bus owners. Finally, the EWIR and corrective action amendments would mean more extended warranties and recalls, which would result in a cost savings for vehicle purchasers because components that they previously had to pay for out-of-pocket would now be repaired or replaced under an extended warranty or recall.

Benefits to Small Businesses

Small businesses that may be affected by the proposed requirements include small fleets and engine repair facilities. As mentioned above, small fleets[12] would benefit financially by paying less for engine repairs and less downtime. This is because under the Proposed Amendments, the manufacturer's warranty period would be significantly lengthened, and owners would not have to pay out-of-pocket for vehicle repairs. In addition, engine repair facilities may also benefit from increased business opportunities due to the lengthened warranty, which would encourage vehicle owners to pursue more timely repairs.

Benefits to Individuals

The Proposed Amendments would benefit California residents mainly from the reductions in NOx resulting in reduced ozone exposure and reduced PM exposure from the secondary formation of NOx to Fine Particulate Matter (PM2.5), and from improvements in California air quality and reduced adverse health impacts.

a. Health Benefits

The Proposed Amendments would reduce NOx emissions and thereby reduce the secondary formation of PM2.5, resulting in health benefits for individuals in California. The value of these health benefits is due to fewer instances of premature mortality, fewer hospital and emergency room visits, and fewer lost days of work. As part of setting the National Ambient Air Quality Standards for Ozone, the U.S. EPA quantifies the health risk from exposure to PM2.5 (U.S. EPA, 2010), and CARB relies on the same health studies for this evaluation. The evaluation method used in this analysis is the same as the one used for CARB's proposed Low Carbon Fuel Standard 2018 Amendments (CARB, 2018a), the Heavy-Duty Vehicle Inspection Program and Periodic Smoke Inspection Program (CARB, 2018b), and the Advanced Clean Trucks (ACT) Regulation (CARB, 2019d)

CARB staff analyzed the value associated with five health outcomes for the business as usual scenario, Proposed Amendments, and alternatives: cardiopulmonary mortality, hospitalizations for cardiovascular illness, hospitalizations for respiratory illness, emergency room visits for respiratory illness, and emergency room visits for asthma. These health outcomes were selected because U.S. EPA has identified these as having a causal or likely causal relationship with exposure to PM2.5.[13] The U.S. EPA examined other health endpoints such as cancer, reproductive and developmental effects, but determined there was only suggestive evidence for a relationship between these outcomes and PM2.5 exposure, and insufficient data to include these endpoints in the national health assessment analysis routinely performed by the U.S. EPA.

The U.S. EPA has also determined a causal relationship between non-mortality cardiovascular effects and short and long-term exposure to PM2.5, and a likely causal

[12] Small businesses are defined here to be California fleets within the trucking industry with three or fewer heavy-duty vehicles.

[13] In this document, we have quantified health benefits due to the reduction in secondary PM 2.5 expected from the Proposed Amendments. We expect the Proposed Amendments would also lead to additional, smaller health benefits due to ambient ozone reductions, but they are not quantified here.

relationship between non-mortality respiratory effects (including worsening asthma) and short and long-term PM2.5 exposure. These outcomes lead to hospitalizations and emergency room visits and are included in this analysis.

In general, health studies have shown that populations with low socioeconomic standings are more susceptible to health problems from exposure to air pollution. However, the models currently used by U.S. EPA and CARB do not have the granularity to account for this impact. The location and magnitude of projected emission reductions resulting from many of the Proposed Amendments are not known with sufficient accuracy to account for the socioeconomic impacts, and an attempt to do so would produce uncertainty ranges so large as to make conclusions difficult. CARB acknowledges this limitation.

Table III.1 shows the annually estimated statewide-avoided premature morality, hospitalization, and emergency room visits. The Proposed Amendments are expected to prevent nearly 3,900 deaths.

The Proposed Amendments may also decrease the occupational exposure of air pollution on California truck operators and other employees who work around truck traffic. However, CARB staff cannot quantify the potential effect of this occupational exposure due to lack of data on typical occupational exposure for these types of workers.

Table III.1. Annual Statewide Avoided Mortality and Morbidity Incidents Under the Proposed Heavy-Duty Omnibus Low NOx Regulation

Calendar Year	Cardiopulmonary Mortality	Hospitalizations for Cardiovascular Illness	Hospitalizations for Respiratory Illness	Emergency Room Visits	Total
2022	0	0	0	0	0
2023	0	0	0	0	0
2024	1	0	0	1	2
2025	7	1	1	3	12
2026	15	2	2	7	26
2027	25	3	4	12	44
2028	36	5	6	17	64
2029	48	7	8	23	86
2030	61	9	10	29	109
2031	73	11	13	35	132
2032	86	13	15	41	155
2033	98	15	18	47	178
2034	111	17	20	53	201
2035	124	19	23	59	225
2036	138	21	26	65	250
2037	151	24	28	70	273
2038	163	26	31	76	296
2039	175	28	33	81	317
2040	186	30	35	86	337
2041	197	31	37	91	356
2042	208	33	39	96	376
2043	218	35	41	100	394
2044	227	36	44	104	411
2045	237	38	46	108	429
2046	246	40	47	112	445
2047	254	41	49	116	460
2048	262	43	51	119	475
2049	270	44	53	123	490
2050	277	45	54	126	502
Total	**3894**	**616**	**735**	**1801**	**7046**

*Rounded to whole numbers

Statewide valuation of health benefits was calculated by multiplying the value per incident in Table III.2 by the statewide total number of incidents for 2022 through 2050 as shown in Table III.1. The estimated total statewide health benefits derived from criteria emission reductions is estimated to be $36.8 billion.

Table III.2. Statewide Valuation from Avoided Health Outcomes Under the Proposed Amendments

Outcome	Value Per Incident	Avoided Incidents	Total Valuation
Avoided Premature Mortality	$9,419,320	3,894	$36.7 billion
Avoided Cardiovascular Hospitalizations	$56,588	616	$34.9 million
Avoided Acute Respiratory Hospitalizations	$49,359	735	$36.3 million
Avoided Emergency Room Visits	$810	1,801	$1.46 million
Total		**7,046**	**$36.8 billion**

b. Monetary Benefits

As discussed above, three elements of the Proposed Amendments would provide cost-savings: the lengthened warranty, the EWIR amendments, and monetized health benefits.

Savings Benefits for Lengthened Warranty

Truck and bus purchasers would experience a savings benefit resulting from the additional repairs that are covered under a longer warranty period. Although CARB staff expects that the added costs associated with the longer warranty periods would ultimately be passed on to the consumers in the form of an increased purchase price for the trucks, some but not all, vehicle buyers would gradually recoup the initial increase in purchase price as they save money on repairs. For these vehicle buyers, the increased purchase price of the vehicle would be offset by savings benefits over time.

Additionally, some vehicle buyers commonly finance their vehicle purchase, and for the increased purchase price they would incur a corresponding increase in the transaction costs associated with financing. For these vehicle buyers, the increased transaction costs are not expected to be offset by the savings benefits. For simplicity, CARB staff assumes that the vehicle purchaser receives these repair cost savings in the sixth year of vehicle ownership (i.e. after the savings from the 5 year warranty under the Step 1 warranty[14] amendments have been realized). So, for example, a vehicle purchased in 2027 would have the savings occur in 2032. The statewide cost savings benefits are shown below in Table III.3.

[14] Step 1 warranty is effective beginning model year 2022.

Table III.3. Statewide Benefits from Lengthened Warranty (2018$)

Calendar Year	Year Savings Occurs	HHDD	MHDD	LHDD	HDO	Total
2027	2032	$0	$0	$0	$900,776	$900,776
2028	2033	$1,195,852	$6,990,817	$2,361,620	$918,834	$11,467,123
2029	2034	$1,223,267	$7,164,144	$2,405,233	$921,511	$11,714,155
2030	2035	$1,247,721	$7,243,949	$2,446,075	$914,997	$11,852,742
2031	2036	$1,266,523	$7,339,707	$2,478,138	$1,690,689	$12,775,056
2032	2037	$7,603,903	$18,813,415	$6,806,212	$1,695,886	$34,919,416
2033	2038	$7,811,766	$19,100,187	$6,952,137	$1,712,171	$35,576,261
2034	2039	$8,084,630	$19,726,513	$7,172,608	$1,728,710	$36,712,461
2035	2040	$8,232,277	$20,086,648	$7,320,115	$1,744,823	$37,383,863
2036	2041	$8,289,588	$20,177,301	$7,365,754	$1,773,682	$37,606,326
2037	2042	$8,344,570	$20,365,667	$7,417,033	$1,788,739	$37,916,009
2038	2043	$8,421,590	$20,417,890	$7,473,924	$1,804,120	$38,117,524
2039	2044	$8,498,661	$20,566,571	$7,528,858	$1,818,631	$38,412,722
2040	2045	$8,595,723	$20,639,071	$7,586,674	$1,832,882	$38,654,350
2041	2046	$8,655,223	$20,724,322	$7,644,716	$1,846,972	$38,871,233
2042	2047	$8,729,630	$20,881,832	$7,707,353	$1,860,753	$39,179,568
2043	2048	$8,808,035	$20,994,606	$7,767,379	$1,874,190	$39,444,210
2044	2049	$8,901,851	$21,163,328	$7,832,117	$1,887,244	$39,784,539
2045	2050	$8,983,662	$21,327,830	$7,894,576	$1,900,009	$40,106,077

Savings Benefits from Proposed EWIR and Corrective Action Amendments

The Proposed Amendments would require manufacturers to more expeditiously repair or replace parts that are identified as having systemic issues as identified via the EWIR program. This would result in a cost savings for vehicle purchasers because components that they previously had to pay for out-of-pocket would now be repaired or replaced under an extended warranty or recall. Savings for repairs that would be covered under the requirements of the Step 1 and Step 2 emissions warranty lengthening amendments were not included as savings in the EWIR amendments (i.e., since they were accounted for in the Step 1 and Step 2 warranty amendments). Therefore, savings attributed to the EWIR and corrective action amendments do not occur until the new lengthened warranty periods have ended. For the 2024 through 2026 model years, for example, the warranty period is 5 years, so savings related to the EWIR and corrective action amendments would start after the warranty period has ended. For model year 2027-2030, the proposed new warranty period would be 7 years, so savings related to the EWIR and corrective action amendments would be realized starting in the 8th year. For model year 2031 and later, the proposed new warranty period would be 10 years, so saving related to the EWIR and corrective action amendments would be realized starting in the 11th year.

Table III.4. Total EWIR and Corrective Action Savings (2018$)

Calendar Year	HHDD	MHDD	LHDD	HDO	Total
2022	$0	$0	$0	$0	$0
2023	$0	$0	$0	$0	$0
2024	$0	$0	$0	$0	$0
2025	$0	$0	$0	$0	$0
2026	$0	$0	$0	$0	$0
2027	$0	$0	$0	$0	$0
2028	$0	$0	$0	$0	$0
2029	$0	$0	$0	$501,295	$501,295
2030	$425,279	$0	$0	$502,875	$928,154
2031	$434,671	$0	$0	$509,144	$943,815
2032	$444,032	$0	$0	$0	$444,032
2033	$0	$0	$0	$0	$0
2034	$0	$0	$0	$398,037	$398,037
2035	$4,732,926	$6,113,069	$1,177	$406,016	$11,253,189
2036	$4,841,431	$6,264,633	$1,199	$407,199	$11,514,463
2037	$4,938,215	$6,334,418	$1,219	$404,321	$11,678,173
2038	$5,012,627	$6,418,153	$1,235	$0	$11,432,016
2039	$0	$0	$0	$0	$0
2040	$0	$0	$0	$0	$0
2041	$0	$0	$0	$418,470	$418,470
2042	$0	$0	$1,631,803	$419,756	$2,051,559
2043	$0	$0	$1,666,789	$423,787	$2,090,576
2044	$0	$0	$1,719,647	$427,881	$2,147,528
2045	$0	$0	$1,755,012	$431,869	$2,186,881
2046	$0	$0	$1,765,954	$439,012	$2,204,966
2047	$0	$0	$1,778,249	$442,738	$2,220,987
2048	$0	$0	$1,791,888	$446,546	$2,238,434
2049	$0	$0	$1,805,059	$450,137	$2,255,196
2050	$0	$0	$1,818,920	$453,665	$2,272,585

Overall Savings Benefits from the Proposed Amendments

Table III.5 below show total monetized statewide savings from the health benefits and the proposed warranty and EWIR requirements between 2022 through 2050 based on Tables III.1, III.2, III.3, and III.4.

Table III.5. Total Savings and Benefits of the Proposed Amendments

Calendar Year	Warranty	EWIR and Corrective Action	Health Benefits	Total Savings
2022	$0	$0	$0	$0
2023	$0	$0	$0	$0
2024	$0	$0	$9,848,838	$9,848,838
2025	$0	$0	$63,788,866	$63,788,866
2026	$0	$0	$144,286,091	$144,286,091
2027	$0	$0	$235,041,003	$235,041,003
2028	$0	$0	$340,317,900	$340,317,900
2029	$0	$501,295	$456,283,204	$456,784,499
2030	$0	$928,154	$572,969,971	$573,898,124
2031	$0	$943,815	$691,214,153	$692,157,968
2032	$900,776	$444,032	$808,352,378	$809,697,186
2033	$11,467,123	$0	$927,670,459	$939,137,583
2034	$11,714,155	$398,037	$1,050,496,579	$1,062,608,772
2035	$11,852,742	$11,253,189	$1,174,715,046	$1,197,820,977
2036	$12,775,056	$11,514,463	$1,299,855,636	$1,324,145,155
2037	$34,919,416	$11,678,173	$1,421,333,178	$1,467,930,768
2038	$35,576,261	$11,432,016	$1,539,835,217	$1,586,843,494
2039	$36,712,461	$0	$1,653,048,516	$1,689,760,977
2040	$37,383,863	$0	$1,759,753,218	$1,797,137,081
2041	$37,606,326	$418,470	$1,861,571,343	$1,899,596,138
2042	$37,916,009	$2,051,559	$1,958,802,445	$1,998,770,013
2043	$38,117,524	$2,090,576	$2,053,806,671	$2,094,014,771
2044	$38,412,722	$2,147,528	$2,146,768,395	$2,187,328,644
2045	$38,654,350	$2,186,881	$2,235,212,836	$2,276,054,068
2046	$38,871,233	$2,204,966	$2,319,434,246	$2,360,510,446
2047	$39,179,568	$2,220,987	$2,398,569,010	$2,439,969,565
2048	$39,444,210	$2,238,434	$2,473,926,015	$2,515,608,658
2049	$39,784,539	$2,255,196	$2,545,490,052	$2,587,529,788
2050	$40,106,077	$2,272,585	$2,611,277,626	$2,653,656,287
Total	$581,394,412	$69,180,356	$36,753,668,894	$37,404,243,661

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IV. FISCAL IMPACTS

i. Fiscal Impacts on Local Government

The proposed amendments are expected to have a fiscal impact on local government fleets who would purchase California-certified medium- and heavy-duty vehicles. Local government would also have increased sale tax revenue through the increased cost of the proposed regulation-certified vehicles.

a. Local Sales Taxes

Sales taxes are levied in California to fund a variety of programs at the state and local level. The Proposed Amendments would increase the cost of each new vehicle and engine sold in the state in 2024 and subsequent model years by about 0.5 to 10.4 percent. The Proposed Amendments would also require additional DEF fluid consumption in California which would result in a direct increase in sales tax revenue collected by local governments. The average local tax rate in California is 0.853 percent (CARB, 2019b). In addition, local governments also collect about 54 percent of the total sales tax revenue (i.e., approximately 4.7 percent out of 8.6 percent sales tax rate). Hence, the overall revenue to local governments would be 5.55 percent of all sales. The annual tax revenue to local governments from 2022 to 2050 is summarized in Table IV.1.

b. Local Government Fleet Costs

Local government fleets are estimated to own 10.7 percent of California's total heavy-duty vehicles using EMFAC and DMV registration data. The same proportion of the total costs outlined in B-1 are assumed to pass through to local government, for new government fleet purchases. So, for example, in calendar year 2025, local government fleets would face approximately $6.09 million of the total statewide cost of $56.9 million due to the Proposed Amendments.

c. Summary of Fiscal Impacts on Local Government

Table IV.1 shows the estimated fiscal impact to local governments due to the Proposed Amendments relative to baseline conditions. The net fiscal impact on local government in 2022 would be a cost of $11,000 and the ongoing fiscal impact on local government would range from $165,000 to $10.5 million in cost within the Proposed Amendments' lifetime of 29 years.

Table IV.1. Fiscal Impacts on Local Government (2018$)

Calendar Year	Local Government Fleet Costs	Local Tax Revenue*	Net Fiscal Impact
2022	$23,219	($11,989)	$11,230
2023	$926,173	($478,234)	$447,939
2024	$340,784	($175,997)	$164,786
2025	$6,092,773	($3,147,174)	$2,945,600
2026	$7,514,893	($3,881,758)	$3,633,135
2027	$6,153,479	($3,179,106)	$2,974,373
2028	$16,098,816	($8,318,724)	$7,780,091
2029	$16,638,429	($8,597,558)	$8,040,871
2030	$16,583,048	($8,570,491)	$8,012,557
2031	$15,574,323	($8,050,615)	$7,523,708
2032	$21,173,222	($10,946,753)	$10,226,468
2033	$21,754,001	($11,249,055)	$10,504,946
2034	$20,415,838	($10,560,903)	$9,854,935
2035	$20,557,680	($10,636,198)	$9,921,482
2036	$20,474,261	($10,594,952)	$9,879,309
2037	$20,426,961	($10,574,293)	$9,852,668
2038	$20,493,469	($10,612,553)	$9,880,917
2039	$20,461,146	($10,599,639)	$9,861,508
2040	$20,466,264	($10,604,203)	$9,862,061
2041	$20,449,519	($10,599,349)	$9,850,170
2042	$20,470,830	($10,614,221)	$9,856,609
2043	$20,658,271	($10,715,271)	$9,943,000
2044	$20,698,507	($10,740,011)	$9,958,497
2045	$20,835,196	($10,814,830)	$10,020,366
2046	$20,967,911	($10,883,717)	$10,084,193
2047	$21,054,551	($10,928,689)	$10,125,862
2048	$21,150,062	($10,978,266)	$10,171,796
2049	$21,232,526	($11,021,070)	$10,211,456
2050	$21,253,613	($11,032,015)	$10,221,597
Total	**$480,939,763**	**($249,117,634)**	**$231,822,130**

*Values presented in the table in parenthesis represent income.

Fiscal Impacts on State Government

The Proposed Amendments are expected to have a fiscal impact on state government agencies from purchasing California-certified vehicles, increased sales tax revenue, and CARB staffing (as explained further, below) required to coordinate and enforce the Proposed Amendments with engine manufacturers.

a. CARB Staffing and Resources

The Proposed Amendments implementation would create additional workload on CARB staff that would be impossible to absorb with existing staff resources. CARB staff estimated an addition of 10 positions (2 Air Pollution Specialists and 8 Air Resources Engineers) would be needed for the Proposed Amendments implementation:

Two Air Resources Engineers would be required starting in 2024 to review certification applications using new strategies and technologies, as well as manage and review the new standardized extended durability testing.

- Two additional Air Resources Engineers would be required starting in 2024 to coordinate test plans with manufacturers, implement new procedures, and verify submitted test data with the amended HDIUT program.

- Two additional Air Resources Engineers would be required starting in 2024 to handle the NOx sensor data submissions and certify the additional OBD certification requirements associated with the newer technologies expected in low NOx engines.

- Two Air Resources Engineers would be required starting 2024 for increased enforcement at dealerships due to the difference in emission standards compared to the federal program.

- Two Air Pollution Specialists would be required starting in 2027 to process anticipated increased EWIR claims and recall.

The summary of incremental CARB staff costs due to the Proposed Amendments is presented in Table IV.2.

b. State Sales Taxes

Sales taxes are levied in California to fund a variety of programs at the state and local level. The Proposed Amendments would result in the sale of more expensive (higher upfront cost) vehicles as well as increased DEF consumption in those trucks in California, which would result in higher sales taxes collected by the state government. The entire population of new California-sold vehicles and DEF consumption over the entire state were used for this analysis. State government collects about 46 percent of the total sales tax revenue (i.e., approximately 3.9 percent out of 8.6 percent sales tax rate) based on established precedent.

Although it is possible the Proposed Amendments could encourage California fleets to hold onto their existing vehicles slightly longer, to purchase used vehicles in lieu of new vehicles in California, or to purchase more out-of-state vehicles, in estimating the costs for the Proposed Amendments, CARB staff did not attempt to quantify any such changes in fleet purchase behavior and hence any state sales tax impacts of such changes in fleet purchase behavior are also not included.

A summary of annual state sales tax revenue from 2022 to 2050 is presented in Table IV.2.

c. State Fleet Costs

The state government fleet is estimated to make up 3.3 percent of California's fleet using data from EMFAC 2017 and DMV registration data. A proportionate amount of the total costs outlined above in Table I-1 are assumed to pass through to the state government. The state government fleet costs are presented in Table IV.2.

d. Summary of Fiscal Impacts on State Government

Table IV.2 shows the estimated fiscal impacts to the state government due to the Proposed Amendments relative to baseline conditions. The fiscal impact on state government in 2022 and 2023 would be $1,000 and $55,000 in revenue, respectively. Starting in 2024, state government would have annual net fiscal cost impact ranging from $561,000 to $1,496,000 within the considered regulations' period of analysis.

Table IV.2. Summary of Fiscal Impacts to State Government (2018$)

Calendar Year	CARB Staffing	State Government Fleet Costs	State Sales Tax Revenue	Net Fiscal Impact
2022	$0	$7,161	($8,550)	($1,389)
2023	$0	$285,642	($341,039)	($55,397)
2024	$1,512,000	$105,102	($125,485)	$1,491,617
2025	$1,504,000	$1,879,080	($2,243,507)	$1,139,572
2026	$1,504,000	$2,317,677	($2,767,166)	$1,054,511
2027	$1,864,000	$1,897,802	($2,265,860)	$1,495,941
2028	$1,862,000	$4,965,055	($5,927,975)	$899,080
2029	$1,862,000	$5,131,478	($6,126,674)	$866,804
2030	$1,862,000	$5,114,398	($6,106,281)	$870,117
2031	$1,862,000	$4,803,296	($5,734,844)	$930,452
2032	$1,862,000	$6,530,059	($7,796,495)	$595,564
2033	$1,862,000	$6,709,178	($8,010,352)	$560,826
2034	$1,862,000	$6,296,473	($7,517,608)	$640,866
2035	$1,862,000	$6,340,219	($7,569,837)	$632,382
2036	$1,862,000	$6,314,492	($7,539,120)	$637,371
2037	$1,862,000	$6,299,904	($7,521,703)	$640,200
2038	$1,862,000	$6,320,416	($7,546,193)	$636,222
2039	$1,862,000	$6,310,447	($7,534,291)	$638,156
2040	$1,862,000	$6,312,025	($7,536,176)	$637,850
2041	$1,862,000	$6,306,861	($7,530,010)	$638,851
2042	$1,862,000	$6,313,434	($7,537,857)	$637,577
2043	$1,862,000	$6,371,242	($7,606,877)	$626,365
2044	$1,862,000	$6,383,652	($7,621,693)	$623,958
2045	$1,862,000	$6,425,808	($7,672,025)	$615,783
2046	$1,862,000	$6,466,739	($7,720,894)	$607,845
2047	$1,862,000	$6,493,460	($7,752,797)	$602,662
2048	$1,862,000	$6,522,916	($7,787,967)	$596,950
2049	$1,862,000	$6,548,349	($7,818,332)	$592,017
2050	$1,862,000	$6,554,853	($7,826,097)	$590,756
Total	**$49,210,000**	**$148,327,216**	**($177,093,707)**	**$20,443,510**

* Values presented in the table in parenthesis represent income

V. ALTERNATIVES TO THE REGULATION

i. Alternative 1

Alternative 1 was proposed by the South Coast Air Quality Management District in their letter to CARB staff on May 24, 2019, titled “Comments for Staff White Paper – California Air Resources Board Staff Current Assessment of the Technical Feasibility of Lower NOx Standards and Associated Test Procedures for 2022 and Subsequent Model Year Medium-Duty and Heavy-Duty Diesel Engines.” (SCAQMD, 2019) Under this alternative, the all the elements contained in CARB staff’s Proposed Amendments would remain, but they would be implemented on an earlier timeline.

The revised NOx standards for the FTP, RMC, Clean Idle, and the LLC, as well as the PM standards and the initial implementation of new in-use procedures with the Moving Average Window (MAW), would be moved two years earlier than the Proposed Amendments (i.e., from 2024 to 2022 model year engines). In addition, the FTP, RMC, and LLC standards, as well as the in-use procedures proposed to take effect in 2027, would be implemented 3 years earlier, in 2024. A summary of the accelerated timeline for this alternative is provided in Table V.1. Alternative 1 would result in a quicker transition to the sale of low NOx engines in California and a faster achievement of emissions reductions.

Table V.1. Summary and Timeline of Alternative 1

	Standards, Test Procedures, and Elements	Units	Baseline (B)	Model Year 2022	Model Year 2024	Model Year 2027	Model Year 2031
1)	FTP/RMC-SET	g/bhp-hr NOx	0.20	0.050	0.020	0.02	0.02
2)	LLC	g/bhp-hr NOx	---	0.20	0.040	0.040	0.040
3)	Idling	g/hr NOx	30	10	5	5	5
4)	HDIUT						
	Method		Current NTE	Binned MAW	Binned MAW w/ Cold Start	Binned MAW w/ Cold Start	Binned MAW w/ Cold Start
	In-Use Threshold	g/bhp-hr NOx	0.45	1.5x Standards	1.5x Standards	1.5x Standards	1.5x Standards
5)	DDP		(35-50)% × UL	Baseline	100% UL aging	100% UL aging	100% UL aging
6)	UL (HHD/MHD/LHD/HDO)	10^3×miles	435/185/110/110*	Baseline	Baseline	600/270/190/155*	800/350/270/200*
7)	Warranty (HHD/MHD/LHD/HDO)	10^3×miles	350/150/110/50*	Baseline	Baseline	450/220/150/110*	600/280/210/160*
8)	EWIR	---	EWIR	Baseline	Modified EWIR	Modified EWIR	Modified EWIR

* Diesel Class 8; GVWR >33,000 lbs. / Diesel Class 6-7; 19,500 < GVWR ≤ 33,000 lbs. /Diesel Class 4-5; 14,000 lbs. < GVWR ≤ 19,500 lbs. / Heavy-Duty Otto (gasoline).

Note: Each row highlights the baseline and implementation conditions of each of the elements in the proposed amendments by year.
FTP/RMC = Current and proposed NOx standards certified under the heavy-duty transient Federal Test Procedure and the Ramped Modal Cycle of the supplemental emissions test.
LLC = Proposed NOx standards certified under the Low Load Cycle.
Idling = Current and proposed NOx standards certified under the supplemental idling test procedure.
HDIUT Method = Current and proposed Heavy-Duty In-Use Test Methods.
HDIUT In-Use Threshold = Current and proposed NOx standards using the HDIUT Methods.
DDP = Current and proposed modifications to the Durability Demonstration Program.
NTE= Not-to-Exceed
UL = Current and proposed useful life periods for heavy-duty diesel- and Otto-cycle engines/vehicles.
Warranty = Current and proposed warranty period for heavy-duty diesel- and Otto-cycle engines/vehicles.
EWIR = Current and proposed modifications to the Emissions Warranty Information and Reporting Program and Corrective Action Procedures.

a. Benefit:

Similar to the Proposed Amendments, under Alternative 1, truck and bus purchasers would realize savings due to the proposed warranty and EWIR and corrective action amendments, which were estimated at approximately $651 million from 2022 to 2050. There would also be health benefits under Alternative 1. The total monetized health benefits for the avoided mortality, hospitalization, and emergency room visits from 2020 to 2050 were estimated at $40.3 billion as presented in Table V.2. Hence, the total benefits under Alternative 1 were estimated to be approximately $41.0 billion.

Table V.2. Valuation of Statewide Health Benefits for Alternative 1

Outcome	Avoided Incidents	Valuation
Avoided Premature Mortality	4272	$40,242,961,056
Avoided Cardiovascular Hospitalizations	672	$38,018,250
Avoided Acute Respiratory Hospitalizations	802	$39,582,855
Avoided Emergency Room Visits	1980	$1,603,706
Total	7,726	**$40,322,165,867**

b. Cost:

The total cost of Alternative 1 was assessed using the same modeled baseline conditions used for the Proposed Amendments. The annual costs for the elements of Alternative 1 are presented in Table V.3. The overall cost of Alternative 1 was estimated to be approximately $4.74 billion over the 29 years of the analysis period, 2022 through 2050. Thus, the cost of this alternative was estimated to be $250 million more than the Proposed Amendments, a 5.56 percent increase in cost for the period of analysis.

Table V.3. Annual Summary of Costs Associated with Alternative 1

Calendar Year	Standards, Certification, and New Technology	Annual DEF Consumption	In-Use Amendments	Lengthened Warranty	Durability Demonstration	EWIR and Corrective Action Amendments	ABT	Total Costs
2022	$1,789,577	$4,377	$132,624	$0	$0	$0	$217,000	$2,143,577
2023	$43,649,446	$1,230,638	$56,957	$0	$8,612,420	$0	$43,400	$53,592,861
2024	$43,692,958	$2,432,885	$57,078	$0	$850,000	$328,320	$43,400	$47,404,642
2025	$90,786,372	$3,939,839	$59,481	$0	$140,810	$10,237,296	$43,400	$105,207,197
2026	$91,816,698	$5,469,792	$60,198	$0	$11,511,176	$10,336,778	$43,400	$119,238,042
2027	$80,045,679	$7,035,917	$61,678	$1,069,205	$869,431	$10,641,299	$43,400	$99,766,610
2028	$109,539,586	$8,622,186	$62,336	$13,611,269	$754,981	$21,017,003	$43,400	$153,650,761
2029	$111,797,840	$10,244,132	$63,714	$13,904,492	$1,137,957	$21,502,340	$43,400	$158,693,874
2030	$96,736,169	$11,892,921	$64,657	$14,068,992	$13,545,139	$21,825,015	$43,400	$158,176,292
2031	$96,282,989	$13,565,016	$65,544	$15,163,761	$1,707,090	$21,921,155	$43,400	$148,748,956
2032	$134,783,615	$15,280,264	$67,378	$41,448,718	$2,001,917	$7,445,446	$43,400	$201,070,738
2033	$137,481,896	$15,812,480	$68,759	$42,228,382	$2,041,017	$7,596,388	$43,400	$205,272,322
2034	$121,521,857	$16,427,830	$71,025	$43,577,031	$2,085,403	$7,841,967	$43,400	$191,568,513
2035	$121,265,142	$16,772,402	$72,362	$44,373,973	$2,131,965	$7,983,740	$43,400	$192,642,983
2036	$119,537,729	$17,105,293	$72,778	$44,638,032	$2,175,676	$8,035,462	$43,400	$191,608,370
2037	$118,057,423	$17,415,968	$73,351	$45,005,620	$2,211,745	$8,098,670	$43,400	$190,906,177
2038	$116,470,502	$19,300,350	$73,792	$45,244,815	$2,242,112	$8,152,780	$43,400	$191,527,752
2039	$115,117,319	$19,920,738	$74,373	$45,595,209	$2,262,263	$8,212,366	$43,400	$191,225,667
2040	$114,501,103	$20,226,153	$74,900	$45,882,018	$2,277,510	$8,268,410	$43,400	$191,273,494
2041	$113,726,998	$20,516,054	$75,347	$46,139,454	$2,292,944	$8,322,800	$43,400	$191,116,997
2042	$113,194,894	$20,797,440	$75,954	$46,505,442	$2,308,595	$8,390,443	$43,400	$191,316,168
2043	$112,594,172	$22,440,736	$76,498	$46,819,567	$2,324,872	$8,452,813	$43,400	$192,752,059
2044	$112,202,975	$23,028,468	$77,180	$47,223,532	$2,341,762	$8,526,676	$43,400	$193,443,993
2045	$112,437,873	$23,601,250	$77,817	$47,605,191	$2,359,323	$8,596,601	$43,400	$194,721,455
2046	$112,674,805	$24,142,753	$78,451	$47,977,842	$2,378,024	$8,666,507	$43,400	$195,961,781
2047	$112,834,056	$24,348,447	$79,048	$48,336,754	$2,396,662	$8,733,137	$43,400	$196,771,505
2048	$113,036,856	$24,554,099	$79,688	$48,730,929	$2,415,887	$8,803,268	$43,400	$197,664,128
2049	$113,193,816	$24,753,806	$80,268	$49,065,347	$2,434,502	$8,863,687	$43,400	$198,434,827
2050	$113,193,816	$24,936,098	$80,268	$49,065,347	$2,449,278	$8,863,687	$43,400	$198,631,895
Total	$2,993,964,163	$455,818,331	$2,113,504	$933,280,923	$82,260,462	$275,664,054	$1,432,200	$4,744,533,637

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c. Reason for Rejection

Although Alternative 1 would achieve greater NOx reductions sooner, however the accelerated timeline of Alternative 1 would not provide enough lead time for the development of the interim engines in 2022 and the low NOx engines in 2024. Without sufficient time for engine manufacturers to conduct research, development, and durability testing, products would likely not be able to meet the stringent criteria. Manufacturers have identified that five to six years of lead time would be required for full product development from proof of concept to production product. The Proposed Amendments would provide manufacturers with necessary lead time for engineering development for the changes required in 2024 (CARB, 2019a) and the more significant changes needed in 2027 (i.e., cylinder deactivation and light-off SCR). Because Alternative 1 did not provide the necessary lead time for engineering development and product feasibility, it was rejected.

Alternative 2

Alternative 2 is based on input received during an online workgroup meeting held in June 2019. Timothy French of Truck and Engine Manufacturers Association (EMA) submitted a nationwide program alternative (EMA, 2019) Under Alternative 2, engine manufacturers would volunteer to nationally certify to an FTP and RMC NOx standard that would be less stringent than the standard in the Proposed Amendments. Under Alternative 2, California would presumably benefit from cleaner California-certified engines and cleaner federally certified vehicles operating in California (federally certified heavy-duty vehicles are responsible for over half of the total vehicle miles traveled by heavy-duty vehicles in California).

Under Alternative 2, the national NOx emission standard would be 0.15 g/bhp-hr on the FTP and the RMC cycle, the in-use HDIUT threshold would be 0.22 g/bhp-hr, and the LLC standard would be 0.7 g/bhp-hr for 2024 to 2026 model year engines. EMA's proposal also claimed it would achieve an approximate 50 percent reduction in the real-world in-use NOx emissions for the 2027 and subsequent model years. CARB staff interpreted this statement to mean that the standards for the FTP, RMC, and in-use HDIUT threshold would be cut in half (compared to today's standards) for the 2027 and subsequent model year engines. A summary of Alternative 2 is presented in Table V.4.

Table V.4. Summary and Timeline of Alternative 2, EMA Alternative

	Standards, Test Procedures, and Elements	Units	Baseline (B)	Model Year 2024	Model Year 2027
1)	FTP/RMC-SET	g/bhp-hr NOx	0.20	0.15	0.10
2)	LLC	g/bhp-hr NOx	---	0.70	0.70
3)	Idling	g/hr NOx	30	Baseline	Baseline
4)	HDIUT				
	Method		Current NTE	EMA modified NTE	EMA modified NTE
	In-Use Threshold	g/bhp-hr NOx	0.45	0.22	0.22
5)	DDP		(35-50) % × UL	Baseline	Baseline
6)	UL (HHD/MHD/LHD/HDO)	10^3×miles	435/185/110/110*	Baseline	Baseline
7)	Warranty (HHD/MHD/LHD/HDO)	10^3×miles	350/150/110/50*	Baseline	Baseline
8)	EWIR	---	EWIR	Baseline	Baseline

* Diesel Class 8; GVWR >33,000 lbs. / Diesel Class 6-7; 19,500 < GVWR ≤ 33,000 lbs. /Diesel Class 4-5; 14,000 lbs. < GVWR ≤ 19,500 lbs. / Heavy-Duty Otto (gasoline).

Note: Each row highlights the baseline and implementation conditions of each of the elements in the proposed amendments by year.
FTP/RMC = Current and proposed NOx standards certified under the heavy-duty transient Federal Test Procedure and the Ramped Modal Cycle of the supplemental emissions test.
LLC = Proposed NOx standards certified under the Low Load Cycle.
Idling = NOx standards certified under the supplemental idling test procedure.
HDIUT Method = Current and proposed Heavy-Duty In-Use Test Methods.
HDIUT In-Use Threshold = Current and proposed NOx standards using the HDIUT Methods.
DDP = Durability Demonstration Program.
NTE= Not-to-Exceed
UL = Useful life periods for heavy-duty diesel- and Otto-cycle engines/vehicles.
Warranty = Warranty periods for heavy-duty diesel- and Otto-cycle engines/vehicles.
EWIR = Emissions Warranty Information and Reporting Program and Corrective Action Procedures

a. Benefits

Alternative 2 contains less stringent emission standards than the Proposed Amendments and would contain no revisions to today's existing warranty and useful life periods or the EWIR and corrective action programs. Alternative 2 is modeled to have about 7.8 percent less health benefits than the Proposed Amendments, and because it is not clear whether all, or indeed any engine manufacturers would follow through with utilizing this Alternative, these modeled benefits are arguably speculative. Alternative 2's total monetized health benefits for avoided mortality, hospitalization, and emergency room visits were estimated to be $33.9 billion as presented in Table V.5.

Table V.5. Valuation of Statewide Health Benefits for Alternative 2[15]

Outcome	Avoided Incidents	Valuation (Million 2018$)
Avoided Premature Mortality	3592	$33,832,142,243
Avoided Cardiovascular Hospitalizations	569	$32,194,723
Avoided Acute Respiratory Hospitalizations	679	$33,519,662
Avoided Emergency Room Visits	1660	$1,344,726
Total	6,500	$33,899,201,355

b. Cost:

The total costs of Alternative 2 were assessed using the same modeled baseline conditions used for the Proposed Amendments. The annual costs for the elements of Alternative 2 are presented in Table V.6. The overall cost of Alternative 2 is approximately $900 million over the 29 years of the analysis period, 2022 through 2050. Thus, the cost of this alternative was estimated to be $3.59 billion less than the Proposed Amendments, 80 percent decrease in cost for the period of analysis.

[15] Note that the Table assumes Alternative 2 could be fully enforced, which as discussed below, is doubtful because it involves engines certified and sold outside California.

Table V.6. Annual Summary of Costs Associated with Alternative 2

Calendar Year	Standards, Certification, and New Technology	Annual DEF Consumption	Total Costs
2022	$0	$0	$0
2023	$0	$0	$0
2024	$20,088	$1,545	$21,633
2025	$3,941,570	$420,143	$4,361,713
2026	$4,008,132	$845,130	$4,853,263
2027	$4,353,185	$1,281,636	$5,634,820
2028	$33,840,077	$2,162,896	$36,002,973
2029	$34,546,979	$3,063,977	$37,610,956
2030	$29,702,274	$3,979,971	$33,682,246
2031	$29,455,548	$4,908,913	$34,364,461
2032	$29,627,069	$5,864,260	$35,491,329
2033	$29,606,469	$6,841,192	$36,447,661
2034	$29,937,065	$7,849,423	$37,786,488
2035	$29,855,919	$8,459,450	$38,315,369
2036	$29,612,892	$9,069,376	$38,682,268
2037	$29,427,955	$9,675,538	$39,103,493
2038	$29,207,663	$9,844,221	$39,051,884
2039	$29,038,930	$10,001,759	$39,040,689
2040	$28,862,853	$10,153,279	$39,016,133
2041	$28,842,124	$10,298,525	$39,140,648
2042	$28,880,753	$10,426,204	$39,306,957
2043	$28,898,479	$10,540,653	$39,439,132
2044	$28,966,883	$10,632,570	$39,599,453
2045	$29,015,942	$10,715,051	$39,730,993
2046	$29,258,239	$10,800,873	$40,059,113
2047	$29,481,631	$10,887,552	$40,369,183
2048	$29,717,967	$10,975,872	$40,693,839
2049	$29,940,915	$11,064,447	$41,005,361
2050	$29,940,915	$11,144,126	$41,085,041
Total	**$697,988,516**	**$201,908,583**	**$899,897,099**

c. Reason for Rejection

From 2022 through 2050 calendar years, Alternative 2 would achieve about eight percent less emission benefits than the Proposed Amendments. Although Alternative 2 could be more cost-effective than the Proposed Amendments and would achieve nearly as much benefits, it was rejected for several reasons. First, Alternative 2 would achieve less reductions of NOx emissions than the Proposed Amendments. . Furthermore, CARB staff also believes there is an intrinsic advantage to the Proposed Amendments pushing manufacturers to deploy technically forcing, yet technically feasible, cost-effective technology with dramatically lower NOx emissions than today's truck engines as quickly as possible. The success of California's standards in 2024 and beyond will

set a model for U.S. EPA to follow and make it more likely that federally certified trucks of the future are lower-emitting. Accordingly, Alternative 2 was rejected.

However, CARB staff is cognizant of the potential advantages that nationally harmonized standards provide, including simplicity, efficiency, and cost savings. Hence, to encourage manufacturers to design and produce a harmonized set of 50-state engines and vehicles, the Proposed Amendments include a proposed optional 50-state-directed engine standard for manufacturers to voluntarily certify to the same standard nationally beginning in MY 2024, as discussed further in Section A.1.1.1.2 of Chapter III of the Staff Report. CARB staff is hopeful that many manufacturers will choose to use this option in the years that the CARB's Heavy-Duty Omnibus Regulation is in effect but before the U.S. EPA's Cleaner Truck Initiative has been adopted and implemented.

For the purposes of the primary cost estimates, CARB staff has taken a conservative approach and assumed that no manufacturer would choose the 50-state option. CARB staff believes this is the most likely outcome based on the following:

- CARB staff participated in extensive discussions and negotiations with individual manufacturers and EMA regarding a possible voluntary program for the 2024 to 2026 model years, and the strictest standard EMA would consider agreeing to were much less stringent than 0.10 g/bhp-hr.
- Trucks meeting a 0.10 g standard would cost more to make than trucks meeting today's 0.2 g standard (~$1,000/engine incremental cost) and manufacturers would need to pass this cost on to their customers. Since manufacturers that chose the option would have to make all engines nationally to the standard, they would likely be competing against competitors with cheaper trucks.
- Even though the per engine cost to comply with a 0.1 g/bhp-hr standard would be lower than meeting a 0.05 g/bhp-hr standard, the manufacturer would have to pay that per engine cost on many more engines (the national-directed population of medium- and heavy-duty engines is approximately 10 times the California-directed population). Hence, depending on a manufacturer's California sales vs. national sales, a manufacturer's compliance costs under the 50-state option would in many cases be many times higher than just complying with 0.2 g/bhp-hr standard nationally engines and a 0.05 g/bhp-hr standard in California.

Sensitivity Analysis for the Adoption of the Low NOx Optional 50 State Standards

As described above, the optional 50-state directed engine standards would provide manufacturers the flexibility to certify their 2024 through 2026 MY engines to a less stringent NOx standard, if they meet that standard for every engine family they produce nationwide. The optional less stringent FTP, RMC-SET, and LLC NOx standards would be at 0.10, 0.10, and 0.30 g/bhp-hr, respectively. Because the 50-state-directed standards are less stringent, it would be cheaper for manufacturers to comply with them on a per engine basis. Because it is unclear how many, if any, manufacturers would utilize the 50-state-directed option, the primary cost analysis described in the Staff

Report assumes no manufacturers participate in the 50-state-directed option.[16] This section provides a sensitivity analysis of the change in costs on a per engine basis, total cost, and the cost-effectiveness of the program if there were 50 percent or 100 percent utilization of the optional 50-state directed engine standards.

i. Technology Costs for a 50-State Directed Engine

Incremental Engine and Aftertreatment Technology Costs

For diesel engines, the incremental aftertreatment technology costs would be the same as for the primary standards in the Proposed Amendments. However, there would be zero incremental engine technology costs because EGR-cooler bypass technology would not be required to meet the 0.10 FTP and RMC-SET or 0.30 LLC NOx emission standards. A summary of diesel engine technology and cost estimates for the Optional 50-state directed engine standards is presented in Table V.7, which can be compared to the cost for the primary cost analysis shown in Table I.2 above. There would be no incremental costs associated with Otto cycle engines meeting the optional 50-state directed standards.

[16] Given that the Truck and Engine Manufacturers Association has stated that the 50-state-directed standards are not workable and that manufacturers would not certify to them, assuming no manufacturers participate in the primary emission benefit analysis seems prudent (EMA, 2020).

Table V.7. Summary of Technologies and Adjusted Incremental Costs (2018$) for Meeting the 2024 through 2026 Optional 50-state-directed Standards Based on NREL Survey

		6/7-Liter Diesel	12/13-Liter Diesel
Applicable MYs		**2024-2026**	**2024-2026**
Engine Technology[a]	EGR Cooler Bypass	na	Na
	Cylinder Deactivation	na	Na
	Other	na	Na
Aftertreatment Technology[a]	Light-off SCR	na	Na
	DOC (subtotal)	$10	$89
	DPF (2018 baseline system only)[b]	($17)	($44)
	SCR + ASC + DEF Dosing (subtotal)	$621	$784
	OBD sensors and controllers (NOx, Ammonia, temp sensors)	$333	$330
	Other*	$175	$150
Total Incremental Hardware Cost to Manufacturer		**$1,122**	**$1,309**
Incremental Research and Development Costs to Manufacturer[c]		**$85**	**$354**
Incremental Cost to Simultaneously Meet Phase 2 GHG Standards[d]		**$100**	**$501**
Total Incremental Cost		**$1,307**	**$2,164**

Note: ASC- Ammonia slip catalyst.

[a] Values are only shown for technologies applicable to that application.
[b] Values in parentheses represent savings compared to the baseline 2018 technology and costs.
[c] Note that the research and development costs in Table V.7 were estimated by NREL based on original equipment manufacturer shareholder reports and adjusted by CARB staff to fit the Proposed Amendments. They are intended to represent fixed research and development costs distributed on a per engine basis, based on the population of engines expected to be subject to the Proposed Amendments in the legal baseline.
[d] Incremental cost to meet Phase 2 GHG emission standards was derived using U.S. EPA's cost estimate for the federal Phase 2 GHG Regulation.

Similar to the primary standards' technology cost assessment, CARB staff applied a steep learning curve (U.S. EPA, 2016), as used in previous U.S. EPA analyses, to the costs associated with the new engine and aftertreatment system technologies needed to comply with the optional less stringent standards to reflect improvements and cost reductions in the manufacturing processes over time. Table V.8 summarizes the total incremental cost of engine and aftertreatment system technologies as well as research and development, for each engine type once the learning curve effects were applied, from 2022 to 2050 MY engines. Note that starting with 2027 MY engines, this optional 50-state directed engine standards would be no longer available and engine manufacturers would be required to certify their CA engines with the more stringent primary standards, hence the incremental technology costs for 2027 and subsequent MY engines would be the same as the primary standards in the Proposed Amendments.

Table V.8. Total Incremental Costs of Engine Technologies, Aftertreatment System Technologies, and Research and Development Based on Engine Size and Fuel Type to Meet the Proposed Heavy-Duty Low NOx FTP, RMC-SET, LLC, and Idle Standards for MY 2022 through 2050 Engines (2018$ per engine)

MY Engine	6/7-liter Diesel	12/13-liter Diesel	6/7-liter Gasoline
2022	$0	$0	$0
2023	$0	$0	$0
2024	$1,307	$2,164	$0
2025	$1,307	$2,164	$0
2026	$1,114	$1,923	$0
2027	$3,912	$5,173	$411
2028	$3,912	$5,173	$411
2029	$3,306	$4,438	$411
2030	$3,233	$4,349	$411
2031	$4,350	$6,159	$411
2032	$4,350	$6,159	$411
2033	$3,681	$5,326	$411
2034	$3,601	$5,226	$411
2035	$3,524	$5,129	$411
2036	$3,448	$5,035	$411
2037	$3,375	$4,944	$411
2038	$3,304	$4,855	$411
2039	$3,258	$4,798	$411
2040	$3,213	$4,742	$411
2041	$3,169	$4,687	$411
2042	$3,126	$4,633	$411
2043	$3,083	$4,580	$411
2044	$3,063	$4,554	$411
2045	$3,042	$4,528	$411
2046	$3,022	$4,503	$411
2047	$3,002	$4,478	$411
2048	$2,982	$4,453	$411
2049	$2,982	$4,453	$411
2050	$2,982	$4,453	$411

DEF Consumption Costs

Because the Proposed Amendments would require SCR systems to operate during more of vehicles' actual operating hours than today's engines, for example, even during low load conditions, the optional 50-state directed standards would likely require the consumption of more DEF. Because the 50-state-directed standards would be less stringent than the MY 2024-2026 standard in the Proposed Amendments, this increased DEF consumption would be less than for the Proposed Amendments, as summarized in Table V.9.

Table V.9. Incremental Annual DEF Consumption Costs by Engine Class (2018$ per engine)

Engine Class	Proposed Amendments Primary Cost Analysis: MY 2024-2026	Optional 50-State-Directed: MY 2024-2026
HHDD	$89.84	$59.89
MHDD	$36.97	$24.65
LHDD	$36.63	$24.42
MDDE-3	$19.61	$13.07
MDOE-3	$0.00	$0.00
HDO	$0.00	$0.00

ii. Sensitive Cost Analysis for Utilization of the Optional 50-State Directed Standards

The total statewide costs associated with the Proposed Amendments assuming 100 percent of manufacturers use the optional 50-state-directed option are shown in Table V.10 below.

Table V.101. Proposed Amendments Estimated Incremental Increase in Costs for the Statewide Fleet if All Manufacturers Use Optional 50-State-Directed Standards

Calendar Year	Standards, Certification, and New Technology	In-Use Amendments	Lengthened Warranty	Durability Demonstration	EWIR and Corrective Action Amendments	ABT	Total Costs on Manufacturers	Annual DEF Consumption	Total Costs Passed to Vehicle Buyers
2022	$0	$0	$0	$0	$0	$217,000	**$217,000**	$0	**$217,000**
2023	$0	$0	$0	$8,612,420	$0	$43,400	**$8,655,820**	$0	**$8,655,820**
2024	$308,888	$132,657	$0	$850,000	$328,320	$43,400	**$1,663,265**	$3,090	**$1,666,355**
2025	$37,473,221	$59,481	$0	$140,810	$10,237,296	$43,400	**$47,954,207**	$840,286	**$48,794,493**
2026	$37,943,922	$60,198	$0	$11,511,176	$10,336,778	$43,400	**$59,895,474**	$1,690,260	**$61,585,734**
2027	$35,831,125	$61,678	$1,069,205	$869,431	$10,641,299	$43,400	**$48,516,138**	$2,562,683	**$51,078,822**
2028	$109,539,586	$62,336	$13,611,269	$754,981	$21,017,003	$43,400	**$145,028,575**	$4,148,952	**$149,177,527**
2029	$111,797,840	$63,714	$13,904,492	$1,137,957	$21,502,340	$43,400	**$148,449,742**	$5,770,898	**$154,220,640**
2030	$96,736,169	$64,657	$14,068,992	$13,545,139	$21,825,015	$43,400	**$146,283,371**	$7,419,687	**$153,703,058**
2031	$96,282,989	$65,544	$15,163,761	$1,707,090	$21,921,155	$43,400	**$135,183,940**	$9,091,782	**$144,275,722**
2032	$134,783,615	$67,378	$41,448,718	$2,001,917	$7,445,446	$43,400	**$185,790,474**	$10,811,407	**$196,601,881**
2033	$137,481,896	$68,759	$42,228,382	$2,041,017	$7,596,388	$43,400	**$189,459,842**	$12,569,884	**$202,029,726**
2034	$121,521,857	$71,025	$43,577,031	$2,085,403	$7,841,967	$43,400	**$175,140,684**	$14,384,391	**$189,525,074**
2035	$121,265,142	$72,362	$44,373,973	$2,131,965	$7,983,740	$43,400	**$175,870,582**	$15,398,720	**$191,269,302**
2036	$119,537,729	$72,778	$44,638,032	$2,175,676	$8,035,462	$43,400	**$174,503,078**	$16,411,590	**$190,914,668**
2037	$118,057,423	$73,351	$45,005,620	$2,211,745	$8,098,670	$43,400	**$173,490,209**	$17,415,968	**$190,906,177**
2038	$116,470,502	$73,792	$45,244,815	$2,242,112	$8,152,780	$43,400	**$172,227,402**	$19,300,350	**$191,527,752**
2039	$115,117,319	$74,373	$45,595,209	$2,262,263	$8,212,366	$43,400	**$171,304,929**	$19,920,738	**$191,225,667**
2040	$114,501,103	$74,900	$45,882,018	$2,277,510	$8,268,410	$43,400	**$171,047,341**	$20,226,153	**$191,273,494**
2041	$113,726,998	$75,347	$46,139,454	$2,292,944	$8,322,800	$43,400	**$170,600,943**	$20,516,054	**$191,116,997**
2042	$113,194,894	$75,954	$46,505,442	$2,308,595	$8,390,443	$43,400	**$170,518,728**	$20,797,440	**$191,316,168**
2043	$112,594,172	$76,498	$46,819,567	$2,324,872	$8,452,813	$43,400	**$170,311,322**	$22,756,630	**$193,067,953**
2044	$112,202,975	$77,180	$47,223,532	$2,341,762	$8,526,676	$43,400	**$170,415,525**	$23,028,468	**$193,443,993**
2045	$112,437,873	$77,817	$47,605,191	$2,359,323	$8,596,601	$43,400	**$171,120,205**	$23,601,250	**$194,721,455**
2046	$112,674,805	$78,451	$47,977,842	$2,378,024	$8,666,507	$43,400	**$171,819,028**	$24,142,753	**$195,961,781**
2047	$112,834,056	$79,048	$48,336,754	$2,396,662	$8,733,137	$43,400	**$172,423,058**	$24,348,447	**$196,771,505**
2048	$113,036,856	$79,688	$48,730,929	$2,415,887	$8,803,268	$43,400	**$173,110,029**	$24,554,099	**$197,664,128**
2049	$113,193,816	$80,268	$49,065,347	$2,434,502	$8,863,687	$43,400	**$173,681,021**	$24,753,806	**$198,434,827**
2050	$113,193,816	$80,268	$49,065,347	$2,449,278	$8,863,687	$43,400	**$173,695,797**	$24,936,098	**$198,631,895**
Total	**$2,753,740,588**	**$1,999,501**	**$933,280,923**	**$82,260,462**	**$275,664,054**	**$1,432,200**	**$4,048,377,728**	**$411,401,885**	**$4,459,779,614**

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The cost and cost-effectiveness of the Proposed Amendments with 0, 50 and 100 percent utilization of the optional 50-state-directed standards are presented in Table V.11 below. As shown in Table V.11, because the program costs are dominated by the cost in meeting the 2027 standards, the utilization of the 50-state-directed standards makes a relatively small difference in overall cost of the Proposed Amendments. A 50 percent utilization of the optional standards would decrease the total costs from 2022 through 2050 calendar years by only $17 million dollars when compared to the primary standards in the Proposed Amendments, while full utilization of the optional standards would decrease the total costs from 2022 through 2050 calendar years by $35 million. Because the 50-state-directed standards would increase emission benefits while at the same time reducing cost, their impact on cost-effectiveness is greater, reducing overall cost-effectiveness from $5.45/lb to $4.95/lb, which is 9 percent more cost-effective, if all manufacturers used the 50-state-directed standards.

Table V.11. Summary of Cost-Effectiveness for the Proposed Amendments with Various Levels of Utlilization of the 50-State-Directed Option

Percent of Manufacturers Using 50-State-Directed Option	Total Cost of Regulation	Total Savings of the Regulation	Total NOx Benefits [Tons]	Cost-Effectiveness $/Ton	Cost-Effectiveness $/lb
Proposed Amendments (0% of Mfrs)	$4,494,764,136	$650,574,767	352,797	$10,896	$5.45
(50% of Mfrs)	$4,477,271,875	$650,574,767	368,841	$10,375	$5.19
(100% of Mfrs)	$4,459,779,614	$650,574,767	384,886	$9,897	$4.95

The actual cost impact on fleets would depend on the number of new California-certified heavy-duty vehicles that fleets would purchase during the lifetime of this cost analysis. A lifetime analysis including initial purchase price increase, lifetime DEF consumption, lifetime savings from warranty and EWIR amendments, net lifetime cost impact, and percent increase in lifetime cost from the assumed purchase price is presented in Table V.12 for vehicle purchases with 2024 through 2026 MY engines utilizing the optional 50-state directed standards for each vehicle class, can be compared to Table II.5 in the previous section for the primary cost analysis, which shows a 2.6 percent increase in purchase price for 2024 to 2026 MY engines.

Table V.12. Lifetime Analysis for Vehicles with 2024 to 2026 MY Engines with the Optional 50-state directed standards

	Increase in Purchase Price	Lifetime DEF Cost	Lifetime Savings	Lifetime Net Impact	Assumed Baseline Purchase Price	Net Costs as % of Purchase Price
HHDD	$3,459	$599	$60	$3,998	$169,637	2.4%
MHDD	$2,226	$246	$0	$2,472	$103,165	2.4%
LHDD	$1,444	$244	$0	$1,688	$57,694	2.9%
HDO	$96	$0.00	$143	-$48	$94,089	-0.1%
MDDE-3	$1,311	$131	$0	$1,442	$52,040	2.8%
MDOE-3	$2	$0	$0	$2	$44,459	0.0%
Population Average	$2,075	$303	$34	$2,345	$107,782	2.20%

VI. Cost-Effectiveness

One metric that can be used to quantify cost-effectiveness of the Proposed Amendments and alternatives is the ratio of total monetized benefits divided by total monetized costs. A comparison of this type is an appropriate cost-effectiveness measure if the harm associated with increased emissions is fully captured in the estimates of monetized benefits. A benefit-cost ratio greater than one implies that the Proposed Amendments' benefits are higher than their costs. Benefits include both health benefits and cost savings after subtracting tax impacts to State and Local Governments. A summary of the calculated benefit-cost ratio is presented in Table VI.1 for the Proposed Amendments, Alternative 1, and Alternative 2. As shown in Table VI.1, the benefit-cost ratio of the Proposed Amendments is over eight, indicating the benefits greatly outweigh the costs.

CARB staff also calculated the program's cost-effectiveness as a function of the program's net cost[17] per pound NOx reduction. The calculations for costs and benefits were conducted for the 29 years of the proposed regulation between 2022 and 2050. The total statewide cost for the Proposed Amendments, Alternative 1, and Alternative 2 were estimated to be $4.49, $4.74, and $0.900 billion, respectively. The EMFAC 2017 model estimated the total statewide NOx benefits for the Proposed Amendments, Alternative 1, and Alternative 2 to be 353,000, 390,000, and 325,000 tons of NOx reduced, respectively. Cost-effectiveness is defined to be the cost per unit of NOx reductions. Thus, the cost-effectiveness of the Proposed Amendments, Alternative 1, and Alternative 2 was estimated to be $5.45, $5.26, and $1.38 per pound NOx reduction, respectively. A summary of cost, savings, NOx benefits, and cost-effectiveness are presented in Table VI-1.

[17] Net cost was calculated by subtracting the total saving from the total cost

Table VI.1. Cost, NOx Benefits, and Cost Effectiveness of the Proposed Amendments, Alternative 1, and Alternative 2

	Total Cost	Total Saving	Monetized Health Benefit	Tax Revenue	Total NOx Benefits [Tons]	Cost-Effectiveness (Benefit-Cost Ratio)	Cost-Effectiveness [$/lbs]
Primary	$4,494,764,136	$650,574,767	$36,753,668,894	$426,211,341	352,797	8.23	$5.45
Alternative 1	$4,744,533,637	$650,574,767	$40,322,165,867	$449,856,752	389,127	8.54	$5.26
Alternative 2	$899,897,099	$0	$33,899,201,355	$85,334,769	324,922	37.6	$1.38