Appendix F
Emissions Inventory Methods and Results for the Proposed Advanced Clean Trucks Regulation

I. OVERVIEW

This appendix presents the methodology and results of the emissions inventory analysis. Staff used the latest available data on population, activity and in-use emissions for vehicles operating in California to estimate BAU baseline emissions and to assess the impacts of the Proposed ACT Regulation on both criteria (NO_X and $PM_{2.5}$) and greenhouse gas (GHG) emissions. Staff produced BAU baseline and Proposed ACT Regulation scenario emissions inventories by running the EMFAC2017 model v1.0.2[1] to estimate tank-to-wheel (TTW) emissions. Staff developed well-to-tank (WTT) GHG emissions[2] that relied heavily upon established, publicly available data from Low Carbon Fuel Standard (LCFS) regulation and CA GREET 3.0.

II. EMISSIONS INVENTORY METHODS

An emissions inventory (for any source category) can be calculated as the product of a pollutant emissions rate per some unit of source activity, and a measure of that source's activity. Staff employed methods and data incorporated into EMFAC2017[3] to estimate both BAU baseline (i.e., without the proposed rule) and the regulatory scenario (with the proposed rule) emissions inventories. EMFAC2017 provides activity and emissions for on-road vehicles that operate within California.

While EMFAC2017 provided methods and data for TTW emissions, WTT GHG emissions represent the upstream emission differences between reduced use of conventional fuel and increased generation of electricity and hydrogen due to the Proposed ACT Regulation. The conventional fuel types under the BAU baseline include diesel, gasoline, and natural gas. The well-to-wheel emissions (WTW) are the combination of TTW emissions and WTT emissions associated with producing and delivering the fuel to the vehicles.

A. Vehicle Population and Vehicle Miles Travelled

Using population and activity data from EMFAC2017, staff constructed an emissions inventory for medium- and heavy-duty trucks and buses operating in California.

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[1] California Air Resources Board (CARB) (2018). Mobile Source Emissions Inventory, EMFAC2017 v1.0.2. Available: https://www.arb.ca.gov/msei/msei.htm.

[2] California Air Resources Board (CARB) (2019). VISION Well-to-Tank (WTT) Emission Factor Tool.

[3] California Air Resources Board (CARB) (2018). EMFAC2017 Volume III – Technical Documentation v.1.0.2, July 20, 2018. Available: https://www.arb.ca.gov/msei/downloads/emfac2017-volume-iii-technical-documentation.pdf.

EMFAC2017 inventory is based on a 2016 base year with future years forecasted for population and VMT. More details on the population and emissions estimates for heavy-duty vehicles can be found in the EMFAC2017 technical support documentation.[4]

The Proposed ACT Regulation gradually increases the percentage of ZEVs required to be sold in California starting with 2024 MY vehicles. The proposed rule applies different sales requirement fractions three vehicle groups: Class 2b-3, Class 4-8, and Class 7-8 Tractors. The Class 2b-3 vehicle inventory is comprised of two EMFAC vehicle categories: LHDT1 (light heavy-duty trucks with GVWR 8,501-10,000 lbs.) and LHDT2 (light heavy-duty trucks with GVWR 10.001-14,000 lbs.). The Class 4-8 vocational vehicles included instate buses, instate non-tractor Class 7 and 8 heavy trucks (>26,000 lbs.), and instate Class 4 – 6 trucks (14,001-26,000 lbs.). The truck inventory was adjusted to exclude public vehicles already required to be purchased under AB 739. The bus inventory was adjusted to account for light duty vehicles that are included in this EMFAC vehicle category and to exclude transit and shuttle buses, which already have to meet the Innovative Clean Transit (ICT) [5] or Zero-Emission Airport Shuttle Bus (ASB)[6] regulations. Instate vehicles include vehicles that are registered by International Registration Plan (IRP) as well as California Department of Motor Vehicles (DMV).

The ACT requirements only apply to vehicles that are originally sold in California (i.e., *First Sold in CA*). To estimate the portion of new vehicle sales specific to California, staff reviewed the *First Sold* data field values in the California DMV data from 2014 through 2017. The *First Sold* data field identifies a calendar year for vehicles first sold in California. The International Registration Program vehicles are not required to have this field populated in the DMV data sets and they were excluded from this analysis. The average percentages of vehicles first sold in California from DMV data between 2014-2017 by vehicle type were used to develop trends to estimate future new sales. The estimated first sold percentages as shown in Table 1 were then applied to the total new sales forecasted by EMFAC2017. For instate buses and vehicles below 14,001 lbs. GVWR, it was assumed that the rate of first sold in California is 100 percent.

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[4] California Air Resources Board (CARB) (2018). EMFAC2017 Volume III – Technical Documentation, Section 3.2.3.1. March 1, 2018. Available: https://www.arb.ca.gov/msei/downloads/emfac2017-volume-iii-technical-documentation.pdf.

[5] California Air Resources Board, Innovative Clean Transit (web link: https://ww2.arb.ca.gov/our-work/programs/innovative-clean-transit, Last accessed June, 2019)

[6] California Air Resources Board, Zero-Emission Airport Shuttle (web link: https://ww2.arb.ca.gov/our-work/programs/zero-emission-airport-shuttle, Last accessed June, 2019)

Table 1: Average Percentages for First Sold in California by Vehicle Type

Age	Class 4-6 Vocational	Class 7 Vocational	Class 8 Vocational	Class 7 Tractor	Class 8 Tractor
-1 or 0	90.97%	85.01%	89.78%	84.31%	89.00%
1	88.38%	80.35%	85.80%	82.10%	86.61%
2	85.68%	76.22%	81.86%	76.91%	79.17%
3	83.07%	72.74%	78.34%	69.92%	68.61%
4	80.74%	70.02%	75.59%	62.30%	56.87%
5	78.90%	68.18%	74.00%	55.25%	45.87%
6	77.76%	67.35%	73.92%	49.92%	37.55%
7	77.50%	67.35%	73.92%	47.51%	33.85%
8	77.50%	67.35%	73.92%	47.51%	33.85%
9+	77.50%	67.35%	73.92%	47.51%	33.85%

Similarly, the DMV *Body Type Model* data field identifies tractors and this field is used to differentiate between tractor and vocational vehicles. The average percentage of tractors between 2014-2017 by vehicle type and age were used to develop trends to split out tractors and non-tractor portions of the truck population. These tractor percentages are displayed in Table 2.

The ZEV vehicle percentages required by the proposed ACT regulation were further adjusted to remove the impact of previous heavy-duty vehicle rules. The California Greenhouse Gas Emissions Standards for Medium- and Heavy-duty Engines and Vehicles, and the Amendments to the Tractor-Trailer GHG Regulation (CA Phase 2 GHG) were adopted by the Board in February 2018.[7] The ICT regulation and ASB regulation were adopted by the Board in December 2018 and June 2019; therefore, transit buses, cutaways, double-decker buses, 60-foot articulated buses, and motor coach buses are excluded from ACT annual sales requirement since those vehicles are subject to other regulations such as ICT and ASB.

Table 2: Average Percentages for Tractors in California by Vehicle Type (excluding buses)

Age	Class 7	Class 8
-1 or 0	32.94%	77.70%
1	33.48%	76.57%

[7] California Air Resources Board, Staff Report: Initial Statement of Reasons for Proposed Rulemaking Proposed California Greenhouse Gas Emission Standards for Medium- and Heavy-Duty Engines and Vehicles and Proposed Amendments to the Tractor-Trailer GHG Regulation, December 19, 2017 (web link: https://www.arb.ca.gov/regact/2018/phase2/isor.pdf, last accessed June 2019).

Age	Class 7	Class 8
2	33.86%	75.35%
3	34.09%	74.05%
4	34.17%	72.67%
5	34.11%	71.22%
6	33.93%	69.71%
7	33.62%	68.14%
8	33.20%	66.51%
9	32.67%	64.83%
10	32.03%	63.10%
11	31.31%	61.33%
12	30.50%	59.53%
13	29.61%	57.69%
14	28.64%	55.83%
15	27.62%	53.95%
16	26.54%	52.05%
17	25.41%	50.14%
18	24.23%	48.22%
19	23.02%	46.30%
20	21.79%	44.38%
21	20.53%	42.47%
22	19.27%	40.58%
23	18.00%	38.70%
24	16.73%	36.85%
25	15.47%	35.02%
26	14.22%	33.22%
27	13.00%	31.47%
28	11.82%	29.75%
29	10.67%	28.08%
30	9.57%	26.47%
31	8.52%	24.91%
32	7.53%	23.41%
33	6.61%	21.98%
34	5.77%	20.63%
35	5.01%	19.35%
36	4.34%	18.15%
37	3.77%	17.04%
38	3.31%	16.02%
39	2.96%	15.09%
40	2.72%	14.27%
41	2.62%	13.55%
42	2.65%	12.95%
43	2.65%	12.46%
44	2.65%	12.09%

B. Emissions Rates

EMFAC2017 included the latest emissions and deterioration rate updates as detailed further in the EMFAC2017 technical support documentation.[4] A 50 percent reduction of $PM_{2.5}$ brake wear emissions[8] was applied to ZEVs because of regenerative braking[9] capability. Tire wear emissions were not included in this analysis. TTW GHG emissions were converted from EMFAC2017 CO_2 tons to CO_2e million metric tons (MMT).[10]

WTT emission factors were provided in a fuel based unit, which is CO_2e emissions per million British Thermal Units (MMBTU). WTT emission factors for gasoline and diesel fuels are based on LCFS scenario assumptions, which rely on sales of ethanol, biodiesel, and renewable diesel volume under LCFS, as well as consideration of increasing volumes of low-carbon ethanol in gasoline through 2030. Emission factors for power generation are calculated based on California's power generation mix under SB 100 renewable requirements (a 60 percent renewable portfolio standard by 2030 with zero-carbon power plants in 2045). The amount of renewable hydrogen produced for fuel cell electric vehicles (FCEVs) is consistent with SB 1505 requirements and the data is from currently-funded California hydrogen stations. These assumptions consider the unique conditions in California and show that driving electric medium and heavy-duty vehicles produce significantly lower emissions than their conventional counterparts do. In order to calculate and separate the benefits that occur within and outside of California, two sets of WTT emission factors were provided, one for AB 32 boundary and another for LCFS boundary. AB32 boundary covers GHG emissions associated with activities occurring within California territory and GHG emissions from power generation imported to California. LCFS boundary considers GHG emissions for the entire life cycle of fuels regardless where emission activities occur. The upstream (WTT)

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[8] California Air Resources Board (CARB) (2018). Proposed Fiscal Year 2018-19 Funding Plan for Clean Transportation Incentives For Low Carbon Transportation Investments and the Air Quality Improvement Program, Page A-8. Release date: September 21, 2018. Available at: https://www.arb.ca.gov/msprog/aqip/fundplan/proposed_1819_funding_plan.pdf?_ga=2.78221207.2207588831.1559317089-1632999103.1458687259.

[9] National Renewable Energy Laboratory (NREL) (2008). BAE/Orion Hybrid Electric Buses at New York City Transit: A Generational Comparison. Revised March, 2008. Available: https://afdc.energy.gov/files/pdfs/42217.pdf.

[10] California Air Resources Board (CARB) (2018). EMFAC2017 Volume III – Technical Documentation, Page 32. March 1, 2018. Available: https://www.arb.ca.gov/msei/downloads/emfac2017-volume-iii-technical-documentation.pdf.

activities includes feedstock processing/transport, fuel production, and fuel product transport/distribution.

Combining WTT emission rates with the EMFAC2017's fuel usage outputs, staff calculated the corresponding GHG emissions. EMFAC2017 does not estimate energy or fuel consumptions for ZEVs. The conventional fuel consumption difference under the BAU baseline and with the proposed ACT regulation is caused by the replacement of conventional vehicles having internal combustion engines with ZEVs. It is assumed that the total VMT of both scenarios are the same. However, ZEVs generally have higher fuel efficiency than conventional vehicles and the VMT driven by ZEVs require less energy. The conventional fuel consumption difference between two scenarios were converted to electricity or hydrogen use for ZEVs by incorporating Energy Economy Ratios (EERs)[11].

The impacts of the proposed ACT regulation on criteria and GHG emissions were estimated for a Baseline scenario and a Proposed Rule scenario. Table 3 provides a summary of the ZEV sales requirements for new vehicle sales in California. For the Proposed Rule scenario, it was assumed that 10% of the ZEVs sold as Class 7 and 8 Tractors in California would be fuel cell electric vehicles (FCEVs) and all the remaining ZEVs sold would be battery electric vehicles (BEVs).

(1) **Baseline** scenario represents the existing forecasted emissions inventory without the proposed ACT rule.
(2) **Proposed Rule** scenario represents the proposed ACT regulation, which requires an increasing percentage of new vehicle sales in California to be ZEVs beginning with model year 2024.

Table 3: ZEV Sales Requirements Under the Proposed ACT Regulation

Model Year	Class 2b-3*	Class 4-8**	Class 7-8 Tractors
2024	3%	7%	3%
2025	5%	9%	5%
2026	7%	11%	7%
2027	9%	13%	9%
2028	11%	24%	11%
2029	13%	37%	13%
2030+	15%	50%	15%

* Excludes pickups until MY2027
**Excludes Class 7-8 Tractors

[11] California Air Resources Board (CARB) (2015). Low Carbon Fuel Standard Regulation, Table 4. Available: https://www.arb.ca.gov/regact/2015/lcfs2015/lcfsfinalregorder.pdf.

III. RESULTS

A. Vehicle Population and VMT

Figures 1 through 4 show the forecasted vehicle population. It shows that the proposed ACT regulation could result in more than 232,000 zero emission vehicles operating on California roadways by 2040. Figure 5 shows the forecasted VMT using methods described in Section II.A. As seen in the figure, a significant portion of the VMT for vehicles operating in California come from vehicles that are not first sold in California.

Figure 1: Projected Vehicle Population – Class 2b-3 Group

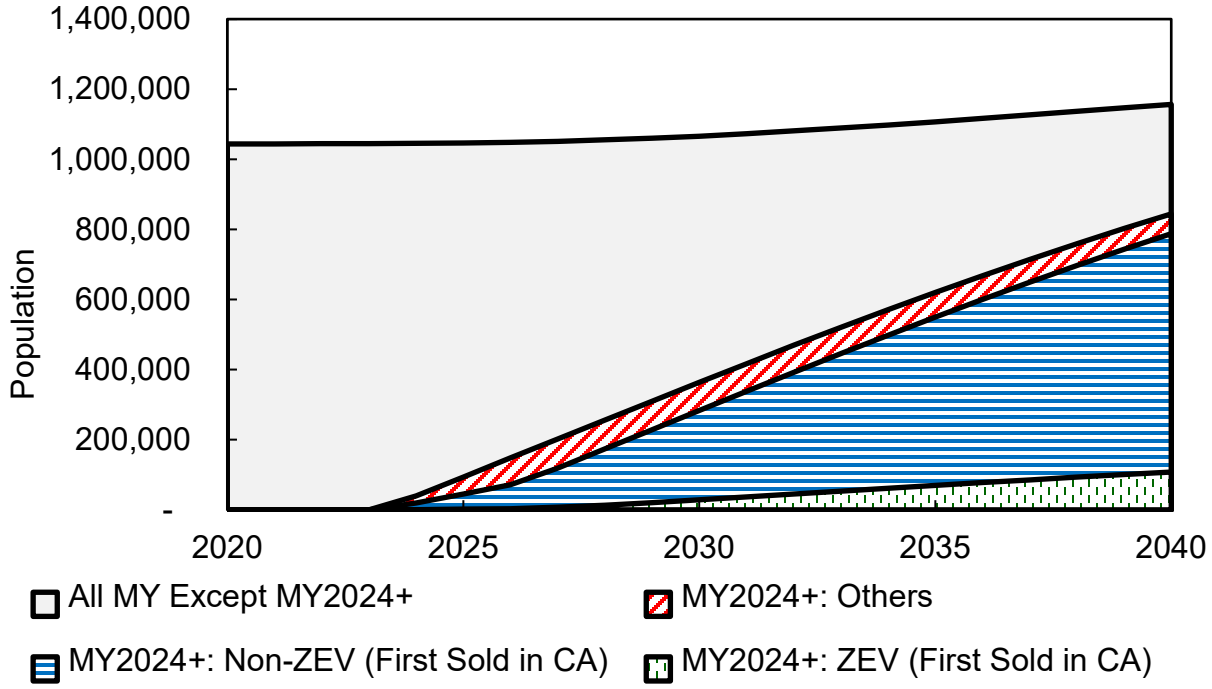


Figure 2: Projected Vehicle Population – Class 4-8 Group

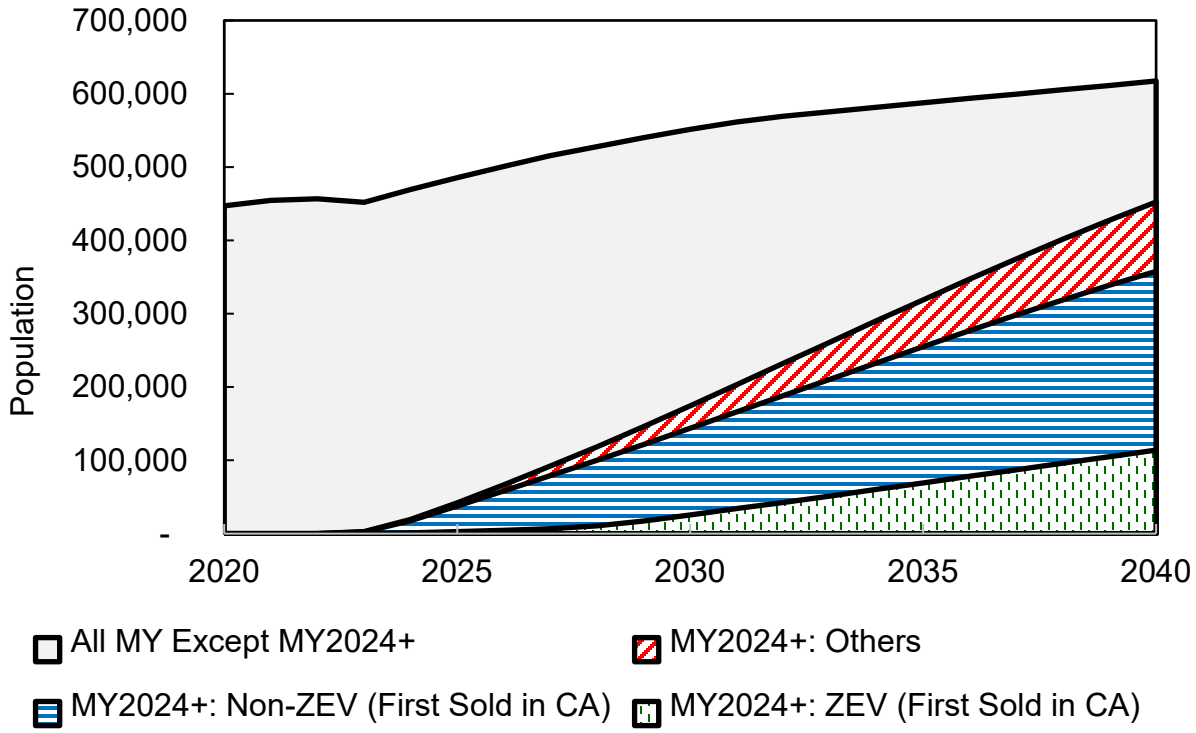


Figure 3: Projected Vehicle Population – Class 7-8 Tractor

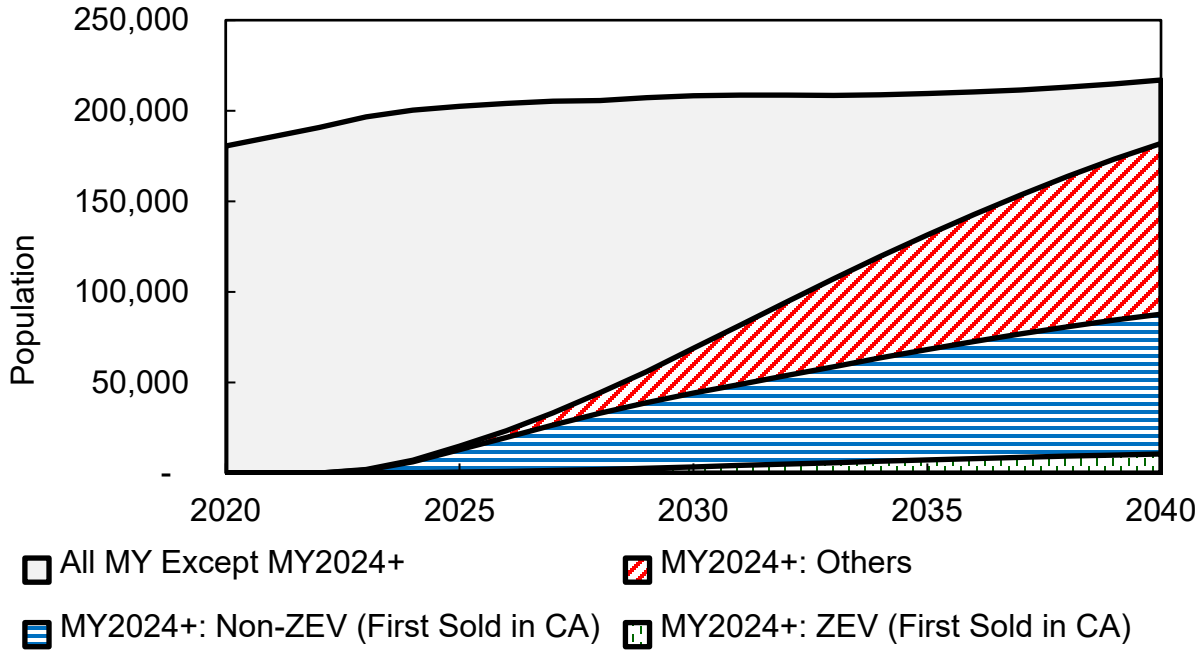


Figure 4: Projected Vehicle Population – Total Instate Vehicles

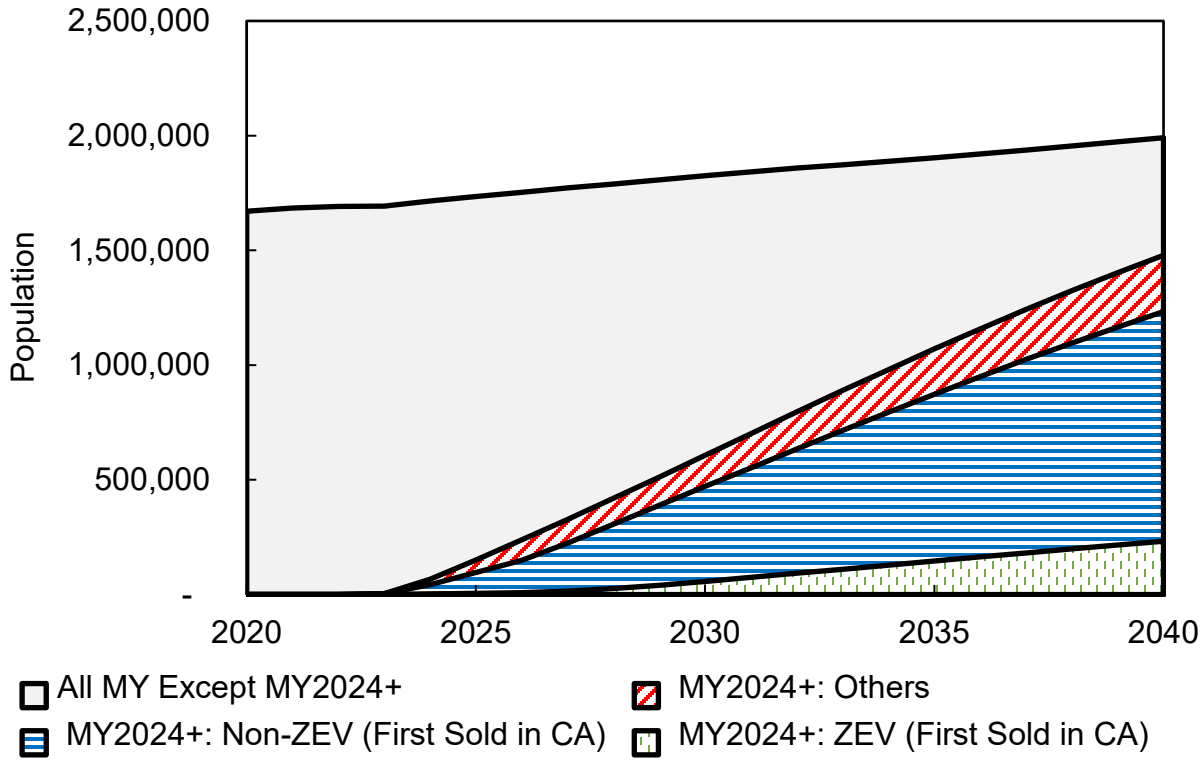
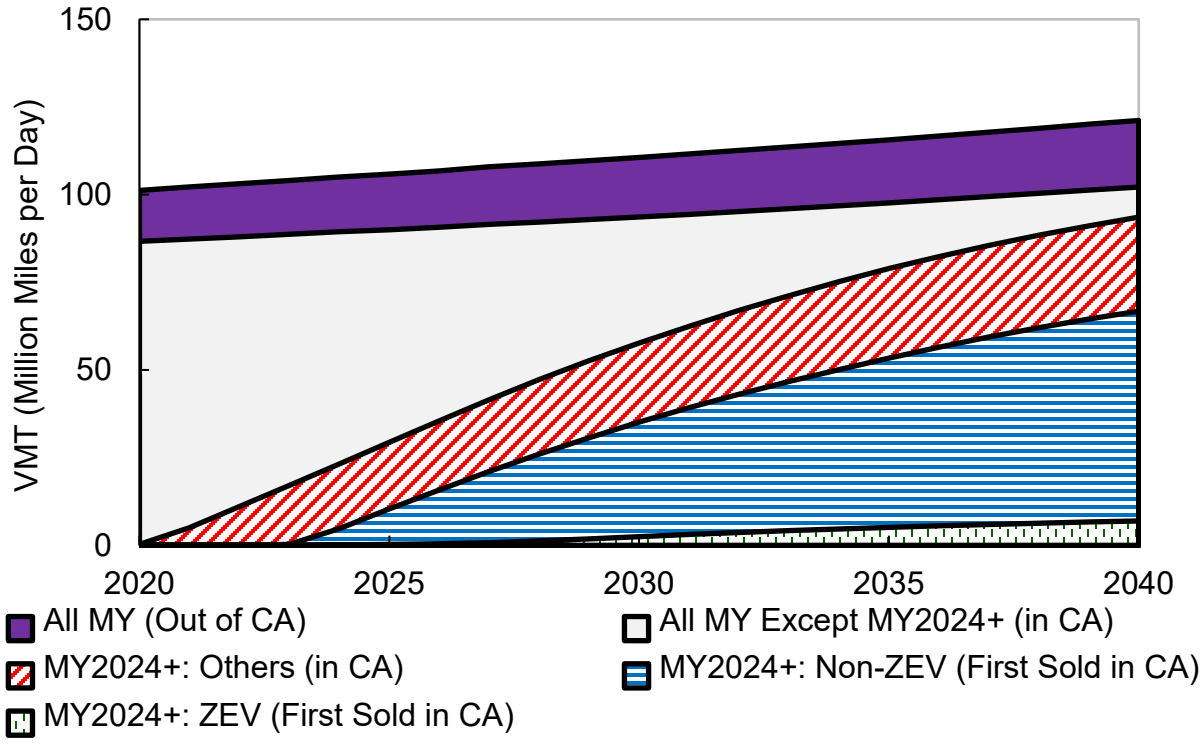


Figure 5: Projected Vehicle Miles Travelled (VMT)



B. Emissions

TTW emissions of NO_X and $PM_{2.5}$ are summarized in Figures Figure **6** through Figure **13**, and Tables 4 and 5. By 2040, NO_X and $PM_{2.5}$ emissions from Class 2b-3 trucks are estimated to be reduced by 138 tons per year and 32 tons per year, respectively. For Class 4-8 vocational vehicles, emissions reductions per year are estimated to be 4,001 tons of NOx and 96 tons of $PM_{2.5}$ by 2040. For Class 7-8 tractors, by 2040 the NO_X and $PM_{2.5}$ emissions are estimated to be reduced by 1,163 tons per year and 16 tons per year, respectively. For all vehicles, by 2040, the NOx and $PM_{2.5}$ emissions are estimated to be reduced by 5,301 tons per year and 144 tons per year, respectively.

Figure 6: Tank-to-Wheel Emissions of NOx for Class 2b-3

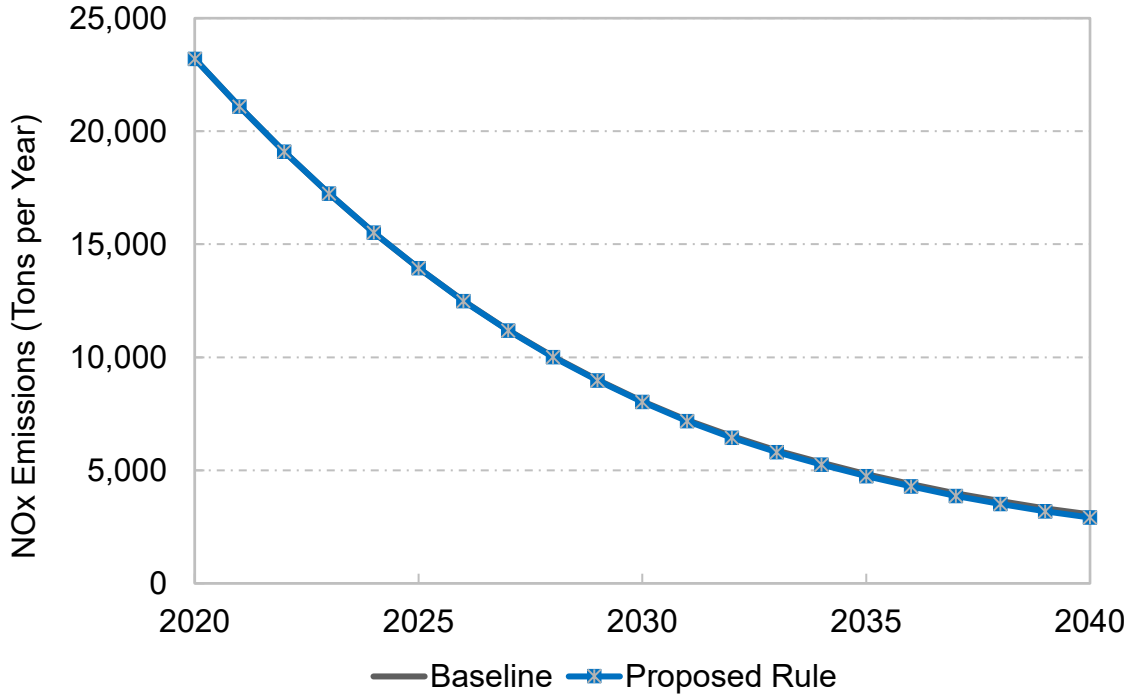


Figure 7: Tank-to-Wheel Emissions of $PM_{2.5}$ (Brake Wear Included) for Class 2b-3

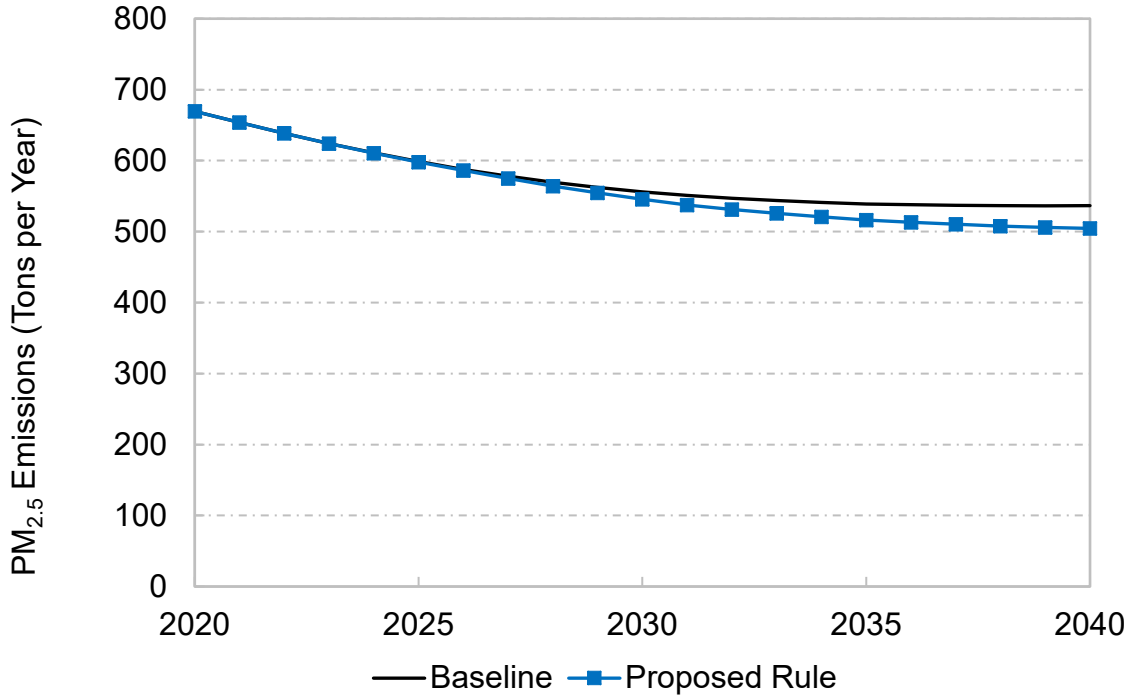


Figure 8: Tank-to-Wheel Emissions of NOx for Class 4-8

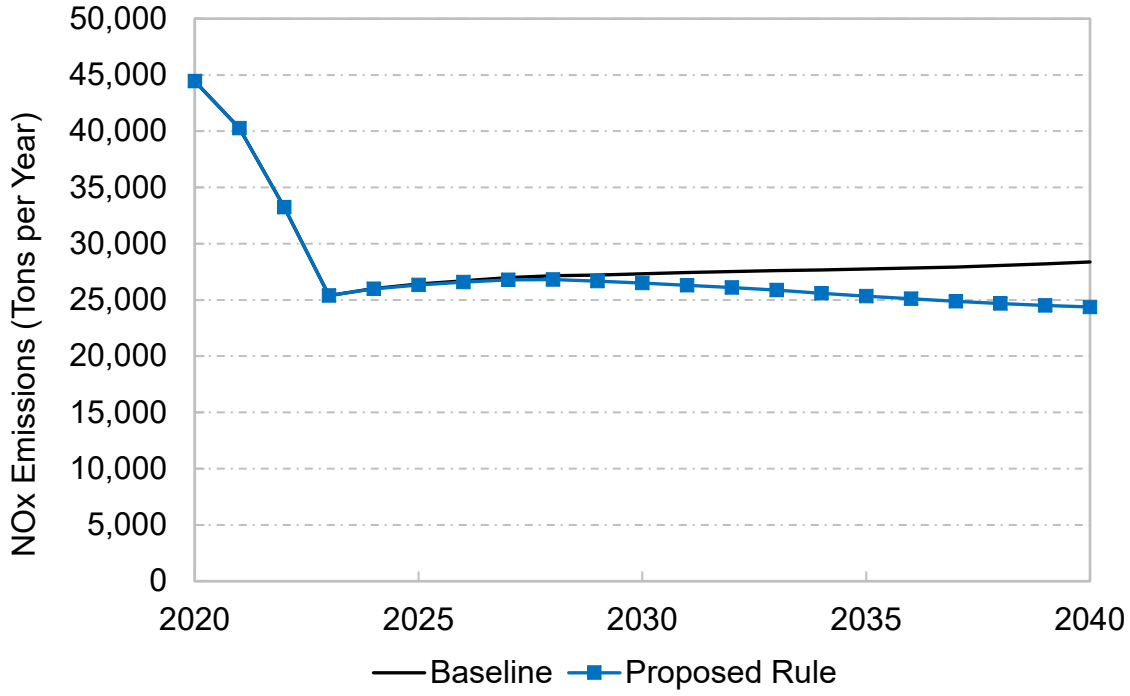


Figure 9: Tank-to-Wheel Emissions of $PM_{2.5}$ (Brake Wear Included) for Class 4-8

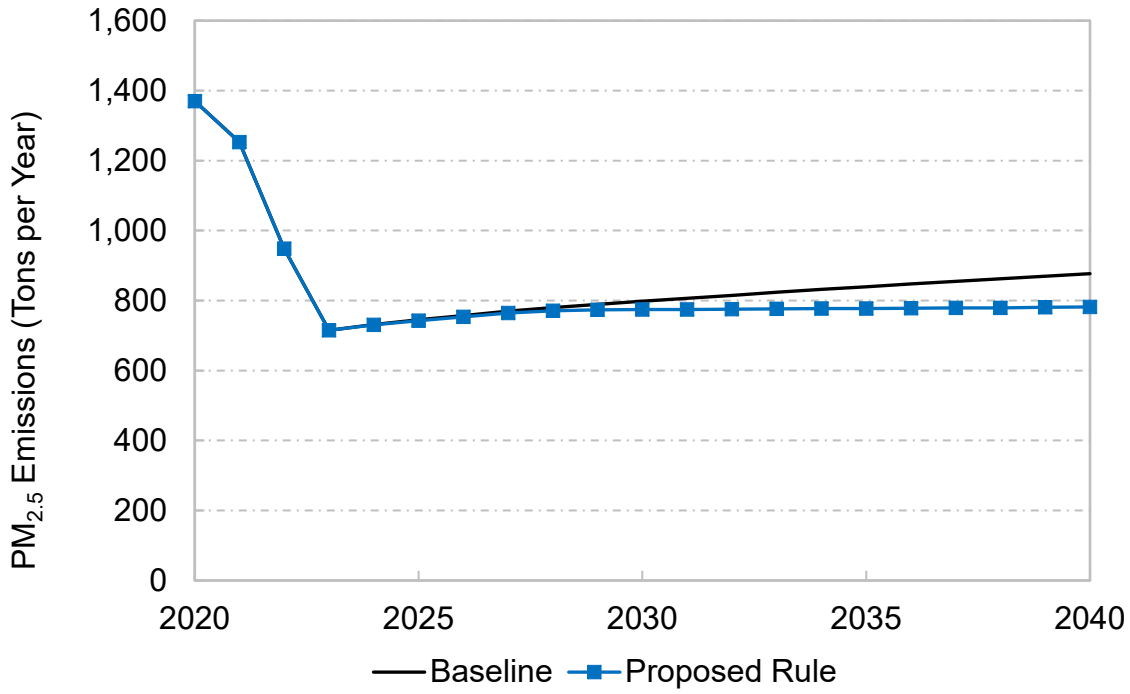


Figure 10: Tank-to-Wheel Emissions of NOx for Class 7-8 Tractors

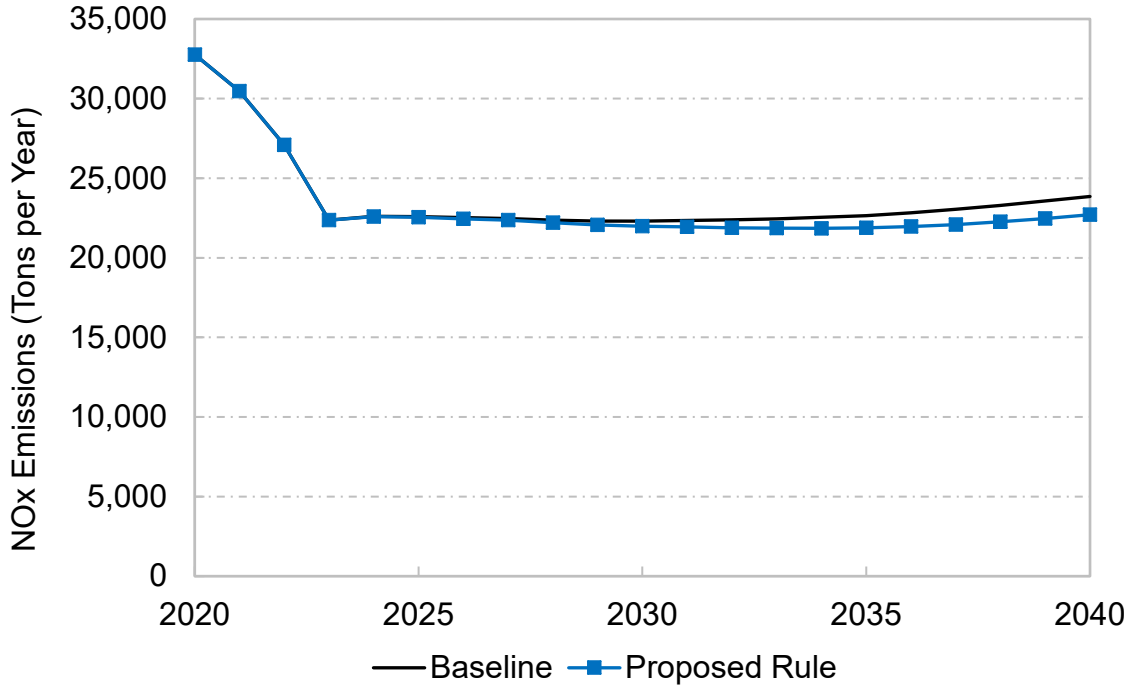


Figure 11: Tank-to-Wheel Emissions of $PM_{2.5}$ (Brake Wear Included) for Class 7-8 Tractors

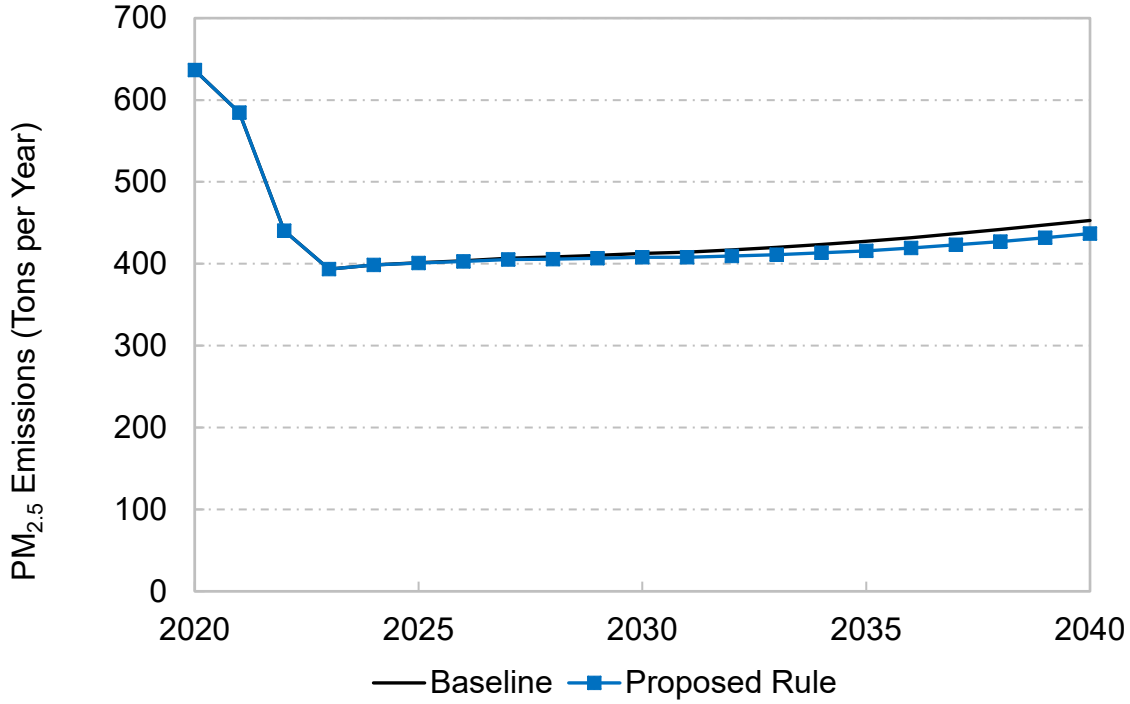


Figure 12: Tank-to-Wheel Emissions of NOx for All Instate Vehicles

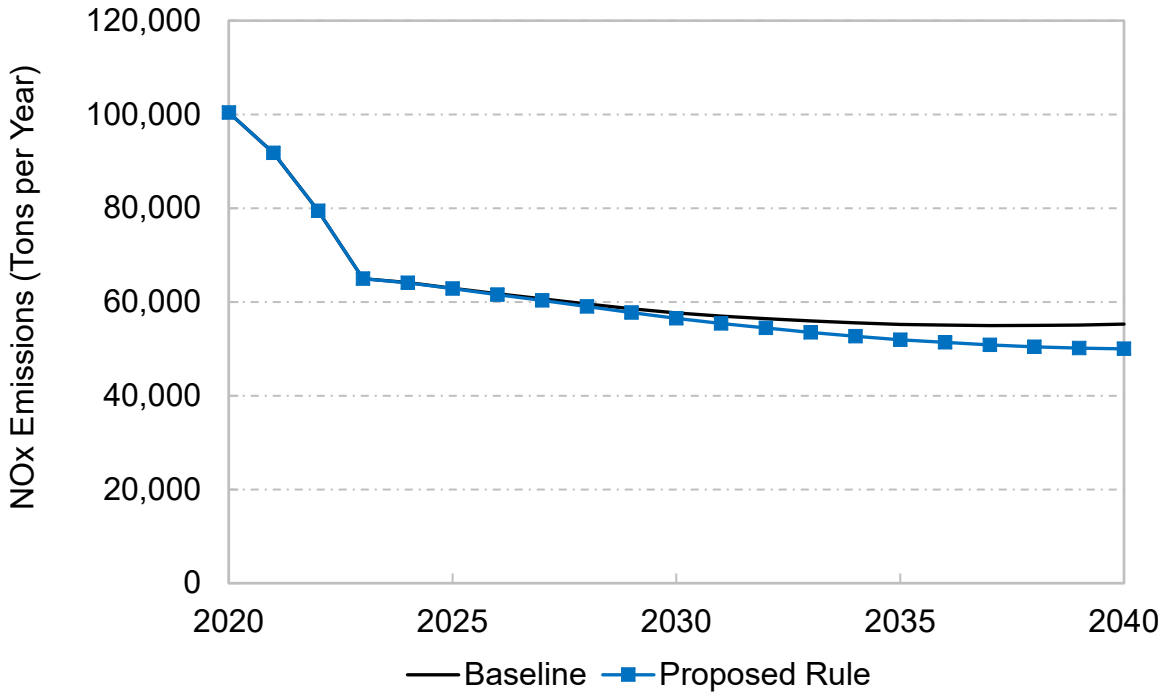


Figure 13: Tank-to-Wheel Emissions of $PM_{2.5}$ (Brake Wear Included) for All Instate Vehicles

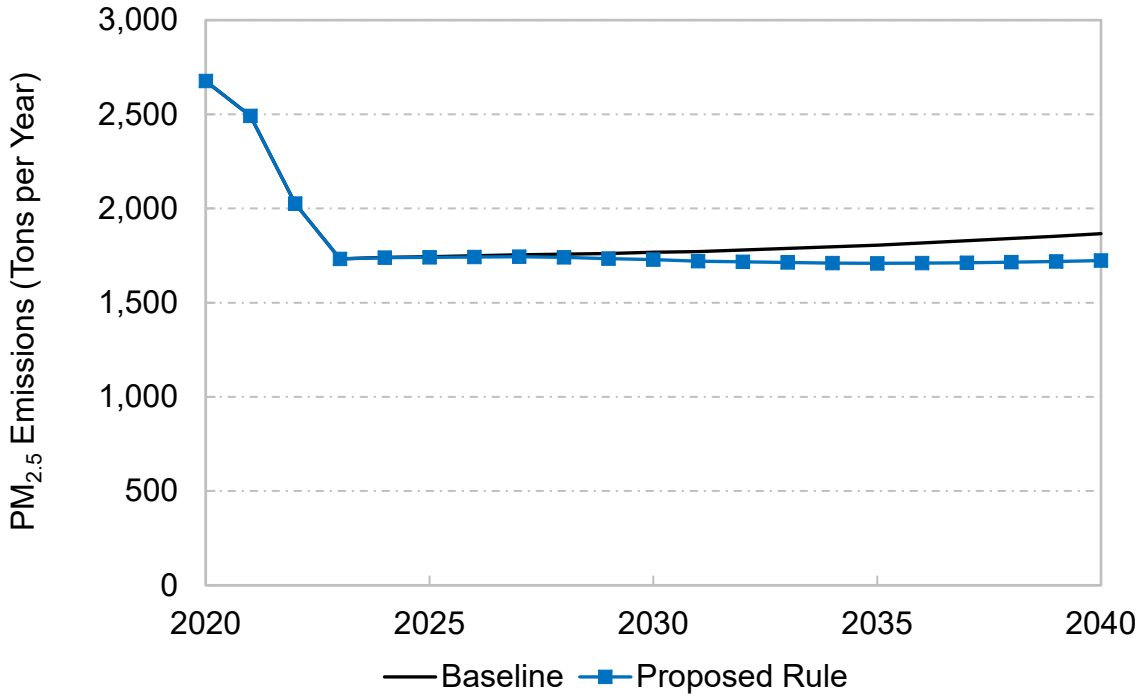


Table 4: Tank-to-Wheel NOx Emissions (Tons per Year)

Year	Class 2b-3 Trucks		Class 4-8 Vocational		Class 7-8 Tractors	
	Baseline	Proposed Rule	Baseline	Proposed Rule	Baseline	Proposed Rule
2020	23,205	23,205	44,439	44,439	32,766	32,766
2021	21,089	21,089	40,270	40,270	30,460	30,460
2022	19,094	19,094	33,248	33,248	27,095	27,095
2023	17,239	17,239	25,387	25,383	22,360	22,358
2024	15,517	15,516	26,020	25,986	22,602	22,588
2025	13,944	13,942	26,412	26,336	22,580	22,546
2026	12,495	12,490	26,708	26,575	22,518	22,452
2027	11,201	11,189	26,979	26,770	22,471	22,360
2028	10,034	10,014	27,156	26,815	22,368	22,200
2029	9,001	8,971	27,213	26,667	22,306	22,068
2030	8,062	8,021	27,309	26,489	22,313	21,991
2031	7,228	7,176	27,424	26,308	22,347	21,937
2032	6,510	6,448	27,517	26,091	22,385	21,884
2033	5,879	5,807	27,608	25,863	22,448	21,854
2034	5,333	5,251	27,670	25,597	22,538	21,851
2035	4,830	4,738	27,736	25,332	22,655	21,878
2036	4,391	4,289	27,824	25,091	22,827	21,962
2037	3,984	3,872	27,927	24,868	23,039	22,091
2038	3,633	3,513	28,052	24,673	23,288	22,261
2039	3,317	3,187	28,199	24,506	23,564	22,466
2040	3,050	2,912	28,375	24,374	23,860	22,697

Table 5: Tank-to-Wheel $PM_{2.5}$ Emissions (Brake Wear Included, Tons per Year)

	Class 2B-3 Trucks		Class 4-8 Vocational		Class 7-8 Tractors	
Year	Baseline	Proposed Rule	Baseline	Proposed Rule	Baseline	Proposed Rule
2020	669	669	1,370	1,370	636	636
2021	654	654	1,253	1,253	585	585
2022	639	639	948	948	440	440
2023	624	624	715	715	393	393
2024	611	611	732	731	399	398
2025	599	598	745	743	401	401
2026	588	586	757	753	404	403
2027	578	575	770	764	407	405
2028	570	564	780	771	408	406
2029	562	554	789	774	410	407
2030	556	545	798	775	413	408
2031	551	538	806	775	414	408
2032	547	531	815	776	417	409
2033	544	526	824	776	420	411
2034	541	521	832	777	424	413
2035	539	516	840	777	427	416
2036	538	513	847	778	432	419
2037	537	510	855	779	437	423
2038	537	508	862	779	442	427
2039	536	506	870	780	447	432
2040	536	505	877	782	453	437

WTT, TTW, and WTW GHG emissions under the BAU baseline and with the Proposed ACT Regulation are shown in Figures Figure **14** through Figure **16**. They show that annual GHG emission reductions with the proposed ACT regulation begin in 2023 and achieve to a WTW GHG emission 1.68 MMT CO2e per year in 2040 of which 1.48 MMTCO2e is within AB32 boundary. Table 6 displays the BAU baseline and Proposed Rule GHG emissions in MMT of CO_2e per year for WTT and TTW, and WTW.

Figure 14: Well-To-Tank GHG Emissions (CO_2e MMT per Year)

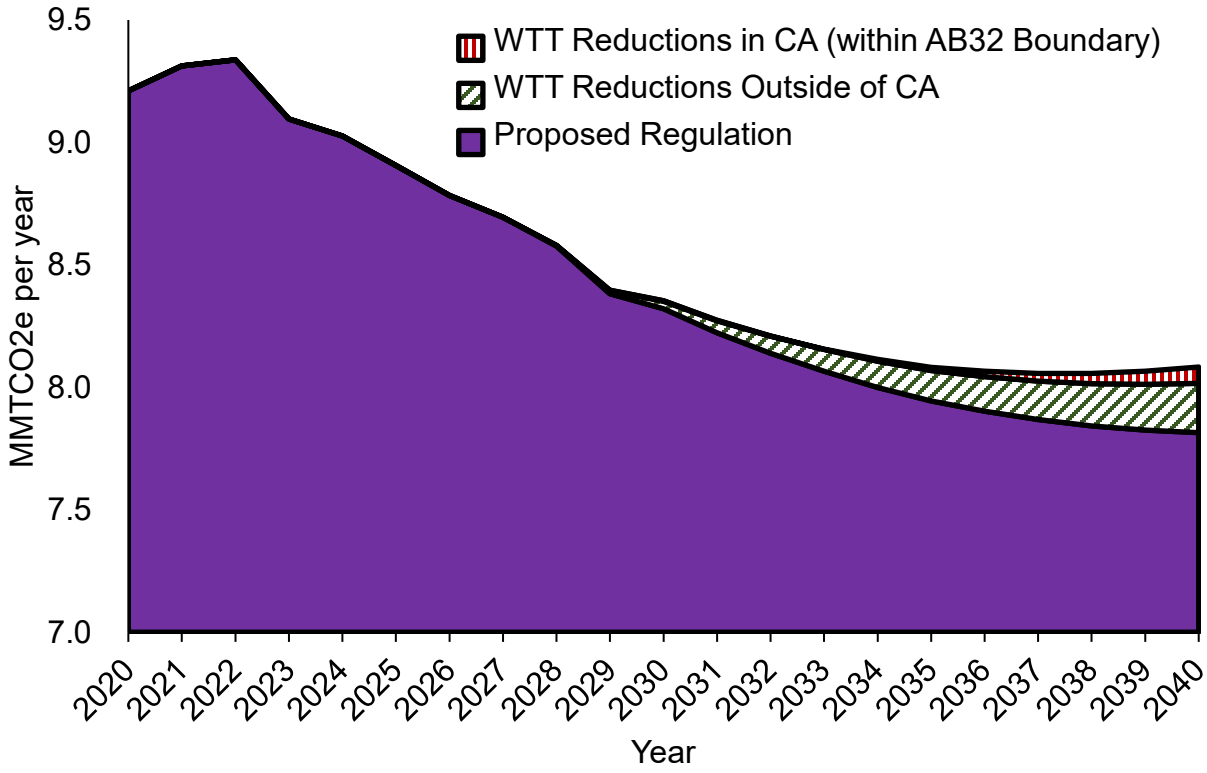


Figure 15: Tank-To-Wheel GHG Emissions (CO_2e MMT per Year)

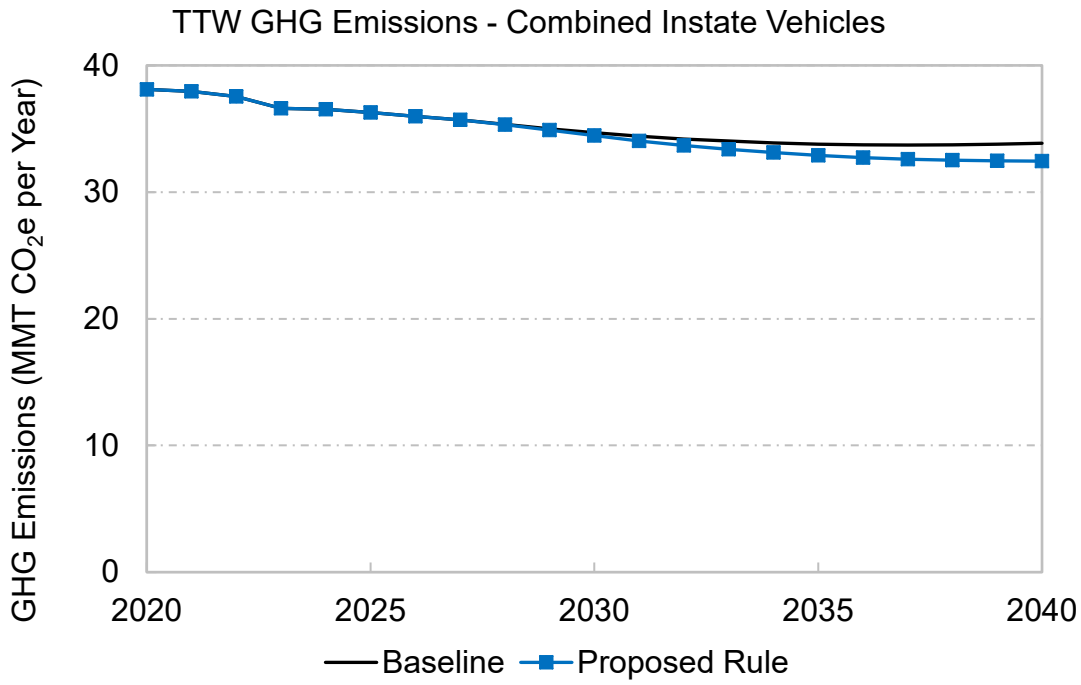


Figure 16: Well-To-Wheel GHG Emissions (CO_2e MMT per Year)

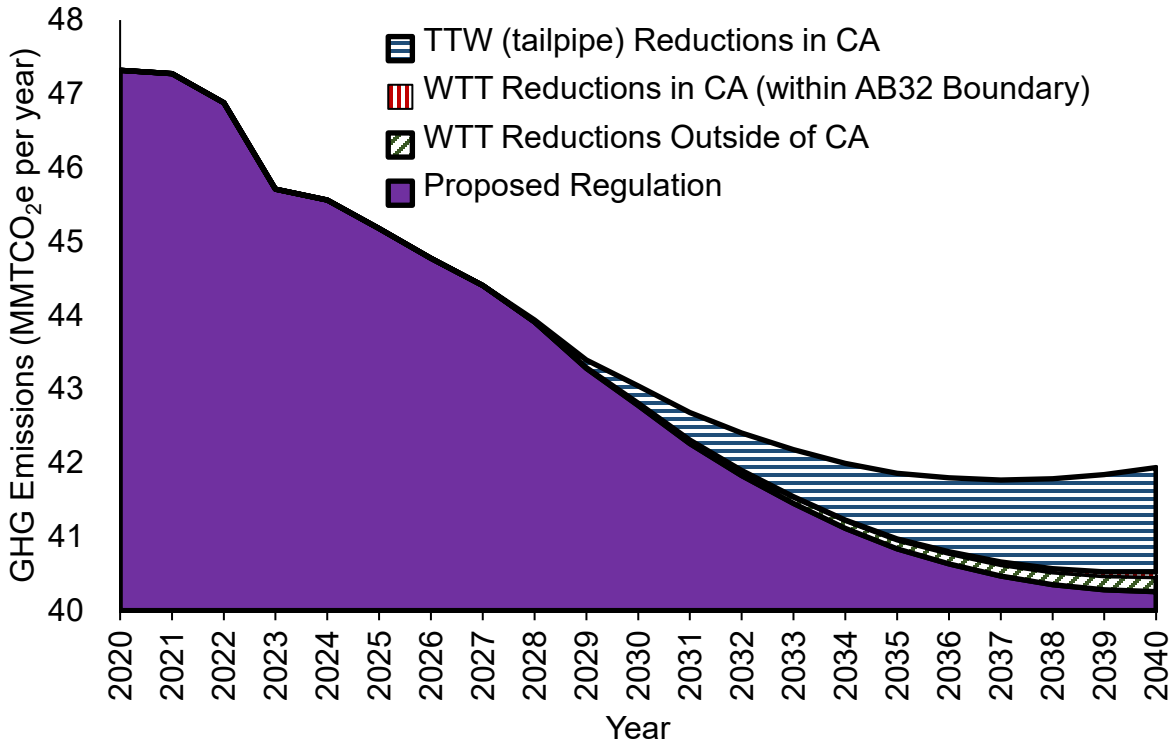


Table 6: Well-To-Wheel[12] GHG Emissions (CO_2e MMT per Year)

Year	WTW Emissions (MMTCO2e/year)		Emissions Reduction (MMTCO2e/year)			
	Baseline	Proposed Rule	Within AB32 Boundary		Outside of AB32 Boundary	Total WTW
			TTW	WTT	WTT	
2020	47.32	47.32	0.000	0.000	0.000	0.000
2021	47.27	47.27	0.000	0.000	0.000	0.000
2022	46.88	46.88	0.000	0.000	0.000	0.000
2023	45.71	45.71	0.000	0.000	0.000	0.000
2024	45.56	45.56	0.000	0.000	0.000	0.000
2025	45.17	45.17	0.000	0.000	0.000	0.000
2026	44.77	44.77	0.000	0.000	0.000	0.000
2027	44.41	44.40	0.001	0.000	0.000	0.001
2028	43.93	43.91	0.023	-0.001	0.003	0.025
2029	43.39	43.28	0.102	-0.002	0.013	0.114
2030	43.04	42.78	0.237	-0.003	0.032	0.266
2031	42.68	42.26	0.373	-0.003	0.051	0.421
2032	42.41	41.83	0.507	-0.001	0.070	0.576
2033	42.18	41.45	0.638	0.002	0.088	0.728
2034	41.99	41.11	0.765	0.007	0.107	0.879
2035	41.86	40.83	0.886	0.014	0.124	1.024
2036	41.80	40.63	1.002	0.022	0.141	1.165
2037	41.77	40.47	1.113	0.032	0.157	1.302
2038	41.79	40.35	1.218	0.042	0.173	1.433
2039	41.84	40.28	1.318	0.054	0.187	1.560
2040	41.94	40.26	1.414	0.067	0.202	1.682

[12] While WTW emissions are calculated within LCFS boundary, staff identified emissions reductions that occur within/outside of AB32 boundary.

IV. REFERENCE LIST

The following documents are the technical, theoretical, or empirical studies, reports, or similar documents relied upon in proposing these regulatory amendments, identified as required by Government Code, section 11346.2, subdivision (b)(3). Additionally, each appendix references the documents upon which it relies, as required by Government Code, section 11346.2, subdivision (b)(3).

Note: Each "Explanatory Footnote" is a footnote containing explanatory discussion rather than referencing specific documents relied upon.

1. California Air Resources Board (CARB) (2017). Mobile Source Emissions Inventory, EMFAC2017. Last updated March 1, 2018. Available: https://www.arb.ca.gov/emfac/2017/?_ga=2.94695390.354866373.1568046467-1498484642.1563211446.

2. California Air Resources Board (CARB) (2019). VISION Well-to-Tank (WTT) Emission Factor Tool.

3. California Air Resources Board (CARB) (2018). EMFAC2017 Volume III – Technical Documentation. March 1, 2018. Available: https://www.arb.ca.gov/msei/downloads/emfac2017-volume-iii-technical-documentation.pdf.

4. California Air Resources Board (CARB) (2018). EMFAC2017 Volume III – Technical Documentation, Section 3.2.3.1. March 1, 2018. Available: https://www.arb.ca.gov/msei/downloads/emfac2017-volume-iii-technical-documentation.pdf.

5. California Air Resources Board, Innovative Clean Transit (web link: https://ww2.arb.ca.gov/our-work/programs/innovative-clean-transit, Last accessed June, 2019)

6. California Air Resources Board, Zero-Emission Airport Shuttle (web link: https://ww2.arb.ca.gov/our-work/programs/zero-emission-airport-shuttle, Last accessed June, 2019)

7. California Air Resources Board, Staff Report: Initial Statement of Reasons for Proposed Rulemaking Proposed California Greenhouse Gas Emission Standards for Medium- and Heavy-Duty Engines and Vehicles and Proposed Amendments to the Tractor-Trailer GHG Regulation, December 19, 2017 (web link: https://www.arb.ca.gov/regact/2018/phase2/isor.pdf, last accessed June 2019).

8. California Air Resources Board (CARB) (2018). Proposed Fiscal Year 2018-19 Funding Plan for Clean Transportation Incentives For Low Carbon Transportation Investments and the Air Quality Improvement Program, Page A-8. Release date: September 21, 2018. Available at: https://www.arb.ca.gov/msprog/aqip/fundplan/proposed_1819_funding_plan.pdf?_ga=2.78221207.220758831.1559317089-1632999103.1458687259.

9. National Renewable Energy Laboratory (NREL) (2008). BAE/Orion Hybrid Electric Buses at New York City Transit: A Generational Comparison. Revised March, 2008. Available: https://afdc.energy.gov/files/pdfs/42217.pdf.

10. California Air Resources Board (CARB) (2018). EMFAC2017 Volume III – Technical Documentation, Page 32. March 1, 2018. Available: https://www.arb.ca.gov/msei/downloads/emfac2017-volume-iii-technical-documentation.pdf.

11. California Air Resources Board (CARB) (2015). Low Carbon Fuel Standard Regulation, Table 4. Available: https://www.arb.ca.gov/regact/2015/lcfs2015/lcfsfinalregorder.pdf.