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POLICY UPDATE

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California's Heavy-duty omnibus regulation: Updates to emission standards, testing requirements, and compliance procedures

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On December 22nd, 2021, the California Air Resources Board (CARB) adopted a new "Omnibus" regulation which updates standards, testing and compliance mechanisms for nitrogen oxide (NO_x) and particulate matter (PM) emissions from on-road heavy-duty vehicles for model years (MY) 2024 through 2031[1]. This regulation follows CARB's 2016 State Strategy for the State Implementation Plan[2], which established the legally binding plan to lower NO_x emissions to meet the National Ambient Air Quality Standards. This new regulation will reduce per-vehicle heavy-duty NO_x emission limits by 90% by 2031, leading to an estimated 30% reduction in overall heavy-duty NO_x emissions by 2050.

This policy update summarizes key elements of this regulation and provides information on technology pathways for meeting these new standards, the estimated costs and benefits of the omnibus regulation, and the international implications of this rulemaking.

KEY ELEMENTS

UPDATES TO NO_x AND PM EMISSION LIMITS

The Omnibus regulation updates NO_x and PM emission limits for heavy-duty vehicles[3] starting in MY 2024 and updates them again for MY 2027 and 2031, ultimately leading

1 California Air Resources Board, "Heavy-Duty Omnibus Regulation," accessed January 3, 2022, https://ww2.arb.ca.gov/rulemaking/2020/hdomnibuslownox

2 California Air Resources Board, "2016 State Strategy for the State Implementation Plan," https://ww2.arb.ca.gov/resources/documents/2016-state-strategy-state-implementation-plan-federal-ozone-and-pm25-standards.

3 Heavy-duty vehicles refer to diesel and Otto vehicles with a gross vehicle weight rating (GVWR) greater than 10,000 lbs.

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to a 90% reduction in the NO_x limit. In conjunction with these updates, in-use on-road testing protocols and evaluation are significantly revised, and a new low-load testing cycle (LLC) will be added for all diesel heavy-duty engines in MY 2024.

Current NO_x aftertreatment technologies deployed on heavy-duty vehicles in the U.S. and Canada tend to lose efficiency at low exhaust temperatures that occur during low-load operations like urban driving.[4] The LLC, which will be used in addition to the existing federal test procedure (FTP), a ramped modal cycle version of the supplemental emission test (RMC-SET), and idling cycles, will allow for better control of NO_x emissions in urban driving environments.

To better regulate heavy-duty vehicles over their real-world lifetimes, useful life provisions for heavy-duty vehicles will be updated beginning in MY 2027. Heavy-duty engines must comply with emission standards for the duration of their useful life. For all heavy-duty vehicles, useful life provisions are measured in both years and vehicle miles traveled, with an additional measurement in operational hours for Class 8 diesel vehicles. Useful life ends when the first of these thresholds is crossed. Table 1 shows the updates to useful life definitions through 2031. Figure 1 shows updated NO_x emissions standards through 2031 for both the existing FTP and RMC-SET cycles and the new LLC cycle. Additionally, because of the increased durability requirements, Class 8 heavy-duty diesel vehicles will have 2 standards starting in MY 2027, one for 435,000 miles (current useful life) and a more lenient limit for the full useful life.

Table 1. Updated useful life provisions for heavy-duty vehicles in vehicle miles and years. For Class 8 diesel vehicles, operational hours are also shown.

Model Year	Useful Life (miles)			
	Class 4-5 Diesel 14,001-19,500 lbs	Class 6-7 Diesel 19,501-33,000 lbs	Class 8 Diesel > 33,000 lbs	Heavy-Duty Otto > 14,000 lbs
Current–2026	110,000 miles 10 years	185,000 miles 10 years	435,000 miles 10 years 22,000 hours	110,000 miles 10 years
2027–2030	190,000 miles 12 years	270,000 miles 11 years	600,000 miles 11 years 30,000 hours	155,000 miles 12 years
2031 and beyond	270,000 miles 15 years	350,000 miles 12 years	800,000 miles 12 years 40,000 hours	200,000 miles 15 years

4 Francisco Posada, Huzeifa Badshah, Felipe Rodriguez, *In-use NO_x emissions and compliance evaluation for modern heavy-duty vehicles in Europe and the United States,* (ICCT: Washington, DC, 2020), https://theicct.org/publications/inuse-nox-hdvs-us-eu.

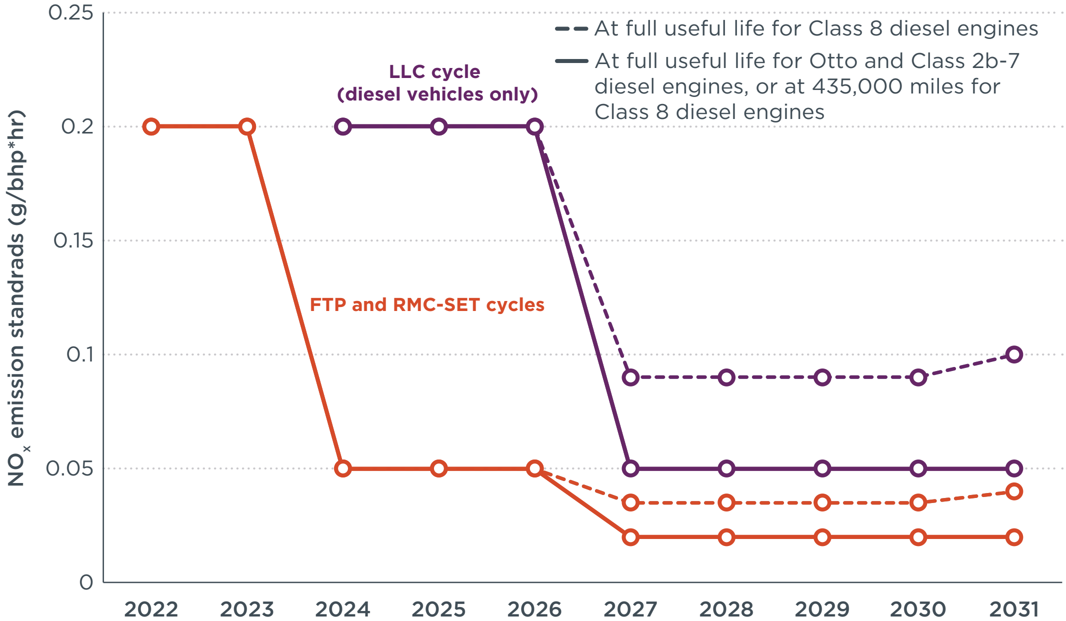

Figure 1. Updated NO_x emission limits for FTP/RMC-SET and LLC cycles

In addition to the limits displayed in Figure 1, idling limits for diesel heavy-duty vehicles will be reduced from 30 g/hr currently to 10 g/hr in MY 2024 and to 5 g/hr in MY 2027.

The regulation will also update emission limits for PM. While PM limits are currently set at 0.01 gram per brake horsepower-hour (g/bhp-hr), all heavy-duty engines on the market in California are currently certified under that limit, with many closer to 0.001 g/bhp-hr.[5] To prevent technological backslide, the PM emissions limit will be updated to 0.005 g/bhp-hr in MY 2024. Updated NO_x and PM standards for all heavy-duty engines are shown in Table 2.

Table 2. Updated NO_x and PM standards for heavy-duty diesel and Otto engines

	NO_x					PM
	FTP/RMC-SET		LLC (diesel only)		Idling (diesel only)	FTP/ RMC-SET
Current	0.2 g/bhp-hr		N/A		30 g/hr	0.01 g/bhp-hr
MY 2024	0.05 g/bhp-hr		0.2 g/bhp-hr		10 g/hr	0.005 g/bhp-hr
	At full useful life for diesel Class 2b-7, Otto engines; at 435,000 miles for Class 8 diesel	At full useful life for Class 8 diesel	At 435,000 miles	At full useful life		
MY 2027	0.02 g/bhp-hr	0.035 g/bhp-hr	0.05 g/bhp-hr	0.09 g/bhp-hr	5 g/hr	0.005 g/bhp-hr
MY 2031	0.02 g/bhp-hr	0.04 g/bhp-hr	0.05 g/bhp-hr	0.1 g/bh-hr	5 g/hr	0.005 g/bhp-hr

5 California Air Resources Board, "Heavy Duty Engines and Vehicles, including Urban Buses, and Engines Used in Diesel or Incomplete Medium-Duty Vehicles of 8501-14000 Pound GVWR Executive Orders – 2019," (updated August 2021), https://ww3.arb.ca.gov/msprog/onroad/cert/mdehdehdv/2019/2019.php.

UPDATES TO IN-USE TESTING

CARB introduced updates to in-use vehicle testing to increase the percentage of NO_x emissions accounted for in tests and to more accurately capture the full range of conditions in which heavy-duty vehicles operate. Under the current not-to-exceed (NTE) testing protocol, vehicles are measured under normal driving conditions and emissions are collected continuously. Emissions data are included in an evaluation only if a specific set of operating conditions are met for a period of time (30 seconds minimum); thus, only about 5% of testing time-periods are typically included.[6] Under the NTE protocol, an engine is compliant if at least 90% of the valid periods have emissions under the limit.

CARB is instituting a switch to a 3-bin moving average window (3-Bin MAW) for diesel engines to increase the percentage of tests that are considered and to ensure emissions compliance across a much broader range of operating conditions. Under this method, instead of eliminating driving periods that don't match specific standards, periods will be sorted into bins for compliance. With the new 3-Bin MAW, the averaged (sum-over-sum)[7] emission of every window will need to fall below 2 times the limit for the corresponding cycle from 2024 to 2029 and 1.5 times the limit starting in 2030.

Windows are sorted into 3 bins based on the CO_2 output during the testing window normalized to the Family Certification Level (FCL) of the engine family, which is the CO_2 emission rate at maximum power output. If the normalized CO_2 emission rate of a window is less than 6%, that window is considered idle and binned accordingly. Between 6 and 20% normalized CO_2 emissions, the window is considered low load, corresponding to the LLC limit. Over 20% normalized CO_2 emissions is considered medium/high load and compared to the FTP limit. These bins are summarized in Table 3. For Otto engines, windows will not be binned by CO_2 emissions and all will be compared to the FTP emissions limit.

Table 3. Summary of bins for 3-Bin MAW in-use testing method

Bin	Normalized average window CO_2 emissions rate	Sum-over-sum emissions limit (MY 2024-2029)	Sum-over-sum emissions limit (from MY 2030)
Idle	≤ 6%	2.0 × idle limit	1.5 × idle limit
Low	6% - 20%	2.0 × LLC limit	1.5 × LLC limit
Medium/High	> 20%	2.0 × FTP limit	1.5 × FTP limit

Starting in MY 2027, manufacturers will also be required to include cold-start periods (defined as periods where the engine coolant temperature is less than 70°C) in their in-use testing procedures. Table 4 lists the most important differences between the NTE and 3-Bin MAW in-use testing methods.

6 Christian Bartolome, Lee Wanf, Henry Cheung, Stephan Lemieux, Kim Heroy-Rogalski, William Robertson, "*Toward Full Duty Cycle Control: In-Use Emissions Tools for going beyond the NTE,*" CRC Real-World Emissions Workshop (2018).

7 Sum-over-sum emissions refers to the total emissions during a period divided by the length of the period for idle periods, or to the total emissions divided by the normalized CO_2 output for low-, medium-, and high-load periods.

Table 4. Summary of differences between current NTE and 3-Bin MAW in-use testing methods

	NTE (Current)	3-Bin MAW (starting 2024)
Averaging period (seconds)	30	300
Interval between periods (seconds	30	1
Low-load and idle periods	Excluded	Sorted into separate bins
Cold start periods	Excluded	Included starting in 2027
Percentage of test time included	4.9	60.1[8]
Percentage of NO_x emissions included	5.7	61.6[8]
Compliance criteria	90th percentile emission period must match FTP limit	Window average must not exceed 2x the limit of corresponding test cycle (1.5x from MY 2030)

Finally, to ensure that manufacturers are accurately representing their vehicles' usage, CARB will require manufacturers to submit test plans for approval prior to testing.

UPDATES TO AVERAGING, BANKING, AND TRADING (ABT)

To resolve the new discrepancies between California and EPA emission standards, CARB is instituting a new California-only averaging, banking, and trading program (CA-ABT) starting with MY 2022. The CA-ABT program will maintain the same averaging sets as the federal program (Otto, light heavy-duty diesel, medium heavy-duty diesel, and heavy heavy-duty diesel), but will use the updated emission limits and useful life provisions to calculate credits and deficits. Manufacturers will be allowed to transfer a portion of their nationwide ABT credits to their CA-ABT credit pool. This portion will be capped at the fraction of the manufacturer's US sales that occurred in California for a given model year, and only credits generated since 2010 will be transferrable.

Credits for diesel and Otto engines will be generated the same way as the federal program, using:

$$Emissions\ Credits = (Std - FCL)\left(\frac{g}{bhp\text{-}hr}\right) \times CF\left(\frac{bhp\text{-}hr}{mile}\right) \times UL(miles) \times Sales$$

where Std is the FTP emission standard for a given year and vehicle class; CF is the transient cycle conversion factor; UL is the full useful life of the vehicle class for a given year, and Sales is the total sales volume of an engine family in California.

To promote deployment of heavy-duty zero-emission vehicles (ZEVs), CARB will allow manufacturers to generate NO_x credits through the sale of zero-emission powertrains. A manufacturer's ZEV NO_x credits will be calculated in the following way:

$$ZEV\ NO_x\ \ credits = Std\left(\frac{g}{bhp\text{-}hr}\right) \times ECF\left(\frac{bhp\text{-}hr}{mile}\right) \times UL(miles) \times Sales$$

where Std is the FTP NO_x emission standard for a corresponding diesel vehicle; ECF is the transient cycle conversion factor; UL is the useful life of the corresponding diesel vehicle class for a given year, and Sales is the total sales volume in California

8 Percentage calculated by CARB using analysis of heavy-duty in-use testing in Europe's Euro VI MAW procedure.

of a given zero-emission powertrain family in that year. These credits can be used to counteract emissions in any averaging set, regardless of weight class or engine type. The ZEV crediting program will terminate after MY 2026.

CARB is also allowing manufacturers to generate additional CA-ABT credits through early compliance. Table 5 shows early compliance multipliers for 2022 through 2030. ZEVs will not be eligible for these early compliance multipliers.

Table 5. Early compliance multipliers for NO_x emissions credits

Model Year	Complying with regulations for model years	Early compliance multiplier
2022–2023	2024–2026	1.5
	2027–2030	2
	2031 and beyond	2.5
2024–2026	2027–2030	1.5
	2031 and beyond	2
2027–2030	2031 and beyond	1.5

The CA-ABT will also introduce age limits for banked credits. All banked credits will need to be used within 5 model years of when they were generated, or they will expire.

WARRANTY

CARB is setting new, lengthened warranty periods to better match the real-world lifetimes of heavy-duty vehicles and encourage proper maintenance and durability of emission control systems. The first phase of lengthened warranties was instituted in 2018 for MY 2022.[9] The HD Omnibus regulation adds two new phases beginning in MY 2027 and 2031. Like the useful life provisions, warranty periods are measured in vehicle miles, years, and operational hours, with the warranty period ending when the first of these thresholds is crossed. These updated warranty periods are shown in Table 6.

Table 6. Lengthened warranty periods for heavy-duty vehicles in vehicle miles traveled, years, and operational hours

Model Year	Minimum Warranty (miles)			
	Class 4-5 diesel 14,001-19,500 lbs	Class 6-7 diesel 19,501-33,000 lbs	Class 8 diesel > 33,000 lbs	Heavy-duty Otto > 14,000 lbs
Current	100,000 miles 5 years 3,000 hours	100,000 miles 5 years 3,000 hours	100,000 miles 5 years 3,000 hours	50,000 miles 5 years
2022–2026	110,000 miles 5 years	150,000 miles 5 years	350,000 miles 5 years	50,000 miles 5 years
2027–2030	150,000 miles 7 years 7,000 hours	220,000 miles 7 years 11,000 hours	450,000 miles 7 years 22,000 hours	110,000 miles 7 years 6,000 hours
2031 and beyond	210,000 miles 10 years 10,000 hours	280,000 miles 10 years 14,000 hours	600,000 miles 10 years 30,000 hours	160,000 miles 10 years 8,000 hours

9 California Air Resources Board, “On-Road Heavy-Duty Warranty Regulations,” 2018.

In addition to updated warranty periods, CARB is also instituting changes to the warranty reporting process.

TECHNOLOGY PATHWAYS

The Omnibus regulation is technology-neutral, meaning manufacturers can use any combination of engine and aftertreatment technologies to meet the emission standards. For diesel vehicles, some NO_x curtailment can come from engine design, but most reduction will likely come from upgrades in the aftertreatment process.[10]

Current aftertreatment technology, shown in Figure 2, is capable of meeting the FTP cycle standards set for MY 2024, but minimal component changes will likely be needed to meet the added LLC standards. Figure 2 shows two technology pathways for aftertreatment that manufacturers are expected to utilize to meet the MY 2024 standards. One of these pathways simply uses a heated urea stream. The other splits the selective catalytic reduction (SCR) volume in two and places one before the first diesel oxidation catalyst (DOC). The first SCR would then also use a heated urea inlet. While this pathway is a larger departure from the current technology, it has the advantage of more closely resembling the technologies that will likely be needed for the MY 2027 standards.

More substantial updates will likely be needed to meet the MY 2027 standards, both to meet the LLC and FTP standards and to comply with the cold-start testing being introduced that year. Three technology pathways that can achieve these standards are shown in Figure 2. All three options employ a close-coupled SCR (ccSCR), which uses engine heat to reach higher temperatures more quickly. The first pathway is very similar to the 2027 split-SCR pathway, the main difference being an increased SCR volume. The second configuration is more compact by combining the second SCR with the DPF. The final pathway instead combines the DOC and DPF into a catalyzed soot filter (CSF). All three of these pathways have been demonstrated to reduce NO_x emissions to the levels required in the MY 2027 standards.[10]

10 Francisco Posada, Aaron Isenstadt, Huzeifa Badshah, *Estimated cost of diesel emissions-control technology to meet future California low NO_x standards in 2024 and 2027,* (ICCT: Washington, DC, 2020), https://theicct.org/publications/cost-emissions-control-ca-standards. Chris Sharp, *Update on heavy-duty low NO_x demonstration programs at SWRI,* (SWRI, 2019), https://ww2.arb.ca.gov/our-work/programs/heavy-duty-low-nox/heavy-duty-low-nox-meetings-workshops.

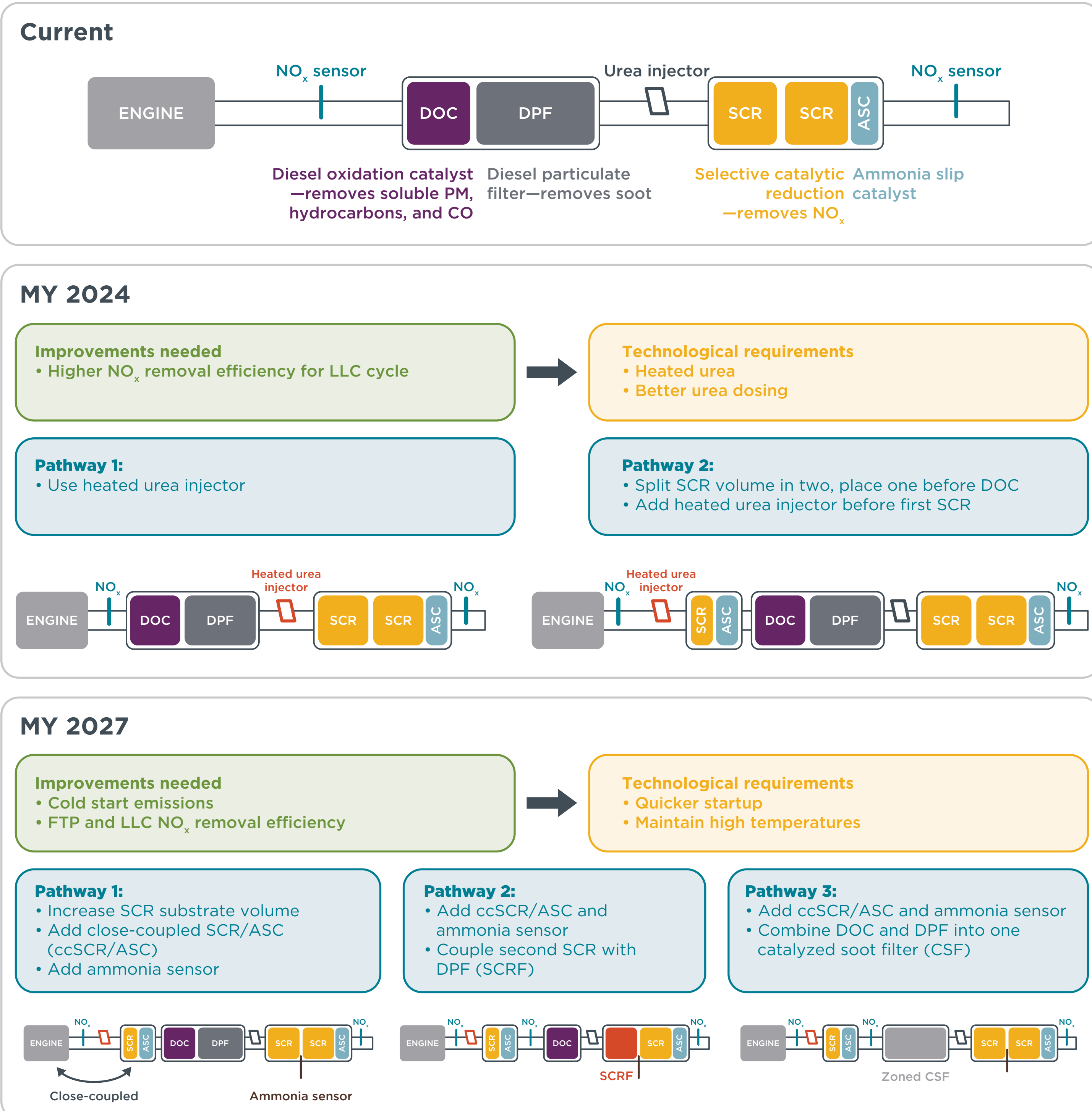

Figure 2. Technology pathways for diesel aftertreatment to meet 2024 and 2027 emissions standards

Commercial gasoline and natural gas vehicles both use 3-way catalysts (TWC) to reduce emissions. Several commercial engines using this technology already meet the 2031 standard. Thus, CARB expects that manufacturers will be able to meet future standards for these vehicles solely with modest improvements to the TWC.[11]

PROJECTED COSTS AND BENEFITS

The amendments to emissions standards, testing, and crediting are projected to reduce NO_x emissions by California heavy-duty vehicles by almost 30% by 2050.[12] These reductions are enumerated in Table 7.

Table 7. NO_x emissions in tons per day with and without HD omnibus regulation

Year	Without new amendments (NO_x tpd)	With new amendments (NO_x tpd)	Reduction (NO_x tpd)	% Reduction
2024	210	209	0.4	0.2%
2031	218	194	23	11%
2040	232	177	55	24%
2050	258	182	76	29%

CARB calculated the projected costs of compliance for diesel and gasoline engines including aftertreatment processes.[12] These costs are displayed in Figure 3. Costs increase as standards become more stringent and decrease through manufacturer learning.

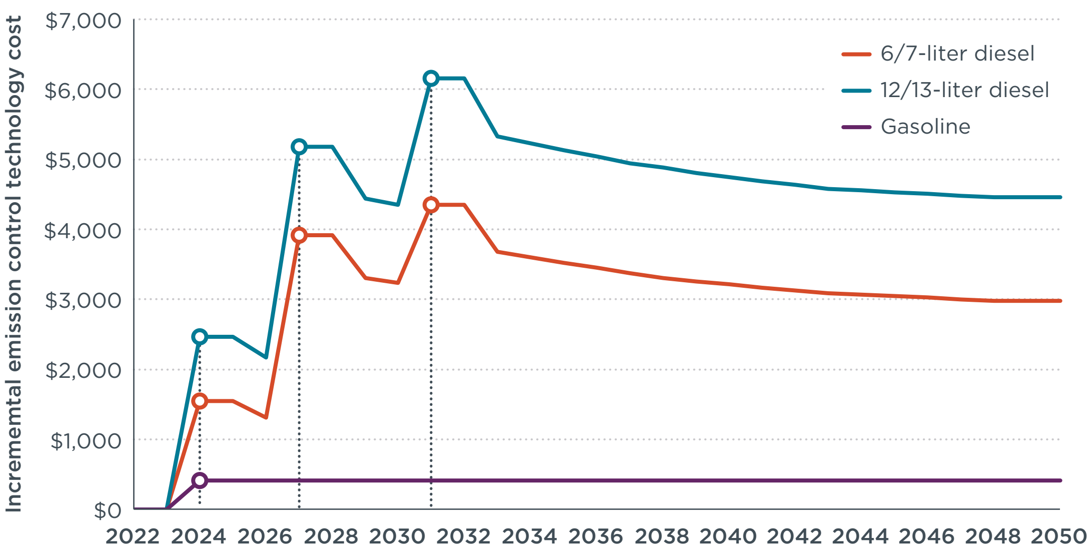

Figure 3. Incremental emission control cost per engine through 2050 for compliance with HD omnibus regulation

Table 8 shows projected monetary costs and benefits from the year 2022 to 2050, as calculated by CARB. The projected benefits of this regulation are valued at $37.4 billion dollars between 2022 and 2050. The overwhelming majority of those benefits come as health benefits from avoided premature deaths and respiratory and

11 California Air Resources Board, "Heavy-Duty Omnibus Initial Statement of Reasons" (2020), https://ww2.arb.ca.gov/sites/default/files/classic/regact/2020/hdomnibuslownox/isor.pdf.

cardiovascular hospitalizations. Additional benefits arise from increased length and coverage of warranties.

The total projected cost of the new regulations is estimated to be approximately $4.5 billion. Most of these costs can be attributed to the additional technologies needed to meet the new NO_x and PM standards. There are also significant costs to manufacturers to cover the extended warranty requirements.

Table 8. Costs and benefits of the regulation

Benefits	
Health benefits	$ 36.8 billion
Non-health benefits	$ 651 million
Total benefits	**$ 37.4 billion**
Costs	
Low emissions technology costs	$ 3.2 billion
Extended warranty and reporting costs	$ 1.2 billion
Testing, crediting, and compliance costs	$ 86 million
Total costs	**$ 4.5 billion**
Net benefit	**$ 33 billion**
Cost-benefit ratio	**8.3**
Cost-per-reduction	**$12,740 per ton NO_x**
	$ 6.37 per lb NO_x

INTERNATIONAL CONTEXT

California's Omnibus rulemaking will have important implications globally for developments in technology and policy. In the United States, CARB and the EPA have historically aligned their respective criteria pollutant emissions regulations for heavy-duty engines and vehicles. CARB's latest regulatory action is requiring manufacturers to bring cleaner engines and vehicles to the market starting in MY 2024. The EPA is expected to finalize updates to the federal emission standards for on-road commercial vehicles by the end of 2022, but due to manufacturer lead-time stipulations, MY 2027 could be the first year of tightened emissions requirements.[12] As such, there will be a bifurcated market starting in MY 2024, as manufacturers will have to demonstrate compliance with California's more stringent emissions standards while also maintaining compliance at the federal level. The heavy-duty engine and vehicle manufacturing industry has consistently maintained a strong preference for harmonized regulations across the U.S. and Canada, given the highly integrated nature of the North American market and the desire to avoid the additional costs associated with having to develop specialized products. As such, California's Omnibus regulation will be a significant input into the EPA's rulemaking process, as there will likely be significant pressure from industry to develop a nationwide program in which manufacturers can be deemed to comply with California's

12 "Executive Order on Strengthening American Leadership in Clean Cars and Trucks," The White House, accessed August 24, 2021, https://www.whitehouse.gov/briefing-room/presidential-actions/2021/08/05/executive-order-on-strengthening-american-leadership-in-clean-cars-and-trucks/.

regulation simply by complying with the federal standards.[13] With a long history of harmonizing its pollutant emissions regulation with the U.S., Canada is also expected to commence a rulemaking process in the near-term, and CARB's regulation will feature prominently as Environment and Climate Change Canada revises its criteria pollutant standards for heavy-duty engines and vehicles.

Another dynamic that will likely weigh heavily in the EPA's rulemaking process is the fact that several states have expressed interest in adopting California's Omnibus regulatory package. In addition to giving California the authority to set its own vehicle emission regulations, Section 177 of the U.S. Clean Air Act gives states the option of adopting California's regulatory programs in lieu of those at the federal level. A contingent of states electing to adopt the Omnibus regulation would put that much more pressure on the EPA to develop a federal regulation that is harmonized with California.

Outside of the U.S. and Canada, Europe is in the process of developing Euro VII, the next round of pollutant standards for heavy-duty engines and vehicles. A regulatory proposal is expected from the European Commission as soon as December 2021, and indications are that the required levels of NO_x reductions will be similar in magnitude to the MY 2027 levels in CARB's Omnibus regulation.[14] Given that major manufacturers such as Daimler and Volvo are active in both the North American and European markets, it is likely that the technology advancements being developed to achieve NO_x levels to meet California's requirements will be very similar to those deployed as part of the Euro VII rollout. There are, however, several key differences between CARB's omnibus regulation and plans for EURO VII. Euro VII will regulate particulate number (PN) along with PM, which allows for more control at very low emission limits. Euro VII will also include standards for ammonia emissions, which are not regulated by CARB. The 3-Bin MAW method used by CARB for diesel engines also differs slightly from the European method. The Euro VI in-use testing method only covers windows with average power greater than 20% of the maximum engine power, and only requires 90% of valid windows to match the limit. It is expected that this method will be updated in Euro VII to cover a wider range of operating conditions and introduce two additional limits—a budget limit for short tests, and a higher limit which would require compliance across 100% of windows, in a method similar but not identical to the 3-Bin MAW used by CARB.[15]

13 "California: Heavy-Duty Emissions", TransportPolicy.net, accessed August 24, 2021, https://www.transportpolicy.net/standard/california-heavy-duty-emissions/.

14 Pierre-Louis Ragon, Felipe Rodríguez, *Estimated cost of diesel emissions control technology to meet future Euro VII standards*, (ICCT: Washington, DC, 2021), https://theicct.org/publications/cost-diesel-emissions-control-euro-vii-apr2021.

15 Stefan Hausberger, Konstantin Weller, Markus Ehrly, "Scenarios for HDVs: Summary Emissions limits and Test Conditions," (CLOVE, 08/04/2021), https://circabc.europa.eu/sd/a/b706ffba-f863-4d23-809d-20d9f18ecba4/AGVE.