ICCT **POLICY UPDATES** SUMMARIZE REGULATORY AND OTHER DEVELOPMENTS RELATED TO CLEAN TRANSPORTATION WORLDWIDE.

POLICY UPDATE

JULY 2023

U.S. heavy-duty vehicle NO_X standards: Updates to emission limits, testing requirements, and compliance procedures

Prepared by Yihao Xie

In December 2022, the U.S. Environmental Protection Agency (EPA) adopted the final rule, "Control of Air Pollution from New Motor Vehicles: Heavy-Duty Engine and Vehicle Standards."[1] The rule updates testing procedures, compliance mechanisms, and emission limits for nitrogen oxides (NO_x) and other pollutants from engines used in on-road medium- and heavy-duty vehicles (MHDVs) for model year (MY) 2027 and beyond. The new standards will reduce allowable per-engine heavy-duty NO_x emissions by up to 82.5% starting in 2027 compared to the current 2010 standards.[2] The updated NO_x standards belong to a series of EPA rulemakings collectively referred to as the Clean Trucks Plan, first announced in 2021, which seek to reduce greenhouse gas emissions and other harmful air pollutants from heavy-duty trucks. The other two components of the Clean Trucks Plan are 1) the proposed MHDV greenhouse gas standards Phase 3 rule for MY 2027 and later; and 2) the multipollutant standard proposal for light- and medium-duty vehicles for MY 2027 and later.

This policy update summarizes key elements of the regulation, referred to as the EPA CTP-NO_x rule, and provides information on technology pathways for meeting the new standards and on the rule's estimated costs and benefits. It also summarizes developments in HDV NO_x standards in other parts of the world.

KEY ELEMENTS OF THE EPA CTP-NO_X REGULATION

UPDATED EMISSION LIMITS

The EPA CTP-NO_x regulation lowers heavy-duty engine (HDE) NO_x emission limits from 200 mg/bhp-hr in the 2010 standards to 35 mg/bph-hr for Class 4–5 diesel and

1 U.S. Environmental Protection Agency, "Control of Air Pollution from New Motor Vehicles: Heavy-Duty Engine and Vehicle Standards", December 20, 2022, https://www.epa.gov/system/files/documents/2023-01/new-motor-veh-air-poll-control-hd-eng-veh-stnd-frm-2022-12-20.pdf

2 The percentage reduction cited here is the reduction in NO_x emission numerical values under the Federal Test Procedure (FTP) and the Supplemental Emission Test (SET) duty cycles for Otto-cycle HDVs and Class 4-5 diesel HDVs. The numerical values for other HDV classes and under off-cycle conditions are different than 82.5%.

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Otto-cycle engine trucks and 50 mg/bhp-hr for Class 6–8 diesel trucks starting in MY 2027. Following California Air Resources Board's (CARB) precedent, the 2027 standard adds a new low-load testing cycle (LLC) to the existing Federal Test Procedure (FTP) to better capture emissions under different operating conditions, such as during urban driving when NO_X aftertreatment technologies tend to lose efficiency due to low exhaust temperatures.[3]

Under the new regulation, manufacturers can use an interim in-use compliance allowance for Class 6–8 diesel HDVs and engines (i.e., medium HDEs and heavy HDEs), which is awarded after EPA evaluates that they meet the final standards in use in the real world. Manufacturers will add the compliance allowance of 15 mg/bhp-hr to the NO_X standard that applies for each duty cycle and non-idle off-cycle for both in-use field testing and laboratory testing. EPA did not set an expiration date for the interim in-use compliance allowance.

Table 1 compares the existing and new NO_X standards under different drive cycles for engine classes. The EPA CTP-NO_X regulation also sets a 5 mg/bhp-hr particulate matter (PM) emissions limit beginning in MY 2027, a 50% reduction from the current 10 g/bhp-hr limit.

Table 1. Current and updated NO_X emission standards for heavy-duty diesel and Otto engines

	Current	MY 2027	
	All HD Engines	Otto-cycle HDVs, Class 4–5 diesel HDVs	Class 6–8 diesel HDVs [a]
Federal Test Procedure (FTP), in mg/bhp-hr	200	35	50
Supplemental Emission Test (SET), in mg/bhp-hr	200	35	50
Low-Load Cycle (diesel only), in mg/bhp-hr	N/A	50	65
Idle (diesel only),[b] in g/hr	N/A	10	

[a] Values include the 15 mg/bhp-hr in-use compliance allowance.
[b] The idle standard is voluntary, but manufacturers certifying to the optional idle standard must comply with the standard and related requirements as if they were mandatory. For MY 2024 to MY 2026, engine manufacturers can voluntarily certify to an idle NO_X standard of 30.0 g/hr.

UPDATES TO OFF-CYCLE TESTING

Following similar actions by CARB and the European Union, the new regulation replaces the not-to-exceed (NTE) testing approach for diesel engines with a two-bin moving average window (MAW) methodology that allows emissions collected across a much wider range of operating conditions to be used in determining in-use emission compliance.[4] Driving periods, or windows, are sorted into two bins based on carbon dioxide (CO_2) output during the testing window and normalized to the engine's nominal maximum CO_2 rate, defined as the engine's rated maximum power multiplied by the engine's CO_2 family certification level for the FTP certification cycle. A window with a normalized CO_2 emission rate lower than 6% is considered idle. Windows with over 6% normalized CO_2 emissions are considered non-idle. These bins and the emission limits are summarized in Table 2.

3 Huzeifa Badshah, Francisco Posada, and Rachel Muncrief, "Current State of NO_X Emissions from In-Use Heavy-Duty Diesel Vehicles in the United States," (ICCT: Washington, DC, 2019), https://theicct.org/publication/current-state-of-nox-emissions-from-in-use-heavy-duty-diesel-vehicles-in-the-united-states/.

4 Francisco Posada, Huzeifa Badshah, and 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.

Table 2. Summary of bins for two-bin MAW off-cycle testing method

Bin	Normalized average window CO_2 emissions rate	Emissions limit
Idle (1)	≤ 6%	1.0 × idle limit
Non-idle (2)	> 6%	1.5 × (0.25 × LLC limit + 0.75 × SET limit) [a]

[a] The 15 mg/bhp-hr interim in-use compliance allowance applies to medium and heavy HDEs.

The new regulation allows for a low ambient temperature adjustment to the emission limits because, the agency states, colder temperatures can impair the engine's ability to keep the temperature in the aftertreatment system above the minimum level required by selective catalytic reduction (SCR), The regulation incorporates a temperature-based adjustment below 25 °C (77 °F) to the final numerical NO_X standards, as shown in Table 3. The final temperature-adjusted numerical NO_X standard is the sum of the specified NO_X standard in the off-cycle bin and the calculated temperature adjustment. The in-use compliance allowance for Class 6–8 diesel HDVs in off-cycle Bin 2 also applies here.

Table 3. Temperature adjustments to the in-use NO_X standards

Off-cycle bin	NO_X emissions limit	Temperature adjustment*
Bin 1	10.0 g/hr	$(25.0 - T_{amb}) \times 0.25$
Bin 2	58 mg/bhp-hr	$(25.0 - T_{amb}) \times 2.2$

*T_{amb} is the mean ambient temperature over a shift-day in degrees Celsius.

USEFUL LIFE AND WARRANTY

In the new regulation, EPA updates useful life requirements beginning in MY 2027, extending the useful life measured in years and vehicle miles traveled and adding hours-based useful life values to the standards. HDEs must maintain compliance with emission standards throughout their useful life, which ends when the first of these thresholds is crossed. Table 4 shows the useful life definitions through 2031. Manufacturers of Class 8 diesel vehicles are also required to demonstrate in laboratory conditions that the emissions control technology is durable through the final useful life mileage, equivalent to 750,000 miles, before the vehicles are produced.

Table 4. Current and updated useful life provisions for heavy-duty vehicles in vehicle miles, years, and hours

Model year	Useful life			
	Class 4–5 diesel 14,001–19,500 lb	Class 6–7 diesel 19,501–33,000 lb	Class 8 diesel > 33,000 lb	Heavy-duty Otto > 14,000 lb
Current through 2026	110,000 miles 10 years	185,000 miles 10 years	435,000 miles 10 years	110,000 miles 10 years
2027 and beyond	270,000 miles 15 years 13,000 hours	350,000 miles 12 years 17,000 hours	650,000 miles 11 years 32,000 hours	200,000 miles 15 years 10,000 hours

Starting from MY 2027 EPA also sets significantly longer warranty periods to better reflect HDVs' real-world lifetimes and encourage maintenance of emissions control components to ensure continued optimal operation while in use. Table 5 summarizes the emission-related warranty periods for HDEs in the long term. Like the useful life provisions, warranty periods are measured in vehicle miles, years, and operational hours, with the warranty period ending when the first threshold is crossed.

Table 5. Current and updated emission-related warranty periods for heavy-duty vehicles in vehicle miles, years, and hours

Model Year	Warranty			
	Class 4–5 diesel 14,001–19,500 lb	Class 6–7 diesel 19,501–33,000 lb	Class 8 diesel > 33,000 lb	Heavy-duty Otto > 14,000 lb
Current through 2026	50,000 miles 5 years	100,000 miles 5 years	100,000 miles 5 years	50,000 miles 5 years
2027 and beyond	210,000 miles 10 years 10,000 hours	280,000 miles 10 years 14,000 hours	450,000 miles 10 years 22,000 hours	160,000 miles 10 years 8,000 hours

UPDATES TO AVERAGING, BANKING, AND TRADING

In the new regulation, EPA has lowered the family emission limit (FEL) cap from 200 mg/bhp-hr to 65 mg/bhp-hr for MYs 2027–2030 and to 50 mg/bhp-hr for MY 2031 and later. The updated averaging, banking, and trading (ABT) system calculates NO_x credits based on a single NO_x FEL using FTP cycle emissions data. It also maintains the same averaging sets (Otto, light heavy-duty diesel, medium heavy-duty diesel, and heavy heavy-duty diesel). The credit program for hydrocarbons and PM is discontinued beginning in MY 2027.

EPA included several mechanisms in the standard to generate NO_x emission credits to facilitate compliance flexibility and reward the early introduction of engines and vehicles that meet future standards. Manufacturers have the option to generate transitional credits between MY 2022 and MY 2026 with engines certified to an FEL below the current MY 2021 emission standard, and use the credits in MY 2027 and beyond. The transitional credit program provides four pathways to generate NO_x emissions credits whose values and expiry years are based on the extent to which the engines comply with MY 2027 and MY 2031 standards (Table 6). Separately, NO_x emissions credits used in MY 2027 and later will have a five-year credit life, consistent with EPA's CO_2 credit life provisions. Early adoption credit multipliers are excluded from the new rule and manufacturers will not be allowed to generate NO_x emission credits from zero-emission heavy-duty vehicles after 2026.

Table 6. Summary of transitional NO_x credits from MY 2022 to MY 2026

Pathway	2026 Service class pull ahead credits	Full credits	Partial credits	Discounted credits
Model Year(s)	**2026**	**2024–2026**	**2024–2026**	**2022–2026**
Certification standard	All models in heavy heavy-duty service class, FEL ≤ 50 mg/bhp-hr	Any model, any class, FEL < 200 mg/bhp-hr	Any model, any class, FEL < 200 mg/bhp-hr	Any model, any class, FEL < 200 mg/bhp-hr
Other requirements	Meet all other 2027 requirements, including LLC and off-cycle standards and useful life and warranty periods	Meet all other 2027 requirements including LLC and off-cycle standards and useful life and warranty periods	Meets all other 2027 requirements including LLC and off-cycle standards, except certified to current (shorter) useful life and warranty period	Meets only pre-2027 requirements
Credit expiration	MY 2034	MY 2032	MY 2032	MY 2029
Credit value	Full	Full	Partial (due to shorter useful life)	Discounted to 60%

An interim production volume allowance is also included in the new rule, through which manufacturers can use NO_x emissions credits to certify heavy HDEs compliant with MY 2010 requirements in MYs 2027 to 2029. The production volume allowance is 5% of the average U.S. directed production volumes of heavy HDEs for model years 2023 through 2025 (engines certified to the CARB Omnibus regulation are not eligible for this allowance).

ON-BOARD DIAGNOSTICS

The new rule is harmonized with CARB's 2019 on-board diagnostic (OBD) regulations, with a few exceptions. The final requirements will be mandatory from MY 2027 and are optional for earlier model years.[5] Exceptions where the rule does not fully align with CARB include different useful like requirements and the option for small manufacturers that have not previously certified an engine in California to delay compliance with the EPA rule up to three model years, among others.

The updated OBD program enables more accurate collection of SCR, diesel particulate filter (DPF), and diesel exhaust fluid operational parameters. This will facilitate preventive maintenance and reduce costs for operators to ensure real-world emission reductions over the useful life of the vehicle.

TECHNOLOGY PATHWAYS

The EPA CTP-NO_x regulation does not prescribe any specific engine or aftertreatment technologies to manufacturers. For diesel vehicles, most NO_x curtailment will come from upgrades in the aftertreatment process. Aftertreatment technologies will likely require substantial updates to meet the MY 2027 LLC and FTP NO_x limits and to comply with cold start testing. Figure 1 showcases three technology pathways that can meet these stricter standards. All three configurations employ a close-coupled SCR (ccSCR), which uses engine heat to reach higher temperatures more quickly. The first design splits SCR volume in two and places one before the first diesel oxidation catalyst. The first SCR would then also use a heated urea inlet.[6] The second configuration is more compact by combining the second SCR with the DPF. The final pathway combines the diesel oxidation catalyst (DOC) and DPF into a catalyzed soot filter. All three pathways have been demonstrated to reduce NO_x emissions to the levels required in the MY 2027 standards.

5 Final Regulation Order HD OBD Enforcement Regulation Title 13, California Code of Regulations, Section 1971.5, Enforcement of Malfunction and Diagnostic System Requirements for 2010 and Subsequent Model-Year Heavy-Duty Engines, California Air Resources Board, 2022, https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2021/obd2021/fro-hdobdenforcement.pdf; Final Regulation Order. HD OBD Regulation. Title 13, California Code of Regulations, Section 1971.1, On-Board Diagnostic System Requirements 2010 and Subsequent Model Year Heavy-Duty Engines, California Air Resources Board, 2022, https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2021/obd2021/fro-hdobd.pdf.

6 Posada, Badshah, and Rodriguez, "In-use NO_x Emissions and Compliance Evaluation for Modern Heavy-Duty Vehicles in Europe and the United States."

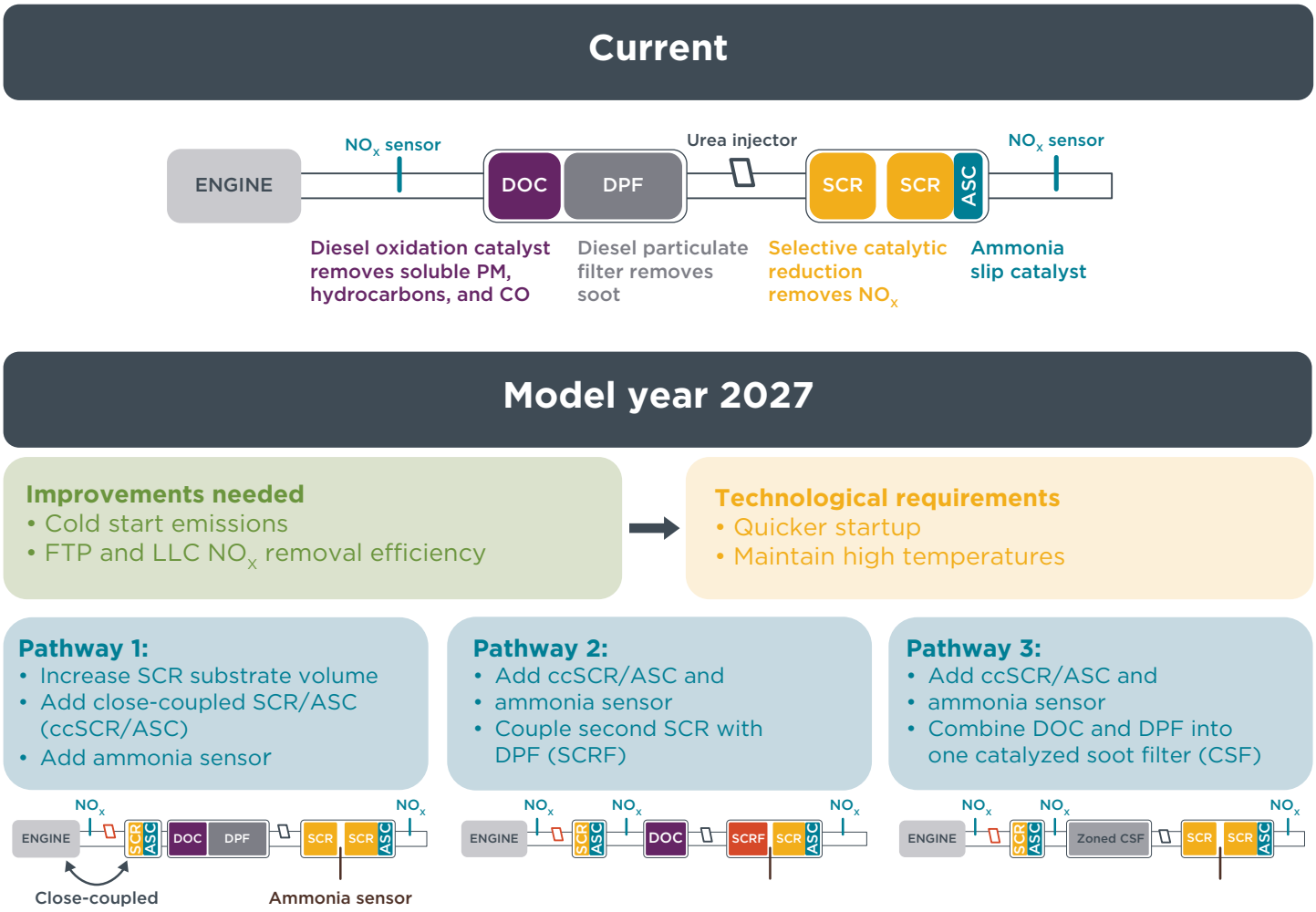

Figure 1. Technology pathways for diesel aftertreatment technologies to meet 2027 emissions standards

PROJECTED COSTS AND BENEFITS

EPA projects that the tightened emission limits, updated test cycles, extended useful life and warranty periods, and compliance crediting will reduce NO_x emissions from U.S. on-road heavy-duty vehicles by 14% in 2030, 44% in 2040, and 48% in 2045 compared to today's standards. EPA also projects the updated standards will lead to an 8% reduction in primary exhaust $PM_{2.5}$ emissions, a 23% reduction in volatile organic compound emissions, and an 18% decrease in CO emissions in 2045.

EPA's analysis reveals that the largest predicted improvements in both ozone and $PM_{2.5}$ concentrations will occur in areas with the worst baseline air quality, and that a higher-than-average percentage of people of color reside in these areas. The new standards will deliver the greatest reductions in $PM_{2.5}$ and ozone concentrations to non-Hispanic African-American communities.

EPA also calculated the direct costs that manufacturers would incur to meet the final standards—that is, the upfront emissions-reduction technology costs per engine. Direct costs include the cost of materials and labor to manufacture the component/engine. EPA's calculation of emissions control system baseline costs and the incremental costs associated with complying with the final regulation are shown in Figure 2.

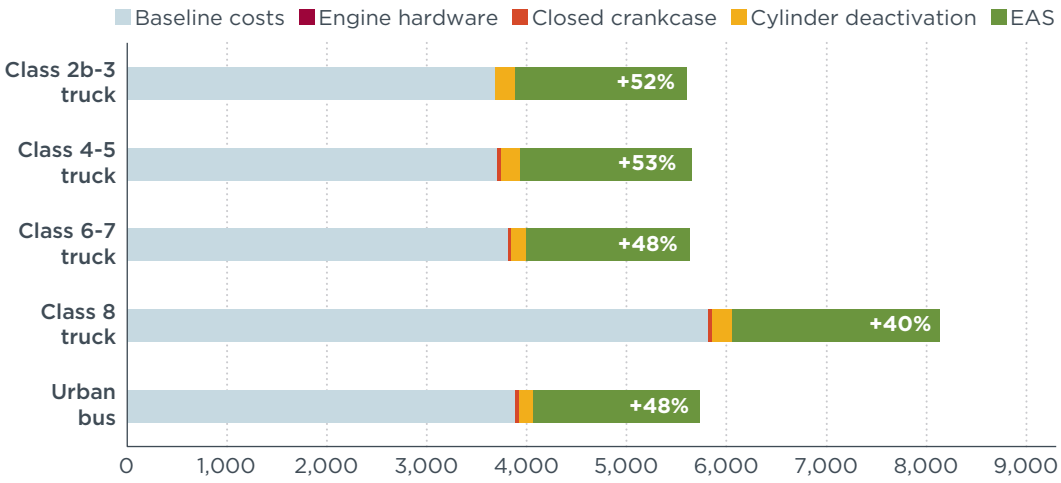

Figure 2. Direct manufacturing cost baseline and increments per diesel vehicle, by regulatory class (in 2017 U.S. dollars)

EPA estimates the updated NO_x regulation will provide the United States with a substantial net welfare gain. Table 7 summarizes EPA's projected monetary costs and benefits from 2027 to 2045. The total projected cost of the new regulation in 2045 is estimated to be approximately $55 billion at a 3% discount rate, or $39 billion at a 7% discount rate. Most costs can be attributed to additional technologies to meet the more stringent NO_x standards (direct cost) and the longer warranty and useful life requirements (indirect cost). The total health benefits from reductions in human exposure to ambient $PM_{2.5}$ and ozone between 2027 and 2045 are valued at $91 billion to $260 billion at a 3% discount rate and $53 billion to $150 billion at a 7% discount rate. In annualized terms, the net benefit in 2045 would be $6.9 billion to $29 billion with a 3% discount rate or $5.8 billion to $25 billion with a 7% discount rate.

Table 8. Cumulative costs and benefits of EPA regulation at different discount rates from 2027 to 2045, in 2017 U.S. dollars

	3% discount rate	7% discount rate
Direct technology cost	$14 billion	$10 billion
Indirect cost	$33 billion	$24 billion
Total operating cost	$1.4 billion	$1.4 billion
Other costs	$6.6 billion	$3.6 billion
Total costs	$55 billion	$39 billion
Total benefits	$91–$260 billion	$53–$150 billion
Net benefits	$36–$205 billion	$14– $111 billion
Cost-benefit ratio	1.65–4.72	1.39–3.85

COMPARISON TO CALIFORNIA OMNIBUS REGULATION

In December 2021, CARB adopted a new Omnibus regulation that updates standards, testing, and compliance mechanisms for NO_x and PM emissions from on-road heavy-duty vehicles, beginning with MY 2024.[7] The Omnibus regulation is broadly similar in scope to the EPA CTP-NO_x standards. The EPA rule adopts provisions similar to the CARB rule, including adding LLC to better reflect real-world driving conditions, replacing NTE standards with a work-based window approach, and extending the useful life and warranty periods. CARB Omnibus regulation has three phases (MY 2024,

7 "Heavy-Duty Omnibus Regulation," California Air Resources Board, accessed December 22, 2021, https://ww2.arb.ca.gov/rulemaking/2020/hdomnibuslownox.

MY 2027, and MY 2031+) and different NO_x emission limits under the FTP/Ramped Modal Cycle (RMC)–SET, LLC, and Idle cycles. In addition, the useful life and warranty requirements are different in the two regulations. For a better reflection of the full range of HDV operating conditions, the CARB Omnibus regulation adopts a three-bin MAW (idle, low-load, and high-load operations), while the EPA rule follows a two-bin MAW, where low-load and high-load operations are combined into a single non-idle bin. Unlike the EPA CTP-NO_x regulation, the CARB Omnibus rule has no in-use interim compliance allowances, and the emission standards are the same for in-use field testing and laboratory testing. Zero-emission HDVs can generate NOx credits from 2024 through 2026 under the CARB Omnibus rule but not under the EPA CTP-NO_x regulation.

On July 6, 2023, CARB announced a Clean Truck Partnership with ten major truck manufacturers in the United States and the Truck and Engine Manufacturers Association.[8] As one of the terms of the partnership, CARB agreed to harmonize the Omnibus regulation with the EPA CTP-NO_x regulation. Specifically, CARB proposes to incorporate the interim compliance allowance for Class 6–8 diesel HDVs with a sunset date of MY 2035, and temperature adjustment function between 5 °C and 20 °C for MYs 2027 to 2030, and between 0–5 °C from MY 2031 onwards. CARB will also propose a single national ABT program for NO_x standards for MHDVs co-administered by EPA and CARB.

INTERNATIONAL CONTEXT

In November 2022, the European Commission presented a proposal for Euro 7 emission standards for HDVs.[9] The proposed standards will lower total NO_x emissions from trucks and buses by 56% in 2035 compared to Euro 6. This magnitude of emission reductions is on par with the MY 2027 levels in CARB's Omnibus regulation. That suggests Euro 7 will feature similar approaches and platforms that rely on state-of-the-art aftertreatment technologies to control NO_x emissions, especially under low-load conditions, corresponding to urban driving and at low temperatures when the SCR process is less efficient. Euro 7 will also include standards for ammonia emissions, which are not regulated by CARB or EPA.[10] The two-bin MAW method used by EPA for diesel engines also differs slightly from the current European method in the Euro 6 standards. Euro 7 will improve its in-use testing method to cover a wider range of operating conditions and introduce two additional limits—a budget limit for short tests, and a higher limit that would require compliance across 100% of windows.

China has not formally begun formulating its next-stage HDV emission standards but is expected to announce a timeline before 2025, according to its 14th Five-Year Plan.[11] Environment and Climate Change Canada is expected to begin a rulemaking process in the near term to tighten HDV NO_x emissions. Canada has historically aligned pollutant emission regulations with the United States, and the EPA CTP-NO_x regulation is expected to inform and influence Canada's latest regulations.

8 California Air Resources Board, "CARB and truck and engine manufacturers announce unprecedented partnership to meet clean air goals", July 6, 2023, https://ww2.arb.ca.gov/news/carb-and-truck-and-engine-manufacturers-announce-unprecedented-partnership-meet-clean-air

9 European Commission, "Commission proposes new Euro 7 standards to reduce pollutant emissions from vehicles and improve air quality," November, 10, 2022, https://ec.europa.eu/commission/presscorner/detail/en/ip_22_6495. The Euro 7 standards will replace the currently separate Euro 6 emissions standards for passenger cars and vans and Euro VI for trucks and buses. The new standards for LDVs and HDVs are collectively referred to as Euro 7; Roman numerals are no longer used.

10 Both EPA and CARB consider whether ammonia emissions are excessive when evaluating manufacturers' applications for certification.

11 National Development and Reform Commission, People's Republic of China, "National 14th Five-Year Plan for Energy Saving and Emission Reduction," January 27, 2022, https://www.ndrc.gov.cn/fggz/hjyzy/jnhnx/202201/t20220127_1313521_ext.html.