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Estimated cost of diesel emission control technology to meet Euro 7 standards for heavy-duty vehicles

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In November 2022, the European Commission proposed stricter pollutant emissions limits for light- and heavy-duty vehicles for a regulation known as Euro 7.[1] Reductions in pollutant emissions can be achieved by equipping a vehicle with additional emission control technology on both the engine and aftertreatment systems, and several technology options have been considered by the industry to meet these standards.

In April 2021, the ICCT published a paper that assessed the costs of a range of technology options that could meet targets for heavy-duty vehicles (HDVs) that aligned with the recommendations of the Consortium for ultra Low Vehicle Emissions (CLOVE), which was contracted by the European Commission to support preparation of the Euro 7 standards. The CLOVE recommendations that were based on the performance of its medium-technology package ("HD3") extended vehicle durability requirements and would have resulted in a 90% reduction in nitrogen oxides (NO_x) emissions under the low-load and cold-start operations that are common in urban driving, and this is in line with California's regulation.[2] In the April 2021 paper, we estimated the incremental cost to comply with CLOVE's HD3 proposition would range from €1,400 to €4,300.[3]

The November 2022 regulatory proposal from the European Commission is, however, less stringent than what CLOVE recommended. Given this, we recently surveyed engine aftertreatment system (EATS) manufacturers and other automotive Tier 1 suppliers

1 European Commission, "Proposal for a Regulation of the European Parliament and of the Council on Type-Approval of Motor Vehicles and Engines and of Systems, Components and Separate Technical Units Intended for Such Vehicles, with Respect to Their Emissions and Battery Durability (Euro 7) and Repealing Regulations (EC) No 715/2007 and (EC) No 595/2009," 2022, https://ec.europa.eu/commission/presscorner/detail/en/ip_22_6495.

2 Stefan Hausberger, Konstantin Weller, Markus Ehrly, and CLOVE partners, "Supplements to the Scenarios for HDVs Emission Limits and Test Conditions," (Presented at the Advisory Group on Vehicle Emission Standards, Brussels, April 27, 2021), https://circabc.europa.eu/sd/a/e0063651-4e84-4b95-aac4-edb85a719764/AGVES-2021-04-27-HDV_Exhaust-v6b.pdf; California Air Resources Board, "Heavy-Duty Engine and Vehicle Omnibus Regulation and Associated Amendments," 2020, https://ww2.arb.ca.gov/rulemaking/2020/hdomnibuslownox.

3 Pierre-Louis Ragon and Felipe Rodriguez, "Estimated Cost of Diesel Emissions Control Technology to Meet Future Euro VII Standards," (ICCT: Berlin, 2021), https://theicct.org/sites/default/files/publications/tech-cost-euro-vii-210428.pdf.

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to generate new estimates that reflect the technology required to meet the less stringent emissions limits proposed by the European Commission and that factor in the technology developments over the past 2 years. Here we present those estimates of the incremental cost per vehicle to meet the European Commission's proposed limits for HDVs.

KEY ELEMENTS OF THE EUROPEAN COMMISSION'S EURO 7 PROPOSAL FOR HDVS

Four elements of the proposed Euro 7 regulation most affect the amount of technology required for emissions control in HDVs:

1. Emissions limits are applied under real-driving conditions as opposed to the engine dynamometer testing in Euro VI, and this requires vehicle manufacturers (original equipment manufacturers or OEMs) to comply under a wider range of operating conditions. The new test conditions put greater emphasis on the low-load and cold-start conditions that are common in urban driving.
2. NO_x emissions limits are lower and introduced over extended real-driving conditions; there are also new limits on nitrous oxide (N_2O) and ammonia emissions that require different catalyst system design.
3. Limits on particulate matter (PM) are tightened and limits on particulate number (PN) emissions for particles as small as 10 nm (previously the smallest regulated were 23 nm) are introduced. This requires different filter design.
4. Durability requirements, measured in full useful life, are extended, and this might require replacing parts of the emission control system throughout its lifetime. Warranty requirements are not extended.

Table 1 summarizes the proposed regulatory limits for those four elements. In all cases, the Commission's proposal is less stringent than what CLOVE recommended in 2021.

Table 1. Key elements of the Euro 7 regulation that impact the amount of technology required in heavy-duty vehicles.

Regulated component	Euro VI	Euro 7 recommendations (HD3) from CLOVE (April 2021)	European Commission's Euro 7 regulatory proposal (November 2022)	Main sub-system impacted
NO_x emission limit (90^{th} percentile)	460 mg/kWh	80 mg/kWh	90 mg/kWh	SCR system
NO_x emission limit (100^{th} percentile)	—	230 mg/kWh	350 mg/kWh	SCR system
N_2O emissions limit (90^{th} percentile)	—	60 mg/kWh	100 mg/kWh	SCR system
PN_{10} emissions limit (90^{th} percentile)	—	$1x10^{11}$ #/kWh	$2x10^{11}$ #/kWh	DPF
Full useful life (km)	700,000 km	1,200,000 km (+71%)	875,000 km (+25%)	SCR system, DPF

Note: SCR = selective catalytic reduction. DPF = diesel particulate filter.

TECHNOLOGY TO MEET THE EUROPEAN COMMISSION'S PROPOSED LIMITS

Based on the regulatory elements described above, industry experts estimate that complying with the proposed Euro 7 limits would require the following four aftertreatment technology upgrades, in addition to a typical Euro VI emission control system:

1. **Additional close-coupled catalyst and urea injection**. To achieve higher conversion of NO_x emissions under cold-start and low-load conditions, an additional selective catalytic reduction (SCR) stage is placed upstream of the diesel oxidation catalyst (DOC) in a typical Euro VI aftertreatment layout. Close-coupling this additional SCR stage to the engine achieves faster light-off at low engine exhaust temperatures. The downstream catalyst (DOC) can integrate the ammonia slip conversion (ASC) function, eliminating the need for an additional ASC. This requires minimal changes to the DOC design. Industry experts estimate that the total SCR volume, split between the close-coupled and underfloor stages, must increase by 20% to 30% between Euro VI and Euro 7 systems to achieve the required level of NO_x control over the extended durability requirements. In addition, enhanced substrate design is needed that leads to an increase of 20% to 30% in substrate costs. OEMs will also need to calibrate the dosing of urea between both SCR stages to optimize the NO_x conversion rate while minimizing slip of ammonia and N_2O; that will be an additional cost.
2. **Use of vanadium-based catalysts.** Typical Euro VI aftertreatment systems mostly rely on zeolite-supported copper catalysts (Cu-zeolites). To meet Euro 7 limits, several OEMs are considering using vanadium-based catalysts, as they have several advantages over their Cu-zeolite counterparts. They rely on a simpler chemistry that makes them cheaper and minimizes the formation of N_2O resulting from the catalytic reduction stage, which helps comply with the new N_2O emission limits. They are a suitable, low-cost alternative to copper catalysts for the close-coupled SCR stage, where the exhaust temperature is easier to control than in a post-filter location.
3. **Electric catalyst heating.** To further accelerate SCR warm up to the light-off temperature, OEMs can opt for an electric catalyst heater upstream of the close-coupled SCR; this improves performance during cold start and at low engine loads. Industry suppliers estimate that 25%–30% of their European customers are considering the use of an electric catalyst heater (ECH). Catalyst heating reduces the need for larger catalyst volumes, increased catalyst loading, or advanced urea injection strategies.
4. **Use of ultra-high filtration diesel particulate filters.** Meeting the proposed PM and PN limits requires the use of ultra-high-filtration diesel particulate filters (DPFs). Enhanced design is required to increase the filtration efficiency while ensuring only a small drop in pressure across the filter, to avoid a CO_2 penalty. Most OEMs want to avoid the use of a second filter downstream of the underfloor SCR, and EATS manufacturers consider this achievable with enhanced filter design. Meeting the Euro 7 requirements is expected to increase DPF costs by 10%–20%.

No additional engine technologies were considered. Several engine and power train technologies, including mild-hybridization, cylinder deactivation (CDA), and enhanced exhaust gas recirculation (EGR) flow design can simultaneously reduce both CO_2 and NO_x emissions. While we understand that North American OEMs are considering those technologies to comply with the latest HDV regulations in the United States, the Tier 1 suppliers with whom we consulted suggested that European OEMs are not. Therefore, only aftertreatment technology was considered in our cost estimate.

The resulting configuration, shown in Figure 1, is a typical Euro VI system of DOC + DPF + SCR/ASC complemented by an upstream close-coupled SCR with dual urea injection, an optional ECH, and a higher filtration DPF.

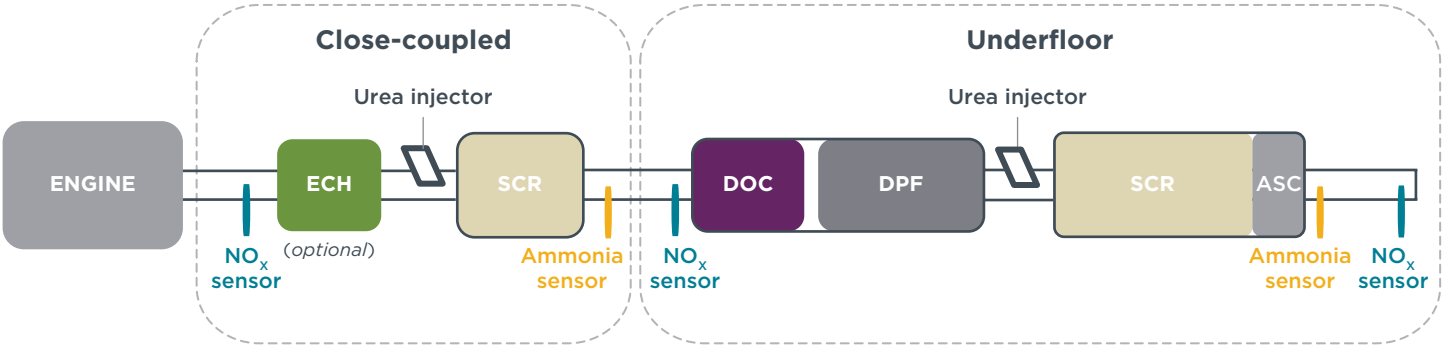

Figure 1. Example engine aftertreatment system configuration to comply with Euro 7 heavy-duty diesel emission limits.

Meeting the increased durability requirements will require higher catalyst volumes, enhanced substrate design, or in extreme cases might require catalyst and sensor replacements. Particulate filters also need to be serviced for ash every 240,000–320,000 km.

ESTIMATED COST OF TECHNOLOGY

Our cost estimates include direct manufacturing costs (DMCs) and indirect costs that cover investments in research and development and the calibration and validation efforts required for new technology. Indirect cost multipliers that are representative of the automotive industry were obtained from the United States Environmental Protection Agency and applied to DMCs.[4] Assuming implementation of the Euro 7 regulation in 2027 and using ICCT's Roadmap model, we project 3 million Euro 7 HDVs will be sold in Europe by 2050, which is in the same order of magnitude as the 4.1 million Euro VI vehicles expected to be sold between 2015 and 2050.[5] We therefore carry over the same indirect cost multipliers as in previous studies.

The full methodology for assessing the costs of technology is explained in the April 2021 paper.[6] We did not attempt to model the impacts of supply chain shortages, inflation, and geopolitical instability on the costs of emission control systems.

Figure 2 shows our estimates of the costs for a low-cost system without ECH and where the cost increases are on the lower-end of the range provided by industry experts, and a high-cost system with ECH and cost increases on the higher-end of the provided range. We find that the level of stringency proposed by the European Commission for the Euro 7 regulation would result in incremental costs for emission control systems ranging from €1,300 to €2,400 in 2027 compared to a typical Euro VI system. The impact assessment study supporting the regulatory proposal estimated incremental costs of €2,800.[7]

4 U.S. Environmental Protection Agency and U.S. Department of Transportation, "Greenhouse Gas Emissions and Fuel Efficiency Standards for Medium- and Heavy-Duty Engines and Vehicles–Phase 2," 81 Fed. Reg. 206, October 25, 2016, https://www.gpo.gov/fdsys/pkg/FR-2016-10-25/pdf/2016-21203.pdf.

5 ICCT, "Roadmap Model Documentation," 2023, https://theicct.github.io/roadmap-doc/.

6 Ragon and Rodriguez, "Estimated Cost of Diesel Emissions Control Technology to Meet Future Euro VII Standards."

7 Leonidas Ntziachristos et al., "Euro 7 Impact Assessment Study," (European Commissions: Brussels, 2022), https://op.europa.eu/de/publication-detail/-/publication/213be66d-5f1c-11ed-92ed-01aa75ed71a1/language-en.

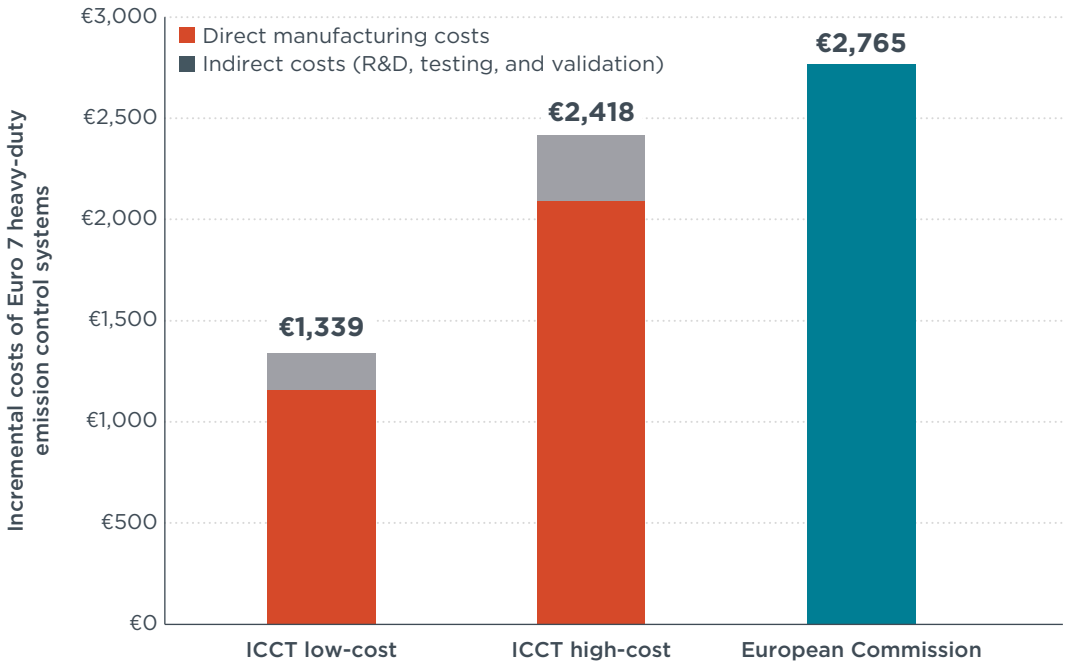

Figure 2. Estimated incremental costs of Euro 7 heavy-duty emission control systems.

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