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Authors

Dhole, Anuj
Ramji, Aditya
Fulton, Lewis
[et al.](#)

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**DESIGNING A SELF-FINANCING INCENTIVE PROGRAM FOR ZERO-EMISSION
TRUCKS IN CALIFORNIA: A MARKET-BASED, FEEBATE-INSPIRED POLICY
FRAMEWORK**

Anuj Dhole ^a (corresponding author)

Email: aadhole@ucdavis.edu

ORCID: <https://orcid.org/0009-0004-0204-0062>

Aditya Ramji ^a

Email: adiramji@ucdavis.edu

ORCID: <https://orcid.org/0000-0002-7614-6431>

Lewis Fulton ^a

Email: lmfulton@ucdavis.edu

ORCID: <https://orcid.org/0000-0001-8292-3420>

Daniel Sperling ^a

Email: dsperling@ucdavis.edu

ORCID: <https://orcid.org/0000-0002-8744-7651>

Roland Hwang ^a

Email: rojhwang@ucdavis.edu

ORCID: <https://orcid.org/0009-0009-5707-2041>

^a Institute of Transportation Studies, University of California, Davis, Davis, California (95616)

ABSTRACT

Until the price gap between diesel and zero-emission trucks (ZETs) shrinks significantly, policy intervention is necessary to accelerate the transition to ZETs. California and others have imposed annual sales requirements on truck manufacturers, coupled with purchase incentives with a limited state funding. To minimize the fiscal impact of government-funded incentives, we propose a self-financing rebate program for Class 4-8 trucks, using California as a case study. This is the first known study of truck feebates in the U.S. context, and likely globally. Under the scheme, diesel truck purchase or ownership would incur a fee, while ZET purchases would receive rebates. We consider various policy designs premised on revenue-neutrality (no cost to government) and minimizing cost burdens for transitioning fleets. Two design options are explored with multiple scenarios: a one-time upfront fee on diesel trucks at the point of sale or an annual fee on all operating diesel trucks, with the revenue used to finance rebates on ZET purchases. As an example, a one-time fee of 7% of the new diesel truck purchase price (~\$5,100 to \$20,400 per truck) or an annual fee of \$290-\$820 per diesel truck, depending on the class, could support rebates for 74,600 ZETs. Rebates decline from up to \$277,000 in the first year to up to \$40,000 in the last year as ZET sales spur. Any “excess” revenues could support ZET transition by funding charging infrastructure or incentivizing used ZETs. The annual fee approach provides the broadest funding base with modest fees.

Keywords: feebates, zero-emission, trucks, incentives, electrification, policy

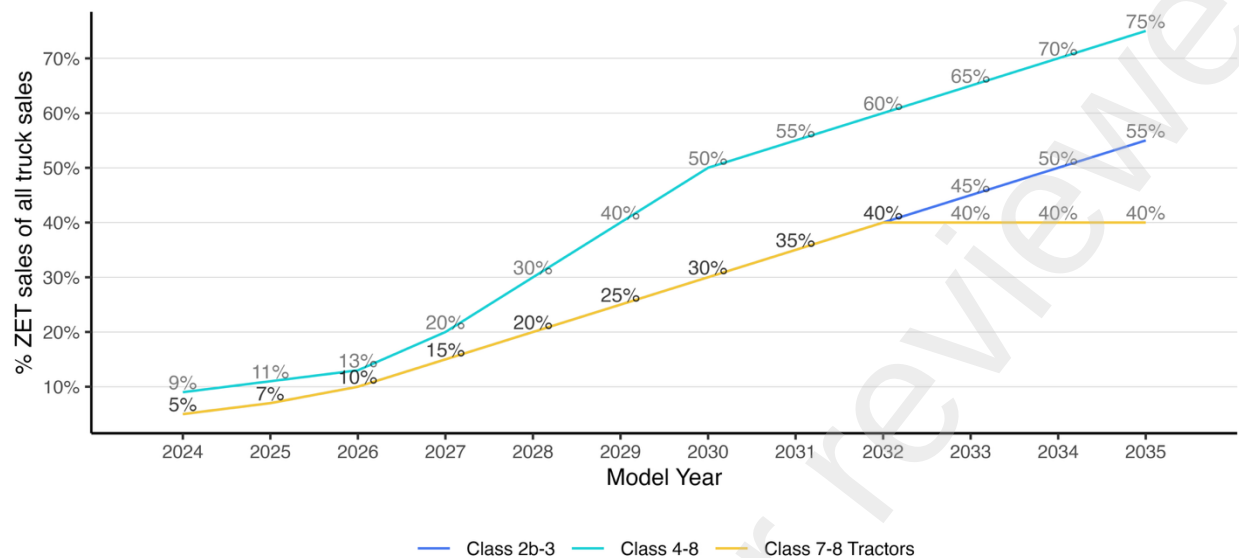
1. INTRODUCTION

The freight sector is a backbone of the U.S. economy, employing over 20 million in 2022 and contributing \$389 billion to GDP in 2021 (Bureau of Transportation Statistics, 2021). At the same time, medium and heavy-duty trucks (MHDTs), which constituted about 5% of the U.S. vehicle fleet in 2022, contributed 23% of the greenhouse gas emissions from the transportation sector (U.S. Environmental Protection Agency, 2024c). Truck emissions also pose health risks to populations around freight corridors and workers employed by the freight sector (Federal Highway Administration, 2023; Federal Motor Carrier Safety Administration, 2024; U.S. Environmental Protection Agency, 2024a). Electrification of trucks (including with hydrogen) remains a key strategy for clean transportation.

Various policies have been, and will be, adopted to address diesel truck emissions. National and European interventions include GHG emission and fuel efficiency standards, subsidizing and requiring vehicle charging and hydrogen refueling stations, and purchase subsidies (Chu et al., 2024; The European Parliament And The Council Of The European Union, 2023, 2024; U.S. Environmental Protection Agency, 2024b; U.S. Environmental Protection Agency et al., 2016).

Perhaps the most comprehensive and aggressive intervention has been in California. It adopted the Advanced Clean Trucks (ACT) rule in 2021, requiring truck manufacturers to have an increasing percentage of sales as zero-emission from 2024 – 2035, including a credit banking and trading mechanism (see Figure 1 for specific sales targets) (California Air Resources Board, 2023a). California also adopted the Advanced Clean Fleets (ACF) rule in 2023 requiring fleets to purchase ZETs, as way to create demand for ZETs and complement the ACT rule (California Air Resources Board, 2023c, 2023f). While the federal government in power sought to void these regulations (Lazo & Reyes-Velarde, 2025) – with California withdrawing the

1 ACF in January 2025 (California Air Resources Board, 2025a) – these types of policies are likely to prevail
 2 eventually and will certainly be replicated elsewhere.¹



Note: 2035 targets apply for model years 2035 and later

Figure 1. ZEV sales targets as per the Advanced Clean Trucks (ACT) Rule

Multiple challenges impact the scaled deployment of ZETs, including: (i) high upfront cost; (ii) range anxiety and infrastructure availability; (iii) grid capacity; and, (iv) payload trade-off with large battery packs (California Air Resources Board, 2021b, 2023e). Cost is especially critical in the near term. Depending on the truck class, a ZET cost up to three times that of an equivalent diesel truck in 2023 (Xie et al., 2023). Given these challenges, especially the higher cost, purchase incentives are an essential policy lever for promoting ZET uptake (Burke & Miller, 2020).

California's ACT rule includes a mechanism that credits manufacturers for sales of ZETs while generating deficits for sales of internal combustion engine (ICE) trucks. Since these credits are tradable, each manufacturer has two options to comply with the ACT sales requirements: (i) sell enough ZETs to meet the requirements, or (ii) purchase credits from other manufacturers at a mutually acceptable price. While some manufacturers may benefit from the sale of credits, their effect on the final prices is uncertain and may remain unknown since manufacturers are not required to reveal credit prices (California Air Resources Board, 2021a).²

The cost of purchase incentives to government can be substantial, and will need to be in place for many years – until cost reductions from economies of scale and innovation bring ZET costs closer to diesel trucks.

¹ ACF was expected to be a demand-side ZET program, complementary to the supply-side ACT. ACF required certain fleets to phase-in ZETs and could have resulted in 100% ZET operations by the end of 2035 for the targeted fleets.

² Manufacturers that only sell ZETs are likely to benefit from credit trading the way some light-duty vehicle manufacturers benefitted from selling credits (Epp, 2025). Effects of ACT credit trading on ZET prices remains to be seen since truck markets have lower sales volumes than the light-duty vehicle market.

As of June 2025, California had a purchase incentive program to reduce the cost of ZETs and buses for buyers, called the hybrid and zero-emission truck and bus voucher incentive project (HVIP), launched in 2010. In 2024, it offered a base incentive between \$45,000 and \$120,000 for class 4 to class 8 trucks and tractors. There are a few conditions for adjustments to this base amount. Large fleets that operate more than 500 trucks get only 50% of the incentive amount, fleets that operate 101 to 500 trucks get 80% of the incentive, and small fleets that operate 20 or fewer trucks receive double the incentive. Additionally, class 8 drayage trucks and refuse trucks receive an extra 25% on the base incentive, trucks purchased by small fleets domiciled in a disadvantaged community receive an extra 15%, and class 8 fuel-cell trucks receive double the incentive (California Climate Investments et al., 2024).

Separately, when applicable, the U.S. Inflation Reduction Act 2022 (US IRA) offered a tax credit up to 30% of the ZET price not exceeding \$7500 for ZETs less than 14,000 pounds, and up to \$40,000 for heavier ZETs, which is essentially applied as an upfront incentive to the purchase price of ZETs and could be claimed in addition to the California HVIP by consumers in the state (Internal Revenue Service, 2024; SAFE & Electrification Coalition, 2022).

Even these large incentives provided by HVIP and US IRA remain insufficient in the near term to achieve purchase price parity, with final ZET prices still too high to attract scaled adoption (Table 1). Another concern is that the longevity of HVIP and US IRA credits is vulnerable to wavering political commitments, undermining investor and buyer confidence and certainty. HVIP, for instance, is limited by total funding apportioned to the program by the state of California, which is a part of a larger \$9.1 billion Zero-Emission Vehicle Package (ZEV Package) appropriated to the California Air Resources Board (CARB) in the 2021 budget, to be spent over 5 years (California Air Resources Board, 2024b).

Table 1. An illustration of the effect of HVIP incentives, if available, on prices of heavy-duty Class 8 tractors by three fuel types in California.

Fuel Type	Diesel	Battery-electric	Fuel-cell electric
Initial Price, 2024	\$180,000	\$ 500,000	\$ 500,000
HVIP base incentive	-	\$ 120,000	\$ 120,000
HVIP modifier incentive	-	-	\$ 120,000
Inflation Reduction Act Tax credits	-	\$ 40,000	\$ 40,000
Price after incentive	\$ 180,000	\$ 340,000	\$ 220,000
Price disparity with diesel after incentive		\$ 160,000	\$ 40,000

Note: Truck prices are approximate for 2024, taken from the Transportation Transitions Model, UC Davis (Miller et al., 2025). Other modifier incentives can be stacked in both battery-electric and fuel-cell tractors like small fleet adjustment and disadvantaged community modifier. They have been ignored in this illustration since they apply in specific cases only.

Each year CARB prepares a funding plan for the upcoming financial year and allocates funding for various programs depending on need and priorities (California Air Resources Board, 2024a). Table 2 shows funding allocation for ZETs in the HVIP for years 2021-22 to 2024-25 (California Air Resources Board, 2021c, 2022b, 2023d, 2024b). As can be seen, the HVIP incentive allocation declined from \$678 million in 2021-22 to about \$20 million in 2024-25, largely driven by annual budgetary constraints. HVIP stopped accepting new applications for standard funds and drayage trucks since November and December 2024 respectively, and private fleets with 50 or more trucks were ineligible to apply for HVIP incentives from January 1, 2025 (California HVIP, 2024). As of May 2025, all new HVIP applications were closed, with possibility of some incentives for smaller fleets to be renewed (California Air Resources Board, 2025c, 2025d). This uncertainty around the scale and coverage of the HVIP impacts fleets who are making decisions on the purchase of ZETs and OEMs looking to sell sufficient ZETs to meet the ACT regulatory requirements.

Thus, while reliance on state budgets may not be sustainable to provide certainty, it calls for the need to explore suitable alternatives.

Table 2. Funding available for zero-emission trucks under HVIP from 2021 to 2025

Project Category	2021-22 (\$ million)	2022-23 (\$ million)	2023-24 (\$ million)	2024-25 (\$ million)
HVIP standard	569	265	-	-
Drayage Trucks	40	157	80	-
Innovative Small e-Fleets	-	35	14	15
Zero-emission truck loan pilot, truck loan assistance program	29	34	-	5
Other projects that include funding for ZETs with other vehicle types	40	75	-	-
Total	678	566	94	20

Source: California Air Resources Board, 2021c, 2022b, 2023d, 2024a.

Note: Numbers rounded to the nearest whole number.

Motivated by these concerns about erratic government spending commitments, the burden placed on taxpayers, and the severe policy uncertainty around the ZEV regulations in California we explore the application of a market-based feebate mechanism for incentivizing and promoting the sale of ZETs. In the case of California – and other jurisdictions adopting similar policies – this new mechanism could functionally replace HVIP, providing a market-based alternative to support compliance with ZEV sales requirements mandated under the ACT regulation. The choice of this specific policy tool as a solution is based on interviews with truck fleets and staff with California regulatory agencies and the state legislature. The research question is whether feebates can be a sustainable source to generate funding for ZET incentives that is independent of government budgets without imposing a substantial financial burden on fleets. Our goal is to perform an independent analysis of a few options for policymakers to consider. This study is the first application of market-based feebates for ZETs that we know of.

This analysis explores different incentive (i.e. rebate) and fee scenarios that can be revenue neutral or revenue positive, while minimizing the burden of fees and maximizing the coverage of incentives. In the process, we offer a methodological framework and several principles for the feebate design that addresses the duration of the program and price impacts, based on truck sales and stock for the state of California. The primary goal is to make ZETs more affordable, bringing them closer to upfront price parity – in some cases, even less expensive in terms of total cost of ownership – by reducing their price disparity with comparable diesel trucks. The rest of the paper is structured as follows: literature review of market-based mechanisms for incentivizing zero-emission vehicles globally; methods and results for various scenarios and feebate options; and summary and conclusions.

2. LITERATURE REVIEW

Medium and Heavy-Duty Trucks (MHDTs) have diverse applications and use cases, even within the same weight classes. Long-haul trucks (typically class 8) can be used for 300 to 800 miles per day and more than 100,000 miles per year with no fixed routes (Fleming et al., 2021; Phadke et al., 2021). On the other hand, class 7-8 short-haul trucks typically operate less than 250 miles per day for regional deliveries, while single-unit short haul trucks operate up to 60 miles per day for local deliveries (Federal Highway Administration, 2000; Geotab, 2025). Drayage trucks (typically class 8 tractors) are used for delivering shipping containers between specific areas such as ports and rail-yards, and operate within 100-mile distances with fixed and predictable route conditions (Harrison et al., 2007). Delivery trucks (classes 4-7) are used for short-distance urban deliveries (usually under 100 miles per day) with multiple stops (Lee et al., 2013). Vocational trucks include garbage trucks, dump trucks and cement mixers from classes 4-6 (medium-duty) and classes 7-8

(heavy-duty). They also usually travel short distances but use a power take-off unit to transfer power from engine to auxiliary devices (like hydraulic pumps or compressors) (Fleming et al., 2021).

With such diverse applications, decarbonizing MHDTs pose significant challenges. ZETs cost more than conventional fuel trucks, and they weigh more, imposing payload penalties for the fleets (Miller et al., 2017; Tol et al., 2022; Xie et al., 2023). Other technological limitations include longer refueling time and range limitations (Moultak et al., 2017). Fleets may thus have to purchase a greater number of trucks to fully replace an equivalent diesel fleet, which further increases costs (Giuliano et al., 2021). There have been concerns about resale value of light-duty electric vehicles (Roberson et al., 2024), and ZETs are yet to be deployed at scale to effectively determine their resale value. This also poses challenges for small fleets that mainly procure used trucks and cannot benefit from the incentives that are mainly offered for new ZET purchases. Finally, charging infrastructure for ZETs requires large investment, higher capacity chargers, and possibly costly grid upgrades (Giuliano et al., 2021; Spiller et al., 2023).

Accelerating the sale of ZETs will require sustainable and substantial incentives. Incentives have proven to be an effective way to promote electrification in other vehicle segments (Hall et al., 2020; IEA, 2021; Lindberg & Fridstrøm, 2015). One study estimated that for light-duty EVs, a \$1000 per-vehicle incentive corresponds to a 2.6% increase in EV sales in the U.S. (Jenn et al., 2018). Some studies suggest principles of incentive program design like offering direct upfront incentives at purchase, expanding the coverage of incentives to specific segments of consumers including equity criteria, long-term certainty of incentive programs, and using polluter-pays principle for funding the schemes (Ramji, Das, et al., 2024; Tankou et al., 2024; Yang et al., 2016).

Countries in Europe offer a range of tax discounts and feebate-style incentives for ZETs. While many countries pay a fixed incentive for smaller trucks, Belgium and Germany pay between 22.5% - 80% of the incremental cost of ZETs. Countries like Croatia, Greece, Malta and Sweden pay between 20% - 40% of the total ZET price, while many other countries determine incentive level based on vehicle price or weight class (ACEA, 2023; Radziukevich, 2024). Germany's program announced in 2021 paid 80% of the incremental cost of ZETs over diesels supported over 8000 ZETs in 3 years (Mobility Portal, 2024). The program was expected to last until 2025 but was terminated in January 2024 due to a lack of funding (Quecke, 2024). Austria, Finland and Germany included a clear target end date for the incentive program, while France and Greece have also defined a price and/or incentive cap (ACEA, 2023).

Market-based mechanisms for generating incentives, such as feebates, follow the polluter-pays principle and have been applied in several sectors including transportation, energy, agriculture, fuels, and manufacturing (Batini et al., 2020; Johnson, 2006; World Bank, 2022). Feebates, in the case of vehicles, involves imposing a fee on the sale (or use) of vehicles based on their emissions (typically measured as their CO₂ emissions or gCO₂/km) above a determined threshold, while vehicles below the threshold receive a rebate (Ramji, 2024). In the transportation sector, feebates have proven to be effective in promoting light-duty zero-emission vehicle sales in multiple countries, including France, United Kingdom, Germany, Sweden, Italy, Singapore and New Zealand (Ramji, 2024; Wappelhorst, 2022).

German and Meszler (German & Meszler, 2010) and Ramji et al. (Ramji, Fulton, et al., 2024) have identified best practices for designing a feebate system that may apply to MHDTs, which including metrics such as GHG emissions/km as a fee criterion and use of continuous and non-linear fee functions instead of step functions. To improve the political acceptability and policy efficacy of feebates when looking at multiple classes of vehicles (such as in MHDTs), each class can have its own feebate system (Johnson, 2006). A feebate system can be more effective when used as a complementary policy along with other policies like purchase mandates and emissions standards (Axsen et al., 2022).

Design flexibility of feebates can allow policymakers to ensure an equitable system that incentivizes cleaner vehicles with limited fiscal burden on governments and taxpayers (Fazeli et al., 2017; Fridstrøm & Østli, 2017). Feebates can be designed to respond to market changes without regulatory intervention, which increases certainty in the market (Johnson, 2006). Importantly, because feebates are premised on revenue

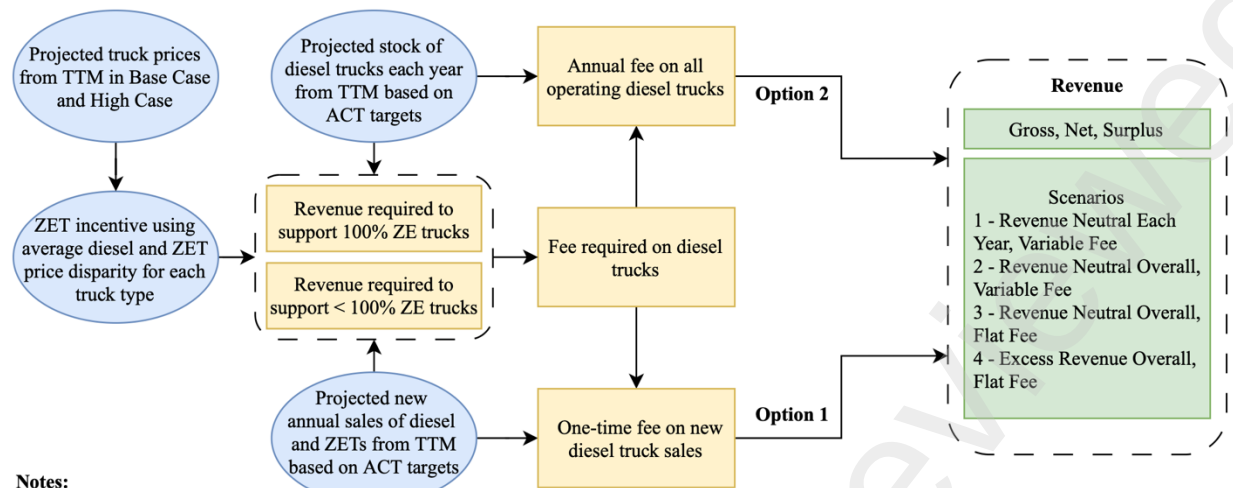
–neutrality, they can be politically acceptable (Brand et al., 2013; Martin et al., 2014). For all these reasons, feebates can be attractive market-based programs for ensuring a self-sufficient funding stream to incentivize clean or, in this case, zero-emission vehicles.

To date, feebate systems have used vehicle GHG emissions as the fee criteria, they have been applied only to new sales and not the stock, and they have been applied only for light-duty vehicles (Ledna et al., 2022; Wang et al., 2022; Xie et al., 2023). Feebates could be an effective strategy to accelerate ZET adoption and retire old trucks from the fleet (Fulton & Gruen, 2024).

3. METHODOLOGY

Conceptually, the model proposed for this market-based program is simple: revenue is generated from fees on polluting diesel trucks to incentivize ZETs. We rely on some key policy and economic principles to design the feebate. First, the fee imposed on polluting trucks should be minimal to ensure affordability for fleets. Affordable fee levels can also improve political feasibility and general acceptance of the program. Second, the program should aim for revenue neutrality (at the very least) over the duration of the program. Revenue neutrality is an explicit indicator of the intention of the program, while keeping the focus on the goal to accelerate ZET transition. While designing a revenue neutral program by projecting future cash flows is challenging, outlining strategies to handle excess revenue or deficits can help us in achieving this goal. Third, the program should have a target end date with a clear phase-out intention. This ensures that the program is predictable and ensures positive market signal, boosting market confidence in ZETs.

The analytical methodology is presented in Figure 2. Five truck types are considered with gross vehicle weight (GVW) rating of 14,001 pounds and above – class 8 long-haul, class 8 short-haul, class 4-6 medium-duty delivery, class 4-6 medium-duty vocational, and class 7-8 heavy-duty vocational; and three types of powertrains – diesel, battery-electric and fuel-cell. We used the UC Davis Transportation Transitions Model (TTM) to forecast the annual sales (Figure 3), truck stock (Figure 4) and price disparities between diesel and ZETs (Figure 5). The price disparities in TTM are projected by accounting for expected reductions in the cost of producing ZETs, including declining costs of batteries, fuel-cell systems and hydrogen fuel, as well as economies of scale over time (Fulton et al., 2019; Miller et al., 2025). While there is considerable uncertainty about these future prices, the projections here reflect a successful introduction and market growth of trucks around the US, leading to volume-related benefits. The price disparities in Figure 5 are presented as an average of the price differentials between diesel and the two zero-emission technologies considered, i.e. battery electric and fuel-cell. Other aspects of Figure 5 are described later in this section.



Notes:

- TTM - Transportation Transitions Model, UC Davis
- ZET - Zero-emission Truck
- ACT - Advanced Clean Trucks rule of California
- Analysis period - 2025 to 2035
- Scenarios 1 and 2 not worked out for Option 3
- Truck types analyzed - class 8 long-haul, class 8 short-haul, medium-duty delivery, medium-duty vocational, and heavy-duty vocational
- Powertrains analyzed - diesel, battery-electric and fuel-cell electric.
- Incentive amount for all truck types estimated using an average of the price disparities between diesel and both zero-emission power trains.

Figure 2. Methodological framework

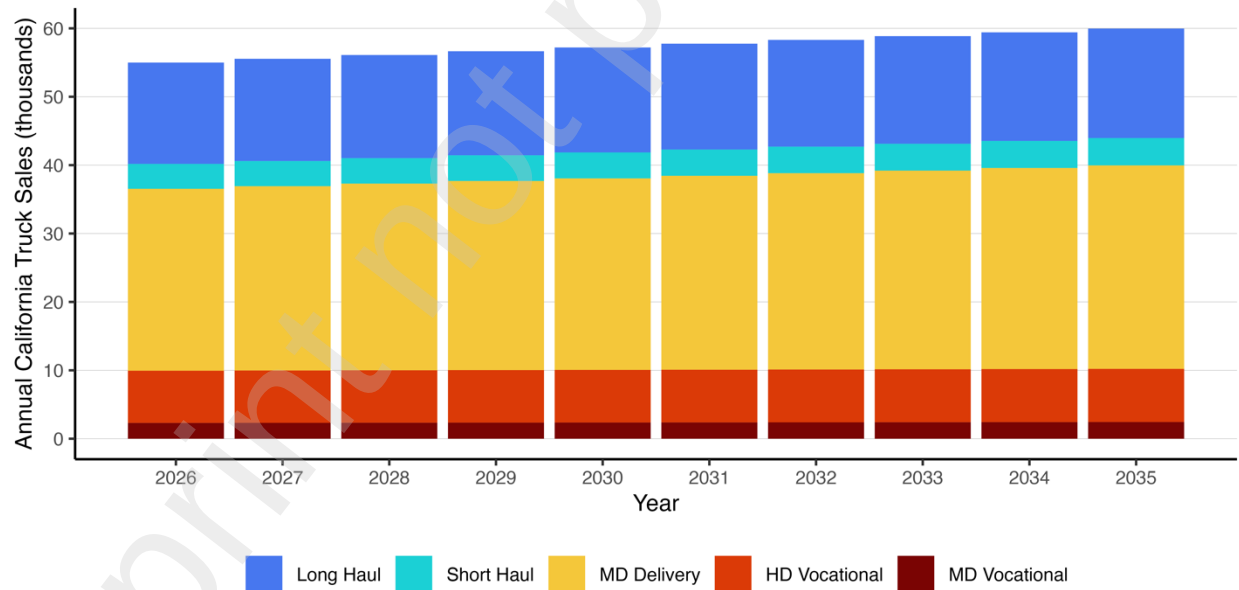


Figure 3. Projected total truck sales by truck type in California. (Note: MD – Medium-Duty, HD – Heavy-Duty)

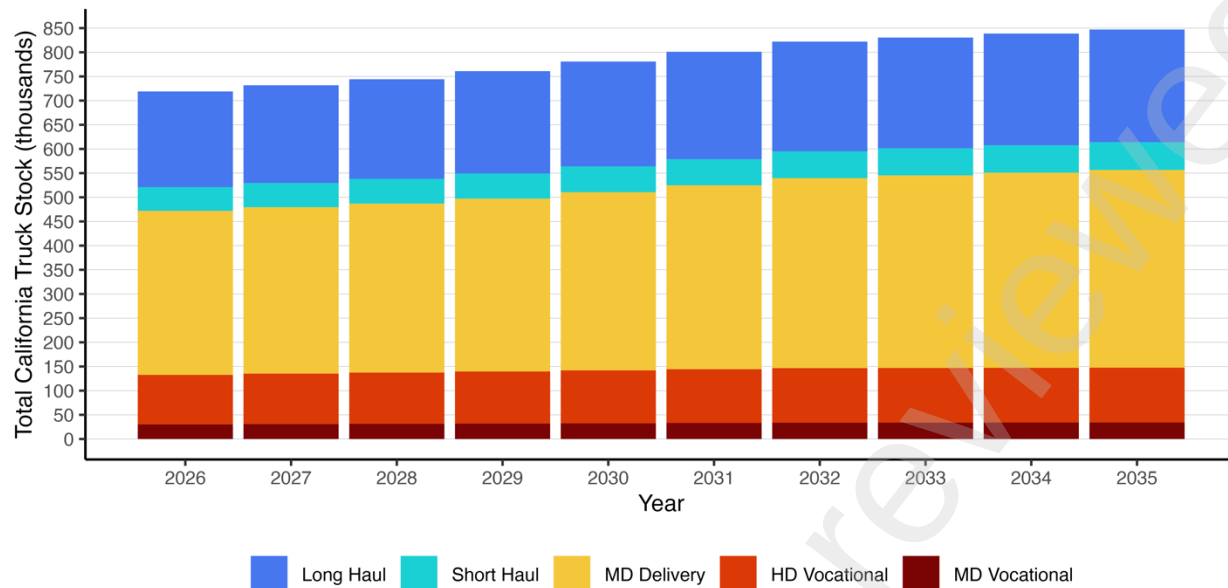


Figure 4. Projected truck stock by truck type in California. (Note: MD – Medium-Duty, HD – Heavy-Duty)

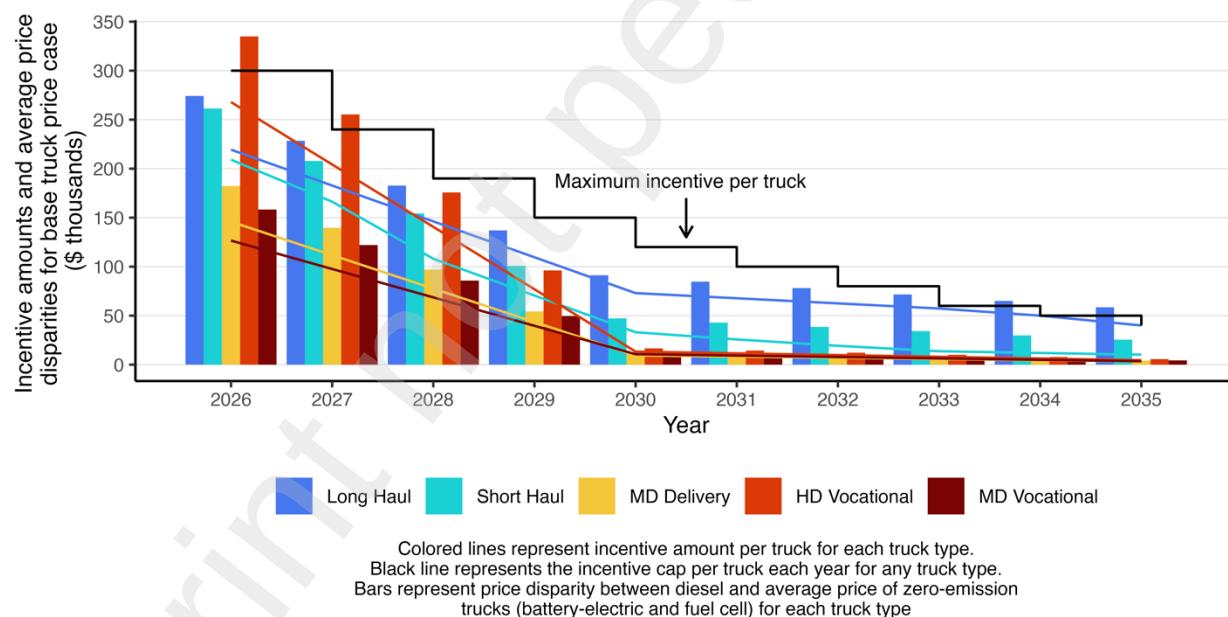


Figure 5. Incentive per truck and average price disparity between diesel and zero-emission trucks (ZET minus diesel price, using average price of battery-electric and fuel cell), by year and truck type. (Note: MD – Medium-Duty, HD – Heavy-Duty)

The annual share of ZET adoption for each truck type is based on California's ACT regulatory targets for 2026 to 2035 (Figure 6; right-hand chart). The sales share of fuel-cell trucks of all ZET sales are presented in the left-hand chart of Figure 6 (and the remaining share of all ZETs being battery electric). We have excluded class 2b-3 trucks (gross vehicle weight rating between 8,501 and 14,000 pounds) from this analysis since OEMs can use credits from class 2b-3 light duty trucks fungibly across either the ACT

regulation or the Advanced Clean Cars II (ACC II) regulation to comply with the zero-emission light-duty vehicle sales requirement rule of California (Bui et al., 2022; California Air Resources Board, 2022d).

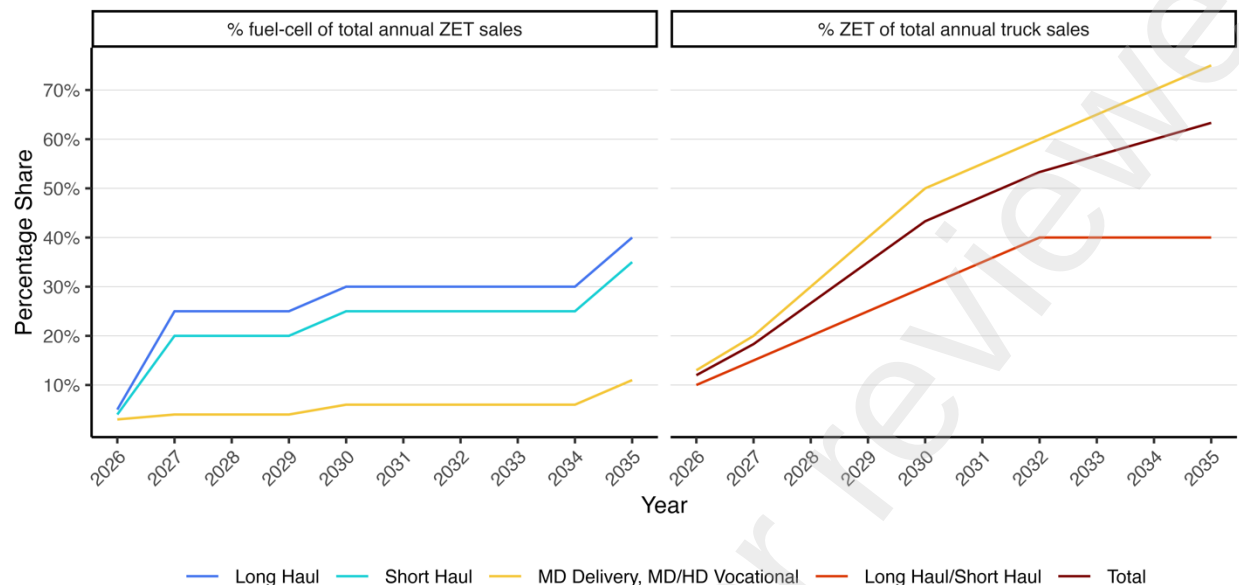


Figure 6. Assumptions on fuel-cell and overall ZET percentage sales shares. (Note: MD – Medium-Duty, HD – Heavy-Duty)

The levels of incentives for all ZETs were designed based on two criteria: (i) average price differential with equivalent diesel trucks; and, (ii) an incentive cap (Figure 5). We set the incentive amount at 80% of the average price disparity between diesel and the two ZET powertrains drawing from literature³. This approach would significantly reduce the upfront price gap, while leaving some room for the manufacturers to offer additional incentives and possibly eliminate the price gap. Substantially reducing the upfront purchase price of ZETs can also provide total cost of ownership benefits to ZETs (Basma et al., 2023). Thus, an 80% viability gap funding is guaranteed in the proposed program (subject to the second criterion discussed below). In comparison, while HVIP paid an incentive of up to 90% of the total price of the truck, most trucks would receive a much lower incentive (California Climate Investments et al., 2024).

Our second criterion sets a ceiling for incentives across all truck types, limiting the ZET prices within realistic ranges, with the incentive cap combined with the subsidy driving OEMs to innovate on technology to reduce costs⁴. We capped the maximum incentive at \$300,000 for 2026 (which could be more than the sum of HVIP base incentive, HVIP modifier incentive, and federal tax credit shown in Table 1 for most fleets). We then lower the ceiling annually by 20% from 2027 until the end of the program. A 20% annual reduction leads to a maximum incentive of \$40,265 in 2035 – which is about 13% of the first-year ceiling – leading to a smooth phase out of the incentive in 2036. Annual reduction in the ceiling could lead to technology and R&D improvements, reducing costs with scale and innovation.

³ We demonstrate this methodology on average price disparity to keep the program design technology-agnostic. This methodology can be extended to each powertrain separately based on the needs of the policymakers.

⁴ In combination with the first criteria, this also establishes a price ceiling for the ZETs.

To determine the target number of ZETs that receive an incentive, we assume that only a subset of ZET sales is supported each year. For this, we refer to the number of vehicles supported by the California Vehicle Rebate Project (CVRP), as an example. CVRP was an incentive program for light-duty electric vehicles in California implemented from 2010 to 2023. CVRP supported about 45% of the electric vehicles sold every year in its initial year and about 20% in the later years (Center for Sustainable Energy, 2024). We assume that 50% of the ZETs sold are supported from 2026 to 2027, 40% from 2028 to 2030, 30% from 2031 to 2033 and 20% in 2034 and 2035. We start with a higher share of supported vehicles compared to CVRP to account for the higher price disparity and affordability challenges in the case of trucks compared to light duty vehicles. To estimate how many ZETs would be supported under the program, we applied the assumed support percentages to projected ZET sales from the TTM, based on ACT sales targets. This approach yields an estimated 74,600 supported ZETs over the life of the program, out of a total of about 242,000 ZETs expected to be sold during the same period (Figure 7).

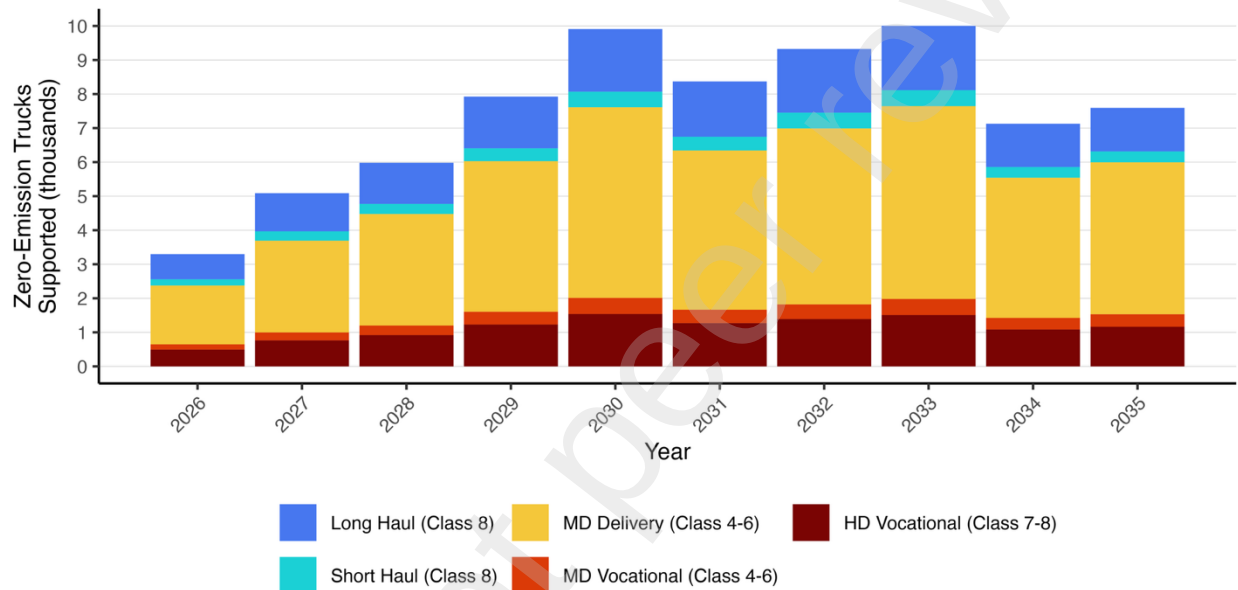


Figure 7. Number of zero-emission trucks supported during the program.

The objective of the analysis was to estimate the fee levels required on the diesel trucks to support a pre-determined percentage of annual ZET sales at the incentive levels described earlier. We define two fee design alternatives: (i) *Option 1*: a one-time, upfront fee during purchase of a new diesel truck; and (ii) *Option 2*: an annual fee on the entire diesel truck stock. The one-time fee follows a traditional feebate design approach used for light-duty vehicles affecting only new sales, while the second option is an innovative approach that affects the entire truck stock of California. The second fee option is suitable for commercial vehicles that pay an annual registration renewal fee, in the California context, as described under the Commercial Vehicle Registration Act (CVRA) (Department of Motor Vehicles, State of California, 2004a).

4. MATHEMATICAL FORMULATION

To design multiple policy options, each fee option is evaluated across four scenarios for each truck type by following our design principles. We designed all scenarios to ensure that the program is at least revenue-neutral overall. Specifically:

1. In **Scenario 1 (Variable Fee, Revenue Neutral Each Year)**, we adjust the fee so that it ensures revenue neutrality every single year of the program. This scenario shows the minimum level of fee

required each year for each of the truck typologies to ensure revenue neutrality. Each truck type is treated as a distinct system, ensuring that the revenue generated from the fees of a specific truck type is exclusively utilized to provide incentives to ZETs of the same truck type.

2. In **Scenario 2 (Variable Fee, Revenue Neutral Overall)**, we adjust the fee to ensure revenue neutrality over the program's duration. This scenario design allows us to distribute the revenue across multiple years, thus ensuring more stability in the cash flow. Each truck type is treated as a distinct system like Scenario 1.
3. In **Scenario 3 (Flat Fee, Revenue Neutral Overall)**, we adjust the fee to ensure revenue neutrality over the program's duration without treating each truck type as a separate system. We combine revenue from all the truck types into a single pool and design a flat fee over the program, rationalized across different truck types by redistributing the revenue between them.
4. In **Scenario 4 (Flat Fee, Excess Revenue Overall)**, we impose a flat and rationalized fee for each truck type similar to Scenario 3, but at higher levels. The benefit of designing this scenario is that it ensures that none of the years are revenue deficit, thus making the program completely independent of the government budgets.

The program must impose a fee on diesel trucks to raise revenue that is sufficient to pay the incentives for the target number of ZETs. To estimate the required revenue each year, we multiplied the ZET sales each year for each truck type by the target incentive levels (equation 1). Revenue generated was calculated by multiplying the fee levels for each truck type for each year by the number of ZETs supported in those years. We calculated the net revenue by taking the difference between the generated and required revenues and estimated the cumulative net revenue for each year (equation 2).

Let:

t: truck type

T: set of truck types

y: year

Y: set of years for the program

Parameters:

$I_{t,y}$: Incentive per zero-emission truck

$e_{t,y}$: Percentage of zero-emission trucks eligible to receive an incentive

$S_{t,y}^{ZET}$: Zero-emission truck annual sales

$S_{t,y}^D$: Diesel trucks available (annual sales for Option 1 and stock for Option 2)

$X_{t,y}$: Price of a new diesel truck for Option 1 and annual registration renewal fee (weight fee) under CVRA for Option 2

$F_{t,y}^n$: Estimated fee level in Scenario n applied on diesel trucks (on new truck sales for Option 1 and on stock for Option 2)

$R_{t,y}^R$: Revenue required to support target share of zero-emission trucks

$R_{t,y}^G$: Revenue generated from available diesel trucks at the estimated fee level F

$R_{t,y}^N$: Net revenue generated

$$R_{t,y}^R = I_{t,y} \cdot S_{t,y}^{ZET} \cdot e_{t,y} \quad \forall t \in T, y \in Y \#(1)$$

$$R_{t,y}^N = R_{t,y}^G - R_{t,y}^R \#(2)$$

The required revenue remains unchanged across scenarios, but the method to estimate the fee levels varies slightly between scenarios. In Scenario 1, we estimate the fee required on diesel trucks by dividing the estimated annual revenue by the number of diesel trucks available each year (equation 3). Generated revenue for each year is calculated by multiplying the estimated fee by the number of diesel trucks available in each year and separately for each truck type (equation 4).

$$F_{t,y}^1 = \frac{R_{t,y}^R}{S_{t,y}^D} \quad \#(3)$$

$$R_{t,y}^G = F_{t,y}^1 \cdot S_{t,y}^D = R_{t,y}^R \quad \forall t \in T, y \in Y \quad \#(4)$$

For Scenario 2, we estimate the fee by dividing “average” revenue required per year (equation 6) during the program by the number of diesel trucks available each year (equation 5). Generated revenue for the entire program is estimated by adding the product of the fee for each year and number of diesel trucks available in those years, separately for all truck types (equation 7).

$$F_{t,y}^2 = \frac{\bar{R}_t^R}{S_{t,y}^D} \quad \#(5)$$

$$\bar{R}_t^R = \frac{\sum_{y \in Y} R_{t,y}^R}{|Y|} \quad \#(6)$$

where $\bar{R}_t^R$ is the average revenue required per year and $|Y|$ is the number of years.

subject to:

$$\sum_{y \in Y} R_{t,y}^G = \sum_{y \in Y} F_{t,y}^2 \cdot S_{t,y}^D = \sum_{y \in Y} R_{t,y}^R \quad \forall t \in T \quad \#(7)$$

In Scenario 3, we first estimate the total revenue required for all truck types for all years and then adjust the fee levels such that the cumulative net revenue is positive and close to zero in the last year of the program (this makes the program revenue-neutral overall) (equation 8-11).

$$F_{t,y}^3 = \alpha \cdot X_{t,y} \quad \#(8)$$

Solve for α :

$$\alpha = \frac{\sum_{t \in T} \sum_{y \in Y} R_{t,y}^R}{\sum_{t \in T} \sum_{y \in Y} (X_{t,y} \cdot S_{t,y}^D)} \quad \#(9)$$

subject to:

$$\sum_{t \in T} \sum_{y \in Y} (F_{t,y}^3 \cdot S_{t,y}^D - R_{t,y}^R) \geq 0 \quad \forall y \in Y \quad \#(10)$$

$$\sum_{t \in T} \sum_{y \in Y} R_{t,y}^G = \sum_{t \in T} \sum_{y \in Y} (F_{t,y}^3 \cdot S_{t,y}^D) = \sum_{t \in T} \sum_{y \in Y} (\alpha \cdot X_{t,y} \cdot S_{t,y}^D) \quad \#(11)$$

In Scenario 4, we estimate minimum fee levels for all truck types to maintain a positive cumulative net revenue in all years, also ensuring they are of the same proportion of a new diesel truck price for one-time fee option and annual registration renewal fees for annual fee option. (equations 12-14).

$$F_{t,y}^4 = \alpha \cdot X_{t,y} \quad \#(12)$$

Solve for α :

$$\alpha = \frac{\sum_{t \in T} \sum_{y \in Y} R_{t,y}^R}{\sum_{t \in T} \sum_{y \in Y} (X_{t,y} \cdot S_{t,y}^D)} \quad \#(13)$$

subject to:

$$\sum_{t \in T} \sum_{y'=1}^y (F_{t,y'}^4 \cdot S_{t,y'}^D - R_{t,y'}^R) \geq 0 \quad \forall y \in Y \quad \#(14)$$

$$\sum_{t \in T} \sum_{y \in Y} R_{t,y}^G = \sum_{t \in T} \sum_{y \in Y} (F_{t,y}^4 \cdot S_{t,y}^D) = \sum_{t \in T} \sum_{y \in Y} (\alpha \cdot X_{t,y} \cdot S_{t,y}^D) \quad \#(15)$$

Combining the revenue from all truck types in Scenarios 3 and 4 gives us more flexibility in setting the fee levels rationally (by ensuring α is equal across all truck types). The estimated fee for Option 1 is represented as a percentage of the diesel truck price for each year.

5. RESULTS AND DISCUSSION

This section presents comparative results for the one-time fee (Option 1) and the annual fee (Option 2). We discuss the revenue generated (Figure 8) for both fee options followed by the estimated fee levels (Figure 9).

5.1 Revenue generated

In Scenario 1, the total revenue generated is the same for both fee options with an average of \$336 million/year. There is a large variation in the revenue generated each year while the net revenue stays zero each year of the program. The revenue generated is about \$600 million in 2026, increasing to almost \$750 million in 2027 and then drops significantly thereafter reaching \$76 million in 2035. The large variation is attributed to the need to generate “just enough” revenue every year to support the required number of ZETs and a substantial reduction in the price disparity between ZETs and diesel trucks in later years of the program. The proportion of revenue generated from each truck type also varies throughout the program. Combined revenue generated from medium-duty delivery, heavy-duty vocational and long-haul trucks forms a significant portion of the total revenue from 2026 to 2029 while the revenue from long-haul trucks dominates for the rest of the years.

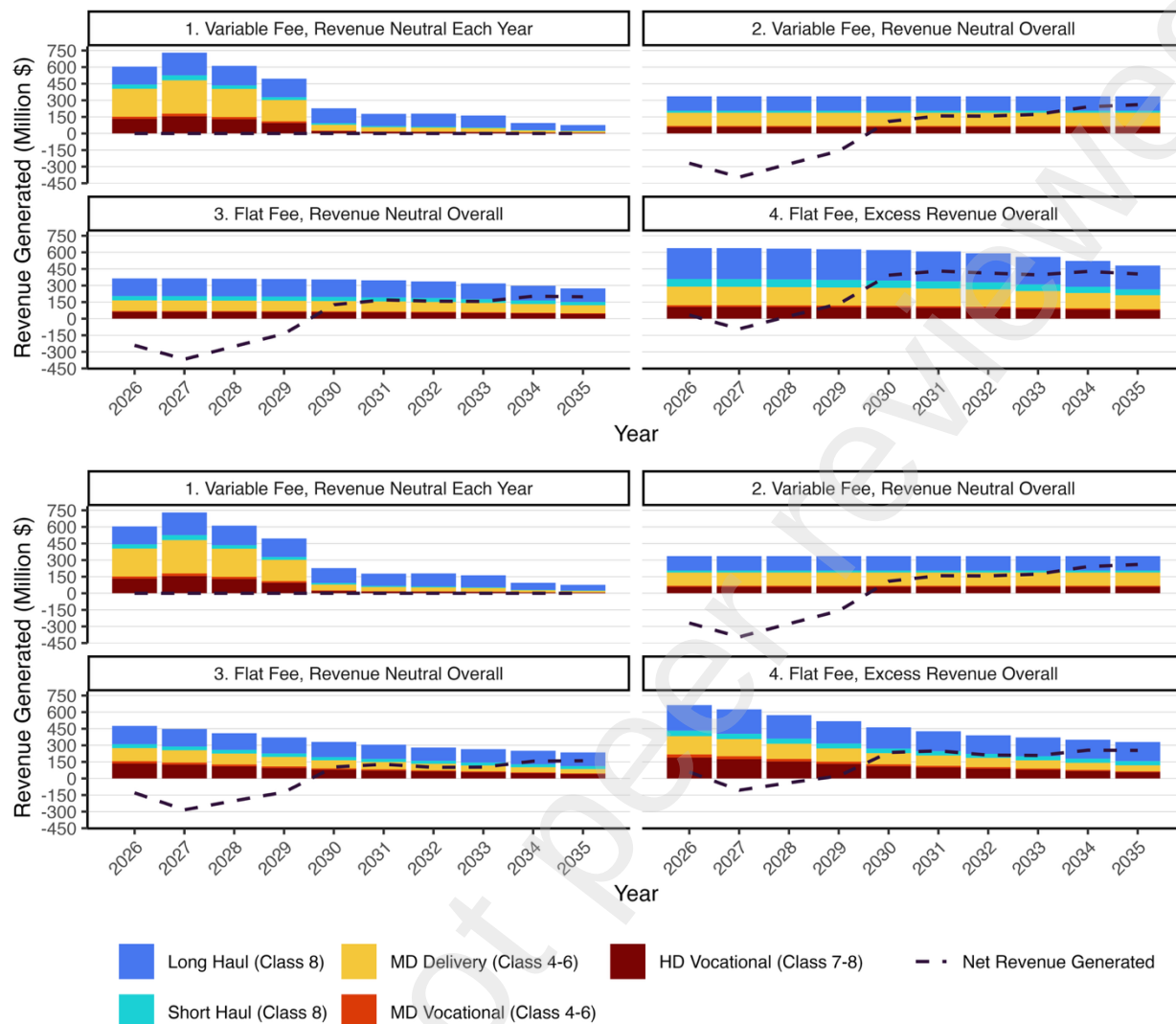


Figure 8. Revenue generated in the one-time fee (Option 1) (top) and annual fee (Option 2) (bottom)

In Scenario 2, the total revenue generated is \$336 million/year for both fee options and is equal for all years. Since the goal of Scenario 2 is overall revenue neutrality, revenue neutrality in individual years is not required. The net revenue from 2026 to 2029 is negative in Scenario 2 causing a deficit of \$740 million, while excess revenue is generated from 2030 onwards which make up for these deficits. We discovered that deficits occur in certain years regardless of the revenue distribution across the program, hence we assume an equal revenue distribution in this scenario.

The distribution of revenue generated in Scenario 3 is slightly different between the two fee options with an average of \$337 million/year for both. The one-time fee generates almost \$475 million in 2026 which falls to \$236 million in 2035. Revenue generated from annual fee is closer to the average in all years, generating \$364 million in 2026 and \$274 million in 2035. The difference between the two fee options can be attributed to the number of diesel trucks that generate the revenue (new diesel sales for one-time fee and diesel truck stock for annual fee). Diesel truck sales fall sharply from 2026 to 2035 while the stock reduces gradually, bringing in more stability to the revenue. Scenario 3 results in net revenue deficits in the early

years of the program and excess in the later years with a near-zero cumulative net revenue by the end of the program⁵.

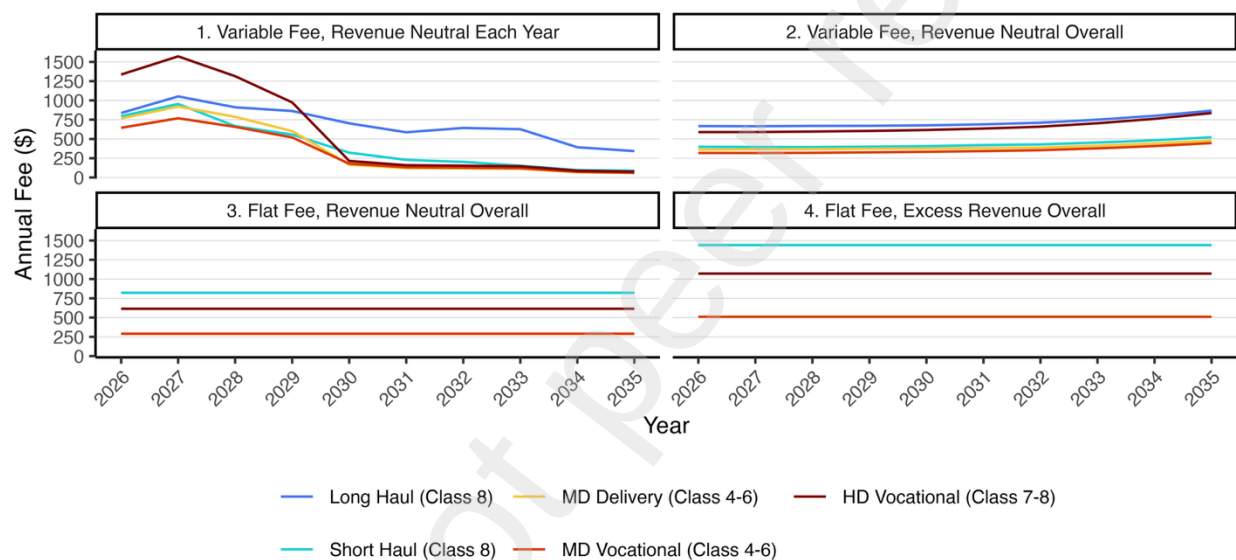
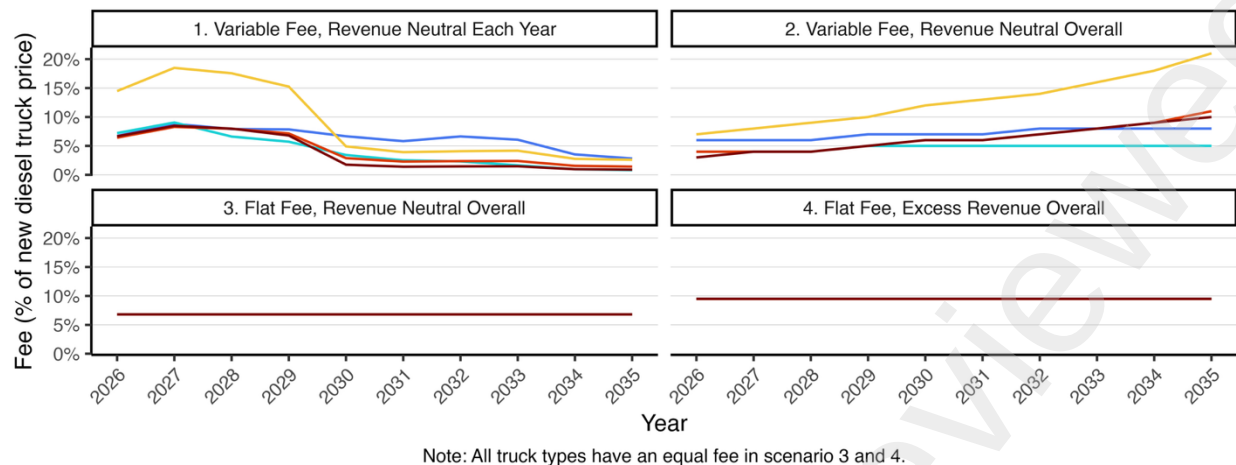
Scenario 4 generates an excess revenue overall with an average of \$471 million/year and \$592 million/year for the one-time fee and annual fee respectively. The distribution of the revenue throughout the program follows similar patterns as Scenario 3 for both fee options. For the years 2026 and 2035, the one-time fee option generates \$663 million and \$330 million, while the annual fee generates \$638 million and \$480 million respectively. The fee was designed to achieve a near-zero cumulative net revenue in 2027 – the year with highest revenue requirement – thus avoiding deficits. This fee was then applied as a flat rate throughout the program, generating an excess revenue in other years. While a net revenue deficit is observed for the years 2027-2028, this is compensated by the excess revenue already generated in 2026. Since the funding base for the one-time fee (new diesel truck sales) decreases rapidly, a lower overall revenue is generated than the annual fee option.

5.2 Fee

Scenario 1 results in a variable fee throughout the program with a peak in 2027 for both fee options as shown in Figure 9. The peak in 2027 is caused by the largest revenue requirement due to a quick ramp up of ZET sales while the price disparity is still high (refer Figure 5 Figure 6). Medium-duty delivery trucks have the highest fee from 2026 to 2029 for the one-time fee driven by largest ZET sales volumes (Figure 7). In case of annual fee, heavy duty vocational trucks have the highest fee during the same time, driven by the largest price disparity. The differences in the two fee types are caused by the size of the funding base (annual sales/stock of diesel trucks), which is larger in the case of annual fee option.

Scenario 2 results in a more stable and an increasing fee in both fee options since the revenue is distributed equally across all years. Medium-duty delivery trucks have the highest one-time fee due to larger sales volumes throughout the program, while long-haul trucks have the highest annual fee because they consistently have high price disparity (even in later years of the program). The increase in the fee levels for most truck types in the one-time fee option is much sharper than the annual fee option from 2026 to 2035, owing to a faster decline in the funding base (new diesel truck sales). For example, the fee for medium duty delivery trucks triples from 2026 to 2035, while the fee for long-haul trucks increases by 30% in the same period for the annual fee option.

⁵ The cumulative net revenue was more than zero because we rounded up the fee levels to nearest significant digits.



Note for scenarios 3 and 4: Fee for long-haul is equal to short-haul trucks; fee for MD delivery is equal to MD vocational trucks.

Figure 9. Revenue generated in the one-time fee (Option 1) (top) and annual fee (Option 2) (bottom)

Scenarios 3 and 4 have been designed to result in flat fees for both fee options. In the case of one-time fee option, the fee is equal for all truck types at 7% and 9.5% of the new diesel truck price for Scenarios 3 and 4 respectively as shown in Table 3. For annual fee option, the fees have been designed based on the mid-point annual weight fee charged under the Commercial Vehicle Registration Act (CVRA) (Department of Motor Vehicles, State of California, 2004a). The annual fee is about 67% of the weight fee in Scenario 3, while it is about 13%-14% more than the weight fee for Scenario 4. Table 3 shows a comparison between both fee types and the current weight fee under the CVRA. The one-time fee estimates in Table 3 have been calculated based on the truck price assumptions from the TTM model.

The four scenarios represent the various policy design options available to the policy makers. A program design based on Scenario 1 could be the most focused option of all scenarios since “just enough” revenue is generated each year. This is also, however, the limitation of this design, since it is impossible to predict the required revenue. This design also creates a wide variation in the fee, with lower fee in the later years of the program.

Table 3. Estimated fees on diesel trucks for Scenario 4.

Segment	Option 1: One-time fee		Option 2: Annual Fee			
	Scenario 3 (7% of upfront price)	Scenario 4 (9.5% of upfront price)	Scenario 3	Scenario 4	Current CVRA Weight Fees (annually per truck)	CVRA Reference Weight Class (pounds of gross vehicle weight)
Class 8 Long-haul	~ \$12,200	~ \$17,100	\$820	\$1,440	\$1,270	50,001–54,999
Class 8 Short-haul	~ \$10,900	~ \$15,200	\$820	\$1,440	\$1,270	50,001–54,999
Class 4-6 Medium- duty Delivery	~ \$5,100	~ \$7,100	\$290	\$510	\$447	15,001–20,000
Class 4-6 Medium- duty Vocational	~ \$10,000	~ \$14,000	\$290	\$510	\$447	15,001–20,000
Class 7-8 Heavy-duty Vocational	~ \$28,500	~ \$20,400	\$615	\$1,070	\$937	35,001–40,000

4.3. Overall assessment of the scenarios for the one-time fee and annual fee options

The fee design in Scenario 2 is an improvement over Scenario 1 since the fee increases with time. However, the fee increase is much more rapid for Option 1, bringing in affordability concerns. The fee increase could be even more rapid if the ZET prices do not reduce over time as assumed in this paper. A caveat in this program design is that supplementary revenue will be necessary from other sources in the initial years to compensate for the deficits (which can be earned back in the later years from the excess revenue).

Scenarios 3 and 4 ensure a flat fee, which ensures predictability. These scenarios allowed us to design a more rational fee structure by treating the revenue generated from all truck types as a unified pool of funds for both fee options. Scenario 3 would require supplementary revenue in the early years of the program which can be compensated through the excess generated in the later years.

5. FINDINGS AND POLICY IMPLICATIONS

In this paper, the primary aim has been to demonstrate the role of feebates as a policy choice to support a self-financing incentive program to accelerate the adoption of zero-emission trucks in California. We have tested two fee options – a one-time fee at the point of sale as a percentage of new diesel truck price (Option 1) and an annual fee on the entire diesel truck stock (Option 2). For a more realistic analysis, we have assumed that 50% of the ZETs are supported in 2026 and 2027, 40% from 2028 to 2030, 30% from 2031 to 2033, and 20% in 2034 and 2035. We tested four scenarios for both fee options leading to different fee levels. Scenarios 1 and 2 result in a variable fee throughout the program, while Scenarios 3 and 4 result in a fixed fee throughout the program. Table 4 provides a summary of the results for the self-financing ZET incentive program.

The scenarios were designed to be at least revenue-neutral over the program duration. The revenue required in a particular year is identical across scenarios since it is guided by the price disparity between zero-emission and diesel trucks, incentive amounts per ZET, and the number of diesel and ZETs sold each year (all of which are identical across scenarios). The goal of Scenario 1 is annual revenue neutrality, which leads to a large variation in the fee required over the program. This variation in the fee – especially when it declines over time – could send a wrong market signal and could encourage fleets to hold diesel trucks for a longer time. We modelled revenue neutrality over the program duration in Scenario 2 by distributing the revenue required equally over 10 years of the program. This results in fees that increase from 2026 to 2035 by up to 200% (Option 1) and up to 41% (Option 2). Scenario 2 also leads to a revenue deficit in the early years of the program requiring supplementary revenue from other sources.

Table 4. Summary of results of feebate designs with the lowest fee.

Fee option	Option 1				Option 2			
Type of fee	One-time fee on new sales as a percentage of new diesel truck price				Annual fee on diesel truck stock			
Percentage share of new ZET sales incentivized	50% in 2026-2027 40% from 2028 to 2030 30% from 2031 to 2033 20% in 2034 and 2035				50% in 2026-2027 40% from 2028 to 2030 30% from 2031 to 2033 20% in 2034 and 2035			
Revenue utilization	Each truck type is an independent system		Unified pool of funds from all truck types		Each truck type is an independent system		Unified pool of funds from all truck types	
Scenario	1	2	3	4	1	2	3	4
Long-haul (class 8)	3 – 9%	6 – 8%			\$343 – 1052	\$665 – 867	Fixed: \$820	Fixed: \$1440
Short-haul (Class 8)	1 – 9%	4 – 6%			\$90 – 954	\$395 – 522		
Medium-duty Delivery (Class 4-6)	3 – 18%	8 – 24%	Fixed: 7%	Fixed: 9.5%	\$60 – 921	\$362 – 480	Fixed: \$290	Fixed: \$510
Medium-Duty Vocational (Class 4-6)	1 – 8%	4 – 12%			\$60 – 769	\$318 – 447		
Heavy-Duty Vocational (Class 7-8)		4 – 11%			\$75 – 1572	\$589 – 836	Fixed: \$615	Fixed: \$1070
Gross revenue (\$ billion)	3.4	3.4	3.4	4.7	3.4	3.4	3.4	5.9
Net revenue (\$ billion)	0	0	0	1.5	0	0	0	2.6

Scenarios 1 and 2 use fee levels “derived” from the required revenues, treating each truck type as a separate system. In contrast, Scenarios 3 and 4 treated all truck types as a unified pool of funds to establish flat fee levels throughout the program duration. The fee levels in the one-time fee option were adjusted to be equal for all truck types (same percentage of a new diesel truck price), while the annual fee was adjusted to be of

the same proportion of the weight fee charged annually in California under the Commercial Vehicle Registration Act (CVRA).

Scenario 3 mirrors the revenue flow of Scenario 2, with deficits in some years, but achieving overall revenue-neutrality. A program design outlined by Scenario 3 should be supported by the sources of supplementary revenue in the initial years. Such sources should ideally be separate from state budgets. A proposed amendment to the Low Carbon Fuel Standard (LCFS) Clean Fuels Reward Program includes incentives for battery-electric MHDs, which could be an ideal source for such supplementary revenue (California Air Resources Board, 2025b).

In contrast, Scenario 4 generates excess revenue – representing a program design that is independent of external funding requirements. However, policy makers should explicitly strategize the utilization of excess revenue – ideally within ZET ecosystem – to make the program effectively revenue-neutral. \$2.6 billion of excess revenue in Scenario 4 in Option 2 can support 17,000 350 kW DC fast chargers that cost \$150,000 each (Gamage et al., 2023). The excess revenue can also be rolled over to support purchase incentives for used ZETs, support incentives for retrofitting of old internal combustion engine trucks, or similar programs that can promote faster and more equitable adoption of ZETs. California is also expected to lose over \$700 million revenue in the next decade from diesel excise tax and sales tax (Petek, 2023). Thus, an alternative use of excess revenue from the program could be to supplement this revenue loss, if acceptable to the policymakers.

We find that the annual fee option could be more affordable as compared to the one-time fee option. Annual fee could have a minimal impact on the operating internal-combustion engine trucks, while providing sufficient revenue for the incentive program. In Scenario 3, for example, long-haul and short-haul trucks have the highest annual fee, which is \$820 (about 0.5% of a new diesel truck price). For comparison, the one-time fee on new diesel long-haul and short-haul trucks sold would be 7% during the program (approximately \$12,200 and \$10,900 respectively). It could take up to 15 years for the annual fee payments to add up to the amount of a one-time fee (Table 5).

Table 5. A comparison of Option 1 and Option 2 affordability in Scenario 3

Segment	Option 1 One-time Fee	Option 2 Annual Fee	Time required for annual fee to be equal to one-time fee
Long-haul	7% (~ \$ 12,200)	\$ 820	~ 15 years
Short-haul	7% (~ \$ 10,900)	\$ 820	~ 13 years
Medium-duty Delivery	7% (~ \$ 5,100)	\$ 290	~ 18 years
Medium-duty Vocational	7% (~ \$ 10,000)	\$ 290	~ 35 years
Heavy-duty Vocational	7% (~ \$ 20,400)	\$ 615	~ 33 years

Scenario designs and supporting assumptions represent the various options available to the policy makers. The first two scenarios represent the tradeoffs between two approaches to revenue neutrality and the effect on the stability of the fee levels. Scenario 3 offers stability to the fee while remaining revenue-neutral but would still require external funding in the initial years. Scenario 4 offers a completely independent program while also preserving fee stability. All the scenarios support only a subset of ZET sales (~ 74,600 ZETs during the program) – representing a realistic case where the policymakers can prioritize incentive payments to a select few ZETs. For comparison, HVIP has been able to support about 14,000 zero-emission vehicles (includes trucks, buses and retrofits) over 14 years of the program with \$1.5 billion funding (California HVIP, 2024).

Supporting a subset of ZET sales through incentives might be enough to drive sufficient sales volumes and help manufacturers achieve economies of scale. Determining the eligibility criteria for incentives will require a thorough analysis of the efficacy of HVIP and similar incentive programs in other geographies.

HVIP has pre-approved voucher amounts for eligible truck models, determined “*in consultation with the vehicle manufacturer, based upon the vehicle invoice sale price, typical industry standard costs for that vehicle technology and type, and other factors*” (California Climate Investments et al., 2024). While HVIP prohibits price inflation by manufacturers, it does not guarantee or encourage price reductions. Our incentive design tackles this problem by applying the incentive towards price disparity, with a decreasing incentive/price ceiling, establishing clear price targets for the market.

To evaluate the sensitivity of fee levels to the number of ZETs supported, we applied scenario 3 (revenue-neutral overall with a flat fee) to a scenario where all new ZETs receive an incentive, while assumptions on truck prices and sales volumes remained unchanged (Table 6). The number of ZETs supported triple, the one-time fee almost doubles, and the annual fee is about 2.5 times the case when a subset of ZETs is supported. While fee increments are non-linear across both options, the annual fee exhibits a stronger proportional relationship with the number of ZETs supported.

Table 6. Comparison of the cases when all trucks versus a subset of trucks are supported.

Segment	All ZETs supported from 2026 to 2035		Subset of ZETs supported: 50% (2026-2027), 40% (2028-2030), 30% (2031-2033), 20% (2034-2035)	
	Option 1 (Scenario 3)	Option 2 (Scenario 3)	Option 1 (Scenario 3)	Option 2 (Scenario 3)
Long-haul	13.5% (~24,200)	\$ 2090	7% (~ \$ 12,200)	\$ 820
Short-haul	13.5% (~21,650)	\$ 2090	7% (~ \$ 10,900)	\$ 820
Medium-duty delivery	13.5% (~10,100)	\$ 740	7% (~ \$ 5,100)	\$ 290
Medium-duty vocational	13.5% (~19,800)	\$ 740	7% (~ \$ 10,000)	\$ 290
Heavy-duty vocational	13.5% (~40,400)	\$ 1550	7% (~ \$ 20,400)	\$ 615
Revenue required	\$ 8.6 billion	\$ 8.6 billion	\$3.4 billion	\$3.4 billion
ZETs supported	~ 210,000		~ 74,600	

We have attempted to minimize the impact of the feebate program on the fleets. The question of equity still arises since the trucks are owned by fleets of varying sizes and paying capacities. About 71% of the trucks in the U.S. are owned by fleet operators with one or two trucks, about 21% are owned by fleet operators with 3 to 100 trucks, and only about 8% of the trucks are owned by fleet operators with over 100 trucks (Federal Motor Carrier Safety Administration, 2024).

ACT regulation included a one-time fleet reporting requirement for large fleets and government fleets that operate medium- and heavy-duty trucks in California (California Air Resources Board, 2022a). The responding fleets included 5% of the trucks owned by fleets operating 1 to 50 trucks, 7% operating 51 to 100 trucks, 19% operating 101 to 500 trucks and 69% operating 501 or more trucks. We call them Small, Medium, Large and Enterprise fleets respectively for this analysis. We present a potential re-design of the annual fee in Scenario 3 assuming the same distribution of fleet sizes that qualify for the fee payment in this program and maintained the weighted average at the earlier estimated levels (Table 7). Small fleets get an 80% discount compared to the weighted average, Medium fleets get a 60% discount, Large fleets get a 20% discount, and Enterprise fleets pay a 17% premium. While the actual distribution of truck operators by size may be different in California, this method can still be applied to ensure equity in the fee design based on paying capacity. If the distribution is closer to the U.S. levels, fees can be designed to apply higher premiums on Large and Enterprise fleets.

Table 7. Illustrating the consideration of equity for the annual fee (Option 2).

Truck Type	Weighted Average	Small Fleets (5% trucks)	Medium Fleets (7% trucks)	Large Fleets (19% trucks)	Enterprise Fleets (69% trucks)
Class 8 Long-haul	\$ 820	\$164	\$328	\$656	\$963
Class 8 Short-haul	\$ 820	\$164	\$328	\$656	\$963
Class 4-6 Medium-duty Delivery	\$ 290	\$58	\$116	\$232	\$340
Class 4-6 Medium-duty Vocational	\$ 290	\$58	\$116	\$232	\$340
Class 7-8 Heavy-duty Vocational	\$ 615	\$123	\$246	\$492	\$721

The annual fee for the feebate program can be charged along with the CVRA registration renewal fee (weight fee), which is charged annually to commercial vehicles above 10,000 pounds registered in-state and out-of-state (Department of Motor Vehicles, State of California, 2004a). Table 8 shows a comparison of annual CVRA weight fee in California and the annual fee in the Scenario 3 of the feebate system. We have adjusted the annual fees for the feebate program such that they are proportional to the CVRA annual fee for each segment. If the ZET prices are close to our forecasts in this analysis, the revenue required to fund a ZET feebate program could be less than the revenue generated from CVRA registration renewal fees. The CVRA fee has not been revised at least since 2004 (Department of Motor Vehicles, State of California, 2004b). This could offer an opportunity for policymakers to stack an annual feebate fee or simply revise the CVRA fee and allocate the additional revenue to ZET incentives.

Table 8. A comparison of annual CVRA fee in California and the annual fee in the Scenario 3 of the feebate system.

Segment	Gross vehicle weight (pounds)	Commercial Vehicle Registration Act (CVRA) Fee (per year)	Annual Fee on Diesel Trucks (Scenario 3) (per year)
Long-haul	50,001–54,999	\$1,270	\$ 820
Short-haul	50,001–54,999	\$1,270	\$ 820
Medium-duty Delivery	15,001–20,000	\$447	\$ 290
Medium-duty Vocational	15,001–20,000	\$447	\$ 290
Heavy-duty Vocational	35,001–40,000	\$937	\$ 615

6. CONCLUSIONS

This study presents a first-of-its-kind analysis on assessing feebates in the context of medium and heavy-duty trucks for a revenue-neutral self-financing ZET incentive program and sets the framework for further analysis. Such a program can serve as a reliable source of funds for the state (or any geography) for ZET incentives without relying on general budgets. The program design provides enough flexibility to strike a balance between managing costs for fleets and supporting enough ZETs to drive volumes for manufacturers. We have only focused on California for this analysis, but it could be even more effective if more states adopt a similar program, since the overall market size would grow faster.

A major benefit of an annual fee is that trucks that are not sold in the state can also be covered under this system, monitored and enforced through the operating fleets registration system. While these trucks have

not been accounted for in this analysis, this would lower the fee per truck even further. We also found that an annual fee could be a more affordable option for the fleets, with much lower (and back-loaded) overall costs, and seems a better choice to accelerate ZET adoption since it affects all the diesel trucks in operation and has the least impact on those fleets that transition to ZETs fastest. This could encourage the fleets to give up their oldest trucks since they might be better-off buying new ZETs with incentives. We designed the incentives to bridge 80% of the estimated price gap between diesel and ZETs, and future studies can study their effect on operating economics of the fleets. While the fees can be scaled to the tailpipe emissions of the diesel trucks, that remained a limitation for this study in the absence of data on model-wise fuel efficiency ratings.

A fee and rebate type of program is just one option to promote ZET sales. The effects of credit trading and banking available in the ACT regulation has been treated as exogenous to this program. The possible effect of ACT credits on truck prices frequently came up in our discussions with various stakeholders. While these effects are difficult to predict, the proposed feebate program provides three key benefits: (i) credit banking and trading cannot accelerate the turnover of old trucks since it is applicable only on new truck sales, unlike the annual fee proposed in this program which applies to all operating diesel trucks. (ii) credits are traded between manufacturers which provides no incentive for fleets to buy ZETs. (iii) since credit trading is not public, there is no transparency on the prices of these credits. The number of credits traded by each manufacturer is the only information available in public, while the proposed feebate-based program is market-based, encouraging price transparency.

Overall, the feebate scheme assessed in this paper can help accelerate ZET adoption in the wake of regulatory uncertainty and budget constraints – all while helping the state achieve its ZEV sales targets.

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AUTHOR CONTRIBUTIONS

The authors confirm contribution to the paper as follows: Conceptualization, methodology and interpretation of results: Anuj Dhole, Aditya Ramji, Lewis Fulton, Daniel Sperling; Data curation: Lewis Fulton; Formal analysis, investigation, original draft manuscript preparation, project administration: Anuj Dhole, Aditya Ramji, Lewis Fulton; funding acquisition, software, resources, supervision, validation, review and editing: Aditya Ramji, Lewis Fulton, Daniel Sperling, Roland Hwang. All authors reviewed the results and approved the final version of the manuscript.

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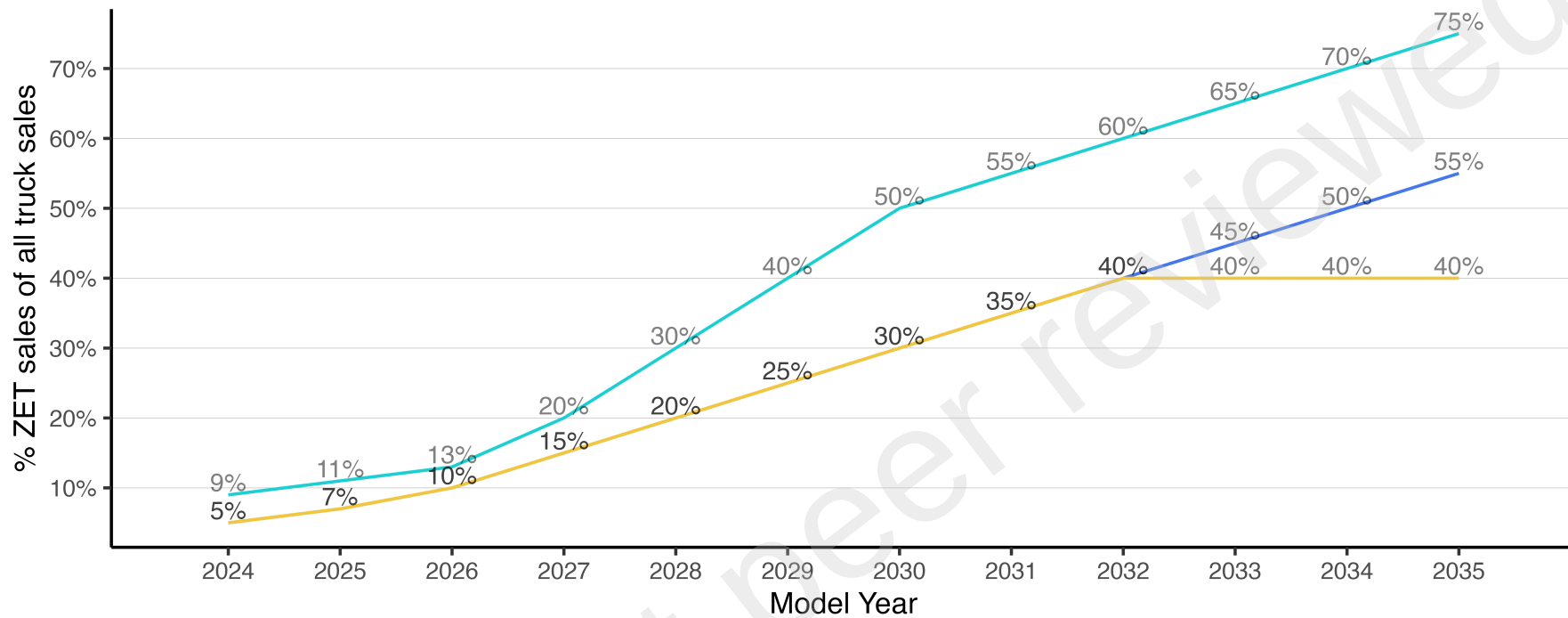
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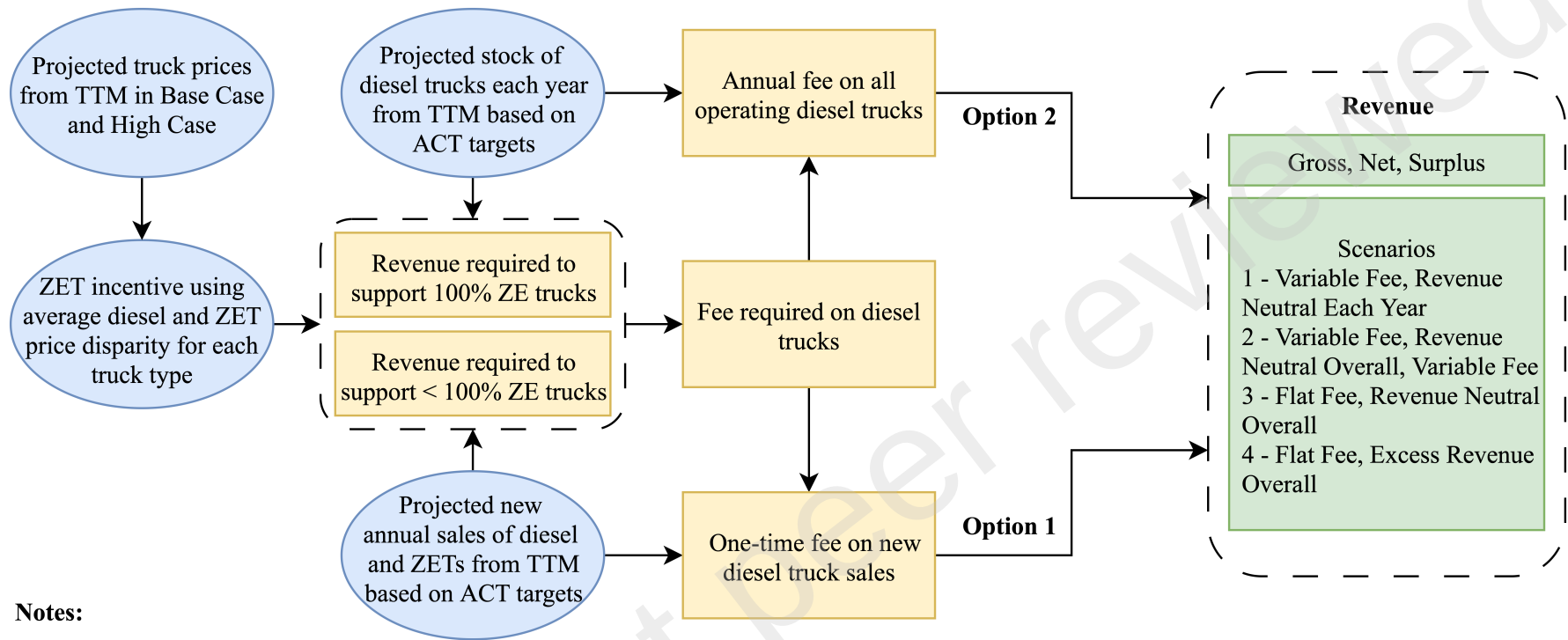
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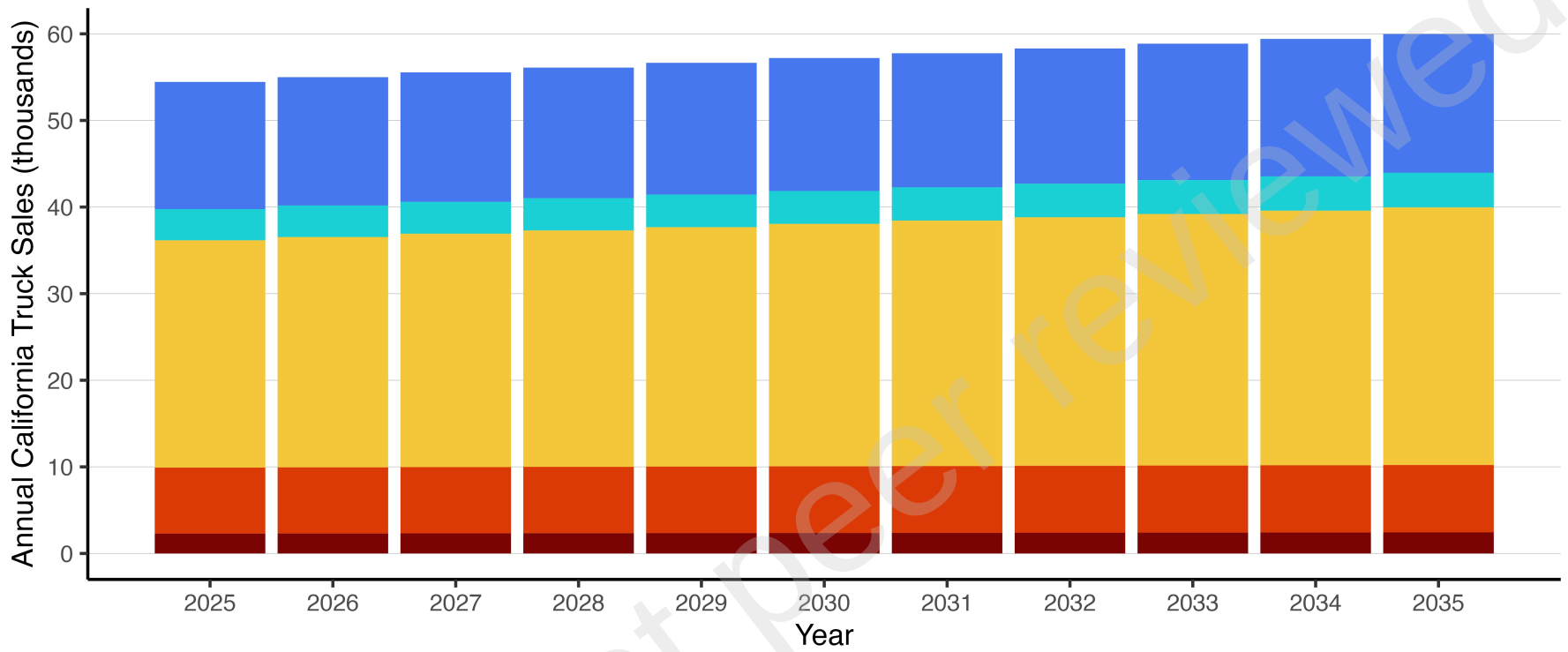
Class 2b-3 Class 4-8 Class 7-8 Tractors

Note: 2035 targets apply for model years 2035 and later

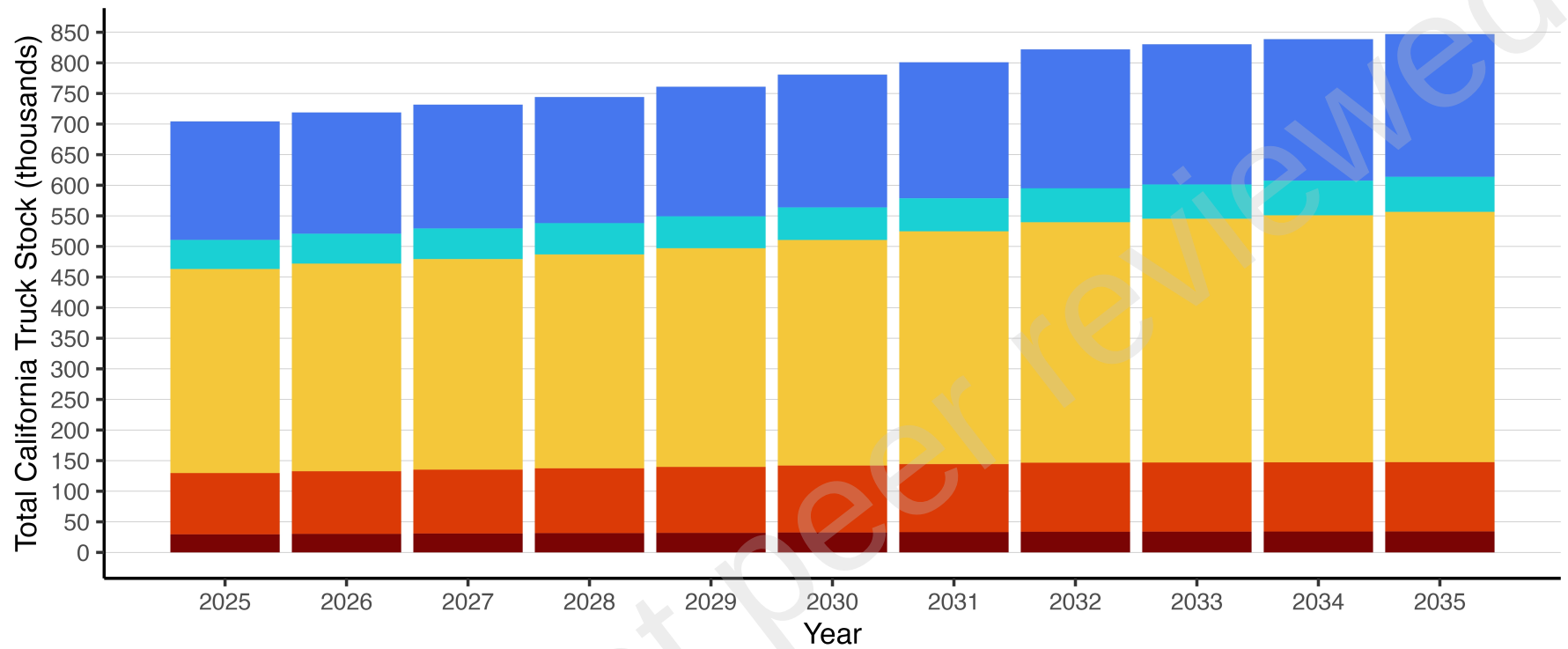


Notes:

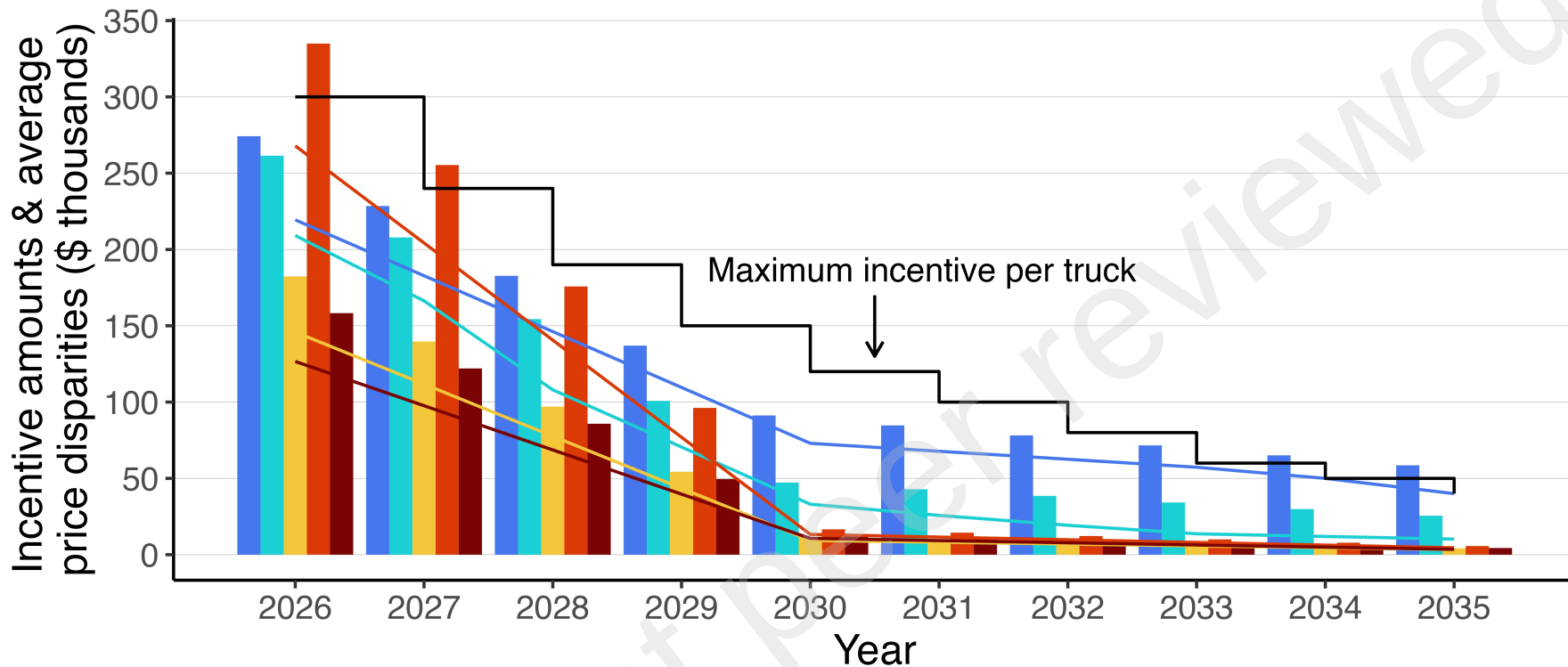
- TTM - Transportation Transitions Model, UC Davis
- ZET - Zero-emission Truck
- ACT - Advanced Clean Trucks rule of California
- Analysis period - 2025 to 2035
- Scenarios 1 and 2 not worked out for Option 3
- Truck types analyzed - class 8 long-haul, class 8 short-haul, medium-duty delivery, medium-duty vocational, and heavy-duty vocational
- Powertrains analyzed - diesel, battery-electric and fuel-cell electric.
- Incentive amount for all truck types estimated using an average of the price disparities between diesel and both zero-emission power trains.



Long Haul Short Haul MD Delivery HD Vocational MD Vocational



Long Haul Short Haul MD Delivery HD Vocational MD Vocational

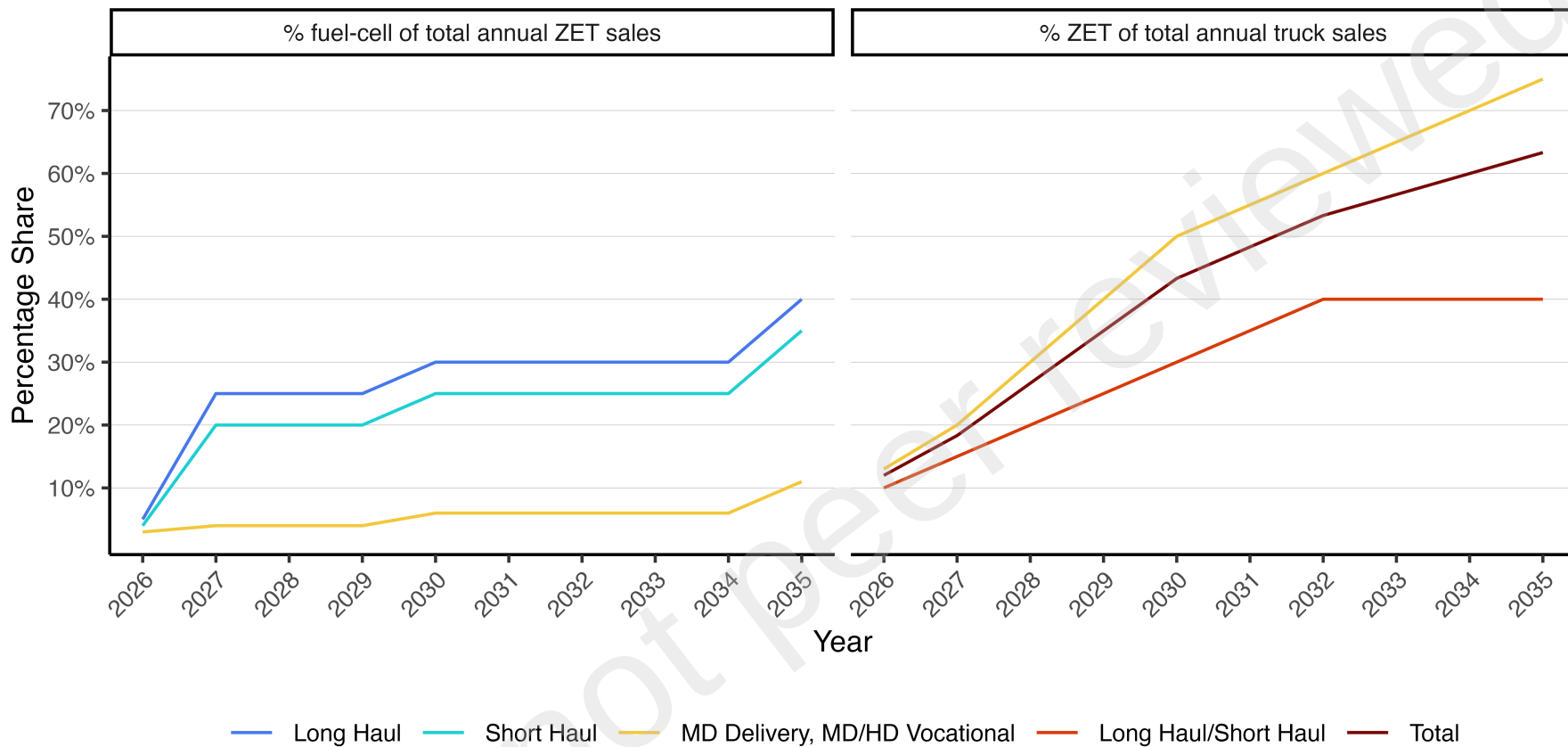


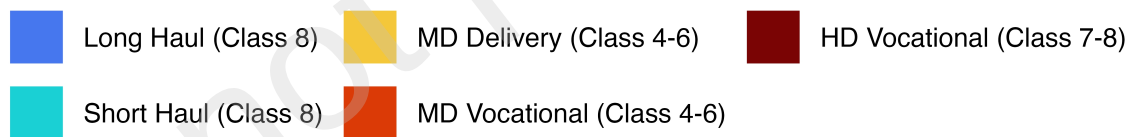
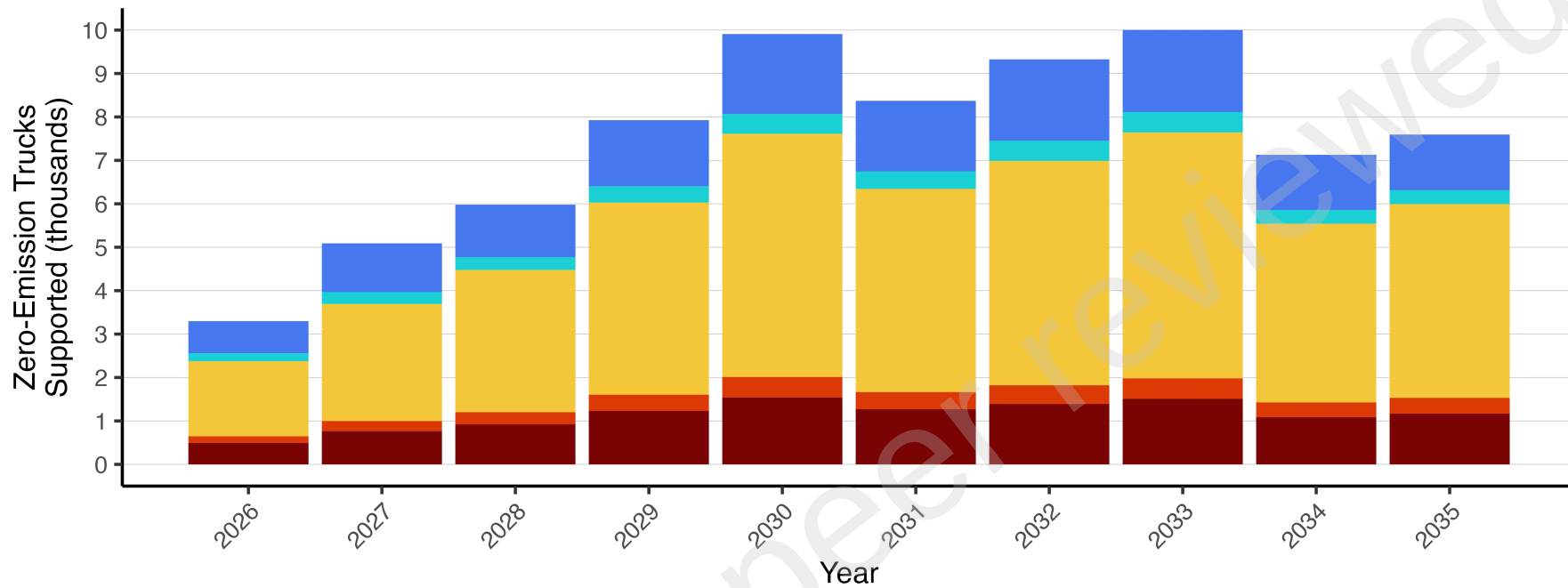
■ Long Haul
 ■ Short Haul
 ■ MD Delivery
 ■ HD Vocational
 ■ MD Vocational

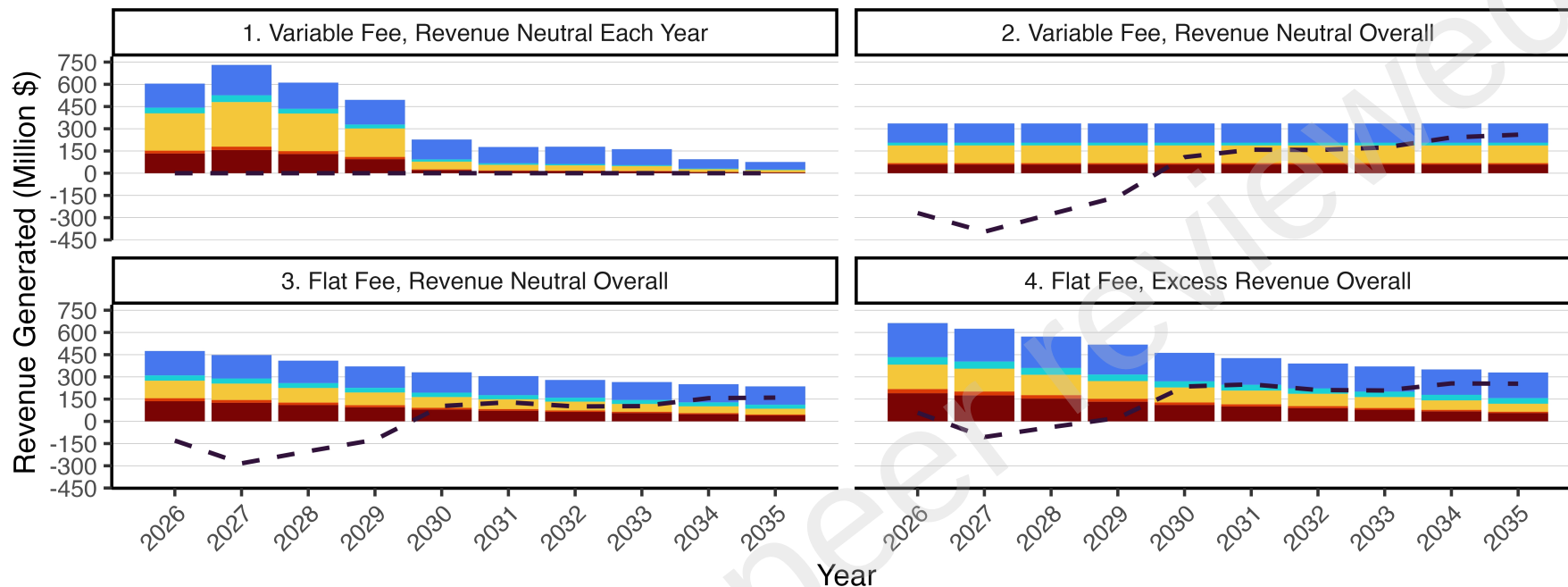
Colored lines represent incentive amount per truck for each truck type.

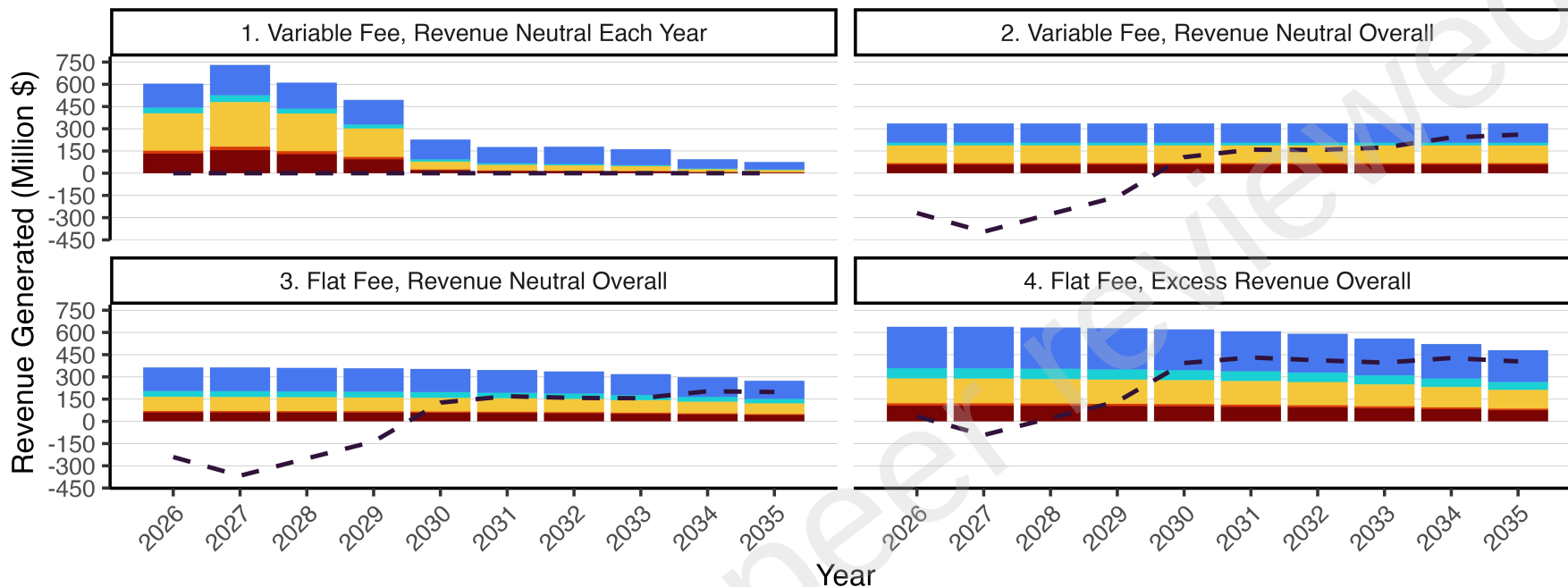
Black line represents the incentive cap per truck each year for any truck type.

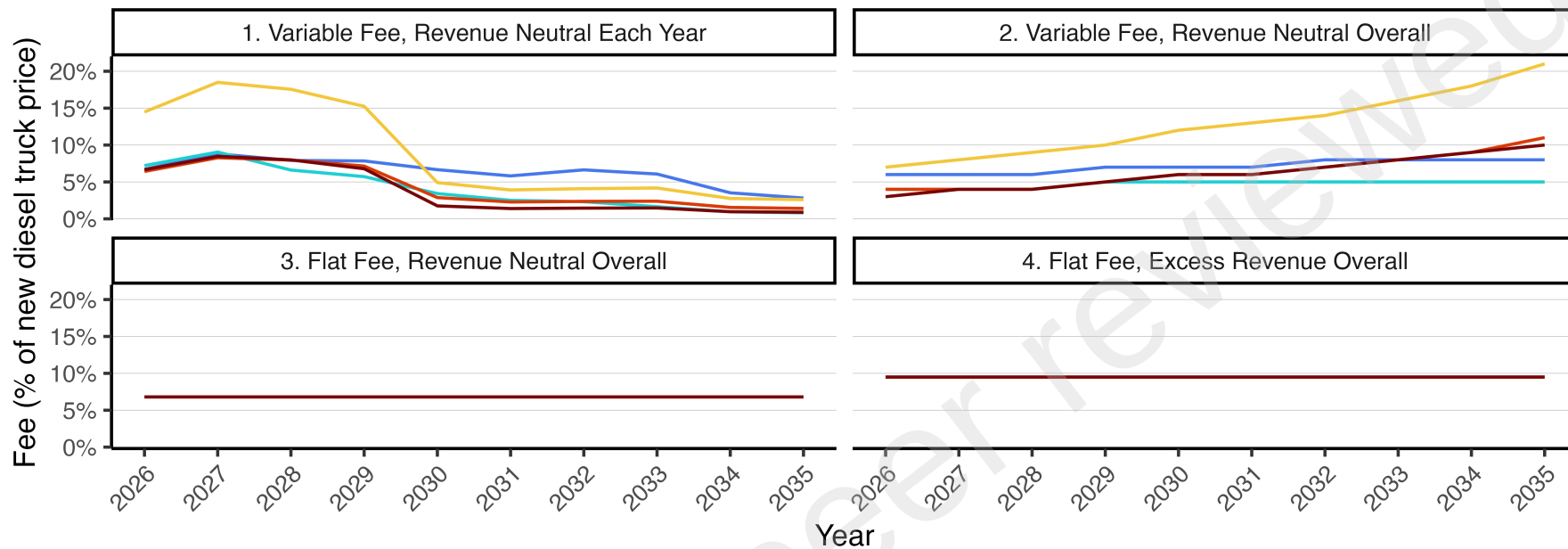
Bars represent price disparity between diesel and average price of zero-emission trucks (battery-electric and fuel cell) for each truck type





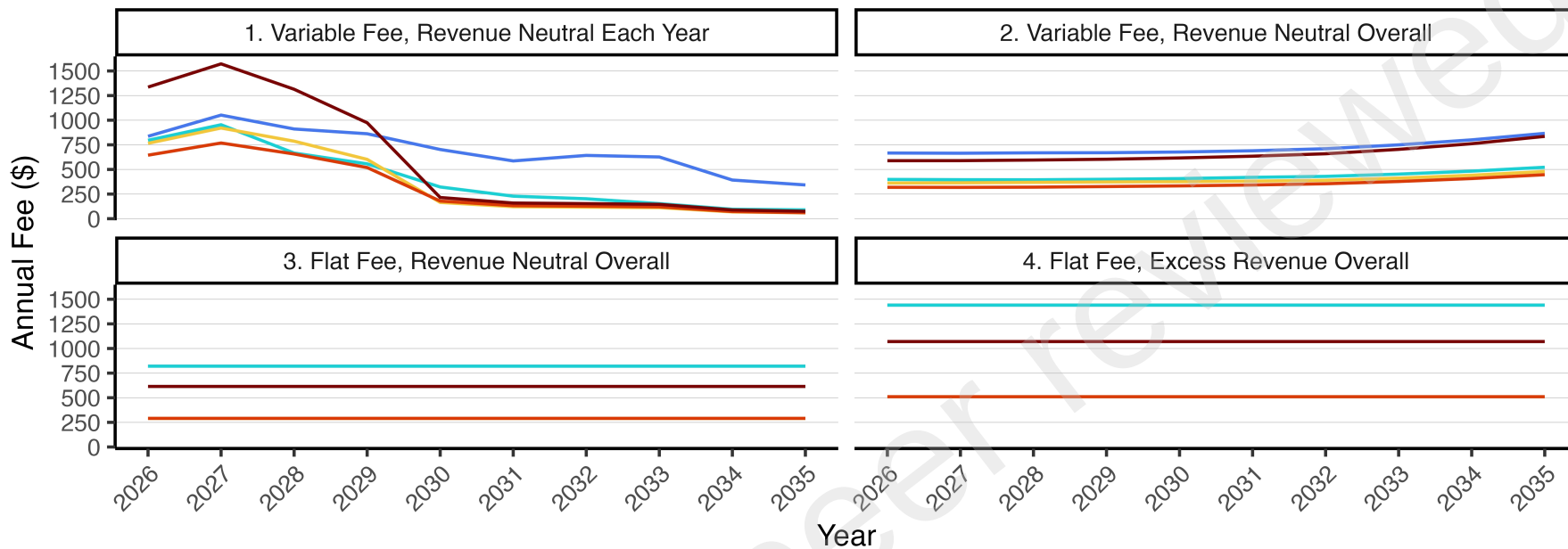






Long Haul (Class 8) MD Delivery (Class 4-6) HD Vocational (Class 7-8)
 Short Haul (Class 8) MD Vocational (Class 4-6)

Note: All truck types have an equal fee in scenario 3 and 4.



— Long Haul (Class 8) — MD Delivery (Class 4-6) — HD Vocational (Class 7-8)
 — Short Haul (Class 8) — MD Vocational (Class 4-6)

Note for scenarios 3 and 4: Fee for long-haul is equal to short-haul trucks; fee for MD delivery is equal to MD vocational trucks.