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ANALYZING THE IMPACT OF THE INFLATION REDUCTION ACT ON ELECTRIC VEHICLE UPTAKE IN THE UNITED STATES

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This is an updated version to correct an earlier misstatement on our methodology on how the value of the Inflation Reduction Act tax credits are calculated. The previous version can be found at https://theicct.org/wp-content/uploads/2023/01/ira-impact-evs-us-jan23.pdf.

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EXECUTIVE SUMMARY

The Inflation Reduction Act (IRA) of 2022 will move electric vehicle (EV) sales into the fast lane for consumers in the United States across all vehicle types. The $370 billion allocated to climate and clean energy investments dramatically expands tax credits and incentives to deploy more clean vehicles, including commercial vehicles, while supporting a domestic EV supply chain and charging infrastructure buildout.

IRA transportation sector provisions will accelerate the shift to zero-emission vehicles (ZEVs) by combining consumer and manufacturing policies. Consumer tax credits for new and used EVs and tax credits for commercial EVs, along with individual and commercial charging infrastructure tax credits, will increase sales. Domestic supply-chain incentives and investments will boost EV manufacturing and battery production. Critical mineral mining and refining incentives will bolster industrial development.

These investments come at a critical time as the U.S. pivots toward a clean transportation future, helping reduce the 23 percent of total U.S. greenhouse gas (GHG) emissions that come from road transportation. The IRA clean transportation provisions will speed progress towards the Biden administration's EV and climate goals. The U.S. Environmental Protection Agency (EPA) expects to release proposed rulemakings for GHG standards for both light-duty vehicles (LDVs) and heavy-duty vehicles (HDVs) in 2023, and these standards can build upon the progress made by the IRA.

This study assesses the future impact of the IRA on electrification rates for LDV and HDV sales in the United States through 2035. We analyze the value of the personal and commercial EV tax credits, factoring in the various supply chain, income, and price caps on new EVs, and combine this with new estimates of future light-duty and heavy-duty EV cost declines. We find that, on average over the period 2023–2032, the IRA tax credits will reduce light-duty EV purchase costs by $3,400 to $9,050. Using methodologies from the Energy Policy Simulator, we project how these changing costs and incentives over time will affect the LDV and HDV markets in the United States.

We consider Low, Moderate, and High scenarios, depending on how certain provisions of the IRA are implemented and how the value of incentives is passed on to consumers. For LDVs, we also consider a range of states that may ultimately adopt California's new Advanced Clean Cars rule (ACC II), which requires increasing EV sales shares for automakers. For HDVs, we consider states that have adopted California's Advanced Clean Trucks rule and its ZEV targets. These results do not consider federal GHG standards for model years 2027 and beyond.

Figure ES-1 shows the range in our projected EV and ZEV sales shares for LDVs and HDVs from 2023 to 2035. This figure presents our Low, Moderate, and High scenarios, compared to a baseline (no IRA incentives) scenario. Here, we use the term EVs for new light-duty battery electric vehicles (BEVs) and plug-in hybrid electric vehicles (PHEVs). For heavy-duty, the term ZEVs includes new BEVs and hydrogen fuel cell electric vehicles (FCEVs). Used EVs are not included in this analysis.

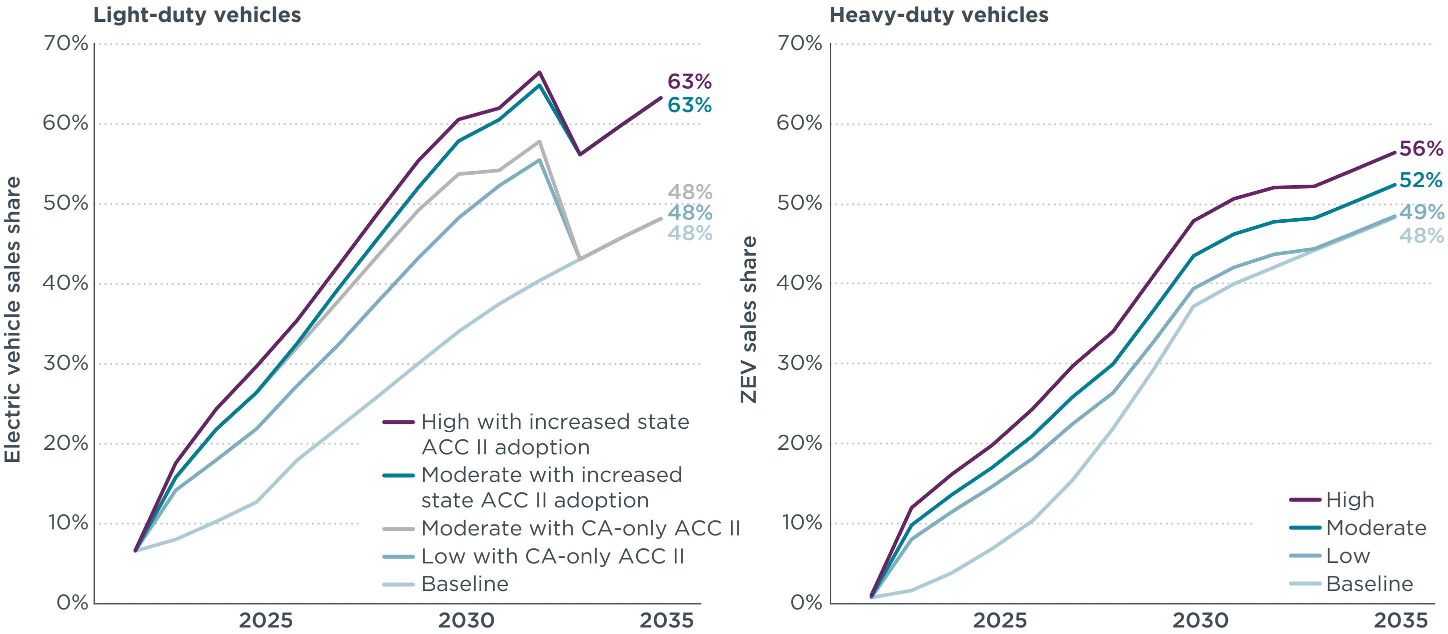

Figure ES-1: Baseline, Low, Moderate, and High projections of EV sales share for light-duty vehicles, considering ACC II adoption in only California versus increased states (left), and ZEV sales share for heavy-duty vehicles with the IRA incentives, 2023-2035 (right)

From these results we draw the following conclusions and policy recommendations:

- **The IRA will accelerate electrification.** For both the light and heavy-duty sectors, we find rapid EV uptake when considering both expected manufacturing cost reductions and the IRA incentives, as well as state policies. By 2030, we find a range of a 48%–61% EV sales share in the light-duty sector, increasing to 56%–67% by 2032, the final year of the IRA tax credits. For heavy-duty, we estimate a range of 39%–48% ZEV sales share by 2030 and 44%–52% by 2032.
- **The IRA enables more stringent federal vehicle standards at a lower cost and higher benefit to consumers.** By providing thousands of dollars in financial incentives to LDV and HDV purchasers, the IRA unlocks widespread consumer benefits while furthering the administration's decarbonization goals. With the IRA, EPA can set more stringent federal LDV and HDV GHG standards than would have been possible otherwise, at lower cost and higher benefit to consumers and manufacturers.
- **The IRA alone is not enough to meet our climate goals.** Previous analyses have found that higher rates of electrification than what we show here will be necessary to meet the U.S. Nationally Determined Contribution (NDC) and to be aligned with the Paris Climate Agreement to limit global warming to well below 2 degrees Celsius.
- **Federal standards can lock in and build on the pace of electrification from the IRA.** The EV and ZEV sales shares we present are not guaranteed and there remains uncertainty in the electrification transition, especially after the IRA tax credits expire. Federal standards can serve as a backstop to ensure the electrification momentum from the IRA continues, particularly after the incentives expire in 2032. Our results suggest that to be technology forcing and deliver substantial climate benefits above the baseline, federal standards would need to drive electrification rates significantly higher than 50% by 2030 for LDVs and above 40% by 2030 for HDVs.

- **Additional action is needed by government and industry.** This analysis shows that, given costs and consumer preferences, electrification can be rapid. It does not account for other non-financial barriers such as lead time for vehicle manufacturing and charging infrastructure development; these challenges are largest in the heavy-duty sector. The rates of electrification we project here can only be achieved if government and industry invest quickly in ZEV assembly and infrastructure.

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INTRODUCTION

U.S. climate policy took a major step forward with the passage of the Inflation Reduction Act (IRA) of 2022. The $370 billion allocated to climate and clean energy investments are expected to deliver deep emission reductions across all sectors of the economy. Such investments come at a critical time as the country seeks to pivot towards clean energy and transportation, reverse its laggard position, and emerge as a global leader on electric vehicles (The White House, 2021). In 2021, the Biden administration called for a 50% electric vehicle sales share for passenger vehicles in 2030 in order to strengthen U.S. leadership on clean vehicles, create good-paying jobs, expand clean vehicle manufacturing, and export electric vehicles globally. The administration also has targets for commercial vehicles: in 2022, the United States committed to a minimum zero-emission heavy-duty vehicle (HDV) sales share of 30% by 2030 and 100% by 2040 (Minjares, 2022).

Several key on-road transportation sector provisions are included in the IRA which will greatly accelerate the shift to plug-in electric and hydrogen fuel cell electric vehicles.[1] Consumer tax credits for new and used electric vehicles, tax credits for electric commercial vehicles, and individual and commercial charging infrastructure tax credits will accelerate market growth. At the same time, domestic supply-chain incentives and investments for electric vehicle manufacturing, battery production, and critical mineral mining and refining will bolster industrial development. This package of demand and supply side policies will be critical to putting the United States on a path to transportation decarbonization.

This white paper analyzes the impact of the IRA on light- and heavy-duty electric vehicle market growth in the United States through 2032. Using recent data on electric and conventional vehicle prices, the analysis models consumer vehicle purchase decisions for electric and internal combustion engine vehicle technologies, taking new federal tax credits into account. The methodology section describes the overall analytical approach, the IRA provisions considered, and how they are applied to develop hypothetical scenarios of future EV sales. The results section summarizes the modeling results for electric vehicle sales and sales shares from 2023 through 2035. This is followed by a discussion of policy implications and conclusions.

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[1] The IRA's definition of clean vehicles includes plug-in hybrid electric vehicles (PHEVs), battery electric vehicles (BEVs), and fuel cell electric vehicles (FCEVs). In this research note, the term electric vehicles (EVs) refers to both PHEVs and BEVs, unless otherwise specified.

METHODOLOGY

This analysis largely follows the methodology of a 2022 Energy Innovation Policy & Technology LLC® study examining the IRA's impacts on the ground transportation sector (Baldwin & Orvis, 2022). This analysis uses a customized model based on the Energy Policy Simulator (EPS), an open-source policy model (Energy Innovation, 2022). The model forecasts sales of new vehicles from a choice function.[2] In this study, the model is updated to include the most recent data on U.S. combustion and electric vehicle costs, battery pack costs, vehicle energy consumption, fuel and electricity prices, and charging behavior for electric vehicles. It includes battery electric, plug-in hybrid electric, and gasoline vehicles for light-duty, and battery electric, fuel cell electric, and diesel vehicles for heavy-duty. The light-duty vehicle and battery data on costs, technical specifications, and charging behavior are from a 2022 ICCT assessment of U.S. electric vehicle costs (Slowik, Isenstadt, Pierce, & Searle, 2022). The heavy-duty data are obtained from multiple sources, which are described in detail below. The analysis also incorporates state-level implementation of California's Advanced Clean Cars II and Advanced Clean Trucks Rules to evaluate the combined impact of state regulations and federal incentives on national electric vehicle uptake (California Air Resources Board, 2022a; California Air Resources Board, 2019).

LIGHT-DUTY VEHICLES

The consumer vehicle choice model uses a logit allocation function to estimate the impact of select IRA incentives on new light-duty vehicle sales. The logit function allocates new vehicle purchases to electric and combustion vehicle technologies based on a total cost of ownership (TCO) analysis. The TCO considers purchase, fuel, maintenance, insurance, parking, license, and registration costs, in addition to monetized barriers (e.g., range anxiety) and tax credits and incentives. A 15% discount rate is applied for all future-year ownership expenditures.

The two key inputs to the logit function are the logit exponent and the shareweights. The logit controls the sensitivity of the choice function to the TCO. A higher absolute value for the exponent will push a higher share of sales to the vehicle type with the lowest TCO as compared to a lower exponent. We utilized the same logit exponent values as used in the Global Change Assessment Model (GCAM) v6, which can be found in the model's input data (Joint Global Change Research Institute, n.d.). The shareweights represent non-cost considerations, such as consumer preference and vehicle availability. The shareweights also serve as a calibrating parameter so that the historical sales share in the allocation aligns with historical sales data. A shareweight value of 0 means the allocation will not assign any of the vehicle shares to that technology. The greater a shareweight is relative to the other shareweights, the greater share it will receive in an allocation. For this analysis, we calibrate shareweights in historical years to align the sales share with historical data, and then phase the shareweight to a value of 1 by 2030 using an s-curve. This approach attempts to reflect non-price barriers to EV adoption such as consumer preference and vehicle availability, which are eliminated by 2030. The shareweights for battery-electric light-duty vehicles start at 0.26 in 2021, based on calibration to align with historical sales shares,

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[2] The choice function uses the modified logit choice function as outlined in the GCAM model. The modified logit computes sales shares using technology-specific shareweights and ownership costs and a common exponent. For more information, see: https://jgcri.github.io/gcam-doc/choice.html. The original Energy Innovation® analysis also modeled vehicle fleet turnover, vehicle stock, and energy consumption and emissions. See https://energyinnovation.org/wp-content/uploads/2022/11/Implementing-the-Inflation-Reduction-Act-A-Roadmap-For-Federal-And-State-Transportation-Policy.pdf

then increase to 0.73 in 2025 and 0.99 in 2030. This 2030 shareweight reflects our expectation that electric vehicle uptake in 2030 will be driven primarily by costs, as opposed to being constrained by supply chains, and that consumer preference difference will be marginal (Joint Global Change Research Institute, n.d.).

The IRA tax credits and incentives applied in this analysis of light-duty electric vehicles include Personal Tax Credits for Clean Passenger Vehicles (30D) worth up to $7,500 and Advanced Manufacturing Production Tax Credits (45X) for batteries worth up to $45 per kilowatt-hour. Per the IRA, several requirements must be met for new passenger vehicles and their buyers to be eligible for the full clean passenger vehicle tax credit. The analysis incorporates estimates of the share of new vehicles that can meet the new domestic assembly and battery sourcing requirements, and applies eligibility restrictions based on the new manufacturer's suggested retail price (MSRP) and adjusted gross income (AGI) caps. More details about these estimates and how they are developed can be found in Baldwin and Orvis (2022). We do not explicitly consider leased vehicles in our analysis and only model the effect of the Personal Tax Credit for light-duty vehicles. Due to uncertainty on how the restriction on battery component and critical mineral sourcing from "entities of concern" will be implemented, we did not account for this requirement in this analysis.

Average U.S. light-duty vehicle prices for 2023 through 2035 are key inputs to the consumer choice model. Purchase price data for new cars, crossovers, SUVs, and pickups, which together represent all light-duty vehicle sales in the United States, are taken from a 2022 ICCT study of conventional and electric vehicle costs (Slowik, Isenstadt, Pierce, & Searle, 2022). Conventional vehicle prices are compared to battery electric vehicles (BEVs) with electric ranges from 150 to 400 miles and plug-in hybrid electric vehicles (PHEVs) with ranges of 20 to 70 miles. Data on the electric range of U.S. electric vehicle sales in 2020 and 2021 are used to calculate the sales-weighted average electric range of new BEVs and PHEVs, and thus the average costs, for the 2022 base year.[3] The average electric range of new BEVs and PHEVs is assumed to increase through 2030. For new BEVs, the sales-weighted average electric range increases from 250 miles in 2022 to 300 miles by 2030. For PHEVs, the sales-weighted average electric range increases from 30 miles in 2023 to 50 miles by 2030. The number of annual electric vehicle sales in each light-duty vehicle class is assumed to resemble that of all new light-duty vehicles in the United States in 2020: 27% cars, 35% crossovers, 23% SUVs, and 15% pickups.[4]

Figure 1 illustrates the sales-weighted average conventional and electric vehicle prices applied in the analysis for 2022 through 2035, before any IRA incentives or tax credits are applied. Average BEV prices decline from about $40,300 in 2022, to about $30,800 by 2030, and to $29,200 by 2035. Price parity with gasoline vehicles is achieved around the 2027–2028 timeframe, driven by continued technological advancements and reduced battery costs.[5] Conventional vehicle prices increase from about $32,000 in 2022, to about $33,100 by 2030, and to about $33,700 by 2035, along with their improved efficiency. PHEVs have the highest prices due to the complexity of having both the combustion and electric powertrain.

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[3] Based on EV-Volumes, (2022), https://www.ev-volumes.com/

[4] Cars are 27%, crossovers are 35%, SUVs are 23%, and pickups are 15%. Based on data from the National Highway Traffic Safety Administration (2022).

[5] Based on Slowik, Isenstadt, Pierce, & Searle (2022), the battery pack cost estimate applied in this analysis is $131 per kilowatt-hour (kWh) in 2022, $105/kWh in 2025, $74/kWh in 2030, and $63/kWh in 2035. These values are for a BEV with a nominal 50 kWh battery pack and were informed by a 2022 review of battery cost projections from technical research studies, automaker announcements, and other expert sources.

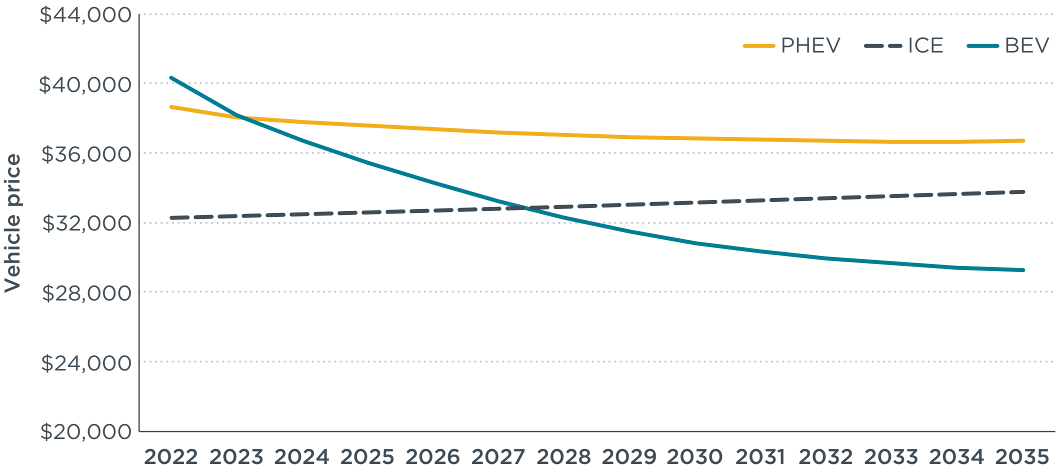

Figure 1. Sales-weighted average conventional and electric vehicle prices applied in this analysis

Several additional factors contribute to the TCO for electric and combustion vehicles that are used in the consumer choice model logit function. Annual fuel costs are calculated using data on conventional and electric vehicle fuel efficiency, annual gasoline and electricity prices, and electric vehicle charging behavior from Slowik, Isenstadt, Pierce, and Searle (2022), and annual vehicle miles traveled is from the Energy Policy Simulator (Energy Innovation, 2022). Per-mile maintenance costs are also from the 2022 ICCT study. Annual vehicle insurance, parking, licensing, and registration costs are from the Energy Policy Simulator and identical for each vehicle technology. This analysis estimates the cost of range anxiety and charging time for BEVs as an additional component of the TCO calculation. The average electric vehicle ownership costs attributed to range anxiety decline from about $8,000 in 2022 to $5,500 in 2030 due to greater electric vehicle range and faster charging speeds. Figure 2 illustrates the average TCO for BEVs, PHEVs, and internal combustion engine (ICE) vehicles in this analysis for a 6-year ownership period and 15% discount rate for future-year expenses. As shown, ICE vehicles have the lowest 6-year ownership costs in 2022 and 2025. By 2030, BEVs have lower 6-year ownership costs than their PHEV and ICE vehicle counterparts, which is primarily due to substantial reductions in vehicle price.

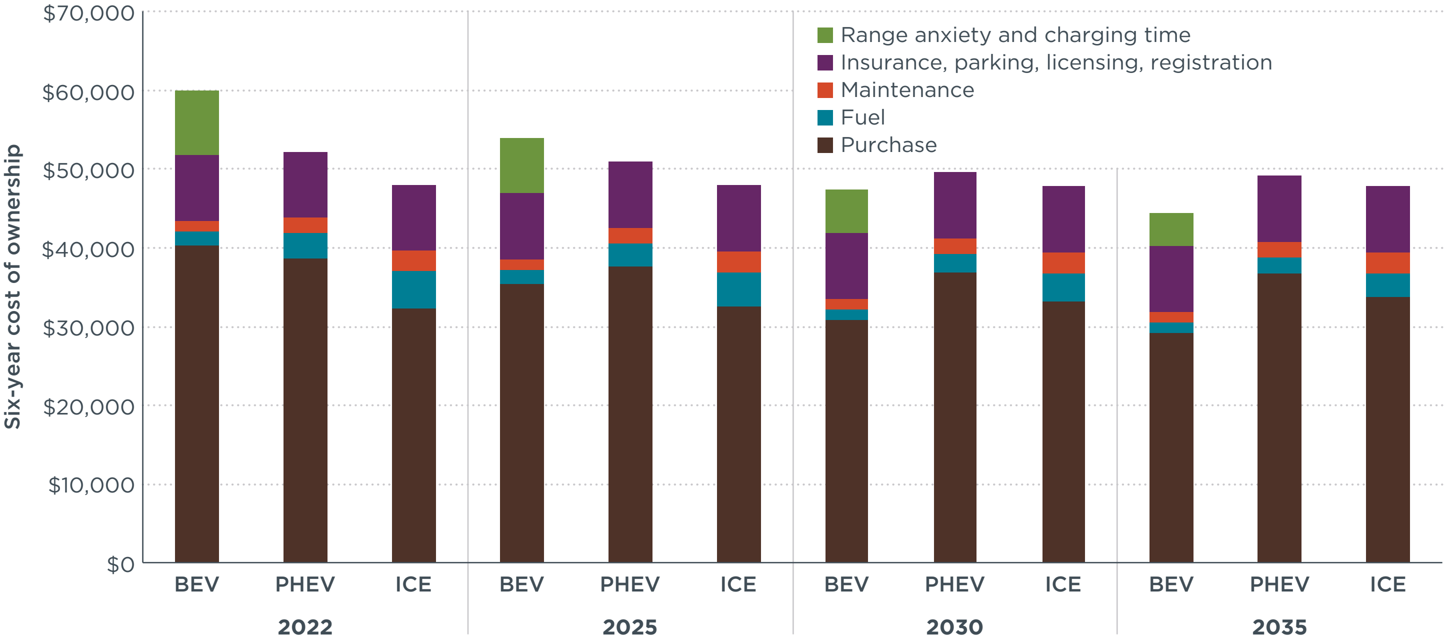

Figure 2. Net present value of six-year ownership costs for new BEVs, PHEVs, and ICE vehicles in 2022, 2025, 2030, and 2035

The IRA tax credits affect the consumer choice model by reducing the TCO for electric vehicles. To analyze the impact of the IRA on U.S. electric vehicle market growth, the analysis includes three hypothetical IRA scenarios—Low, Moderate, and High—that reflect different assumptions surrounding the various IRA provisions. We compare these scenarios against a baseline scenario that excludes the IRA provisions. Table 1 summarizes the three IRA scenarios and how the various electric vehicle incentives, tax credits, and eligibility restrictions are applied for the Passenger Clean Vehicle Tax Credit (30D) and the Advanced Manufacturing Production Tax Credit (45X), using BEVs as an example. The details are discussed below.

Table 1. Summary of Low, Moderate, and High IRA scenarios and how the incentives are applied to battery electric vehicle prices

IRA provision		IRA scenario		
		Low	**Moderate**	**High**
Passenger clean vehicle tax credit (30D)	Domestic battery assembly	100% of new BEVs are eligible for the full $3,750 value		
	Critical minerals sourcing	In 2023, it is assumed that 100% of new BEVs meet the critical minerals sourcing requirements and thus are eligible for the full $3,750. For future years, the share of new vehicles that meet the requirements are as follows:		
		76% in 2025 56% in 2030 55% in 2032	79% in 2025 72% in 2030 78% in 2032	82% in 2025 89% in 2030 100% in 2032
	MSRP eligibility	87% of new BEVs qualify		
	AGI eligibility	68% of new BEVs qualify in 2023 and 77% qualify in 2030		
	Final vehicle assembly	Sufficient North American assembly capacity to meet demand		
	Average 30D incentive value 2023–2032:	**$3,400**	**$5,000**	**$6,150**
Advanced manufacturing production tax credit (45X)	Value of $45/kWh battery credit passed to consumer, with phase out by 2033	0% for all years	25% in 2023 50% in 2024–2029 37.5% in 2030 25% in 2031 12.5% in 2032 0% in 2033	50% in 2023 100% in 2024–2029 75% in 2030 50% in 2031 25% in 2032 0% in 2033
	Average 45X incentive value 2023–2032:	**$0**	**$1,450**	**$2,900**
Average incentive value of 30D and 45X combined, 2023-2032:		**$3,400**	**$6,450**	**$9,050**

Note: Numbers in table are rounded.

Passenger Clean Vehicle Tax Credit (30D). Up to $7,500 in consumer incentives are available via the new Passenger Clean Vehicle Tax Credit (30D). Receiving the full amount of $7,500 requires that new electric vehicles meet new requirements for domestic battery assembly and sourcing of critical minerals, each worth up to $3,750 (Plug In America, 2023). Based on a previous Energy Innovation® analysis, we estimate that 100% of new electric vehicles will comply with the domestic battery assembly requirements and thus be eligible for the full $3,750 tax credit in each IRA scenario (Baldwin & Orvis, 2022). The share of new electric vehicles that qualify for the critical minerals incentive, and thus the average value of incentives, are also based on Baldwin & Orvis (2022), which used data on electric vehicle battery mineral composition, market shares, and the share of batteries that are sourced domestically or by free trade agreement countries. Beginning in 2023, it is assumed that 100% of new electric vehicles meet the critical mineral requirement for that year. As electric vehicle production increases, a smaller share of new vehicles meet the critical mineral sourcing requirements thereafter. By 2030, it is assumed that 56% of new sales meet the requirements under the IRA Low scenario, 72% meet them under the IRA Moderate scenario, and 100% meet the requirements under the IRA High scenario.

The average value of tax credits is further reduced due to new eligibility restrictions based on the MSRP, adjusted gross income (AGI), and final vehicle assembly. The new tax credits include an MSRP cap of $55,000 for sedans and $80,000 for SUVs and pickup trucks. The credits also include an AGI cap of $150,000 for individuals and $300,000 for a joint household. It is estimated that 87% of new BEVs will meet the MSRP requirements for all years in the analysis. It is estimated that 68% of new BEV sales meet the AGI limits in 2023, which increases to 77% in 2030 as the market expands beyond early adopters to the majority market. There is also an entities of concern provision that disqualifies any new electric vehicles from the tax credit if any of the battery components or minerals are manufactured, assembled, extracted, processed, or recycled by a foreign entity of concern beginning in the 2024–2025 timeframe.[6] Here, we did not account for any reduction in incentive eligibility based on this requirement because it is not yet clear how it will be implemented. Eligibility for the incentive is also contingent on the vehicle being assembled in North America; future manufacturing capacity in North America was estimated by Bui, Slowik, and Lutsey (2021) and found to be sufficient to meet demand, thus not restricting incentive eligibility. More information about the Clean Vehicle Tax Credit, the eligibility requirements, and how these incentives are quantified, are outlined in Baldwin and Orvis (2022).

Advanced Manufacturing Production Tax Credit (45X). For the Advanced Manufacturing Production Tax Credit (45X), up to $45/kWh of the battery production tax credit can be passed on to consumers in the form of reduced upfront vehicle price. From 2024 through 2029, the assumed percentage of the tax credit value passed to consumers is 0% in the Low scenario, 50% in the Moderate scenario, and 100% in the High scenario. For 2023, these values are reduced by a factor of two. By 2030, the 45X production tax credit begins to phase out, and the percentage passed through is reduced by 25% per year until fully expiring in 2033. More details about the modeling of the battery production tax credit are in Baldwin and Orvis (2022).

For each IRA scenario, the table shows the average value of consumer incentives from the clean vehicle tax credit, battery credit, and both incentives combined over the 2022–2033 timeframe. We find that, on average, consumer incentives for new electric vehicle purchases are worth $3,400 in the IRA Low scenario, $6,450 in the IRA Moderate scenario, and $9,050 in the IRA High scenario.

Based on the data from Table 1, Figure 3 shows the average value the IRA incentives (30D) and tax credits (45X) that are applied to average new battery electric vehicle prices for the Low, Moderate, and High IRA scenarios, which include the Personal Tax Credit for Clean Passenger Vehicles (30D) and the Advanced Manufacturing Production Tax Credit (45X) for batteries. Both incentives expire after 2032.
As shown, the sales-weighted average value of BEV incentives in the baseline scenario without the IRA quickly phase down as more manufacturers meet the 200,000-vehicle threshold. In the IRA High scenario, where most new electric vehicles meet all IRA eligibility requirements, the sales-weighted average incentive value is about $10,500 in 2024 and declines to about $6,800 in 2032. The decline in the average incentive per vehicle is due to the decreasing share of new vehicles that meet the minerals sourcing requirements, along with the phase out of the battery production tax credit beginning in 2030. In the IRA Low scenario, where fewer new electric vehicles comply with the IRA incentive provisions and there are no battery tax credits passed through to consumers, the average incentive is about $3,400 per vehicle in 2024, $2,600 in 2027, and $4,500 in 2032; the “U” shaped curve is the

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[6] Beginning in 2024, new plug-in vehicles will not qualify for the tax credit if the battery components were manufactured or assembled by a foreign entity of concern. Starting in 2025, vehicles will not qualify for the tax credit if the battery’s critical minerals are extracted, processed, or recycled by a foreign entity of concern. Foreign entities of concern are entities that are “owned by, controlled by, or subject to the jurisdiction or direction of a government of a foreign country that is a covered nation (i.e., China, Russia, Iran, or North Korea).” (Bond, 2022).

result of a combination of a declining share of new vehicles that meet the critical minerals sourcing requirements and an increasing share of consumers that meet the AGI caps. Average incentives per vehicle in the IRA Moderate scenario decline from about $7,300 in 2024 to about $5,600 in 2032.

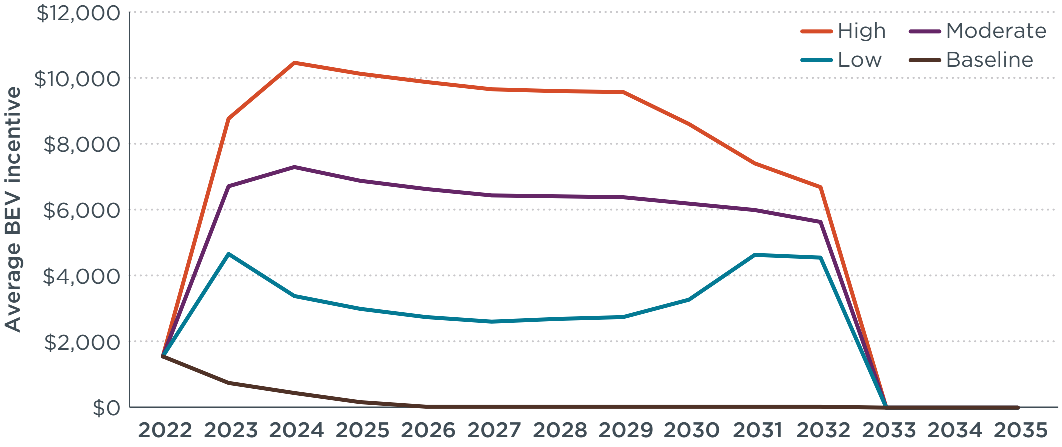

Figure 3. Summary of average IRA incentive values applied to battery electric vehicle prices in the IRA Low, Moderate, and High scenarios

The average BEV incentive values from Figure 3 are applied to the purchase price data for the modeling of consumer choice. Figure 4 shows the average vehicle purchase price for conventional and battery electric vehicles with incentives for the Baseline and Low, Moderate, and High IRA scenarios. As shown, with incentives in the IRA scenarios, upfront price parity is reached in the 2023–2025 timeframe, which is about 3–5 years sooner than without incentives. In the High IRA scenario, the IRA incentives and tax credits reduce electric vehicle prices by up to $10,500, and new BEVs are about $7,000 to $11,000 cheaper than conventional vehicles in the 2025–2030 timeframe.

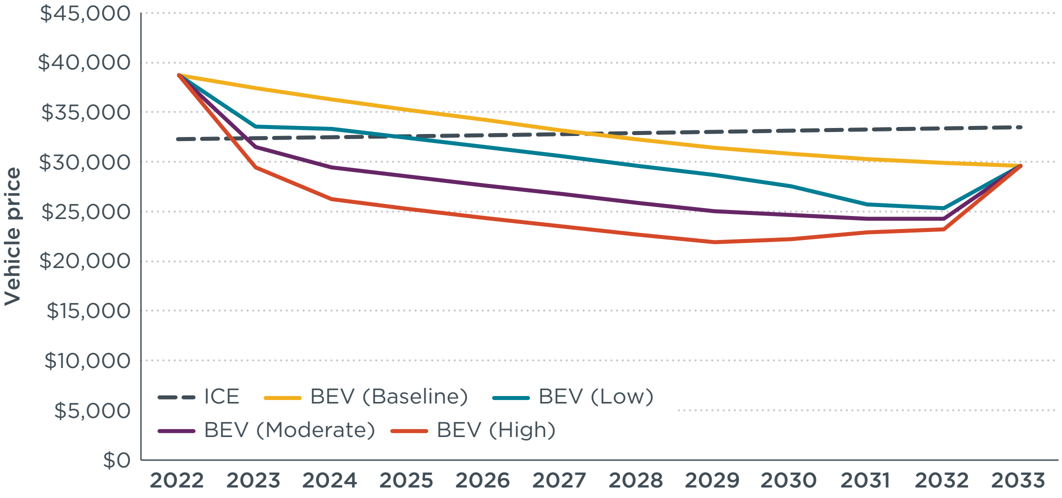

Figure 4. Sales-weighted average new ICE and BEV prices with IRA incentives and tax credits applied

Two additional scenarios are combined with the three IRA scenarios above to incorporate the effects of the state-level Advanced Clean Cars II (ACC II) regulation on national electric vehicle uptake.[7] First, a California-only scenario assumes that California is the only state that implements the ACC II regulation, which requires 100% of new light-duty vehicle sales in the state to be battery electric, hydrogen fuel cell electric, or plug-in hybrid electric by 2035. Second, an Increased ACC II state adoption scenario assumes that all of the states that have adopted ACC I will also adopt ACC II, including California, Colorado, Connecticut, Delaware, Maine, Maryland, Massachusetts, Minnesota, Nevada, New Jersey, New Mexico, New York, Oregon, Rhode Island, Vermont, Virginia, and Washington. States that adopt ACC II are assumed to implement the regulation by model year 2026 or 2027. In both scenarios, the annual targets from California's regulation are used to model electric vehicle uptake in the states adopting ACC II, which are incorporated into the national-level projections from the IRA analysis. The modeled electric vehicle shares in states adopting ACC II increase from 35% in 2026, to 68% in 2030, and to 100% in 2035 (California Air Resources Board, 2022a). The results section discusses the impact of these additional scenarios on our findings in more detail.

HEAVY-DUTY VEHICLES

This study assesses heavy-duty vehicles in Classes 4–8. The retail prices for different zero-emission heavy-duty truck and bus classes are estimated using a bottom-up approach following a methodology developed in two previous ICCT studies: Basma, Saboori, and Rodríguez (2021) and Basma, Zhou, and Rodríguez (2022). This approach considers the vehicle's technical specifications and the individual component manufacturing costs, such as the battery, fuel cell, hydrogen tank, electric drive, electric auxiliaries, and others. These costs are summarized in Sharpe and Basma (2022) and are adjusted to consider average inflation in the United States between 2020 and 2022. The aggregated vehicle manufacturing cost is then converted into retail price using indirect cost multipliers that capture expenses related to research and development, overhead, marketing and distribution, warranty expenditures, and profit markups, as defined in U.S. Environmental Protection Agency and U.S. Department of Transportation (2016). The diesel vehicle retail prices are estimated by averaging publicly available price data in Hunter, Penev, Reznicek, Lustbader, Birky, and Zhang (2021), Burnham, et al. (2021), International ZEV Alliance (2020), California Air Resources Board (2022b), Argonne National Laboratory (2022), Burke and Sinha (2020), and Nair, Stone, Rogers, and Pillai (2022). These retail price estimates are detailed further in a separate publication (Xie, Basma, & Rodríguez, in press).

Retail prices of heavy-duty BEVs and hydrogen fuel cell electric vehicles (FCEVs) before and after IRA incentives are compared with diesel heavy-duty vehicles in Figure 5. Even before IRA incentives are applied, BEVs are projected to reach retail price parity prior to 2030 for Class 4–5 and Class 6–7 rigid trucks, refuse trucks, and transit buses. The IRA incentives accelerate the dates of retail price parity for BEVs to prior to 2030 for Class 8 rigid trucks, short-haul tractor trucks, and all bus classes. Long-haul tractor trucks are the only class for which BEVs do not reach retail price parity within the timeframe of this study, even after IRA incentives. However, the incentives roughly halve the price premium of BEVs compared to diesel long-haul tractor trucks in 2030. In contrast to BEVs, FCEVs are projected to reach retail price parity with diesels only for refuse trucks and some bus classes. As in the case of BEVs, the IRA incentives substantially reduce the price premium of FCEVs for all classes.

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[7] See Bui, Hall, and Searle (2022).

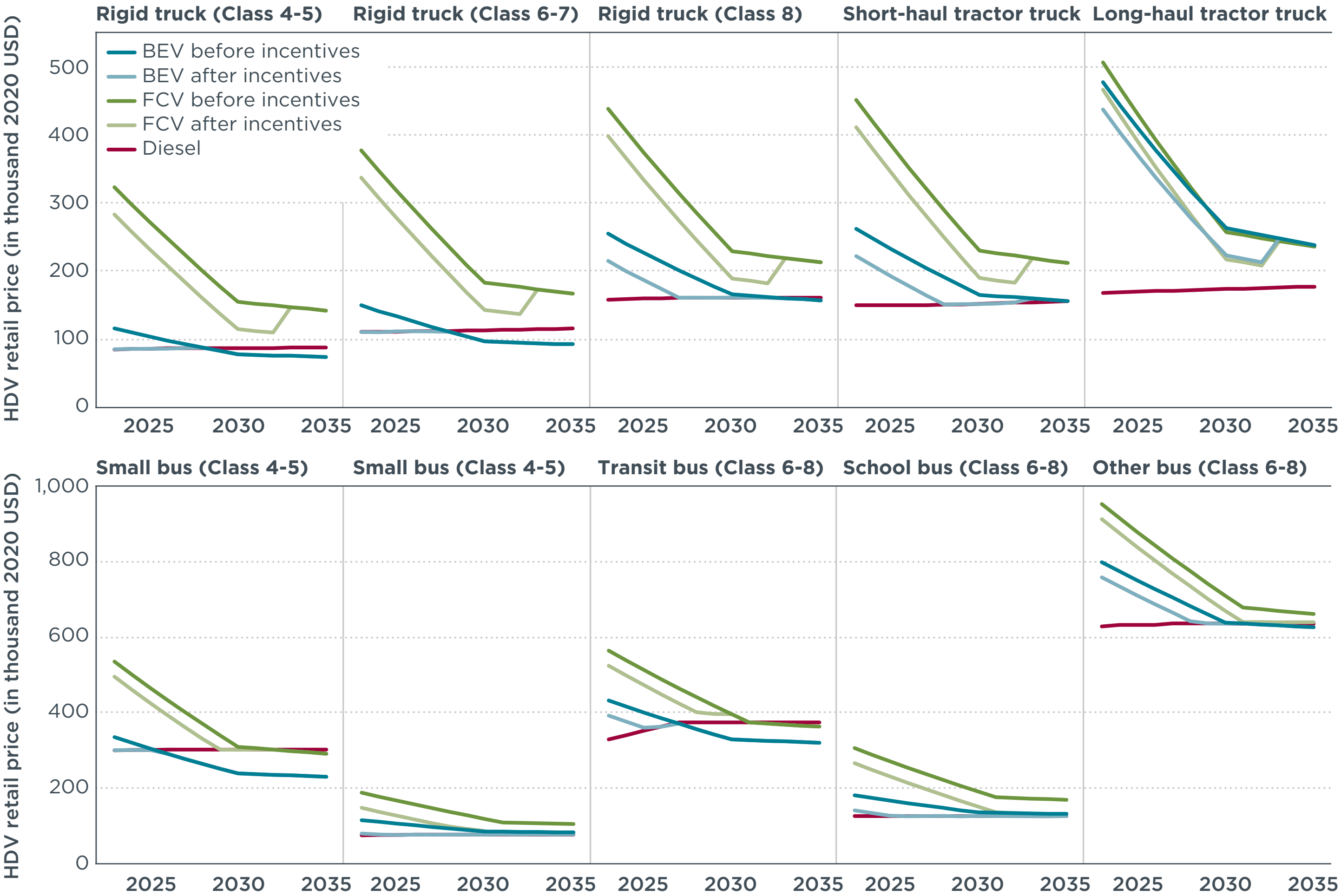

Figure 5. Comparison of BEV and FCEV retail prices with diesel heavy-duty vehicles before and after IRA incentives

The technical specifications of the vehicles are defined based on commercial zero-emission heavy-duty trucks and buses currently available in the United States. Battery and hydrogen tank sizes are based on the vehicle's fuel consumption per mile and the average daily mileage. These parameters are provided in the appendix.

The vehicles' miles per gallon (MPG) are estimated by averaging data based on NREL (2021), ANL (2021), and CARB (2020), and the vehicle average daily mileage data is extracted from MOVES3 for each heavy-duty vehicle class. For small buses, we assumed the same efficiency as for rigid trucks (Class 4–5) for each type of technology. For diesel school buses and other diesel buses, we assumed vehicle efficiency follows the Phase 2 standards for coach buses for model year 2027. For school buses, we assumed the same ratio of BEV to diesel and FCEV to diesel efficiency as for rigid trucks (Class 6–7). For other battery electric and fuel cell electric buses, we assumed the same energy efficiency ratios as for long-haul tractor trucks.

Heavy-duty BEV and FCEV costs are further reduced by the amount of the Qualified Commercial Clean Vehicles Tax Credit (45W) for the years in which it applies (2023–2032). Per the IRA provisions, the value of the tax credit is calculated as the lesser of the incremental cost of a BEV or FCEV compared to its diesel equivalent using the estimated costs in Figure 5, 30% of the cost of the vehicle, or $40,000 (Internal Revenue Service, 2022). We also apply the Advanced Manufacturing Production Tax

Credits (45X) for batteries, based on the battery sizes in Table A1 in the appendix and following the same assumptions as described in the section on light-duty vehicles.

Because vehicle sales shares are projected based on the total cost of ownership, fuel and charging costs are also incorporated in our model. Forecasted diesel prices are taken from the U.S. Energy Information Administration (2022). We estimate the trucks' charging costs by accounting for average electricity rates, charging station costs, and estimated grid upgrade costs. This includes a combination of public and private charging, depending on the vehicle class. Electricity rates vary among and within states depending on utility regulation, type of utility, the presence of regional utilities, and other factors. For this analysis, we collected electricity rate data for seven representative states (California, New York, Texas, Florida, Georgia, Illinois, and Washington), covering different geographic regions and a broad price spectrum while focusing on states with high trucking activity. The electricity rates offered by the biggest utility in each state are used, focusing on primary grid connection applications in which there is a connection to the high-voltage distribution grid. We include demand charges. We then calculate the weighted-average charging cost at the U.S. federal level, providing higher weights for states with higher trucking activity. Data for charging equipment and grid upgrade expenses are adopted from Jesse, Mishra, Miller, Borlaug, Meintz, and Birky (2022). Electricity rate data for the states listed above were collected from PG&E (2022), National Grid US (2022), PSE (2022), ComEd (2022), FPL (2022), Oncore (2022), and Georgia Power (2022). The resulting federal average charging cost in 2022 is 0.1728 $/kWh, out of which ~ 0.047 $/kWh corresponds to charging station and grid upgrade costs.

We follow the methodology developed in a previous ICCT study to estimate the cost of hydrogen fuel for heavy-duty FCEVs. We assume electrolysis is performed on-site at hydrogen refueling stations using renewable electricity, producing green hydrogen (Zhou & Searle, 2022). Thus, the at-the-pump hydrogen price consists of two components, the green hydrogen production cost and the hydrogen refueling station cost. This model, while compromising a smaller production capacity, avoids costs and potentially prolonged infrastructure construction, such as pipelines, to deliver hydrogen. We factor in the impacts of the IRA on hydrogen production costs by applying the renewable electricity (section 45 and 45Y) and clean hydrogen (section 45V) tax credits from 2023 to 2032. Detailed methodology and results for our estimated green hydrogen costs are in the appendix.

We assume the Advanced Clean Trucks (ACT) rule is followed in states that had adopted it as of October 2022 (California Air Resources Board, 2019). The ACT rule requires heavy-duty vehicle manufacturers to sell zero-emission vehicles (ZEVs) as increasing shares of their annual sales from 2024 to 2035. By 2035, ZEV sales would need to be 75% of Class 4–8 straight truck sales and 40% of tractor truck sales to meet these requirements. The states that have adopted the ACT rule include California, Massachusetts, New Jersey, New York, Oregon, and Washington (Electric Trucks Now, 2022). Our assumptions on ZEV uptake in ACT states are the same for all scenarios.

The model structure is the same as for light-duty vehicles above, and shareweights from the GCAM input data are also used.

RESULTS

This section summarizes the findings for new U.S. electric vehicle sales and sales shares from 2023 through 2035. The results are presented first for light-duty vehicles followed by heavy-duty vehicles.

LIGHT-DUTY VEHICLES

Figure 6 summarizes the findings of light-duty electric vehicle shares for 2022 through 2035 for the five scenarios: baseline, IRA Low with California-only ACC II, IRA Moderate with California-only ACC II, IRA Moderate with increased state ACC II adoption, and IRA High with increased state ACC II adoption.

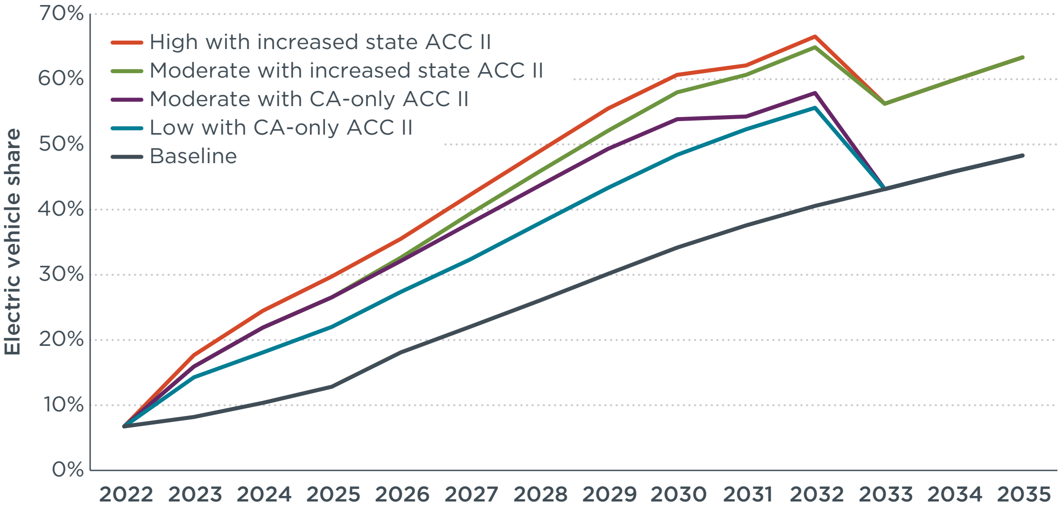

Figure 6. U.S. light-duty electric vehicle sales share for five scenarios, 2022–2035

As shown, electric vehicle sales shares under the baseline scenario increase from about 7% in 2022 to about 13% by 2025, 34% by 2030, and 48% by 2035. With the IRA, electric vehicle prices are reduced and electric vehicle sales shares increase. Under the IRA Low scenario with California-only ACC II adoption, national electric vehicle sales shares reach about 22% by 2025 and about 48% by 2030. Under the IRA High scenario with increased state ACC II adoption, national electric vehicle sales shares increase to about 30% by 2025 and about 61% by 2030. The gap in electric vehicle sales shares between the baseline scenario with no IRA and the IRA scenarios illustrate the effect of the purchase incentives and battery tax credits on consumer purchase decisions. Compared to the baseline scenario, the projected electric vehicle sales shares are nearly doubled in the IRA High with increased state ACC II adoption scenario. Based on our analysis, 2030 electric vehicle sales shares with the IRA range from about 48% (Low) to about 61% (High), indicating the potential for the policy to deliver on President Biden's 2030 50% electric vehicle sales share target.

The decline in electric vehicle sales shares from 2032 to 2033 is due to the expiration of the IRA Personal Tax Credits for Clean Passenger Vehicles (30D) and Advanced Manufacturing Production Tax Credits (45X) for batteries at the end of 2032. By 2033, electric vehicle shares under the IRA Low and IRA Moderate with California-only ACC II scenarios are identical to that of the baseline, because the baseline scenario also assumes that California is the only state with the ACC II regulation. For the IRA High and IRA Moderate scenarios with increased state ACC II adoption, the 2033 electric vehicle sales shares are about 15% greater than the baseline due to increased sales in additional states with the ACC II regulation. From 2033 to 2035, electric vehicle shares continue to increase as technology costs continue to decline (Figure 1).

Table 2 summarizes the electric vehicle sales shares from 2022 through 2035 for the five scenarios, which are identical to the data from Figure 6. The electric vehicle shares include both BEVs and PHEVs. PHEVs, which on average have higher purchase prices than both battery electric and conventional vehicle technologies, account for 12%–14% of the electric vehicle sales in 2023, and this fraction declines to 5%–8% by 2035, depending on the scenario.

Table 2. Summary of electric vehicle sales shares for five scenarios, 2022–2035

Scenario	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
Baseline	6.7%	8.1%	10.3%	12.8%	18.0%	22.0%	26.0%	30.1%	34.1%	37.6%	40.5%	43.2%	45.8%	48.2%
Low with CA-only ACC II	6.7%	14.3%	18.0%	21.9%	27.3%	32.3%	37.9%	43.3%	48.3%	52.3%	55.6%	43.2%	45.8%	48.2%
Moderate with CA-only ACC II	6.7%	15.9%	21.9%	26.5%	32.1%	37.8%	43.6%	49.3%	53.8%	54.3%	57.9%	43.2%	45.8%	48.2%
Moderate with increased state ACC II adoption	6.7%	15.9%	21.9%	26.5%	32.6%	39.3%	45.8%	52.1%	57.9%	60.6%	64.9%	56.2%	59.8%	63.3%
High with increased state ACC II adoption	6.7%	17.7%	24.4%	29.8%	35.5%	42.2%	48.9%	55.5%	60.6%	62.0%	66.5%	56.2%	59.8%	63.3%

Table 3 summarizes the findings for electric vehicle sales shares in non-ACC II states, calculated as the difference between the national-level projections from Table 2 and state-level projections for ACC II states based on the annual regulatory requirements, and taking total light-duty vehicle sales into account. Electric vehicle sales shares in the non-ACC II states lag those of ACC II states. Under the baseline scenario, EV shares in non-ACC II states increase from about 16% in 2026, to about 30% by 2030, and to about 35% by 2032. With the IRA, across all modeled scenarios, incentives reduce electric vehicle prices and sales increase as a result. In the IRA Low scenario, EV sales shares in non-ACC II states increase from about 26% in 2026, to about 46% in 2030, and to about 52% in 2032. Electric vehicle sales shares are highest under the IRA High scenario, increasing from about 36% in 2026, to about 56% in 2030, and to about 57% in 2032. Sales shares in non-ACC II states under the IRA Moderate scenario are approximately halfway between the Low and High scenarios and are identical for the California-only ACC II and increased state ACC II scenarios. The decline in non-ACC II state EV sales shares after 2032 is due to the expiration of the IRA incentives, and EV sales shares in non-ACC II states are consistent across all scenarios over this timeframe.

Table 3. Summary of electric vehicle share in all non-ACC II states combined, 2026–2035

Scenario	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
Baseline	15.8%	19.2%	22.7%	26.2%	29.6%	32.4%	34.9%	37.2%	39.3%	41.3%
Low with CA-only ACC II	26.3%	30.9%	36.1%	41.2%	45.7%	49.2%	52.0%	37.2%	39.3%	41.3%
Moderate with CA-only ACC II	31.7%	37.1%	42.6%	48.0%	51.9%	51.4%	54.7%	37.2%	39.3%	41.3%
Moderate with increased state ACC II adoption	31.2%	37.1%	42.6%	48.0%	51.9%	51.4%	54.7%	37.2%	39.3%	41.3%
High with increased state ACC II adoption	35.8%	41.7%	47.6%	53.3%	56.2%	53.7%	57.3%	37.2%	39.3%	41.3%

HEAVY-DUTY VEHICLES

Figure 7 presents our estimated sales shares of heavy-duty ZEVs, which includes both battery electric and hydrogen fuel cell electric vehicles, in the IRA Low, Moderate, and High scenarios, compared to a baseline (no IRA incentives) scenario. The projected ZEV sales shares vary greatly across truck and bus categories, for example from 11% to 17% for long-haul tractor trucks and from 70% to 77% for Class 4-5 rigid trucks in 2035. For all vehicle categories, ZEV sales shares increase continually until 2030, when the battery production tax credit begins to phase out and the small bus ZEV sales share declines slightly. ZEV sales shares for short- and long-haul tractor trucks are projected to decline in 2032–2033 as the Qualified Commercial Clean Vehicles Tax Credit phases out. ZEV sales shares of all vehicle categories are projected to increase steadily after 2033 as ZEVs continue to become more cost competitive.

Aggregate sales-weighted average heavy-duty ZEV sales shares in 2030 are projected to be 39% in the IRA Low scenario, 44% in the IRA Moderate scenario, and 48% in the IRA High scenario. These shares increase in 2035 to 47%, 52%, and 56% for the IRA Low, Moderate, and High scenarios, respectively.

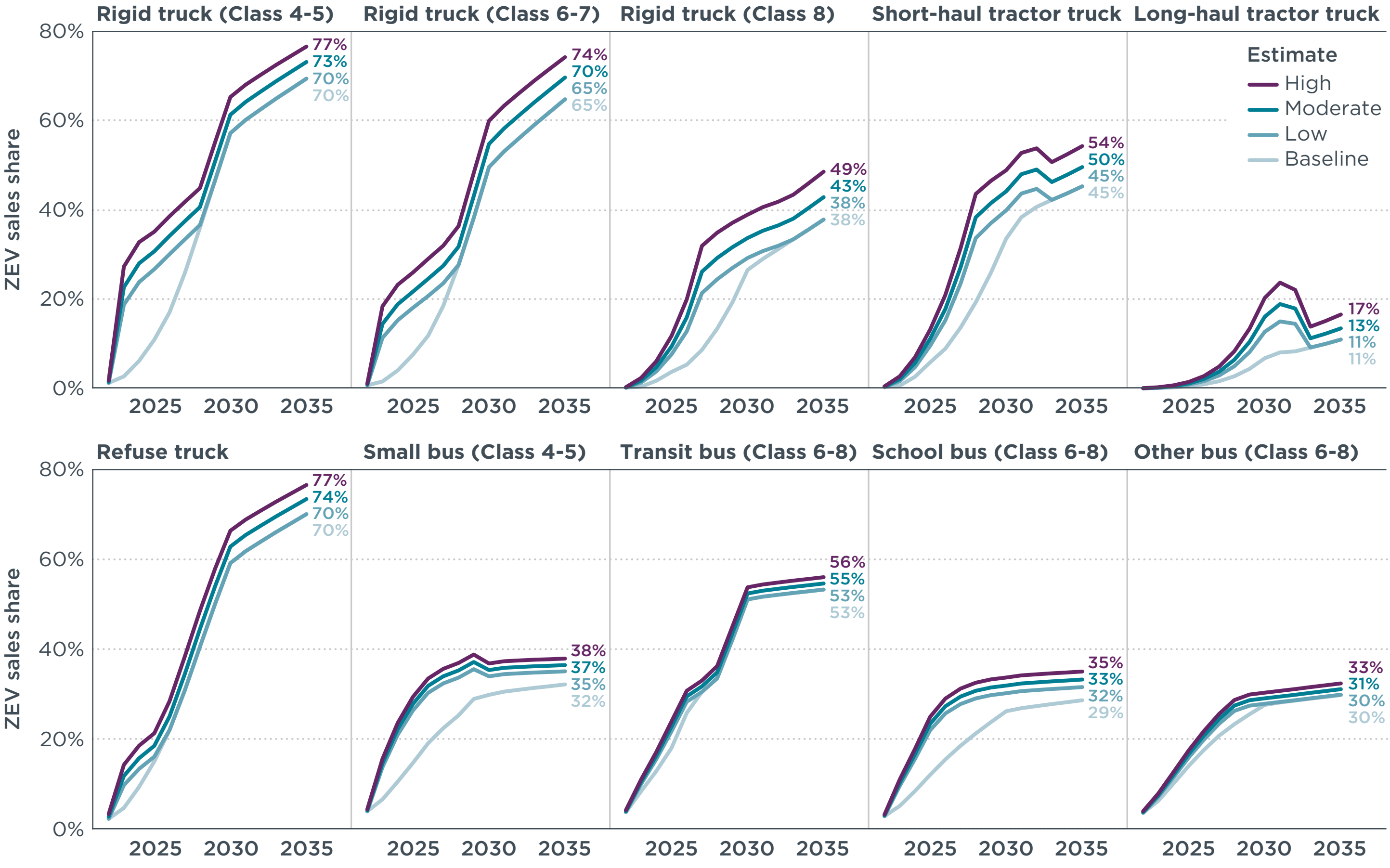

Figure 7. Baseline, IRA Low, IRA Moderate, and IRA High scenarios for U.S. heavy-duty ZEV (BEV + FCEV) sales shares by category, 2022–2035

Our modeling indicates that FCEVs will play only a limited role in the ZEV transition. Table 4 presents the shares of total sales and of ZEV sales that are projected to be FCEVs for each HDV class from 2023 to 2035 in the IRA Moderate scenario. These trends are similar in the IRA Low and High scenarios. For all truck and bus classes, ZEV sales are projected to be dominated by BEVs. Among truck classes, FCEVs make up less than 1% of total sales in all years. FCEVs are projected to have slightly higher adoption among buses, reaching 6.6% of total sales of transit buses in 2035. The reason FCEVs are projected to play such a limited role in the ZEV transition is due to market fundamentals; in contrast to BEVs, which are projected to have substantially lower operating costs, FCEVs are projected to have higher operating costs than diesels since hydrogen will continue to be more expensive than diesel.

Table 4. FCEV share of total sales and share of ZEV sales by HDV category in the IRA Moderate scenario

FCEV share of total sales in IRA Moderate scenario														
HDV class	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
Rigid truck (Class 4-5)	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.2%	0.2%	0.2%	0.0%	0.0%	0.1%
Rigid truck (Class 6-7)	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.1%	0.2%	0.2%	0.1%	0.1%	0.1%
Rigid truck (Class 8)	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.2%	0.5%	0.7%	0.8%	0.3%	0.3%	0.4%
Short-haul tractor truck	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.1%	0.3%	0.4%	0.4%	0.3%	0.3%	0.3%
Long-haul tractor truck	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Refuse truck	0.0%	0.0%	0.0%	0.1%	0.1%	0.2%	0.3%	0.5%	0.5%	0.5%	0.5%	0.6%	0.6%	0.7%
Small bus (Class 4-5)	0.0%	0.1%	0.1%	0.1%	0.2%	0.3%	0.4%	0.8%	1.4%	1.5%	1.6%	1.7%	1.9%	2.0%
Transit bus (Class 6-8)	0.0%	0.5%	0.5%	0.6%	1.3%	1.6%	1.7%	3.3%	5.9%	6.0%	6.2%	6.3%	6.5%	6.6%
School bus (Class 6-8)	0.0%	0.0%	0.0%	0.0%	0.1%	0.1%	0.2%	0.3%	0.4%	0.6%	0.7%	0.9%	1.1%	1.4%
Other bus (Class 6-8)	0.0%	0.1%	0.1%	0.1%	0.1%	0.2%	0.3%	0.4%	0.6%	0.7%	0.9%	1.1%	1.4%	1.6%

FCEV share of ZEV sales in IRA Moderate scenario														
HDV class	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
Rigid truck (Class 4-5)	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.1%	0.3%	0.3%	0.3%	0.1%	0.1%	0.1%
Rigid truck (Class 6-7)	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.2%	0.3%	0.3%	0.3%	0.1%	0.1%	0.1%
Rigid truck (Class 8)	0.0%	0.0%	0.1%	0.1%	0.1%	0.1%	0.2%	0.6%	1.6%	1.9%	2.2%	0.8%	0.8%	0.8%
Short-haul tractor truck	0.0%	0.0%	0.1%	0.1%	0.1%	0.1%	0.2%	0.3%	0.7%	0.8%	0.9%	0.6%	0.6%	0.6%
Long-haul tractor truck	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.2%	0.2%	0.2%
Refuse truck	0.0%	0.0%	0.1%	0.3%	0.4%	0.5%	0.7%	0.9%	0.7%	0.7%	0.8%	0.8%	0.9%	1.0%
Small bus (Class 4-5)	0.3%	0.5%	0.4%	0.4%	0.7%	0.9%	1.1%	2.1%	4.0%	4.2%	4.5%	4.8%	5.1%	5.5%
Transit bus (Class 6-8)	0.6%	4.9%	3.3%	2.5%	4.6%	4.9%	4.8%	7.6%	11.3%	11.4%	11.5%	11.7%	11.9%	12.1%
School bus (Class 6-8)	0.3%	0.2%	0.2%	0.2%	0.3%	0.4%	0.6%	0.9%	1.4%	1.8%	2.2%	2.8%	3.4%	4.1%
Other bus (Class 6-8)	0.8%	0.7%	0.6%	0.6%	0.7%	0.8%	1.0%	1.4%	2.0%	2.5%	3.1%	3.7%	4.4%	5.1%

DISCUSSION AND POLICY RECOMMENDATIONS

This analysis finds that, with the combined effects of the IRA and technology improvements that will drive down ZEV manufacturing costs, the United States will see rapid electrification over the coming decade. By 2030, we find a range of 48%–61% EV sales share in the light-duty sector, increasing to 56%–67% by 2032, the final year of the IRA tax credits. For heavy-duty, we estimate a range of 39%–48% ZEV sales share by 2030 and 44%–52% by 2032.

We find that the Biden administration's goals of a 50% light-duty EV sales share and a 30% heavy-duty ZEV sales share by 2030 are likely to be exceeded with the influence of the IRA. In the case of heavy-duty vehicles, the administration's target could be exceeded considerably.

However, other analysis has found that the Biden administration's electrification goals would not be sufficient to meet its climate goals. Slowik and Miller (2022) assessed the greenhouse gas (GHG) reductions from light-duty vehicles that are necessary to be compatible with the Paris Climate Agreement to limit global warming to well below 2 degrees Celsius. That analysis found that EV sales shares would need to reach 67% by 2030, coupled with a 3.5% annual increase in the efficiency of combustion engine vehicles, to be compatible with the Paris Agreement. That EV share is higher than the range of results we model here for 2030. Comparing the analysis presented here with the Paris-compatible scenario in Slowik and Miller also shows that, even if all the states that have adopted ACC I also adopt ACC II, the combination of state action and the IRA would still not be sufficient to meet our climate goals.

Other analysis suggests that higher heavy-duty vehicle electrification rates than projected here may also be needed. Buysse, Kelly, and Minjares (2022) find that a heavy-duty ZEV sales share of 46% by 2030 would be needed to be compatible with a scenario of 2 degrees Celsius.

In an earlier analysis using the Energy Policy Simulator model, Orvis, Gopal, Rissman, O'Boyle, Baldwin, and Busch (2022) found that the IRA would significantly reduce GHG emissions, but not enough to put the United States on track to meet is Nationally Determined Contribution commitment to reduce GHG emissions by 50%–52% in 2030 compared to 2005 levels. Thus, additional policy action in the United States is likely necessary to avert the worst effects of climate change.

This analysis is relevant for the U.S. Environmental Protection Agency's next round of rulemaking on light-duty and heavy-duty vehicles. The agency plans to release new proposals for GHG standards by the end of March 2023 (U.S. Environmental Protection Agency, 2022). Because our analysis projects EV and ZEV penetration rates in the absence of federal standards, it can be viewed as a baseline for the purposes of setting those standards. To deliver climate benefits, the new standards will need to advance technology improvements, which could include both electrification as well as efficiency improvements in combustion engine vehicles, faster than is expected under the baseline. Our analysis suggests that setting light-duty standards consistent with an EV penetration rate significantly greater than 50% and heavy-duty standards consistent with a ZEV penetration rate significantly greater than 40% in 2030 may be necessary to deliver additional climate benefits. Another way of viewing our results is that, because of the opportunity for the IRA to deliver such high electrification rates, the federal GHG standards can achieve even greater EV and ZEV penetration and consumer benefits at potentially little additional cost to consumers and automakers.

There is also a role for federal GHG standards to act as a backstop to the IRA and ensure continued growth in EV and ZEV sales shares. The IRA tax credits are set to expire after 2032, and we find that progress in electrification slows after that year. In addition, there is uncertainty in any policy and it is possible that the tax credits could be affected by new legislation or by changes in implementation by future administrations. Setting strong federal GHG standards can help ensure progress in EV and ZEV deployment continues in the face of uncertainty in IRA implementation.

Our modeling approach carries limitations. The GCAM model logit function is based on a single numerical value that orders consumer purchase preferences. This choice indicator approach does not necessarily capture individual preferences, local variations in cost, and other personal factors that would result in economically inferior choices. Furthermore, should battery prices not decline as predicted or consumer acceptance of electric vehicles stalls, our forecasts could be overly optimistic. Conversely, our estimates could be overly conservative if these factors all turned positive.

There are two key non-financial barriers not accounted for in this study: manufacturing lead time and charging infrastructure lead time. These are both greater challenges for the heavy-duty sector than for LDVs. While EVs accounted for 7% of LDV sales in the first half of 2022 in the United States, heavy-duty ZEV sales number only in the hundreds per year at present (Mock & Yang, 2022; Buysse, 2022). Heavy-duty ZEV assembly lines will need to ramp up quickly to deliver the ZEV numbers we project will be demanded on the basis of cost and consumer preferences. Charging infrastructure for heavy-duty vehicles is also expected to take significantly more time to install than for light-duty, since HDV charging depots will increase the demand on the electricity grid at each location to a much greater extent than LDV charging, necessitating time-consuming grid upgrades (Helou et al., 2022). Utilities, industry, and the government will all need to act early to begin making these changes to enable ZEV deployment.

We find that hydrogen is unlikely to play a major role in decarbonizing the U.S. road transportation sector, even when considering the IRA incentives for hydrogen. In this study, we model the cost of green hydrogen, including the incentives from both the clean hydrogen and renewable electricity tax credits in the IRA. We find that the resulting cost of green hydrogen at the pump will still be very high through 2035 (see Table A1 in the appendix). We estimate a sales share of less than 1% for hydrogen FCEVs in each of the truck classes analyzed here. We find up to a 7% FCEV penetration in transit buses, with less than a 2% FCEV sales share for the other bus classes in 2035 (Table 4). Our analysis suggests that battery electric technology will dominate electrification for heavy-duty vehicles. We did not consider light-duty hydrogen vehicles in this analysis.

New guidance from the Treasury Department in December 2022 establishes leased vehicles as eligible for the commercial vehicle tax credit of $7,500 (Internal Revenue Service, 2022). We did not explicitly consider leased light-duty vehicles in our analysis, but do not expect it would greatly change our results. The share of new EVs that are leased has been declining, representing only about 10% of new electric vehicles in the third quarter of 2022 (Webb, 2022). Moreover, the commercial vehicle tax credit is capped at the incremental cost of a BEV compared to a conventional vehicle. As our cost analysis finds that most light-duty EVs will reach cost parity with gasoline vehicles before 2030, we expect the commercial vehicle tax credit to offer a financial benefit compared with the personal tax credit for only the next few years.

We note several uncertainties and limitations, as well as opportunities for additional research. The projections of EV and ZEV uptake in this study are dependent on the choice of logit exponents and shareweights. In this analysis, these parameters are selected to reflect historical consumer preferences for conventional technology and supply chain constraints. In the future, consumer preferences could change to a greater extent than explored here. Future supply chain development, particularly for materials used in battery production, is uncertain, as is infrastructure availability. Infrastructure needs for the heavy-duty sector, purchase price and total cost of ownership projections for battery electric and fuel cell electric heavy-duty vehicles, and analysis of the heavy-duty vehicle electrification pace necessary to meet our climate goals, will be addressed in forthcoming ICCT publications.

CONCLUSIONS

This study assesses the combined impacts of technology improvement and the IRA tax incentives on EV and ZEV deployment rates from 2023 to 2035. From the results presented here, we draw the following conclusions:

- The IRA can potentially drive high rates of electrification over the coming decade. By 2030, we find a range of 48%–61% EV sales share in the light-duty sector, increasing to 56%–67% by 2032, the final year of the IRA tax credits. For heavy-duty, we estimate a range of 39%–48% ZEV sales share by 2030 and 44%–52% by 2032.
- Additional policy is needed in the United States to avert the worst impacts of climate change. The rates of electrification estimated in this analysis are not high enough to be compatible with the Paris Agreement goals or the U.S. Nationally Determined Contribution.
- Battery electric technology will likely play a much larger role than hydrogen in decarbonizing the road transportation sector. This analysis finds less than 1% penetration of hydrogen FCEVs in all truck classes, including long-haul tractor-trailers. We find 7% FCEV penetration for transit buses and 2% or lower FCEV sales shares for other bus classes.
- To deliver substantial additional climate benefits, the U.S. Environmental Protection Agency's federal GHG standards for both light- and heavy-duty vehicles may need to be consistent with electrification rates well above 50% for light-duty and above 40% for heavy-duty vehicles in 2030.
- Strong federal GHG standards for light- and heavy-duty vehicles will also be needed to ensure that the electrification benefits of the IRA continue after the tax credits expire and in case implementation of the tax credits changes.
- Additional action is needed by governments and industry to resolve non-financial barriers to electrification. This includes planning ahead to build charging infrastructure for heavy-duty vehicles and investing in the manufacturing of new vehicle technologies.

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APPENDIX

HEAVY-DUTY VEHICLE PARAMETERS

Table A1. Battery sizes in kWh, 2023–2035

	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
Rigid truck (Class 4–5)	135	134	132	131	129	128	126	125	122	121	120	119	118	117
Rigid truck (Class 6–7)	205	203	201	198	196	194	192	190	185	184	182	181	179	178
Rigid truck (Class 8)	400	396	391	387	383	378	374	370	361	358	355	352	349	347
Short-haul tractor truck	455	450	445	440	435	430	426	421	411	407	404	401	398	394
Long-haul tractor truck	1,157	1,138	1,120	1,101	1,083	1,064	1,046	1,027	990	977	965	952	940	927
Refuse truck	405	401	396	392	388	383	379	374	366	363	360	357	354	351
Small bus (Class 4–5)	120	119	117	116	115	114	112	111	108	107	107	106	105	104
Transit bus (Class 6–8)	450	445	440	435	431	426	421	416	406	403	400	396	393	390
School bus (Class 6–8)	180	179	178	177	176	174	173	172	170	169	168	167	166	165
Other bus (Class 6–8)	680	679	678	677	676	674	673	672	670	668	666	664	662	660

Table A2. Summary of HDVs retail prices before incentive, 2023–2035

HDV class		2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
Rigid truck (Class 4–5)	**Diesel**	86k	87k	87k	88k	88k	88k	88k	88k	88k	88k	89k	89k	89k
	BEV	117k	111k	105k	99k	94k	89k	84k	79k	78k	77k	77k	76k	75k
	FCV	324k	298k	273k	249k	225k	201k	178k	156k	153k	151k	148k	146k	143k
Rigid truck (Class 6–7)	**Diesel**	112k	112k	112k	113k	113k	113k	114k	114k	115k	115k	116k	116k	117k
	BEV	151k	142k	135k	127k	119k	112k	105k	98k	97k	96k	95k	94k	94k
	FCV	378k	348k	319k	291k	263k	236k	209k	184k	181k	178k	174k	171k	168k
Rigid truck (Class 8)	**Diesel**	159k	160k	161k	161k	162k	162k	162k	162k	162k	162k	162k	162k	162k
	BEV	256k	241k	228k	215k	202k	190k	178k	167k	165k	163k	161k	160k	158k
	FCV	439k	407k	375k	345k	315k	286k	258k	230k	227k	223k	220k	217k	214k
Short-haul tractor truck	**Diesel**	151k	151k	151k	151k	151k	152k	152k	153k	154k	155k	155k	156k	157k
	BEV	263k	248k	233k	219k	205k	192k	179k	166k	164k	163k	161k	159k	157k
	FCV	452k	418k	385k	352k	321k	290k	260k	231k	227k	224k	220k	216k	213k
Long-haul tractor truck	**Diesel**	169k	170k	171k	172k	172k	173k	174k	175k	175k	176k	177k	178k	178k
	BEV	478k	443k	410k	378k	348k	318k	291k	264k	259k	254k	249k	244k	239k
	FCV	507k	468k	430k	393k	358k	323k	290k	258k	254k	249k	245k	241k	237k
Refuse truck	**Diesel**	302k	303k	303k	304k	304k	304k	304k	304k	304k	304k	304k	304k	304k
	BEV	337k	322k	307k	293k	279k	266k	253k	241k	239k	237k	236k	234k	232k
	FCV	537k	502k	468k	435k	403k	372k	341k	311k	308k	304k	300k	297k	293k
Small bus (Class 4–5)	**Diesel**	77k	78k	78k	79k	79k	79k	79k	79k	79k	79k	79k	79k	79k
	BEV	117k	113k	108k	104k	99k	95k	91k	87k	87k	86k	86k	85k	85k
	FCV	190k	179k	169k	159k	149k	139k	130k	120k	111k	110k	109k	108k	107k
Transit bus (Class 6–8)	**Diesel**	331k	342k	354k	365k	376k	376k	376k	376k	376k	376k	376k	376k	376k
	BEV	434k	418k	402k	387k	373k	358k	344k	331k	329k	327k	326k	324k	322k
	FCV	566k	540k	515k	490k	466k	443k	420k	398k	376k	373k	370k	367k	365k
School bus (Class 6–8)	**Diesel**	128k	128k	128k	128k	128k	128k	128k	128k	128k	128k	128k	128k	128k
	BEV	183k	176k	169k	162k	156k	150k	143k	138k	137k	136k	135k	134k	134k
	FCV	308k	290k	273k	256k	240k	224k	208k	193k	178k	176k	174k	173k	171k
Other bus (Class 6–8)	**Diesel**	630k	634k	634k	634k	638k	638k	638k	638k	637k	637k	637k	637k	637k
	BEV	800k	776k	752k	729k	707k	684k	662k	640k	638k	635k	633k	630k	628k
	FCV	954k	917k	880k	845k	810k	777k	743k	711k	680k	676k	671k	667k	663k

Notes: Prices are in U.S. dollars. The blue shaded cells indicate the years in which purchase price parity is reached between each ZEV technology and diesel vehicles, and later.

Table A3. Sales shares of heavy-duty vehicles by category in the IRA Moderate scenario, 2023–2035

HDV class		2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
Rigid truck (Class 4–5)	**BEV**	23%	28%	31%	34%	38%	41%	51%	61%	64%	66%	69%	71%	73%
	Diesel	77%	72%	69%	66%	62%	59%	49%	39%	36%	33%	31%	29%	27%
	FCV	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Rigid truck (Class 6–7)	**BEV**	14%	19%	22%	25%	28%	32%	43%	55%	58%	61%	64%	67%	70%
	Diesel	86%	81%	78%	75%	72%	68%	57%	45%	42%	39%	36%	33%	30%
	FCV	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Rigid truck (Class 8)	**BEV**	2%	5%	9%	16%	26%	29%	32%	33%	35%	36%	38%	40%	43%
	Diesel	98%	95%	91%	84%	74%	71%	68%	66%	65%	63%	62%	59%	57%
	FCV	0%	0%	0%	0%	0%	0%	0%	1%	1%	1%	0%	0%	0%
Short-haul tractor truck	**BEV**	2%	6%	11%	18%	27%	38%	41%	44%	48%	49%	46%	48%	49%
	Diesel	98%	94%	89%	82%	73%	62%	58%	56%	52%	51%	54%	52%	50%
	FCV	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Long-haul tractor truck	**BEV**	0%	1%	1%	2%	4%	6%	10%	16%	19%	18%	11%	12%	13%
	Diesel	100%	99%	99%	98%	96%	94%	90%	84%	81%	82%	89%	88%	87%
	FCV	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Refuse truck	**BEV**	12%	16%	19%	25%	34%	44%	54%	63%	65%	67%	69%	71%	73%
	Diesel	88%	84%	81%	75%	65%	55%	46%	37%	34%	32%	30%	28%	26%
	FCV	0%	0%	0%	0%	0%	0%	1%	0%	0%	1%	1%	1%	1%
Small bus (Class 4–5)	**BEV**	15%	22%	28%	32%	34%	35%	37%	34%	34%	35%	35%	35%	35%
	Diesel	85%	78%	72%	68%	66%	65%	63%	65%	64%	64%	64%	64%	63%
	FCV	0%	0%	0%	0%	0%	0%	1%	1%	2%	2%	2%	2%	2%
Transit bus (Class 6–8)	**BEV**	10%	16%	22%	28%	30%	33%	40%	47%	47%	47%	48%	48%	48%
	Diesel	89%	84%	77%	70%	68%	65%	56%	47%	47%	46%	46%	46%	45%
	FCV	1%	1%	1%	1%	2%	2%	3%	6%	6%	6%	6%	6%	7%
School bus (Class 6–8)	**BEV**	10%	17%	23%	27%	29%	31%	31%	32%	32%	32%	32%	32%	32%
	Diesel	90%	83%	76%	73%	70%	69%	68%	68%	67%	67%	67%	67%	67%
	FCV	0%	0%	0%	0%	0%	0%	0%	0%	1%	1%	1%	1%	1%
Other bus (Class 6–8)	**BEV**	8%	12%	17%	21%	24%	27%	28%	29%	29%	29%	29%	29%	30%
	Diesel	92%	88%	83%	79%	75%	72%	71%	71%	70%	70%	70%	69%	69%
	FCV	0%	0%	0%	0%	0%	0%	0%	1%	1%	1%	1%	1%	2%

GREEN HYDROGEN COSTS

We estimate the production cost of green hydrogen using a discounted cashflow (DCF) model, which calculates the current value of investing in a product by accounting for the producer's future annual cash flows. Detailed model assumptions, including the capital and operational costs and financial assumptions, can be found in Zhou & Searle (2022). For the IRA scenarios in this analysis, we use the same DCF model but change certain inputs following the provisions under this law. The tax credits are only applied in years 2023 to 2032, indicating that only producers that started operating early in 2023 would receive the full 10-year credits. The credits are valued at $0.026 per kWh and up to $3 per kg hydrogen, respectively, in 2023, subject to inflation adjustment in future years. Therefore, we assume a 2% annual inflation rate in this study. Per the IRA, the actual amount of hydrogen tax credit is dependent on its life-cycle greenhouse gas emissions—the higher the emissions, the lower the tax credit. In general, green hydrogen has low enough emissions to qualify for the highest $3 per kg hydrogen credit,[8] and the two sets of clean energy tax credits can be combined. In addition, section 6417 of the IRA includes a "direct pay" provision for clean hydrogen producers, where the tax credits are refundable for the first five years of operation. Further, under section 6418, both renewable electricity and clean hydrogen producers are eligible for tax "transferability" by selling their unused tax credits to a buyer who has the tax burden. However, the credits might be transferred, i.e., traded, at a discounted or lower value and could incur due diligence costs (Burton & Vozarova, 2022). Thus, without further details from the IRA, we apply a 15% discount rate to the $0.026 per kWh or $3 per kg hydrogen credit values when the unused renewable electricity or clean hydrogen credits are being transferred. Table A4 shows the estimated levelized green hydrogen production cost with and without the IRA tax credits.

Table A4. Levelized production cost of a new green hydrogen production plant entering the market in a given year, with and without the IRA clean energy tax credits.

Year	With no tax credit	With IRA tax credits
2020	5.59	NA
2021	5.48	NA
2022	5.41	NA
2023	5.35	3.29
2024	5.29	3.40
2025	5.21	3.52
2026	5.16	3.69
2027	5.09	3.93
2028	5.02	4.19
2029	4.95	4.43
2030	4.85	4.58
2031	4.80	4.65
2032	4.75	4.68
2033	4.70	NA
2034	4.59	NA
2035	4.54	NA

The hydrogen refueling station (HRS) cost is based on the study by Reddi et al. (2017). Using the results from that study, we assume the levelized HRS cost to be $6 per kg hydrogen in 2020, decreasing linearly to $2.3 per kg in 2050. These values are consistent with the assumptions in Zhou & Searle (2022), which were based on a European study (European Commission, 2021). The decreasing cost is a result of economies of scale and greater utilization of the HRS. Section 13404 of the IRA provides tax credits to eligible HRSs of up to $100,000. We therefore assume a minor 4% lower HRS cost for the IRA scenario.

The estimated hydrogen price in a given year is the cost of a new project entering production in that year and does not necessarily represent the price to the consumer.

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[8] See Zhou, Swidler, Searle, and Baldino (2021).

The consumer price will be set based on competition between all hydrogen suppliers, including those that began production in earlier years. In order to estimate a price more representative of the market for each year, we average the costs of producers beginning production in that year and of all producers that began production in earlier years. We thus implicitly assume a linear increase in the number of new hydrogen producers over time. For example, the at-the-pump hydrogen price in 2030 is the average of the 2020–2022 costs when there were no policy incentives and the 2023–2030 costs with the IRA tax credits. Figure A1 shows the at-the-pump green hydrogen price when a new project enters the market each year between 2020 and 2035 and the calculated market price considering all operating projects in that year.

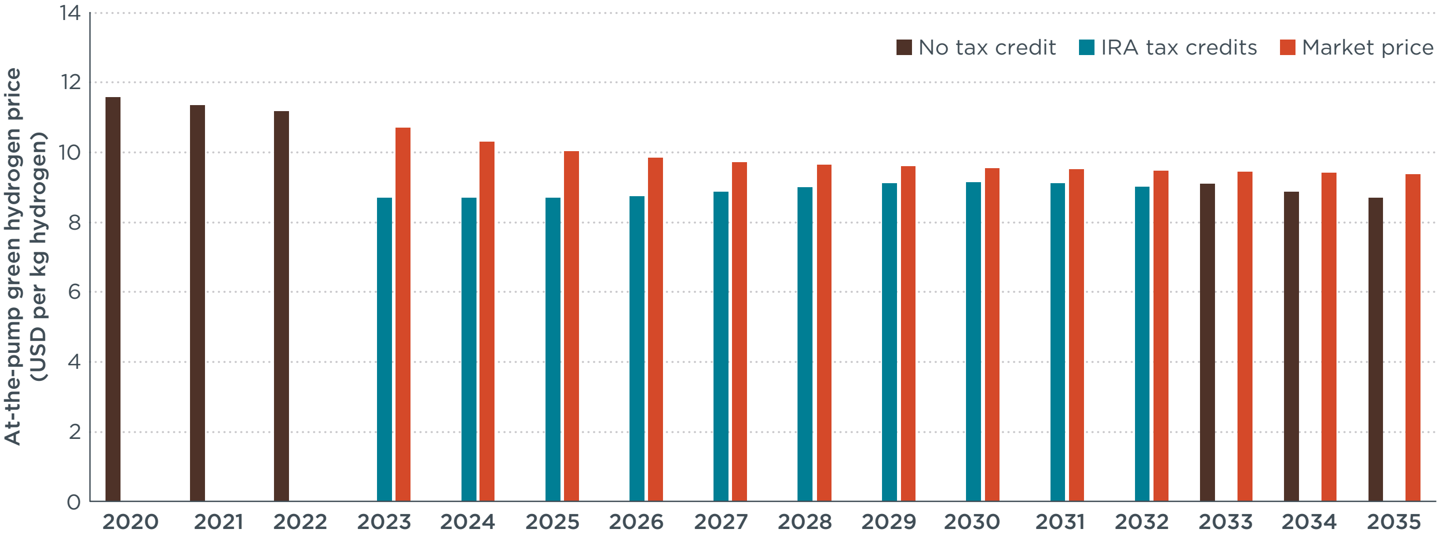

Figure A1. At-the-pump green hydrogen price

DETAILED RESULTS TABLES

Table A5. Projected BEV, PHEV, and total EV sales shares for light-duty vehicles nationwide, 2022–2035

Scenario		2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
Baseline	BEV	5.3%	7.1%	9.2%	11.5%	16.0%	19.7%	23.5%	27.5%	31.5%	34.9%	37.8%	40.6%	43.2%	45.7%
	PHEV	1.4%	1.1%	1.2%	1.3%	2.1%	2.3%	2.5%	2.6%	2.7%	2.7%	2.6%	2.6%	2.6%	2.5%
	Total EV	6.7%	8.1%	10.3%	12.8%	18.0%	22.0%	26.0%	30.1%	34.1%	37.6%	40.5%	43.2%	45.8%	48.2%
IRA Low with CA-only ACC II	BEV	5.3%	12.3%	15.9%	19.6%	24.4%	29.2%	34.6%	40.0%	45.1%	49.2%	52.5%	40.6%	43.2%	45.7%
	PHEV	1.4%	2.0%	2.2%	2.3%	2.9%	3.1%	3.3%	3.3%	3.2%	3.2%	3.1%	2.6%	2.6%	2.5%
	Total EV	6.7%	14.3%	18.0%	21.9%	27.3%	32.3%	37.9%	43.3%	48.3%	52.3%	55.6%	43.2%	45.8%	48.2%
IRA Moderate with CA-only ACC II	BEV	5.3%	13.8%	19.7%	24.2%	29.2%	34.8%	40.6%	46.4%	50.9%	51.0%	54.8%	40.6%	43.2%	45.7%
	PHEV	1.4%	2.1%	2.2%	2.3%	2.9%	3.0%	3.0%	2.9%	2.9%	3.2%	3.1%	2.6%	2.6%	2.5%
	Total EV	6.7%	15.9%	21.9%	26.5%	32.1%	37.8%	43.6%	49.3%	53.8%	54.3%	57.9%	43.2%	45.8%	48.2%
IRA Moderate with increased state ACC II adoption	BEV	5.3%	13.8%	19.7%	24.2%	29.0%	34.7%	41.0%	47.5%	53.1%	55.1%	59.6%	51.0%	54.6%	58.2%
	PHEV	1.4%	2.1%	2.2%	2.3%	3.6%	4.7%	4.8%	4.6%	4.8%	5.5%	5.3%	5.2%	5.2%	5.1%
	Total EV	6.7%	15.9%	21.9%	26.5%	32.6%	39.3%	45.8%	52.1%	57.9%	60.6%	64.9%	56.2%	59.8%	63.3%
IRA High with increased state ACC II adoption	BEV	5.3%	15.5%	22.5%	27.7%	32.1%	38.2%	44.9%	51.7%	56.5%	56.5%	61.2%	51.0%	54.6%	58.2%
	PHEV	1.5%	2.1%	2.0%	2.0%	3.4%	4.0%	4.0%	3.8%	4.1%	5.5%	5.3%	5.2%	5.2%	5.1%
	Total EV	6.7%	17.7%	24.4%	29.8%	35.5%	42.2%	48.9%	55.5%	60.6%	62.0%	66.5%	56.2%	59.8%	63.3%

SENSITIVITY ANALYSIS RESULTS

Light-duty vehicles

A key component of the logit allocation that determines sales shares is the logit exponent used, which determines the sensitivity of the allocation to the cost parameter. We utilize values from GCAM for this modeling (Joint Global Change Research Institute, n.d.), but note that these values do not appear to be empirically grounded nor updated recently. Given the importance of this component for determing sales shares, the electric vehicle share findings were tested for their sensitivity to variations to the logit exponent. Compared to our analysis above that uses a GCAM value of -8, alternative GCAM values of -6 and -10 (i.e., adding 2 or -2) were applied, reflecting relatively greater and lesser consumer sensitivity to TCO when making purchase decisions. Figure A2 illustrates how the findings of electric vehicle shares vary with adjustments to the logit exponent, indicated by the red hashed area surrounding the black hashed line. As shown, adusting the logit exponent to -6 and -10 has the greatest effect on projections for electric vehicle shares around the 2030–2031 timeframe, at about +/- 5%; this is because of the incentive. The sensitivity analysis shown in Figure A2 is for the Moderate IRA + increased ACC II adoption scenario, but the effects of adjusting the logit exponent are similar for all scenarios.

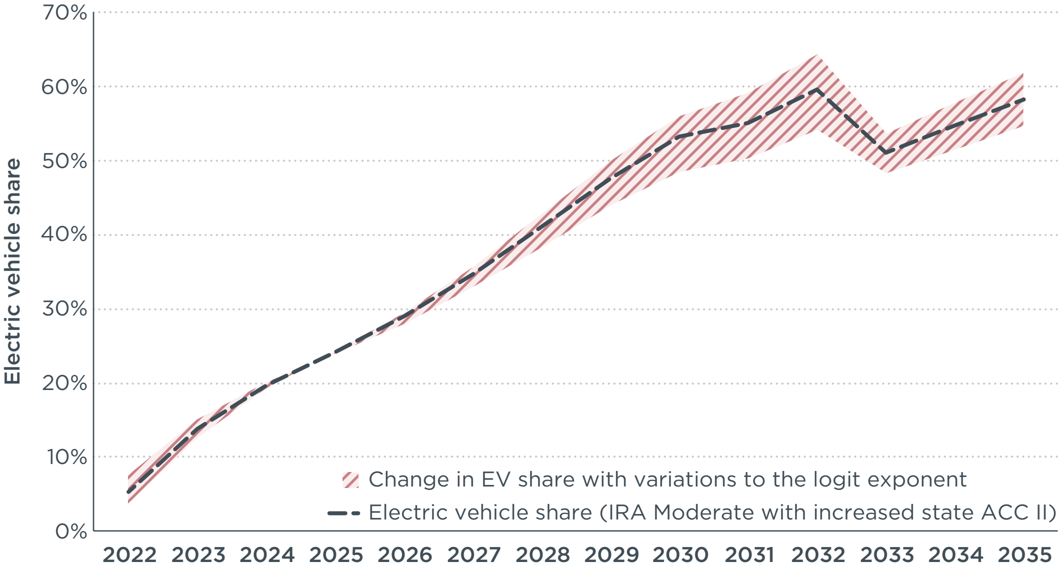

Figure A2. Sensitivity of electric vehicle share findings to variations to the logit exponent, reflecting greater and lesser consumer sensitivity to TCO in purchase decisions. Findings are shown for the IRA Moderate with increased state ACC II adoption scenario.

Heavy-duty vehicles

As with the light-duty vehicle analysis, we test the heavy-duty electric vehicle share findings for their sensitivity to variations to the logit exponent. Compared to the central case of a GCAM value of -8 for non-buses and -3 for buses, alternative GCAM values of -6 and -10 for non-buses and -1 and -5 for buses (i.e., adding 2 or -2) were applied, reflecting relatively greater and lesser consumer sensitivity to TCO, as for light-duty vehicles above. The red hashed areas surrounding the black line in Figure 9 illustrate how the BEV shares for each category of trucks and buses varies with adjustments to the logit expoent. The BEV sales shares for small buses, transit buses, and school buses are more sensitive to the assumption on the logit exponent, while those for short and long haul tractor trucks, Class 8 rigid trucks, and Class 6–8 other buses, are less sensitive to the logit exponent. The sensitivity analysis shown in Figure 9 is for the IRA Moderate scenario, but the effects of adjusting the logit exponent are similar for all scenarios.

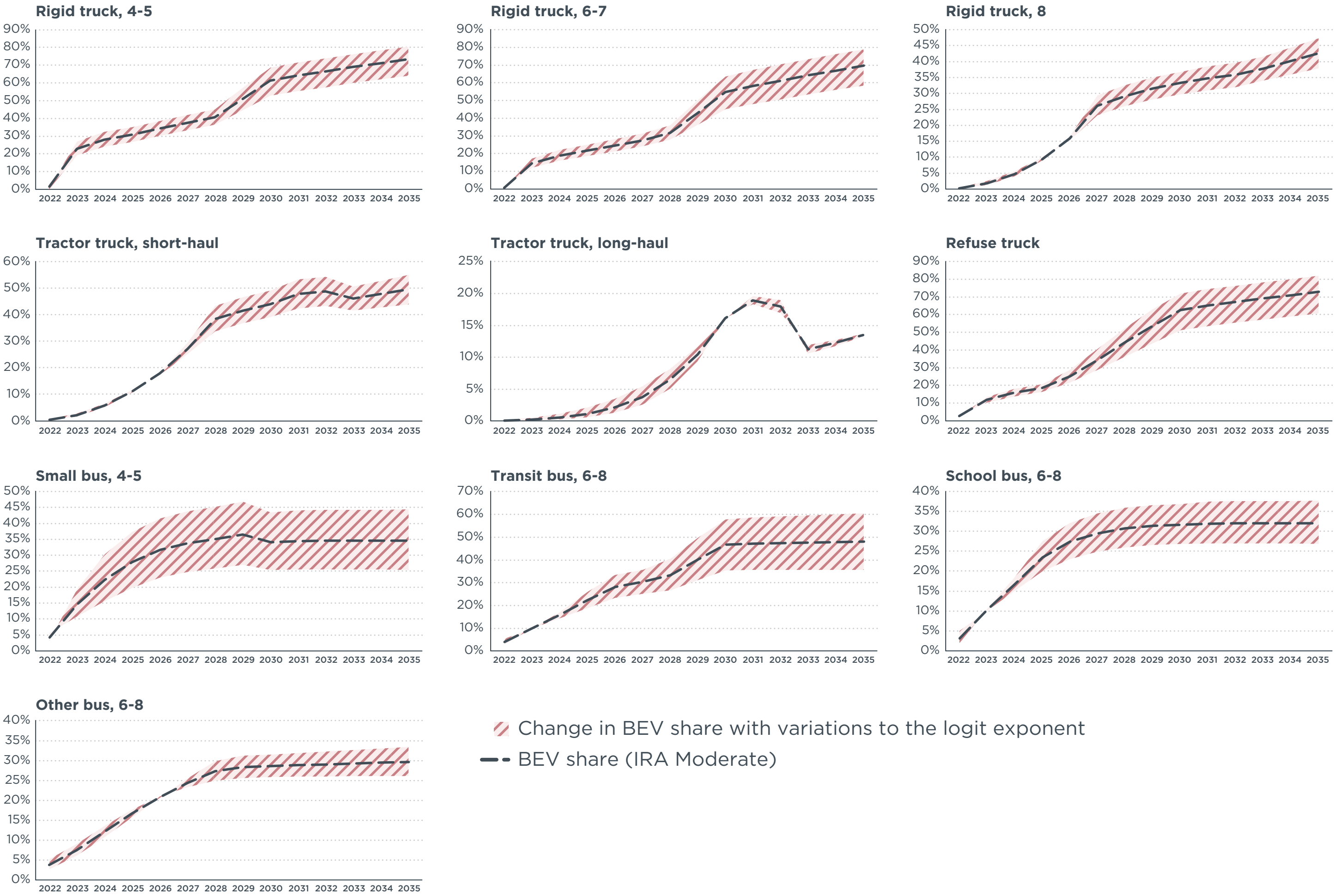

Figure A3. Sensitivity of BEV share findings to variations to the logit exponent for U.S. heavy-duty BEV sales shares by category in the IRA Moderate scenario, 2022–2035.