


State Advanced Clean Cars II Programs

Technical Report–Methodologies and Assumptions

February 2023

The business of sustainability

Acknowledgements

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About ERM

ERM partners with the world's leading organizations, creating innovative solutions to sustainability challenges and unlocking commercial opportunities that meet the needs of today while preserving opportunity for future generations. Our diverse team of world-class experts supports clients across the breadth of their organizations to operationalize sustainability, underpinned by our deep technical expertise in addressing their environmental, health, safety, risk, and social issues. M.J. Bradley & Associates (MJB&A) was acquired by ERM Group company in 2022. For more information, we encourage you to visit our website, www.erm.com or www.sustainability.com.

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INTRODUCTION

ERM was commissioned by the Natural Resources Defense Council and the Sierra Club to develop a state-based modeling framework that could be used to estimate the costs, benefits, and net societal benefits of state-level requirements for manufacturers to increase sales of zero-emission new light-duty vehicles (LDV). The modeling framework included all on-road vehicles less than 8,500 pounds gross vehicle weight, encompassing passenger cars, crossovers, SUVs, and light pickup trucks.

Collectively in the United States, the LDV fleet includes more than 253 million vehicles that annually travel more than 2.5 trillion miles and consume 340 billion gallons of petroleum fuels (Oak Ridge National Laboratory 2022). Internal combustion engine (ICE) vehicles included in the LDV fleet emit criteria (smog forming) and greenhouse gas (GHG) emissions from their tailpipes that contribute to air pollution and global warming.

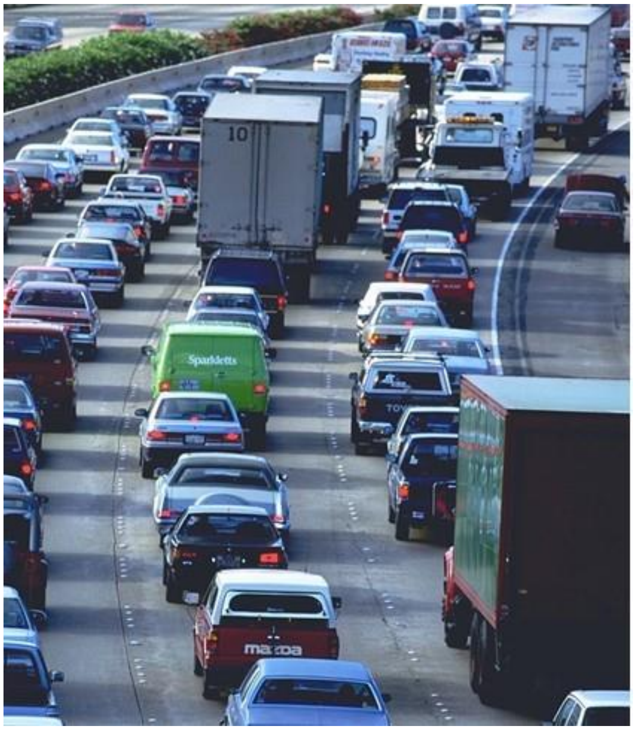
Advanced Clean Cars I and II

In 2012, California's Air Resource Board (CARB) adopted a regulation package to address criteria and GHG emissions from new LDVs. This package, known as the Advanced Clean Cars (ACC) program, included more stringent versions of the Low Emission Vehicle (LEV) regulation for GHG and criteria emissions, and the manufacturer mandate to increase sales of zero-emission vehicles (ZEVs).

In 2022, CARB adopted the second phase of ACC, called ACC II, which further increased the stringency of both the LEV criteria and ZEV standards starting with model year (MY) 2026. The main goal of the ACC II program is to have all new passenger cars, light trucks, and SUVs sold in California be ZEV by 2035. To accomplish this, CARB developed a compliance trajectory starting in 2026 and ramping up through 2035.

This technical report summarizes the analytical methodologies and data sources used to develop and populate the modeling framework. Detailed results from using the framework to estimate net benefits of ACC II in various states will be published in separate reports.

This current work builds on ERM's prior framework and reports to evaluate medium- and heavy-duty (M/HD) emissions impacts from policy enactment, conducted in consultation with the Union of Concerned Scientists and NRDC. That work investigated policies to mitigate the significant emissions burden from medium and heavy-duty trucks by switching to low- and zero-emission alternatives. This project explores the remaining light-duty on-road vehicle fleet and the specific benefits of state-level ACC II adoption.



POLICY SCENARIOS

In the individual state-level reports, ERM used the modeling platform described here to model three specific policy scenarios:

- ACC II Flex: State adopts California's ACC II regulation and manufacturers use some compliance flexibilities discussed below. Due to these flexibilities, manufacturers would be able to sell fewer ZEVs needed for compliance—as an example, New York's flexibilities would result in a reduction of about 11 percent of total sales in MY 2026 (i.e., to about 24 percent of sales as opposed to the 35 percent of sales nominally required in that model year). A similar reduction of about 10 to 12 percent from the nominal requirement is assumed in each year for MYs 2027 through 2030, with full compliance needed in MY 2031 and beyond in New York. Under this scenario, new ICE vehicles purchased between MY 2026-2034 will be certified to CARB's LEV standards. Other states will have similar but different compliance trajectories based on the extent to which manufacturers make use of the available ACC II flexibilities.
- ACC II Flex + Clean Grid: Manufacturers follow the sales trajectories in the ACC II Flex scenario discussed above. Additionally, the state decarbonizes their electric grid faster than currently required. Individual states will have specific decarbonization targets. For examples, New York will reach 100 percent clean generation by 2035, while Colorado is assumed to reach 100 percent clean generation by 2040.
- ACC II Full + Clean Grid: State adopts California's ACC II regulation and manufacturers do not use compliance flexibilities discussed below. Under this scenario, manufacturers follow the compliance schedule shown on Figure 1 (ACC II Full). This scenario also incorporates a decarbonized grid and uses the same generation emissions trajectory as the ACC II Flex + Clean Grid scenario.

All three of these state policy scenarios will be compared with a baseline "business as usual" scenario in which all new LDVs sold in the state continue to meet existing United States Environmental Protection Agency (USEPA) emission and NHTSA fuel economy standards[1] and ZEV sales increase only modestly, never reaching more than a third of new vehicle sales each year.[2] Figure 1 shows example state ZEV sales trajectories for each scenario.

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[1] Emission standards are assumed to remain constant after model year 2026.

[2] The baseline ZEV sales assumptions were provided by Shulock Consulting for use in this analysis.

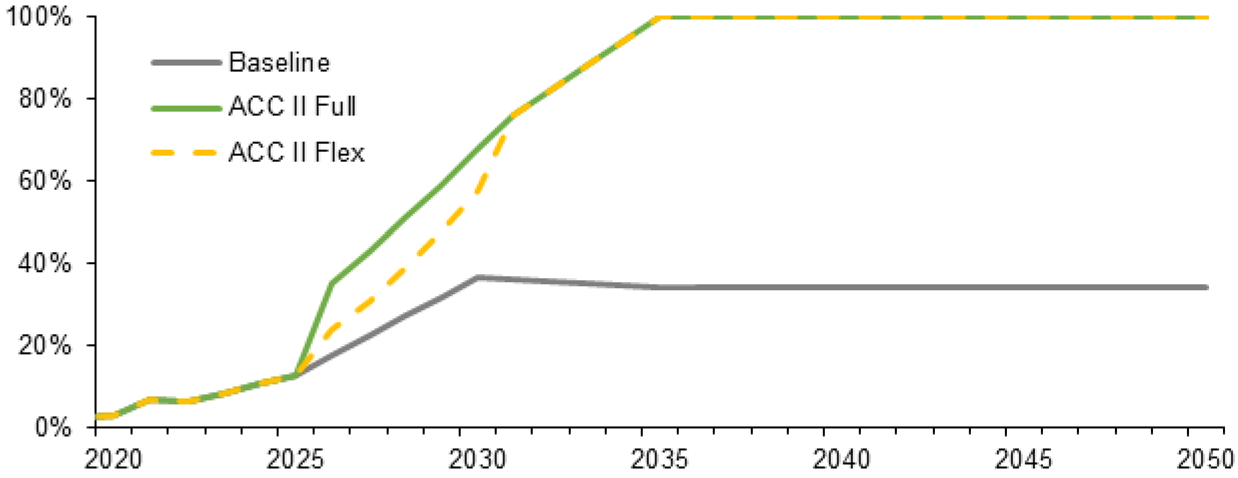

Figure 1: Annual Zero-Emission Vehicle Sales in ACC II Scenarios

As described below, the modeling framework assumes that state LDV annual vehicle miles traveled (VMT) will continue to grow through 2050 as projected by the Energy Information Administration, as the economy and population continue to grow.[3]

SCOPE OF THE MODELING FRAMEWORK

The modeling framework encompasses five interconnected analyses that together estimate the climate, air quality/health, and economic impacts of each policy scenario relative to the baseline scenario. These analyses are summarized in Table 1. Climate and air quality impacts are estimated on the basis of changes in LDV fleet fuel use and include both tailpipe emissions and "upstream" emissions from production of the transportation fuels used in each scenario. This includes the petroleum fuels (gasoline and, diesel) used by conventional ICE vehicles and the electricity used by ZEVs, which under ACC II include both battery electric (BEV) and plug-in hybrid electric (PHEV) vehicles.

Table 1: Modeling Framework Scope

Analysis	Scope
Fuel Use & Emissions Analysis	■ Change in fuel use (diesel, gasoline, electricity, hydrogen); ■ Change in GHG emissions (CO_2, CH_4, N_2O); ■ Change in criteria pollutants (NOx, PM); ■ Includes tailpipe and upstream emissions; ■ Estimate monetized value of net emission reductions.
Health Impacts Analysis	■ Change in premature deaths, hospital visits, and reduced activity and lost workdays due to lower NOx and PM emissions; ■ Estimate monetized value of net health benefits.
Economic & Jobs Analysis	■ Change in spending on vehicle purchase, fuel, and maintenance; ■ Charging infrastructure investments; ■ Change in net jobs, gross domestic product (GDP), and wages across the economy.

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[3] Per the latest EIA projections, future LDV VMT growth will vary by state and region depending on differences in population and economic growth.

Analysis	Scope
Utility Impact Analysis	■ Change in electricity use and load; ■ Utility net revenue; ■ Impact on electricity rates.
GAP Analysis	■ Estimate state-level charging infrastructure needs.

To evaluate climate impacts, the analysis estimates changes in all combustion related GHGs, including carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). To evaluate air quality impacts, the analysis estimates changes in nitrogen oxide (NOx) and particulate matter (PM) emissions and resulting changes in health metrics such as premature deaths, hospital visits, and lost workdays.

The economic analysis estimates the change in annual LDV fleet-wide spending on vehicle purchase, charging infrastructure to support ZEVs, vehicle fuel, and vehicle and infrastructure maintenance. Currently, ZEVs are more expensive to purchase than equivalent ICE vehicles, but they have lower fuel and maintenance costs. In addition, recent cost projections have shown that ZEVs are rapidly approaching cost parity with ICE vehicles, adding to the fuel and maintenance savings received by vehicle owners (Slowik et al. 2022).

The utility impacts analysis assesses the total statewide change in electricity load (kW) and throughput (kWh) for light-duty ZEV charging, as well as the additional revenue and net revenue that would be received by the state's electric utilities for providing this power.[4] Based on projected utility net revenue, the analysis estimates the potential effect on state electricity rates for residential and commercial customers.

The infrastructure gap analysis estimates the total number of vehicle chargers—both home-based chargers and shared "public" ones—that will be required to support the increase in light-duty ZEVs under each scenario compared with the existing charging network in the state.

METHODOLOGIES AND ASSUMPTIONS

This section discusses the methodologies and major assumptions used in each section of the modeling framework. As noted, some assumptions will be common to all states, and some will vary by state. Some illustrative examples of assumptions that vary by state, are provided here; more detail on the specific state-level assumptions used will be provided in the state reports.

All dollar values cited in this report are constant 2021$, unless otherwise noted.

ACC II ZEV Sales Assumptions

The ACC II regulation provides manufacturers with several types of flexibilities that can ease their transition to the required ZEV sales levels. The regulation measures compliance in terms of "vehicle values," which are obtained by placing ZEVs, or through other provisions under which manufacturers can earn vehicle values, which then can be used to offset specified portions of the regulatory requirement for MY 2026 through 2031. Manufacturers can also, within limits, use vehicle values earned in one state to meet their compliance obligation in another state. The flexibilities available under the regulation include the following:

- Early Compliance Vehicle Values—earned by ZEVs sold in the state in the two model years prior to the start of the ACC II program. For example, in New York, vehicle values will be earned for ZEV sales greater than 7 percent in MY 2024 and 2025. (ZEV sales up to 7 percent in MY 2024 and 2025

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[4] Utility net revenue is revenue minus the costs of procuring the necessary bulk electricity.

are treated as ACC I ZEV credits, which then become “Converted Vehicle Values” as described below).

- Converted Vehicle Values—surplus ZEV credits earned under the ACC I regulation, which then are “converted” into vehicle values usable for ACC II compliance.
- Environmental Justice Vehicle values—earned for:
  - Low manufacturer suggested retail price (MSRP) ZEVs;
  - ZEVs placed in community car share programs; and
  - ZEVs coming off-lease and delivered to dealerships that participate in vehicle incentive programs targeted at low-income community members.
- Proportional Fuel Cell Allowance—awarded to manufacturers that sell fuel cell vehicles in one state, which then can be used in other states.
- “Pooling”—vehicle values earned by manufacturers that over comply with the regulation in one state (i.e., place more ZEVs than required), which then can be transferred to another state that has lower sales.

Not all flexibilities are available in all model years, and the use of each flexibility is limited by the regulation to ensure that manufacturers must still place a significant number of actual ZEVs to achieve compliance. The limitations are defined in the regulation as a percentage of the ZEV requirement in each model year. Table 2 shows the maximum allowable use of each flexibility in each model year.

Table 2: Maximum Flexibility Use, as Percent of Requirement

	2026	2027	2028	2029	2030	2031
Early Compliance	15%	15%	15%	-	-	-
Converted*	15%	15%	15%	15%	15%	-
Environmental Justice	5%	5%	5%	5%	5%	5%
Proportional Fuel Cell	10%	10%	10%	10%	10%	-
Pooling	25%	20%	15%	10%	5%	-
Total	**70%**	**65%**	**60%**	**40%**	**35%**	**5%**

**The regulation allows manufacturers that exceed a threshold level of Environmental Justice placements to allocate their cumulative allowance of converted vehicle values as desired across model years, rather than limiting the use in any model year to 15 percent of the requirement. The Shulock Consulting projections assume that manufacturers do not make use of the Environmental Justice flexibilities in the different states, so the cumulative option is not addressed here.*

Because the total ZEV percent sales requirement increases each year, the value of a given “percent of requirement” limitation also increases. Thus, it is helpful to view the limitations in terms of their percent of total sales. Table 3 shows the maximum allowable use of each flexibility, expressed as a percent of total sales. For example, in MY 2026 the limitation on early compliance vehicle values is 15 percent of the MY 2026 ZEV requirement of 35 percent, or 5.25 percent of total sales. In MY 2027, 15 percent of the 43 percent ZEV requirement is 6.45 percent of total sales.

Table 3: Maximum Flexibility Use, as Percent of Total Sales

	2026	2027	2028	2029	2030	2031
Early Compliance	5.25%	6.45%	7.65%	0.00%	0.00%	0.00%
Converted*	5.25%	6.45%	7.65%	8.85%	10.20%	0.00%
Environmental Justice	1.75%	2.15%	2.55%	2.95%	3.40%	3.80%
Proportional Fuel Cell	3.50%	4.30%	5.10%	5.90%	6.80%	0.00%
Pooling	8.75%	8.60%	7.65%	5.90%	3.40%	0.00%
Total	**24.50%**	**27.95%**	**30.60%**	**23.60%**	**23.80%**	**3.80%**

As these tables show, if every manufacturer took maximum advantage of every flexibility, the number of ZEVs required would decrease substantially. However, this is very unlikely. Manufacturers have different electrification strategies that will result in different compliance strategies. Pooling is only available for manufacturers that over comply in another state. ZEV-only manufacturers such as Tesla, Rivian, and Lucid will have no need for flexibilities at all. Therefore, the likely use of flexibilities will be less than the maximum allowable use shown above. The estimates in this report are based on Shulock Consulting’s assessment of a reasonable statewide impact, considering all the relevant factors. As an example, Table 4 shows the net ZEV credit breakdown for all flexibilities in New York.

Table 4: Projected ZEV Credits in New York ACC II Scenarios, Percent of Total Sales

		2026	2027	2028	2029	2030	2031
Requirement		**35.0%**	**43.0%**	**51.0%**	**59.0%**	**68.0%**	**76.0%**
ZEV Credits	Early Compliance	3.3%	3.3%	2.8%	-	-	-
	Converted	5.3%	6.5%	7.7%	8.9%	10.2%	-
	Environmental Justice	-	-	-	-	-	-
	Proportional FCEV	0.2%	0.2%	0.3%	0.3%	0.3%	-
	Pooling	2.4%	2.3%	1.4%	2.1%	-	-
ZEVs Needed After ZEV Crediting		**23.8%**	**30.7%**	**38.8%**	**47.7%**	**57.5%**	**76.0%**

Vehicle Population and VMT

ERM used MOVES3 to determine the starting vehicle population and age distribution for each state using 2022 values for passenger cars, passenger trucks, and light commercial trucks (excluding Class 2b trucks) aggregated to a single LDV category. To evolve the vehicle population through time, NHTSA's survival rates were used as well as census region specific growth rates for LDVs based on EIA's Annual Energy Outlook 2022 (NHTSA 2006, EIA 2022a). For this analysis, ICE vehicles and ZEVs were assumed to have the same survival rates. Combining the annual ZEV sales with the model year breakdown for each calendar year results in a realistic ZEV population growth.

Since emissions are based on the number of miles driven by vehicles and vehicles drive different numbers of miles depending on their age, a careful calculation of VMT was required. NHTSA's age-dependent travel mileage schedule was used to get total ZEV and ICE miles by year.

Fuel Use and Emissions Analysis

The modeling framework used vehicle population and VMT assumptions discussed above for input into ERM's State Emission Pathways (STEP) Tool to generate, for each year through 2050, total fuel/energy use by the LDV fleet at the state level under each modeled scenario (ERM 2022). Fuel use by fuel type (gasoline, diesel, electricity) was then analyzed for a single LDV category encompassing the major vehicle types (passenger car, crossover, SUV, and light pickup truck). Modeled changes in fleet energy use (i.e., reduction in fossil fuels and increases in electricity) were then used as inputs to the emissions and economic analyses.

GHG Emissions

The STEP Tool is a spreadsheet-based multi-sector model that allows users to analyze state and regional energy use and their CO_2 emission trajectories under a range of economy-wide policy scenarios. It lets users build detailed custom policy scenarios by selecting from various policy options in each sector of the economy—electric, transportation, residential, commercial, and industrial—while tracking in real time the associated overall electricity generation, portfolio mix, total energy use by fuel type, and VMT by type. The inclusion of multiple sectors of the economy allows users of the STEP Tool to examine certain energy use interactions among the different sectors of the economy (e.g., the impact of electric vehicles on both the electric and transportation sectors).

To produce scenario projections quickly and efficiently, the STEP Tool uses a non-optimization approach to solve for and calculate future energy use and CO_2 emissions. It does not try to reach any equilibrium condition or optimize the system for any variables. Instead, it records each user selection to construct one or more policy scenarios and then calculates their impacts in terms of changes to existing patterns of energy use. It makes use of heuristics and simplifying assumptions to produce projections at an indicative level. STEP Tool outputs can be generated for the entire U.S. economy or for individual states or groups of states.

The STEP Tool relies, for the most part, on publicly available data sets from federal and state-level government agencies to build up detailed characterizations of historic energy use patterns for each sector of the economy. Various sections of the EIA's Annual Energy Outlook and State Energy Data System data sets are used to add further detail to the final representation of the sectors in the STEP Tool and to provide a way to cross-check against a second calculation of overall energy use and associated emissions in the sector. For this modeling framework the STEP Tool was updated to the latest available data sets, including FHA 2019 fleet data and EIA's Annual Energy Outlook 2022 (USDOT FHA 2019, EIA 2022a).

The STEP Tool incorporates assumed future improvements in fleet average vehicle fuel economy (MPG) as the fleet turns over to new conventional ICE vehicles compliant with current USEPA and NHTSA new vehicle and engine fuel economy and GHG emission standards. These improvements are reflected in the baseline scenario, and all analyzed policy scenarios.

The framework models in-use LDVs and their VMT for individual states, but assumes that vehicles within a given state, will remain within that state throughout their lifetime. This simplifying assumption results in no vehicle migration to other states and simulates the full benefits of policy scenarios for the target state. Note that even if light-duty ZEVs migrate out of a given state, their benefits would continue to be realized, just in a different location.

For each policy scenario, annual net reductions in GHG emissions compared with the baseline are estimated on the basis of modeled changes in fuel use (gasoline, diesel, and electricity). Calculated GHG emissions include CO_2, CH_4, and N_2O, with the latter two expressed in carbon dioxide– equivalent terms (CO_2-e) using their global warming potential over a 100-year period (GWP100 = 25 for CH_4 and 298 for N_2O), as estimated by the United Nations Intergovernmental Panel on Climate Change's Fifth Assessment Report (United Nations Intergovernmental Panel on Climate Change 2014).

Estimated GHG emissions include tailpipe emissions from gasoline and diesel vehicles[5] and upstream emissions from production and delivery of the different fuels, including from generation of electricity to charge ZEVs.

Different tailpipe emission factors were used between the baseline scenario and the modeled ACC II scenarios. For the baseline scenario, gasoline and diesel vehicles (g/mile) were derived from the latest version of USEPA's MOtor Vehicle Emission Simulator (MOVES3) model by mapping STEP Tool vehicle types to vehicle types in MOVES (USEPA 2021b). For ACC II scenarios, ERM relied on CARB's ACC II modified version of EMission FACtor (EMFAC) model to project gasoline and diesel vehicle tailpipe emissions (g/mile) under the LEV standard (CARB 2021).

Upstream emission factors (g/gallon for diesel and gasoline, g/kWh for electricity, g/kg for hydrogen) were developed using the Greenhouse Gases, Regulated Emissions, and Energy Use in Technologies (GREET) Model developed by Argonne National Laboratory (2022).

For electricity the framework uses weighted average GHG emission factors (g CO_2/kWh, g CH_4/kWh, g N_2O/kWh) that were developed using GREET emission factors for coal, natural gas combined cycle, and zero-emitting electricity generation, and state-specific assumptions for the percentage of generation from each of these sources each year.

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[5] EVs are assumed to have zero tailpipe GHG emissions.

The state-specific grid mix assumptions were developed using decarbonization goals and policies within individual states. Current grid generation source distribution was taken from National Resources Defense Council's grid projections using ICF International's Integrated Planning Model (IPM) (USEPA 2020). For each state there are two scenarios: (1) a BAU grid mix representing current policy and (2) a decarbonized grid mix reflecting more aggressive federal energy policy. The BAU case was developed in the fall of 2022 and reflects state and federal policy as of August of that year (i.e., including the Inflation Reduction Act of 2022), with assumptions around fuel costs, technology costs, and performance drawn from EIA's Annual Energy Outlook 2022 and NREL's Annual Technology Baseline 2021. Analysis of new, state-specific electricity policies, such as from more stringent Renewable Portfolio Standards, was beyond the scope of this study but would be expected to increase the usage of these renewable resources.

The decarbonized grid mi-+x is an illustrative example of a clean energy standard reaching 100 percent clean energy during the analysis timeframe but varies depending on individual state trajectories. In this modeling of clean energy, all zero-emitting resources are eligible, including nuclear and renewable resources such as wind, solar, and hydropower. The extent to which nuclear and hydro sources are included in the decarbonization scenario varies by state. The framework applies the BAU grid mix to the baseline and ACC II Flex scenarios. The decarbonized grid mix is applied to both the ACC II Flex (ACC II Flex + Clean Grid) and ACC II Full (ACC II Full + Clean Grid) scenarios, to illustrate the added benefit of enacting an aggressive Clean Energy Standard on the ACCII scenarios.

Figures 2 through 5 show the BAU and decarbonized grid mix assumptions for New York and Colorado, to illustrate the range of differences in assumed grid mixes across different states. Note that Colorado currently has a lot more natural gas generation and less zero-emitting generation than New York, and this is projected to continue under the BAU scenario through 2050.[6] Under the decarbonized scenario, the two states are assumed to have different decarbonization trajectories, with New York achieving 100 percent zero-emitting generation by 2035, while Colorado is assumed to reach this level after 2040.

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[6] The NRDC IPM modeling results show a very small amount of biomass in the scenarios (less than 1%). For purposes of the ERM analysis, biomass electricity generation is not included in the "zero-emitting" category due to the NOx and PM emissions released. Because a small percentage of the grid mix is projected to be biomass and oil generation, for simplicity these sources were combined with coal and modeled as coal generation.

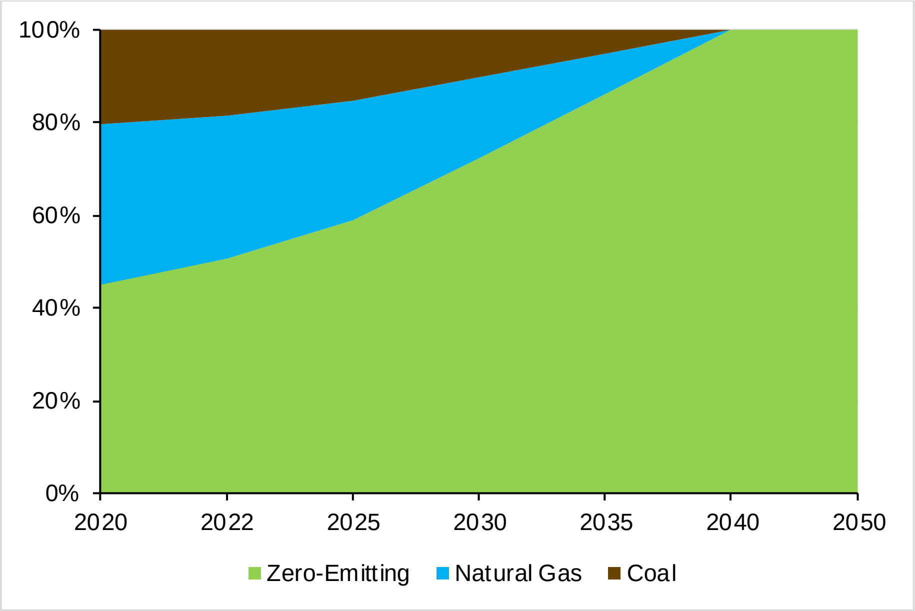

Figure 2: New York Baseline Grid Mix Assumption

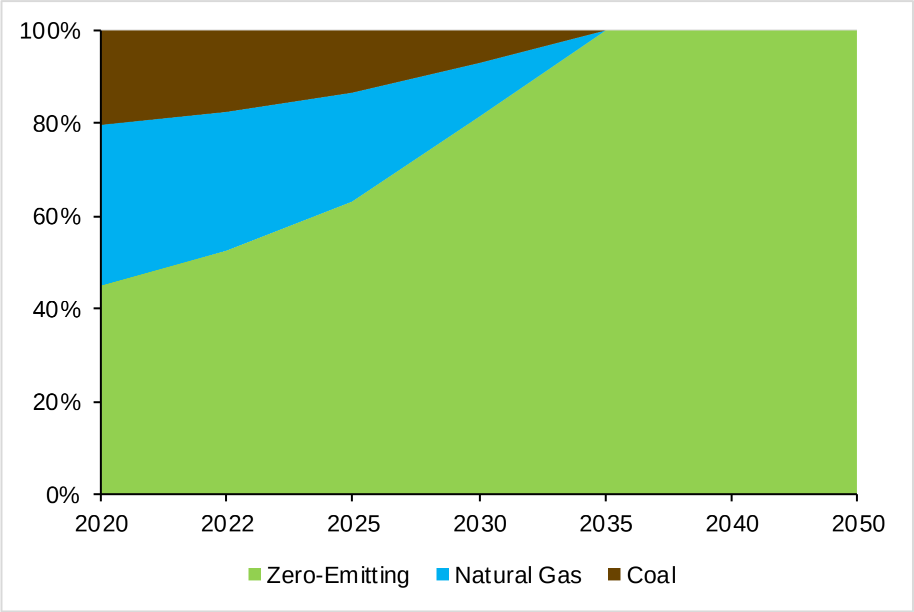

Figure 3: New York Decarbonized Grid Mix Assumption

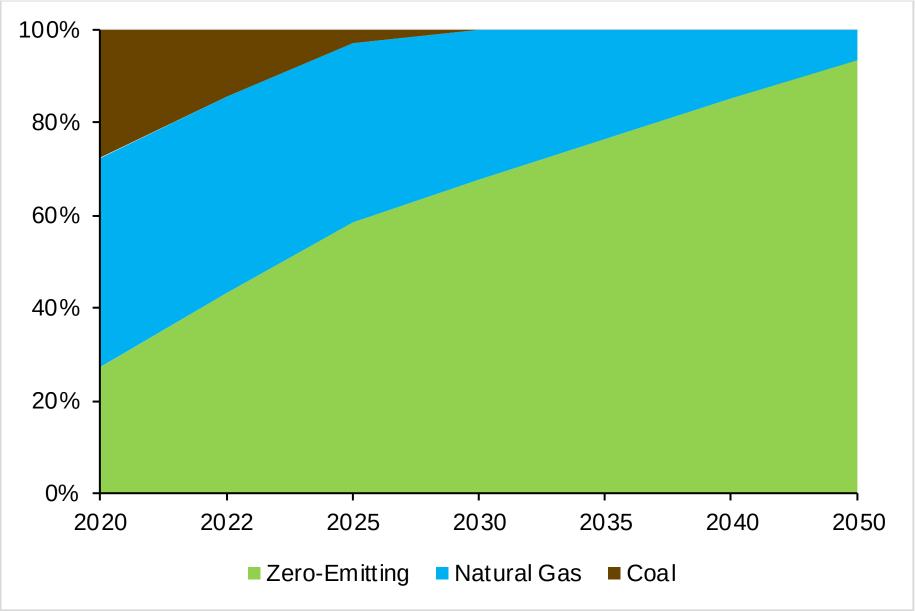

Figure 4: Colorado Baseline Grid Mix Assumption

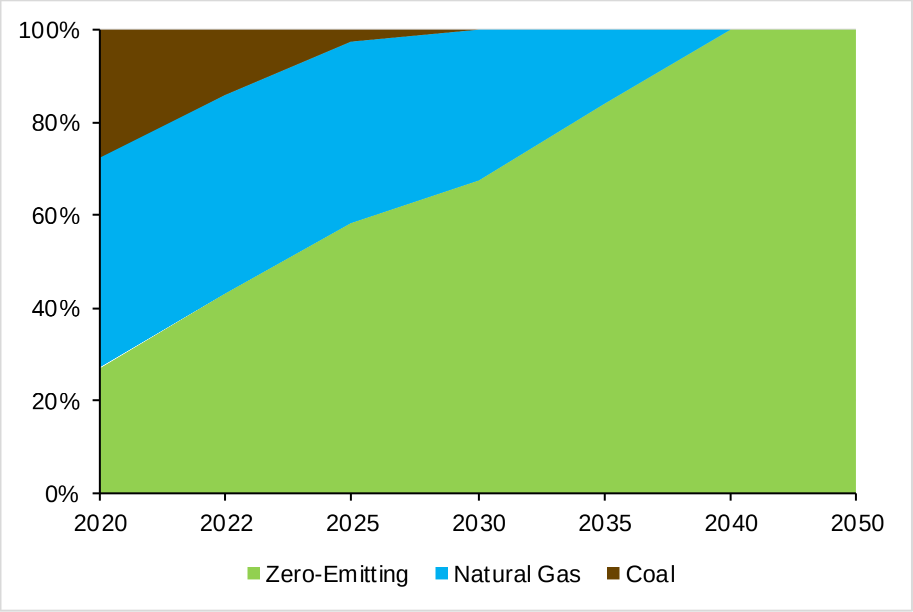

Figure 5: Colorado Decarbonized Grid Mix Assumption

To calculate the monetized value of the net GHG reductions in each policy scenario (relative to the baseline scenario) the framework uses values for the Social Cost of Greenhouse Gases (CO_2, CH_4, and N_2O) that were developed by the U.S. Government's Interagency Working Group on Social Cost of Greenhouse Gases (Interagency Working Group on Social Cost of Greenhouse Gases 2021). The social value of GHG reductions represents projected societal cost savings from avoiding the negative effects of climate change, if GHG emissions are reduced enough to keep long-term warming below 2 degrees Celsius from preindustrial levels. The values used for CO_2 are $51 per metric ton (2021$) in 2021, rising to $85/MT in 2050; the values for CH_4 are $1,500/MT in 2021, rising to $3,100/MT in 2050; and the values for N_2O are $18,000/MT in 2021, rising to $33,000/MT in 2050.

The Interagency Working Group published social cost estimates based on average modeling results using 2.5 percent, 3 percent, and 5 percent discount rates, as well as 95th percentile results using a 3 percent discount rate. This framework uses the average values resulting from a 3 percent discount rate, which is in the middle of the range of estimated values. Total monetized GHG reduction benefits would be approximately 72 percent lower if using average values resulting from a 5 percent discount rate, 49 percent greater if using average values resulting from a 2.5 percent discount rate, and three times greater if using 95th percentile values resulting from a 3 percent discount rate.

Criteria Pollutant Emissions

Annual net reductions in emissions of the criteria pollutants nitrogen oxide (NOx) and particulate matter (PM) relative to the baseline are estimated based on modeled changes in fuel use (gasoline, diesel, and electricity) for each scenario, as well as modeled uptake of vehicles that meet the requirements of ACC II's LEV standards, if applicable.

As with estimated GHG emissions, estimated NOx and PM emissions include tailpipe emissions from gasoline and diesel vehicles[7] and upstream emissions from these fuels, as well as generation and delivery of electricity to charge ZEVs.

Tailpipe NOx and PM emission factors for gasoline and diesel vehicles (g/mile) were derived from the USEPA's MOVES3 model run at a national level allowing for a calculation of emission factors for each model year in calendar years 2020 to 2050 at a five-year increment (USEPA 2021b). The model year distribution of ICE vehicles within the scenario was used to calculate a fleet average emission factor for the baseline scenario and an ACC II scenario in five-year increments between 2020 and 2050. As the market share of ZEVs increases, younger model years will have a higher percentage of ZEVs as compared to older model years. This causes the fleet-wide emission factor for ICE vehicles to be higher for the ACC II scenario compared to the baseline since the average age of ICE vehicles is higher and more polluting as a result. A secondary adjustment was made to the emission factors for the ACC II scenarios to account for the adoption of LEV IV standards for ICE vehicles as part of ACC II. ERM requested from CARB their EMFAC model run used for their analysis of ACC II impacts in California. The relative change between CARB's pre- and post-ACC II adoption emission factors were used to modify emission factors of ICE vehicles in the ACC II scenarios starting with MY 2026. This has the effect of reducing the MOVES3 NOx and PM emission factors to capture the impact of the ACC II changes.

It should be noted that this analysis focuses on tailpipe exhaust emissions and does not include particulate matter from vehicle friction brakes, or tire wear, regardless of vehicle type or technology. It remains uncertain how brake- and tire-wear emissions from ZEVs will compare to ICE vehicles. Brake-wear emissions may decrease due to regenerative braking and tire-wear emissions may increase, owing to the increased weight of ZEVs compared to ICE vehicles. Some studies have found these two effects cancel each other out, leaving ZEVs with similar brake- and tire-wear emissions. Due to the uncertainty around not only the magnitude of the change but also the sign of the change, these emissions are not modeled.

Upstream NOx and PM emission factors (g/gallon for diesel and gasoline, g/kWh for electricity) were developed using the GREET Model developed by Argonne National Laboratory (2022).

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[7] EVs are assumed to have zero tailpipe co-pollutant emissions.

In developing NOx and PM emission factors for electricity (EV charging), the same assumptions for generating sources (electricity) were applied as when developing GHG emission factors, as described above.

Health Impacts Analysis

To estimate the monetized value of health benefits resulting from reduced NOx and PM emissions, ERM used the USEPA's CO-Benefits Risk Assessment (COBRA) Health Impacts Screening and Mapping Tool (USEPA 2021a). For a given change in annual PM and/or NOx emissions (MT) within a given geography, COBRA estimates the resulting change in ambient PM concentration and the resulting public health impacts. Estimated public health impacts include changes in premature mortality, hospital admissions and emergency room visits for asthma, reduced cases of acute bronchitis, exacerbated asthma and other respiratory symptoms, and reduced activity days and lost work days. COBRA also estimates the total monetized value of these health impacts ($/MT).

The COBRA health impact values for New York are shown in Table 5. For Highway Vehicles and for Fuel Combustion, Electric Utilities, these values represent impacts in New York from changes in emissions in New York. However, the values for Fuel Combustion, Petroleum Fuels Production represent impacts nationally from national changes in emissions. While the majority of modeled emission changes from vehicle use and electricity generation will be local to the state being modeled, the same is not true for upstream emissions from producing petroleum fuels. The majority of these emissions occur from production and refining of crude oil to gasoline and diesel fuel. These activities do not happen in every state; for example, New York has very little crude oil production, and no major oil refineries. For gasoline and diesel fuel sold and used in New York, production and refining happen in other states. Most of the health benefits estimated by the framework will accrue to residents of the state being studied, but those associated with reduced petroleum fuel production will accrue to residents of other states. Moreover, there are additional health benefits (not captured by the modeling) that will accrue to residents of adjacent states from ZEV miles driven in these states.

The avoided health incidents due to ACC II adoption in New York, and their monetized value, are provided in the New York report.

Table 5: Annual Health Impacts of NOx and PM Emissions—New York

			NOx		PM	
			2021	2050	2021	2050
Highway Vehicles	Premature Deaths	Incidents/1,000 MT	1.4	1.4	58.5	57.0
	Hospital Admissions	Incidents/1,000 MT	0.9	0.9	40.1	39
	Emergency Room Visits	Incidents/1,000 MT	0.4	0.4	19.9	19.4
	Minor Cases	Incidents/1,000 MT	925	901	42,031	40,942
	Monetized Value	2021$/MT	$17,089	$16,646	$713,495	$695,000
Fuel Combustion, Electric Utilities	Premature Deaths	Incidents/1,000 MT	0.7	0.6	24.9	24.2
	Hospital Admissions	Incidents/1,000 MT	0.4	0.4	16.7	16.3
	Emergency Room Visits	Incidents/1,000 MT	0.2	0.2	7.6	7.4
	Minor Cases	Incidents/1,000 MT	388	378	16,896	16,458
	Monetized Value	2021$/MT	$8,125	$7,914	$303,449	$295,583
Fuel Combustion, Petroleum Fuels Production	Premature Deaths	Incidents/1,000 MT	1.2	1.4	20.3	23.8
	Hospital Admissions	Incidents/1,000 MT	0.7	0.9	12.1	14.2
	Emergency Room Visits	Incidents/1,000 MT	0.4	0.4	6.7	7.9
	Minor Cases	Incidents/1,000 MT	642	751	11,889	13,895
	Monetized Value	2021$/MT	$14,344	$16,764	$247,657	$289,445

As shown, health impacts per unit of emissions vary depending on the source, with the highest impacts from highway vehicles (tailpipe) and lower impacts from producing petroleum fuels (upstream refining) and from electricity production.[8] As such, the framework calculates the health impacts of modeled emission changes from the three different sources separately and sums the results to estimate net effects (reduced tailpipe and upstream petroleum production emissions and increased emissions from electricity generation).

Also note that the magnitude of health effects (incidents/1,000 MT, 2021$/MT) will vary by state, primarily according to relative population density; in more densely populated locations more people will be exposed to a given quantity of emissions, resulting in greater total health impacts. The framework uses COBRA health impact values specific to the state being modeled.

COBRA only estimates health impacts from changes in ambient PM concentrations, due to PM emitted directly from combustion sources and "secondary" PM generated via chemical reactions in the atmosphere from combustion gases, including NOx. In many locations, changes in NOx emissions also affect the formation of ground-level ozone, particularly in the summer. Ground-level ozone also has negative effects on human health. The potential ozone-related health benefits from net reductions in NOx emissions under the modeled policy scenarios are not captured by the modeling framework; hence the estimated net health benefits of the modeled ACC II scenarios are a conservative estimate.

Economic & Jobs Analysis

Increased purchase of ZEVs under the modeled ACC II scenarios will have a significant impact on annual operating costs for vehicle owners. ZEVs are currently more expensive to purchase than "baseline" gasoline and diesel vehicles and will also require purchase and installation of electric vehicle charging

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[8] The higher impact from highway vehicles is due to greater population exposure because emissions are at ground level.

infrastructure. In addition to the up-front purchase cost, this infrastructure has ongoing annual inspection and maintenance costs.

On the other hand, regionally produced electricity is less expensive than gasoline and diesel fuel, so ZEVs will have lower annual fuel costs than baseline ICE vehicles. ZEVs are also projected to have lower lifetime maintenance costs than the diesel and gasoline vehicles they replace.[9]

Fuel Costs

Net incremental fuel costs for each scenario were calculated each year using estimated changes in total motor gasoline, diesel fuel, and electricity calculated by the STEP Tool, and projected annual energy prices. For gasoline and diesel fuel, regional average projected prices from the EIA's Annual Energy Outlook 2022 were used (EIA 2022b). EIA projects that the average price of gasoline nationally will increase from $3.23/gallon in 2021 to $3.31/gallon in 2050, and that the average price of diesel fuel will increase from $3.42/gallon to $3.82/gallon (2021$).[10] Projected regional prices vary slightly from the national average but have a similar trajectory over time.

This analysis framework assumes that all light-duty ZEVs will pay residential electric rates. For each state, an average 2021 rate for residential customers ($/kWh) was calculated on the basis of total sales (MWh) and total revenue from residential customers reported to the EIA by utilities in the state (EIA 2021). For electricity costs in future years, the analysis assumes the same year-to-year percentage change as EIA's estimate of future average regional residential electricity rates (EIA 2022b). EIA estimates that, unlike diesel and gasoline, residential electricity rates will be stable in many regions (in 2021$), resulting in U.S. average costs in 2050 that are as much as 3 percent lower than in 2021. The analysis framework does not directly use EIA estimates for regional residential electricity rates, because they mask potentially significant differences in rates for different states in the same region. For example, the average residential rate in New York in 2021 was $0.172/kWh, while in New Jersey it was $0.148/kWh; these states are in the same EIA region.

Vehicle Purchase and Maintenance Costs

Incremental purchase costs and incremental maintenance costs for light-duty ZEVs were estimated based on an analysis by ICCT (Slowik et al. 2022), assessing U.S. light-duty electric vehicle costs using a bottom-up vehicle component-level approach for both BEV and PHEVs across the major light-duty vehicle classes (cars, crossovers, SUVs, and pickups). As part of ICCT's analysis, they also included conventional gasoline vehicle costs as comparison to their electric counterparts.

Estimated incremental EV purchase costs for LDVs were calculated as the difference between a conventional gasoline vehicle and a corresponding BEV or PHEV of the same size. ICCT provided estimated costs for model years 2022 to 2035 vehicles for different vehicle classes, as well as specified vehicle ranges (i.e., 200-mile, 300-mile). Given uncertainty around long-term vehicle pricing, model years 2036 and beyond assume the same incremental cost as 2035 for a given vehicle. ERM analyzed the incremental costs for different vehicle classes and battery ranges to develop a single weighted average light-duty incremental cost category. To perform this aggregation for individual states, ERM utilized vehicle registration data by body type. Using New York as an example, ERM assumed that passenger cars represented 44 percent, crossovers 27 percent, SUVs 10 percent, and pickups 19 percent. Since ICCT's data was split out by ZEV technology (BEV, PHEV) and vehicle range, ERM assumed a vehicle technology and range distribution for their aggregation. This assumed distribution is shown in Table 6.

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[9] For example, ZEVs do not require engine oil changes and will likely have less brake wear due to regenerative braking.

[10] Note that AEO2022 does not reflect current socioeconomic events such as the war in Ukraine, which has put increased strain on fuel prices.

Table 6: ZEV Purchase Distribution

	2022	2030	2040	2050
PHEV (25 miles)	5%	2%	4%	4%
PHEV (50 miles)	5%	3%	6%	6%
BEV (200 miles)	27%	20%	10%	10%
BEV (300 miles)	64%	75%	80%	80%

Using New York as an example, Table 7 illustrates the aggregated LDV incremental costs for ZEVs based on New York's vehicle registration split and ERM's assumed split of ZEVs by technology and range.

Table 7: Incremental ZEV Purchase Costs—New York

	2022	2030	2040*	2050*
LDV Weighted Average	$9,591	-$2,677	-$4,470	-$4,470

** ICCT's analysis projected costs through 2035—ERM's analysis assumes these incremental costs are held constant for 2036 and beyond.*

Incremental maintenance costs for ZEVs compared with conventional vehicles are also taken from the ICCT report and are calculated for both BEV and PHEVs. Maintenance costs are assumed to be $0.02/mile lower for PHEVs, and $0.034/mile lower for BEVs than for comparable ICE vehicles. An overall weighted average LDV maintenance savings was calculated assuming 95 percent BEVs and 5 percent PHEVs, resulting in a calculated $0.033/mile ZEV savings.

Fueling Infrastructure Costs

To estimate charging infrastructure needs for light-duty ZEVs, the framework uses a charging scenario model that calculates required charging capacity (kW/vehicle) and daily peak demand (kW/vehicle) based on typical daily energy use, available charging time, and charging location (home or public). Fifty-eight percent of PHEVs and 75 percent of BEVs are assumed to use overnight home-based charging. Home chargers are assumed to be either Level 1 (e.g., a standard 120V outlet) or Level 2, which requires a dedicated 208-240V circuit but can reduce charging times and provide flexibility to coincide with utility designated charging periods. Level 1 chargers can only add about 3 to 5 miles of range per hour, while a Level 2 can add 12 to 80 miles of range per hour, depending on the rating of the charger (Moloughney 2021). For public charging, two types of chargers were modeled—public Level 2 and direct current fast-charging (DCFC) ports, with the latter able to provide 150 to 350 kW of energy and the ability to replenish 3 to 20 miles of range per minute of charging (Moloughney 2021).

The charging model analyzes driver behavior (i.e., when will ZEVs be plugged in and start charging), after they arrive at home on a daily basis. For each state, assumed home and work arrival times are based on responses to the Department of Transportation's 2017 Annual Household Travel Survey from residents of that state (USDOT FHA 2017). The distribution of ZEVs between BEV and PHEV within the charging model follows the assumptions shown in Table 6 above. The charging model looks at individual state annual average VMT by an LDV and assumes that vehicle will operate 312 days per year. Dividing the total annual mileage by 312 derives the daily miles driven per vehicle. Using this daily mileage, along with average energy use (kWh/mi) for LDVs, the charging model calculates the daily charge required per day (kWh). Charging is assumed to proceed at the average charge rate until the battery is full.

Charging for the different state analyses is assumed to follow a "managed" charging profile where a portion of ZEV owners participate in a utility offered charging program and owners plug in and charge their vehicles during designated periods of lower energy demand, rather than just charging their vehicles as soon as they arrive at home. The efficacy of individual utility managed charging programs will vary by location, but for simplicity, the charging model assumes that 70 percent of state ZEV owners will follow the managed charging profile and only charge their vehicles during designated periods. The remaining 30 percent are assumed to plug in and charge their vehicles upon arrival at home based on the Annual Household Travel survey results. The percentage of vehicles starting charge each hour of the day will therefore vary by state.

The resulting average required charger capacity, and daily peak demand are shown in Table 8.

Table 8: Average Light-Duty ZEV Charging Infrastructure Requirements

	Average Charger Capacity (kW/vehicle)		Daily Peak Demand kW/vehicle
	Home	**Public**	
LDVs	7.07	0.47	0.84

Home charging infrastructure costs ($/kW) were developed using publicly available purchase pricing for a hardwired Level 2 charger. ERM selected a 9.6 kW Clipper Creek HCS-50 as the modeled home charger, which results in an estimated $75/kW in 2022 (2021$) for purchase and delivery of the charger. To estimate the installation cost of this charger, ERM assumed an average labor rate of $120 per hour, 4 hours for installation, plus $50 in materials. The resulting infrastructure installation cost in 2022 is $58/kW, which is assumed to remain constant over time (in constant dollars).

Public charging infrastructure costs ($/kW) were estimated using data developed by the International Council on Clean Transportation (Hall and Lutsey 2019). ICCT estimates that in 2020 the purchase cost of chargers averaged $450–$500/ kW depending on size. These costs are projected to fall by 18–25 percent through 2040 (2021$) as the market matures and sales increase. ICCT also estimates that installation costs are about $208/kW for installation of publicly accessible chargers; however, installation costs are not projected to fall over time (in constant dollars).

To estimate total infrastructure costs each year, the number of new ZEVs purchased in that year is multiplied by the average required charging capacity of home and public chargers (kW/vehicle) and the average charger cost ($/kW).

Jobs Analysis

This analysis framework uses IMPLAN software to estimate net macroeconomic effects on jobs, wages, and GDP of the modeled ACC II scenarios relative to the baseline. IMPLAN is a proprietary input–output modeling system that uses data from the U.S. Bureau of Economic Analysis, Bureau of Labor Statistics, U.S. Census Bureau, and other sources (IMPLAN 2021). Private companies, governmental agencies, and academic institutions regularly use IMPLAN to evaluate the macroeconomic effects of policies, programs, and specific infrastructure investments.

Within an economy, IMPLAN depicts interindustry relationships, such as how output from one sector becomes input in another sector. It uses multipliers to assess the interindustry effects. The estimation of multipliers relies on input–output models and a technique for quantifying interactions among firms, industries, and social institutions within a local, regional, or national economy.

IMPLAN assigns each industrial or service activity (e.g., agriculture, mining, manufacturing, trade, services) to an economic sector. The number of sectors is determined by the desired level of detail.

Using detailed U.S. Department of Commerce information, IMPLAN relates the purchases of goods and services each industry makes from other industries to the value of output in each industry. In so doing, IMPLAN describes the supply chain of each industry in terms of output, value added, labor income, employment levels, and state and local tax revenue.

For example, if an EV charging developer starts a major capital expenditure project, it purchases construction materials, hires local labor and contractors, leases equipment, and uses other in-state and out-of-state suppliers. Those suppliers then have their own associated expenses and wages that spread the money throughout the economy. IMPLAN models these transactions throughout the economy to calculate the total economic impact of the investment.

As depicted on Figure 6, IMPLAN estimates three types of impacts, which are combined to estimate the total impact of each modeled policy scenario:

- *Direct impact*—the initial change in the value of the output, employment, and labor earnings from the activity or project;
- *Indirect impact*—the resulting increase in the output, employment, and labor earnings in the industries supporting the activity or project; and
- *Induced impact (household spending)*—the resulting increase in spending by workers in the analyzed industry and the supplying industries whose earnings are affected by the increase in output from the various industries.

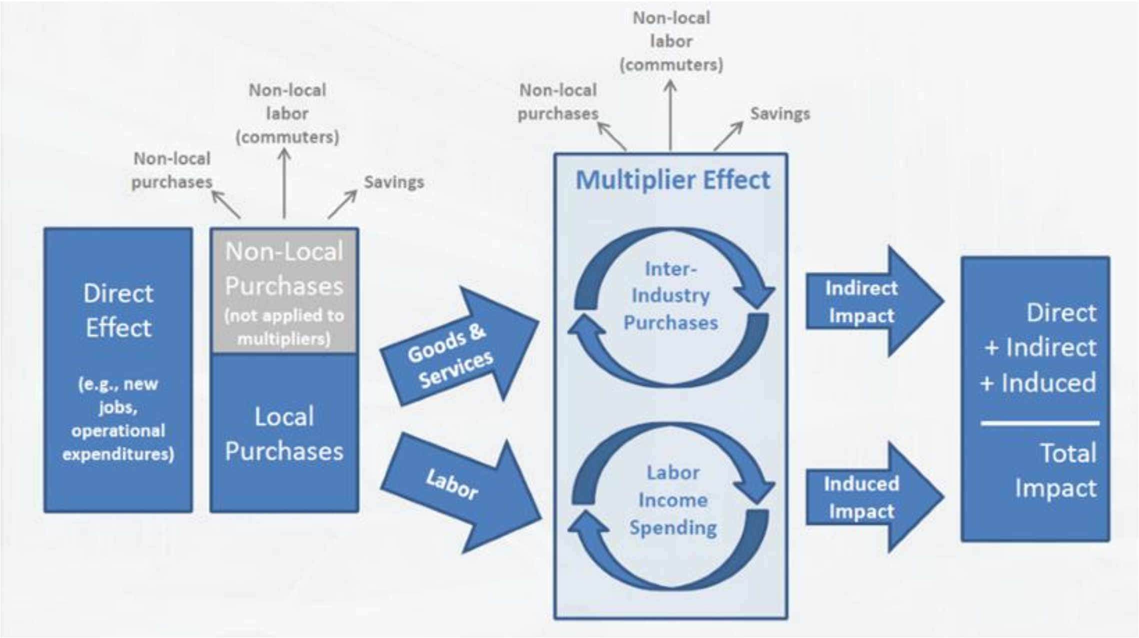

Figure 6: Input–Output Conceptual Model

For this analysis, net changes to three national-level macroeconomic metrics from increased ZEV uptake were estimated:

- Employment—A job in IMPLAN is equal to the annual average of monthly jobs in an industry. One job lasting 12 months equals two jobs lasting 6 months or three jobs lasting 4 months. A job can be either full time or part time.
- Labor income—This comprises all forms of employment income, including employee compensation (wages and benefits) and proprietor income.

- GDP—Also known as value added, this result captures the compensation of employees, proprietor income, taxes on production and imports less subsidies (previously indirect business taxes and non-tax payments), and gross operating surplus. Value added is the value of output less the value of intermediate consumption; it is a measure of the contribution to GDP made by an individual producer, industry, or sector.

To calculate these effects, outputs from the cost analysis were summarized to calculate the net annual change in spending within relevant "industries" for input to IMPLAN, as summarized in Table 9.

Incremental spending on fueling infrastructure was disaggregated to spending for equipment purchase and for installation (construction), as these components of total cost affect significantly different industries. Similarly, net incremental ZEV purchase cost was separated into reductions in spending on conventional drivetrains (ICE engine and transmission) and increased spending on electric drivetrains and storage batteries.

Table 9: IMPLAN Inputs

Cost Element		Incremental Spending	IMPLAN Industry/Commodity
Energy	Gasoline, diesel	Decrease	3154—Refined petroleum products
	Electricity	Increase	3039—Electricity
	Hydrogen	Increase	3039—Electricity
Maintenance	Vehicle maintenance	Decrease	512—Automotive repair and maintenance
	Charger maintenance	Increase	60—Maintenance and repair construction of non-residential structures
Fueling Infrastructure	Purchase	Increase	329—Power, distribution, and specialty transformer manufacturing (60%) 339—All other misc. electrical equipment (40%)
	Installation	Increase	55—Construction of new commercial structures
Vehicle Manufacturing	Engine and transmission	Decrease	349—Motor vehicle transmission and power train parts (47%) 347—Motor vehicle gasoline engines (41%) 284—Other engine equipment; includes diesel engines (12%)
	ZEV batteries	Increase	333—Storage batteries
	ZEV electric drivetrain	Increase	330—Motor and generator manufacturing (50%) 329—Power, distribution, and specialty transformer manufacturing (50%)

Note that for this modeling framework IMPLAN was run at the national level to calculate net economic changes to the U.S. economy from implementation of each modeled ACC II scenario in each state. When spending within an industry changes, there is some "leakage" due to imports of equipment and supplies from other countries; that is, some of the increased spending results in job, wage, and GDP changes in these exporting economies and is not included in IMPLAN results for the U.S. economy. The amount of leakage (e.g., domestic content) can influence the impacts felt within the economy. This analysis, consistent with the intent of the Biden Administration's tax credits under the Inflation Reduction Act, assumes 100 percent of economic activity related to ZEV manufacturing in all industries will be domestically produced. This assumption differs from manufacturing of ICE vehicles and their components, which have varying percentages of domestic content—for this analysis U.S. content ranges from 65 percent to 84 percent, depending on the ICE component.

Note that IMPLAN estimates only those changes in economic activity that flow directly from changes in spending within the affected industries; it does not assess potential secondary effects from major structural changes in the economy. For example, IMPLAN does not estimate how significant changes in demand for a commodity (e.g., fuel) will affect the market price of that commodity, or how market price changes will affect economic activity in the sectors of the economy that are not being directly modeled. IMPLAN also does not assess how vehicle owners would spend, invest, or distribute net annual operating cost savings (from vehicle purchase, fuel, and maintenance) that could result from greater ZEV penetration in later years of the analysis, or the resulting indirect and induced effects from distribution of these savings.

To address this latter issue of future net vehicle operating cost savings, and utility net revenue from LD ZEV charging (see Utility Impact Analysis, below), this analysis models what would happen if a portion of the vehicle savings (or losses) and utility net revenue were passed on to consumers in the form of lower prices. In the case of vehicle owner savings, it is assumed that a portion of these savings are re-spent within the economy. In the case of utility net revenue, it is assumed that a portion of this net revenue would be returned to residential and commercial customers via future electricity rate reductions, in accordance with normal rate-setting procedures of public utility commissions.

IMPLAN cannot reflect price changes. Therefore, these net vehicle owner savings and utility net revenue are treated as an increase in income for consumers since their current income will now be able to purchase more goods. For conservatism, the model allocates 80 percent of annual net vehicle owner savings and 80 percent of utility net revenue to increased consumer income. This increased consumer income is allocated in IMPLAN among nine income levels according to percent of total economy-wide demand attributable to each income level. The net vehicle owner savings are allocated using general consumer demand for all commodities, and utility net revenue is allocated using demand for electricity. For example, the income ranging from $50,000 to $70,000 has 12 percent of demand for all commodities, and 14 percent of electricity demand. Note that the income increase being passed on to consumers is based on net savings, considering both the higher and the lower costs. For some states in the early years of the analysis period (prior to approximately 2025), annual net vehicle owner savings are negative (a net cost) and the allocated change in consumer income is also negative (lower, not higher, income).

Utility Impact Analysis

On the basis of the results of the fuel and emissions and cost analyses discussed above, the framework estimates annual incremental electric load (MW), throughput (MWh), and utility revenue (2021$ millions) from LD ZEV charging under each modeled ACC II scenario. The framework then uses EIA estimates for average regional transmission and generation costs and state-specific estimates of incremental peak capacity costs ($/MW-year)[11] to estimate the utilities' cost of providing this energy (EIA 2022c). By subtracting this cost from incremental revenue, the framework estimates the annual net revenue (revenue minus costs) that utilities will realize due to the incremental EVs in each scenario, compared with the baseline.

In general, a utility's costs to maintain its distribution infrastructure increase each year with inflation, and these costs are passed on to utility customers in accordance with rules established by the state public utilities commission via periodic increases in residential and commercial electric rates. The net revenue resulting from increased ZEV charging can be used to support system operations, in effect putting downward pressure on future rate increases for all utility customers, whether they are ZEV owners or not. Based on estimated net revenue and estimated total system throughput, the framework estimates the

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[11] These estimates are generated from a range of sources, depending on the state, including capacity market prices, utility integrated resource plans, and estimates from the regional transmission operator.

potential reductions in future rates for commercial and residential customers from increased ZEV penetration in each policy scenario.

Infrastructure Gap Analysis

To estimate charging infrastructure needs for LD ZEVs, the framework uses a charging scenario model that calculates, for different vehicle types, the required number of chargers and charger capacity (kW/vehicle) based on typical daily energy use, available charging time, and charging location (home based or public). Table 10 summarizes assumed charging locations and resulting estimates of charging needs (ports per 1,000 ZEVs) for New York as an example.

Table 10: Example Charging Infrastructure Needs (Ports per 1,000 ZEVs)—New York

Metric			LDVs
Charging Location	Home		74%
	Public		26%
Ports/1,000 ZEVs	Home Chargers	L1	20
		L2	733
	Public Chargers	L2	4.5
		DCFC	2.8

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