The Benefits of Protective Advanced Clean Car Standards in Colorado

An Examination of Cost Savings, Greenhouse Gas Emission Reductions, and Health Benefits

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Executive Summary

Colorado can achieve a wide range of economic, environmental, and health benefits by adopting the Advanced Clean Car Program already in place in 10 other states. Doing so in 2018 is particularly timely given that federal government is threatening to roll back the greenhouse gas (GHG) emissions standards that are scheduled to become more stringent each year through 2025 and that gasoline prices are rising and at 4-year highs for Colorado drivers.

In 2010 and 2012, the Environmental Protection Agency (EPA) adopted standards to reduce greenhouse gas (GHG) emissions from cars and trucks built in model years (MYs) 2012–2025. EPA projected that the combined National Program for MYs 2012-2025 would save families more than $1.7 trillion dollars and reduce GHG emissions by 6 billion metric tons over the lifetime of the vehicles sold in MYs 2012-2025.[1] Although these standards were the result of an unprecedented consensus-building negotiation among the federal government, state governments, automakers, labor, environmental groups, and consumer groups, reports have indicated that EPA Administrator Scott Pruitt will soon take action to significantly relax the 2021-2025 GHG standards, with the most likely outcome being a proposal to freeze the level of the current 2020 standards until at least 2025. If Administrator Pruitt pursues this course of action, states like Colorado will face significant impacts, including both substantial increases in GHG and criteria pollutant emissions (e.g., fine particulate, ozone precursors) and significantly higher fuel costs for consumers due to less efficient vehicles that use more fuel.

Should EPA act to relax its GHG standards, an alternative exists for individual states like Colorado. The Clean Air Act allows the State of California to adopt separate vehicle emissions standards, and also permits other states to adopt California's vehicle standards. So far, 9 other states across the country have taken advantage of this approach and adopted California's Advanced Clean Car Program. Accordingly, Colorado could preserve the benefits now at risk due to Administrator Pruitt's threatened regulatory roll back by adopting the California vehicle standards (which are currently the same as EPA's current greenhouse gas and criteria pollution standards) along with the California zero-emission vehicle (ZEV) program (referred to, collectively, as the Advanced Clean Car Program).

This report analyzes the costs and benefits to Colorado and its residents if Colorado adopts the Advanced Clean Car Program, compared to a scenario where the EPA standards are frozen at 2020 levels and Colorado takes no action. We summarize our key findings below.

Cost savings to Colorado consumers

The net costs to consumers in Colorado to implement the Advanced Clean Car Program would be negative – meaning that the program would not only reduce pollution, but also lead to cost savings for Coloradans. This paper uses EPA's OMEGA automotive technology optimization model, and two sets of vehicle technology cost assumptions, to evaluate the impacts of Colorado's potential action on the owner of a Model Year 2025 vehicle. The first set of vehicle technology cost assumptions is based on those that EPA used in its original January 2017 Final Determination that reaffirmed the 2022-2025 GHG standards.[2] The second, lower, set of vehicle technology cost assumptions is based on updated

[1] USEPA Regulatory Announcement, EPA-420-F-12-051, August 2012.
[2] USEPA Final Determination on the Appropriateness of the Model Year 2022-2025 Light-Duty Vehicle Greenhouse Gas Emissions Standards under the Midterm Evaluation, U.S. EPA, EPA-420-R-17-001, January 2017.

cost estimates based on information developed by the International Council for Clean Transportation (ICCT) and electric battery costs published in Bloomberg.

This paper also utilizes two projections of future fuel prices. Both come from the 2016 Annual Energy Outlook (2016AEO) developed by the Energy Information Administration (EIA), which is part of the U.S. Department of Energy: 1) the reference case, which they considered to be their best estimate of future fuel prices, and 2) the high crude oil price case, which is as described. Gasoline prices have risen by over 50 cents per gallon over the last 18 months, to a 4-year high, and are already at the level projected for 2025 in EIA's reference case. In this executive summary, we present fuel savings using future fuel price projections that are the arithmetic average of the AEO2016 reference and high crude oil price cases. In the body of the report, we present fuel savings for the reference and high crude oil price cases separately.

Table ES-1 shows, for the Colorado Advanced Clean Car Program, key economic metrics relative to a baseline where the EPA GHG standards are frozen at 2020 levels. These metrics include average initial vehicle cost increases (with the range reflecting the two sets of technology cost assumptions described above), lifetime consumer fuel savings due to lower vehicle fuel consumption (using the average fuel price projections from the two AEO2016 cases described above and a discount rate of 3%), the payback period for consumers who purchase a new vehicle with cash (the payback period represents the "break even" point, and the vehicle will continue to achieve fuel savings until it is retired from the fleet), and net consumer lifetime savings (as the lifetime fuel savings far exceeds the average vehicle cost increase). Table ES-1 also accounts for Colorado and Federal tax credits for electric vehicles, which further accelerate consumer payback periods should Colorado adopt the Advanced Clean Car Program.

Table ES-1: Key Consumer Economic Metrics for MY 2025 Vehicles Under the Colorado Advanced Clean Car Program

	Average Vehicle Cost	Lifetime Fuel Savings	Payback (years)	Net Consumer Savings
No ZEV Tax Credit	$1,503-1,779		4.9-6.0	$2,452-2,771
CO ZEV Tax Credit	$1,054-1,330	$4,231-4,274	3.3-4.3	$2,901-3,220
CO + US ZEV Tax Credits	$382-647		1.2-2.0	$3,584-3,892

As Table ES-1 shows, adopting the Advanced Clean Car Program offers Colorado consumers the lowest average up front vehicle cost increase and shortest payback period when considering available Colorado and Federal ZEV tax credits. Taking fuel savings and currently available tax credits into account, consumers purchasing vehicles outright would see payback periods as short as 1.2-2.0 years, and every dollar invested in new technology will ultimately save 6 to 11 more dollars in future fuel savings. But, even when all tax credits are excluded from the analysis, the lifetime fuel savings still exceed the higher up front cost by more than a 2-to-1 factor.

While the analysis reflected in Table ES-1 assumes that consumers purchase their vehicles with cash, it is important to highlight that the 60% of consumers that purchase new vehicles with loans will have a positive cash flow immediately as the monthly fuel savings due to more efficient vehicles, will exceed the increase in the monthly loan payment due to more expensive vehicle technology.

The final column in Table ES-1 shows that, under a Colorado Advanced Clean Car Program, the net consumer lifetime savings (lifetime fuel savings minus incremental average vehicle cost) will vary from

$2,452-3,892. Assuming total new vehicle sales in Colorado of 285,000 vehicles per year in 2025, this means that Coloradans would save $700 million to $1.1 billion, depending on the tax credits, over the lifetimes of the MY 2025 vehicles. These savings would grow in the post-2025 timeframe if Colorado adoption of the Advanced Clean Car Program continued to promote automotive technology innovation that would entail lower technology costs and greater technology effectiveness over time.

Lower greenhouse gas and other air pollutants in Colorado

Should Colorado adopt the Advanced Clean Car Program, GHG emissions (carbon dioxide equivalent (CO_2e)) would decrease by 2.4 million metric tons in 2030 and by 4.3-4.4 million metric tons in 2040. Roughly 90% of these emission reductions would be within the confines of Colorado.

Table ES-2 presents the impacts of the Colorado Advanced Clean Car Program on emissions of criteria pollutants within the confines of Colorado, assessing these benefits both with and without anticipated California Tier 4 emission standards for criteria air pollutants. The parentheses show that Colorado emissions for each of these pollutants would be lower under the Colorado Advanced Clean Car Program.

Table ES-2: Criteria Emissions Impacts in Colorado Relative to Relaxed EPA GHG Standards (U.S. tons per year)

	VOC	NOx	PM2.5	SOx
Without Benefit of California Tier 4 Emission Standards				
2030	(586)	(216)	(36)	(89)
2040	(1247)	(834)	(97)	(159)
With Benefit of California Tier 4 Emission Standards				
2030	(687)	(308)	(45)	(89)
2040	(1960)	(1590)	(153)	(159)

Because the net cost of adopting the Colorado Advanced Clean Car Program is negative, i.e., the lifetime consumer fuel savings exceed the incremental vehicle technology costs, the cost per ton of achieving these emission reductions are also negative.

Health benefits in Colorado

We used EPA's COBRA model in conjunction with the emission reductions shown in Table ES-2 to estimate the monetized value of health impacts of a Colorado Advanced Clean Car Program. In 2030, the annual value of health benefits of adopting the Advanced Clean Car Program ranged from $6-13 million, increasing to $16-37 million in 2040. All of these health impacts are due to changes in ambient PM levels and do not include any value associated with reduced ozone or GHG which would, of course, enhance these benefits.

Long-term automotive technology innovation and emissions reductions

While the analysis in this report primarily focuses on the 2025 timeframe, the benefits of the Colorado Advanced Clean Car Program would extend beyond near term cost savings and emission benefits. The ZEV component of the Advanced Clean Car Program is the single greatest driver of ongoing innovation in electric vehicle technology and is essential if Colorado and the rest of the country are to reach long-term climate and air quality goals. Battery electric vehicles hold the most promise of any vehicle technology to reduce long-term GHG emissions, especially when the electricity is supplied by renewable resources. They also hold great promise in reducing emissions and improving air quality in urban and suburban areas. In the process, they also bring new investment in technology and infrastructure. And adopting the Advanced Clean Car Program in Colorado would increase consumer choice for vehicles, as experience in other states shows that a wider range of electric vehicles are offered in states that adopt such programs.

Introduction

This report examines the vehicle cost, fuel savings, and emission consequences in Colorado of EPA weakening its current greenhouse gas (GHG) standards for cars and light trucks for the 2021 model year (MY) and beyond. EPA recently announced that it was rescinding its January 2017 Final Determination that the 2022-2025 GHG standards were feasible and appropriate and that it was considering modifications to the 2021 standard, as well.[3] While EPA has not yet taken final action weakening the 2021-2025 standards, for the purposes of this analysis and consistent with recent reporting, we assume that the relaxation of the GHG standards will be significant, potentially maintaining the 2020 standards indefinitely.

The remainder of this report lays out an action which Colorado could take in response to such a weakening of federal standards and estimates the state-specific impacts of this action on vehicle costs, consumer fuel savings, and emissions of GHG and criteria pollutants. The report also estimates health impacts associated with this action. The methodology underpinning this analysis is consistent with previous analyses conducted by EPA in these areas, such as those used in its Proposed[4] and Final Determinations[5] regarding the 2022-2025 GHG standards for cars and light trucks. We also build on these analyses by assessing the potential to further reduce compliance costs by considering future technological advancement in both GHG control technology and vehicle electrification.

Background

The U.S. currently has a "one-vehicle" program for regulating GHG emissions. While both EPA and the state of California have their own regulatory programs for light-duty vehicles, California and federal standards are currently aligned. The only exception pertains to the Zero Emission Vehicle (ZEV) Program, which has no federal corollary. Thus, in addition to complying with the GHG standards, vehicle manufacturers must demonstrate compliance with the California ZEV Program in California and in the nine other states that have adopted the California Advanced Clean Car Program.[6] Because Section 177 of the Clean Air Act permits other states to adopt the California vehicle emission control program, these states are commonly referred to as the Section 177 states. Here, we will refer to California and the other nine states as the "Advanced Clean Car States."

As described above, Administrator Pruitt recently revoked EPA's previous determination that the MY 2022-2025 standards remained appropriate, indicating in a new Final Determination his view that these standards were no longer feasible.[7] EPA has indicated that it will review the level of the 2021 standards, as well as the 2022-2025 standards and, as indicated in recent press reports, EPA could decide to hold the MY 2021 and later GHG standards constant at their 2020 levels.

Table 1 shows EPA's most recent projection of the average CO2 emissions from cars and light trucks under its GHG standards for the 2020-2025 MYs. These standards apply to emissions over two EPA

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[3] 82 Fed. Reg. 39,551.
[4] Proposed Determination on the Appropriateness of the Model Year 2022-2025 Light-Duty Vehicle Greenhouse Gas Emissions Standards under the Midterm Evaluation, U.S. EPA, EPA-420-R-16-020 November 2016.
[5] Final Determination on the Appropriateness of the Model Year 2022-2025 Light-Duty Vehicle Greenhouse Gas Emissions Standards under the Midterm Evaluation, U.S. EPA, EPA-420-R-17-001 January 2017.
[6] The nine states which have opted into the California vehicle program are: Connecticut, Maine, Maryland, Massachusetts, New Jersey, New York, Rhode Island, Vermont, and Oregon.
[7] 82 Fed. Reg. 14,671

test cycles—one focusing on city driving and one focusing on highway driving—and also vary depending on the vehicle's footprint, which is measured in square feet and is the product of a vehicle's wheelbase and its track width (in lay terms, the area defined by the centers of the four tires touching the ground). Since vehicles have widely varying sizes and their relative sales vary from year to year, the sales-weighted, fleet-average footprint varies from year to year. Thus, the applicable GHG standard for the average vehicle will vary and can only be known with certainty after the fact.

Table 1: Projected Fleet-Wide CO2 Emissions Under the Current EPA GHG Standards (g/mi)

Model Year	Cars	Light Trucks	Light-Duty Fleet
2020	187	266	226
2021	177	246	211
2022	169	234	201
2023	162	223	191
2024	154	212	182
2025	147	202	173

California has already determined that the 2022-25 standards are appropriate[8], and so, should Administrator Pruitt now weaken the standards as he has indicated, this would return the U.S. to a two-vehicle GHG program with the California standards applicable in 10 states and the weaker federal program applicable elsewhere. This potential for a two-vehicle GHG program in 2021 and beyond is the backdrop for the analysis conducted in this report.

To assess the potential benefits of Colorado adopting the Advanced Clean Car Program, we assume EPA relaxes its current GHG standards by effectively holding the 2020 GHG standards constant indefinitely. As Table 1 shows, under EPA's existing standards, the fleet average CO2 emission level for the 2025 MY is 53 g/mi lower than that for the 2020 MY. Weakening the standards by holding the 2020 standard constant would increase CO2 emissions from light-duty vehicles by 31% in 2025. Should EPA take a less extreme approach to weakening the standards, the lost greenhouse gas benefits would be lower, but still substantial.

In addition to addressing GHG emissions, the Advanced Clean Car Program also includes standards for criteria air pollutants, including volatile organic compounds (VOC), nitrogen oxides (NOx), and fine particulate matter (PM2.5). California is in the process of developing strengthened "Tier 4" emission standards for VOC, NOx, and PM2.5 emissions. Adopting the Advanced Clean Car Program would likewise encompass California's criteria emission standards applicable to cars and light trucks. Thus, in addition to having a cleaner motor vehicle fleet with respect to GHG emissions, vehicles sold in Colorado would also have lower VOC, NOx and PM2.5 emissions. Adopting the Advanced Clean Car Program would provide Coloradans with significant climate and health benefits.

The other aspect of the Advanced Clean Car Program is the California ZEV program. The California ZEV program consists primarily of a set of minimum "ZEV" sales requirements. The ZEV sales requirements for 2018 MY and beyond are shown in Table 2.

[8] California's Advanced Clean Cars Midterm Review Summary Report for the Technical Analysis of the Light Duty Vehicle Standards, California EPA, Air Resources Board, January 18, 2017, https://www.arb.ca.gov/msprog/acc/mtr/acc_mtr_finalreport_full.pdf.

Table 2: California ZEV Program		
Model Year	Total ZEV Credit Required	Max. Compliance Using PHEV
2018	4.50%	2.50%
2019	7.00%	3.00%
2020	9.50%	3.50%
2021	12.00%	4.00%
2022	14.50%	4.50%
2023	17.00%	5.00%
2024	19.50%	5.50%
2025 and beyond	22.00%	6.00%

Table 2 shows that the ZEV credit requirement is 9.5% for the 2020 MY, increasing to 22% for 2025 and beyond. When assessing these percentages, it is important to underscore that a single electrified vehicle can generate more than one ZEV credit. For example, a battery powered vehicle with no gasoline engine (BEV) and a 200 mile range on a single charge generates 3.36 ZEV credits. A plug-in hybrid electric vehicle (or PHEV, a vehicle with both an electric battery/motor and a gasoline engine) capable of 40 miles of electric-only operation on a single charge generates 1.07 ZEV credits. In addition to setting minimum ZEV credit levels for ZEVs, the California ZEV program also limits the number of ZEV credits which can be generated by PHEVs. The last column of Table 2 shows these caps on ZEV credits from PHEV sales. This cap effectively requires manufacturers to sell a minimum number of BEVs in meeting the overall ZEV credit requirement.

Under the current "one-vehicle," national GHG emission program, manufacturers must comply with the GHG emission standards shown in Table 1 across their entire national sales and comply with the ZEV credit requirements with their sales in California and the other nine Advanced Clean Car States.

Greenhouse gas emission control scenarios

Table 3 describes the three GHG emission control scenarios considered in this analysis. Each scenario affects three relevant areas of the country: 1) California and those states which have adopted the Advanced Clean Car Program (GHG and ZEV standards), 2) the remaining states other than Colorado, and 3) Colorado. Since Colorado currently is not one of the states which has adopted the Advanced Clean Car Program, without any action on Colorado's part, the GHG standards in Colorado would be those that apply in the remaining states.

One advantage for Colorado associated with adopting the Advanced Clean Car Program is that this program already exists. Mechanisms also exist for certifying vehicles and tracking their sales in the Advanced Clean Car States. For criteria pollutants, California handles vehicle certification. Manufacturers usually opt to provide California with their vehicle sales for California and all 177 states combined. Colorado would need to ensure that only California certified vehicles were sold in the state, if they so desired. Thirteen states other than California are already doing this, the first starting in 1993.

California likewise handles the certification of ZEVs for compliance with the ZEV program. Advanced Clean Car States have to keep track of ZEV sales and submit them to California. Compliance with the ZEV program requirements is determined using sales broken down into three regions: 1) California, 2) eastern Advanced Clean Car S tates, and 3) western Advanced Clean Car States. Colorado would presumably join the western Advanced Clean Car States region which currently only consists of Oregon. Thus, compliance is addressed centrally and not done by individual Advanced Clean Car States.

Regarding the California GHG standards, there is currently no separate compliance process. Compliance with EPA's national GHG standards is considered to provide compliance with California's GHG requirements. Should EPA relax its standards and California retain its standards, this mutual compliance arrangement will no longer exist. We anticipate that the separate Advanced Clean Car Program GHG compliance process would be similar to that for either the criteria emissions or ZEV Program, requiring minimal effort on the part of Advanced Clean Car States.

The focus of this analysis is to assess the emissions and health impacts of Colorado adopting the Advanced Clean Car Program.

Table 3: 2025 Scenarios

	Advanced Clean Car States	Remaining States other than Colorado	Colorado
Current Standards	Table 1 GHG standards plus ZEV program	Table 1 GHG standards	Table 1 GHG standards
Potential Relaxed Scenario	Table 1 GHG standards plus ZEV program	2020 MY GHG Standards in Table 1	2020 MY GHG Standards in Table 1
Colorado Clean Car Program	Table 1 GHG standards plus ZEV program	2020 MY GHG Standards in Table 1	Table 1 GHG standards plus ZEV program

The first scenario in Table 3 shows the GHG and Advanced Clean Car State standards currently in place. As mentioned above, Colorado is part of the large group of states where manufacturers simply have to comply with the national GHG standards shown in Table 1. The second scenario shows the impacts of

EPA weakening the federal standards in Colorado, assuming Colorado does not adopt the Advanced Clean Car Program. The third scenario shows how adopting the Advanced Clean Car Program would protect Colorado against a weakening of the federal standards. There are lead-time requirements associated with a state adopting the Advanced Clean Car Program. It is unlikely that Colorado could adopt the Advanced Clean Car Program in time for it to be effective for the 2021 MY. Thus, we assume here that, if Colorado would decide to adopt the Advanced Clean Car Program, it would be effective with the 2022 MY.

To evaluate the costs and benefits of the three scenarios described in Table 3, we must first develop a Colorado-specific vehicle fleet, including an estimate of current ZEV sales in the state of Colorado. The next section describes how we modified the composition of the new vehicle fleet as projected by EPA to account for current ZEV sales in Colorado.

Development of a Colorado-specific vehicle fleet

In support of EPA's Proposed Determination, the agency developed a description of the 2015 model year (MY) light-duty vehicle fleet, including sales by vehicle model. EPA used this 2015 baseline fleet to project the 2025 MY fleet, assuming the characteristics of each vehicle model remained the same. However, sales across manufacturers, cars and light trucks, and vehicle categories (e.g., compact cars and small multi-purpose vehicles (MPVs)) were adjusted using private and governmental sources (including, for example, the Annual Energy Outlook published by the Department of Energy and a long-range vehicle sales forecast purchased from IHS-Polk Automotive).[9]

EPA modified this 2025 fleet further to account for the requirements of California's ZEV program applicable in Advanced Clean Car States. As described in Table 2 above, in 2025, California requires that manufacturers generate ZEV credits equivalent to 22% of their 2025 sales, with at most 6% of these credits coming from PHEVs. The ZEV credits assigned to each BEV or PHEV sold are a function of the all-electric range of the vehicle. Several manufacturers are presently marketing ZEVs in the U.S. However, the level of these sales in 2015 is inadequate to meet the California ZEV program requirements for 2025. EPA projected that the additional ZEVs needing to be sold in 2025 would have an all-electric range which achieves the greatest number of ZEV credits per vehicle: essentially 200 miles for BEVs (3.36 ZEV credits per vehicle) and 40 miles for PHEVs (1.07 ZEV credits per vehicle). EPA also assumed that manufacturers would maximize the generation of ZEV credits from PHEVs (6% as shown in Table 2) and generate their remaining ZEV credits from BEV sales.

EPA's projection of the 2025 fleet starts from the number of BEVs and PHEVs sold in 2015. Using the all-electric range of each of these current BEVs and PHEVs and estimates of the fraction of each manufacturer's EVs sold in Advanced Clean Car States, EPA determined the number of ZEV credits that these vehicles would generate in the 2025 reference fleet. EPA then estimated how many additional PHEVs and BEVs would need to be sold to meet the ZEV program requirements in the Advanced Clean Car States. EPA then added these PHEVs and ZEVs to its 2025 reference fleet, reducing sales of non-EV (internal combustion engine or ICE) vehicles in those vehicle categories technically capable of being converted to BEV or PHEV designs. With respect to specific manufacturers, EPA proportionately reduced ICE vehicles capable of electrification so that the sales of each manufacturer in 2025 remained at the same level before and after accounting for the ZEV program.

We made two changes to the 2025 EPA reference fleet to assess the impact of Colorado adopting the Advanced Clean Car Program. First, ZEV sales significantly increased in Colorado in the 2017 MY due to an increase in the Colorado tax credit available to ZEV purchasers. As this change occurred after 2015, it is not reflected in either EPA's 2015 baseline or 2025 reference fleets. Thus, our first adjustment was to reflect these increased sales of ZEVs in Colorado in 2017 to the 2025 reference fleet for Colorado. Second, we projected the number of additional PHEVs and BEVs which would need to be sold by each manufacturer to comply with the ZEV program's requirement, notwithstanding the fact that the ZEV program does not require each participating state to individually meet these targets. Each of these modifications is described further below.

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[9] Chapter 1, Proposed Determination on the Appropriateness of the Model Year 2022-2025 Light-Duty Vehicle Greenhouse Gas Emissions Standards under the Midterm Evaluation**:** Technical Support Document, U.S. EPA, EPA-420-R-16-021 November 2016; The data and process used by EPA to develop the 2015 baseline fleet and 2025 reference fleet are described in the Draft Technical Assessment Report: Midterm Evaluation of Light-Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards for Model Years 2022-2025 (TAR) published in July 2016.

Modified vehicle fleet prior to Colorado adoption of Clean Car Program

Table 4 shows ZEV sales data for the state of Colorado in 2015 and 2016 which were provided by state personnel. This data was provided for each manufacturer, but only fleet-wide totals are shown below.

Table 4: ZEV Sales in Colorado

	BEV	PHEV	Total
	Provided by State Personnel		
2015	1,278	486	1,774
2016	---	---	2,711
	AAM website		
2015	1,277	621	1,898
2016	1,571	1,140	2,711
2016 (8 months)	895	670	1,565
2017 (8 months)	1,882	827	2,709
2017 (estimated)	3,303	1,407	4,693
Ratio: 2017/2015	2.587	2.266	---
	Projection Used in this Study		
2017 (estimated)	3,585	790	4,376

The state did not have data for 2017, when sales were expected to increase significantly due to the increase in state-funded credits for ZEV purchases. To estimate Colorado sales by manufacturer in 2017, we used the fleet-wide sales estimates for BEVs and PHEVs for Colorado from the Alliance of Automobile Manufacturers (AAM),[10] which are also shown in Table 4. The AAM and Colorado state data match very closely for EVs sold in 2015 and total BEV and PHEV sales in 2016. The reason for the different estimate for PHEVs in 2015 could not be determined. However, this difference has no substantive impact on our analysis.

The AAM tool allows sales to be estimated by month and included data for 8 months of 2017 (i.e., through August of that year). To estimate total sales in 2017, we assumed that the ratio of total to 8-month sales in 2016 and 2017 were the same and scaled the 2017 8-month totals accordingly. We then applied the ratio of 2017 to 2015 sales from the AAM data to 2015 sales data from Colorado staff to derive estimated 2017 sales, which are shown in the last section of Table 4.[11]

These figures include one further manufacturer-specific adjustment. In 2015, GM sales consisted entirely of PHEVs. However, by 2017, GM had introduced the Bolt BEV. To approximate this model introduction, we assumed that GM PHEV sales were the same in 2017 as 2015 and that any growth in 2017 sales were due to the Bolt.

We added these additional 2017 vehicle sales to EPA's 2025 reference fleet by increasing the sales of PHEVs and BEVs already present in the baseline fleet. There were a few cases where a manufacturer had sold PHEVs or BEVs in 2017 but sold no such vehicles in 2015 and therefore had no PHEVs or BEVs in the 2015 EPA baseline fleet. In these cases, we allocated the additional 2017 ZEV sales to PHEVs or BEVs models added by EPA to represent new ZEVs needed to meet CA ZEV program

[10] https://autoalliance.org/energy-environment/zev-sales-dashboard/

[11] Since the time of this analysis, the AAM database has been updated to include all 2017 sales. They indicate that our projection of 2017 PHEV sales was slightly low and our projection of BEV sales was somewhat high. The differences are very small relative to the number of PHEVs and BEVs which would needed to be added to Colorado sales under the Clean Car Program. Thus, these differences would not affect the results of this analysis in any significant way.

requirements. At this point in the process, we did not project any further increase in ZEV sales in Colorado absent adoption of the ZEV program. This is consistent with EPA's modeling in support of its review of the 2025 standards, where all vehicle technology in the reference case is held at the level found in the 2015 fleet (i.e., the most recent historical, or verifiable fleet).

Colorado ZEV sales needed to comply with the Advanced Clean Car Program

EPA used two steps to estimate the additional ZEV sales in the Advanced Clean Car States needed to comply with the Advanced Clean Car Program in 2025.[12] First, EPA determined each manufacturer's ZEV sales in these states which were already present in its 2025 reference fleet. As mentioned above, for each model year after 2015, EPA developed projections of each vehicle model's sales using growth factors for total vehicle sales, changes in car/truck sales ratio and shifts in vehicle preferences (for example, compact cars versus small multi-purpose vehicles (MPVs)).[13] These growth factors applied equally to ZEVs and gasoline or diesel-powered vehicles. EPA made the same adjustments to ZEV model sales as were made to gasoline or diesel power vehicle sales.

Second, EPA determined the number of additional ZEVs manufacturers needed to sell to comply with the ZEV program in the Advanced Clean Car States. As mentioned above, EPA assumed that manufacturers would maximize PHEV credits subject to the California program's constraints (6% ZEV credits attributable to PHEVs). EPA assumed these PHEVs would have an all-electric range of at least 40 miles, and so each would generate 1.07 ZEV credits. EPA assumed the remaining required ZEV credits (16%) would be satisfied by the sale of BEVs with a 200 mile range, each of which would generate 3.36 ZEV credits per 200-mile BEV sold.

EPA subtracted the 2025 projected sales of PHEVs and BEVs in the Advanced Clean Car States (step 1) from the required levels (step 2) to determine the number of additional ZEVs needed to meet the program requirement. EPA added these additional ZEV sales to specific manufacturers' 2025 fleets by adding new ZEV vehicle models.

We used this process to determine the number of additional ZEV sales that would be needed in Colorado to comply with the ZEV element of the Advanced Clean Car Program. In the process of determining compliance with the ZEV program in the Advanced Clean Car States, EPA obtained data on the breakdown of each manufacturer's U.S. sales inside of and outside of the Advanced Clean Car States. As Colorado is currently outside of the Advanced Clean Car States, we assumed that Colorado's sales by manufacturer matched that developed by EPA for the non-Advanced Clean Car States. We estimated total vehicle sales in Colorado by multiplying sales outside of the Advanced Clean Car States by the ratio of Colorado's population (5,540,545) to that of the non-Advanced Clean Car States (91,450,417)[14]. This resulted in 2015 estimated vehicle sales in Colorado of 287,000 and 2025 sales of 285,000. We then applied the ZEV percentage requirements to each manufacturer's 2025 sales in Colorado and subtracted the Colorado ZEV sales shown in Table 4 (extrapolated to 2025). The result was that an additional 11,001 BEVs and 14,558 PHEVs would need to be sold in Colorado in 2025

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[12] EPA's documentation in its Draft Technical Assessment Report and its Proposed Determination provide a more detailed description of this process.

[13] EPA developed these projections based on a combination of private and governmental data, including, for example, the Annual Energy Outlook published by the Department of Energy.

[14] "Annual Estimates of the Resident Population for the United States, Regions, States, and Puerto Rico: April 1, 2010 to July 1, 2016" (XLSX). United States Census Bureau. Retrieved 8 June 2017. We related Colorado's population to the non-Advanced Clean Car States population as we already had available the split of each manufacturer's sales in the Advanced Clean Car States and non-Advanced Clean Car States areas.

should the state adopt the Advanced Clean Car Program. Numerous manufacturers have announced plans to introduce PHEVs and BEVs in the next few years. California's midterm review of the 2022-2025 GHG standards mentioned above contains an extensive analysis of current and future ZEV technology, sales and cost. It appears that consumers will have a wide range of vehicles to choose from when considering the purchase of a ZEV.

We allocated these sales to the new ZEV models EPA added to the fleet to simulate manufacturers' compliance with the ZEV program in the Advanced Clean Car States. We spread these ZEV model sales across manufacturers proportionately and also proportionately reduced the sales of ICE vehicles that EPA identified as convertible to ZEV such that total manufacturer sales remained constant. Finally, we shifted projected Colorado vehicle sales to the Advanced Clean Car States sales fleet.

Vehicle sales in Advanced Clean Car States and outside this region

When EPA evaluated the costs of various GHG scenarios for the final rule establishing the 2017-2025 standards and for the Proposed Determination reviewing the feasibility of the 2022-2025 standards, EPA always modeled a single national fleet of vehicle sales. All vehicles, whether sold in the Advanced Clean Car States or outside of this region, were assumed to meet the same GHG standards. The only difference between vehicles in the two regions was that those sold in the Advanced Clean Car States also met the requirements of the ZEV program. Effectively, the Advanced Clean Car Program increased the number of ZEVs sold across the entire U.S. to a smaller degree than it did in the Advanced Clean Car States. As the Advanced Clean Car Program had already been established prior to the 2017 and later GHG standards, the ZEVs needed to meet the program's requirements in the Advanced Clean Car States were added to the 2025 vehicle fleet prior to the evaluation of the cost of the GHG standards.

For the purposes of our analysis, we assume that EPA will relax its GHG standards and California will retain its GHG standards. Thus, manufacturers will be complying with two distinct sets of GHG standards in the two regions of the U.S. This requires that EPA's OMEGA model be run separately for the two regions. This constitutes the primary difference between the costs developed by EPA with the OMEGA model and those developed here.

We separated total U.S. sales into sales in the two regions using the breakdowns of each manufacturer's sales in the two regions. These data were the same sales splits that EPA used to determine the number of ZEVs to add to the fleet to enable compliance with the Advanced Clean Car Program in the Proposed Determination. As described above, they were also used here to determine the number of additional ZEV sales needed in Colorado should Colorado adopt the Advanced Clean Cars Program.

As the sales split for each manufacturer applied to total car plus light truck sales, we applied them to total sales. Thus, the breakdown of each manufacturer's sales by model inside and outside of the Advanced Clean Car States region is the same. The percentage of each manufacturer's U.S. sales in the Advanced Clean Car States differs. As Colorado is not currently one of the Advanced Clean Car States, its breakdown of sales by manufacturer and model reflect that of the non-Advanced Clean Car States. Under the scenario where Colorado does not opt into the Advanced Clean Car Program, Colorado sales remain with those of the non-Advanced Clean Car States. Under the scenario where Colorado opts into the Advanced Clean Car Program, Colorado sales in their entirety move out of the non-Advanced Clean Car States region and into the Advanced Clean Car States region.

Vehicle compliance costs under a Colorado Advanced Clean Car Program

We next estimated the costs of each scenario identified in Table 3 above. For the first two scenarios, we developed vehicle cost estimates for the 2025 model years, as was done by EPA in the Proposed Determination. All of the inputs needed to determine costs in 2030 are present in the EPA digital files used to develop the input files for the OMEGA model. The difference between technology costs in 2025 and 2030 in terms of real dollars are due to further "learning". For most technologies, the effect of learning over these five years is small: 5% or less. For PHEVs and BEVs, however, projected costs in 2030 are significantly lower than in 2025. Thus, for the Colorado Advanced Clean Car Program, as it would significantly increase the number of PHEVs and BEVs in the Colorado fleet, we developed PHEV and BEV cost estimates for 2030. We substituted these 2030 PHEV and BEV costs for the 2025 costs. For all three GHG scenarios, vehicle costs for all other control technologies (e.g., direction injection, turbochargers, 8-speed transmissions, etc.) are those for 2025.

We developed two cost estimates using different estimates of the costs of various technologies. The first uses EPA's methodology from the Proposed Determination. The second uses more recent information showing GHG reducing technology is associated with both lower cost and increased emission reduction potential.

Vehicle compliance costs using EPA technology assessments

This set of compliance cost estimates relies entirely on the cost and effectiveness projections for technology developed by EPA for the Proposed Determination. We evaluated EPA's current GHG standards using the single U.S. new vehicle sales fleet and with the two regional fleets discussed above. The evaluation using U.S. sales is consistent with and comparable to EPA's analysis in the Proposed Determination. The separate evaluation of compliance costs for vehicles sold in the Advanced Clean Car States and the remaining U.S. is helpful as it provides a basis for comparison.

The relaxed EPA scenario was also assessed using EPA's OMEGA model. The only changes made to the EPA input files to the model were to reflect the two regional fleets and the relaxation of GHG standards for non-Advanced Clean Car States. Colorado is part of these non-Advanced Clean Car States in this second scenario.

Estimating vehicle costs for the Colorado Advanced Clean Car Program is slightly more complicated. Once the ZEVs needed to comply with the Advanced Clean Car Program are in the vehicle fleet, the remaining cost to bring the entire Advanced Clean Car States fleet (including Colorado) into compliance with the California GHG standards can be determined using the OMEGA model. However, the cost of the additional ZEVs needed to comply with the Advanced Clean Car Program must be determined outside of the OMEGA model. EPA's OMEGA model is not designed to estimate the cost of a sales requirement for a specific GHG control technology, like that required by the Advanced Clean Car Program. Thus, we estimated these costs using EPA's estimates of the cost per vehicle of PHEV and BEV technology. These costs were developed and made available to the OMEGA model should a manufacturer require this technology in order to meet the GHG standards.

As mentioned above, we will project the fuel savings resulting from the GHG standards using two sets of fuel price projections. The OMEGA model utilizes fuel prices when projecting which technologies manufacturers could use to meet the requisite GHG standards. We only used EIA's fuel price projections from the reference case of their 2016 AEO in our OMEGA model runs. We could have duplicated these runs with EIA's high fuel price projections. However, this would have had extremely small effects on the technology added and the resulting vehicle cost. The reason for this is that the technology being added by OMEGA is almost entirely applied to gasoline vehicles. Since a change in gasoline price affects all the cost effectiveness of these technologies in the same way, there is little effect on the decision to add one technology versus another. We confirmed this by reviewing the results of EPA modeling, performed for the Proposed and Final Determinations, using the exact same sets of price projections being considered here: the AEO2016 reference case and the AEO2016 high fuel price case. EPA evaluated the costs of both fuel price projections. The average vehicle cost to comply with the 2021 GHG standards was $25 higher with the high fuel price projections. The average vehicle cost to comply with the 2025 GHG standards was $34 higher with the high fuel price projections. Thus, the cost of complying with the 2025 GHG standards compared to the 2021 GHG standards was only $9 higher with the high fuel price projections. The higher compliance costs with higher gasoline prices was likely due to a slight increase in the application of EV technology for manufacturers with the highest average compliance costs. Even this small change is unlikely in our modeling of Colorado due to the ZEV portion of the Advanced Clean Car program.

The results of the OMEGA modeling for the three scenarios are shown in Table 5. The costs applicable to Colorado vehicles are highlighted in **bold**. The reader should note that all costs are incremental to technology already being utilized in the 2015 MY new vehicle fleet.

Table 5: Additional Vehicle Costs Relative to the 2015 Fleet Under Various GHG Control Scenarios ($2015 per vehicle)

	Non-Advanced Clean Car States	Advanced Clean Car States	All Vehicles Sold in U.S.
2025 EPA GHG Standards Modeled as a Single Fleet (from EPA's Final and Proposed Determinations)			
No. of Vehicles Sold	N/A	N/A	16.4 million
Total Compliance Cost	N/A	N/A	$22.6 billion
Cost per vehicle	N/A	N/A	$1378
2025 EPA GHG Standards Modeled as Two Vehicle Fleets			
No. of Vehicles Sold	11.6 million	4.8 million	16.4 million
Total Compliance Cost	$17.4 billion	$4.9 billion	$22.3 billion
Cost per vehicle	**$1496**	$1,024	$1,358
Non-Advanced Clean Car States Fleet Meets 2020 EPA GHG Standards, No Action by Colorado			
No. of Vehicles Sold	11.6 million	4.8 million	16.4 million
Total Compliance Cost	$4.4 billion	$4.9 billion	$9.3 billion
Cost per vehicle	**$377**	$1,024	$566
Non-Advanced Clean Car States Fleet Meets 2020 EPA GHG Standards, Colorado Adopts Advanced Clean Car Program (Costs do not include the cost of additional ZEVs)			
No. of Vehicles Sold	11.3 million	5.1 million	16.4 million
Total Compliance Cost	$4.3 billion	$5.2 billion	$9.5 billion
Cost per vehicle	$377	**$1,028**	$578

The first two sections of Table 5 show the costs to meet EPA's existing MY 2025 standards modeled using two different analytical approaches. The first section estimates compliance costs for the entire country as whole, while the second estimates compliance costs separately for the Advanced Clean Car States and non-Advanced Clean Car States. The results of these two approaches are very similar, with only minor differences based on the scope of allowable credit trading and the approach to accounting for upstream GHG emissions attributable to ZEVs. Our modeling also includes the additional ZEVs sold in Colorado between 2015 and 2017.

The "two-vehicle" run of the model also shows, perhaps counterintuitively, higher per-vehicle costs in the non-Advanced Clean Car States as compared to the Advanced Clean Car States. This is because the ZEVs needed to meet the requirements in the Advanced Clean Car States have zero GHG emissions (and very low GHG emissions even in EPA's previous analysis), which allows the ICE vehicles in the Advanced Clean Car States to have higher GHG emission levels than those in the other states and still meet the standards. Neither our analysis nor the EPA analysis incorporates the cost of the ZEVs needed to meet the Advanced Clean Car Program as this program pre-dates the EPA GHG program and is not likely to change under any of the scenarios evaluated here. However, for states such as Colorado, which might be considering adopting the Advanced Clean Car Program, the cost of these ZEVs is relevant and our analysis considers and incorporates these ZEV costs below.

The third section of Table 5 shows the vehicle compliance costs if EPA should weaken its 2025 standards to the level of its current 2020 standards. Compliance costs outside of the Advanced Clean Car States decrease to $377 per vehicle, while costs in the Advanced Clean Car States remain the same, as the current GHG standards would continue to apply.

The fourth and last section in Table 5 presents the vehicle compliance costs for the Colorado Advanced Clean Car Program. The cost per new Colorado vehicle is $1,028 per vehicle. This is slightly more than the cost for the Advanced Clean Car States fleet prior to the addition of Colorado—a difference attributable to the manufacturer mix of vehicles sold in Colorado.

The costs shown in this last section do not include the cost of producing the additional ZEV sales associated with meeting the Advanced Clean Car Program in Colorado, which we estimate and discuss in more detail below.

ZEV costs

The Market file[15] used in the OMEGA model contains the cost of adding each technology package to every vehicle in the file. For the ZEV-capable ICE vehicles, these packages include both BEV and PHEV technologies. Using the lists of technology packages in the OMEGA Technology file, we determined which specific packages converted the ICE vehicle to a 200-mile BEV or a 40 mile PHEV. We then selected the cost of these packages from the Market file and applied those costs to the number of ZEVs Colorado would need to comply with the ZEV program. (The costs in the Market file consider the technology already on 2015 vehicles, so current technology costs are not double counted.) As shown in the first column of Table 6, the average per vehicle cost of converting these ICE vehicles to ZEVs is $12,585, which represents a sale-weighted average of the cost of converting vehicles to PHEV and BEV technology. Averaged across all Colorado vehicle sales, this represents an increase per vehicle cost of $1129. Together with the $1,087 cost of reducing GHG emissions from the rest of the Colorado new

[15] The Market file contains a detailed description of each vehicle model present in the baseline fleet (here 2015 MY). This includes the model's manufacturer, vehicle class, engine, transmission, CO2 emission level, technology present on the vehicle. It also contains factors which indicate the degree that each technology package reduces CO2 emissions from that vehicle model and the cost of that technology for that model.

vehicle fleet (from Table 5), this represents a total increase in vehicle cost of $2,216 relative to a 2015 vehicle.

Table 6: Colorado ZEV Costs Using EPA Cost Methodology (Relative to 2015 Vehicles)			
	Without CO ZEV Tax Credit	With CO ZEV Tax Credit	With CO+Federal ZEV Tax Credits
		$ per ZEV	
EPA ZEV Cost (2025)	$12,585	$7,585	$85
EPA ZEV Cost (2030)	$10,285	$5,285	$(2,215)
		Cost of ZEVs per Average Vehicle in Colorado	
EPA ZEV Cost (2025)	$1,129	$680	$(3)
EPA ZEV Cost (2030)	$920	$472	$(201)

Colorado currently provides a $5,000 state tax credit for ZEV purchases. The middle column of Table 6 shows the ZEV cost after applying this credit, which reduces the cost per ZEV by $5,000 and reduces average cost across all new vehicles in Colorado from $1,129 to $680. The federal government currently provides a $7,500 tax credit for ZEV purchases. The effect of both of these credits is shown in the last column of Table 6. As can be seen, the two tax credits combined offset the full additional cost of a ZEV in 2025 over a conventional vehicle using EPA's cost methodology.

Compliance costs generally decrease over time under EPA's cost methodology due to continued "learning" in manufacturing. For more fully mature, conventional technologies, costs in 2030 would be only 5% lower on average, so we did not rerun the OMEGA model to capture these cost decreases. However, EPA projects that BEV and PHEV costs will decrease more substantially, and so we used the EPA learning methodology to develop BEV and PHEV costs in 2030.[16] These costs are also shown in Table 6.

Using EPA's learning curves, the cost of a ZEV in Colorado (a mix of BEV200 and PHEV40 vehicles) would decrease from $12,585 to $10,285 by the year 2030. Averaged across all Colorado sales, the cost would decrease from $1129 per vehicle to $920 per vehicle. With the Colorado ZEV tax credit, the ZEV cost averaged across all new vehicle sales in Colorado would decrease from $680 to $472. With both tax credits, the ZEV cost averaged across all new vehicle sales in Colorado would decrease from a net savings of $3 to a net savings of $201 per vehicle sold.

Table 7 shows the impact of the various GHG scenarios on the average cost of a Colorado vehicle considering both the impact on ICE vehicles from Table 5 and ZEVs from Table 6.

[16] EPA did not publish compliance costs for 2030 in their Proposed Determination modeling. However, they developed and published all of the necessary information to do so. Thus, we believe that it is appropriate to refer to these costs as EPA costs.

Table 7: Total Vehicle Compliance Costs for a Colorado Advanced Clean Car Program (Relative to a 2015 Vehicle) – EPA Costs			
	Without CO ZEV Tax Credit	With CO ZEV Tax Credit	With CO and federal ZEV Tax Credits
EPA ZEV Cost (2025)	$2,157	$1,708	$1,025
EPA ZEV Cost (2030)	$1,948	$1,500	$827

If fuel savings are not considered, a Colorado Advanced Clean Car Program would increase average new vehicle compliance costs, absent ZEV tax credits and relative to the weaker 2020 standards.[17] However, considering both Colorado and federal tax credits, the vehicle costs for the Advanced Clean Car Program would fall to well below the cost of the current EPA 2025 standards (of $1,496).

Table 8 shows the same compliance costs relative to the EPA 2020 standards. These figures show the additional cost of a Colorado decision to opt into the Advanced Clean Car Program. These costs will also be used below to compare to fuel savings of the Colorado Advanced Clean Car Program.

Table 8: Total Vehicle Compliance Costs for a Colorado Advanced Clean Car Program (Relative to EPA 2020 Standards)– EPA Costs			
	Without CO ZEV Credit	With CO ZEV Credit	With CO and federal ZEV Credits
EPA ZEV Cost (2025)	$1,779	$1,330	$647
EPA ZEV Cost (2030)	$1,570	$1,132	$449

Vehicle compliance costs using recent, lower cost data

The International Council on Clean Transportation (ICCT) recently surveyed progress in the development of several technologies which improve the fuel efficiency of light-duty vehicles.[18] These technologies included gasoline direct injection, cooled exhaust gas recirculation (EGR), cylinder deactivation, naturally aspirated Atkinson high compression ratio engines, turbocharged Atkinson (or Miller cycle) engines, electrically boosted turbocharging, weight reduction, diesel engines and electric vehicles. Some of these technologies play a large role in EPA's analyses supporting the Final Determination ("FD"). Others play a more minor role, at least with respect to EPA's projections of cost and effectiveness.

The projected cost of EV battery technology in the 2025 timeframe has decreased even more since this ICCT study.[19] A recent technology review published by Bloomberg Technology projected battery costs of $100 per kW-hr in 2025, 16% less than those projected in the above ICCT study for 2025.[20]

The conventional technological advances projected by ICCT apply in 2025 and, consistent with the above analysis, we assume will remain unchanged in 2030. The ICCT ZEV cost projections are time

[17] The small difference is due to differences in ZEV sales in Colorado and non-Advanced Clean Car States absent the Advanced Clean Car Program.
[18] Lutsey, Nic, Dan Meszler, Aaron Isenstadt, John German and Josh Miller, "Efficiency Technology and Cost Assessment for U.S. 2020-2025 Light-Duty Vehicles", ICCT, March 2017.
[19] Chediak, Mark, The Latest Case for Electric Cars: The Cheapest Batteries Ever, Bloomberg Technology, https://www.bloomberg.com/news/articles/2017-12-05/latest-bull-case-for-electric-cars-the-cheapest-batteries-ever.
[20] These costs are at the level of direct manufacturing costs. Indirect costs were estimated using EPA's methodology.

dependent, with different projections for 2025 and 2030. The Bloomberg battery cost review only addressed costs out to 2025. Thus, we utilize the ICCT ZEV cost projections excluding batteries coupled with the Bloomberg battery costs to project ZEV costs in 2025. We use ICCT's complete ZEV cost projections alone for 2030.

We have used the technology cost projections from the ICCT study in the past to develop inputs to EPA's technology cost methodology and used the outputs from the EPA methodology in OMEGA modeling to estimate the impact on projected costs of manufacturers meeting the current EPA 2025 GHG standards.[21] We use this same methodology here with one change to adjust the ICCT cost projections for ZEV batteries in 2025 to incorporate the even more recent, Bloomberg battery cost of $100 per kW-hr.[22]

Table 9 provides an indication of the changes in cost and effectiveness of several technologies relative to those estimated by EPA. Dashes indicate that no changes were made to the EPA estimates.

Table 9: ICCT Projections for Conventional Technology (2025 and 2030)

	Cost: EPA	Cost: ICCT	Effectiveness: EPA	Effectiveness: ICCT
Gasoline Direct Injection	$196-356	$91-185	---	---
Cooled Exhaust Gas Recirculation	$216	$95-114	---	---
Cylinder Deactivation	$75-149	$129-256	3.5-5.8%	6.5-8.3%
Atkinson Cycle	---	---	3-8%	10-14%
Miller Cycle	$730-1,245	$615-1,049	---	---
Mild Hybrid	---	---	7.0-9.5%	10.5-12.9%

We repeated the OMEGA modeling for the current EPA standards, the potential relaxation of the EPA standards to 2020 levels and a Colorado Advanced Clean Car Program using the ICCT and Bloomberg estimates. The results are shown below in Table 10.

Table 10: OMEGA Modeling Results – Vehicle Compliance Costs for the Three GHG Scenarios ICCT Conventional Technology Costs in 2025

	Non-Advanced Clean Car States	Advanced Clean Car States	All Vehicles Sold in U.S.
2025 EPA GHG Standards Modeled as Two Vehicle Fleets, No Action by Colorado			
Vehicle Sales	11.6 million	4.8 million	16.4 million
Total Compliance Cost	$11.9 billion	$3.7 billion	$15.6 billion
Cost per vehicle	**$1025**	$780	$954
Non-Advanced Clean Car States Fleet Meets 2020 EPA GHG Standards, No Action by Colorado			
Vehicle Sales	11.6 million	4.8 million	16.4 million
Total Compliance Cost	$3.7 billion	$3.7 billion	$7.4 billion
Cost per vehicle	**$314**	$780	$450
Non-Advanced Clean Car States Fleet Meets 2020 EPA GHG Standards, Colorado Adopts Advanced Clean Car Program			
Vehicle Sales	11.3 million	5.1 million	16.4 million
Total Compliance Cost	$3.6 billion	$4.0 billion	$7.53 billion
Cost per vehicle	$314	$782	$458

[21] Effect of Lower Technology Costs on Compliance with EPA's 2025 GHG Standards, EDF, 2017.
[22] ICCT projected battery costs of $119 per kW-hr in 2025.

Table 11 presents ZEV costs using the ICCT and Bloomberg projections.

Table 11: Colorado ZEV Costs Using ICCT and Bloomberg Methodology			
	Without CO ZEV Credit	With CO ZEV Credit	With CO and Federal ZEV Credit
		$ per ZEV	
ICCT-Bloomberg ZEV Cost (2025)	$11,536	$6,536	$(964)
ICCT ZEV Cost (2030)	$10,091	$5,091	$(2,409)
		Cost of ZEVs per Average Vehicle in Colorado	
ICCT-Bloomberg ZEV Cost (2025)	$1,035	$586	$(86)
ICCT ZEV Cost (2030)	$905	$457	$(216)

Using this updated cost data, the cost per ZEV in 2025 is about $1000 less than EPA's cost projection and about $170 less in 2030. When averaged across all new vehicle sales (and accounting for the two ZEV tax credits), the net savings from the ZEV program increases to $86 in 2025 and $216 in 2030.

Table 12 shows average vehicle costs across all Colorado sales for the various scenarios.

Table 12: Total Vehicle Compliance Costs for a Colorado Advanced Clean Car Program (Relative to a 2015 Vehicle) – ICCT and Bloomberg Costs			
	Without CO ZEV Credit	With CO ZEV Credit	With CO and federal ZEV Credits
ICCT-Bloomberg ZEV Cost (2025)	$1,817	$1,368	$696
ICCT ZEV Cost (2030)	$1,687	$1,239	$566

With reduced technology costs and without any ZEV tax credits, a Colorado Advanced Clean Car Program would increase costs $660-790 over that of the current 2025 GHG standards (estimated at $1,025). With both the CO and Federal ZEV tax credits, the average cost per vehicle would actually be $330-460 less than the cost of the current 2025 GHG standards.

Table 13 shows average vehicle costs across all Colorado sales for a Colorado Advanced Clean Car Program relative to the EPA 2020 standards.

Table 13: Total Vehicle Compliance Costs for a Colorado Advanced Clean Car Program (Relative to EPA 2020 Standards)– ICCT and Bloomberg Costs			
	Without CO ZEV Credit	With CO ZEV Credit	With CO and federal ZEV Credits
ICCT-Bloomberg ZEV Cost (2025)	$1,503	$1,054	$382
ICCT ZEV Cost (2030)	$1,373	$925	$252

Lifetime fuel savings and payback periods

We next calculated the lifetime fuel savings per vehicle and the payback period for a Colorado Advanced Clean Car Program. We used EPA's Inventory, Costs and Benefits Tool (ICBT) model to assess fuel savings for 2025 model year vehicles as these vehicles age, are scrapped and are driven less, along with maintenance costs for 2025 vehicles by age and total technology costs for the 2025 new vehicle fleet. All of these lifetime fuel savings and payback periods utilize retail fuel prices, not pre-tax fuel prices, because vehicle owners experience the full retail price of fuel and not pre-tax prices. All of the future fuel savings reflect a 3% annual discount rate to reflect the time value of money, with fuel savings assumed to occur mid-year.

We utilized two projections of future fuel prices. Both come from 2016AEO developed by EIA. We utilize two of the future fuel price cases developed by EIA for their analysis: 1) the Reference Case, which they considered to be their best estimate of future fuel prices, and 2) the High Crude Oil Price Case. Gasoline prices have risen by over 50 cents per gallon over the last 18 months, and are at 4-year highs. With a nationwide average price of about $3 per gallon, current gasoline prices are already at the level projected for 2025 in EIA's Reference Case. Thus, we chose to analyze two fuel price scenarios below, with EIA's AEO2016 Reference Case essentially representing flat fuel prices out to 2025, and its High Fuel Price Case representing continued increases in fuel prices. In the Executive Summary, we simplified the analysis by assuming a single future fuel price scenario based on the arithmetic average of the EIA AEO2016 Reference and High Fuel Price cases.

Table 14 shows the two sets of gasoline price projections for 2020-2040. While EIA presents these prices in $2012 dollars, we present them in terms of $2015 to be consistent with the vehicle costs presented above. These inflation adjustment factors were taken directly from EPA's Fuels input file for their OMEGA modeling performed in support of the Proposed and Final Determinations.

Table 14: Future Gasoline Prices from the 2016 Annual Energy Outlook ($2015 dollars per gallon)

	EIA Reference Case	EIA High Fuel Price Case
2020	$2.74	$3.86
2025	$2.97	$4.53
2030	$3.19	$4.77
2035	$3.47	$5.06
2040	$3.81	$5.23

Table 15 shows fuel savings based on EIA's reference case fuel prices.

Table 15: Average Vehicle Cost, Lifetime Fuel Savings and Payback Period For 2025/2030 MY Vehicles Under the Colorado Advanced Clean Car Program– AEO2016 Reference Fuel Price Case			
	Average Vehicle Cost	Lifetime Fuel Savings	Payback Period (years)
2025: No ZEV Tax Credits	1503-1779		6.5-8.0
2025: CO ZEV Tax Credit	1054-1330	$3141-3181	4.3-5.6
2025: CO and Federal ZEV Tax Credits	382-647		1.5-2.6
2030: No ZEV Tax Credits	1373-1570		5.1-6.0
2030: CO ZEV Tax Credit	925-1122	$3466-3506	3.3-4.1
2030: CO and Federal ZEV Tax Credits	252-449		0.9-1.6

The lower end of each range of vehicle costs shown utilizes the ICCT-Bloomberg cost estimates, while the upper end of the range utilizes the EPA costs. The MY 2025 lifetime fuel savings with the lower ICCT-Bloomberg technology costs are slightly higher ($3181) than with the EPA costs ($3141). This is due to the higher effectiveness estimates for several ICE technologies which reduces the degree of vehicle electrification required by several manufacturers with high GHG levels relative to the standards.

Considering both state and federal tax credits, adopting the Advanced Clean Car Program in Colorado improves the payback period to 1.5-2.6 years in 2025 and even lower in 2030.

Table 16 shows fuel savings based on EIA's high crude oil price case.

Table 16: Average Vehicle Cost, Lifetime Fuel Savings and Payback Period For 2025/2030 MY Vehicles Under the Colorado Advanced Clean Car Program – AEO2016 High Fuel Price Case			
	Average Vehicle Cost	Lifetime Fuel Savings	Payback Period (years)
2025: No ZEV Tax Credits	$1503-1779		3.3-4.0
2025: CO ZEV Tax Credit	$1054-1330	$5321-5361	2.3-2.9
2025: CO and Federal ZEV Tax Credits	$382-647		0.8-1.4
2030: No ZEV Tax Credits	$1373-1570		2.8-3.2
2030: CO ZEV Tax Credit	$925-1122	$5654-5695	1.9-2.3
2030: CO and Federal ZEV Tax Credits	$252-449		0.5-0.9

As can be seen, fuel savings almost double with the higher gasoline prices of EIA's high crude oil price case. The payback periods decrease accordingly. Considering both state and federal tax credits, adopting the Advanced Clean Car Program in Colorado improves the payback period to 0.8-1.4 years in 2025 and less than a year in 2030. Even with no tax credits, the payback period is short – 3.3 to 4.0 years.

While the above analysis assumes that consumers purchase their vehicles with cash, it is important to highlight that the 60% of consumers that purchase new vehicles on loans of 5 years or longer. The average loan is nearly 6 years. In order to indicate the impact of the Colorado Advanced Clean Car Program on a consumer who purchased a vehicle with a six-year loan, we calculate the annual sum of the 12 monthly car payments, incremental insurance costs (1.8% per EPA estimates) and the average annual fuel savings over the six-year period of the loan. Table 17 shows the results for the range of vehicle costs and the two sets of fuel savings.

Table 17: Incremental Monthly Vehicle Payments and Fuel Savings for A Consumer Purchasing a Vehicle Via a 6-Year Loan Under the Colorado Advanced Clean Car Program

	Monthly Car Payment	Monthly Fuel Savings	
		AEO Reference Case	AEO High Fuel Price Case
2025: No ZEV Tax Credits	$26-31	$(20-21)	$(36)
2025: CO ZEV Tax Credit	$18-23	$(20-21)	$(36)
2025: CO and Federal ZEV Tax Credits	$7-11	$(20-21)	$(36)
2030: No ZEV Tax Credits	$24-27	$(23)	$(39)
2030: CO ZEV Tax Credit	$16-20	$(23)	$(39)
2030: CO and Federal ZEV Tax Credits	$4-8	$(23)	$(39)

Using a 4.25% interest rate on a 6 year car loan (real dollars), the purchaser of a new vehicle under the Colorado Advanced Clean Car Program will have a positive cash flow immediately as the monthly fuel savings will exceed the increase in the monthly loan payment due to the more expensive technology, assuming only the Colorado ZEV tax credit. (The positive cash flow is even more dramatic with both tax credits.) The same is true in 2030 with neither tax credit with the lower ZEV cost. This comparison ignores all of the fuel savings which will accrue over the rest of the life of the vehicle, which have already been paid for.

In 2030, with reference case fuel prices, fuel savings will exceed vehicle costs by $145-201 million with no consideration of tax credits. With both tax credits, savings to Colorado drivers will increase to $462-518 million. In 2040, assuming no further reduction in ZEV costs, fuel savings will exceed vehicle costs by $855-912 million with no consideration of tax credits. With both tax credits, savings to Colorado drivers in 2040 will increase to $1.2 billion. With high fuel prices, these net savings will increase to $590-646 million in 2030 and $1.6 billion in 2040, without considering tax credits. Considering both tax credits, net savings would be $907-962 million in 2030 and $1.9-2.0 billion in 2040.

The fact that the fuel savings for a Colorado Advanced Clean Car Program exceed technology costs means that the cost per ton of all of the emission reductions described in the next two sections are negative. Thus, they compare extremely favorably to the cost effectiveness of other emission control programs which would provide comparable benefits.

Greenhouse gas emission impacts

We used the results of the OMEGA modeling described in the previous section in conjunction with EPA's ICBT model to estimate the impacts of the various scenarios on GHG emissions in both 2030 and 2040. For estimates of GHG emissions specific to the state of Colorado, we input Colorado car and light truck sales, described above. CO_2 emission rates for cars and light trucks over the EPA test cycles come directly from the OMEGA model. We assumed that the level of air conditioning and off-cycle emission credits would be the same as those projected by EPA in 2025 in its Proposed and Final Determination modeling and applied those across all scenarios. We converted GHG emissions over EPA's test cycles to on-road emissions using EPA methodology (i.e., dividing by 0.8). We assume a "rebound effect" of 10% consistent with the EPA analyses for the light-duty GHG emissions standards.[23]

EPA's ICBT model also tracks changes in power plant and upstream gasoline-related (crude oil production, refining, and distribution) emissions associated with changes in the demand for electricity and liquid fuel, which are important considerations in assessing the full impacts of a Colorado Advanced Clean Car Program.[24] We used Colorado specific data to estimate power plant emissions to the greatest degree possible. Western Resource Associates (WRA) performed research around EPA's Clean Power Plan. This included data on current and projected future electricity production levels and CO_2 emissions for individual power plants, including those in Colorado. These current data and projections were provided to us for Colorado power plants by WRA.[25] Department of Energy data shows Colorado produces more energy than the state consumes, so we assumed that additional electrical energy needed to power ZEVs would be generated in-state. Based on the information supplied by WRA, current electrical power supply in the Front Range and Colorado as a whole is shown in Table 18, broken down by fuel type.

Table 18: Sources of Electricity Generation in Colorado (Mega W-hr)

Year	Front Range			
	Coal	Natural Gas	Other	Renewables
2017	21,897,437	11,899,225	-	10,331,498
2020	16,503,826	11,638,750	133,432	14,580,853
2030	7,412,802	14,850,754	133,432	24,089,435
	Colorado			
2017	33,064,908	11,899,225	-	10,331,498
2020	27,087,850	11,638,750	133,432	14,580,853
2030	16,353,999	14,850,754	133,432	24,089,435

[23] The rebound effect is the economic construct that relates a change in the cost of driving to a change in the amount of driving, i.e., if driving becomes more expensive, then people will drive less, while if driving becomes cheaper, then people will drive more. This topic received extensive discussion in EPA's GHG rulemakings and the Proposed and Final Determinations. Estimates of the rebound effect seem to be declining over time. Its applicability to the situation being addressed in this report is particularly complex, as the reduction in the cost of driving a mile is coupled with an increase in the cost of the vehicle. Money is fungible, so the decrease in driving costs on the one hand cannot be divorced from the increased cost of the vehicle on the other. As shown in the previous section, the impact of the increased vehicle cost for a person buying a vehicle with a bank loan is mitigated by the reduced cost of driving that vehicle, so the reduced cost of driving is mitigated by the fact that the vehicle owner either pays a higher monthly car payment or has less money in the bank to pay for driving the vehicle. It appears that both costs and savings should be considered together, which has not been the case to date in EPA or NHTSA analyses. Thus, while we use a 10% rebound effect in our analysis here, it could be less with GHG and fuel economy standards, increasing the GHG and criteria emission benefits shown in this analysis.

[24] Upstream gasoline emissions are roughly evenly split between crude oil production and refining. Emissions related to fuel distribution are significant, but much smaller than these other two emission sources.

[25] Personal communication with Stacy Tellinghuisen of WRA, November 10, 2017.

In developing the emission factors for electricity production for the ICBT model in the 2017-2025 rulemaking, EPA used its Integrated Planning Model (IPM) model to project the sources of electricity production nationwide in 2030.[26] This breakdown was 42% coal, 25% natural gas, 28% other, and 4% wind. EPA then examined the location and timing of expected ZEV sales under a Colorado Advanced Clean Car Program and estimated that the incremental electricity used to power ZEVs would be 80% from natural gas, 14% from coal and 6% from wind. Thus, EPA assumed the electricity mix used to power ZEVs would be much more oriented towards natural gas than average electrical power.

As Table 18 demonstrates, however, coal as a source of electrical power in Colorado is decreasing, especially in the Front Range, while use of natural gas and renewables are both increasing. To assess how Colorado may meet the incremental energy demand associated with increased ZEVs, we evaluated the rate of increase in both natural gas and renewables usage and found that roughly one fourth of the increase in power generation came from natural gas and three fourths from renewables. Accordingly, we assumed that incremental energy demand associated with ZEVs in Colorado would be met by these growing sources, projecting that 25% of the power needed to operate ZEVs would come from natural gas and 75% from renewables. We did not see any reason to change this projection for 2040, though it is possible that the portion of incremental electricity from renewable sources used to power ZEVs might be even greater than 75%.

As the ICBT model only contains emission estimates for the mix of power sources described above, we obtained emission rates for natural gas fired power plants from EPA's AP-42 Emission Factor document.[27] We converted these emission rates to grams per kilowatt-hour for input to the ICBT model, assuming that upstream GHG emissions to obtain the natural gas were 20% of power plant emissions and transmission losses were 10% of power plant emissions. We assumed that emissions from renewable sources were zero, which effectively reduced the natural gas emission rates by 75% when averaged with those from renewable sources.

We also used some Colorado-specific information in our assessment of upstream gasoline emissions. We were unable to obtain emission factors specific to the production of crude oil used to produce Colorado gasoline, nor the main local refinery serving Colorado, the Suncor refinery. Thus, we utilized the GHG, NOx, PM2.5 and SOx emission factors already contained in the ICBT model. We plan to update these national emission estimates with more local emission factors as data become available.

We were able to find a study which estimated that 34% of the gasoline used in Colorado was refined in Colorado refineries.[28] The remainder is transported from refineries in Wyoming, Kansas, and Texas. Thus, only 34% of the change in refinery emissions associated with the various GHG standards are expected to occur within the state of Colorado. We extended this fraction to emissions related to crude oil production given that crude oil is produced within Colorado, but we lack more specific information on how a reduction in Colorado gasoline consumption would affect crude oil production geographically.[29] Thus, when presenting the impacts of the various GHG scenarios on criteria emissions, we only included 34% of upstream gasoline emissions. However, as GHG emissions are

[26] Joint Technical Support Document, Final Rulemaking for 2017-2025 Light-Duty Vehicle GHG Standards and Corporate Fuel Economy Standards, EPA and NHTSA, July 2012, EPA-420-R-12-901.

[27] Emission rates for the GHGs were taken from Table 1.4-2, which is generic to all natural gas fired units. These emission rates were: 120,000 for CO_2, 2.3 for methane and 0.644 for N_2O, all in pounds per million standard cubic feet.

[28] Energy Analysts International, "Denver/North Front Range Fuel Supply Costs and Impacts," Report for the Regional Air Quality Council, March 4, 2011.

[29] This is likely a conservative assumption, as crude oil production in Colorado far exceeds that necessary to produce the gasoline consumed in the state. EIA data indicates that Colorado crude oil production in early 2018 is averaging over 400,000 barrels per day (https://www.eia.gov/petroleum/production/). Gasoline consumption in the state is on the order of 140,000 barrels per day. Refineries produce more than 50% of their crude oil input as gasoline.

primarily a national and international concern, we included the entire change in GHG emissions from upstream gasoline-related sources both inside and outside of Colorado here.

The impacts of a potential weakening of the 2021-2025 GHG standards on GHG emissions are shown in Table 19 below. Changes in power plant emissions are not shown as they are very small.

Table 19: GHG Emission Impacts in Colorado if EPA Relaxes 2025 GHG Standards to 2020 Levels (Metric Tons per Year)

	CO_2	N_2O	Methane	CO_2e
		2030		
Vehicle (including rebound)	2,013,385	(4)	(3)	
Upstream Gasoline (34% in Colorado)	498,813	10	2,487	
Total	2,512,198	6	2,484	2,575,974
		2040		
Vehicle (including rebound)	3,529,174	(7)	(6)	
Upstream Gasoline (34% in Colorado)	874,347	17	4,359	
Total	4,403,521	10	4,354	4,515,164

These increased emissions occur solely in the state of Colorado, except for two thirds of the upstream gasoline emissions shown that occur out-of-state. Including the rest of the non-Advanced Clean Car States, vehicle CO_2 emissions would increase by 80 million metric tons in 2030 and 143 million metric tons in 2040. These values are roughly 40% of the total benefits of the 2016-2025 standards promulgated by EPA in 2012, include benefits in the Advanced Clean Car States.

Table 20 shows the emission benefits associated with a Colorado Advanced Clean Car Program, which consists of adopting the California GHG and Tier 4 emission programs plus the ZEV standards. Negative numbers indicate reductions in emissions.

Table 20: GHG Emission Impacts in Colorado for a Colorado Advanced Clean Car Program (Metric Tons per Year)				
	CO2	N2O	Methane	CO2e
	2030			
Vehicle (including rebound)	(1,939,479)	3	3	
Power Plant	57,366	0	1	
Upstream Gasoline (34% in Colorado)	(480,503)	(9)	(2,396)	
Total	(2,362,616)	(6)	(2,392)	(2,424,219)
	2040			
Vehicle (including rebound)	(3,469,842)	6	5	
Power Plant	102,838	1	2	
Upstream Gasoline (34% in Colorado)	(859,648)	(17)	(4,286)	
Total	(4,226,651)	(10)	(4,279)	(4,336,666)

These emission reductions are just slightly smaller than the emission increases which would be due a relaxation of the federal GHG standards to current 2020 levels. The reason for the difference is that a relaxation of the 2021-2025 standards would occur starting in 2021, while Colorado's adoption is not likely possible until 2022. As mentioned above, these GHG emission reductions are achieved with a net cost savings. Thus, the cost per ton of CO2 equivalent is negative.

Criteria emissions

EPA also used the ICBT model to project the impact of various GHG vehicle emission standards on criteria pollutants emissions, retaining EPA's methodology to the greatest extent possible. We updated EPA's methodology, however, to make the analysis more specific to Colorado and to address two ways that vehicle emissions would be reduced under a Colorado Advanced Clean Car Program.

The ICBT model estimates the vehicle emission impacts of rebound VMT, but these impacts use a single set of vehicle emission factors for criteria pollutants, which are only applied to rebound VMT, not total VMT. This is because EPA assumes that changes in federal GHG standards will have no impact on emission standards for criteria pollutants. However, there are two reasons why criteria emission factors may decrease under a Colorado Advanced Clean Car Program.

The first reason relates to the differential fraction of ZEVs in Advanced Clean Car State sales relative to the rest of the country. The primary reason that EPA assumes that their GHG emission standards do not affect criteria emission rates is that both the EPA and California vehicle programs effectively allow manufacturers to average the criteria emissions of their various vehicle models when meeting the standards. We agree with EPA that incremental changes to the GHG standards are unlikely to produce any change in criteria emissions. However, the addition of BEVs to the fleet in selected regions of the country (i.e., the Advanced Clean Car States) appears to produce a different result. Because EPA and California criteria emission standards are generally closely aligned currently, most of the vehicles sold in the U.S. today are "50-state" vehicles. That is, the exact same vehicles (from a criteria emission perspective) are sold in the Advanced Clean Car States as elsewhere. This means that criteria emissions per mile from non-ZEVs are the same inside and outside of the Advanced Clean Car States region. Because of the similarity of the criteria emission standards in the two regions, manufacturers are not taking advantage of the lower ZEV emissions to increase the emissions from their ICE vehicles. Thus, since the ZEV fraction of the fleet is much higher in the Advanced Clean Car States region due to the ZEV program, criteria emissions should be lower.

PHEVs, because they still have a gasoline engine, could emit criteria emissions at the same rate as ICE vehicles. However, BEVs have no exhaust emissions. Therefore, the fleet-average criteria emission rate in Advanced Clean Car States could be lower than those outside of this region by the increased fraction of BEVs in the Advanced Clean Car States fleet. Thus, under a Colorado Advanced Clean Car Program with its increased ZEV sales (4% as discussed above), its criteria emission rate could decrease by 4% for the 2025 MY.

The other reason that criteria emissions would decrease is California's plan to implement Tier 4 criteria emission standards. Under a Colorado Advanced Clean Car Program, this could include California's planned Tier 4 standards for criteria pollutants, resulting in significant reductions in these emissions. As the ICBT model is not designed to include two distinct sets of criteria pollutant emission standards, we had to perform these calculations outside of the ICBT model.

As criteria pollutant emissions from refineries and power plants per unit of energy produced in Colorado are not changing across the various scenarios, we were able to modify the emission factor inputs to the ICBT model to make the model output more specific to Colorado conditions.

To estimate the vehicle emissions of the four criteria pollutants (VOC, NOx, SOx, and PM2.5) outside of the ICBT model, we used many of the same factors used in the ICBT model: 1) VMT per year by vehicle age for car and light trucks, 2) vehicle survival fractions by vehicle age for car and light trucks, 3) for scenarios controlled by federal GHG standards, the emission factors for VOC, NOx, and PM2.5 by vehicle age for car and light trucks, and 4) the sulfur content of gasoline by calendar year.

For the situation where the addition of BEVs to the sales fleet reduces criteria emissions proportionately, the vehicle emissions from the ICBT model can simply be multiplied by 96.1% to project the impact of the Advanced Clean Car Program in Colorado. Upstream emissions from refineries and power plants are unaffected as the ICBT model already incorporates changes to these emissions.

For the situation where California implements Tier 4 emission standards, the criteria emission factors within the ICBT model must be changed. The VOC, NOx, and PM2.5 emission factors in the ICBT model reflect EPA Tier 3 standards for these pollutants, which are 30 mg/mi for VOC+NOx and 3 mg/mi for PM2.5 over the Federal Test Procedure (FTP). California has discussed setting Tier 4 standards of 20 mg/mi for VOC+NOx and 1 mg/mi for PM2.5. The State of California has also focused on the ameliorating deterioration of emissions performance in-use. For example, the VOC+NOx emission factors in the ICBT model indicate that VOC+NOx emissions more than double in the first 10 years of a vehicle's life.

We estimated the on-road impact of California Tier 4 standards by assuming that the California Tier 4 standards would: 1) reduce zero-mile emission rates for VOC and NOx by one third, reflecting the change in the applicable FTP standard from 30 to 20 mg/mi and 2) reduce deterioration from these levels by 75%. We also assumed that California Tier 4 standards would: 1) reduce zero-mile emission rates for PM2.5 by two thirds, reflecting the change in the applicable FTP standard from 3 to 1 mg/mi and 2) again reduce deterioration from this level by 75%. We assume that the Tier 4 standards would initially apply to 2026 MY vehicles and would be phased in, with one third of new vehicles being affected in 2026, two thirds in 2027 and all vehicles in 2028. We believe that California will only allow averaging of sales to meet the Tier 4 standards across vehicles with ICEs. BEVs would not be included. Thus, as we believe is the case today, there would continue to be a further reduction in emissions due to BEV sales.

SOx emissions are handled differently in the ICBT model, as essentially all of the sulfur in the fuel is emitted as some form of SOx. Thus, SOx emissions are solely a function of fuel sulfur level and liquid fuel consumption. Fuel sulfur level is not affected by any of the scenarios being addressed in this study. So, the only factor affecting SOx emissions is fuel consumption, which for a single fuel (i.e., gasoline) is a straightforward function of CO2 emissions. The ICBT model estimates the volume of fuel consumed by light vehicles in each calendar year. It also contains projections of SOx emissions in terms of grams per gallon of fuel. We simply multiplied these two factors to obtain total SOx emissions for the fleet under each scenario.

Power plant emissions of criteria pollutants in Colorado were estimated using the same methodology as discussed above for GHG emissions. All of the electrical energy used by ZEVs in Colorado was assumed to come from natural gas power plants and renewable sources in Colorado. Based on the projected growth in electricity capacity by fuel source, we estimate that 25% of the power needed to operate ZEVs would come from natural gas and 75% from renewables.

Criteria pollutant emission factors were again taken from EPA's AP-42 Emission Factor document for natural gas fired power plants. We again assumed that emissions from renewable sources were zero. We used the NOx emission factor of 100 pounds per standard cubic foot for large wall-fired boilers with flue gas recirculation (Table 1.4-1). Emission rates for the other pollutants were taken from Table 1.4-2, which is generic to all natural gas fired units. These emission rates were: 1.9 for PM2.5, 0.6 for SOx, and 5.5 for VOC, all in pound/standard cubic foot. These emission rates were converted to gram per kW-hr for input to the ICBT model. We assumed that emissions from renewable sources were zero.

As was done for GHG emissions, upstream gasoline emission factors for criteria pollutants were taken from EPA's ICBT model. However, these emission factors were multiplied by 0.34 to account for the fact that Colorado refineries only produce 34% of the fuel used in Colorado and criteria pollutants are primarily a local and regional concern, not national.

These adjusted emission factors were input to EPA's ICBT model. Various runs of the model representing the relevant federal and Colorado scenarios were used to estimate the impacts on emissions in Colorado. The impacts of the potential relaxation of the current federal GHG standards are shown in Table 21.

Table 21: Criteria Emissions Impacts in Colorado – Relaxation of the Current Federal GHG Program to 2020 Levels (U.S. tons per year)				
	VOC	NOx	PM2.5	SOx
		2030		
Vehicle Rebound	(26)	(30)	(1.3)	(0.4)
Upstream Gasoline	464	135	20	79
Total	438	105	19	79
		2040		
Vehicle Rebound	(41)	(42)	(1.8)	(0.7)
Upstream Gasoline	668	237	35	138
Total	627	195	33	137

The impacts of a Colorado Advanced Clean Car Program, assuming that California adopts Tier 4 criteria emission standards, relative to the relaxation of EPA's current GHG standards to 2020 levels are shown in Table 22. The increase in emissions due to rebound VMT and the reduction in emissions from refineries would occur regardless of whether California implemented Tier 4 emission standards or not. The reduction in vehicle emissions (aside from rebound VMT) depends on the implementation of California Tier 4 emission standards. We did not include the cost of these Tier 4 emission standards in our estimation of vehicle costs in the previous section because published costs are not available at this time and we anticipate these costs will be low relative to the net savings of the GHG and ZEV programs.

Table 22: Criteria Emissions Impacts in Colorado of a Colorado Advanced Clean Car Program Relative to Relaxed EPA Standards (U.S. tons per year)				
	VOC	NOx	PM2.5	Sox
		2030		
Vehicle	(262)	(252)	(27)	(14)
Vehicle Rebound	19	22	1	0
Power Plant	3	53	1	0
Upstream Gasoline	(447)	(130)	(19)	(76)
Total	(687)	(308)	(45)	(89)
		2040		
Vehicle	(1345)	(1485)	(121)	(24)
Vehicle Rebound	33	34	1	1
Power Plant	5	94	2	1
Upstream Gasoline	(654)	(233)	(35)	(136)
Total	(1960)	(1590)	(153)	(159)

In order to account for the contributions of the Advanced Clean Car Program separate from the contribution of the Planned Tier 4 program, we show the criteria pollutant emission impacts of a Colorado Advanced Clean Car Program without the benefits of California Tier 4 standards in Table 23.

Table 23: Criteria Emissions Impacts in Colorado Relative to Relaxed EPA Standards– Colorado Adopts CA GHG and ZEV Programs –No California Tier 4 Standards (U.S. tons per year)				
	VOC	NOx	PM2.5	Sox
		2030		
Vehicle	(162)	(160)	(18)	(14)
Vehicle Rebound	19	22	1	0
Power Plant	3	53	1	0
Upstream Gasoline	(447)	(130)	(19)	(76)
Total	(586)	(216)	(36)	(89)
		2040		
Vehicle	(632)	(729)	(65)	(24)
Vehicle Rebound	33	34	1	1
Power Plant	5	94	2	1
Upstream Gasoline	(654)	(233)	(35)	(136)
Total	(1247)	(834)	(97)	(159)

As mentioned above, these emission reductions of criteria pollutants are achieved with a net cost savings. Thus, the cost per ton of the emission reductions are negative.

Finally, while we made no attempt to quantify the potential impact, it is also likely that increased sales of electric vehicles would provide an additional criteria emissions benefit. This is because the primary source of criteria emissions from late-model gasoline vehicles is “excess” in-use deterioration, particularly from the relatively small number of gasoline vehicles that can have excessively high criteria emissions over time due to hardware failure or poor maintenance. Tailpipe emissions from electric vehicles are inherently zero, regardless of hardware failure or maintenance. So, to the degree that electric vehicles are displacing gasoline vehicles, there should be an additional criteria emissions benefit that is not quantified here.

Health impacts

Several EPA models exist which can be used to project changes in human health as a function of changes in emissions or ambient pollutant concentrations. The more extensive of these models is EPA’s BENMAP model. However, BENMAP requires projections of the changes in ambient pollutant levels in order to predict changes in human health. As conducting atmospheric dispersion modeling was beyond the scope of this study, we did not attempt to apply BENMAP here.

The other available model is EPA’s COBRA model. COBRA only requires changes in emissions by state or county in order to predict changes in human health. COBRA also has built in baseline emission inventories for 2017 and 2025. We used those for 2025 here, even though we input changes in emissions (in terms of tons per year, not percentages, which is another option in COBRA) for 2030 and 2040. Thus, we assumed that absolute changes in emissions in 2030 and 2040 will produce similar health impacts as the same emission reductions in 2025. This seems reasonable for a couple of reasons. First, the population exposed to the emissions will likely gradually increase, but this simply means that the estimates made here will be under-estimated to a small degree. Second, it either assumes that health effects are linear with emissions (and ambient pollutant levels) or that ambient pollutant levels in 2030 and 2040 will be near those of 2025.

The health impacts addressed by COBRA seem to be predominantly related to PM2.5 levels. Ambient PM2.5 levels are not expected to decrease dramatically between 2025 and 2040, based on existing emission controls. Thus, again, the estimates provided by COBRA using the 2025 baseline emission inventories should provide health effects which approximate those which would be produced using projected 2030 and 2040 emission inventories.

We input the changes in VOC, NOx, PM2.5 and SOx emissions shown in Tables 18-20 above to the COBRA model at a state level. The predicted changes in health effects in Colorado are shown in Table 24 below. COBRA output seems to indicate that health effects are primarily due to changes in estimated ambient PM2.5 levels, as opposed to ozone.

Table 24: Changes in Health Due to Changes in Emissions in Colorado from COBRA Using Base 2025 Emission Inventories

	Relaxation of the 2022-2025 EPA GHG Standards	Advanced Colorado Clean Car Program
Value of Health Benefits ($)	-3 to -7 million	6 to 13 million
Reduction in Mortality	-0.4 to -0.8	0.7 to 1.5
Value of Health Benefits ($)	-6 to -15 million	16 to 37 million
Reduction in Mortality	-0.7 to -1.6	1.8 to 4.1