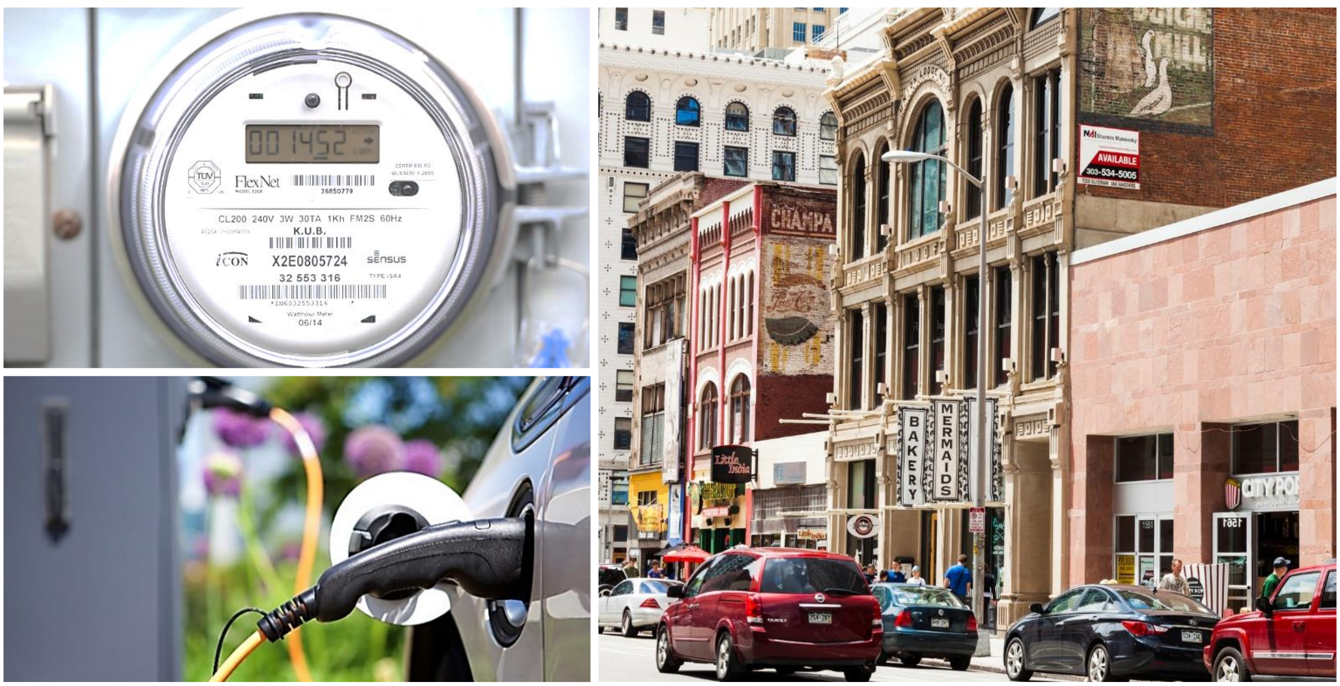
Electric Vehicle Cost-Benefit Analysis

Plug-in Electric Vehicle Cost-Benefit Analysis: Colorado



MJB & A

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Executive Summary

This study estimated the costs and benefits of increased penetration of plug-in electric vehicles (PEV) in the state of Colorado, for two different penetration levels between 2030 and 2050.[1] The "Moderate PEV" scenario is based upon near-term (2025) Zero Emission Vehicle goals adopted by states that together comprise about a third of the automotive market.[2] The "High PEV" scenario is based on the PEV penetration that would be required to achieve long-term goals for economy wide greenhouse gas (GHG) reduction of 80 percent from 2005 levels by 2050.

This study focused on passenger vehicles and trucks; there are opportunities from electrification of non-road equipment and heavy-duty trucks and buses, but evaluation of these applications was beyond the scope of this study.

The study estimated the benefits that would accrue to all electric utility customers in Colorado due to increased utility revenues from PEV charging. This revenue could be used to support operation and maintenance of the electrical grid, thus reducing the need for future electricity rate increases. These benefits were estimated for a baseline scenario in which Colorado drivers plug in and start to charge their vehicles as soon as they arrive at home or work.

The study also evaluated the additional benefits that could be achieved by providing Colorado drivers with price signals or incentives to delay the start of PEV charging until after the daily peak in electricity demand (off-peak charging). Increased peak hour load increases a utility's cost of providing electricity, and may result in the need to upgrade distribution infrastructure. As such, off-peak PEV charging can provide net benefits to all utility customers by shifting PEV charging to hours when the grid is underutilized and the cost of electricity is low.

See Figure 1 for a summary of how the projected utility net revenue from PEV charging might affect average residential electricity bills for all Colorado electric utility customers[3]. As shown in the figure, under the High PEV scenario the average Colorado household could realize nearly $80 in annual utility bill savings in 2050.

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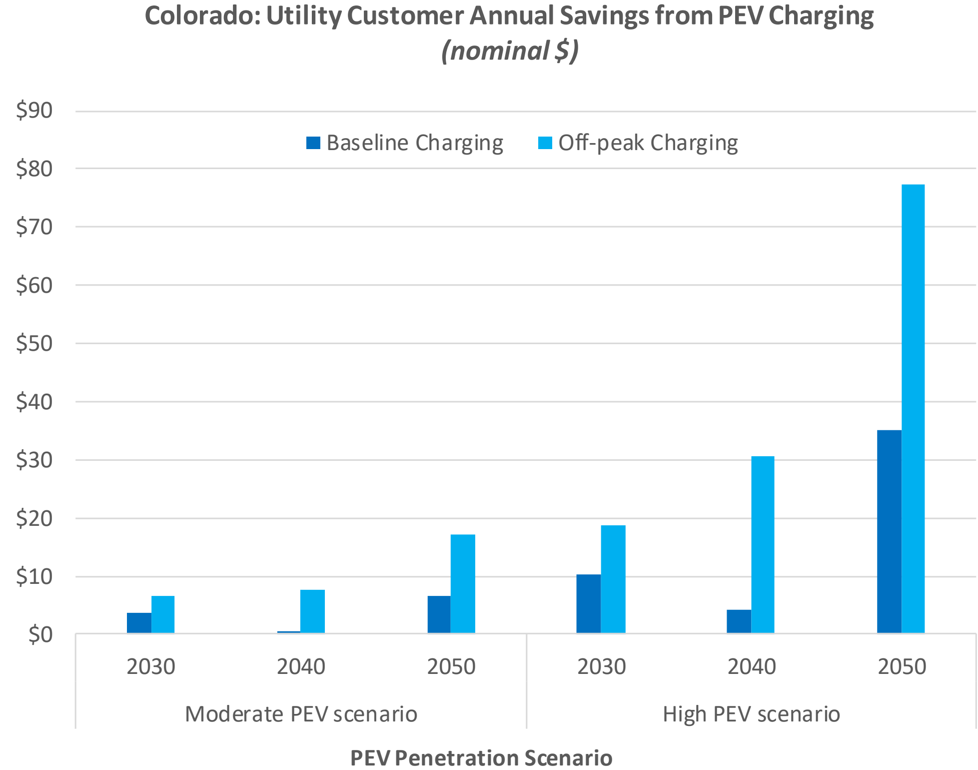
[1] PEVs include battery-electric vehicles (BEV) and plug-in hybrid vehicles (PHEV).

[2] In 2013, six Northeast/Mid-Atlantic states (MD, MA, NY, CT, RI, VT) and two Pacific coast states (CA, OR) joined in a Zero Emission Vehicle Memorandum of Understanding to enact policies that will ensure the deployment of 3.3 million ZEVs by 2025. Colorado is not a signatory of the MOU but has enacted policies found in the other states, such as vehicle purchase incentives, designed to accelerate EV sales.

[3] Based on 2015 average electricity use of 7,728 kWh per housing unit in Colorado.

Figure 1 Potential Effect of PEV Charging Net Revenue on Utility Customer Bills (nominal $)



In addition, the study estimated the annual financial benefits to Colorado drivers – from fuel and maintenance cost savings compared to owning gasoline vehicles, and societal benefits resulting from reduced GHG emissions.

As shown in Figure 2 (Moderate PEV scenario), if Colorado meets short term (2025) goals for PEV penetration, and the increase in percent PEV penetration then continues at the same annual rate in later years, the net present value of **cumulative net benefits from greater PEV use in Colorado will exceed $7.6 billion state-wide by 2050**.[4] Of these total net benefits:

- $300 million will accrue to electric utility customers in the form of reduced electric bills,
- $6.3 billion will accrue directly to Colorado drivers in the form of reduced annual vehicle operating costs, and
- $1.1 billion will accrue to society at large, as the value of reduced GHG emissions.

As shown in Figure 3 (High PEV scenario), if the state meets long-term goals to reduce light-duty fleet GHG emissions by 80 percent from 2005 levels by 2050, which requires even greater PEV penetration, the net present value of **cumulative net benefits from greater PEV use in Colorado could exceed $43 billion state-wide by 2050**. Of these total net benefits:

- $4.1 billion will accrue to electric utility customers in the form of reduced electric bills
- $29.1 billion will accrue directly to Colorado drivers in the form of reduced annual vehicle operating costs, and
- $9.7 billion will accrue to society at large, as the value of reduced GHG emissions.

[4] Using a 3% discount rate

Figure 2 *NPV Cumulative Societal Net Benefits from CO PEVs – Moderate PEV scenario*

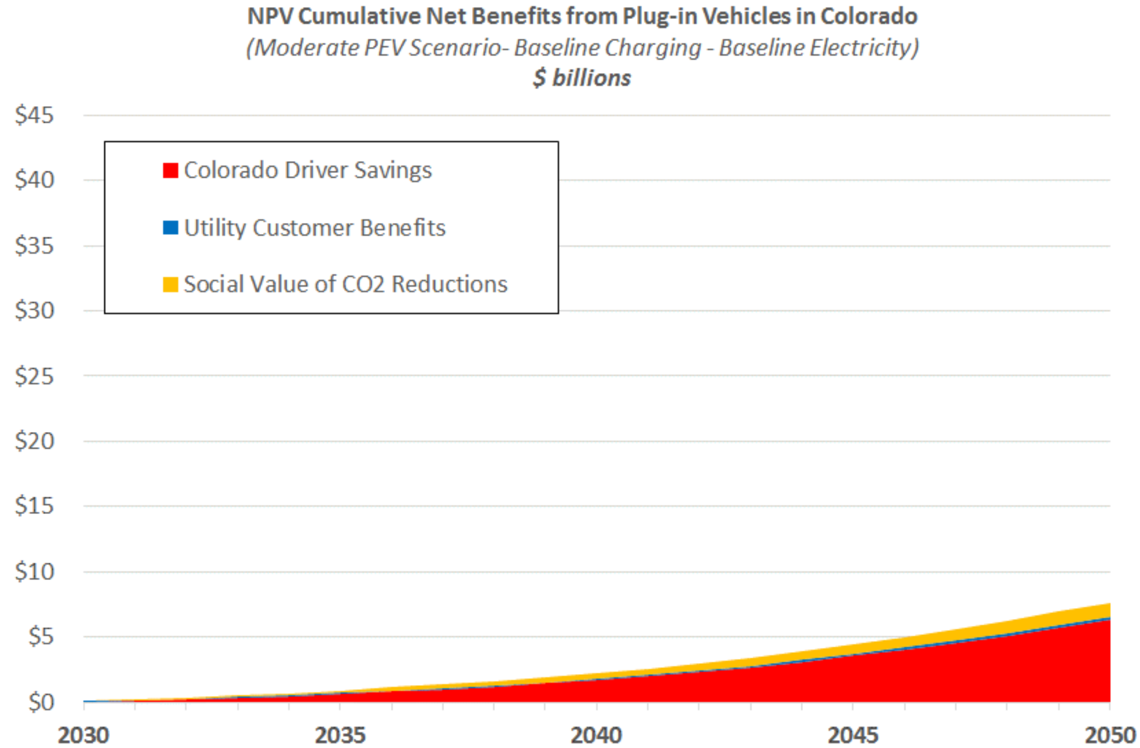
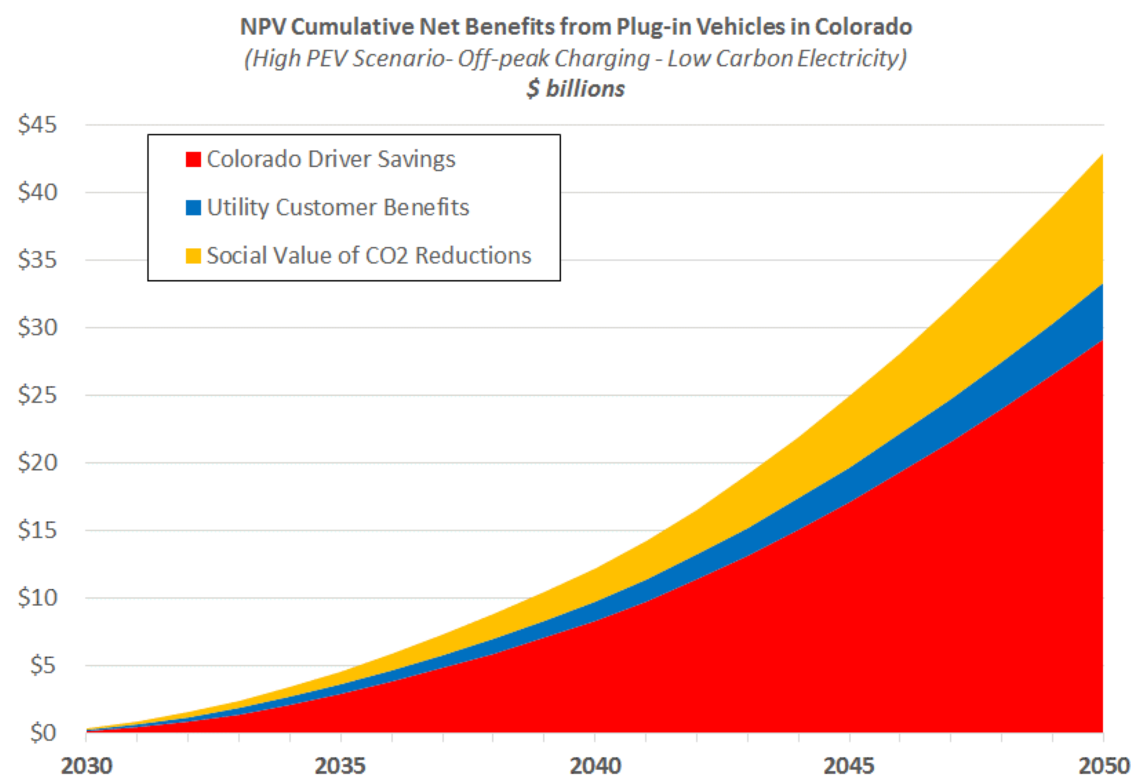


Figure 3 *NPV Cumulative Societal Net Benefits from CO PEVs – High PEV scenario*



Background - Colorado

In November 2007, Governor Bill Ritter Jr. issued Colorado's first Climate Action Plan which set out a plan to protect the state against climate impacts, including goals to reduce GHG emissions. In response to this Climate Action Plan, on April 22, 2008, Governor Ritter issued Executive Order D-004-08, "Reducing Greenhouse Gas Emissions in Colorado" which established goals to reduce GHG emissions 20 percent below 2005 levels by 2020 and 80 percent by 2050.[1] However, in 2010, Governor John Hickenlooper repealed this Executive Order and replaced the 2007 Climate Action Plan with broad climate and transportation policy actions but no measurable or defined emission reduction goals for the state.[2] In light of a lack of statewide climate goals, some cities in Colorado have developed their own climate strategies and set GHG emission reduction goals. For example, Boulder, Denver and Fort Collins have adopted goals to reduce GHG emissions 80 percent below 2005 levels by 2050.[3]

The strategy and policy recommendations provided in the 2015 Climate Action Plan for reducing emissions from Colorado's transportation sector include promotion of alternative fuel vehicle technologies and programs, improving public education and awareness of transportation climate impacts, and providing guidance to state and local planners on how to incorporate smart growth strategy into transportation system design.[4] The state has recently taken action to advance access to charging infrastructure for electric vehicles. On December 19, 2016, Governor Hickenlooper, along with the Governors of Utah and Nevada, announced a joint agreement to develop an electric vehicle charging network along highway corridors in the three states that will span an estimated 2,000 miles.[5] Colorado offers residents one of the most generous rebates for the purchase of alternative fueled vehicles; in May 2016, Governor Hickenlooper signed into law HB 1332 which eliminates previous tax credit requirements for the buyer to calculate the value of the credit they should receive, and instead offers residents a fixed tax credit of $5,000 for the purchase of an electric vehicle, and $2,500 for the lease of an electric vehicle.[6]

As of January 2016 there were about 7,600 PEVs (including battery-electric and plug-in hybrid vehicles) registered in Colorado and they comprised about 0.16 percent of the 4.8 million cars and light trucks registered in the State. In 2014 and 2015, sales of new PEVs in the state were less than one half of one percent of new vehicle sales. [7]

Study Methodology

This section briefly describes the methodology used for this study. For more information on how this study was conducted, including a complete discussion of the assumptions used and their sources, see the report: *Mid-Atlantic and Northeast Plug-in Electric Vehicle Cost-Benefit Analysis, Methodology & Assumptions* (October 2016). This report can be found at:

http://mjbradley.com/sites/default/files/NE_PEV_CB_Analysis_Methodology.pdf

This study evaluated the costs and benefits of two different levels of PEV penetration in Colorado between 2030 and 2050. These PEV penetration scenarios bracket short and long-term policy goals for ZEV adoption and GHG reduction which have been adopted by other states, and localities[5].

Moderate PEV Scenario: Penetration of PEVs equivalent to Colorado's participation in a program similar to the *8-state ZEV Memorandum of Understanding*. Compliance with this scenario would require approximately 6 percent of in-use light duty vehicles in Colorado to be ZEV by 2025. Assuming that the increase in percent

[5] The states of CA, CT, FL, MA, MD, ME, MN, NH, NJ, NY, OR, RI, and VT have all set economy-wide goals of 75-80 percent GHG reduction by 2050. The starting point for the target 2050 GHG reduction percentage varies by state, from 1990 to 2006. The District of Columbia has also adopted a goal to reduce GHG emissions by 80 percent from 2006 levels by 2050.

PEV penetration then continues at the same annual rate in later years, PEV penetration is assumed to be 8.9 percent in 2030, 14.7 percent in 2040, and 20.6 percent in 2050.[6]

High PEV Scenario: The level of PEV penetration required to reduce total light-duty GHG emissions in Colorado in 2050 by 80 percent from 2005 levels with 80 percent carbon free electricity. This will require PEV penetration of 26 percent in 2030, 60 percent in 2040 and 98 percent in 2050.

Both of these scenarios are compared to a baseline scenario with very little PEV penetration, and continued use of gasoline vehicles. The baseline scenario is based on future annual vehicle miles traveled (VMT) and fleet characteristics (e.g., cars versus light trucks) as projected by the Colorado Department of Transportation.

Based on assumed future PEV characteristics and usage, the analysis projects annual electricity use for PEV charging at each level of penetration, as well as the average load from PEV charging by time of day. The analysis then projects the total revenue that Colorado' electric distribution utilities would realize from sale of this electricity, their costs of providing the electricity to their customers, and the potential net revenue (revenue in excess of costs) that could be used to support maintenance of the distribution system.

The costs of serving PEV load include the cost of electricity generation, the cost of transmission, incremental peak generation capacity costs for the additional peak load resulting from PEV charging, and annual infrastructure upgrade costs for increasing the capacity of the secondary distribution system to handle the additional load.

For each PEV penetration scenario this analysis calculates utility revenue, costs, and net revenue for two different PEV charging scenarios: 1) a baseline scenario in which all PEVs are plugged in and start to charge as soon as they arrive at home each day, and 2) an off-peak charging scenario in which a significant portion of PEVs that arrive home between noon and 11 PM each day delay the start of charging until after midnight.

Real world experience from the EV Project demonstrates that, without a "nudge", drivers will generally plug in and start charging immediately upon arriving home after work (scenario 1), exacerbating system-wide evening peak demand.[7] However, if given a "nudge" - in the form of a properly designed and marketed financial incentive - many Colorado drivers will choose to delay the start of charging until off-peak times, thus reducing the effect of PEV charging on evening peak electricity demand (scenario 2). [8]

For each PEV penetration scenario, this analysis also calculates the total incremental annual cost of purchase and operation for all PEVs in the state, compared to "baseline" purchase and operation of gasoline cars and light trucks. For both PEVs and baseline vehicles annual costs include the amortized cost of purchasing the vehicle, annual costs for gasoline and electricity, and annual maintenance costs. For PEVs it also includes the amortized annual cost of the necessary home charger. This analysis is used to estimate average annual financial benefits to Colorado drivers.

Finally, for each PEV penetration scenario this analysis calculates annual greenhouse gas (GHG) emissions from electricity generation for PEV charging, and compares that to baseline emissions from operation of gasoline vehicles. For the baseline and PEV penetration scenarios GHG emissions are expressed as carbon dioxide equivalent emissions (CO_2-e) in metric tons (MT). GHG emissions from gasoline vehicles include direct tailpipe emissions as well as "upstream" emissions from production and transport of gasoline.

For each PEV penetration scenario GHG emissions from PEV charging are calculated based on a baseline electricity scenario and a "low carbon electricity" scenario. The baseline scenario is consistent with the latest EIA

[6] While the 8-state MOU counts fuel cell vehicles and PEVs as zero emission vehicles, this scenario assumes that all ZEVs will be PEV.

[7] The EV Project is a public/private partnership partially funded by the Department of Energy which has collected and analyzed operating and charging data from more than 8,300 enrolled plug-in electric vehicles and approximately 12,000 public and residential charging stations over a two year period.

projections for future average grid emissions in Colorado. The low carbon electricity scenario is based on Colorado reducing average GHG emissions from the electric grid to 80 percent below 2005 levels by 2050.

Net annual GHG reductions from the use of PEVs are calculated as baseline GHG emissions (emitted by gasoline vehicles) minus GHG emissions from each PEV penetration scenario. The monetary "social value" of these GHG reductions from PEV use are calculated using the Social Cost of Carbon ($/MT), as calculated by the U.S. government's Interagency Working Group on Social Cost of Greenhouse Gases.

Study Results

This section summarizes the results of this study, including the projected number of PEVs; electricity use and load from PEV charging; projected GHG reductions compared to continued use of gasoline vehicles; benefits to utility customers from increased electricity sales; and projected financial benefits to Colorado drivers compared to owning gasoline vehicles.

All costs and financial benefits are presented as net present value (NPV), using a 3 percent discount rate.

Plug-in Vehicles, Electricity Use, and Charging Load

Vehicles and Miles Traveled

The projected number of PEVs and conventional gasoline vehicles in the Colorado light duty fleet[8] under each PEV penetration scenario is shown in Figure 4, and the projected annual miles driven by these vehicles is shown in Figure 5.

There are currently 1.834 million cars and 2.938 million light trucks registered in Colorado, and these vehicles travel 50.6 billion miles per year. Both the number of vehicles and total annual vehicle miles are projected to increase by 65 percent through 2050, to 7.882 million light duty vehicles traveling 83.5 billion miles annually.

In order to meet the Moderate PEV scenario, the number of PEVs registered in Colorado would need to increase from approximately 7,600 today to 349,000 by 2025. Assuming the same annual increase in percent PEV penetration in later years, there would be 544,000 PEVs in the state in 2030, 1.02 million in 2040, and 1.6 million in 2050 (Moderate PEV penetration scenario).

In order to put the state on a path to achieve an 80 percent reduction in light-duty GHG emissions from 2005 levels by 2050 (High PEV scenario) there would need to be approximately 1.6 million PEVs in Colorado by 2030, rising to 4.2 million in 2040, and 7.8 million in 2050.

[8] This analysis only includes cars and light trucks. It does not include medium- or heavy-duty trucks and buses.

Figure 4 Projected Colorado Light Duty Fleet

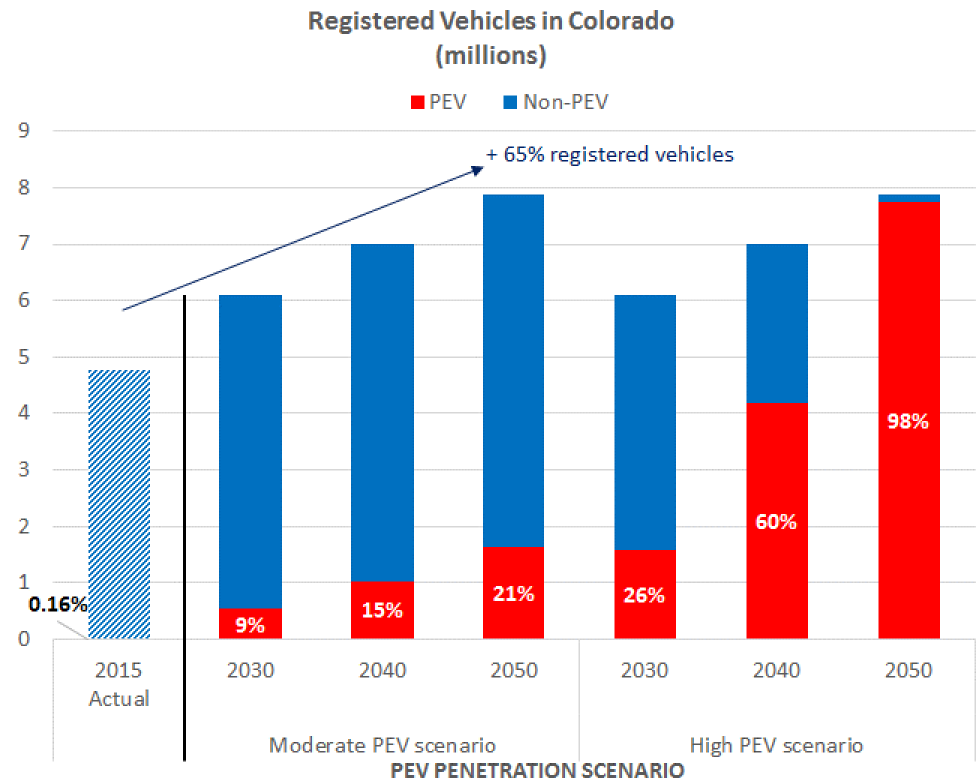
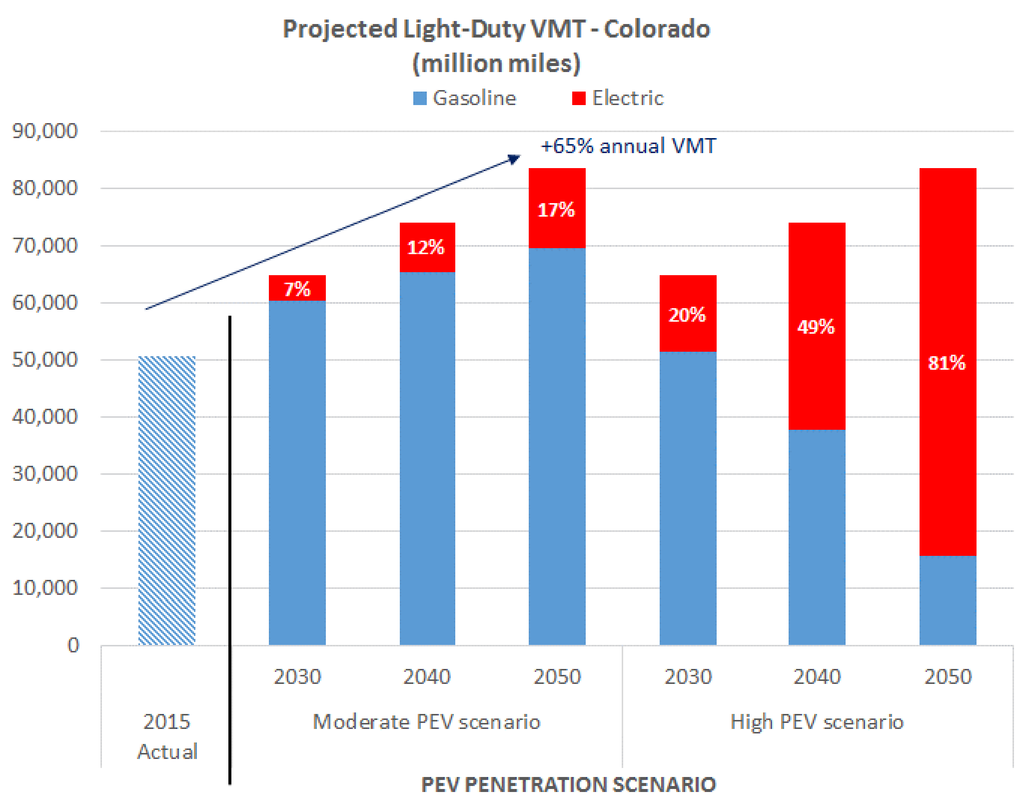


Figure 5 Projected Colorado Light Duty Fleet Vehicle Miles Traveled

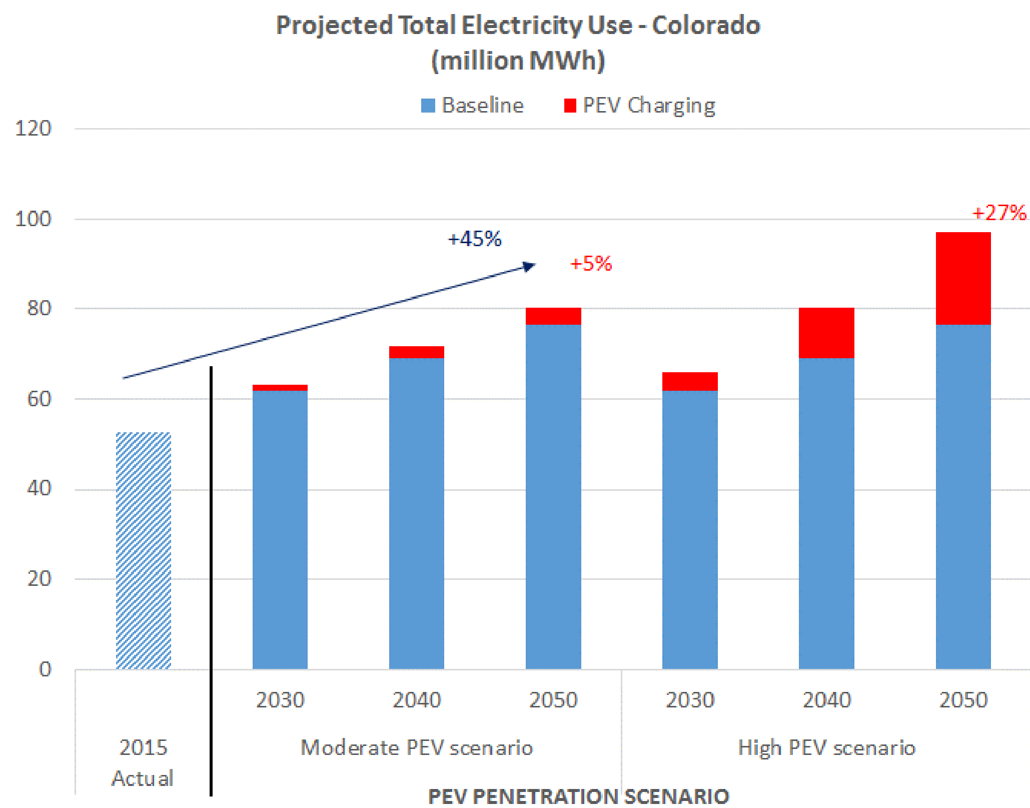


Note that under both PEV penetration scenarios the percentage of total VMT driven by PEVs each year is lower than the percentage of plug-in vehicles in the fleet. This is because PEVs are assumed to have a "utility factor" less than one – i.e., due to range restrictions neither a battery-electric nor a plug-in hybrid vehicle can convert 100 percent of the miles driven annually by a baseline gasoline vehicle into miles powered by grid electricity. In this analysis BEVs with 200 mile range per charge are conservatively assumed to have a utility factor of 87 percent, while PHEVs are assumed to have an average utility factor of 72 percent in 2030, rising to 79 percent in 2050. This analysis estimates that Colorado could reduce light-duty fleet GHG in 2050 by 80 percent from 2005 levels if 81 percent of miles were driven by PEVs on electricity (Figure 5). However, in order to achieve this level of electric miles 98 percent of light-duty vehicles would need to be PEVs (Figure 4).

PEV charging Electricity Use

The estimated total PEV charging electricity used in Colorado each year under the PEV penetration scenarios is shown in Figure 6.

Figure 6 Estimated Total Electricity Use in Colorado



In Figure 6, projected baseline electricity use without PEVs is shown in blue and the estimated incremental electricity use for PEV charging is shown in red. State-wide electricity use in Colorado is currently 52.7 million MWh per year. Annual electricity use is projected to increase to 61.7 million MWh in 2030 and continue to grow after that, reaching 76.5 million MWh in 2050 (45 percent greater than 2015 level).

Under the Moderate PEV penetration scenario, electricity used for PEV charging is projected to be 1.4 million MWh in 2030 – an increase of 2.3 percent over baseline electricity use. By 2050, electricity for PEV charging is projected to grow to 3.9 million MWh – an increase of 5 percent over baseline electricity use. Under the High PEV scenario electricity used for PEV charging is projected to be 4.3 million MWh in 2030, growing to 20.5 million MWh and adding 27 percent to baseline electricity use in 2050.

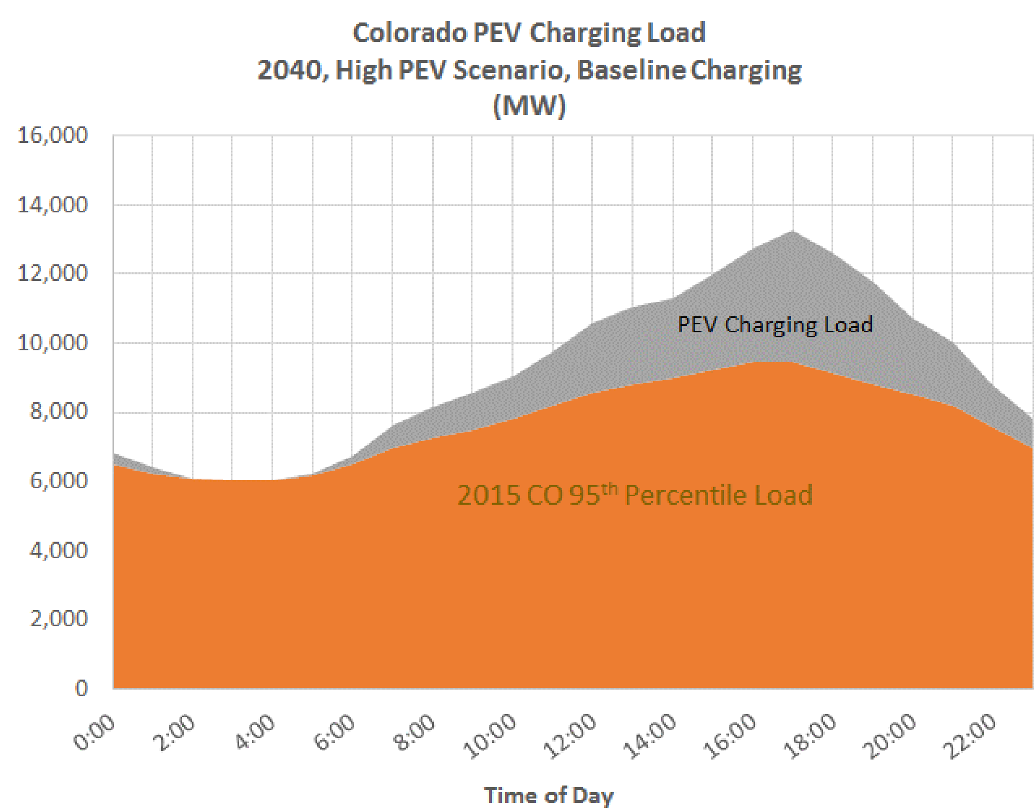
PEV Charging Load

This analysis evaluated the effect of PEV charging on the Colorado electric grid under two different charging scenarios. Under both scenarios 80 percent of all PEVs are assumed to charge exclusively at home and 20 percent are assumed to charge both at home and at work. Under the baseline charging scenario all Colorado drivers are assumed to plug-in their vehicles and start charging as soon as they arrive at home or at work (if applicable) each day. Under the off-peak charging scenario 65 percent of Colorado drivers who arrive at home in the afternoon and early evening are assumed to delay the start of home charging until after midnight – in response to a price signal or incentive provided by their utility[9].

See Figure 7 (baseline) and Figure 8 (off-peak) for a comparison of PEV charging load under the baseline and off-peak charging scenarios, using the 2040 High PEV penetration scenario as an example. In each of these figures the 2015 Colorado 95th percentile load (MW)[10] by time of day is plotted in orange, and the projected incremental load due to PEV charging is plotted in grey.

In 2015 daily electric load in Colorado was generally in the range of 6,000 – 6,500 MW from midnight to 5 AM, ramping up through the morning and early afternoon to peak at approximately 9,400 MW between 3 PM and 5 PM, and then falling off through the late afternoon and evening hours.

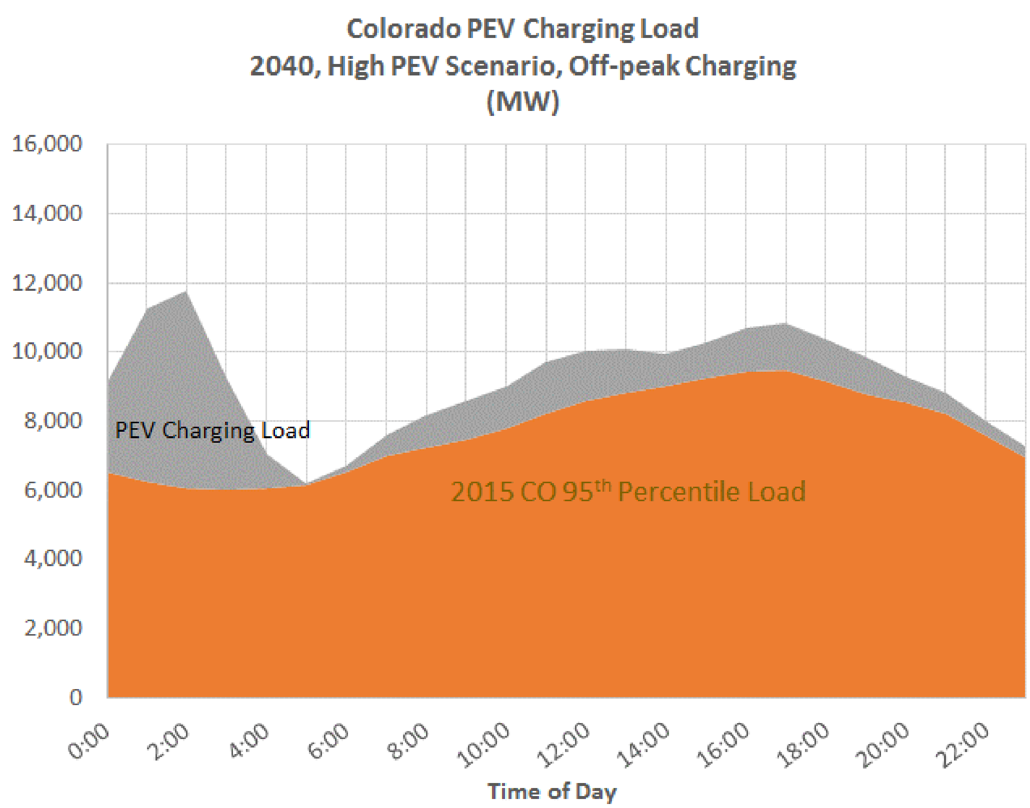
Figure 7 2040 Projected Colorado PEV Charging Load, Baseline Charging (High PEV scenario)



[9] Utilities have many policy options to incentivize off-peak PEV charging. This analysis does not compare the efficacy of different options.
[10] For each hour of the day actual load in 2015 was higher than the value shown on only 5 percent of days (18 days).

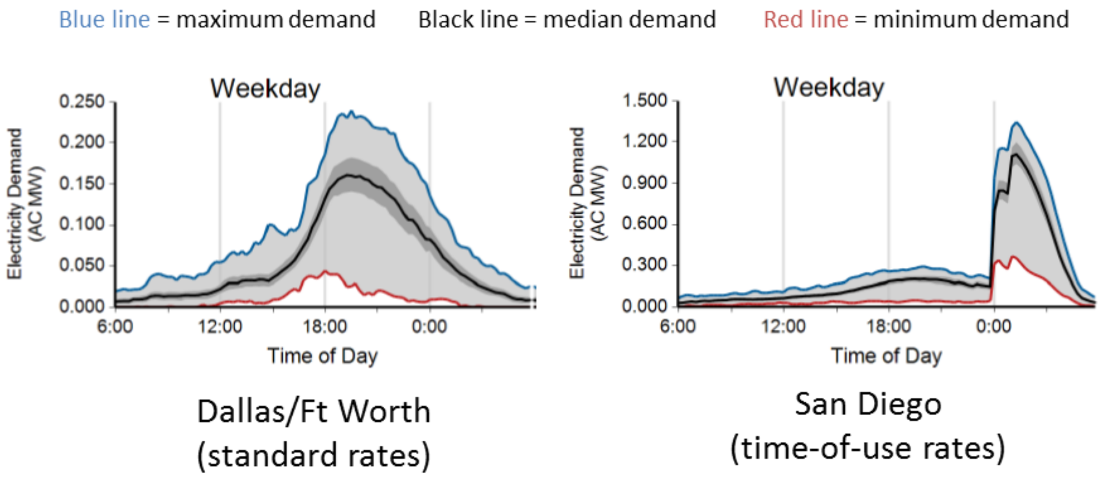
As shown in Figure 7, baseline PEV charging is projected to add load primarily between 8 AM and 11 PM, as people charge at work early in the day and then at home later in the day. The PEV charging peak coincides with the existing afternoon peak load period between 3 PM and 5 PM. As shown in Figure 8, off-peak charging significantly reduces the incremental PEV charging load during the afternoon peak load period, but creates a secondary peak in the early morning hours, between midnight and 3 AM. The shape of this early morning peak can potentially be controlled based on the design of off-peak charging incentives. It should also be noted that those early morning hours are often the hours of the day when wind generation peaks.

Figure 8 2040 Projected Colorado PEV Charging Load, Off-peak Charging (High PEV scenario)



These baseline and off-peak load shapes are consistent with real world PEV charging data collected by the EV Project, as shown in Figure 9. In Figure 9 the graph on the left shows PEV charging load in the Dallas/Ft Worth area where no off-peak charging incentive was offered to Colorado drivers. The graph on the right shows PEV charging load in the San Diego region, where the local utility offered Colorado drivers a time-of-use rate with significantly lower costs ($/kWh) for charging during the "super off-peak" period between midnight and 5 a.m. [9]

Figure 9 PEV Charging Load in Dallas/Ft Worth and San Diego areas, EV Project



See Table 1 for a summary of the projected incremental afternoon peak hour load (MW) in Colorado, from PEV charging under each penetration and charging scenario. This table also includes a calculation of how much this incremental PEV charging load would add to the 2015 95th percentile peak hour load. Under the Moderate PEV penetration scenario, PEV charging would add 491 MW load during the afternoon peak load period on a typical weekday in 2030, which would increase the 2015 baseline peak load by about 5 percent. By 2050, the afternoon incremental PEV charging load would increase to 1,465 MW, adding almost 16 percent to the 2015 baseline afternoon peak. By comparison the afternoon peak hour PEV charging load in 2030 would be only 181 MW for the off-peak charging scenario, increasing to 541 MW in 2050.

Under the High PEV penetration scenario, baseline PEV charging would increase the total 2015 afternoon peak electric load by about 74 percent in 2050, while off-peak charging would only increase it by about 27 percent[11].

Table 1 Projected Incremental Afternoon Peak Hour PEV Charging Load (MW)

		Moderate PEV			**High PEV**		
		2030	**2040**	**2050**	**2030**	**2040**	**2050**
Baseline Charging	PEV Charging (MW)	490.6	927.9	1,465.1	1,433.2	3,787.3	6,984.1
	Increase relative to 2015 Peak	*5.2%*	*9.8%*	*15.5%*	*15.2%*	*40.0%*	*73.8%*
Off-Peak Charging	PEV Charging (MW)	181.2	342.8	541.2	529.4	1,399.0	2,579.9
	Increase relative to 2015 Peak	*1.9%*	*3.6%*	*5.7%*	*5.6%*	*14.8%*	*27.3%*

[11] Given projected significant increases in total state-wide electricity use through 2050, baseline peak load (without PEVs) is also likely to be higher in 2050 than 2015 peak load; as such the percentage increase in baseline peak load due to high levels of PEV penetration is likely to be lower than that shown in Table 1.

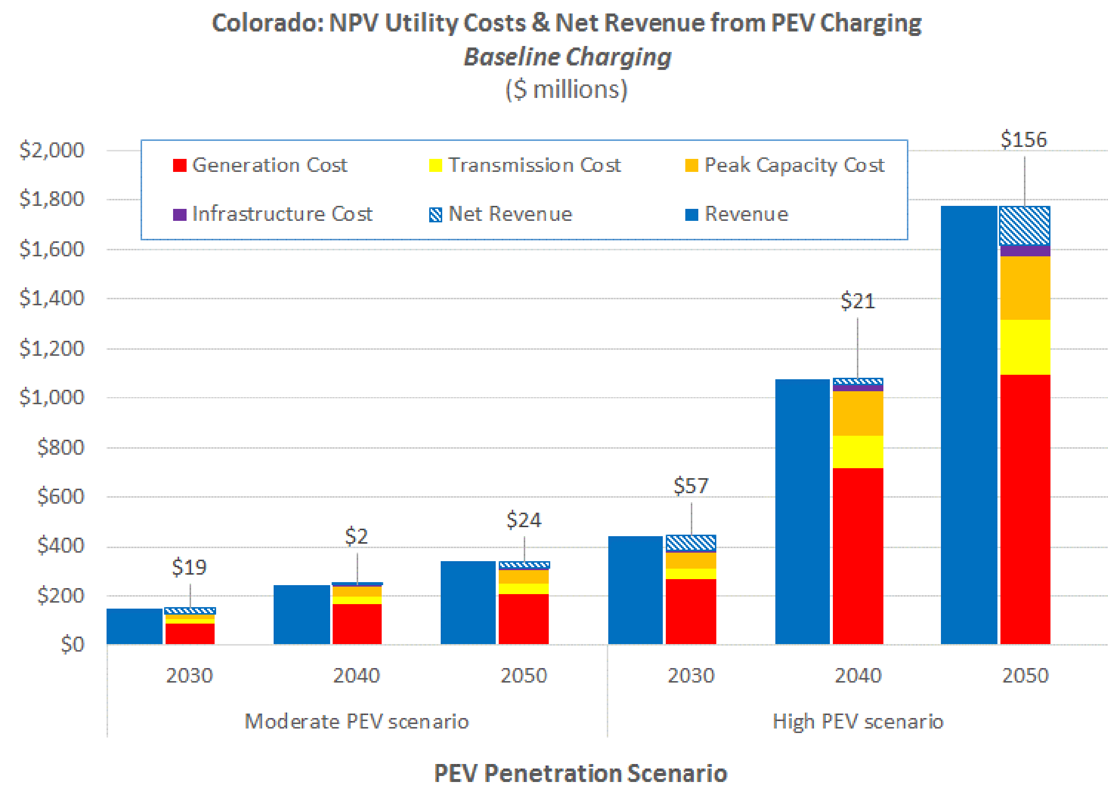
As discussed below, increased peak hour load increases a utility's cost of providing electricity, and may result in the need to upgrade distribution infrastructure. As such, off-peak PEV charging can provide net benefits to all utility customers by bringing in significant new revenue in excess of associated costs.

Utility Customer Benefits

The estimated NPV of revenues and costs for Colorado' electric utilities to supply electricity to charge PEVs under each penetration scenario are shown in Figure 10, assuming the baseline PEV charging scenario.

In Figure 10, projected utility revenue is shown in dark blue. Under the Moderate PEV penetration scenario, the NPV of revenue from electricity sold for PEV charging in Colorado is projected to total $149 million in 2030, rising to $338 million in 2050. Under the High PEV scenario, the NPV of utility revenue from PEV charging is projected to total $443 million in 2030, rising to $1.8 billion in 2050.

Figure 10 NPV of Projected Utility Revenue and Costs from Baseline PEV Charging



The different elements of incremental cost that utilities would incur to purchase and deliver additional electricity to support PEV charging are shown in red (generation), yellow (transmission), orange (peak capacity), and purple (infrastructure upgrade cost). Generation and transmission costs are proportional to the total power (MWh) used for PEV charging, while peak capacity costs are proportional to the incremental peak load (MW) imposed by PEV charging. Infrastructure upgrade costs are costs incurred by the utility to upgrade their own distribution infrastructure to handle the increased peak load imposed by PEV charging.

The striped light blue bars in Figure 10 represent the NPV of projected "net revenue" (revenue minus costs) that utilities would realize from selling additional electricity for PEV charging under each PEV penetration scenario. Under the Moderate PEV penetration scenario, the NPV of net revenue in Colorado is projected to total $19 million in 2030, rising to $24 million in 2050. Under the High PEV scenario, the NPV of utility net revenue from PEV charging is projected to total $57 million in 2030, rising to $156 million in 2050. The NPV of projected annual utility net revenue averages $34 per PEV in 2030, and $15 - $20 per PEV in 2050.

Figure 11 NPV of Projected Utility Revenue and Costs from Off-peak PEV Charging

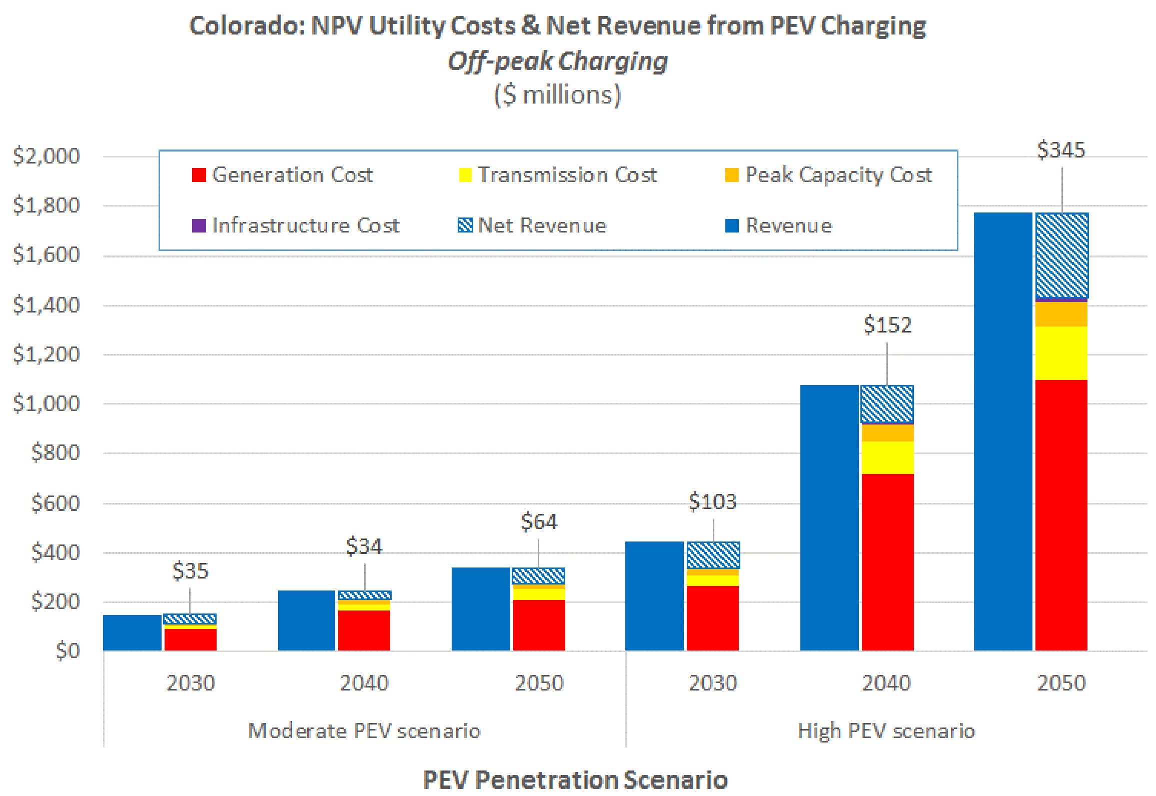
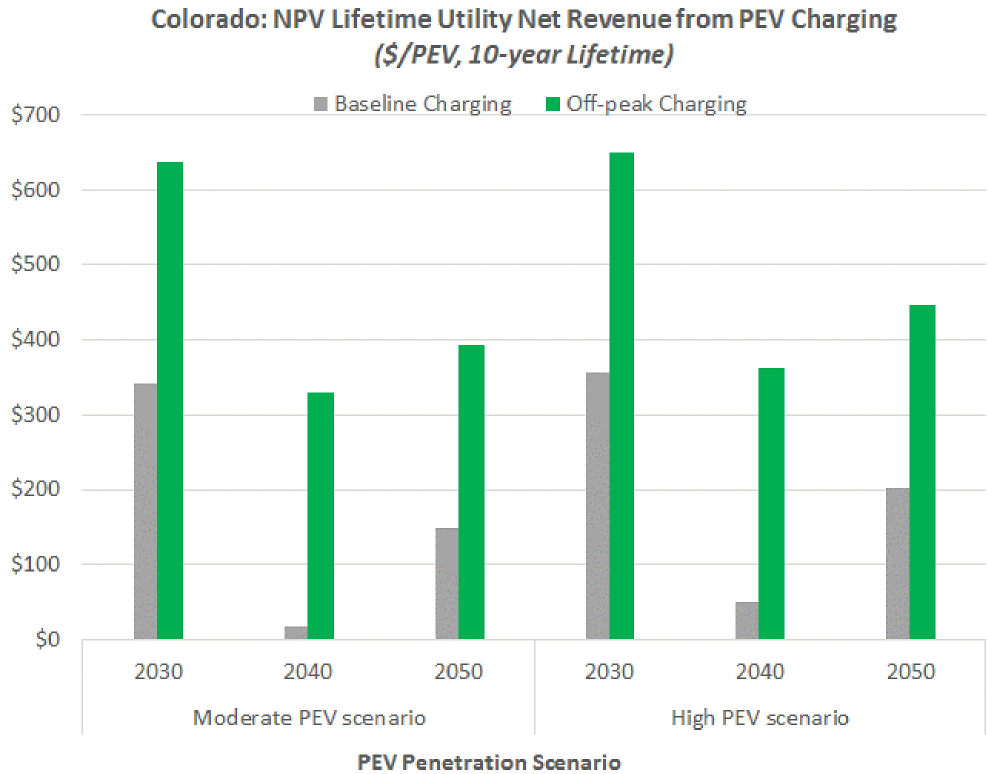


Figure 11 summarizes the NPV of projected utility revenue, costs, and net revenue for off-peak charging under each PEV penetration scenario. Compared to baseline charging (Figure 10) projected revenue, and projected generation and transmission costs are the same, but projected peak capacity and infrastructure costs are lower due to a smaller incremental peak load (see Table 1). Compared to baseline charging, off-peak charging will increase the NPV of annual utility net revenue by $16 million in 2030 and $40 million in 2050 under the Moderate PEV penetration scenario, due to lower costs. Under the High PEV scenario, off-peak charging will increase the NPV of annual utility net revenue by $47 million in 2030 and $189 million in 2050. This analysis estimates that compared to baseline charging, off-peak charging will increase the NPV of annual utility net revenue by $29 per PEV in 2030 and $24 per PEV in 2050.

The NPV of projected life-time utility net revenue per PEV is shown in Figure 12. Assuming a ten-year life, the average PEV in Colorado in 2030 is projected to increase utility net revenue by over $600 over its life-time, if charged off-peak. PEVs in service in 2050 are projected to increase utility net revenue by almost $400 over their life time (NPV) if charged off-peak.

Figure 12 NPV of Projected Life-time Utility Net Revenue per PEV

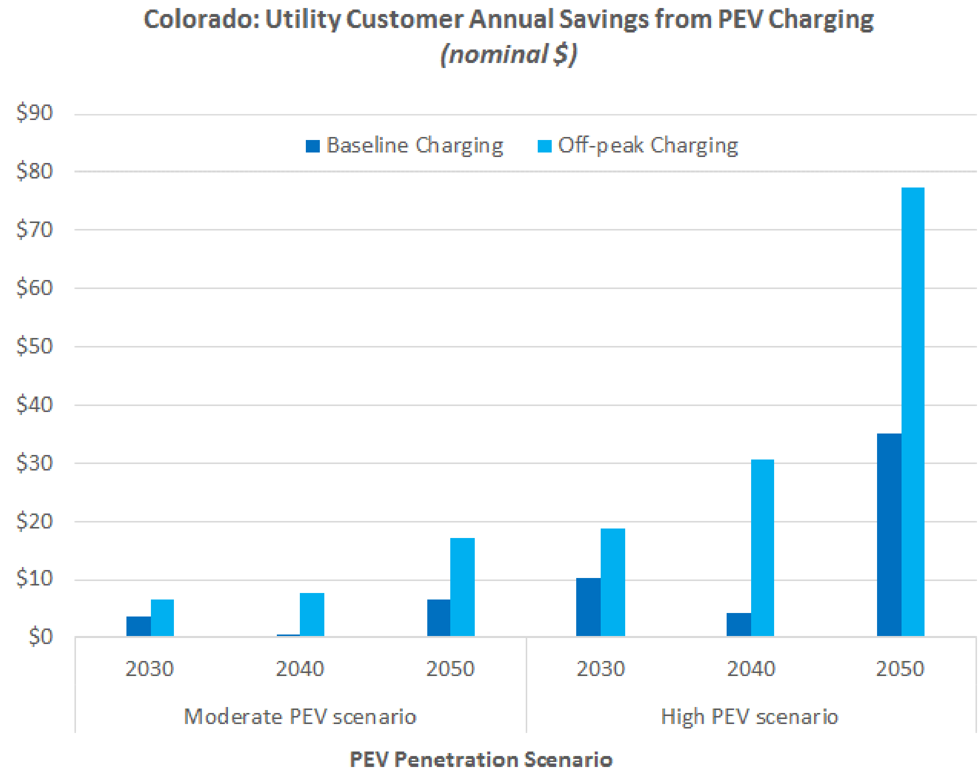


In general, a utility's costs to maintain their distribution infrastructure increase each year with inflation, and these costs are passed on to utility customers in accordance with rules established by the state's Public Utilities Commission (PUC), via periodic increases in residential and commercial electric rates. However, under PUC rules net revenue from additional electricity sales generally offsets the allowable costs that can be passed on via higher rates. As such, the majority of projected utility net revenue from increased electricity sales for PEV charging would in fact be passed on to utility customers in Colorado, not retained by the utility companies. In effect this net revenue would put downward pressure or future rates, delaying or reducing future rate increases, thereby reducing customer bills.

See Figure 13 for a summary of how the projected utility net revenue from PEV charging might affect average residential electricity bills for all Colorado electric utility customers[12]. As shown in the figure, under the High PEV scenario projected average electric rates in Colorado could be reduced up to 4 percent by 2050, resulting in an annual savings of approximately $77 (nominal dollars) per household in Colorado in 2050.

[12] Based on 2015 average electricity use of 7,728 kWh per housing unit in Colorado.

Figure 13 Potential Effect of PEV Charging Net Revenue on Utility Customer Bills (nominal $)



Colorado Driver Benefits

Current PEVs are more expensive to purchase than similar sized gasoline vehicles, but they are eligible for various government purchase incentives, including up to a $7,500 federal tax credit, and a $5,000 state rebate in Colorado. These incentives are important to spur an early market, but PEVs are projected to provide a total lower cost of ownership than conventional vehicles in Colorado on an unsubsidized basis by 2030, as described below.

The largest contributor to incremental purchase costs for PEVs compared to gasoline vehicles is the cost of batteries. Battery costs for light-duty plug-in vehicles have fallen from over $1,000/kWh to less than $400/kWh in the last 5 years; many analysts and auto companies project that battery prices will continue to fall – to below $125/kWh by 2025. [10]

Based on these battery cost projections, this analysis projects that the average annual cost of owning a PEV in Colorado will fall below the average cost of owning a gasoline vehicle by 2030, even without government purchase subsidies.[13] See Table 2 which summarizes the average projected annual cost of Colorado PEVs and gasoline vehicles under each penetration scenario. All costs in Table 2 are in nominal dollars, which is the primary reason why costs for both gasoline vehicles and PEVs are higher in 2040 and 2050 than in 2030 (due to inflation). In addition, the penetration scenarios assume that the relative number of PEV cars and higher cost PEV light trucks will change over time; in particular the High PEV scenario assumes that there will be a

[13] The analysis assumes that all battery electric vehicles in-use after 2030 will have 200-mile range per charge and that all plug-in hybrid vehicles will have 50 mile all-electric range.

significantly higher percentage of PEV light trucks in the fleet in 2050 than in 2030, which further increases the average PEV purchase cost in 2050 compared to 2030.

Table 2 Projected Fleet Average Vehicle Costs to Vehicle Owners (nominal $)

GASOLINE VEHICLE		Moderate PEV scenario			High PEV scenario		
		2030	2040	2050	2030	2040	2050
Vehicle Purchase	$/yr	$4,339	$5,545	$6,969	$4,457	$6,282	$8,025
Gasoline	$/yr	$1,138	$1,477	$1,901	$1,158	$1,620	$2,136
Maintenance	$/yr	$235	$294	$356	$237	$303	$369
TOTAL ANNUAL COST	**$/yr**	**$5,712**	**$7,316**	**$9,226**	**$5,851**	**$8,206**	**$10,529**
PEV		**Moderate PEV scenario**			**High PEV scenario**		
		2030	**2040**	**2050**	**2030**	**2040**	**2050**
Vehicle Purchase	$/yr	$4,772	$5,848	$7,010	$4,887	$6,540	$8,320
Electricity	$/yr	$428	$504	$586	$435	$537	$645
Gasoline	$/yr	$185	$218	$271	$188	$238	$301
Personal Charger	$/yr	$81	$101	$121	$81	$101	$121
Maintenance	$/yr	$121	$156	$190	$122	$159	$194
TOTAL ANNUAL COST	**$/yr**	**$5,587**	**$6,828**	**$8,177**	**$5,713**	**$7,576**	**$9,581**
Savings per PEV	$/yr	**$125**	**$488**	**$1,048**	**$139**	**$630**	**$948**

As shown in Table 2, even in 2050 average PEV purchase costs are projected to be higher than average purchase costs for gasoline vehicles (with no government subsidies), but the annualized effect of this incremental purchase cost is outweighed by significant fuel cost savings, as well as savings in scheduled maintenance costs. In 2030, the average Colorado driver is projected to save $125 – $139 per year compared to the average gasoline vehicle owner, without government subsidies. These annual PEV savings are projected to increase to an average of $488 - $630 per PEV in 2040, and $948 - $1,048 per PEV in 2050, as relative PEV purchase costs continue to fall, and the projected price of gasoline continues to increase faster than projected electricity prices. The NPV of annual savings for the average PEV owner in Colorado is projected to be $89 in 2030, rising to $373 in 2050.

The NPV of total annual cost savings to Colorado drivers from greater PEV ownership are projected to be $44 million in 2030 under the Moderate PEV penetration scenario, rising to $240 million in 2040 and $605 million in 2050. Under the High PEV scenario, the NPV of total annual cost savings to Colorado drivers from greater PEV ownership are projected to be $142 million in 2030, rising to $1.3 billion in 2040 and $2.6 billion in 2050.

GHG Reductions & Societal Benefits

The projected annual greenhouse gas (GHG) emissions (million metric tons carbon-dioxide equivalent, CO_2-e million tons) from the Colorado light duty fleet under each PEV penetration scenario are shown in Figure 14. In this figure, projected baseline emissions from a gasoline fleet with few PEVs are shown in red for each year; the values shown represent "wells-to-wheels" emissions, including direct tailpipe emissions and "upstream" emissions from production and transport of gasoline. Projected total fleet emissions for each PEV penetration scenario are shown in blue; this includes GHG emissions from generating electricity to charge PEVs, as well as GHG emissions from gasoline vehicles in the fleet.

Figure 14 Projected GHG Emissions from the Light Duty Fleet in Colorado

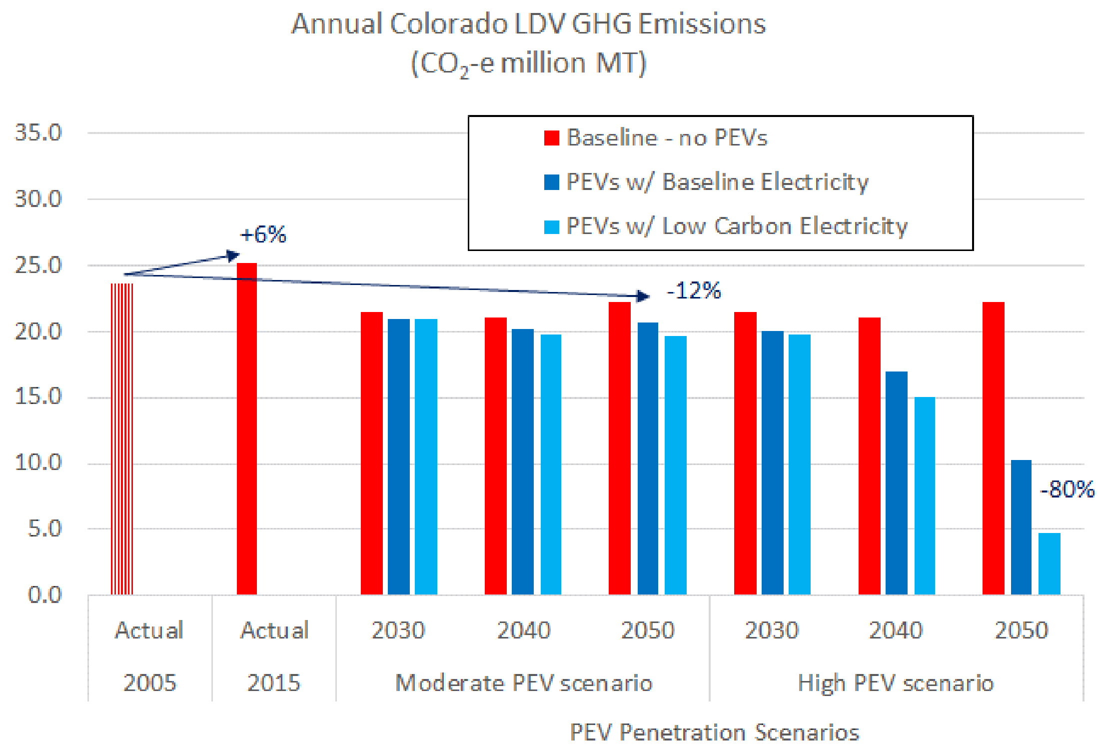
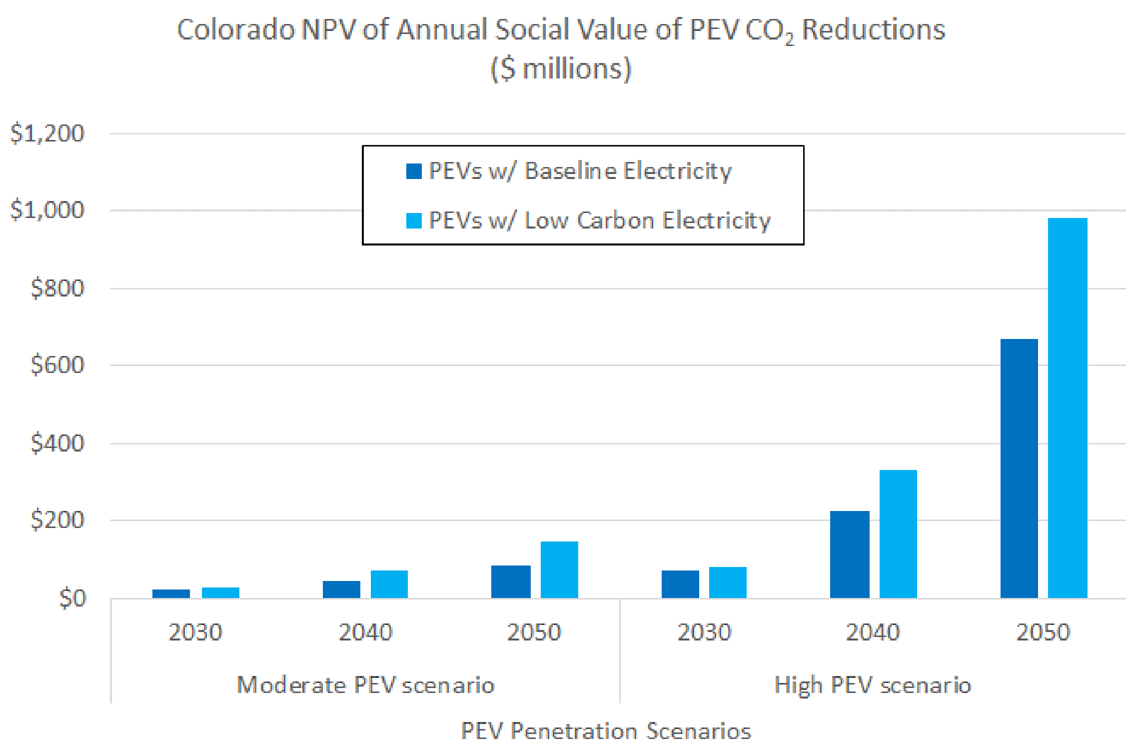


Figure 15 NPV of Projected Social Value of PEV GHG Reductions



For the PEV penetration scenarios, projected GHG emissions are shown for a baseline electricity scenario (dark blue) and a "low carbon" electricity scenario (light blue). The baseline electricity scenario is based on projections of average carbon intensity for Mountain region electricity generation from EIA. The low carbon electricity scenario is based on Colorado achieving long-term goals to reduce total GHG emissions from electricity generation by 80 percent from 2005 levels by 2050.

As shown in Figure 14, GHG emissions from the light duty fleet were approximately 23.7 million tons in 2005, but they increased by 6 percent through 2015, to 25.2 million tons. However, even without significant PEV penetration, baseline annual fleet emissions are projected to fall to 22.2 million tons by 2050, a reduction of 6 percent from 2005 levels and 12 percent from current levels. This projected reduction is based on turnover of the existing vehicle fleet to more efficient vehicles that meet more stringent fuel economy and GHG standards issued by the Department of Transportation and Environmental Protection Agency. Under the Moderate PEV penetration scenario, PEVs are projected to reduce annual light duty fleet emissions by up to 2.6 million tons in 2050 compared to baseline emissions (-12 percent). Under the High PEV scenario, annual GHG emissions in 2050 will be as much as 17.5 million tons lower than baseline emissions (-79 percent).

Figure 15 summarizes the NPV of the projected monetized "social value" of GHG reductions that will result from greater PEV use in Colorado. The social value of GHG reductions represents potential cost savings from avoiding the negative effects of climate change, if GHG emissions are reduced enough to keep long term warming below two degrees Celsius from pre-industrial levels. The values summarized in Figure 15 were developed using the Social Cost of CO_2 ($/MT) as calculated by the U.S. government's Interagency Working Group on Social Cost of Greenhouse Gases.

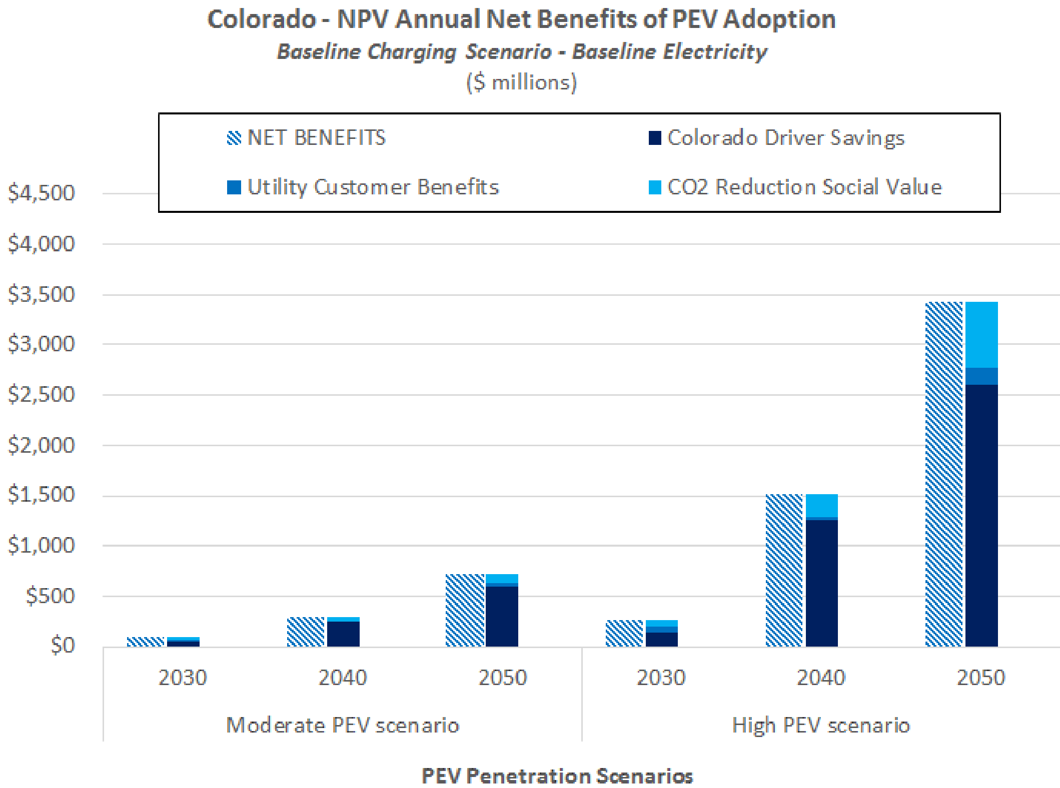
The NPV of the monetized social value of GHG reductions resulting from greater PEV use is projected to total $28 million per year in 2030 under the Moderate PEV penetration scenario, rising to as much as $144 million per year in 2050. Under the High PEV scenario the NPV of the monetized social value of GHG reductions from greater PEV is projected to be $82 million per year in 2030, rising to as much as $982 million per year in 2050.

The NPV of the projected monetized social value of annual GHG reductions averages $48 per PEV in 2030, and $52 - $127 per PEV in 2050.

Total Societal Benefits

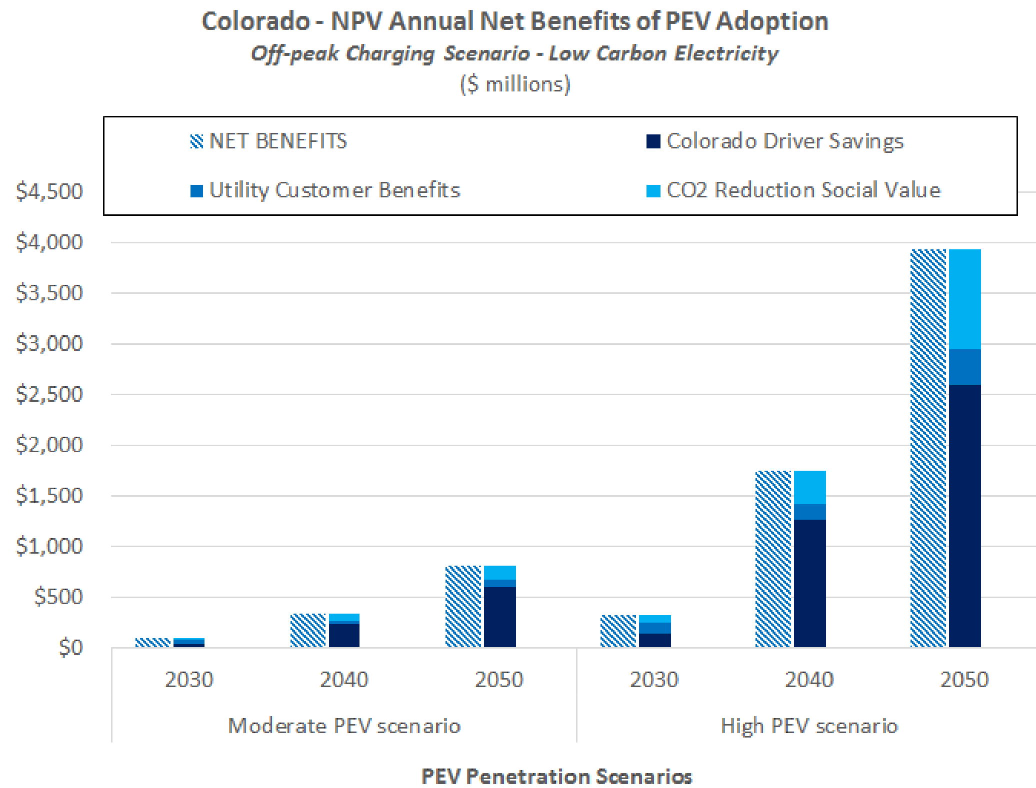
The NPV of total estimated societal benefits from increased PEV use in Colorado under each PEV penetration scenario are summarized in Figures 16 and 17. These benefits include cost savings to Colorado drivers, utility customer savings from reduced electric bills and the monetized benefit of reduced GHG emissions. Figure 16 shows the NPV of projected societal benefits if Colorado drivers charge in accordance with the baseline charging scenario, and if GHG emissions from electricity production follow EIA's current projections for carbon intensity. Figure 17 shows the NPV of projected societal benefits if Colorado drivers charge off-peak, and if Colorado meets goals for high levels of grid de-carbonization by 2050.

Figure 16 Projected NPV of Total Societal Benefits from Greater PEV use in CO – Baseline Charging



As shown in Figure 16, the NPV of annual societal benefits are projected to be a minimum of $714 million per year in 2050 under the Moderate PEV penetration scenario and $3.4 billion per year in 2050 under the High PEV scenario. Approximately 76 percent of these annual benefits will accrue to Colorado drivers as a cash savings in vehicle operating costs, 5 percent will accrue to electric utility customers as a reduction in annual electricity bills, and 20 percent will accrue to society at large in the form of reduced pressure on climate change due to reduced GHG emissions.

Figure 17 Projected NPV of Total Societal Benefits from Greater PEV use in CO – Off-peak Charging



As shown in Figure 17, the NPV of annual societal benefits in 2050 will increase by $99 million under the Moderate PEV penetration scenario, and $500 million under the High PEV scenario if Colorado drivers charge off-peak and the state is successful in decarbonizing the electric grid. Of these increased benefits, approximately half will accrue to electric utility customers as an additional reduction in their electricity bills, and half will accrue to society at large due to lower GHG emissions.

References

[1] Executive Order D-004-08 established a baseline year of 2005, but data tracking began in 2006 so the State revised the goal to adopt a 2006 baseline

[2] *https://www.codot.gov/programs/environmental/Sustainability/colorado-climate-plan-2015*

[3] *https://www.denvergov.org/content/denvergov/en/environmental-health/about-us/news-room/2015/denver-releases-climate-action-plan-with-a-bold-2050-goal.html, and https://www-static.bouldercolorado.gov/docs/January_Climate_Commitment_Draft_1.17_low_res-1-201701241028.pdf?_ga=1.131831247.1717237092.1485287732*

[4] *http://sciencepolicy.colorado.edu/students/envs_4100/ritter_2007.pdf*

[5] *https://www.colorado.gov/governor/news/governors-colorado-utah-and-nevada-announce-joint-action-build-regional-electric-vehicle*

[6] *https://pluginamerica.org/why-go-plug-in/state-federal-incentives/?location=co*

[7] R.L. Polk & Company, Light duty vehicle registrations, by county and state, as of January 2016

[8] Idaho National Laboratory, *2013 EV Project Electric Vehicle Charging Infrastructure Summary Report*, January 2013 through December 2013.

[9] Electric Power Research Institute, *Environmental Assessment of a Full Electric Transportation Portfolio, Volume 2: Greenhouse Gas Emissions*, September 2015

[10] Bloomberg New Energy Finance, *New Energy Outlook 2016, Powering a Changing World*, June 2016

Berman, Brad, www.plug-incars.com , *Battery Supplier Deals Are Key to Lower EV Prices*, February 04, 2016

Coren, Michael, www.qz.com, *Tesla's Entire Future Depends on The Gigafactory's Success, and Elon Musk is Doubling Down*, August 3, 2016.

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This report, and the other state reports, are available at www.mjbradley.com.