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Colorado's Energy Future:
The High Cost of 100 Percent Electric Vehicles

A Joint Analysis by Independence Institute and Center of the American Experiment
Part 3 of 3

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Authors' Note: This report is the third installment in a series of three reports analyzing the costs and reliability impacts of Colorado's climate change mitigation policies. It is a continuation of the work performed by the Center of the American Experiment modeling the cost of renewable energy mandates in states throughout the country.

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EXECUTIVE SUMMARY

- The complete electrification of Colorado's light-duty vehicle fleet, combined with total residential heating electrification and Colorado Governor Jared Polis's goal of a 100 percent renewable electricity grid by 2040 (hereafter, Polis Plan+electrification+EV), would cost Coloradans up to $695.3 billion through 2050.
- The additional generation capacity needed to support total light-duty vehicle electrification alone would cost approximately $74.6 billion through 2050.
- Colorado electricity customers (residential, commercial, and industrial) would see their average monthly electricity bills increase to $907 through 2050. They would peak at an average of $1,279 in 2040.
- To meet Colorado's present-day electricity demand and the additional demand created by electrifying light-duty transportation and home heating with only wind, solar, existing hydropower, and batteries, the state would need to install more than fourteen times the generation capacity currently on the grid.
- Despite this massive increase in installed capacity, Colorado would still experience 25 hours of blackouts spread across three separate events in January and early February 2040 if electricity demand and wind and solar output are similar to 2021.
- Alternatively, Colorado could meet Governor Polis's electric-sector, residential home heating, and light-duty vehicle decarbonization goals on the same timeline, without reliability issues and at roughly a third of the cost, by transitioning the state's generating assets to nuclear energy.

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INTRODUCTION

In August 2022, California became the first jurisdiction anywhere in the world to ban the sale of gas-powered vehicles, setting a deadline of 2035 to phase them out completely.[1] Just one week later, the state was forced to call on its residents to avoid charging their electric vehicles because the state's grid was at imminent risk of facing blackouts.[2]

While the state's appeal to its residents was successful, and blackouts were fortunately avoided, the incident highlighted the growing contradictions in energy policy as governments become increasingly concerned with addressing climate change. Policymakers are increasingly mandating their citizens to replace their gas-powered vehicles and appliances with electric alternatives while simultaneously making electricity generation more expensive and unpredictable.

Despite the irony in California's experience, other progressive jurisdictions have followed the state's example. In the last year, eight more states have decided to join the Golden State in banning the sale of gas-powered vehicles by 2035.[3]

Colorado appears to be set on a slightly softer approach for now, as it is currently considering requiring 80 percent of all car sales to be electric by the next decade rather than the total mandate preferred by California.[4]

With so much policy momentum in Colorado and elsewhere dead set on forcing a transition to electric vehicles, and with California's ill-fated rollout of its gas vehicle ban as a case study of what can go wrong, it's become critical to evaluate the costs and grid reliability impacts such a transition would incur.

With the help of detailed modeling commissioned by the Independence Institute and conducted by energy researchers at the Center of the American Experiment, this report aims to put a price estimate on the state's goal of transportation electrification, focusing specifically on light-duty vehicles while evaluating the grid reliability implications that come with it.

Evaluating both the cost and the grid reliability impacts of such a policy is essential because, as recent polling work conducted by the firm Cygnal shows, affordability and reliability are the two most valued factors on Colorado voters' minds regarding energy policy.[5]

Building on the work done in parts one and two of this series,[6],[7] it will examine the cost of transitioning Colorado's internal combustion engine (ICE) fleet to battery electric, with electrified home heating, on a 100 percent renewable powered electric grid. As in part one, this study also assesses an alternative scenario called the "Lower Cost Decarbonization" (LCD) scenario. This scenario meets the same electrification and grid decarbonization outcomes using new nuclear power plants — both the traditional, gigawatt-scale plants currently generating roughly one-fifth of the country's electricity,[8] and innovative small-modular reactors (SMRs).

Policymakers are increasingly mandating their citizens to replace their gas-powered vehicles and appliances with electric alternatives while simultaneously making electricity generation more expensive and unpredictable.

These technologies offer superior value to wind and solar because they are dispatchable, meaning they can provide power whenever called upon. As a result, the LCD Scenario delivers 100 percent emissions reductions from the status quo at a lower price than under the Polis Plan while fully supporting electric vehicles without sacrificing the electric grid's reliability.

Because much of the foundation of this report was laid in parts one and two of this series—including the political forces driving Colorado's decarbonization push, the dynamics and functionality of a reliable electric grid, the value and cost discrepancies between intermittent and dispatchable resources, and the change in electricity demand caused by electrification mandates—some of the background explanations are abbreviated in this report to avoid redundancy.

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For more details on the assumptions driving this report, or to compare the changes to the state's grid under a policy of decarbonization with and without electrified space heating and transportation, be sure to refer to our previous papers: *Colorado's Energy Future: The High Cost of 100% Renewable Electricity by 2040*[9] and *Colorado's Energy Future: The High Cost of 100% Electric Home Heating*.[10]

LIMITATIONS

It's important to note that this analysis does have some limitations.

First, the lack of more robust hourly electric vehicle charging data specific to Colorado presents challenges. Despite the taxpayer-subsidized movement toward electric vehicles, EV penetration in the Colorado transportation sector is still relatively low. Therefore, high-quality statewide charging data likely does not exist. If it does, our researchers were not aware of any accessible source.

Instead, our modeling assumptions rely on data from Norway, which leads the world in electric passenger vehicle adoption.[11] We extrapolated these data to Colorado while adjusting for the additional vehicle miles traveled (VMT) of the typical Coloradan relative to Norwegians to create an hourly load profile for electric vehicle charging. While highly useful, this is still an imperfect comparison of how widespread EV adoption would look in practice in Colorado.

Furthermore, the final figures in this report do not account for specific additional costs or savings involved in the complete electrification of Colorado's light-duty passenger vehicle sector.

For example, we calculated that light-duty transportation electrification would save Coloradans $154.6 billion in fuel costs through 2050. Coloradans would also experience some savings in vehicle maintenance costs, as electric vehicles currently cost around 4 cents less per mile driven on average to maintain compared with comparable gasoline-powered cars.[12] These savings are not factored into the total additional costs for the scenarios.

At the same time, the total additional cost figures for the Polis Plan+Electrification+EV do not include the premium paid for EVs compared to conventional internal combustion engine (ICE) cars—currently around a $10,000 difference.[13] They also do not include the potential upgrades needed to the electric distribution system or to home fuse boxes to enable more extensive power draws on the system, or costs incurred for building fast-charging stations.

Those additional costs involved in the buildout of public EV-charging stations have the potential to dramatically impact Coloradans' rates and bills, especially if monopoly utilities like Xcel Energy are allowed to build and rate-base them, as is currently authorized by state statute and under consideration with the Colorado Public Utilities Commission.[14]

Finally, this analysis is limited to the impacts of electrifying light-duty passenger vehicles. It does not consider medium- and heavy-duty vehicles, nor does it include other electric transportation options, such as electric bicycles (eBikes) and scooters. This was done both for simplicity in modeling and because Colorado's plan for decarbonizing transportation beyond light-duty vehicles currently is less well-defined than it is for passenger automobiles.

For example, while the state has released a formal plan to increase the market share of light-duty EVs to 100 percent by 2050, it uses the less-specific term "zero-emissions vehicles" when referring to its strategy for medium and heavy-duty vehicles by the same year.[15] This opens the door for an undefined blend of electric and low-carbon fuel-based vehicles like hydrogen-powered trucks in the medium and heavy-duty vehicle sectors. While the exact mix is unclear, including any sizeable share of additional electric medium and heavy-duty vehicles in the state would undoubtedly add to the generation infrastructure needs and, ultimately, the costs arrived at in this analysis.

Nevertheless, the high costs we found for electrifying Colorado's light-duty transportation sector alone, alongside fully electric home heating, with the support of a fully renewable electric grid, highlight how astronomical the total costs would be under a complete electrification scenario.

THE POLIS PLAN+ELECTRIFICATION+EVS

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He issued Executive Order B 2019 002, officially establishing a state government goal of having 940,000 electric light-duty vehicles on the road by 2030, established an official transportation electrification working group, and directed several executive agencies to begin crafting regulations to make his goals a reality.[16]

Since then, Governor Polis's Air Quality Control Commission has instituted regulations requiring auto manufacturers and dealers in the state to make at least 5 percent of their vehicle sales EVs by this year and at least 80 percent by 2032.[17]

Despite this coercion, there are currently less than 64,000 EVs on the road in Colorado, according to state data.[18] That's less than 7 percent of the Governor's goal with only seven years to go. Though the state's ability to meet that 2030 benchmark is uncertain, the Polis administration has continued to set even more ambitious interim targets for total transportation electrification. Earlier this year, the Colorado Energy Office unveiled its updated Colorado EV Plan, creating a new goal of 2.1 million electric passenger vehicles on the road by 2035 and "close to 100% by 2050."[19]

This analysis examines the cost, electricity infrastructure needs, and reliability implications of complying with the Polis Plan analyzed in part one of this series alongside the residential heating electrification modeled in part two, with the added task of converting all of Colorado's light-duty vehicles to EVs by 2050 per the Polis administration's goal.

It compares it to the LCD Scenario, which prioritizes providing the most reliable carbon-free electricity for Colorado ratepayers in the form of new nuclear plants while still supporting a robust electric vehicle fleet for the state's residents.

Complying with the Polis Plan for electricity generation, residential heating, and light-duty transportation will add substantial cost and complexity to maintaining a reliable electric grid compared with the LCD Scenario, which will provide identical emissions reductions and improved reliability outcomes at a lower cost.

As in part one of our analysis, our model does not incorporate federal, state, or local subsidies available to wind, solar, battery storage, or nuclear facilities on the generation side. Nor does it include any tax incentives or rebates made available for purchasing electric vehicles or installing charging infrastructure because subsidies and tax credits do not reduce the cost of producing energy and supporting electric vehicles; they simply socialize a portion of those costs across the tax base.

THE LCD SCENARIO

The Lower Cost Decarbonization (LCD) Scenario seeks to provide a more reliable and affordable path to reducing carbon dioxide emissions from the electricity sector while supporting the added demand created by all-electric space heating and transportation at the same pace and scale envisioned by the Polis Plan—100 percent by 2040.

Under the LCD Scenario, electric utilities in Colorado would continue to utilize existing coal, natural gas, petroleum, hydro, wind, and solar capacity through their scheduled retirement dates—except for the Comanche generating station, which would be retired in 2040 rather than the accelerated date currently set for the end of 2030.

Xcel's coal plants are kept online longer in this scenario to provide reliable baseload electricity while new nuclear power plants are being constructed, substantially reducing the costs associated with the transition.

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New nuclear facilities would take two primary forms: APR-1400s, large-scale pressurized water reactors currently built and deployed by South Korea, and small modular reactors (SMRs).

The APR-1400 is a 1,400 MW power plant built by the Korea Electric Power Corporation (KEPCO). This particular reactor was selected because it has a track record of being built at scale on time and on budget[20]—something other reactor designs have struggled with in recent years.[21]

It also has the advantage of already being certified for use in the United States by the U.S. Nuclear Regulatory Commission.[22]

SMRs are used because they have the potential to offer improved flexibility compared with traditional nuclear plants and baseload fossil fuel plants with carbon capture. That allows them to be used as peaking assets to meet fluctuations in electricity demand throughout a given day.[23]

The LCD Scenario also includes battery storage to help firm up the grid during periods of peak demand. These batteries are charged using the excess generation from the newly built nuclear fleet.

Under the LCD Scenario, Colorado's existing wind and solar facilities can operate through the end of their useful lives (up to 25 years) and then are replaced by new nuclear generation.

New nuclear facilities would take two primary forms: APR-1400s, large-scale pressurized water reactors currently built and deployed by South Korea, and small modular reactors (SMRs).

COLORADO'S CHANGING ELECTRICITY MIX UNDER THE POLIS PLAN+ELECTRIFICATION+EVS

In 2021, Colorado derived approximately 41 percent of its electricity from coal, 26 percent of its electricity from wind, 25 percent from natural gas, five percent from solar, three percent from hydroelectric (excluding pumped storage), and less than one percent from a combination of biomass, petroleum, and pumped storage hydropower (see Figure 1).

This analysis uses 2021 data as a baseline because complete 2022 data on the state's electricity mix were not yet available at the time of this report.

Additionally, only approximately 47,000 electric vehicles were registered on the road in the state in 2021, representing a relatively inconsequential source of demand on the electric grid. That number will have to increase dramatically to meet Governor Polis's 2050 goal.

According to U.S. Census Bureau data, roughly 5.35 million total passenger vehicles are registered in Colorado.[24] The vast majority of those vehicles will have to be converted to battery-electric powered in the next 27 years to meet the Polis goal. With that massive increase in the number of vehicles relying on electricity to operate, there is a need to substantially increase the generation capacity on the grid to support them.

Figure 1. Fossil fuel-based power plants accounted for roughly two-thirds of the electricity generated in Colorado in 2021.

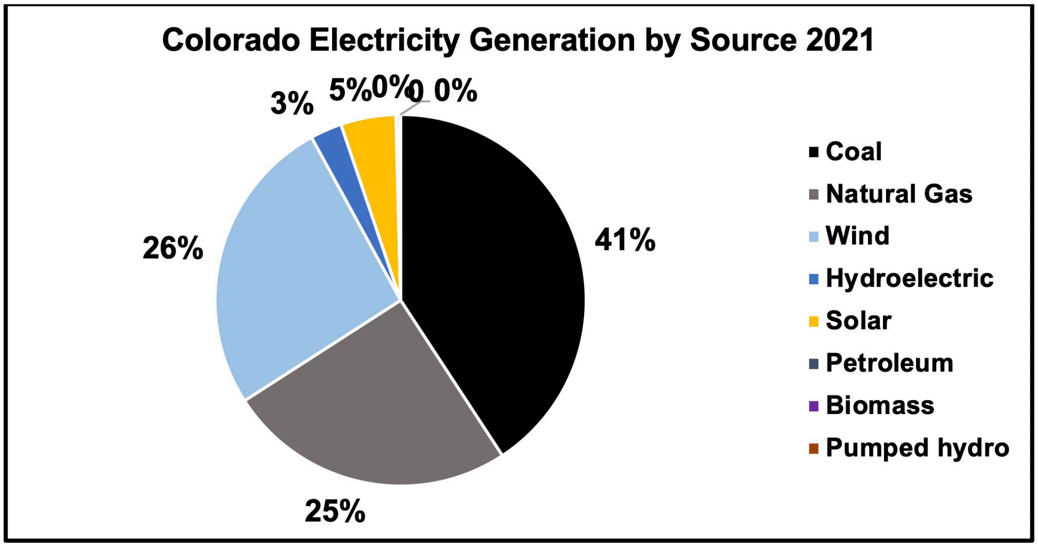
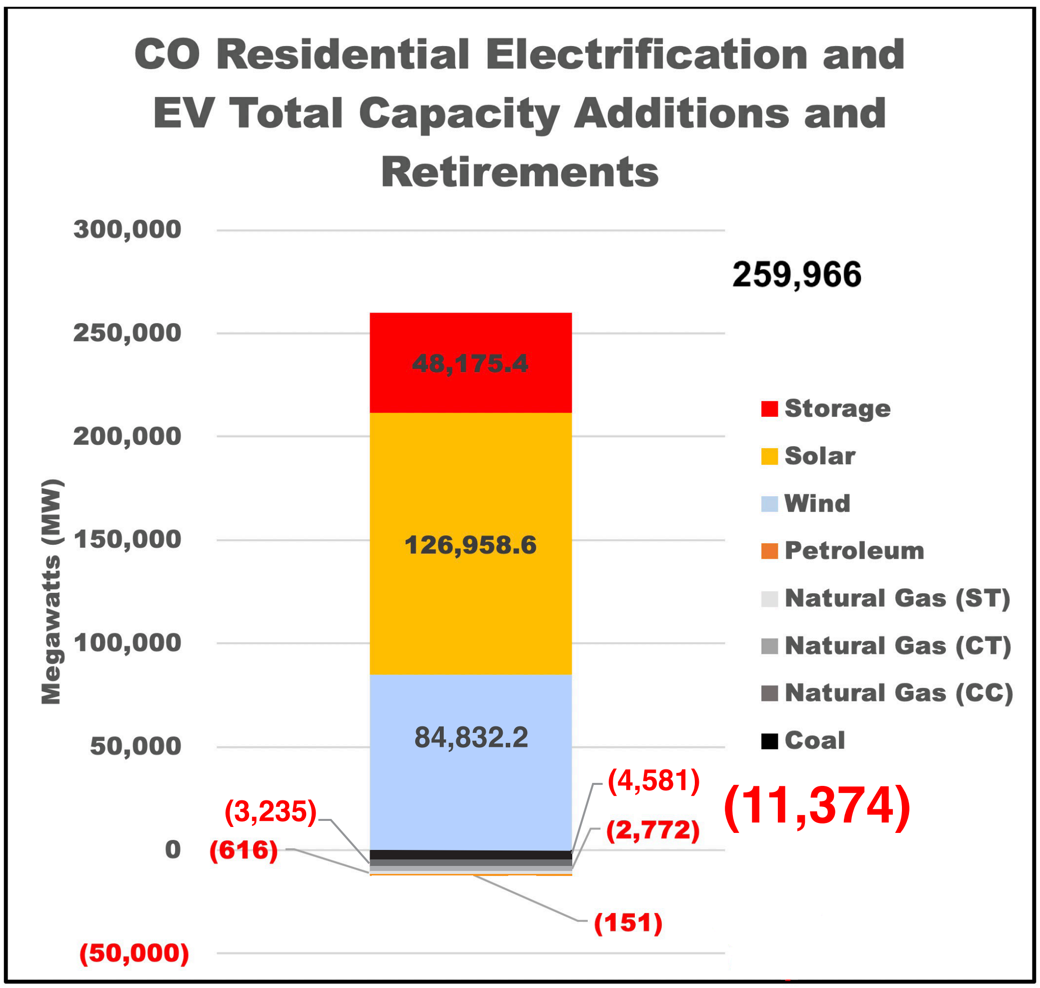


Figure 2. Complying with the Polis Plan while supporting electric home heating and passenger vehicles would require roughly 14 times more installed generation capacity on the state's electric grid to serve load consistently.



American Experiment's model calculates Colorado's new generation mix resulting from compliance with the Polis Plan using wind and solar generation with battery storage to support present-day demand plus the additional load created by electrified home heating and light-duty vehicle transportation.

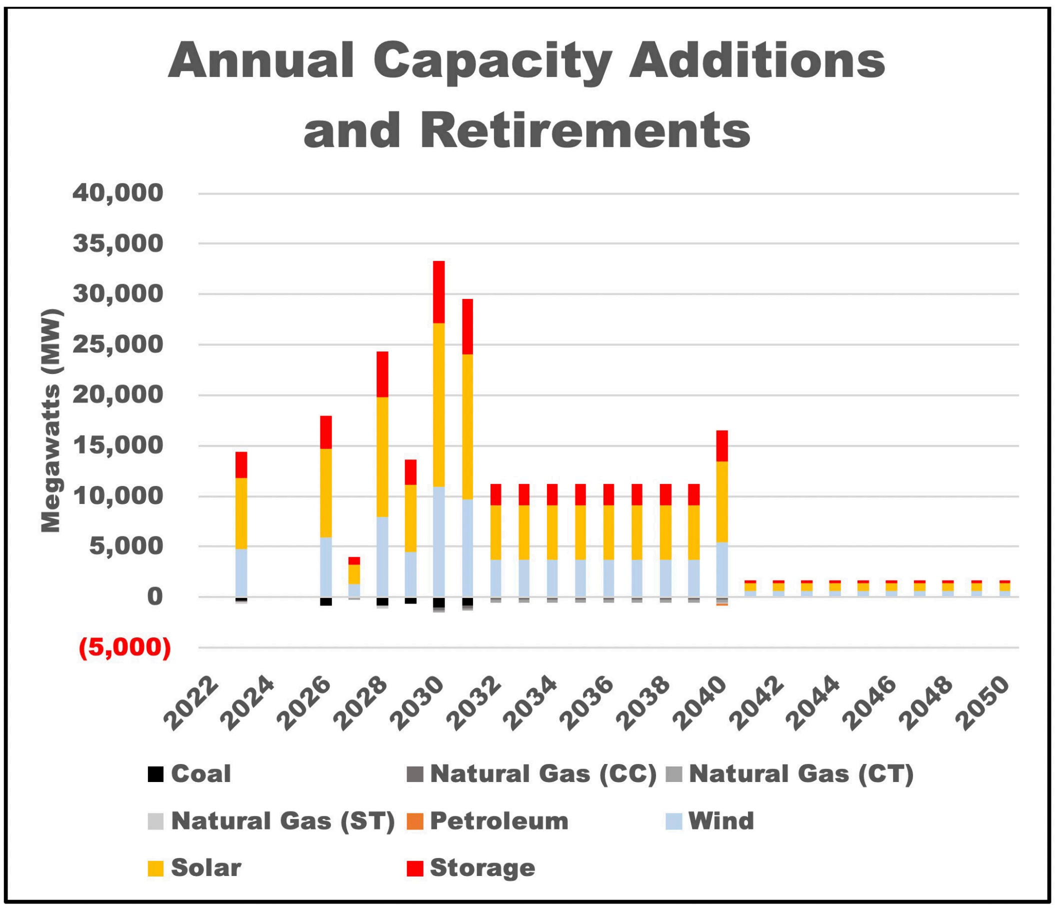
Figure 2 shows the capacity additions and retirements necessary to accommodate that energy mix by 2040, and Figure 3 shows the schedule of those additions and retirements outlined by the model.

To support across-the-board adoption of personal electric vehicles, with the addition of fully electric home heating under a 100 percent renewable energy standard, Colorado's electric utilities would have to invest heavily in new wind, solar, and battery storage facilities to serve load.

We project that by 2040, wind, solar, and battery capacity would need to increase by 259,966 MW. This would represent a roughly fourteenfold increase in the size of the

To support across-the-board adoption of personal electric vehicles, with the addition of fully electric home heating under a 100 percent renewable energy standard, Colorado's electric utilities would have to invest heavily in new wind, solar, and battery storage facilities to serve load.

Figure 3. Installation of new renewable capacity would significantly accelerate over the next decade, peaking in 2030 to account for the closure of the last of Colorado's coal facilities. Installations would continue steadily throughout the decade to support residual electrification conversions.



state's current electric grid in terms of generation capacity over the next couple of decades.

Solar installations would increase the most under the Polis Plan+electrification+EV scenario, from just 1,060 MW in 2021 to 126,959 MW in 2050. Wind capacity would grow from 4,991 MW to just over 84,832 MW in 2050. Finally, battery storage would increase from just 10 MW in 2021 to around 48,175 MW of four-hour storage by 2050. Not only would this be an astronomical increase in installed capacity, but it would also be a substantial increase in capacity over what would already be required under the Polis Plan alone.

We found in part one of this series that to meet current levels of electricity demand with 100 percent renewable generation by 2040 would take 117,729 MW of new renewable capacity—56,276 MW of new solar, 36,603 MW of new wind, and 23,850 MW of battery storage. That extra 142,237 MW of needed capacity directly results from additional electricity demand created by replacing natural gas home heating with heat pumps and resistance heaters and by replacing gasoline-powered vehicles with battery-electric alternatives.

Unlike the Polis Plan, the LCD Scenario would allow coal to continue playing a role in the state's generation mix until 2040, a decade longer than the alternative.

THE LCD SCENARIO

Though it would be subject to the same increase in electricity demand, transportation electrification under the LCD Scenario would require far fewer new capacity additions than the Polis Plan alternative.

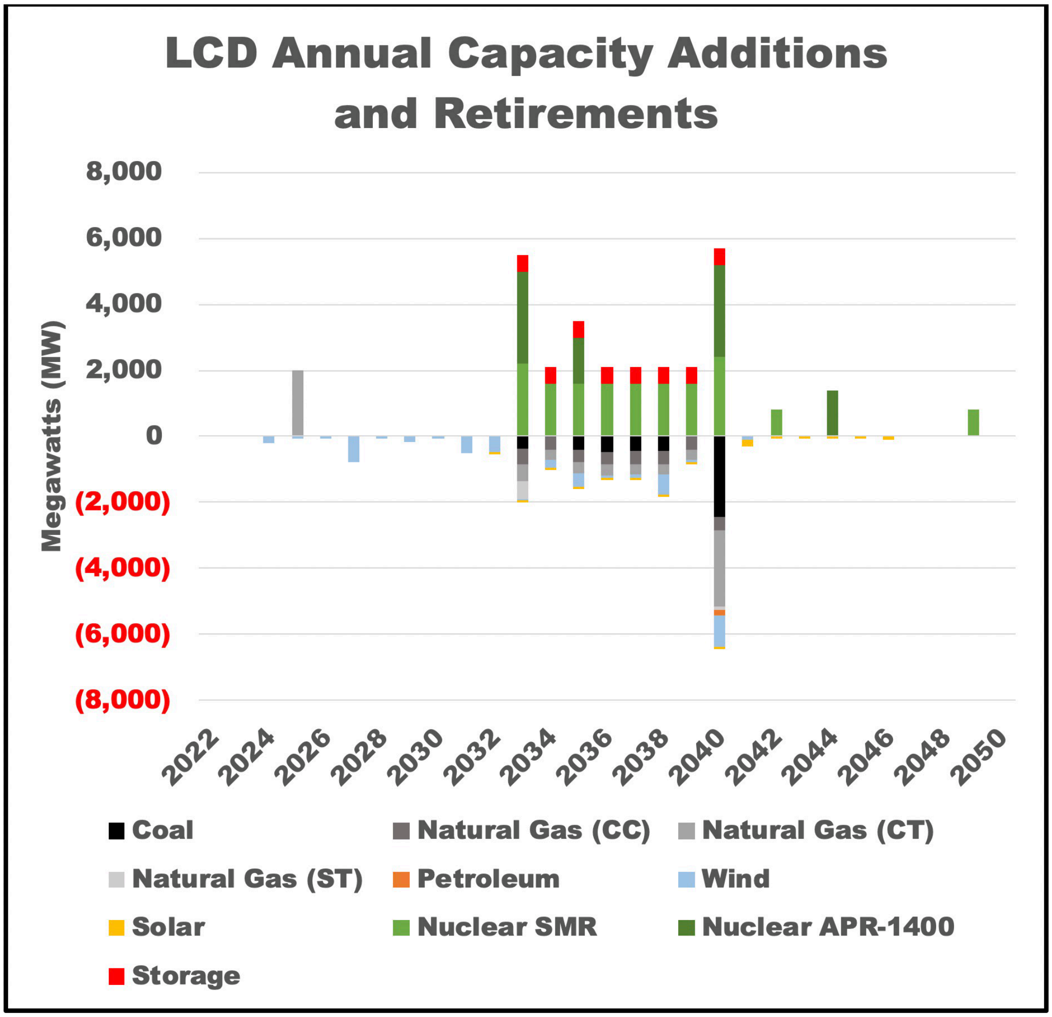
To meet Colorado's electricity demand under the LCD Scenario+electrification+EVs, the state's utilities must build 30,200 MW of replacement generation capacity by 2050. That represents an approximately 60 percent increase in installed capacity relative to the state's current grid.

Unlike the Polis Plan, the LCD Scenario would allow coal to continue playing a role in the state's generation mix until 2040, a decade longer than the alternative. This would help avoid much of the frontloaded costs of new renewable generation required under the Polis Plan and provide extra time for new nuclear generation to come onto the market and get installed on Colorado's grid.

It would also provide an additional decade of relatively affordable and reliable electricity from the state's already paid-for coal fleet before those plants are retired and replaced with carbon-free nuclear energy. The LCD Scenario would also allow Colorado's current installed capacity of wind and solar resources to operate through the end of their useful lives before being retired. Under this scenario, some wind and solar capacity would remain on Colorado's grid through 2040. However, new wind and solar would not be built once the existing capacity is retired to make room for clean, dispatchable generation.

An additional 2000 MW of combustion turbine (CT) natural gas capacity would also be built in 2025 under the LCD Scenario to be used as a peaking asset. This is necessary to help meet increased peak demand caused by early electrification adopters in residential space heating and vehicle charging before the installation of new nuclear

Figure 4. Under the LCD Scenario, existing wind and solar would retire on schedule without repowering. New nuclear generation would begin to come online starting in 2033. Coal and gas-fired generation would be completely phased out by 2040.



plants by the middle of the next decade. This additional gas capacity would be retired in 2040 after sufficient nuclear capacity is online to replace it with the rest of Colorado's carbon-emitting generation (Figure 4).

Small modular nuclear reactors would be the single-largest source of new capacity under the LCD Scenario, with 15,800 MW of new capacity installed by 2040. The scenario would also involve 8,400 MW of large-scale nuclear capacity represented by six new APR-1400 plants. Finally, the scenario would require 4,000 MW of four-hour battery storage (Figure 5).

The amount of new power plant capacity added in the LCD Scenario is substantial. Still, it is far lower than what would be required under the Polis Plan because the new power plants are dispatchable, meaning they are always available and can be ramped up or down as needed. This is critical because it means no need to overbuild for reliability.

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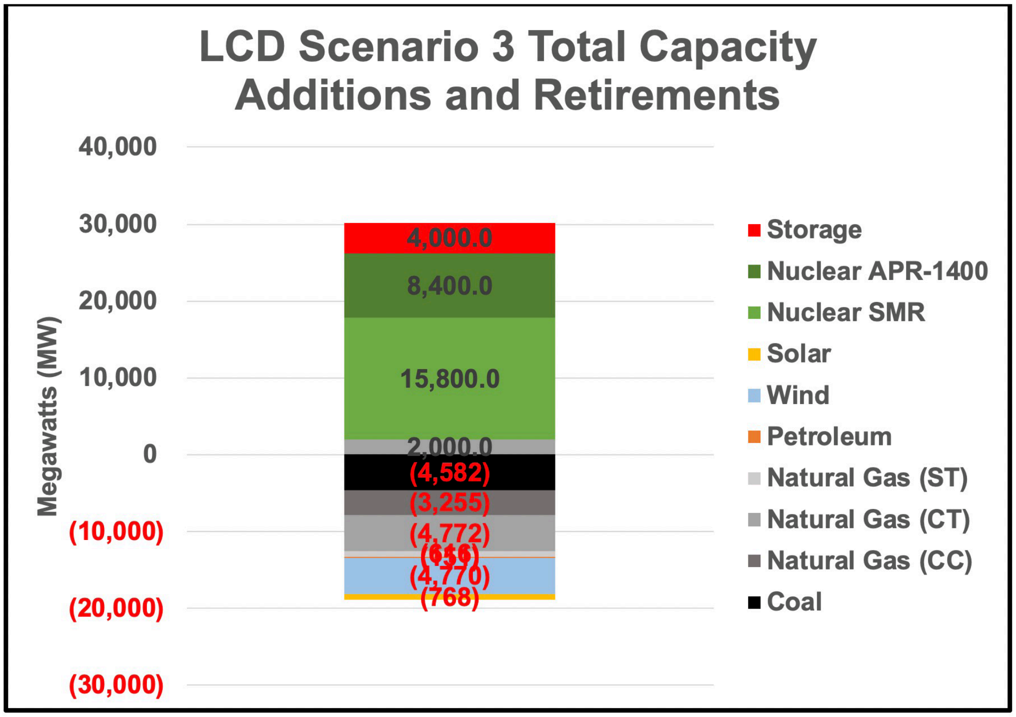
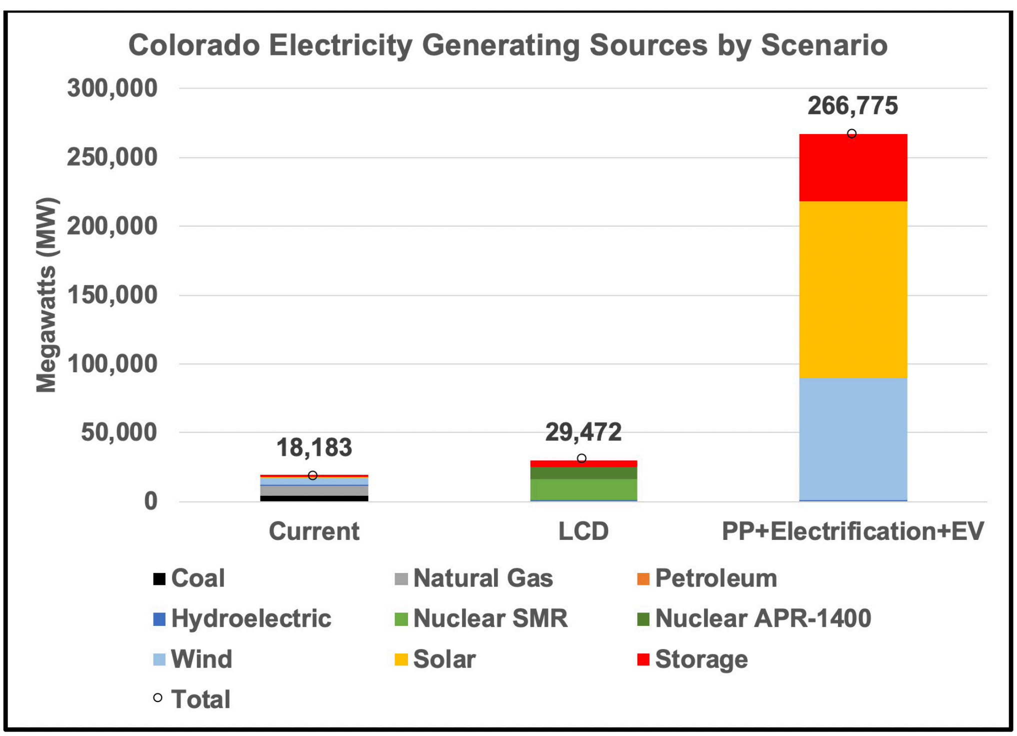
Figure 5. Small modular reactors (SMRs) are valued for their flexibility under the LCD Scenario with residential and transportation electrification. More SMR capacity is installed than any other resource.



Though it would be subject to the same increase in electricity demand, residential electrification under the LCD Scenario would require far fewer new capacity additions than the Polis Plan.

Figure 6. A comparison of the capacity currently serving Colorado as of 2021 vs. what would be required under each decarbonization scenario.



As a result, the LCD Scenario meets the added demand caused by electric vehicle adoption and electrified space heating while meeting the same carbon reduction goals as the Polis Plan, but with a grid roughly eleven percent of the size in terms of installed capacity (Figure 6).

COMPARING THE COSTS OF EACH HIGH-EV PENETRATION SCENARIO

Regardless of the method chosen, completely overhauling the way Colorado generates electricity, produces home heating, and powers its vehicles while building out the requisite generation to support such a move will be costly.

Regardless of the method chosen, completely overhauling the way Colorado generates electricity, produces home heating, and powers its vehicles while building out the requisite generation to support such a move will be costly.

As such, widespread electric vehicle adoption under either the Polis Plan or the LCD Scenario would increase electricity costs for Colorado ratepayers. However, the LCD Scenario would impose far fewer costs while achieving the same carbon reduction goals as the alternative.

As outlined in part one of this report, decarbonizing Colorado's electricity sector under the terms envisioned by the Polis Plan would cost $318.8 billion through 2050.[25] Our research in part two of this series found that complying with statewide home-heating electrification under the same timeline, supported by the same energy mix, would add an additional $301.9 billion in costs over the same timeline.[26] Finally, modeling conducted by the Center of the American Experiment indicates that adding near-unanimous adoption of light-duty electric vehicles on top of these requirements would lead to an additional $74.6 billion in costs for a total price tag of $695.3 billion through 2050 using constant 2022 dollars.

This would result in a near-quintupling of existing average all-sector electricity rates from 10.90 cents per kilowatt hour (kWh) in 2021 to a peak of 50.30 cents per kWh in 2040. All-sector electric rates would average 37.98 cents per kWh over the course of the transition.

The resulting average monthly cost for each Colorado utility customer would more than quintuple to $907 through 2050 after peaking at $1,279 in 2040 (Figure 7).
By comparison, pursuing light-duty vehicle electrification under the LCD Scenario would cost an additional $14.4 billion more than without transitioning the state's vehicle fleet, for a total cost of $209.4 billion through 2050. That represents nearly $486 billion in savings compared with the Polis Plan.

Under the LCD Scenario, all-sector electricity rates would increase by an average of just under 8 cents per kWh to 18.80 cents per kWh over the course of the transition period. They would peak at 26.17 cents per kWh in 2040.

That rise in rates would increase average all-sector monthly electric bills from $180 in 2021 to $666 in 2040. Under this scenario, they would average $450 per month through 2050—less than half the average monthly cost of the Polis Plan+Electrification+EVs.

Figure 7. Comparing the average monthly electricity bills for Colorado residential, commercial, and industrial ratepayers after a switch to electric home heating and vehicles under the Polis Plan and LCD Scenarios.

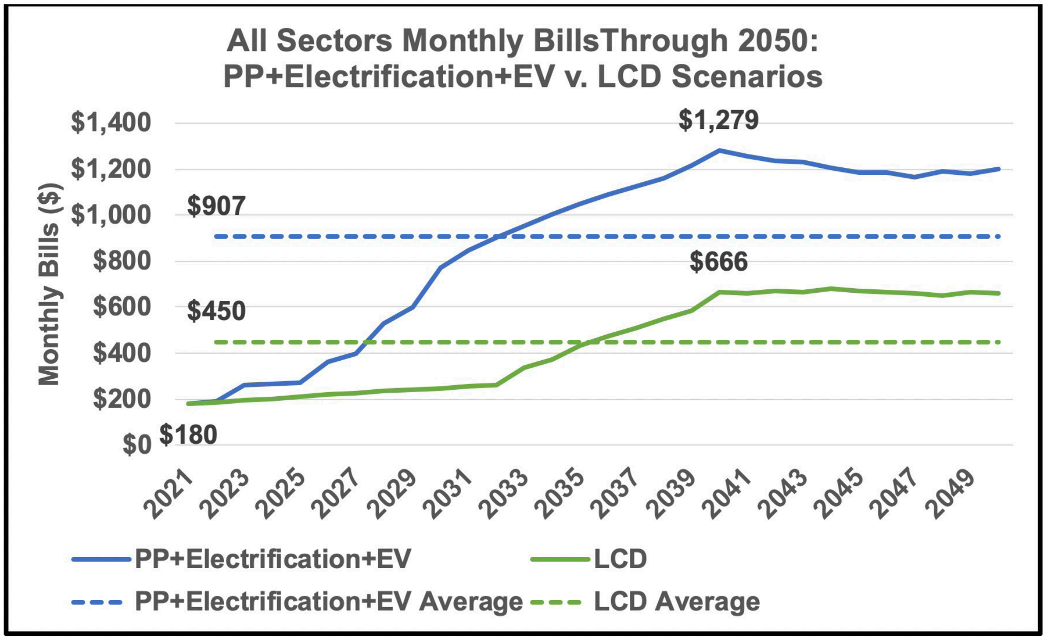


Figure 7 shows the average monthly costs of Colorado residential, commercial, and industrial ratepayers after complying with the Polis Plan and LCD Scenario, plus residential and transportation electrification.

> …the plan would result in an additional $96.3 billion in operating and maintenance (O&M) expenses, $10.8 billion in transmission expenses, and $11 billion in additional property tax expenses.

COST DRIVERS UNDER EACH SCENARIO

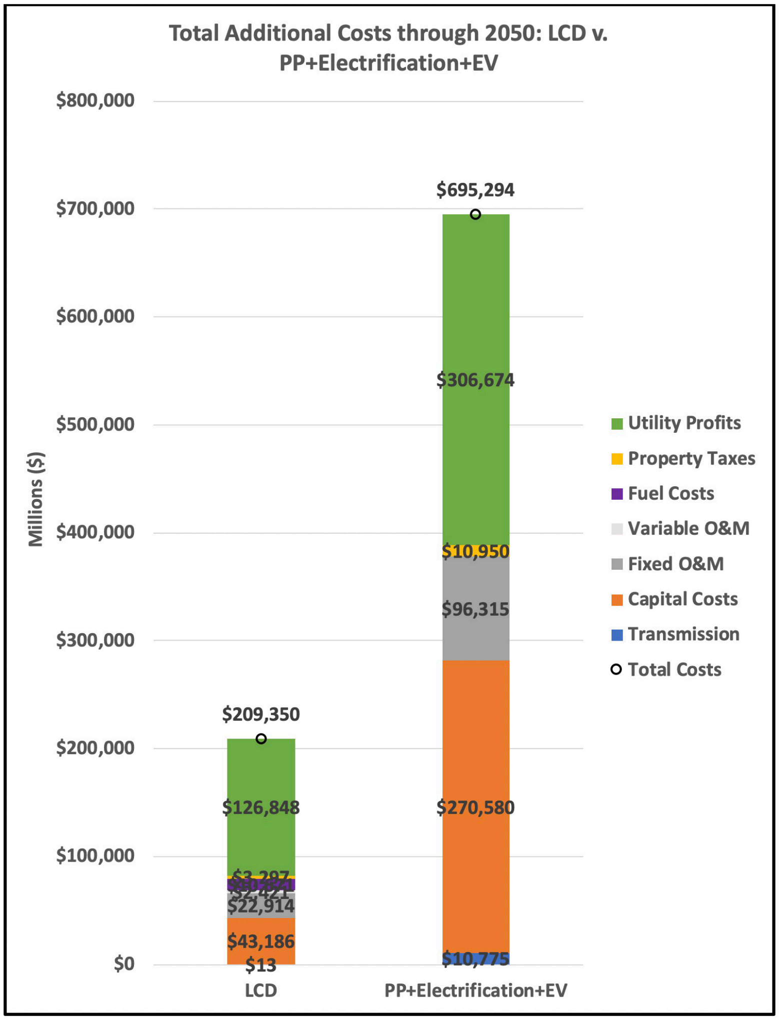
Figure 8 shows the different sources of expense driving the overall cost differential between the two plans.

For a more detailed discussion of the factors driving such a significant cost discrepancy between the two plans, including examining how electric utilities make money and recover costs, see the section entitled "Why There Is Such A Large Cost Gap Between Scenarios" in Part One of this series.[27]

Under the Polis Plan+electrification+EV scenario, the two most significant sources of expenses driving the $695.3 billion price tag consist of $306.7 billion in utility returns and $270.6 billion in additional capital costs. On top of that, the plan would result in an additional $96.3 billion in operating and maintenance (O&M) expenses, $10.8 billion in transmission expenses, and $11 billion in additional property tax expenses.

Under the LCD Scenario, the two most significant sources of expense consist of $126.8 billion in utility returns and $43.2 billion in additional capital costs to build new power plant infrastructure. Those new power facilities would result in an additional $25.3 billion in O&M expenses, $10.7 billion in fuel expenses, $13 million in transmission expenses, and $3.3 billion in additional property tax expenses.

Figure 8. Completely transitioning Colorado's ICE fleet to battery electric under the Polis Plan with residential electrification mandates would cost roughly 3.3 times more than under the LCD Scenario through 2050, driven primarily by higher capital costs to cover new generation investments and much higher utility profits.



THE "ALL-IN" LEVELIZED COST OF ENERGY UNDER EACH SCENARIO

The model used in this report accounts for all the additional system expenses associated with integrating high levels of wind and solar generation on a grid, which are typically excluded from traditional individualized LCOE metrics, and attributes them to the cost of new build wind and solar to get an "all-in" LCOE value. This all-in-levelized cost represents the true cost of delivering the same reliability value of dispatchable generating technologies.[28]

This allows for a more appropriate apples-to-apples comparison between the cost of reliably meeting electricity demand with Colorado's existing energy mix and with the new plants that would be built under the Polis Plan and LCD Scenario.

Data from the most recent Federal Energy Regulatory Commission (FERC) form 1 filing shows Colorado's combined cycle natural gas plants generated electricity for $39.56 per MWh, and coal plants in the state generated electricity for $31.50 per MWh, on average in 2020 (Figure 9).

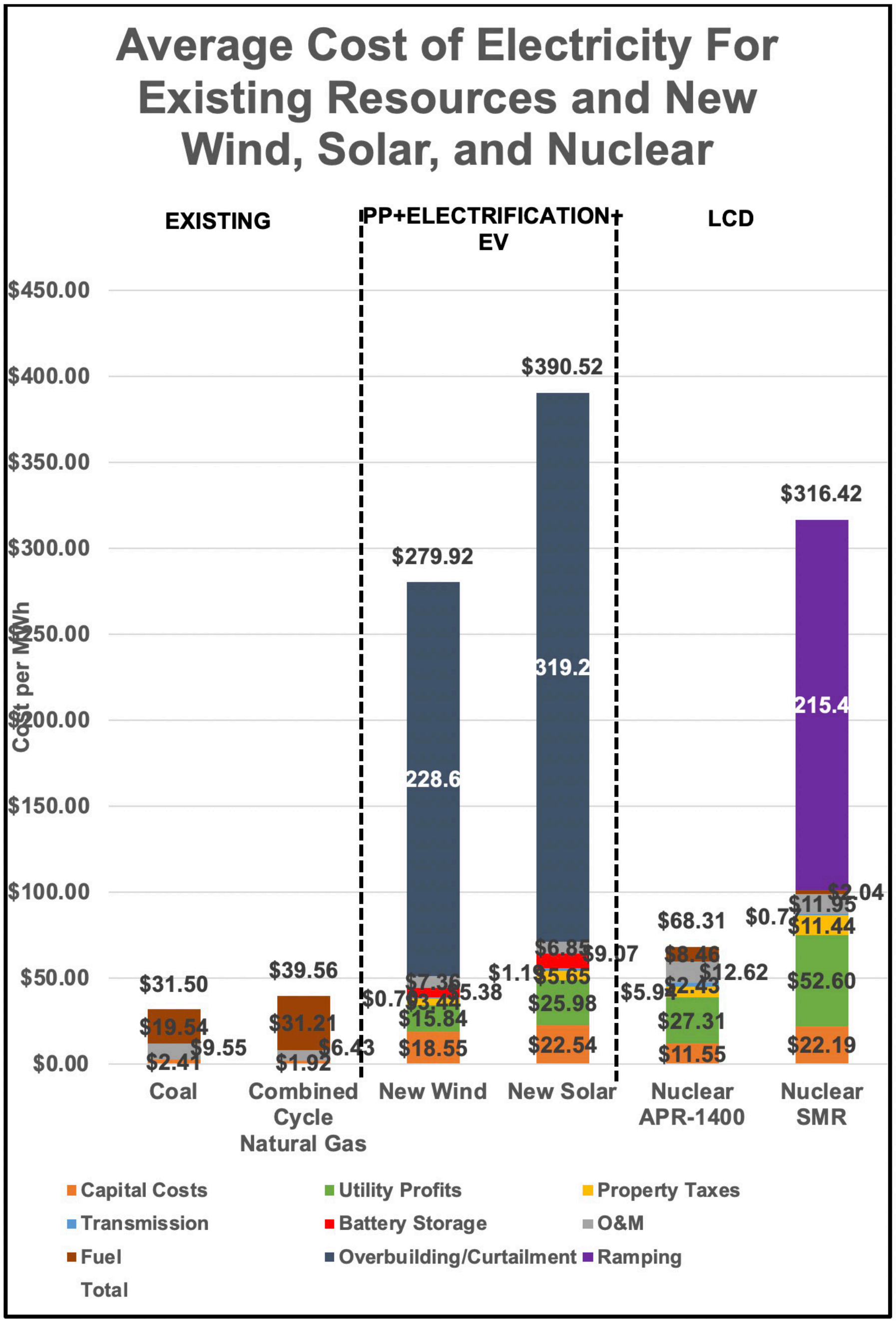
Under the Polis Plan, these affordable and reliable fossil fuel plants would be entirely replaced with intermittent wind, solar, and battery storage by 2040, with continued additions through 2050 to meet the extra demand created by electrified residential space heating and light-duty vehicles.

Under the Polis Plan, these affordable and reliable fossil fuel plants would be entirely replaced with intermittent wind, solar, and battery storage by 2040, with continued additions through 2050 to meet the extra demand created by electrified residential space heating and light-duty vehicles. Figure 9 shows that the all-in LCOE of new wind and solar reaches $279.92 and $390.52 per MWh, respectively, on average throughout the model run.

These all-in LCOE figures for solar and wind are higher than we found in part one of this series. This is due to the need to overbuild renewable generation and transmission under this scenario to meet a higher peak demand created by widespread electric vehicle charging. This extra overbuilding necessitates even more curtailments during off-peak periods, resulting in more wind and solar projects recovering their project costs over fewer megawatt hours (MWhs) of actual generation over their lifetimes.

Under the LCD Scenario, new-build APR-1400 nuclear plants would have an average levelized cost of $68.31 per MWh through 2050. New build nuclear SMRs would have a much higher levelized cost ($316.42/MWh), trailing only new solar in expense, driven primarily by a significant increase in cost per MWh beginning in 2040 and peaking in 2044. This is because SMRs become the primary load following or "peaking" resource under the LCD Scenario. This forces each SMR to generate less electricity overall, thus recovering costs over fewer megawatt hours of generation by the end of the model run. This extra load following cost is labeled "ramping" in the following chart.

Figure 9. Once costs such as property taxes, transmission, utility returns, battery storage, and overbuilding and curtailment are accounted for, new wind costs close to $280/MWh, and new solar costs nearly $391/MWh. Under the LCD Scenario, APR-1400s would become the lowest-cost source of new carbon-free power. SMRs would be expensive due to their use as a peaking resource.



GRID RELIABILITY UNDER EACH SCENARIO

Even without the widespread use of electric vehicles, the bedrock characteristic of a successfully run electric grid must be reliability. But when the very means of transportation for millions of Coloradans is expected to be added to the list of things dependent on its continued function, it becomes even more vital to ensure that reliability isn't undermined.

As the rollout of California's gas-vehicle ban showed, even modest levels of intermittent renewable penetration and a stretch of unfavorable weather can hamper grid reliability and disrupt the use of electric vehicles.

Considering that backdrop, it's worth thinking through how Colorado's grid will be expected to hold up once its energy mix has dramatically changed under the Polis Plan or LCD Scenarios.

THE POLIS PLAN+ELECTRIFICATION+EVS

Our analysis found that adding electric vehicles to the demand on an electric grid configured per the Polis Plan would substantially impair reliability.

> Our analysis found that adding electric vehicles to the demand on an electric grid configured per the Polis Plan would substantially impair reliability.

That's because the Polis Plan would significantly increase the state's dependence on fluctuations in the weather to meet demand while simultaneously adding extra strain to the grid during periods of heavy vehicle charging and home heating. So long as the weather cooperates, this is not a problem (Figure 10). When it does not, blackouts become inevitable (Figure 11).

American Experiment's modeling determined the amount of wind, solar, and battery storage capacity needed for the Polis Plan by using hourly electricity demand data for 2021 and 2022 provided by the U.S. Energy Information Administration and real-world wind and solar capacity factors from the same years. They also added the hourly electric vehicle charging demand data extrapolated from data documented in Norway—in addition to the home heating load profile calculated in part two of this series— to create a hypothetical electricity demand profile for Colorado in 2040 under all-electric home heating and light-duty vehicle mandate.

Using these inputs, the model determined that the 84.8 gigawatts (GW) of wind, 126.9 GW of solar, and 48.2 GW of four-hour battery storage built under the Polis Plan+Electrification+EV scenario would not be able to generate sufficient electricity to meet demand for a combined 25 hours over three capacity shortfall events in 2040 if demand and capacity factor conditions are similar to how they were in 2021 in Colorado. The model also found that a single two-hour capacity shortfall event would occur if 2019 demand and capacity factor conditions were assumed.

Figures 10 and 11 show electricity demand and supply by generation source for a hypothetical period in the future ranging from February 13, 2040, to February 15, 2040. The differences show how an electric grid wholly reliant on intermittent resources is entirely at the mercy of mother nature for positive outcomes.

Figure 10. Under 2022 conditions, there would be no blackouts in 2040, thanks to favorable wind and solar output and relatively low demand.

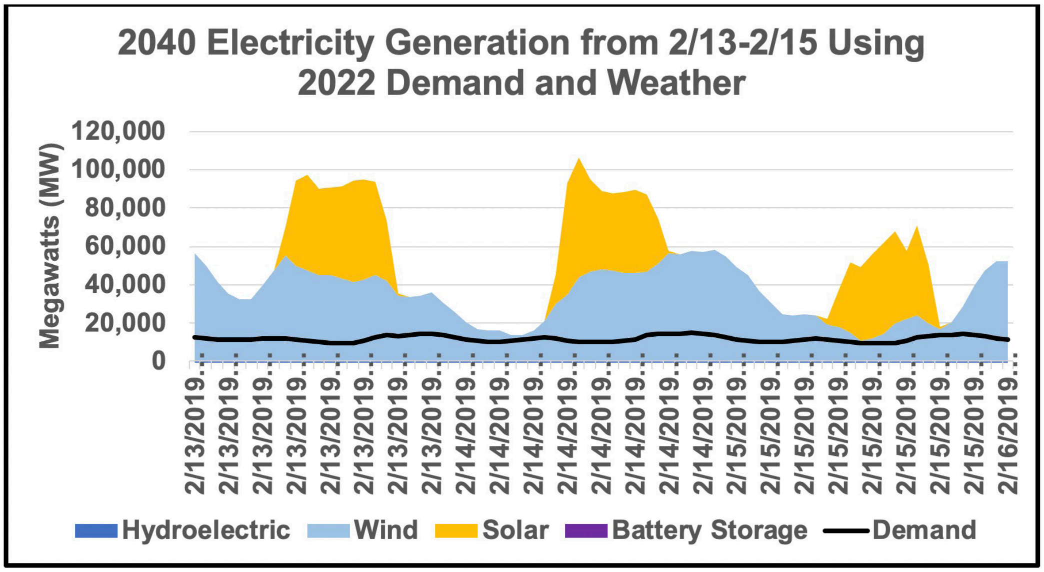
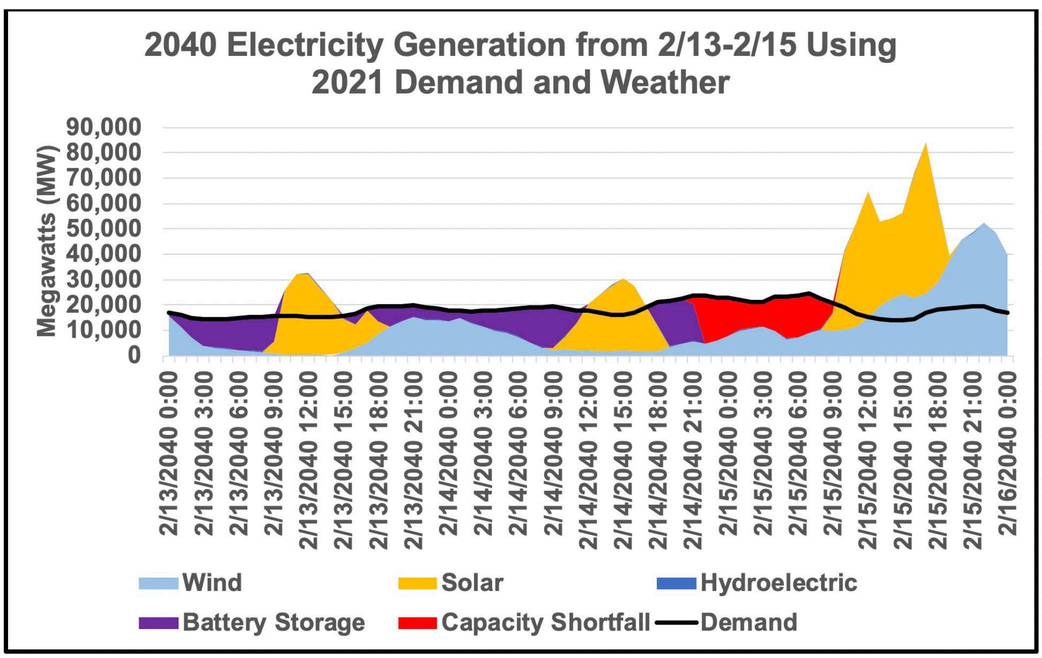


Figure 11. Under 2021 conditions, nearly 260 GW of renewables and battery capacity would not be enough to avoid a blackout (shown in red) due to an extended period of low wind and solar output.



Assuming 2022 demand and weather data, the grid runs under the Polis Plan without a hitch. However, assuming 2021 demand and weather data from the same period, there would be a 13-hour blackout beginning on the evening of February 14 and continuing through the following morning.

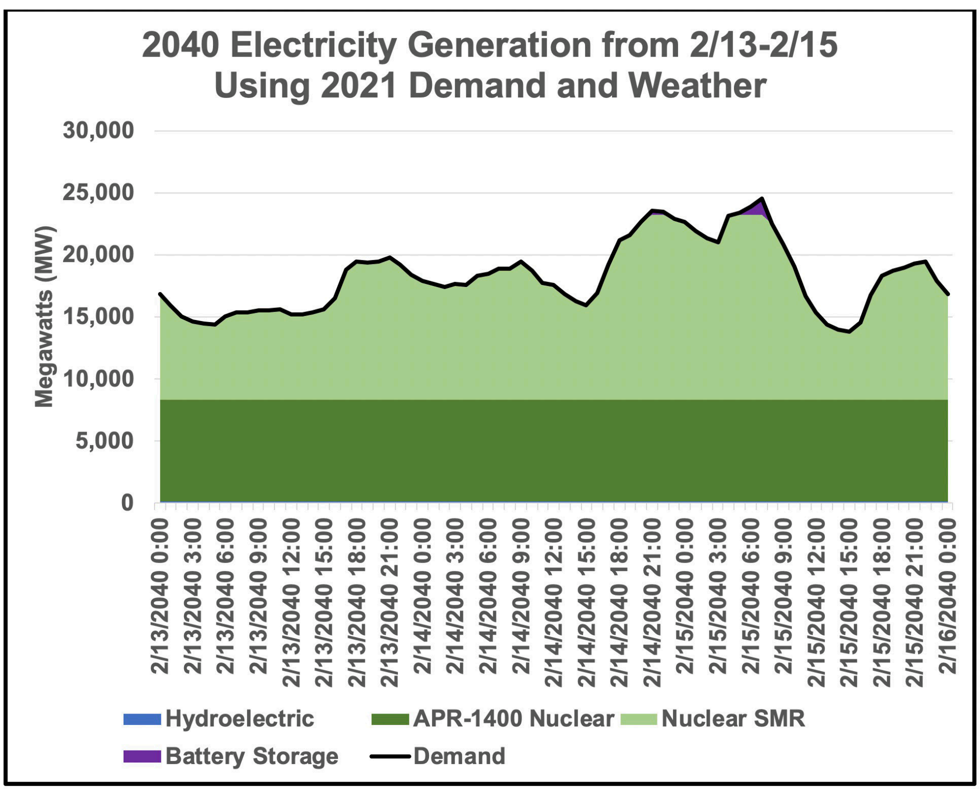
THE LCD SCENARIO

Under the LCD Scenario, Colorado would maintain a reliable grid despite the increased demand for electric home heating and significant electric vehicle usage.

While the Polis Plan would result in multiple capacity shortfalls due to unfavorable demand and weather patterns, Colorado's grid would fare much better under the LCD Scenario.

Under the LCD Scenario, Colorado would maintain a reliable grid despite the increased demand for electric home heating and significant electric vehicle usage. As a result, the model found zero hours of capacity shortfalls regardless of the model year demand and weather conditions chosen. Figure 12 shows enough dispatchable capacity on Colorado's grid in the LCD Scenario to reliably meet electricity demand for every hour the Polis Plan suffered its worst performance.

Figure 12. This is the same period that the wind, solar, and battery storage scenario saw a major 13-hour blackout. In this scenario, the shortfall event never occurs because the grid can use APR-1400 plants as a steady baseload energy source, SMR plants as a ramping resource, and battery storage to cover any extreme peaks.



In the LCD Scenario, SMRs increase and decrease their output to perfectly match changes in electricity demand. APR-1400 nuclear plants and the state's remaining hydroelectric facilities act as baseload power plants, providing steady, reliable power around the clock. The limited battery storage capacity built relative to the Polis Plan discharges only during periods of extreme demand to help firm up the grid.

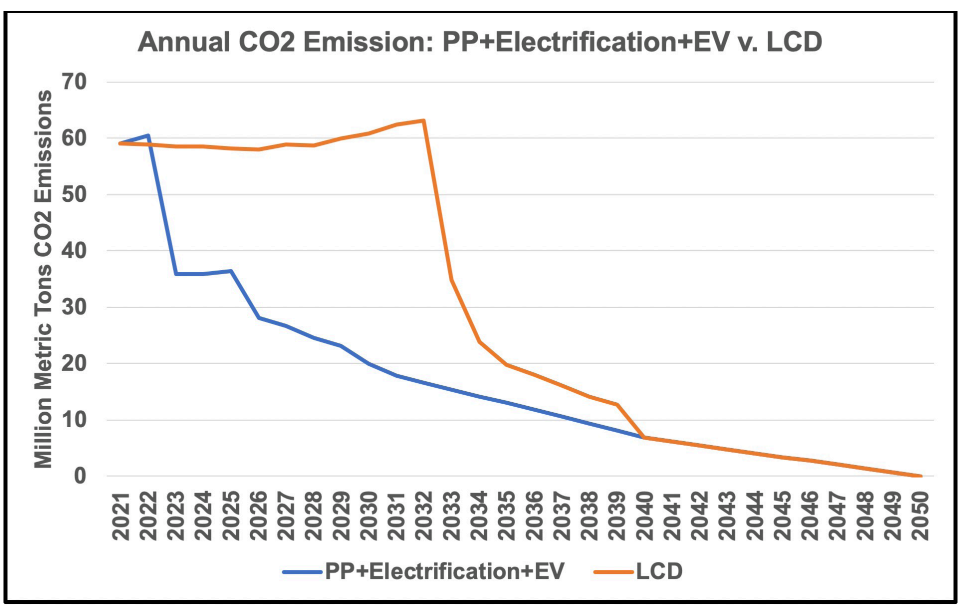
CARBON EMISSIONS REDUCTIONS

The push to replace internal combustion engine vehicles in Colorado, much like the one to replace fossil fuel usage in buildings and power plants, is centered around reducing carbon dioxide emissions to limit the impacts of climate change. Our analysis examined how successfully each modeled proposal accomplishes that goal and what the costs and benefits of doing so reveal.

According to state data, transportation is the leading emitter of any sector in Colorado, displacing electricity in 2020.[29] Light-duty passenger vehicles are currently the single largest source of emissions within the transportation sector.[30] Light-duty passenger vehicle emissions combined with those of the electricity and home heating sectors are approximately 59.1 million metric tons (mmt) of annual CO2 emissions. The Polis Plan and the LCD Scenario would reduce this figure to near zero annually, though each plan would do so at different paces (Figure 13).

In the LCD Scenario, SMRs increase and decrease their output to perfectly match changes in electricity demand. APR-1400 nuclear plants and the state's remaining hydroelectric facilities act as baseload power plants, providing steady, reliable power around the clock.

Figure 13. Under the Polis Plan with home heating and light-duty vehicle electrification, Colorado would avert 1.3 billion metric tons of cumulative CO2 emissions relative to 2021 levels by 2050. This is an average of 44.8 million metric tons of avoided CO2 emissions annually through 2050. Under the LCD scenario, Colorado would avert 880.9 million metric tons by 2050, or 30.4 million metric tons per year through 2050.



Because climate change is a global problem, and since emissions don't respect geographical boundaries, it is essential to put the potential temperature impact of reducing CO_2 emissions by 59.1 million metric tons in a global context using past government estimates as a guide.

In 2015, the Obama Administration unveiled its Clean Power Plan (CPP), a series of Environmental Protection Agency (EPA) guidelines and regulations designed to wring carbon emissions out of the U.S. electricity sector.[31] The Obama administration claimed the CPP would have reduced annual CO_2 emissions nationally by 730 million metric tons by 2030.

The Obama administration's EPA used a climate model called the Model for the Assessment of Greenhouse Gas Induced Climate Change (MAGICC) to determine the CPP's impact on future atmospheric warming. It estimated that the CPP would have reduced future warming by 0.019° C by 2100.

The 59.1 million metric tons of CO_2 no longer emitted from power plants, residential furnaces, and internal combustion engine vehicles currently serving Coloradans under either of the modeled scenarios would account for 8 percent of the 730 million metric tons averted by the CPP. From this figure, we can extrapolate that the Polis Plan and LCD Scenario would avert 8 percent of the 0.019° C by 2100 for a potential future temperature reduction of 0.0015° C by 2100 —an infinitesimal fraction of global temperature reductions required to avert the worst impacts of climate change.

The Social Cost of Carbon

> When evaluating policies to reduce greenhouse gas emissions, it is essential to weigh the cost of reducing emissions against its expected benefits.

When evaluating policies to reduce greenhouse gas emissions, it is essential to weigh the cost of reducing emissions against its expected benefits. If the costs associated with a strategy for reducing emissions exceed the expected benefits, the policy is economically inefficient, and vice versa.

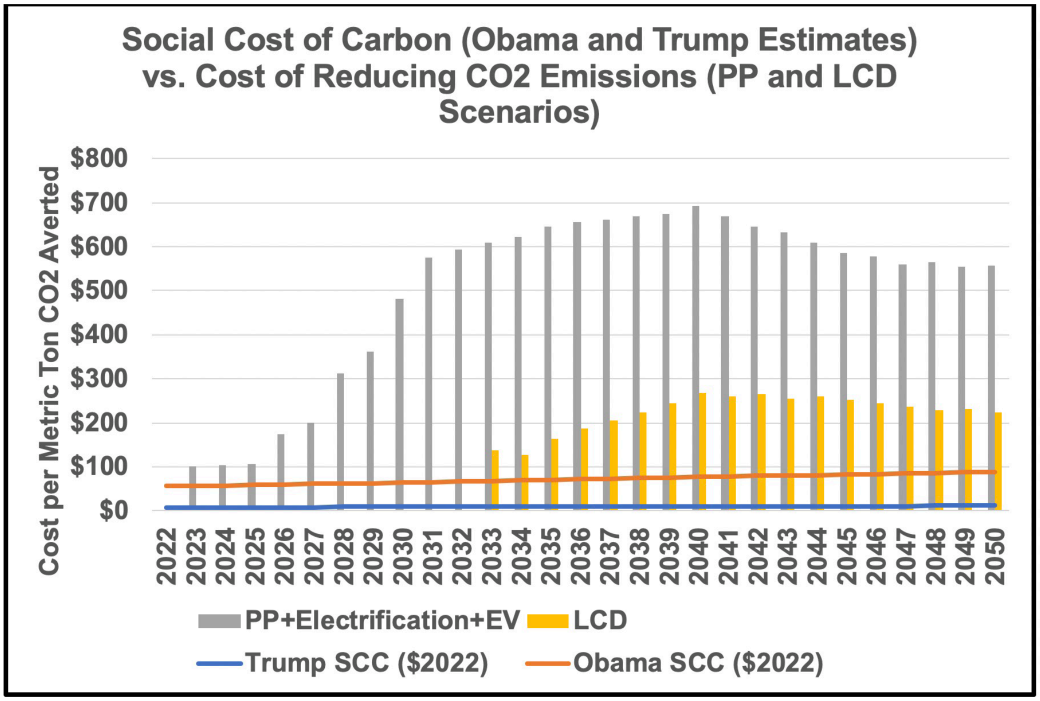
To conduct this cost-benefit analysis, lawmakers, regulators, and private organizations often rely on a metric known as the Social Cost of Carbon (SCC) when weighing their options. The SCC is an attempt to estimate the marginal economic cost (in dollars) of emitting one additional ton of carbon dioxide into the atmosphere based on the damage done by a warming climate. In reverse, it can also be considered the marginal economic benefit of reducing each additional ton of emissions.[32]

Like the LCOE estimates discussed earlier in this report, SCC estimates can have serious shortcomings based on what assumptions are included when arriving at a particular number.[33] Nevertheless, it can help evaluate the economic rationality of pursuing a given climate policy.

Figure 14 shows the cost of reducing each ton of carbon dioxide through the year 2050 under the Polis Plan and the LCD Scenario. It compares it to the different social cost of carbon estimates used by the Obama and Trump administrations.

Under the Polis Plan and residential electrification scenario, the average cost of reducing carbon dioxide emissions would be $548 per metric ton reduced through

Figure 14. The cost of reducing CO2 emissions under the Polis Plan and LCD Scenario exceeds the high and low SCC estimates used by the Obama and Trump administrations, respectively.



2050. Under the LCD Scenario, the average cost of reducing carbon dioxide emissions would be $238 per metric ton reduced through 2050.

While the LCD Scenario would reduce emissions at far lower expense, the average cost of reducing carbon emissions under both scenarios is higher than the different social cost of carbon values the Obama and Trump administrations relied on. This means that the costs of implementing either scenario to reduce emissions would outweigh the economic benefit of doing so.

Given the high cost of reducing carbon dioxide emissions under both the Polis Plan and the LCD Scenario, it would be rational to reevaluate the assumptions of either proposal. While there are undoubtedly non-monetary benefits to reducing power plant and household emissions, the economic costs of implementing each strategy under the timeline envisioned far outweigh the environmental benefit.

Compliance with the 100 percent renewable electricity and all-electric residential space heating and light-duty transportation mandates envisioned by the Polis Plan would cost Coloradans $695.3 billion through 2050.

CONCLUSION

Compliance with the 100 percent renewable electricity and all-electric residential space heating and light-duty transportation mandates envisioned by the Polis Plan would cost Coloradans $695.3 billion through 2050. This would result in the typical Colorado ratepayer paying an average monthly electricity bill of $907 through 2050, up from just $180 in 2021 – a more than five times increase. By contrast, the nuclear-focused LCD Scenario would cost Colorado residents $209.4 billion through 2050. It would average monthly bills for the typical ratepayer by $270 per month over the same period.

Polis Plan costs are driven primarily by the need to massively and rapidly overbuild new wind and solar facilities to bolster the grid and ensure enough generation to support electric home heating and sufficient charging for electric vehicles. That rapid capacity increase drives additional costs associated with the need for new transmission lines to move power and large amounts of battery storage to ensure reliability when the wind does not blow and the sun does not shine. This capacity expansion would also result in added expenses to cover electric utility profits and the property taxes for this massive increase in new physical assets.

Ultimately, the idea behind powering a growing state like Colorado with nothing more than weather-dependent energy and expensive batteries while reorienting how most Coloradans keep warm in the winter and travel daily is little more than an expensive pipe dream.

LCD Scenario costs are driven mainly by the high upfront costs of building new nuclear power plants and four-hour battery storage facilities to quickly replace retiring fossil fuel plants. Those new nuclear plants would also drive increased costs for transmission lines, utility profits, and property taxes, but to a far lesser extent than under the Polis Plan.

Ultimately, the idea behind powering a growing state like Colorado with nothing more than weather-dependent energy and expensive batteries while reorienting how most Coloradans keep warm in the winter and travel daily is little more than an expensive pipe dream. Even under the less costly nuclear scenario modeled here, the extensive and costly nuclear buildout required is likely little more than a theoretical exercise.

Polling shows Coloradan voters are most concerned with the reliability and affordability of their power.[34] Those concerns should not be swept aside to meet arbitrary mandates set by politicians who will be out of office long before the deadlines they set come to pass, and the bill comes due.

APPENDIX

STUDY ASSUMPTIONS:

- Hourly EV charging data from Norway were used to create load profiles.[35]
- These data were adjusted to account for the fact that Colorado residents drive more miles than Norway residents.
- Chargers were assumed to draw 7.6 kW.
- Assumes 940,000 EVs on the road by 2030, under Governor Polis's stated goal, and continues this trend through 2050 until all 5.35 million vehicles in Colorado[36] are transitioned to EVs.

CHARTS

Annual Capacity Additions and Retirements Under Each Plan

Polis Plan+Electrification+EVs

	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
Coal	0	(383)	0	0	(842)	0	(828)	(636)	(1,035)	(857)	0	0	0	0
Natural Gas (CC)	0	(84)	0	0	0	0	0	0	(288)	(288)	(288)	(288)	(288)	(288)
Natural Gas (CT)	0	0	0	0	0	(185)	0	0	(235)	(235)	(235)	(235)	(235)	(235)
Natural Gas (ST)	0	(208)	0	0	0	0	(310)	0	0	0	0	0	0	0
Petroleum	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Wind	0	4,705	0	0	5,876	1,289	7,936	4,439	10,874	9,628	3,651	3,651	3,651	3,651
Solar	0	7,042	0	0	8,795	1,929	11,878	6,644	16,274	14,410	5,465	5,465	5,465	5,465
Storage	0	2,672	0	0	3,337	732	4,507	2,521	6,175	5,468	2,074	2,074	2,074	2,074

2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050	Total
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	(4,581)
(288)	(288)	(288)	(288)	(288)	0	0	0	0	0	0	0	0	0	0	(3,255)
(235)	(235)	(235)	(235)	(235)	0	0	0	0	0	0	0	0	0	0	(2,772)
0	0	0	0	(98)	0	0	0	0	0	0	0	0	0	0	(616)
0	0	0	0	(151)	0	0	0	0	0	0	0	0	0	0	(151)
3,651	3,651	3,651	3,651	5,385	549	549	549	549	549	549	549	549	549	549	84,832
5,465	5,465	5,465	5,465	8,059	821	821	821	821	821	821	821	821	821	821	126,959
2,074	2,074	2,074	2,074	3,058	312	312	312	312	312	312	312	312	312	312	48,175

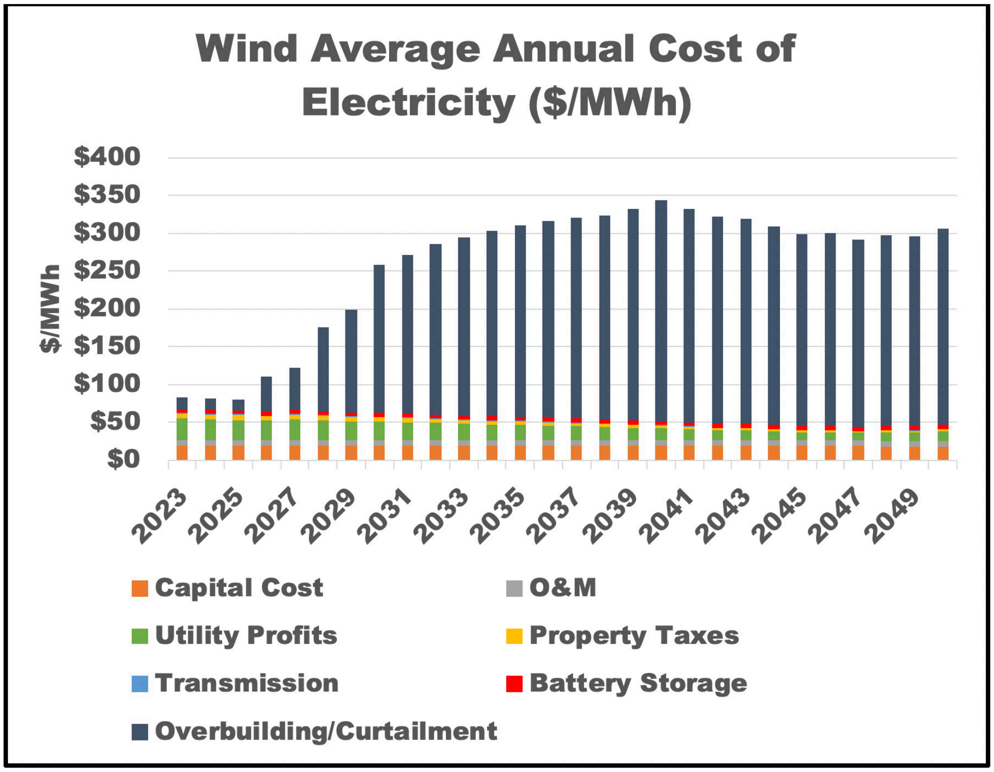
LCD Scenario

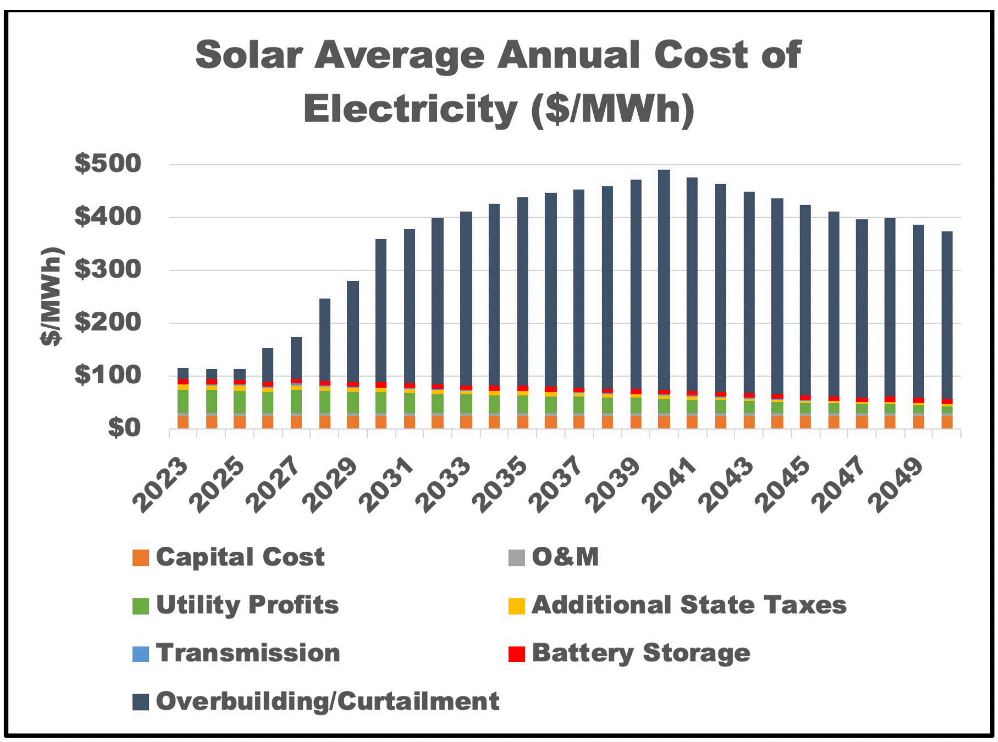
	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
Coal	0	0	0	0	0	0	0	0	0	0	0	(383)	0	(396)
Natural Gas (CC)	0	0	0	0	0	0	0	0	0	0	0	(480)	(396)	(396)
Natural Gas (CT)	0	0	0	0	0	0	0	0	0	0	0	(508)	(323)	(323)
Natural Gas (ST)	0	0	0	0	0	0	0	0	0	0	0	(518)	0	0
Petroleum	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Wind	0	0	(190)	(1)	(61)	(774)	(0)	(174)	(57)	(499)	(478)	(32)	(241)	(418)
Solar	0	0	0	0	0	0	0	0	0	0	(8)	(3)	(3)	(27)
Natural Gas (CT)	0	0	0	2,000	0	0	0	0	0	0	0	0	0	0
Nuclear SMR	0	0	0	0	0	0	0	0	0	0	0	2,200	1,600	1,600
Nuclear APR-1400	0	0	0	0	0	0	0	0	0	0	0	2,800	0	1,400
Storage	0	0	0	0	0	0	0	0	0	0	0	500	500	500

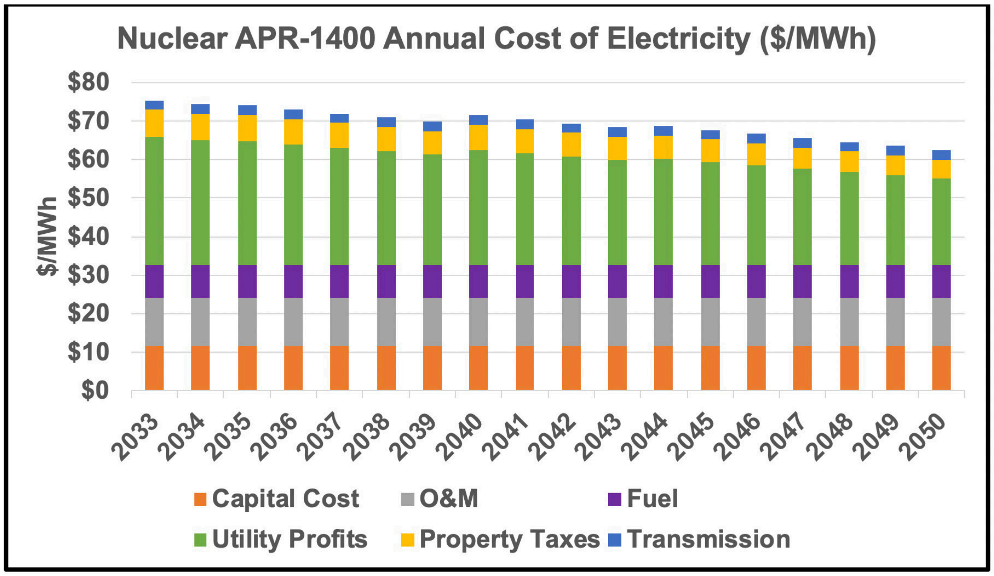
2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050	Total
(465)	(446)	(446)	0	(2,445)	0	0	0	0	0	0	0	0	0	0	(4,582)
(396)	(396)	(396)	(396)	(396)	0	0	0	0	0	0	0	0	0	0	(3,255)
(323)	(323)	(323)	(323)	(2,323)	0	0	0	0	0	0	0	0	0	0	(4,772)
0	0	0	0	(98)	0	0	0	0	0	0	0	0	0	0	(616)
0	0	0	0	(151)	0	0	0	0	0	0	0	0	0	0	(151)
(64)	(80)	(598)	(54)	(953)	(96)	0	0	0	0	0	0	0	0	0	(4,770)
(45)	(30)	(5)	(7)	(65)	(225)	(43)	(70)	(75)	(74)	(87)	0	0	0	0	(768)
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2,000
1,600	1,600	1,600	1,600	2,400	0	800	0	0	0	0	0	0	800	0	15,800
0	0	0	0	2,800	0	0.0	0	1,400	0	0	0	0	0	0	8,400
500	500	500	500	0	0	0	0	0	0	0	0	0	0	0	4,000

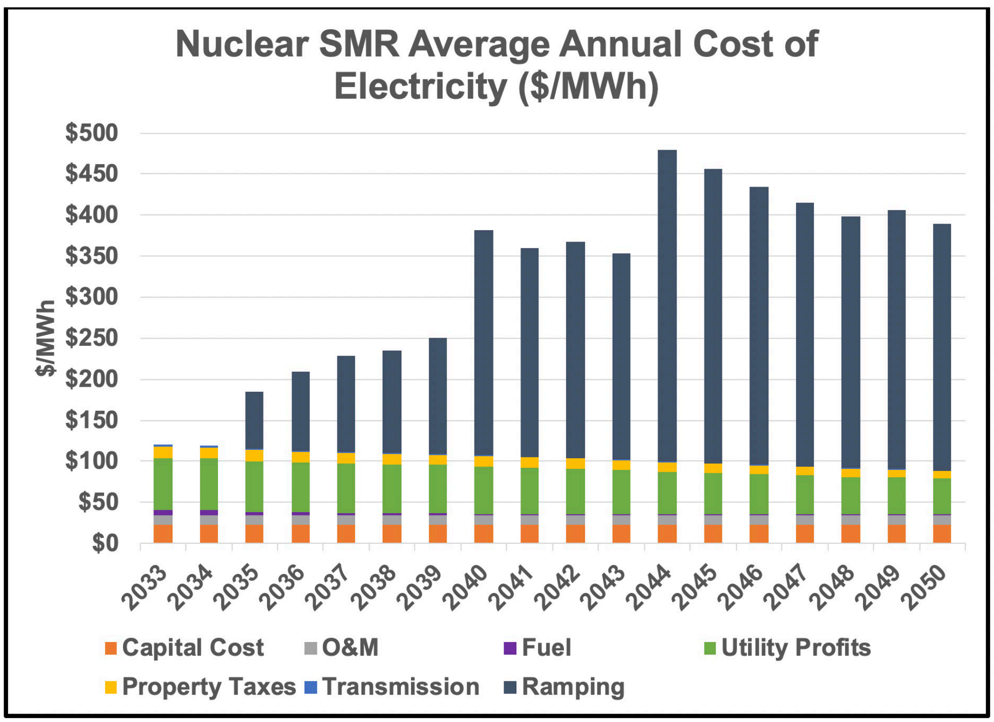
Average Cost of Annual Capacity Additions

Polis Plan+Electrification+ Average Annual Costs by Resource



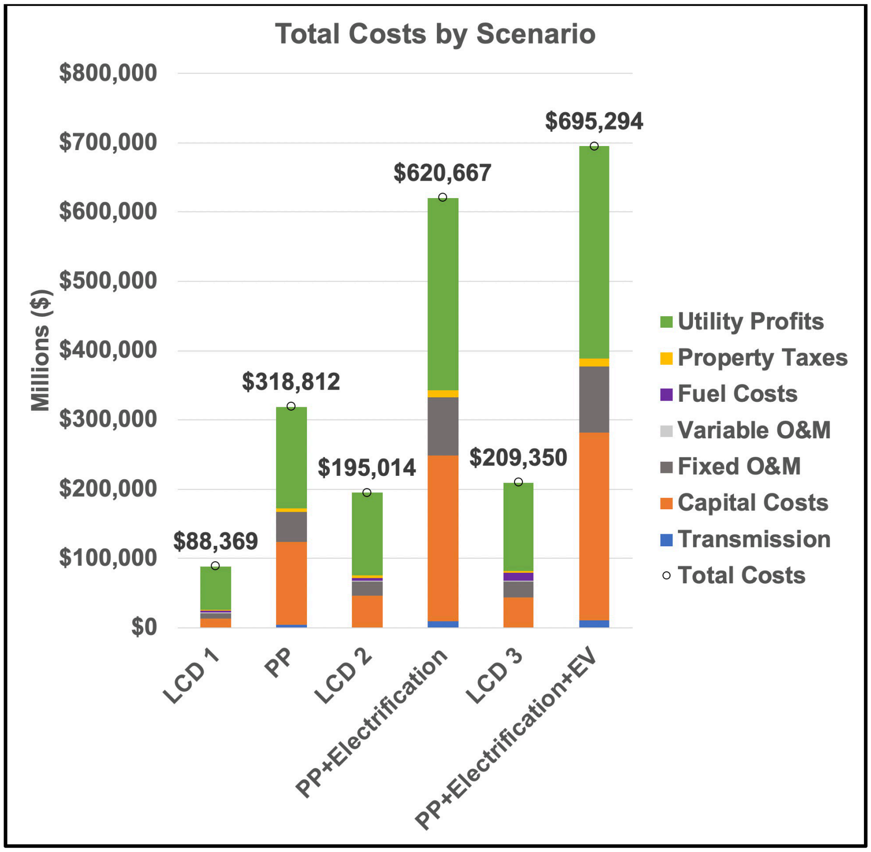


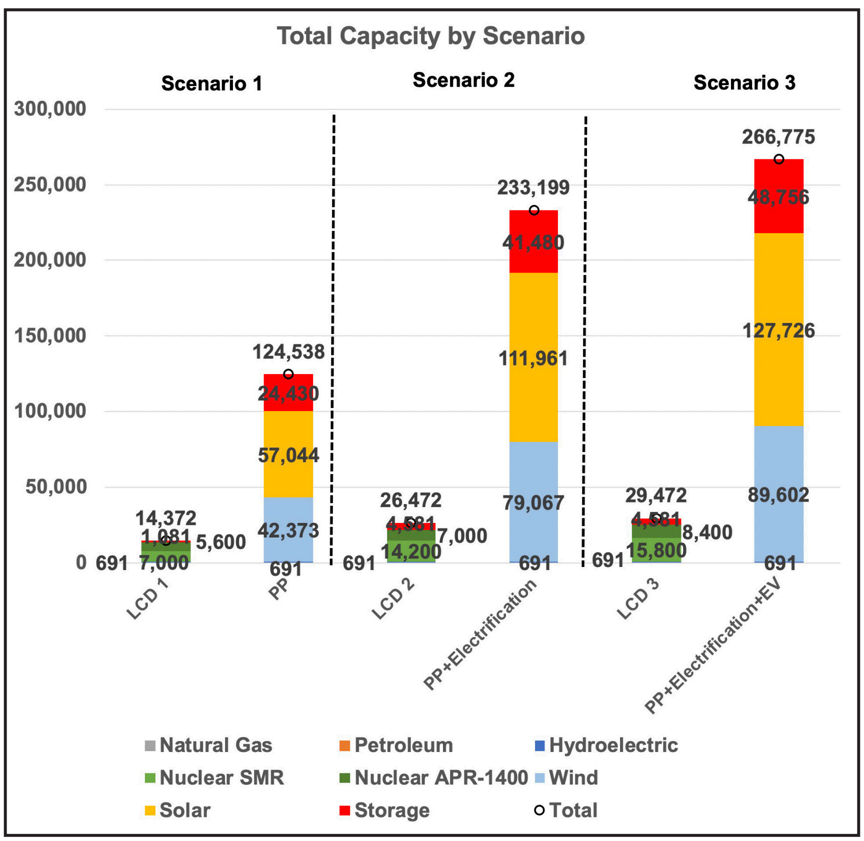




LCD Scenario+Electification+EVs By Resource

Total Capacity and Cost by Scenario for Colorado's Energy Future Series





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