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Colorado's Energy Future:

The High Cost of 100 Percent Electric Home Heating

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

Part 2 of 3

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Authors' Note: This report is the second 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 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 residential heating combined with Colorado Governor Jared Polis's goal of a 100 percent renewable electricity grid by 2040 (hereafter, Polis Plan+electrification) would cost Coloradans up to $620.7 billion through 2050.
- Residential home heating electrification alone would cost approximately $302 billion through 2050.
- Colorado electricity customers (residential, commercial, and industrial) would see their average monthly electricity bills increase to $797 through 2050. They would peak at an average of $1,143 in 2040.
- The typical Colorado household would see their average monthly electricity bills increase to an average of $566 through 2050, and they would reach as high as an average of $856 in 2040.
- To meet Colorado's present-day electricity demand as well as the additional demand created by electrifying home heating with only wind, solar, existing hydropower, and batteries, the state would need to install twelve times the generation capacity currently on the grid.
- Despite this massive increase in installed capacity, Colorado would still experience 26 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 and residential home heating decarbonization goals on the same timeline, without reliability issues and at less than a third of the cost, by transitioning the state's generating assets to nuclear energy.

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INTRODUCTION

"Natural gas, while far from ideal as a fuel source, might play a necessary role in helping us reach the clean energy future our children deserve."

Those are the words of Michael Brune, the former executive director of the Sierra Club, describing his organization's attitude toward working hand and hand with the natural gas industry to go after coal.[1]

Once viewed as a favorable ally of the environmental movement, natural gas has quickly become a pariah. Today, Brune's former group and other climate activists have radically changed their position to outright hostility toward ongoing natural gas use. Now, they are waging an all-out pressure campaign in legislative bodies across the country, urging city councils, state legislatures, and administrative agencies to enact new bans on natural gas in buildings for uses ranging from space and water heating to cooking.

What began as a first-of-its-kind ban on new natural gas hookups in 2019 in Berkeley, California, has turned into a nationwide movement.[2] To date, more than 100 cities plus the state of New York have since passed gas bans of their own to push their citizens toward electrification.[3]

It has even begun to spread in Colorado, despite the state's reputation as an oil and gas powerhouse. Crested Butte became the first jurisdiction in the state to enact a natural gas ban as part of its updated building codes in 2022.[4] It has since been followed by the City of Lafayette,[5] while climate-minded city councilors in Boulder and Denver prepare to do the same.[6]

Even the state has started to creep toward that direction by establishing state minimum building code standards, once entirely the purview of autonomous local governments, that will eventually address the future of natural gas use in buildings statewide in the next year.[7]

While all the policy momentum in Colorado and many other blue jurisdictions across the country has indeed been racing in pursuit of so-called beneficial electrification, there must be more concrete estimates on the costs and grid reliability impacts such a transition would incur. The few studies that have examined the effect of electrification policies in Colorado have focused primarily on cost and have varied wildly in their estimates depending on the inputs and assumptions included—from $50.2 billion to $488 billion.[8]

While all the policy momentum in Colorado and many other blue jurisdictions across the country has indeed been racing in pursuit of so-called beneficial electrification, there must be more concrete estimates on 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 its price estimate on the state's goal of residential building electrification, focusing specifically on space heating, 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 consequential factors on Colorado voters' minds regarding energy policy.[9]

Building on the work done in part one of this series,[10] it will examine the cost of transitioning Colorado's natural gas home heating to electric home heating, using a combination of heat pumps and electric resistance heating, on a 100 percent renewable 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 residential 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,[11] and innovative small-modular reactors (SMRs).

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 supporting fully electric home heating without sacrificing the electric grid's reliability.

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

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 home heating, be sure to refer to our previous paper: *Colorado's Energy Future: The High Cost of 100% Renewable Electricity by 2040.*[12]

LIMITATIONS

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

First, the lack of more robust hourly natural gas data presents challenges. An attempt was made to get data from Xcel, Colorado's largest natural gas utility servicing approximately 1.4 million residents. Unfortunately, our researchers were unsuccessful. Instead, our analysis had to rely on hourly natural gas data from Colorado Springs Utilities, which, as a municipally owned gas provider, is subject to open records requests that enabled us to receive data on which to base our research. Colorado Springs Utilities services approximately 220,000 gas customers, according to its website, so the data it provided is a much smaller sample size than we would have preferred.[13]

An attempt was made to get data from Xcel, Colorado's largest natural gas utility servicing approximately 1.4 million residents. Unfortunately, our researchers were unsuccessful.

Second, the total cost we arrived at to support a 100 percent renewable grid with fully electric residential home heating does not consider certain additional costs and benefits. For example, we calculated that residential electrification would save Coloradans $43.9 billion in fuel costs that would otherwise go toward purchasing natural gas for use in heating.[14] These savings are not factored into the total additional costs for the scenarios.

At the same time, our modeled costs do not include the money spent purchasing and installing heat pumps for each Colorado home, nor do they include potential upgrades needed to the electrical distribution system or to individual home fuse boxes to enable larger power draws on the system to support electric heating appliances. They also do not account for stranded asset costs in the legacy natural gas distribution system that will ultimately fall on the shoulders of ratepayers to cover as more homes transition off gas heating. These costs and benefits would undoubtedly alter the final cost figures we arrived at in our model.

Additionally, the plan for widespread residential home heating is complicated by logistical concerns not accounted for in our analysis. These include well-documented labor shortages for skilled electrical workers needed to install heat pumps and other electrification equipment.[15] They also include land-use concerns from residents living in areas where an enormous amount of renewable generation capacity would need to be built to support electrification. There has already been a well-documented growth in local opposition to renewable energy projects—which are generally more land-use intensive than other energy resources[16]—in rural areas across the country.[17,18]

Our analysis found that the Polis Plan would require an immense amount of new renewable capacity—over 74,000 MW of wind alone, for example. Though wind project land use can vary widely, under a 60 acres of indirect land use per megawatt rule of thumb, our model's wind capacity would require more than 4.4 million acres. To put that into perspective, that's roughly the size of Larimer, Boulder, Broomfield, Adams, Arapahoe, Douglas, Denver, Gilpin, and Clear Creek counties. It's hard to imagine such an extensive buildout of energy infrastructure over such broad swaths of the state not inviting some level of resistance from conservationists, farmers, outdoor recreation interests, or simply run-of-the-mill not-in-my-backyard types.

Finally, we only examine the impact of electrifying residential home heating due to limited time and resources. This unquestionably falls short because the project of so-called beneficial electrification is broader in scope. Indeed, the goal is to replace natural gas use in all buildings—residential, commercial, and industrial—and for all purposes, including cooking, water heating, and more.

Nevertheless, the high costs we found to electrify Colorado's home heating with the support of a fully renewable electric grid highlight how astronomical the total costs would be under a complete electrification scenario.

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THE POLIS PLAN+ELECTRIFICATION

As part of his "Roadmap to 100% Renewable Energy by 2040 and Bold Climate Action," released in 2019, Governor Jared Polis set the stage for the state to attempt economywide building decarbonization.

In addition to, as the name suggests, directing the state to procure 100 percent renewable electricity, Polis directed his administration to "develop a blueprint for building electrification."[19] Beyond the occasional word encouraging electrification, a formal blueprint detailing specific benchmarks has yet to materialize. However, his administration has begun to take small policy steps to shepherd the state and its utilities toward his ultimate goal of total building electrification.

In 2021, Polis signed a bill requiring the state's investor-owned utilities to file plans with the Public Utilities Commission (PUC), demonstrating how they will encourage and promote "beneficial electrification" to their customers every three years.[20] Beneficial electrification is defined in state statute as "a utility's change in the energy source powering an end use from a nonelectric source to an electric source, including transportation, water heating, space heating, or industrial processes."[21]

That same year, he also signed a bill requiring each of the state's gas-distribution utilities (GDUs) to begin filing "Clean Heat Plans" with the PUC demonstrating how they plan to slash their greenhouse gas emissions (GHG) by at least 22 percent by 2030.[22] One of the strategies named in the bill that GDUs must consider is beneficial electrification.

And perhaps most overtly, Polis signed House Bill 1362 in 2022, establishing minimum green energy code requirements that local governments across the state must adopt.[23] Under the bill, local governments must adopt and enforce a code that meets or exceeds the 2021 International Energy Conservation Code (IECC) and the state's model electric-ready and solar-ready code language when updating any other building code after July 1, 2023. Additionally, local governments must adopt the state's "low energy and carbon" code when updating any building code after July 1, 2026, language the Colorado Energy Office Director Will Toor has already said will likely include a ban on natural gas hookups in buildings.[24]

Beyond these early steps to push the state toward full electrification, the Polis administration has yet to officially announce a concrete deadline by which all buildings will be electrified. For our analysis, we assume a 2040 deadline per the Governor's goal for 100 percent renewable energy in the electricity sector.

Complying with the Polis Plan and residential electrification mandates 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.

While that may prove more aggressive than the administration intends, it is likely close to what is planned, given that the state is now under a statutory obligation to reduce economywide GHG emissions 100 percent by 2050.[25]

This analysis examines the cost, electricity infrastructure needs, and reliability implications of complying with the Polis Plan analyzed in part one of this series, with the added task of converting all fuel-based residential home heating to electricity-based resources.

It compares it to the LCD Scenario, which prioritizes providing the most reliable carbon-free electricity for Colorado ratepayers regardless of categorization under any definition of renewable while still supporting electrified home heating statewide.

Complying with the Polis Plan and residential electrification mandates 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 any federal, state, or local subsidies available to wind, solar, battery storage, or nuclear facilities. Nor does it include any incentives or rebates made available for purchasing and installing heat pumps and other electric heating resources because subsidies and tax credits do not reduce the cost of producing energy or space heating; 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 at the same pace and scale envisioned by the Polis Plan—100 percent by 2040.

Under the LCD Scenario, electric companies in Colorado would continue to utilize existing coal, natural gas, petroleum, 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. The state's existing hydroelectric capacity would be kept constant through 2050.

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

Nuclear power plants were selected as the modeled choice for the LCD Scenario because nuclear power is a clean firm resource, meaning it is zero-carbon and can be relied upon to supply electricity whenever needed for as long as it is needed.
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[26]—something other reactor designs have struggled with in recent years.[27]

It also has the advantage of having already been certified for use in the United States by the U.S. Nuclear Regulatory Commission.[28]

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.[29]

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 are allowed to operate through the end of their useful lives (up to 25 years) and then are replaced by new nuclear generation.

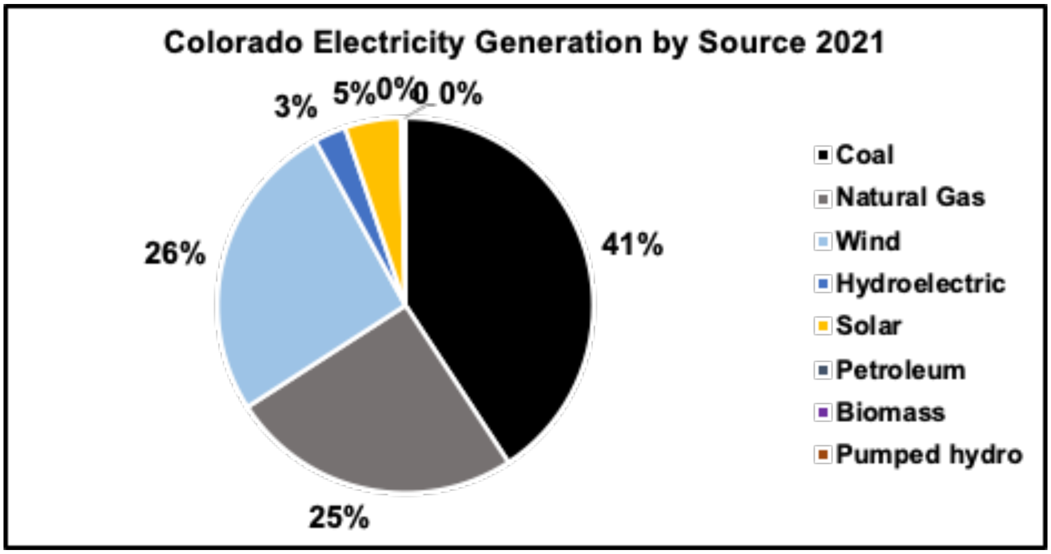
Nuclear power plants were selected as the modeled choice for the LCD Scenario because nuclear power is a clean firm resource, meaning it is zero-carbon and can be relied upon to supply electricity whenever needed for as long as it is needed.

COLORADO'S ELECTRICITY MIX AND NATURAL GAS USAGE BEFORE THE POLIS PLAN+ELECTRIFICATION

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).

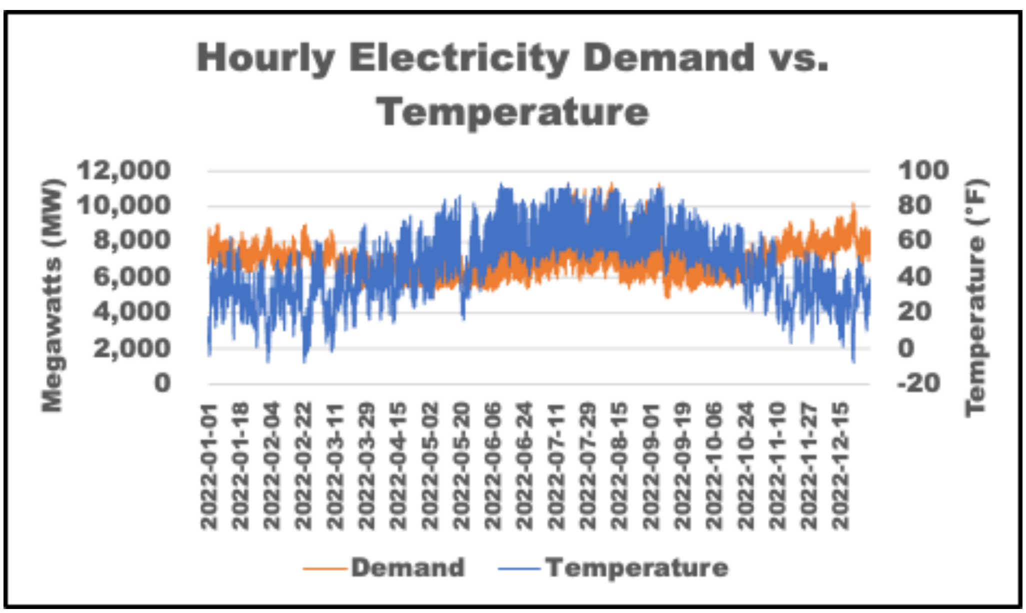
This analysis uses 2021 data as a baseline because complete 2022 data on the state's electricity mix were not yet available at the time of this report.

Figure 1. Coal, Natural Gas, and Petroleum accounted for roughly two-thirds of the electricity generated in Colorado in 2021.



Additionally, Colorado's electric grid currently operates as a summer peaking system (see Figure 2), meaning electricity demand is at its highest each year during the summer months.

Figure 2. Electricity demand currently peaks when it is hottest, primarily driven by an increased use of air conditioning. Winter peaks occur when the temperature drops below freezing.



At the same time, Colorado currently consumes more energy from natural gas than any other source by a wide margin. Natural gas now represents approximately 35 percent of the state's annual energy consumption.[30]

The residential sector is Colorado's largest consumer of natural gas, accounting for more than a third of the state's natural gas demand in 2022.[31] By comparison, the next largest consumer of natural gas in the state, the electricity sector, accounted for less than 30 percent.

The reason behind the residential sector's outsized presence in consumption is that Colorado, with its relatively cold winters, relies heavily on natural gas to stay warm. About 7 out of 10 Colorado households use natural gas as their primary home heating source, according to U.S. Energy Information Administration (EIA),[32] compared with just 47 percent of homes nationwide.[33]

By contrast, just over a quarter of Colorado households currently rely on electricity for home heating,[34] compared with 40 percent of households nationally. The remaining homes currently rely on a mix of liquid propane and wood, predominantly in rural areas of the state.

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

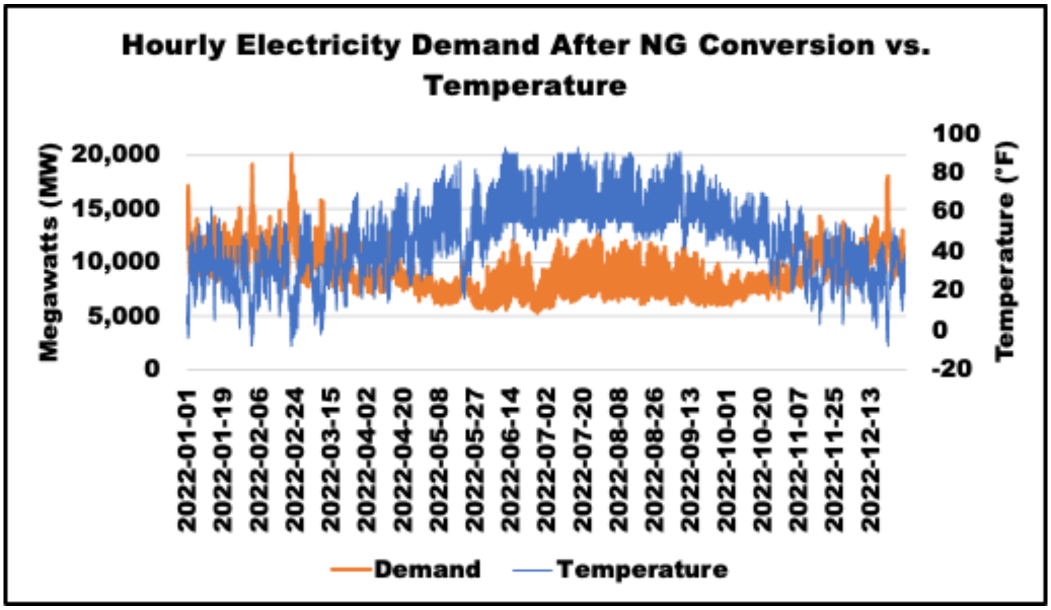
Converting Colorado's current natural gas usage for residential heating to electricity will significantly increase the demand on the state's electric grid. With that added demand comes the need to radically increase the amount of installed generation capacity on the system with the capability of meeting it.

As explained in part one of this report, compliance with the Polis Plan alone would necessitate a nearly sevenfold increase in the state's electric capacity to meet present day demand conditions.[35] Because natural gas is a highly energy-dense fuel,[36] and because it is currently consumed far more than other energy sources, replacing its output with electricity will involve a substantial increase in electricity demand, and, thus, a need for more generation than would otherwise be required.

Converting Colorado's current natural gas usage for residential heating to electricity will significantly increase the demand on the state's electric grid.

Figure 3 shows how simply converting current levels of natural gas demand in Colorado to electricity vastly changes the dynamics of the state's grid.[37]

Figure 3. After converting natural gas demand in million cubic feet (MMcf) to megawatt hours (MWh), Colorado becomes a winter-peaking system.



To support fully electrified 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.

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.

Figure 4 shows the capacity additions and retirements necessary to accommodate that energy mix by 2040, and Figure 5 shows the schedule of those additions and retirements outlined by the model.

To support fully electrified 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 226,390 MW. This would represent a roughly twelvefold increase in the size of the state's current electric grid in terms of generation capacity over the next 17 years.

Solar installations would increase the most under the Polis Plan+electrification scenario, from just 1,060 MW in 2021 to 111,193 MW in 2040. Wind capacity would grow from 4,991 MW to just over 74,298 MW in 2040. Finally, battery storage would increase from just 10 MW in 2021 to around 40,900 MW of four-hour storage by 2040. 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 108,661 MW of needed capacity is the direct result of additional electricity demand created by replacing natural gas home heating with heat pumps and resistance heaters. Despite much of that capacity going unused most of the year, it must be available to ensure the grid can meet demand during winter peaks.

...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.

Figure 4. Complying with the Polis Plan while supporting electric home heating would require roughly 12 times more installed generation capacity on the state's electric grid to serve load consistently.

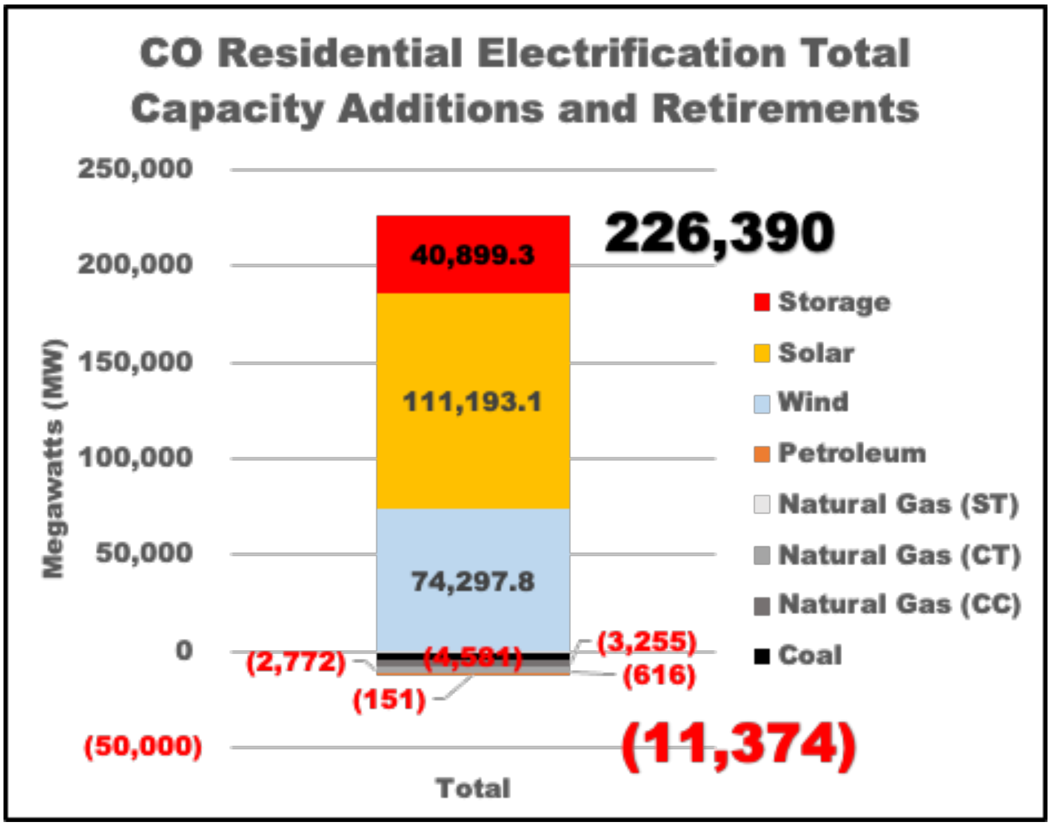
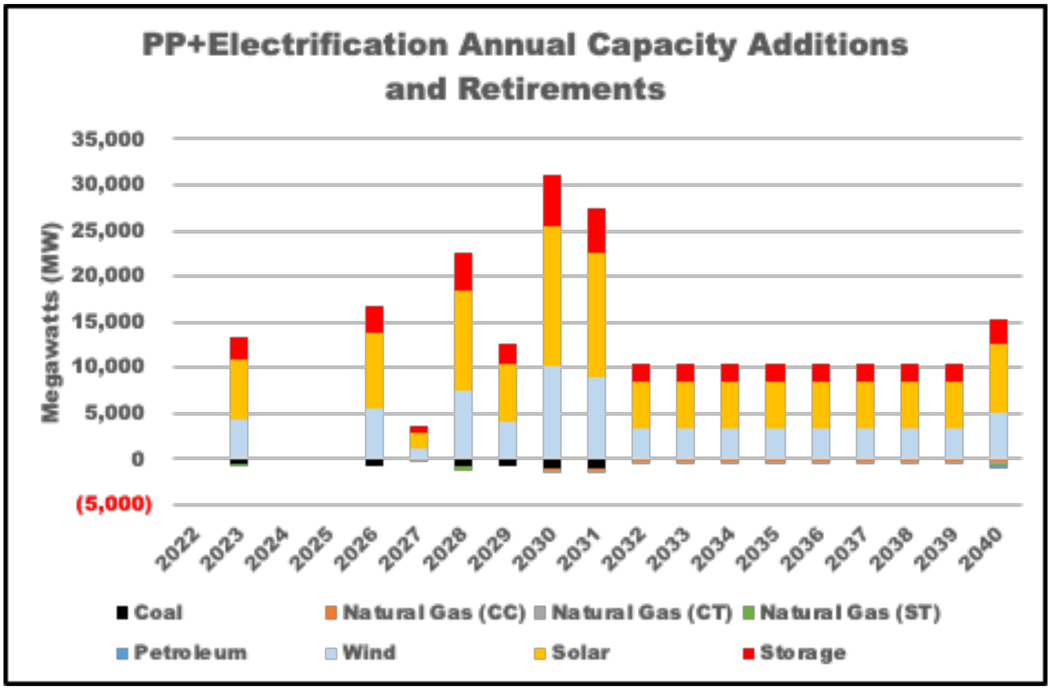


Figure 5. Installation of new renewable capacity would greatly accelerate over the next decade, peaking in 2030 to account for the closure of Colorado's last coal plant. Installations would continue steadily through the rest of the decade.



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THE LCD SCENARIO

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.

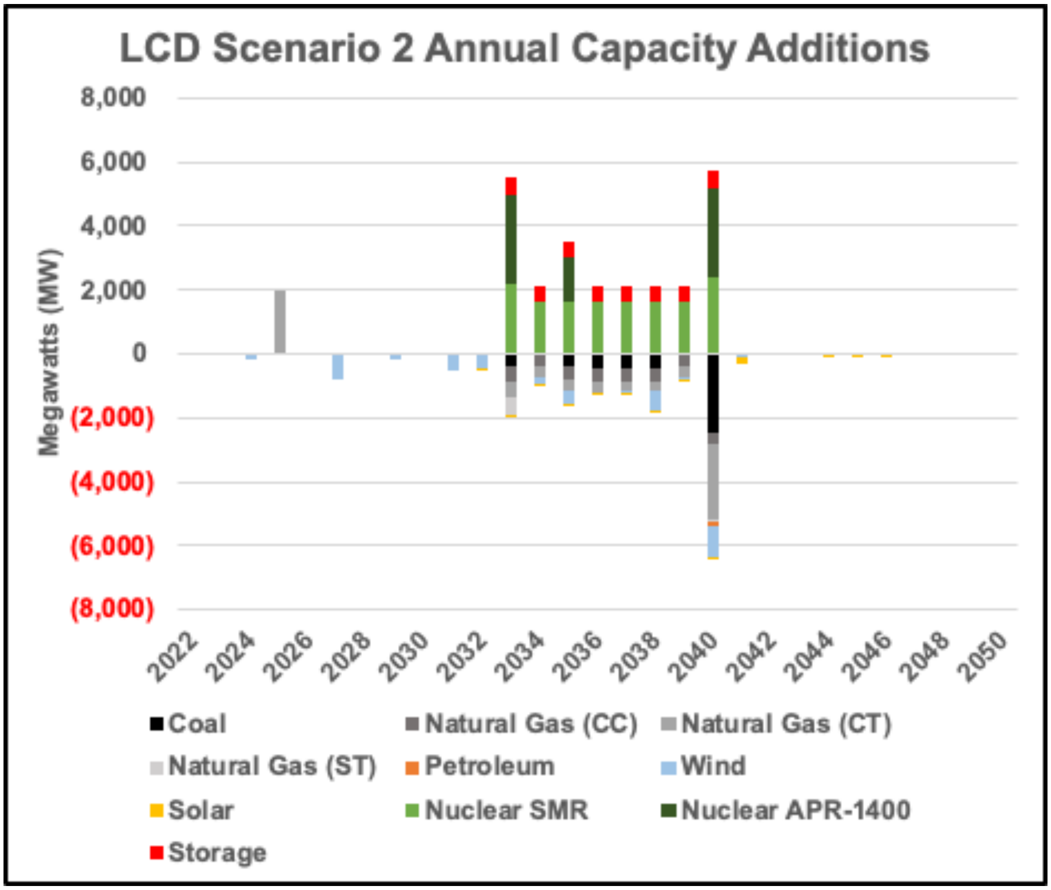
To meet Colorado's electricity demand under the LCD Scenario+electrification, the state's utilities must build 27,200 MW of replacement generation capacity by 2040. That represents an approximately 50 percent increase in installed capacity relative to the state's current grid.

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 such generation is 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 winter demand caused by early electrification adopters before the installation of new nuclear 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 6).

Figure 6. Under the LCD Scenario, existing wind and solar could 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.



Small modular nuclear reactors would be the single-largest source of new capacity under the LCD Scenario, with 14,200 MW of new capacity installed by 2040.

Small modular nuclear reactors would be the single-largest source of new capacity under the LCD Scenario, with 14,200 MW of new capacity installed by 2040. The scenario would also involve 7,000 MW of large-scale nuclear capacity represented by five new APR-1400 plants. Finally, the scenario would require 4,000 MW of four-hour battery storage (Figure 7).

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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As a result, the LCD Scenario meets the added demand caused by electrified home heating while meeting the same carbon reduction goals as the Polis Plan, but with a grid roughly one-eighth of the size in terms of installed capacity (Figure 8).

Figure 7. Small modular reactors (SMRs) are valued for their flexibility under the LCD Scenario with residential electrification. More SMR capacity is installed than any other resource.

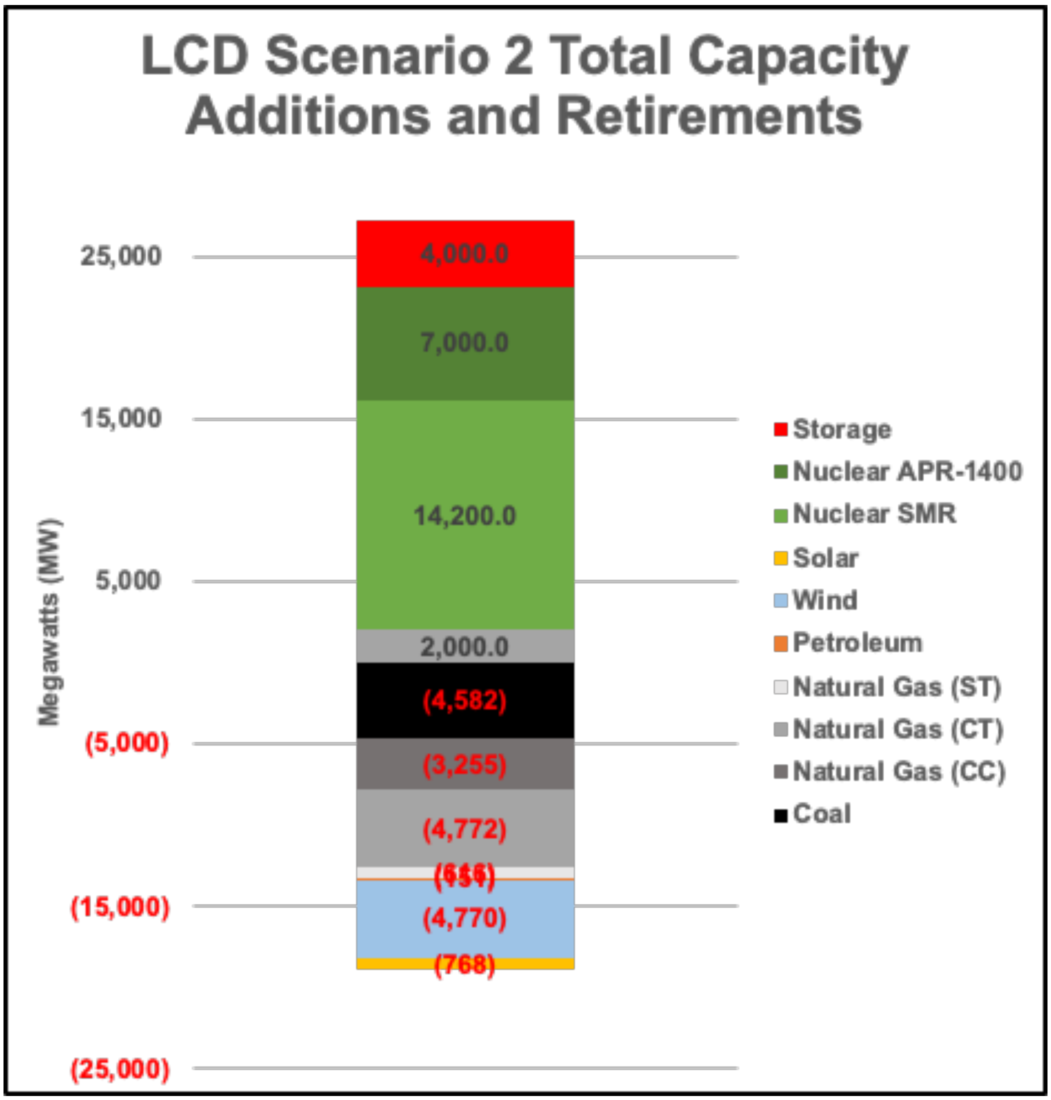
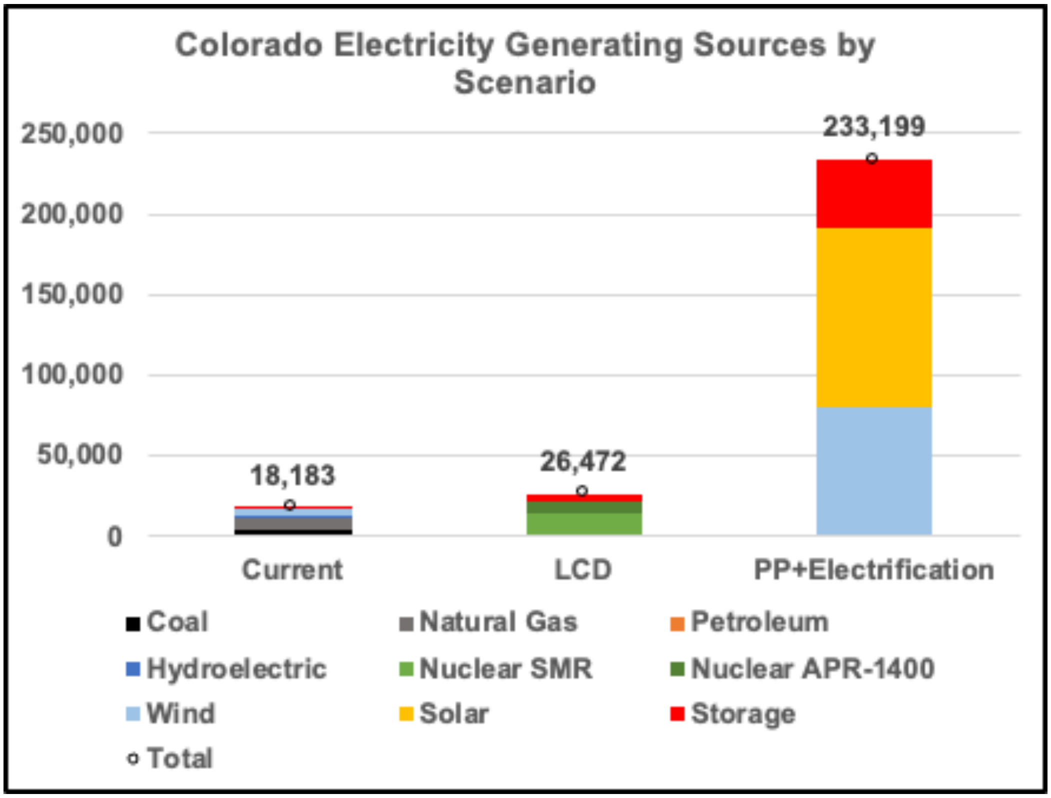


Figure 8. A comparison of the capacity currently serving Colorado as of 2021 vs. what would be required under each decarbonization scenario.



COMPARING THE COSTS OF EACH ELECTRIFICATION SCENARIO

Regardless of the method chosen, completely overhauling the way Colorado produces electricity and home heating while building out the requisite generation to support such a move over the next 17 years will be costly.

As such, residential electrification 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.

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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.[38] Modeling conducted by the Center of the American Experiment indicates that complying with statewide home-heating electrification under the same timeline, supported by the same energy mix, would add an additional $301.9 billion for a total cost of $620.7 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 50.89 cents per kWh in 2040.

All-sector electric rates would average 37.58 cents per kWh over the course of the transition.

The resulting average monthly cost for each Colorado utility customer would more than quadruple to $797 through 2050 after peaking at $1,143 in 2040 (Figure 9).
By comparison, pursuing residential electrification under the LCD Scenario would cost an additional $106.4 billion more than without electrification, for a total cost of $195 billion through 2050. That represents nearly $426 billion in savings compared with the Polis Plan.

Under the LCD Scenario, all-sector electricity rates would increase by an average of just over 8 cents per kWh to 19.22 cents per kWh over the course of the transition period. They would peak at 27.72 cents per kWh in 2040.

That rise in rates would increase average all-sector monthly electric bills from $180 in 2021 to $623 in 2040. Under this scenario, they would average $408 per month through 2050—nearly $400 per month cheaper on average than the Polis Plan.

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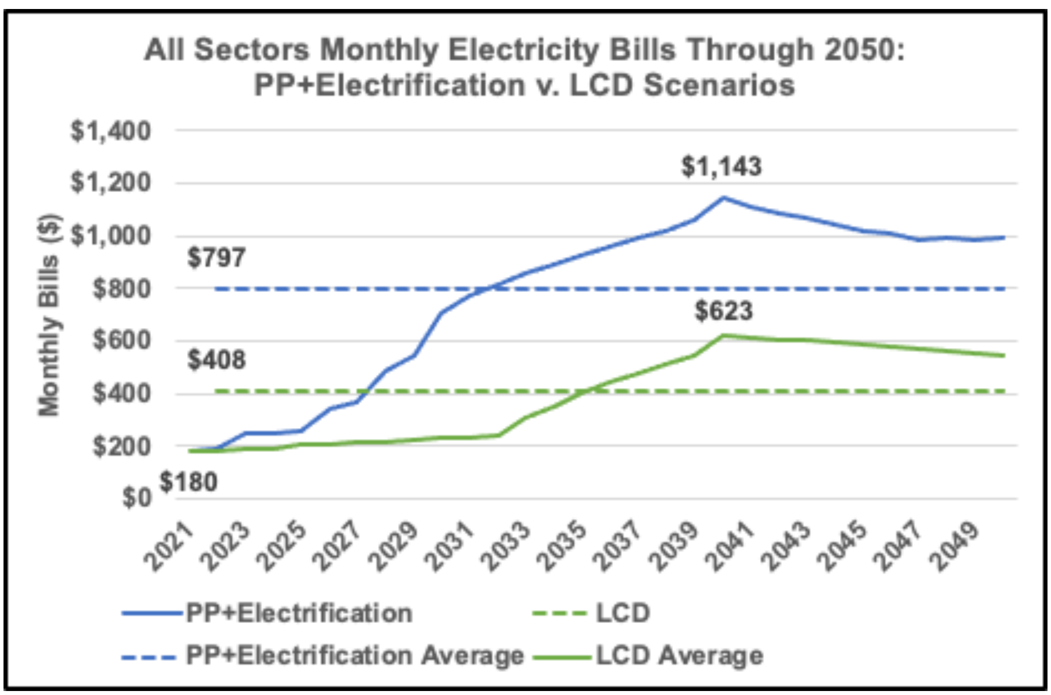
Figure 9 shows the average monthly costs of Colorado residential, commercial, and industrial ratepayers after complying with the Polis Plan and LCD Scenario plus residential electrification.

Figure 9. Comparison of average monthly electricity bills for Colorado residential, commercial, and industrial ratepayers after residential electrification under the Polis Plan and LCD Scenarios.



RESIDENTIAL COSTS

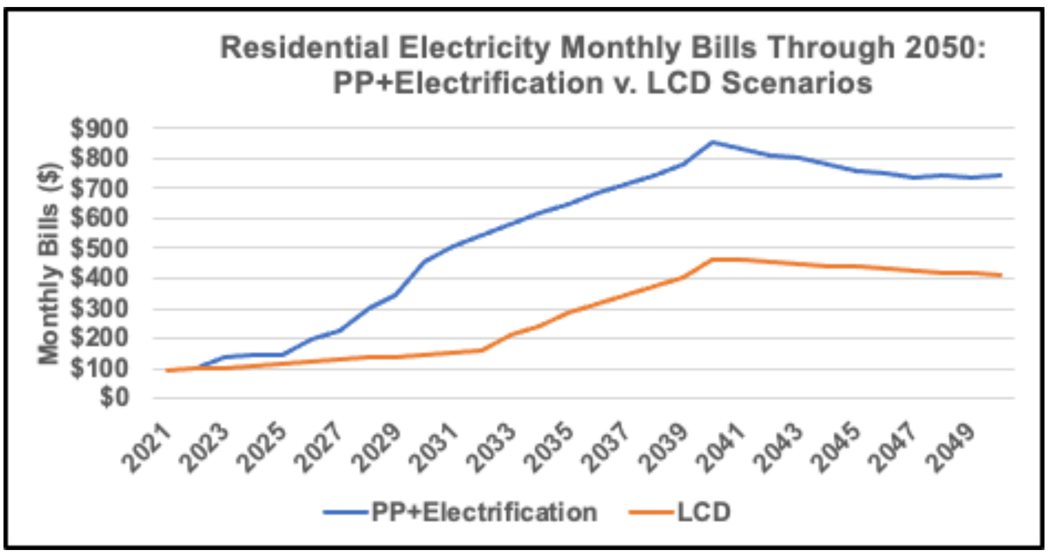
For residential customers, the Polis Plan would more than triple the electric rate paid from 13.07 cents/kWh as of 2021 to an average of 45.06 cents/kWh through 2050. They would peak as high as 61 cents per kWh in 2040.[39]

Those residential rate increases, combined with the increased use of electricity by each household created by all-electric space heating, would cause Colorado families to pay six times more per month on average than they do currently. To pay for the Polis Plan, Colorado residential electricity customers would see their monthly bills increase from an average of $92 per month in 2021 to as high as $856 per month in 2040, for an average monthly bill of $566 through 2050 (Figure 10).

For residential customers, the Polis Plan would more than triple the electric rate paid from 13.07 cents/kWh as of 2021 to an average of 45.06 cents/kWh through 2050.

Under the LCD Scenario, residential electric rates would increase by an average of about 10 cents per kWh, peaking at 33.23 cents/kWh in 2040. That rate increase would cost residential customers an average of an additional $198 per month through 2050, with a peak cost of $466 per month in 2040.

Figure 10. Costs begin rising immediately in the Polis Plan scenario to pay for new wind and solar facility construction. Costs remain low in the initial years of the LCD Scenario while existing power plants are still in use. They begin climbing in the early 2030s as new nuclear facilities are built to replace retiring coal and gas.



COMMERCIAL AND INDUSTRIAL COSTS

Commercial and Industrial electricity customers, despite not being subject to the same electrification mandates analyzed in this report, would nevertheless also see their monthly costs increase under each scenario. The costs to build the extra generation capacity needed to support residential electrification would be socialized across each electric utility's different customer classes.

As a result, commercial customers would see their monthly electricity costs increase by an average of an additional $1,171 per month through 2050 under the Polis Plan. Under the LCD Scenario, the average commercial customer would pay an additional $365 per month through 2050 (Figure 11).

Industrial ratepayers would see their electricity costs increase by more than $16,000 per month through 2050 under the Polis Plan, from an average of $6,573 per month in 2021 to an average of $22,661 per month over the next 27 years. Under the LCD Scenario, the average Colorado industrial customer would pay an extra $5,015 per month over that same period (Figure 12).

Industrial ratepayers would see their electricity costs increase by more than $16,000 per month through 2050 under the Polis Plan, from an average of $6,573 per month in 2021 to an average of $22,661 per month over the next 27 years.

Figure 11. Electricity costs for Colorado businesses would peak at $2,234 per month in 2040 under the Polis Plan. They remain relatively stable through the next decade under the LCD Scenario before increasing to a peak of $1,217 per month on average in 2040.

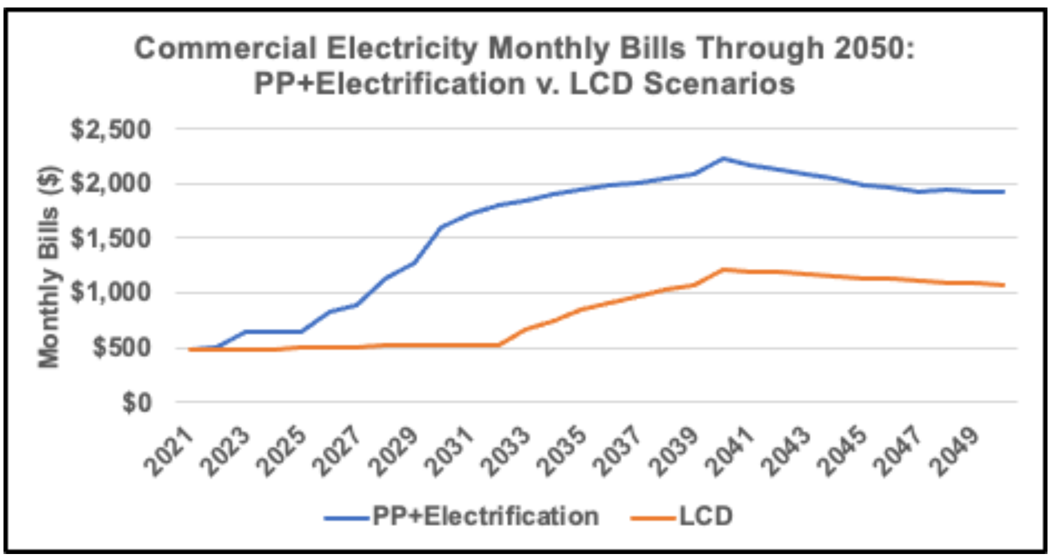
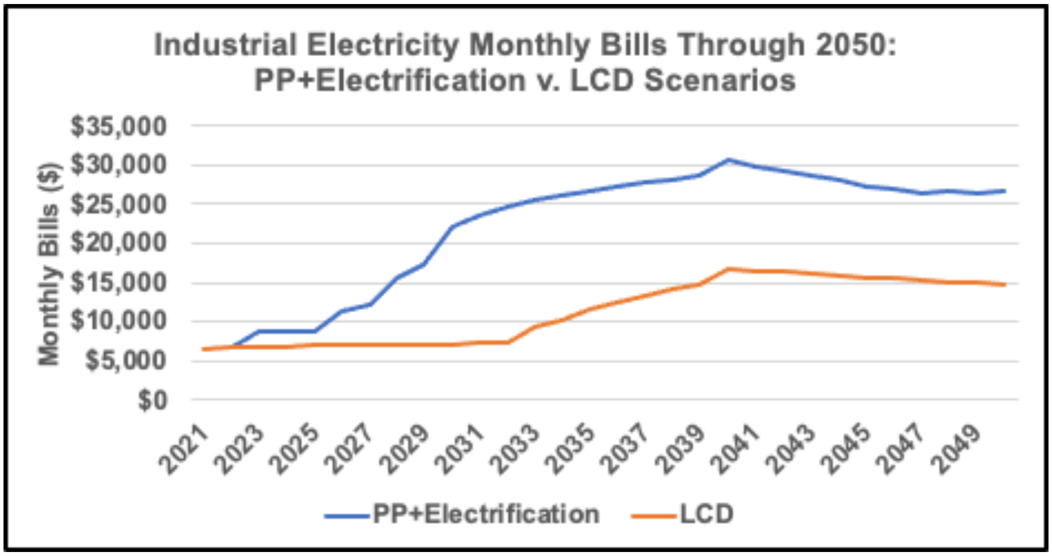


Figure 12. Colorado industrial electricity customers would face a peak average monthly cost of $30,683 in 2040 under the Polis Plan. It would be $16,712 under the LCD Scenario.



BREAKING DOWN THE COSTS

Figure 13 shows the different sources of expense driving the overall cost differential between the two plans.

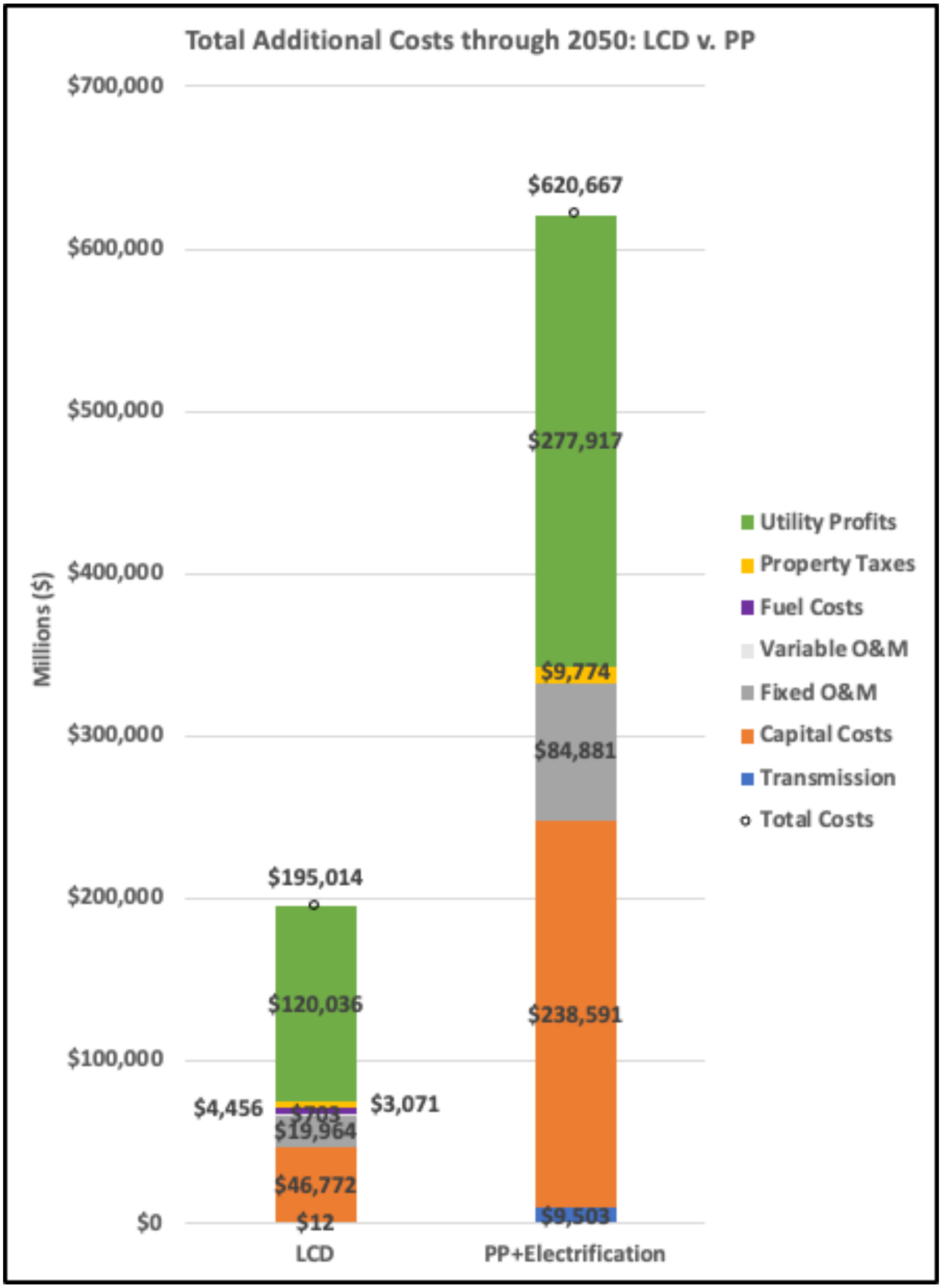
For a more detailed discussion of the factors driving such a large cost discrepancy between the two plans, including an examination of how electric utilities make money and recover costs, see the section entitled "Why There Is Such A Large Cost Gap Between Scenarios" in part one of this series.[40]

Under the Polis Plan+electrification scenario, the two largest sources of expenses driving the $620.7 billion price tag consist of $277.9 billion in utility returns and $238.6 billion in additional capital costs. On top of that, the plan would result in an additional $84.9 billion in operating and maintenance (O&M) expenses, $9.5 billion in transmission expenses, and $9.8 billion in additional property tax expenses.

Under the LCD Scenario, the two largest sources of expense consist of $120 billion in utility returns and $46.8 billion in additional capital costs to build new power plant infrastructure. Those new power facilities would result in an additional $20.7 billion in O&M expenses, $4.5 billion in fuel expenses, $12 million in transmission expenses, and $3.1 billion in additional property tax expenses.

Under the Polis Plan+electrification scenario, the two largest sources of expenses driving the $620.7 billion price tag consist of $277.9 billion in utility returns and $238.6 billion in additional capital costs.

Figure 13. Residential space heating electrification under the Polis Plan would cost roughly 3.2 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.[41]

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 14).

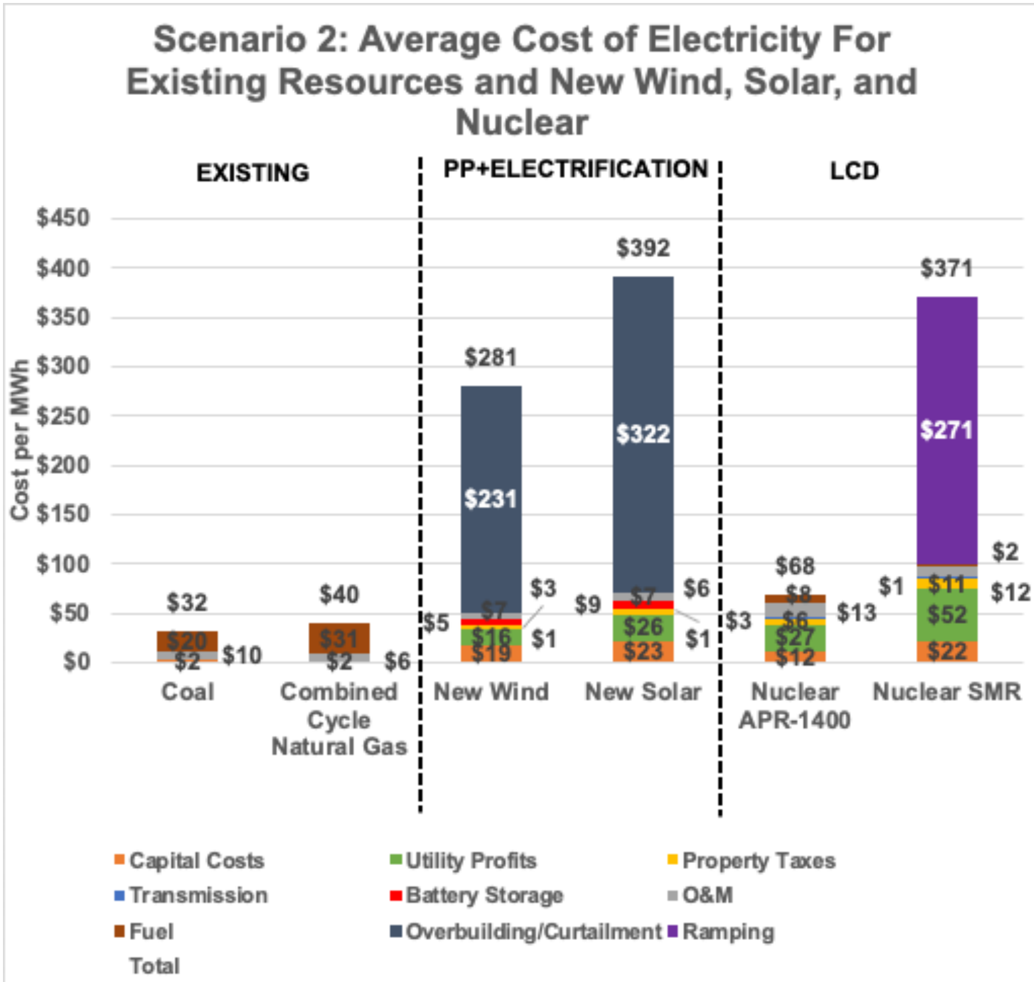
Under the Polis Plan, these affordable and reliable fossil fuel plants would be entirely replaced by wind, solar, and battery storage by 2040 at a sufficient quantity to meet the extra demand created by electrified residential space heating. Figure 14 shows that the all-in LCOE of new wind and solar reaches $281 and $392 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. This is due to the need to overbuild renewable generation and transmission under this scenario to meet a higher peak demand created by electric space heating. 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.

These all-in LCOE figures for solar and wind are higher than we found in part one. This is due to the need to overbuild renewable generation and transmission under this scenario to meet a higher peak demand created by electric space heating.

Under the LCD Scenario, new-build APR-1400 nuclear plants would have an average levelized cost of $68 per MWh through 2050. New build nuclear SMRs would have a much higher levelized cost, trailing only new solar, driven primarily by a significant increase in cost per MWh beginning in 2036 and peaking in 2040. 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 Figure 14.

Figure 14. Once costs such as property taxes, transmission, utility returns, battery storage, and overbuilding and curtailment are accounted for, new wind costs $281 per MWh, and new solar costs $392 per 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 under normal circumstances, the electric grid's reliability is paramount for the health, safety, and prosperity of Colorado's economy. Adding the heat that keeps Coloradans warm during the harshest winter months to the list of things dependent on its continued function makes it much more vital that policymakers are attentive to the grid's resiliency.

Indeed, two of the country's most recent high-profile blackouts—Winter Storm Uri in Texas in 2021 and Winter Storm Eliot in Tennessee and the Carolinas in 2022—occurred due to the strain placed on each state's grid by spiking electric heating demand during a cold snap that also impacted power supplies.[42],[43] In the case of the Texas storm, hundreds of people died due to the extended blackouts.[44]

Given the stakes, it is crucial to evaluate how Colorado's grid will be expected to hold up once its energy mix has dramatically changed, and the source residents rely on for heat shifts with it.

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THE POLIS PLAN

The Polis Plan would seriously undermine the reliability of the state's electric grid by greatly expanding the state's dependence on fluctuations in the weather to meet demand, while simultaneously adding extra strain to the grid during periods of high heating demand. So long as the weather cooperates, this is not a problem (Figure 15). When it does not, blackouts become inevitable (Figure 16).

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 natural gas demand data from the Colorado Springs Utilities, converted into electricity, to create a hypothetical electricity demand for 2040 under all-electric residential space heating.

Using these inputs, the model determined that the 74.3 gigawatts (GW) of wind, 111.2 GW of solar, and 40.9 GW of four-hour battery storage built under the Polis Plan would not be able to generate sufficient electricity to meet demand for a combined 26 hours over three capacity shortfall events in 2040 if demand and capacity factor conditions are similar to how they were in 2021 in Colorado.

Figures 15 and 16 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.

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 three-hour blackout on the morning of February 14 and another 13-hour blackout beginning that evening and continuing through the following morning.

Figure 15. Under 2022 conditions, there would be no blackouts in 2040, thanks to favorable wind and solar output and relatively low demand.

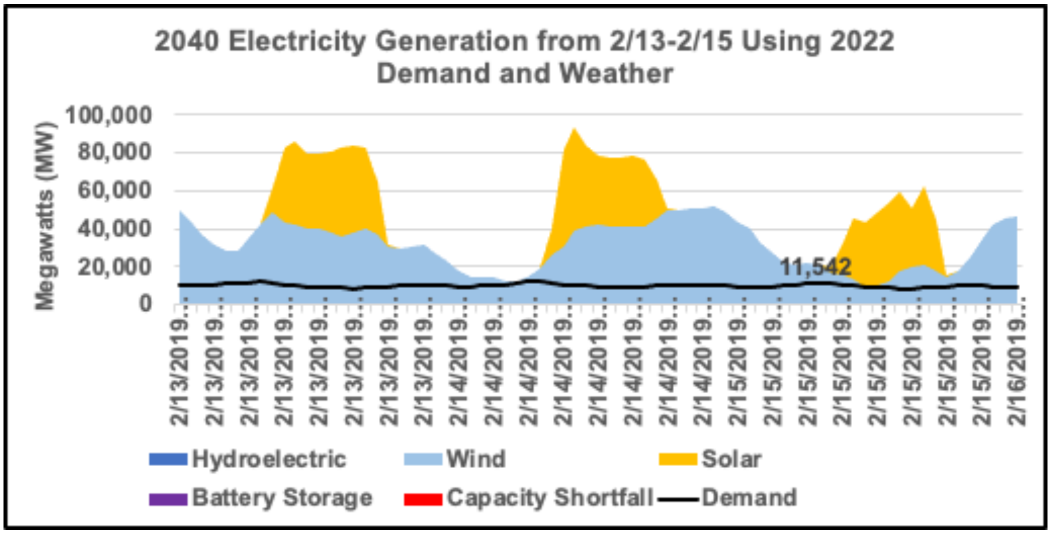
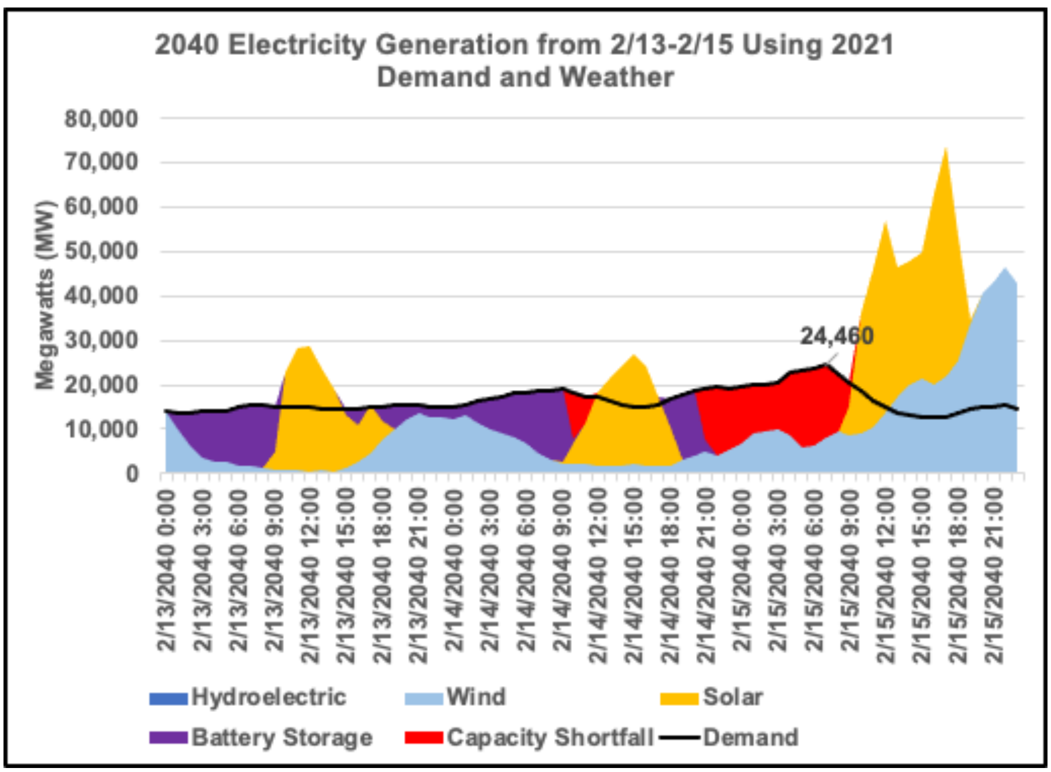


Figure 16. Despite nearly 41,000 MW of four-hour storage on the grid, battery resources could not charge enough to prevent multiple capacity shortfalls (shown in red) due to an extended period of low wind and solar output.



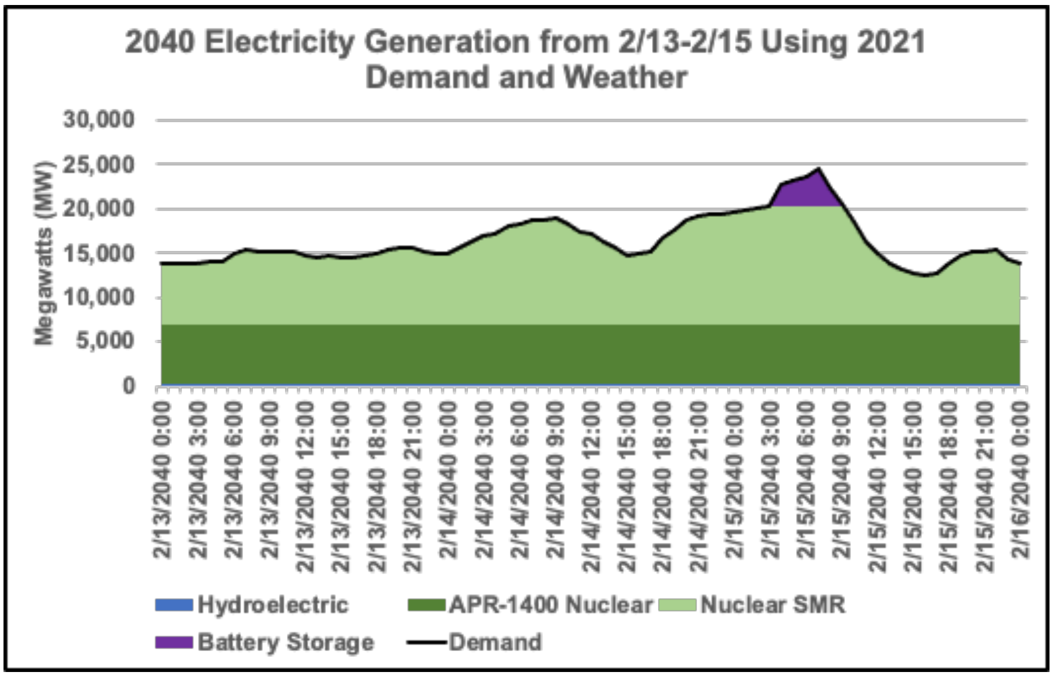
THE LCD SCENARIO

While the Polis Plan would result in multiple capacity shortfalls due to unfavorable demand and weather patterns, resulting in blackouts during the frigid months of February when residents would be most reliant on their electric heating, the state's grid would fare much better under the LCD Scenario.

Under the LCD Scenario, Colorado would maintain a reliable grid and increase the amount of dispatchable capacity at its disposal, resulting in zero hours of capacity shortfalls regardless of the model year demand and weather conditions chosen. Figure 17 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.

> Under the LCD Scenario, Colorado would maintain a reliable grid and increase the amount of dispatchable capacity at its disposal, resulting in zero hours of capacity shortfalls regardless of the model year demand and weather conditions chosen.

Figure 17. This is the same period that the wind, solar, and battery storage scenario saw two separate blackouts totaling 16 hours. 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.

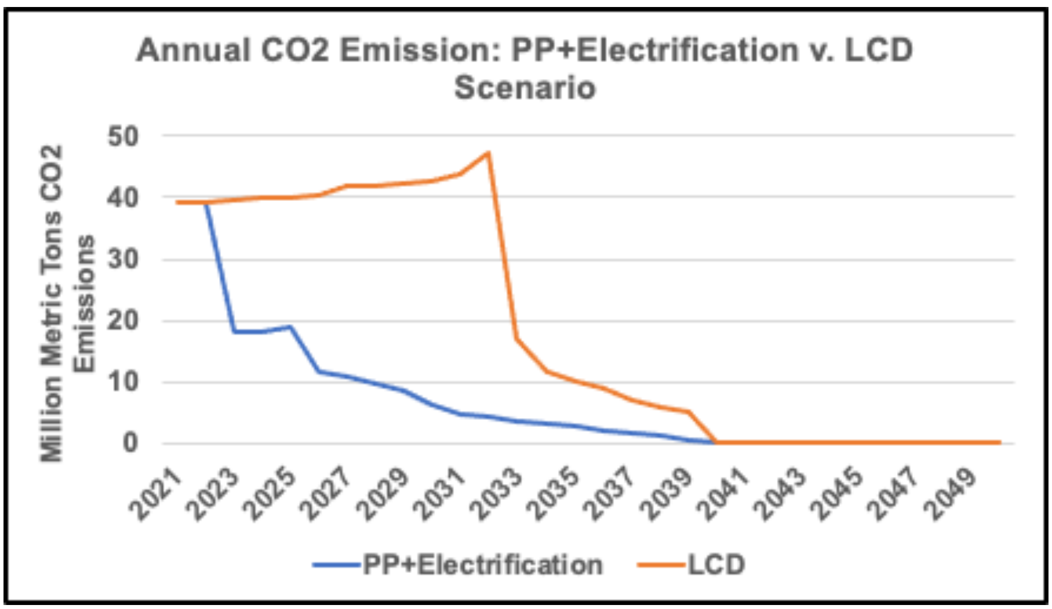
REDUCED CARBON EMISSIONS

The push to replace natural gas home heating, much like the one behind the transition from fossil fuel-based electricity to renewables, 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.

Colorado's electricity sector emitted 31.1 million metric tons of CO2 in 2021, according to federal data,[45] while the state's residential sector emits 8.1 million metric tons attributed to gas use.[46] As such, both the Polis Plan and the LCD Scenario would avert 39.2 million metric tons of annual CO2 emissions, though they would do so at different paces (Figure 18).

The push to replace natural gas home heating, much like the one behind the transition from fossil fuel-based electricity to renewables, is centered around reducing carbon dioxide emissions to limit the impacts of climate change.

Figure 18. By 2040, Colorado would avert 578.4 million metric tons of cumulative CO2 emissions compared to 2021 levels under the Polis Plan and residential electrification scenario. This is an average of 30.4 million metric tons reduced annually through 2040. Under the LCD scenario, Colorado would avert 220.2 million metric tons of total CO2 emissions by 2040 compared to 2021 levels, or 11.6 million metric tons per year.



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 CO2 emissions by 39.2 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.[47] The Obama administration claimed the CPP would have reduced annual CO2 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 39.2 million metric tons of CO2 no longer emitted from power plants and residential furnaces serving Colorado under either of the modeled scenarios would account for 5 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 5 percent of the 0.019° C by 2100 for a potential future temperature reduction of 0.001° C by 2100 —an infinitesimal fraction of global temperature reductions required to avert the worst impacts of climate change.

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THE SOCIAL COST OF CARBON

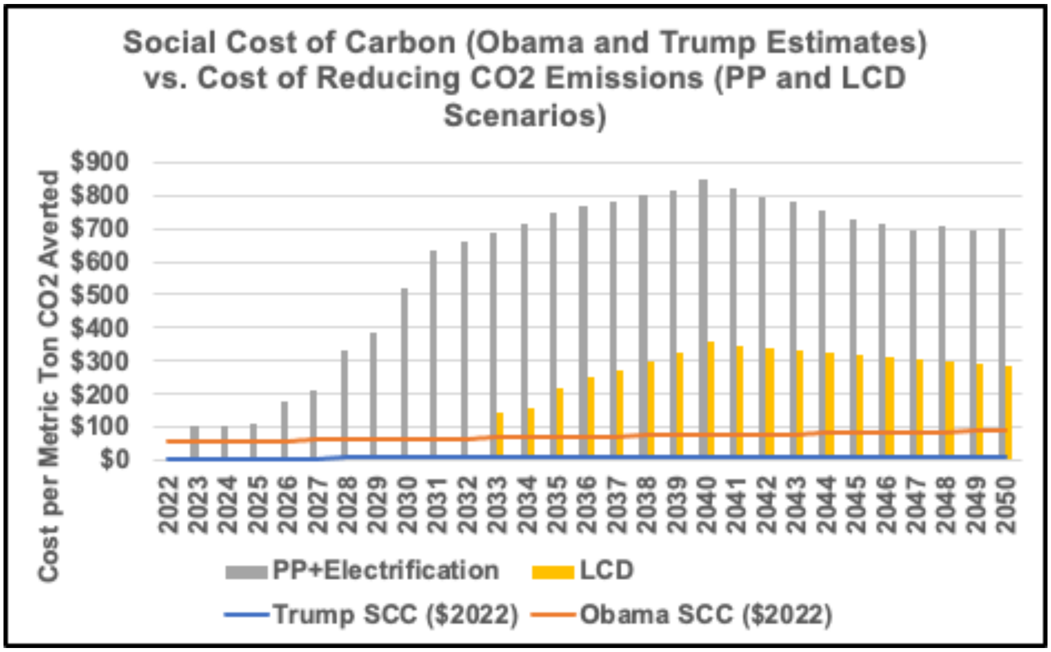
When evaluating policies to reduce greenhouse gas emissions, weighing the cost of reducing emissions against its expected benefits is essential. If the costs associated with a strategy for reducing emissions exceed the expected benefits, the policy is economically inefficient, and vice versa.

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.[48]

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.[49] Nevertheless, it can help evaluate the economic rationality of pursuing a given climate policy.

Figure 19 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.

Figure 19. The cost of reducing CO2 emissions under both the Polis Plan and LCD Scenario exceeds the high and low SCC estimates used by the Obama and Trump administrations, respectively.



Under the Polis Plan and residential electrification scenario, the average cost of reducing carbon-dioxide emissions would be $640 per metric ton reduced through 2050. Under the LCD Scenario, the average cost of reducing carbon-dioxide emissions would be $319 per metric ton reduced through 2050.

Under the Polis Plan and residential electrification scenario, the average cost of reducing carbon-dioxide emissions would be $640 per metric ton reduced through 2050. Under the LCD Scenario, the average cost of reducing carbon-dioxide emissions would be $319 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 relied on by the Obama and Trump administrations. 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-pecuniary benefits to reducing power plant and household emissions, the economic costs of implementing each strategy under the timeline envisioned far outweigh the environmental benefit.

CONCLUSION

Compliance with the all-renewable electricity and all-electric residential space heating envisioned by the Polis Plan would cost Coloradans $620.7 billion through 2050. This would result in the typical Colorado household paying an average monthly electricity bill of $566 through 2050, up from just $92 in 2021 – an increase of more than 600 percent. By contrast, the nuclear-focused LCD Scenario would cost Colorado residents

$195 billion through 2050. It would only increase residential electricity bills by $198 per month for the typical household 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. 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 of new physical assets.

LCD Scenario costs are driven mainly by the high upfront costs of building new nuclear power plants and four-hour battery storage to replace retiring fossil fuel plants quickly. 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 the way many Coloradans keep warm in the winter is little more than an expensive pipe dream. Even under the less costly nuclear scenario modeled here, the extensive 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.[50] State policymakers should heed those concerns with a little more humility in the state's energy policy, letting freely choosing consumers and the market determine how Coloradans ought to heat their homes and power their lives. The alternative is a crash course toward a disastrous combination of expensive and unreliable energy.

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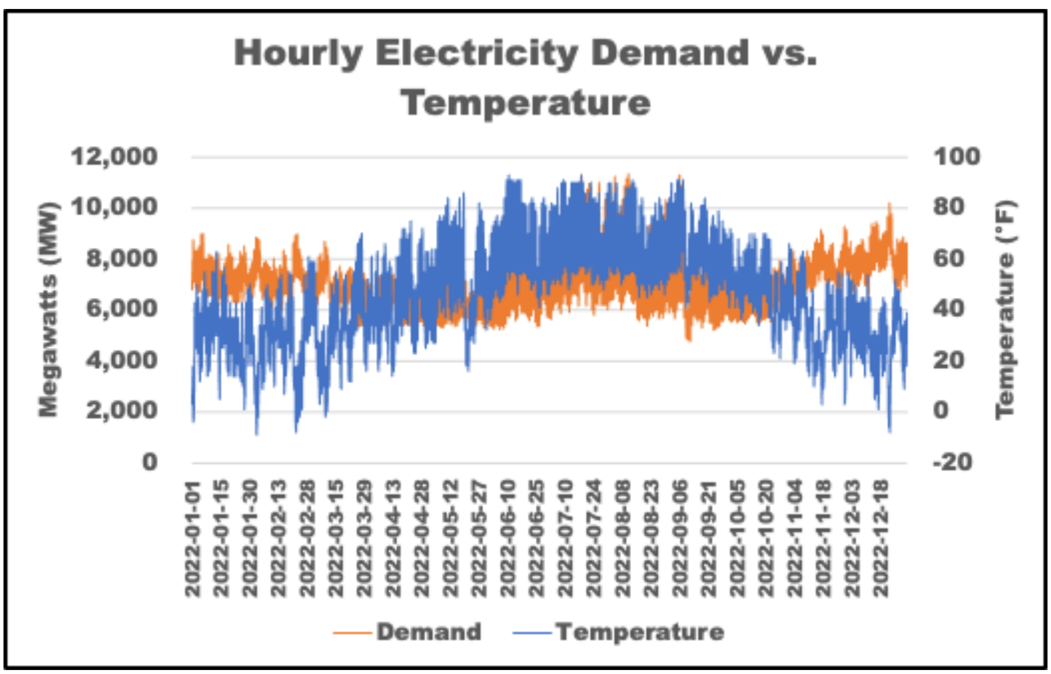
APPENDIX

STUDY ASSUMPTIONS:

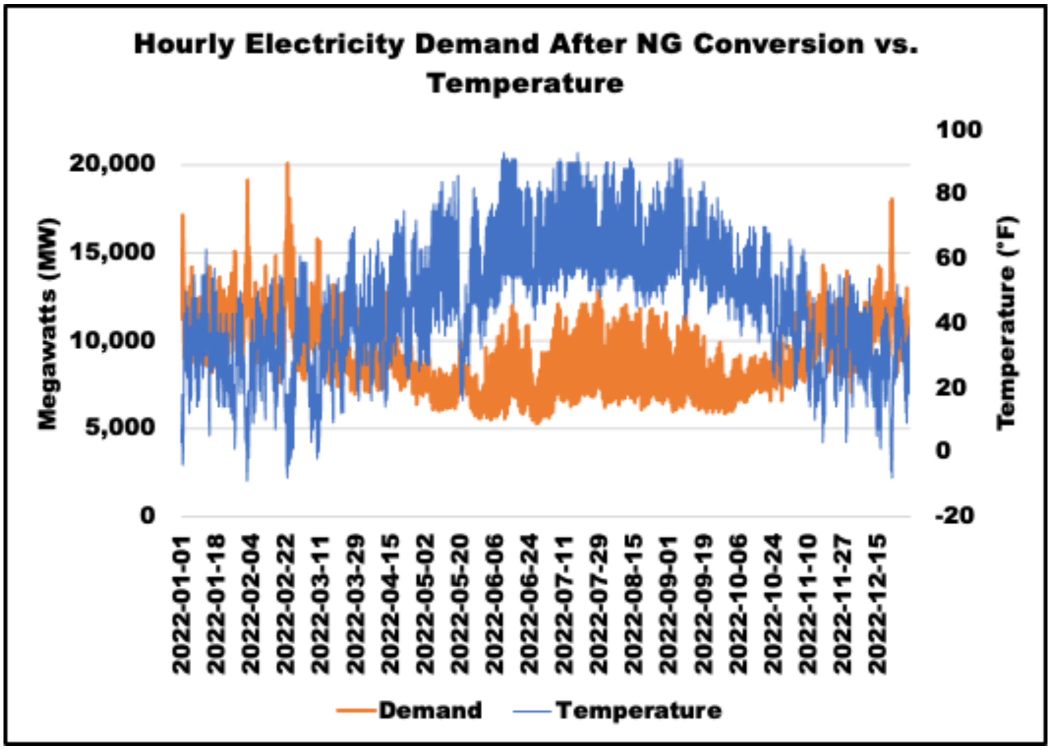
- The Colorado Springs Municipal Utility provided hourly natural gas demand data via an open records request.
- These data were extrapolated to the entire state to create an hourly load shape.
- We converted gas use from million cubic feet (MMcf) to megawatt hours (MWh) and assumed gas furnaces were 85 percent efficient.
- Heat pumps replace natural gas furnaces with electric resistance backup heating available.
- Heat pump specifications were modeled after the Mitsubishi Hyper Heat, a highly touted cold climate heat pump[51] designed to work efficiently at subzero temperatures to determine Coefficient of Performances (COP) and match hourly temperature data from Colorado Springs to determine hourly COPs and electricity demand.

CHARTS:

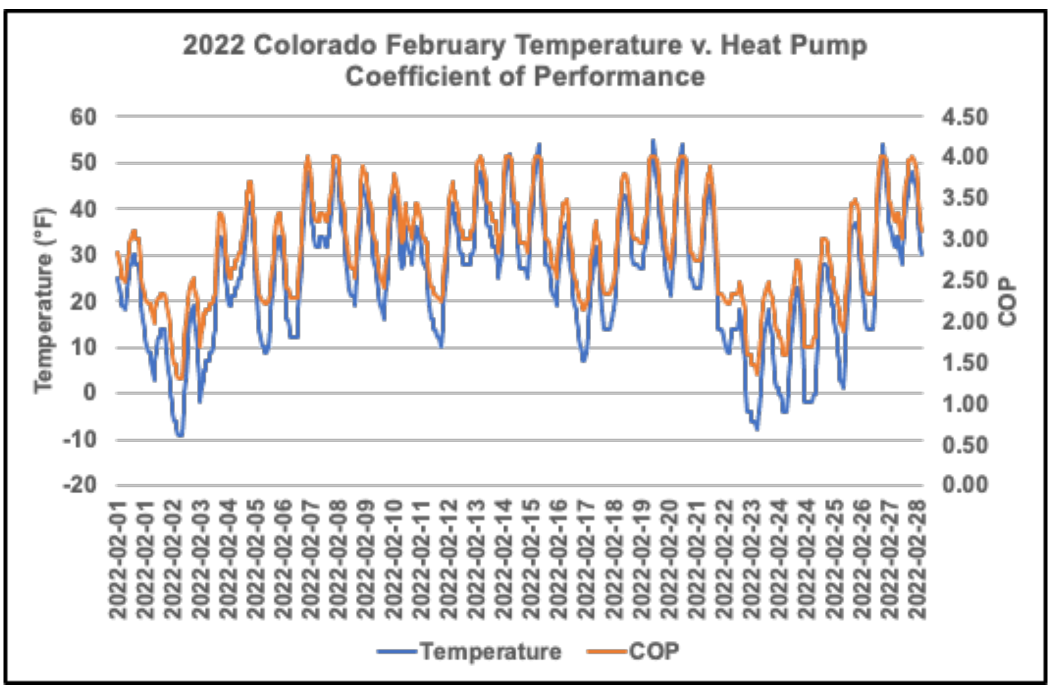
Colorado's 2022 Hourly Electricity Demand and Temperature



Colorado Electricity Demand After Becoming a Winter Peaking System



Modeled Heat Pump Efficiency (Coefficient of Performance) at Different Temperatures



Annual Capacity Additions and Retirements Under Each Plan

Polis Plan+Electrification

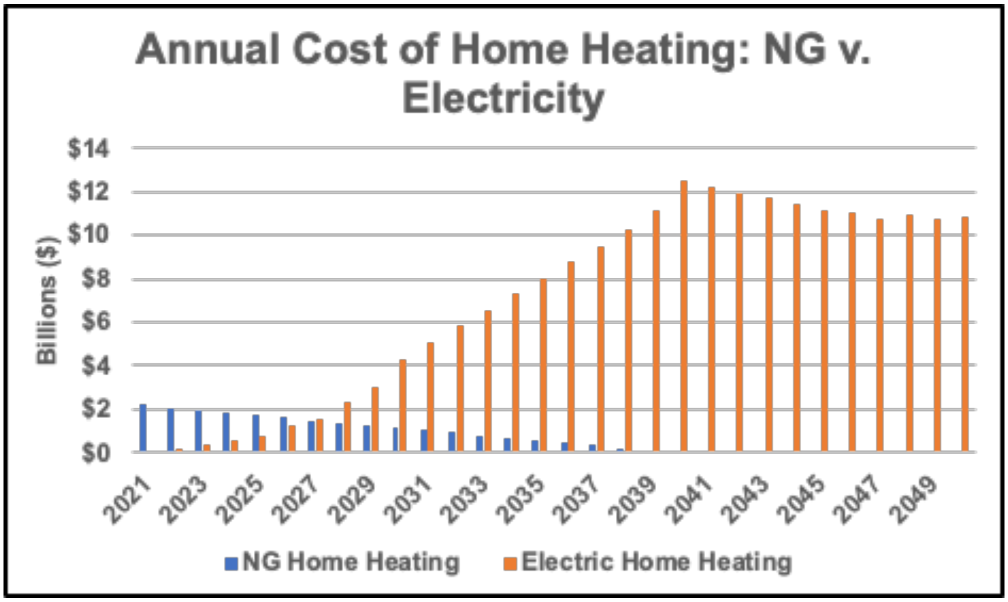
	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	Total
Coal	0	(383)	0	0	(842)	0	(828)	(636)	(1,035)	(857)	0	0	0	0	0	0	0	0	0	(4,581)
Natural Gas (CC)	0	(84)	0	0	0	0	0	0	(288)	(288)	(288)	(288)	(288)	(288)	(288)	(288)	(288)	(288)	(288)	(3,255)
Natural Gas (CT)	0	0	0	0	0	(185)	0	0	(235)	(235)	(235)	(235)	(235)	(235)	(235)	(235)	(235)	(235)	(235)	(2,772)
Natural Gas (ST)	0	(208)	0	0	0	0	(310)	0	0	0	0	0	0	0	0	0	0	0	(98)	(616)
Petroleum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	(151)	(151)
Wind	0	4,406	0	0	5,503	1,207	7,432	4,157	10,182	9,016	3,419	3,419	3,419	3,419	3,419	3,419	3,419	3,419	5,042	74,298
Solar	0	6,594	0	0	8,235	1,807	11,122	6,221	15,239	13,493	5,117	5,117	5,117	5,117	5,117	5,117	5,117	5,117	7,546	111,193
Storage	0	2,425	0	0	3,029	664	4,091	2,288	5,605	4,963	1,882	1,882	1,882	1,882	1,882	1,882	1,882	1,882	2,776	40,899

LCD Scenario

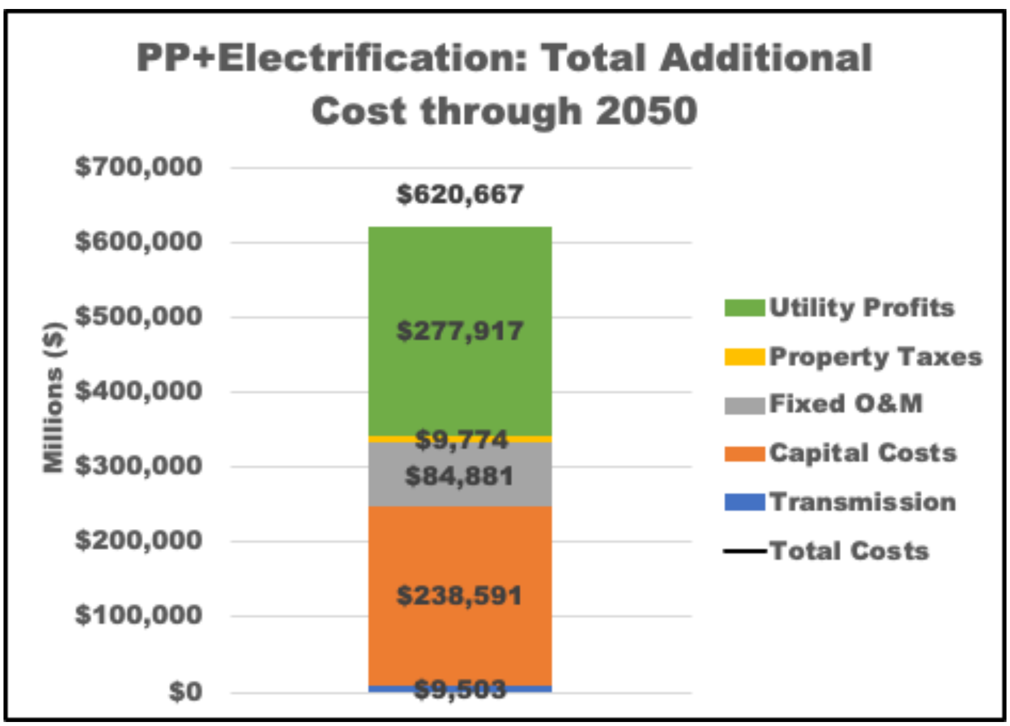
	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036
Coal	0	0	0	0	0	0	0	0	0	0	0	(383)	0	(396)	(465)
Natural Gas (CC)	0	0	0	0	0	0	0	0	0	0	0	(480)	(396)	(396)	(396)
Natural Gas (CT)	0	0	0	0	0	0	0	0	0	0	0	(508)	(323)	(323)	(323)
Natural Gas (ST)	0	0	0	0	0	0	0	0	0	0	0	(518)	0	0	0
Petroleum	0	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)	(64)
Solar	0	0	0	0	0	0	0	0	0	0	(8)	(3)	(3)	(27)	(45)
Nuclear SMR	0	0	0	0	0	0	0	0	0	0	0	2,200	1,600	1,600	1,600
Nuclear APR-1400	0	0	0	0	0	0	0	0	0	0	0	2,800	0	1,400	0
Storage	0	0	0	0	0	0	0	0	0	0	0	500	500	500	500

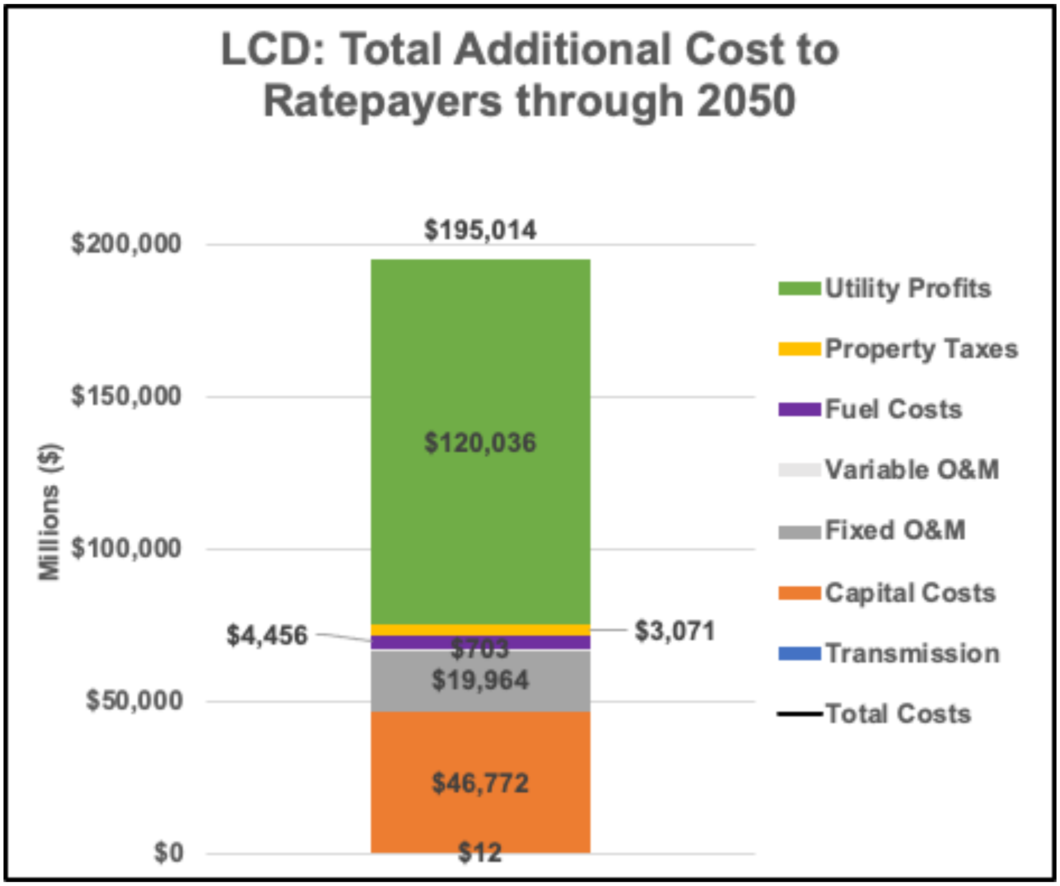
	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050	Total
Coal	(446)	(446)	0	(2,445)	0	0	0	0	0	0	0	0	0	0	**(4,582)**
Natural Gas (CC)	(396)	(396)	(396)	(396)	0	0	0	0	0	0	0	0	0	0	**(3,255)**
Natural Gas (CT)	(323)	(323)	(323)	(2,323)	0	0	0	0	0	0	0	0	0	0	**(4,772)**
Natural Gas (ST)	0	0	0	(98)	0	0	0	0	0	0	0	0	0	0	**(616)**
Petroleum	0	0	0	(151)	0	0	0	0	0	0	0	0	0	0	**(151)**
Wind	(80)	(598)	(54)	(953)	(96)	0	0	0	0	0	0	0	0	0	**(4,770)**
Solar	(30)	(5)	(7)	(65)	(225)	(43)	(70)	(75)	(74)	(87)	0	0	0	0	**(768)**
Nuclear SMR	1,600	1,600	1,600	2,400	0	0	0	0	0	0	0	0	0	0	**14,200**
Nuclear APR-1400	0	0	0	2,800	0	0	0	0	0	0	0	0	0	0	**7,000**
Storage	500	500	500	500	0	0	0	0	0	0	0	0	0	0	**4,000**

Avoided Natural Gas Fuel Costs



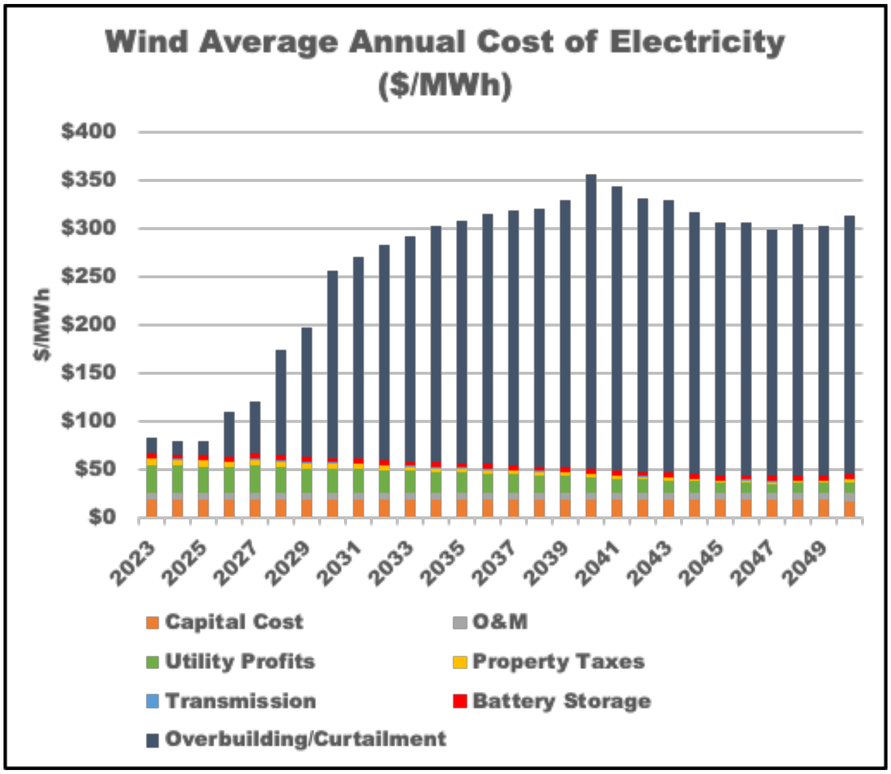
Cost Breakdown by Scenario

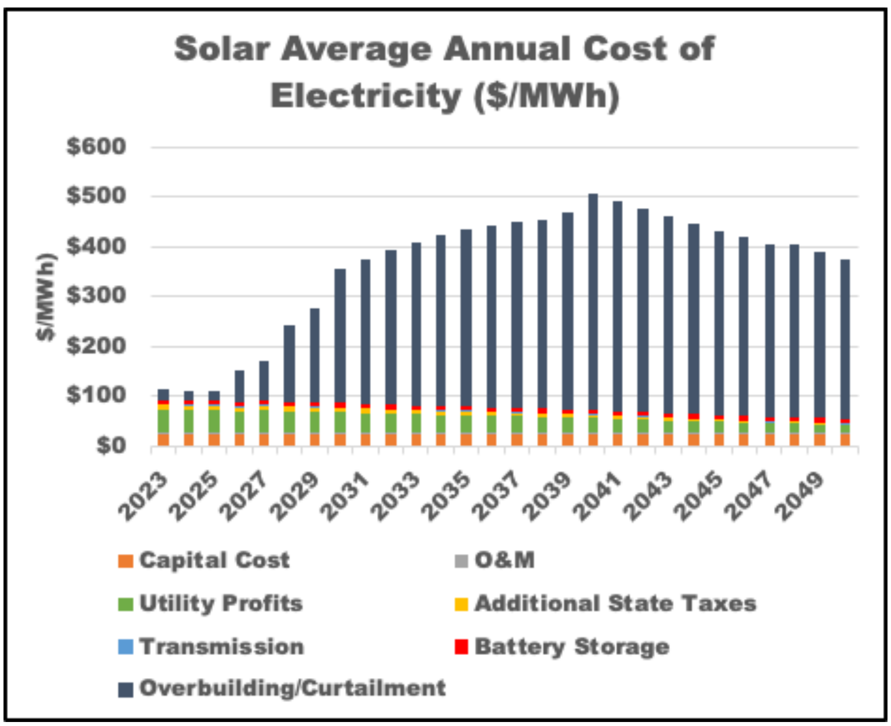


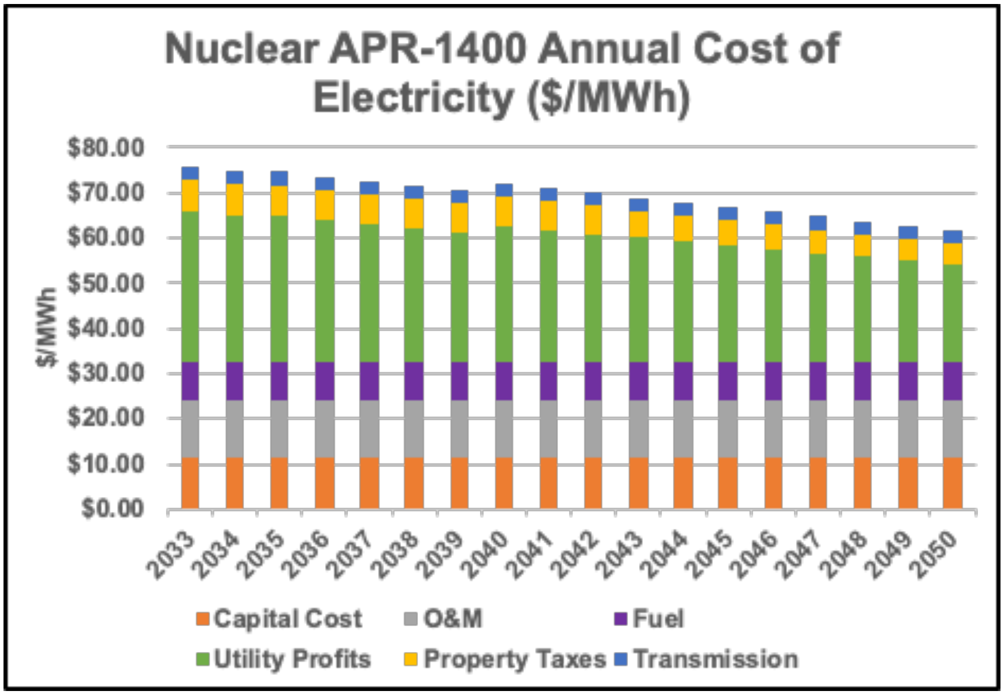

LCD: Total Additional Cost to Ratepayers through 2050
$195,014
$200,000
$150,000
$100,000
$50,000
$0
Millions ($)
$120,036
$4,456
$3,071
$703
$19,964
$46,772
$12
Utility Profits
Property Taxes
Fuel Costs
Variable O&M
Fixed O&M
Capital Costs
Transmission
Total Costs

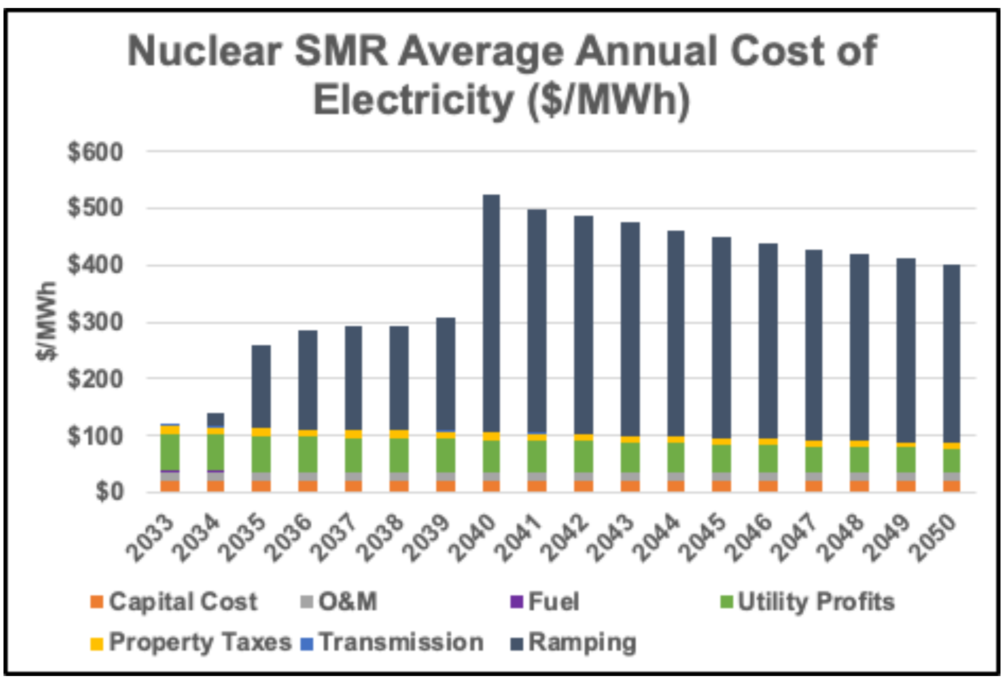
Average Cost of Annual Capacity Additions

Polis Plan+Electrification Average Annual Costs






Nuclear APR-1400 Annual Cost of Electricity ($/MWh)
$/MWh
$80.00
$70.00
$60.00
$50.00
$40.00
$30.00
$20.00
$10.00
$0.00
2033 2034 2035 2036 2037 2038 2039 2040 2041 2042 2043 2044 2045 2046 2047 2048 2049 2050
Capital Cost
O&M
Fuel
Utility Profits
Property Taxes
Transmission


Nuclear SMR Average Annual Cost of Electricity ($/MWh)
$/MWh
$600
$500
$400
$300
$200
$100
$0
2033 2034 2035 2036 2037 2038 2039 2040 2041 2042 2043 2044 2045 2046 2047 2048 2049 2050
Capital Cost
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