ELECTRIFYING THE FUTURE:

CURRENT TRENDS, FUTURE PATHWAYS, AND POTENTIAL CHALLENGES

AMERICAN PUBLIC POWER ASSOCIATION
Powering Strong Communities

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INTRODUCTION

The electrification of end-use technologies, such as electric space and water heating as well as electric vehicles (EVs), offers potential benefits to the environment and consumers. Electrification efforts that are both environmentally beneficial and comparatively economical have been termed beneficial or efficient electrification. As defined by the Electric Power Research Institute, efficient electrification is:

The application of electric-powered end-use technology as a substitute for direct-use fossil-fueled or non-energized processes for customer homes, buildings, industries, or transportation that results in net economic benefit to the customer and net environmental benefits to society.[1]

Potential benefits of electrification include, but are not limited to, reduced CO_2 emissions, more efficient use of energy, long-term fuel savings, and lower overall monthly energy costs. Yet there are several potential challenges, including the following: electrified space heating is still generally more efficient in warmer climates than colder climates, up-front prices for many EV models are higher than for traditional transportation, and the overall cost of converting to electrified end uses may be prohibitive for many customers.

This report analyzes trends in electrification deployment through the current day and discusses potential developments. The first part of this report analyzes currently available data showing relative percentages of electrification in different parts of the United States. Because adoption of space heating is dependent on certain key variables, the first part of this report primarily focuses on this aspect of electrification, though it does relate some current EV market data and future projections. The data reveal that in some regions — particularly the southeast and southwest — electrification of space heating is more prevalent than in other areas of the country. Furthermore, residential customers who have electric heating in their homes do not have higher energy bills than those who primarily rely on fossil fuels, and this is due to higher incidences of electrification in states with comparatively low electric rates and more temperate or warmer climates.

The second part of this report focuses on the future of electrification and identifies at least three major hurdles that need to be overcome to realize wider adoption of electrification. These three factors are the cost of transitioning energy resources to electric, potential (and existing) supply chain constraints associated with the materials needed for batteries, and limitations of the existing electric grid, both in terms of wires and generating capacity. This part includes a discussion of the changing resource mix and how this may impact some of the environmental aspects of electrification.

While there are also associated concerns, these three stand out as the most pressing. There have been multiple studies on all these issues, and this report borrows and expands upon this research. The purpose of this report is to draw out and amplify these barriers to adoption and discuss potential approaches to ameliorating them.

1 Electric Power Research Institute. *The Total Value Test: A Framework for Evaluating the Cost-Effectiveness of Efficient Electrification,* August 2019 (p. 3), https://evtransportationalliance.org/wp-content/uploads/2021/11/2019-EPRI-TVT-paper.pdf

PART ONE —

ELECTRIFICATION TO DATE

ELECTRIC VEHICLE MARKETPLACE

Driven by declining costs, especially in batteries, as well as tax incentives, improving ranges, and public interest, alternative fuel vehicle sales have steadily been increasing over the past decade. Hybrids, plug-in hybrids, and fully electric cars accounted for approximately 11% of light-duty vehicle sales in the fourth quarter of 2021, with EVs alone accounting for 3.4% of light-duty vehicle sales.[2]

California continues to lead the country in EV sales, both by total amount and as a percentage of all vehicle sales, but EV registrations are increasing in some states, including Florida, Texas, and Washington.

The Alternative Fuels Data Center provides state-level data on alternative fueling stations. The data show nearly 120,000 electric vehicle service equipment (EVSE) ports at 47,900 stations around the United States, including 94,825 level 2 chargers and 23,822 DC fast chargers.[3] California alone accounts for over 30% of the EVSE ports (36,353). The next closest state is New York (7,031), followed by Florida (6,368), and Texas (5,326). Half of the states have less than 1,000 EVSE ports, and 14 have less than 100 DC fast charging stations according to the AFDC data.

While there are certain parts of the country with higher rates of EV penetration, outside of California adoption has not been wildly divergent. Electric space and water heating varies significantly by state, as the following analysis shows.

2 U.S. Energy Information Administration, "Electric Vehicles and Hybrids Surpass 10% of U.S. Light-Duty Vehicle Sales," February 9, 2022, https://www.eia.gov/todayinenergy/detail.php?id=51218

3 U.S. Department of Energy, Energy Efficiency and Renewable Energy, Alternative Fuels Center, "Alternative Fueling Station Counts by State, accessed June 2022, https://afdc.energy.gov/stations/states

SPACE HEATING

In 1950, less than 1% of all homes in the United States used electricity as the primary source of heating.[4] By 2000, that had increased to over 30%,[5] and today nearly 40% of homes are primarily heated by electric sources.[6]

Homes heated by electricity are concentrated primarily in two regions: the southeast and the southwest. Notably, these regions are generally warmer and have newer housing stock compared to the rest of the country. Most electric heating applications have traditionally had better efficiency metrics in warmer climates. Additionally, it is less expensive to include electrified equipment in new construction than to retrofit.

Lucas Davis of the Haas School of Business, University of California, Berkeley, identified five factors that lead to higher rates of electrified end uses. Energy prices, geography, and climate are the main factors, with the prevalence of multiunit homes in post-1950 construction and, to a much lesser extent, income levels, as other factors.[7] A close examination of publicly available data largely confirms, though not totally, Davis' thesis.

To measure the relative electric intensity of homes in each state, data were taken from the U.S. Energy Information Administration (EIA) Form EIA-861. All electric utilities report their annualized revenue, sales, and number of customers to EIA. Total residential retail sales for each state were then divided by the total number of residential customers to arrive at average household electricity consumption; this was then multiplied by 1,000 to measure that in kilowatt-hours (kWh). To convert megawatt-hours (MWh) into a British Thermal Unit equivalent to measure against all energy consumption, average household MWh usage (reconverted from kWh) was multiplied by 3.412142.[8] This new figure was then divided by annual per capita energy usage as reported by EIA's State Energy Data System (SEDS) database[9] to arrive at an annual electric usage percentage.

The full state-by-state table is available in Appendix 1. Table 1 shows the top 10 states sorted by percentage of energy used by electricity. While there is a strong correlation between the percentage of homes heated by electricity and the electricity usage percentage, average annual statewide temperatures are a somewhat more significant predictor of electric power utilization. The state with the highest electric usage percentage is Hawaii (90.1%), a state that otherwise falls right into the middle of the pack in terms of the percentage of homes heated by electricity (25th, at 33%). Hawaii is also last in terms of annual household electric usage (6,445.9 kWh). With annual average temperatures of just over 70 degrees, the two-thirds of Hawaiian households heated by sources other than electricity do not need to call on those resources very often.

The next state on the list — Florida — is almost the opposite of Hawaii in its electricity profile, though it is slightly warmer overall. Florida is the fifth most electric

4 United States Census Bureau, "Fuels 1950" [fuels1950.txt], accessed June 2022, https://www2.census.gov/programs-surveys/decennial/tables/time-series/coh-fuels/fuels1950.txt

5 United States Census Bureau, "Fuels 2000" [fuels2000.txt], accessed June 2022, https://www2.census.gov/programs-surveys/decennial/tables/time-series/coh-fuels/fuels2000.txt

6 United States Census Bureau, "Why We Ask Questions About . . . Home Heating Fuel," accessed June 2022, https://www.census.gov/acs/www/about/why-we-ask-each-question/heating/

7 Lucas Davis, "What Matters for Electrification? Evidence from 70 Years of U.S. Home Heating Choices" (Energy Institute WP 309R, Energy Institute at Haas, 2021), pp. 1-2.

8 The exact MWh-to-Btu conversion is 3,412,142.6. Megawatt-hours (MWh) were multiplied by 3.412142 to arrive at a million Btu equivalency.

9 U.S. Energy Information Administration, "Table C14. Total Energy Consumption Estimates per Capita by End-Use Sector, Ranked by State, 2019," accessed June 2022, https://www.eia.gov/state/seds/data.php?incfile=/state/seds/sep_sum/html/rank_use_capita.html&sid=US

Table 1: Top 10 states sorted by electricity share of final energy

State	Percentage of homes heated by electricity (%)	Average annual temperature	Residential RpkWh	Household electric use (kWh per year)	Per capita residential energy consumption (million Btu)	Electricity usage percentage (%)
Hawaii	33.4	70	30.28	6,445.93	24.40	90.1
Florida	91.9	70.7	11.27	13,698.04	54.90	85.1
Arizona	60.5	60.3	12.27	13,364.26	56.60	80.6
Texas	60.4	64.8	11.71	13,583.19	61.00	76.0
Louisiana	63.7	66.4	9.67	14,406.92	68.30	72.0
Mississippi	57.3	63.4	11.17	13,755.95	65.50	71.7
Nevada	35.9	49.9	11.34	11,676.18	56.10	71.0
Virginia	55.4	55.1	12.03	13,142.54	66.80	67.1
Alabama	65.8	62.8	12.57	13,737.23	70.90	66.1
Georgia	55.1	63.5	12.02	12,974.09	67.40	65.7

usage intensive state in the country at 13,689.04 kWh per household per year. It also has the highest proportion of households fueled by electricity at 91.9%. Overall, approximately 85% of residential energy consumption in Florida is from electric sources.

Table 2 sorts the top 10 states as ranked by their per capita energy intensity. The data show that the most energy-intensive states are those with colder climates. The three most energy-intensive states (in terms of per capita consumption) are North Dakota (103.3 million Btu), Montana (98.8), and Wyoming (92.9). All three states have average annual temperatures in the low 40s, and all three rank in the bottom half of states by electrification usage. The remaining states in the top 10 for energy intensity are a mixed bag of cool and temperate climates — the warmest average temperature is Missouri at 54.5 degrees, with electric usage tightly bunched at 47.4% to 50.8%. Maine, ranked 10th in per capita energy usage, is an outlier at 29.5% for electric usage. Maine is also the only state in the northeast in the top 10, with somewhat older housing stock and only 7.4% of homes using electric heat, second-lowest in the country only to Vermont (5.4%).

Although average annual temperature has a significant correlation to per capita energy usage, there are outliers. Cooler states such as New York, ranked 44th at 58.5 million Btu, and others are less energy intensive than warmer states. And some states with relatively high annual average temperatures like Tennessee (average temperature of 57.6 degrees, ranked 15th at 76.8 million Btu), Oklahoma (59.6 degrees, 75.5 million Btu), and Arkansas (60.4 degrees, 75.1 million Btu) rank in the top half of states in terms of energy intensity.

Annual average temperature is an imperfect measure, as there can be wide seasonal disparity within states, and some states have areas within them that are more temperate than other locations.[10] Heating degree days, defined by EIA as "a measure of how cold the temperature was on a given day or during a period of days,"[11] are another tool in determining relative weather patterns. As with average annual temperatures, there is a significant inverse relationship between heating de-

10 For instance, Nevada is in the middle of the pack temperature-wise at 49.9 degrees, but no one who has been to Las Vegas in the summer would think of Nevada as a cool climate, just as anyone who has been to Reno in winter would think of Nevada as a hot desert.

11 U.S. Energy Information Administration, "Units and Calculators Explained: Degree Days," last updated June 23, 2021, https://www.eia.gov/energyexplained/units-and-calculators/degree-days.php

Table 2: Top 10 states sorted by per capita residential energy consumption

State	Average annual temperature	Percentage of homes heated by electricity (%)	Residential RpkWh	Per capita residential energy consumption (million Btu)	Electricity usage percentage (%)
North Dakota	40.4	40.9	10.44	103.30	43.0
Montana	42.7	24.8	11.24	98.80	35.6
Wyoming	42	22.6	11.11	92.90	38.3
Nebraska	48.8	31.0	10.80	87.60	47.4
West Virginia	51.8	44.6	11.8	87.00	49.5
Missouri	54.5	36.8	11.22	86.40	48.7
South Dakota	45.2	32.2	11.75	83.60	50.8
Indiana	51.7	29.9	12.83	79.70	48.2
Maine	41	7.4	16.81	79.00	29.5
Kentucky	55.6	52.8	10.87	78.70	55.8

gree days and electrification. States like Minnesota with a high number of heating degree days have far fewer all-electric homes than states like Florida with relatively few heating degree days.[12]

The correlation between temperature, however measured, and energy intensity and electrification reveals some interesting points about the current state of heating technology. First, home heating is generally more energy intensive than cooling load, and most of the colder climates currently rely predominantly on at-home fueling, particularly natural gas. A National Renewable Energy Laboratory (NREL) study of building stock separated the United States into different regions based on climate, and the cold/very cold region accounted for 49% of national thermal energy use despite accounting for only 34.5% of U.S. housing stock.[13] Space heating was responsible for most of this thermal energy use, especially in mobile homes.

Even in more temperate climates, space heating accounts for a high proportion of thermal energy use. In the mix-humid (mid-Atlantic) region, for instance, space heating accounts for 71% of thermal energy use, the majority of which is fueled by fossil fuels.[14]

In all regions, infiltration is the leading contributor of energy consumption, nearly doubling "all other envelope heat transfer component loads combined."[15] This accidental leakage of cold air is more prevalent in older homes. Today's more energy-efficient homes cut down on the effects of infiltration to a degree, but space heating remains the major source of thermal energy use even in newer homes, especially in colder climates.

A Regulatory Assistance Project (RAP) report states that "[h]eat pumps are the most cost-effective electric space heating (and cooling) technology for most applications, but they are not suitable for all situations."[16] The report lists several factors affecting the efficiency

12 Davis, p. 14.

13 Janet Reyna, Eric Wilson, Aven Satre-Meloy, Amy Egerter, Carlo Bianchi, Marlen Praprost, Andrew Speake, et al., *U.S. Building Stock Characterization Study: A National Typology for Decarbonizing U.S. Buildings. Part 1: Residential Buildings* (NREL/TP-5500-81186, Golden, CO: National Renewable Energy Laboratory, December 2021), p. 30, https://www.nrel.gov/docs/fy22osti/81186.pdf

14 Ibid., p. 36.

15 Ibid., p. 57.

16 Jessica Shipley, Jim Lazar, David Farnsworth, and Camille Kadoch, *Beneficial Electrification of Space Heating* (Montpelier, VT: Regulatory Assistance Project, November 2018), p. 24, https://www.raponline.org/wp-content/uploads/2018/11/rap-shipley-lazar-farnsworth-kadoch-beneficial-electrification-space-heating-2018-november.pdf

of heat pumps, and regional climatic variation is among those factors.[17] The report cites an American Council for Energy-Efficient Economy (ACEEE) study of the impacts of converting from oil and propane furnaces to high-efficiency heat pumps.[18] While the annual fuel cost savings stemming from conversion of sources is high in states like Georgia ($556), it is negative in states like Massachusetts (-$88) and Wisconsin (-$142).[19] As discussed below, heat pump efficiencies are improving even in colder climates, but these relative disparities explain in part why these regions have been slower to adopt electrified heating technologies.

Another correlation worthy of discussion is that between electric prices and electrification. The average residential price per kilowatt-hour in the 25 states (including the District of Columbia) with the highest percentage of Btu attributed to electricity is 12.5 cents. If Hawaii (an outlier of sorts, as mentioned above) is removed, that average is reduced to 11.8 cents. For the 26 states with the lowest percentage of energy attributable to electricity, the average residential rate per kilowatt-hour is 15.1 cents.

Figure 1 shows the relative electrification rate by state based on average residential rates.

The causal link between electric rates and percentage of electrification as an end use is strong. The average electric use percentage of the 25 states with the lowest rates per kilowatt-hour is 59%, with an average of 46% of homes heated by electricity, versus 47% and

17 Other factors include building type, whether space cooling is being installed simultaneously, installed cost of electric appliances, and the cost of energy.

18 Steven Nadel, *Energy Savings, Consumer Economics, and Greenhouse Gas Emissions Reductions from Replacing Oil and Propane Furnaces, Boilers, and Water Heaters with Air-Source Heat Pumps* (Report A1803, Washington, DC: American Council for an Energy-Efficient Economy, July 2018), https://www.aceee.org/sites/default/files/publications/researchreports/a1803.pdf

19 Shipley et al., p. 26.

Figure 1. Electrification percentage by state by residential rate

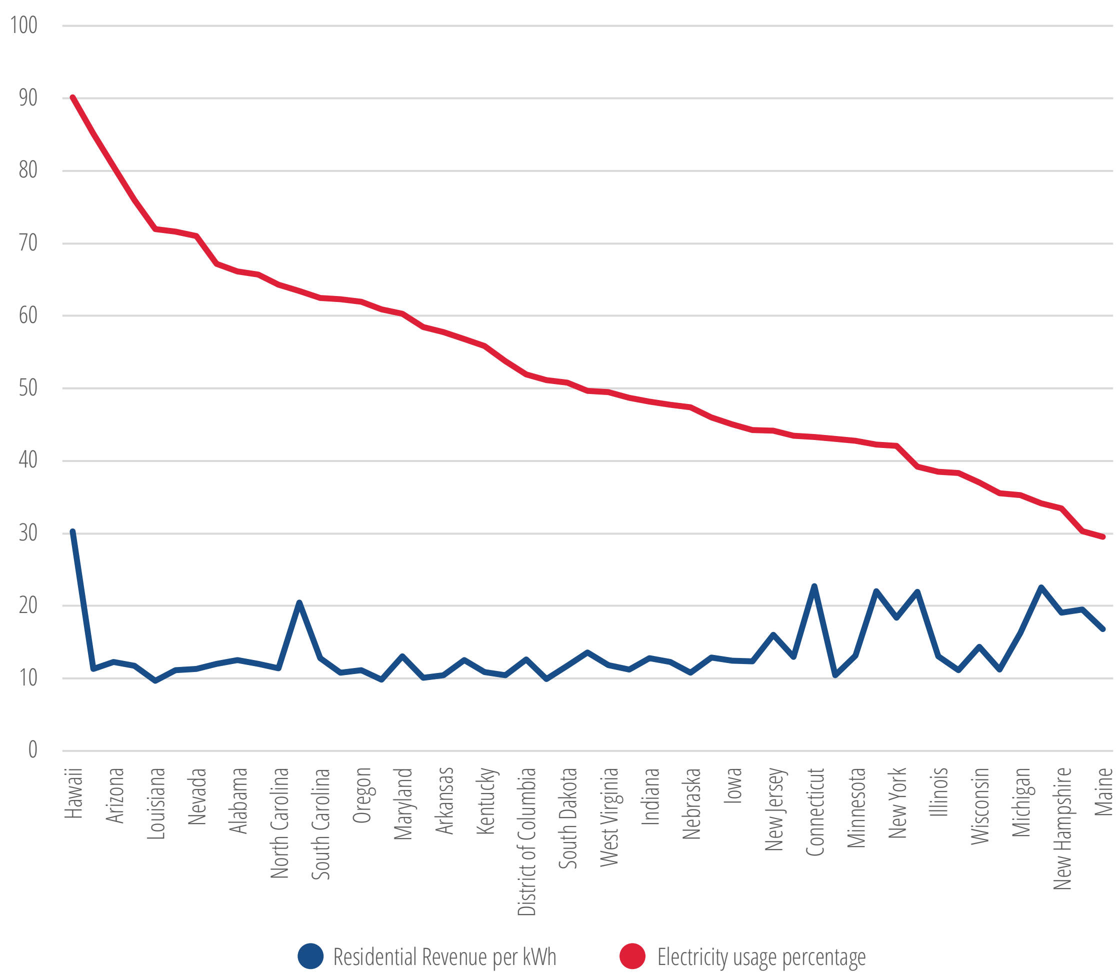
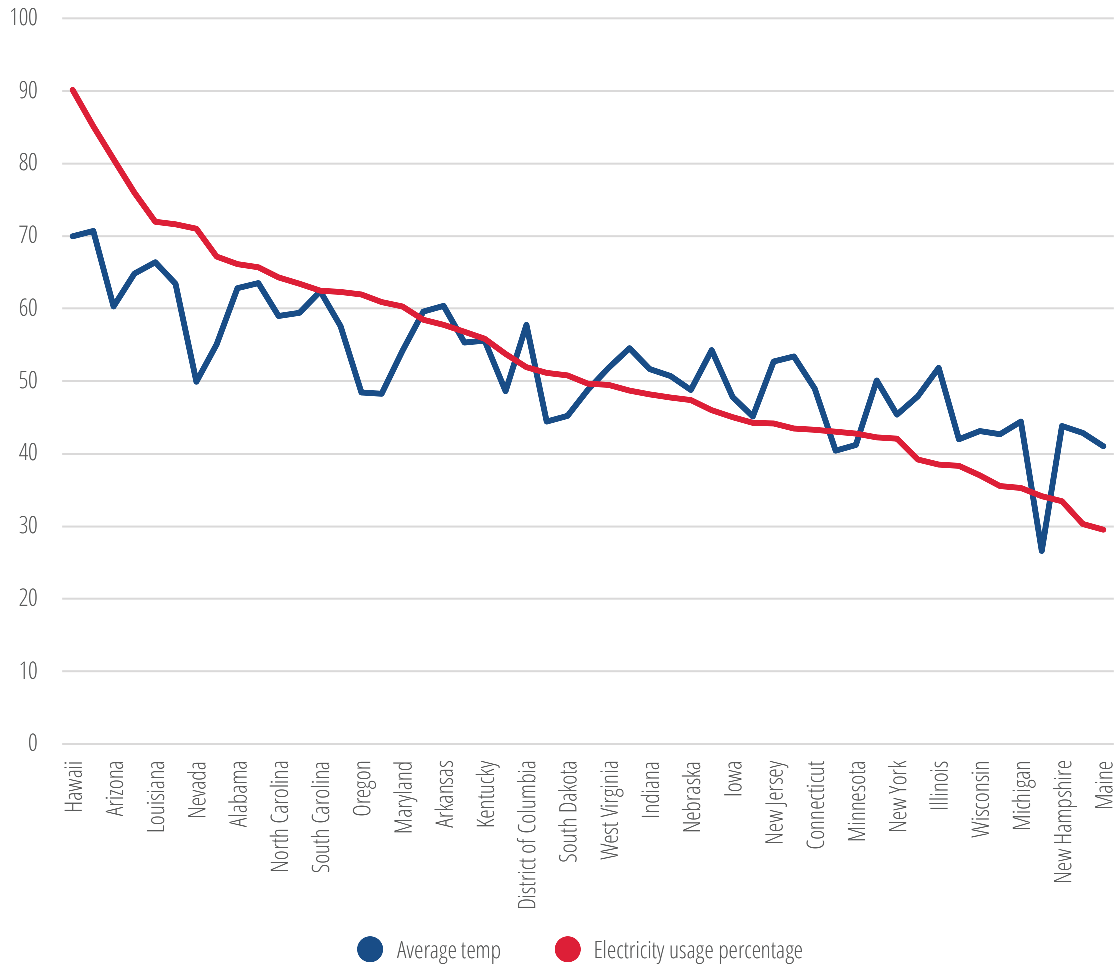


Figure 2. Electrification percentage by state by average temperature



24%, respectively, for the 25 states plus the District of Columbia with the highest rates.

As for temperature, Figure 2 shows a potentially stronger link between average annual temperature and electrification. As average annual temperature declines, so does the percentage of energy fueled by electricity.

Looking at temperature and the percentage of electrified homes, the 25 warmest states plus the District of Columbia have an electrification rate of 61%, with the 25 coolest at 44%, with 47% of homes heated by electricity in the warmest states and 23% in the coolest states.

But among the states with the highest number of electrically heated homes, there is not a lot of disparity in electric rates between the upper and lower halves of this cohort. The states with the 10 highest rates of electrified homes have residential rates that are one-tenth of a cent less than the next 10 states, but they are on average 8 degrees warmer.

As the old saying goes, though, customers pay bills, not rates. Although residential rates tell us much about the relative affordability of electricity, they do not signify what customers actually pay every month. To determine the average monthly bills residential customers pay in each state, average residential revenue per kilowatt-hour was multiplied by annual average household electric usage and then divided by 12 to arrive at a monthly average.

One of the first things that stands out from this analysis is that the old saying above is at least partially true. As shown in Table 3, average bills in Hawaii, like average residential rates, are still the highest in the country at $162.65, but by only about a dollar more than in Connecticut ($161.51), a state with average rates about 7.5 cents less (22.71 cents versus 30.28 cents). Several states with rates about 60%-65% less than Hawaii — Texas, Arizona, South Carolina, and Alabama — have average bills only about $30 less per month.

Table 3: Top 20 states sorted by average monthly residential bill

State	Residential RpkWh	Average monthly bill ($)	Electricity usage percentage (%)	Residential electric spending (%)
Hawaii	30.28	162.65	90.1	95.0
Connecticut	22.71	161.51	43.3	57.0
Alabama	12.57	143.90	66.1	86.6
South Carolina	12.78	138.11	62.5	88.6
Arizona	12.27	136.65	80.6	85.3
Texas	11.71	132.55	76.0	86.0
Massachusetts	21.97	132.20	39.2	52.5
Virginia	12.03	131.75	67.1	77.4
Rhode Island	22.01	130.76	42.2	52.0
Georgia	12.02	129.96	65.7	77.0
Florida	11.27	128.65	85.1	96.1
Mississippi	11.17	128.04	71.7	84.3
Tennessee	10.76	125.71	62.3	84.6
Alaska	22.57	124.65	34.2	54.4
Maryland	13.01	124.55	60.3	70.8
West Virginia	11.8	124.05	49.5	76.2
South Dakota	11.75	121.82	50.8	73.1
Indiana	12.83	120.37	48.2	72.5
New Hampshire	19.04	120.03	33.4	49.0
North Carolina	11.38	118.45	64.3	81.9

And California, the state with the sixth-highest residential rates in the country, falls to 22nd in the category of average monthly electric bill (Table 3).

In terms of electrification, it comes as no surprise that residents with higher electric bills, regardless of rates, also use more electricity. Annual household consumption in the states in the top half of electric bills is 11,309 kWh per annum, versus 9,871 kWh in the states (plus District of Columbia) in the bottom half. Also, unsurprisingly, states with higher average bills tend to be those with higher rates of electricity as a percentage of final energy: over 60% on average in the top 25, with states in the bottom half of bills at slightly less than 48%.

The states with the highest average bills present an interesting and telling disparity. Hawaii, as previously discussed, is the state with the lowest amount of per capita energy consumption and the highest rate of electricity as a percentage of overall energy. Connecticut ranks relatively low in terms of household consumption. Connecticut ranks relatively low in terms of household consumption, at 16th with 8,534 kWh per year, and is in the middle of the pack for energy usage, ranking 30th at 67.2 million Btu per capita. It also ranks 37th in terms of electric usage as a percentage of all energy

Table 4: Top 20 states ranked by highest average energy bills

State	Residential RpkWh	Percentage homes heated by electricity (%)	Household electric use (kWh)	Average monthly electric bill ($)	Electricity usage percentage (%)	Residential electric spending (%)	Total monthly energy expense ($)
Connecticut	22.71	16.8	8,534	161.51	43.3	57.0	283.37
Vermont	19.54	5.9	6,806	110.82	30.3	40.2	275.39
Massachusetts	21.97	16.4	7,221	132.20	39.2	52.5	251.97
Rhode Island	22.01	10.6	7,129	130.76	42.2	52.0	251.43
New Hampshire	19.04	9.9	7,565	120.03	33.4	49.0	244.97
Alaska	22.57	13.1	6,628	124.65	34.2	54.4	229.00
New York	18.36	12.5	7,219	110.45	42.1	49.8	221.87
Maine	16.81	7.4	6,836	95.76	29.5	46.7	205.14
Pennsylvania	13.58	23.5	10,152	114.88	49.7	60.4	190.25
Michigan	16.26	10.1	8,107	109.85	35.2	58.9	186.41
New Jersey	16.03	13.9	8,201	109.55	44.2	60.2	181.88
Maryland	13.01	42.4	11,488	124.55	60.3	70.8	175.97
Hawaii	30.28	33.4	6,446	162.65	90.1	95.0	171.29
Virginia	12.03	55.4	13,143	131.75	67.1	77.4	170.12
Georgia	12.02	55.1	12,974	129.96	65.7	77.0	168.84
South Dakota	11.75	32.2	12,441	121.82	50.8	73.1	166.67
Delaware	12.56	35.1	11,184	117.06	56.8	70.3	166.45
Alabama	12.57	65.8	13,737	143.90	66.1	86.6	166.22
Montana	11.24	24.8	10,299	96.47	35.6	58.1	166.17
Indiana	12.83	29.9	11,259	120.37	48.2	72.5	166.10

consumption at 43.3%. So, while residential customers in the states of Hawaii and Connecticut pay nearly identical electric bills, Connecticut customers pay more overall for the rest of their energy usage simply because they have to cover a much wider gap.

This is shown by EIA's SEDS data, which provide total energy expenditure. According to 2019 data, residential electric expenditures were 95% of total residential energy expenditures in Hawaii, and 57% of total residential energy spending in Connecticut is electric. Extrapolating from the average electric monthly bill estimates, Connecticut's residential customers pay over $100 more per month for their total home energy costs. Table 4 lists the top 20 states sorted by highest energy bills and shows that most have electricity usage percentages lower than average residential electricity usage percentages.

The story is similar for many of the high-percentage electric states. The nine states with the highest electrification rates after Hawaii average out to monthly bills of approximately $129, or just $22 more than the 10 states with the lowest rates of electrification as a percentage of total energy.

To look at the data from a different perspective, the states with the lowest total energy bills average out to 44% of homes heated by electricity, an electric usage percentage of 57.8% and average consumption of 11,654 kWh of electricity per year. For states in the top half of total annual energy bills, those averages are 26%, 48.2%, and 9,653 kWh, respectively. States in the lower half of energy bills also average out to being about 5 degrees warmer than high energy bill states (54 degrees versus 49 degrees) and average out to residential rates of 11.4 cents per kilowatt-hour versus 16.1 cents. The lower cost of electricity and the slightly warmer temperatures thus mitigate the higher cost of electricity.

Electricity does account for a higher share of costs than usage. While all states average out to 52% of total energy consumption for electric, the average percentage of energy bills coming from electric is 69%.

Admittedly, these data do not tell the entire story. A Citizens Utility Board analysis of electric and energy burdens also factors in median income.[20] Therefore, some lower-cost states have a comparatively high energy bill burden because the residents of the state have lower relative incomes. The bottom line, though, is that states with the highest energy bills generally are those with lower rates of home electrification.

Finally, a brief discussion of retail choice may be of merit here. Among the 25 jurisdictions with the highest electrification rates, only four deregulated states (Delaware, Maryland, Texas, and California[21]) and the District of Columbia are among them, with another — Pennsylvania — smack dab in the middle of the rankings. All other retail choice states rank in the 25 states with the lowest electrification percentages, including six of the bottom 12. This is likely a coincidence owing to the fact that retail choice states are predominantly colder states in the northeast and mid-Atlantic with older housing stock, both factors that lead to lower rates of electrification, as discussed earlier.

20 Citizens Utility Board (CUB), *Electric Utility Performance: A State-by-State Data Review* (Chicago, IL: CUB, 2022), https://www.citizensutilityboard.org/wp-content/uploads/2021/07/Electric-Utility-Performance-A-State-By-State-Data-Review_final.pdf. See especially pages 4-12 for a discussion of affordability metrics. It should be noted some of their data are not consistent with the data produced here using, principally, EIA data, possibly due to some methodological differences in defining energy costs.

21 The American Public Power Association has included California among deregulated states in its publications. While residential retail choice has long been suspended, there is still limited retail choice in the commercial and industrial sectors. The recent increase in community choice aggregators (CCAs) adds another retail choice element to California.

PART TWO —

FUTURE DEVELOPMENTS

PREDICTING ECONOMIC IMPACTS OF ELECTRIFICATION

Based on where we have been, can we predict where we are going? The data presented suggest that full-scale deployment of home electrification will entail electrifying areas where electric rates are higher and where climates are traditionally less amenable to electric heating sources. But changes in both pricing and heating technology have already altered the landscape.

In terms of pricing, despite the earlier discussion of electricity being relatively higher in price than heating fuel, the trajectory of prices for both are trending in opposite directions. As Davis notes, average electric prices have declined 58% in real terms since 1950, while average prices for natural gas and oil are up 27% and 79%, respectively.[22] While there have been many fluctuations in both over the years, and electric prices are themselves influenced by natural gas prices,[23] the relative stability of electric prices may ease the transition.

More significantly, changes in technology are erasing some of the efficiency losses in heating in cooler climates.

If electric heating technology continues to grow in efficiency, this will aid the economic argument for electrification, as electrified end uses utilize less energy on a Btu equivalent basis than other forms of fossil-based heating. RAP's study of beneficial electrification posits that "[h]eat pumps, for example, are capable of providing 1.5 to 3 times more heat energy than the heat value of the electrical energy they consume, making them ideal for space and water heating."[24] This is also true of EVs, which convert 60% of the energy they draw into miles traveled, whereas internal combustion engine vehicles convert 20%.[25]

One unknown is the degree to which electrification will be driven by retrofits or new home construction. As previously discussed, areas with higher levels of electrified end uses tend to have slightly newer housing stock. Newer homes are increasingly more likely to be fully electric. If older homes in the regions of the country with lower levels of electrification are replaced rather than being retrofitted, that may affect the economic impact of electrification.

Authors of a Rocky Mountain Institute report studied the relative cost differentials between new construction and retrofitting. They found that electricity generally reduces costs for new homes compared to fossil-fuel heating over the lifetime of appliances. Conversely, for existing homes, electricity increases costs at today's prices compared with new natural gas–fired devices. As explained, "Customers with existing gas service face higher up-front costs to retrofit to electric space and water heating compared with new gas devices — in the case of colder climates in Chicago and Providence — or save too little in energy cost to make up additional capital cost — in the case of Houston and Oakland."[26] The report adds, "for most new home construction, we find electrification reduces costs over the lifetime of the appliances when compared with fossil fuels. However, for the many existing homes currently heated with natural

22 Davis, p. 3.

23 Increasing natural gas prices led to increased wholesale electric prices in 2021, which in turn rebound to the retail market. U.S. Energy Information Admninistration, "Wholesale Electricity Prices Trended Higher in 2021 Due to Increasing Natural Gas Prices," January 7, 2022, https://www.eia.gov/todayinenergy/detail.php?id=50798

24 David Farnsworth, Jessica Shipley, Jim Lazar, and Nancy Seidman, Beneficial *Electrification: Ensuring Electrification in the Public Interest* (Montpelier, VT: Regulatory Assistance Project, June 2018), p. 21, https://www.raponline.org/wp-content/uploads/2018/06/6-19-2018-RAP-BE-Principles2.pdf

25 Ibid.

26 Sherri Billimoria, Leia Guccione, Mike Henchen, and Leah Louis-Prescott, *The Economics of Electrifying Buildings: How Electric Space and Water Heating Supports Decarbonization of Residential Buildings* (Basalt, CO: Rocky Mountain Institute, 2018), p. 6.

gas, electrification will increase costs at today's prices, compared to replacing gas furnaces and water heaters with new gas devices."[27]

The Center for American Progress issued a report that dives into the economics of electrification and retrofitting. To fully electrify all home heating and cooking appliances would require replacing 80 million appliances in 50 million homes. The net energy savings are estimated to be $27 billion per year, but the cost of federal incentives to make this transition would be $8.8 billion to $26.5 billion per year over the next decade.[28] James Sallee posits that offering manufacturers a rebate instead of directly subsidizing consumers would be more economical and create more inducement to electrify homes.[29] Whether it is through demand or supply-side incentives, the study shows the scope of the needed change.

27 Ibid.

28 Trevor Higgins, Ari Matusiak, Bianca Majumder, Sam Calisch, and Debbie Lai, *To Decarbonize Households, America Needs Incentives for Electric Appliances* (Washington, DC: Center for American Progress, June 2021), https://www.americanprogress.org/article/decarbonize-households-america-needs-incentives-electric-appliances/

29 James Sallee, "The Supply-Side Economics of Residential Electrification," *Energy Institute (blog),* Energy Institute at Haas, August 30, 2021, https://energyathaas.wordpress.com/2021/08/30/the-supply-side-economics-of-residential-electrification/

Even new construction of all-electric homes is not without added cost. As noted in an ACEEE report, in a Commonwealth Edison pilot study, an all-electric multifamily unit's construction costs were $214 per square foot, as opposed to $178 per square foot for one built according to ENERGY STAR standards. However, the all-electric property reduced the delivered energy requirement for space heating by 76% and total annual energy costs by 19%.[30]

The pilot report provides more details on this study, which included two six-unit multifamily properties, one built according to ENERGY STAR standards and the other certified under the Passive House Institute US PHIUS+ standards. One notable result was that the property built according to PHIUS+ standards requires approximately 65% less delivered heating energy on a weather-normalized seasonal basis. Notably, the modeling "suggests that most of these savings come from the extremely tight shell combined with heat recovery ventilation and high-performance, triple-pane windows."[31] The windows contributed 30% of the savings "but less than 10% of the incremental cost."[32]

As discussed earlier, infiltration is the largest contributor to space heating consumption. The experimental property shows that efficiency gains from better insulation can be an enormous contributor to energy savings. This has potentially significant implications for electric space heating if it is paired with insulation improvements, which can be done at relatively lower costs, demonstrating that the potential benefits of electric space heating are amplified.

The case study also found that "the air-source heat pumps at the PHIUS+ property are more efficient than the gas furnaces and split-system air conditioners at the ENERGY STAR property on a site-energy basis." What's more, although the PHIUS+ property required approximately 76% less energy for space conditioning, "the measured heating-season efficiency of the PHIUS+ heat pumps is lower than expected for this type of equipment, suggesting that there is potential for even greater energy savings."[33] When all site energy is accounted for

30 Cited in Charlotte Cohn and Nora Wang Esram, *Building Electrification: Programs and Best Practices* (Washington, DC: American Council for an Energy-Efficient Economy, February 3, 2022), p. 56, https://www.aceee.org/research-report/b2201

31 *The Tierra Linda Passive House: A Comparative Case Study Full Report.* January 22, 2021. Prepared for Commonwealth Edison Company by Slipstream, p. 4.

32 Ibid.

33 Ibid., p. 5.

— water heating, lighting, and other appliances — total site energy for the PHIUS+ property is about one-third less.[34]

Despite significant total energy savings, the study also found that "the cost per delivered MMBtu of space heating at the PHIUS+ property is more than twice that of the ENERGY STAR property" due to electricity being a more expensive source than natural gas.[35] In the end, "the annual cost of space heating at the PHIUS+ property ends up being only about 35% less than that of the ENERGY STAR property."[36]

Caution should be used in applying the results of one case study to an entire industry, but the results of the case study are congruent with other comparative analyses. Improved efficiencies are making electric space heating more competitive, if not wholly more economical than traditional methods of space heating. But whether these devices are installed in newly constructed homes or via retrofitting, the costs of the transition will run into the hundreds of billions. Not all of this will be borne directly by consumers, but it will undoubtedly have some bearing on future rates.

34 Ibid.

35 Ibid., p. 27.

36 Ibid.

SUPPLY CHAIN

Another critical element to electrification is the availability of materials and supplies that will undergird these efforts. Of particular importance is the supply and delivery of lithium, which is the backbone of lithium-ion batteries. Those batteries will impact electrification directly through the manufacture of EVs and indirectly for use in both small- and large-scale energy storage. Other materials, such as copper and nickel, are also used in battery production.

This production is precarious for several reasons. Most production today takes place in a select few countries, often on the other side of the world from the United States. As of 2020, Australia was responsible for 48% of global lithium production, with China accounting for 79% of graphite production, and Democratic Republic of the Congo accounting for 69% of the cobalt supply.[37] Some of these countries are experiencing internal political turmoil and/or are geopolitical rivals with the United States.

Increased demand is putting pressure on prices. While the cost of batteries has declined significantly over the past decade, supply chain constraints and increasing demand are causing prices to stagnate. In 2015, the raw materials used in manufacturing batteries accounted for 40% of the cost, but in 2022 that has increased to upward of 80% of the cost.[38] The costs of those materials have spiked in just a couple of years. Lithium prices have increased 700% since January 2020, with nickel increasing by 250%, cobalt and manganese by 100%, and graphite by over 25%.[39]

Finally, there is the question of whether the projected massive increase in demand will soon outstrip supply. In just a few years, demand for lithium-ion batteries increased from 59 gigawatt-hours (GWh) in 2015 to 400 GWh in 2021, and that demand is forecast to increase to 600 GWh in 2022.[40]

This increase in demand comes during a time when both the EV and energy storage markets constitute relatively small shares of overall vehicle and energy markets. Global forecasts of EV demand vary from study to study but generally are in accord that EVs will be a significant share of the vehicle market by the end of the decade. Considering that EVs consist of approximately six times more minerals than a conventional vehicle,[41] this will create an even greater strain on the mineral supply chain.

By one estimate, to meet growing EV demand, lithium production would have to increase sevenfold, while production of other metals would also need to grow substantially. That would entail $250 to $300 billion in capital investments in copper and nickel alone.[42] Unfortunately, some projections do not forecast substantial increases in the raw material. One projection has lithium pegged at only 2% to 5% growth over the next couple

37 Isabeau van Halm, "Concerns for Mineral Supply Chain Amid Booming EV Sales," *Mining Technology,* February 10, 2022, https://www.mining-technology.com/analysis/concerns-for-mineral-supply-chain-amid-booming-ev-sales/

38 Simon Moores and Morgan Bazilian, "EV and Battery Big Talk Must Now Switch to Mining as Supply Chain Bites," April 8, 2022, https://www.benchmarkminerals.com/membership/ev-and-battery-big-talk-must-now-switch-to-mining-as-supply-chain-bites/

39 Ibid.

40 Ibid.

41 van Halm, *Concerns for mineral supply chain*

42 "The Raw-Materials Challenge: How the Metals and Mining Sector Will Be at the Core of Enabling the Energy Transition," McKinsey & Company, January 10, 2022, https://www.mckinsey.com/industries/metals-and-mining/our-insights/the-raw-materials-challenge-how-the-metals-and-mining-sector-will-be-at-the-core-of-enabling-the-energy-transition

of years, with demand soon outstripping supply.[43] More distressingly, some studies predict depletion of traditional lithium reserves as soon as 2038 and others out to 2050, and potentially sooner if EV demand outpaces most forecasts.[44]

There are some pathways for alleviating these constraints. The United States could ramp up domestic U.S. lithium production. Aside from mitigating some of the supply chain issues, this could have some material economic benefit. Assuming domestic EV sales grow to 10 million or so by 2040 as projected by Bloomberg, if all the batteries were manufactured abroad, that would result in $100 billion in imports.[45]

Even an aggressive effort to expand domestic lithium production will not meet all battery demand. As the Federal Consortium for Advanced Batteries puts it:

> While U.S.-based manufacturing of lithium-ion batteries needs to greatly expand to meet the needs of the growing domestic market, the country has a strong foundation on which to build additional manufacturing capacity. Of the 747 GWh of global EV lithium-ion cell manufacturing in 2020, the U.S. capacity is approximately 8% (about 59 GWh). Global cell manufacturing for EVs is anticipated to grow to 2,492 GWh by 2025 with U.S. capacity expected to grow to 224 GWh. However, demand from U.S. annual sales of passenger EVs alone is projected to surpass this anticipated 224 GWh of lithium-ion cell manufacturing capability in 2025.[46]

An estimated 320 GWh of domestic lithium-ion battery production capacity is needed by 2028 for EVs alone, but projections for U.S.-based capacity production are 148 GWh.[47] And all this does not include the lithium needed for energy storage batteries. If lithium is going to continue to be the dominant source of batteries, a considerable amount will need to be purchased overseas — if there is enough to be found.

It is possible that battery recycling can mitigate some of the production shortages, but there are challenges associated with this as well. Some of those challenges are that lithium-ion batteries (LIBs) are highly flammable, and manual dismantling is difficult. A "systematic collection and sorting system for spent LIBs are still lacking, so the mixing of various types of spent LIBs may complicate and render recycling less effective."[48] What's more, "the cost of recycled lithium could be as much as five times that needed to produce the same amount from brine-based processes."[49]

Other technologies and processes could come along to ease some of these concerns, and other material could supplant materials currently used. This happened previously with batteries with high cobalt content. When cobalt prices increased, nickel began to supplant cobalt in batteries.[50] Some type of change is likely necessary to avoid potential supply shortfalls and massive price increases, or else electrification efforts will fall short.

43 Carlito Baltazar Tabelin, Jessica Dallas, Sophia Casanova, Timothy Pelech, Ghislain Bournival, Serkan Saydam, and Ismet Canbulat, "Towards a Low-Carbon Society: A Review of Lithium Resource Availability, Challenges and Innovations in Mining, Extraction and Recycling, and Future Perspectives," *Minerals Engineering* 163 (2021): 106743, https://doi.org/10.1016/j.mineng.2020.106743

44 Ibid.

45 *National Blueprint for Lithium Batteries: 2021-2030* (Washington, DC: Federal Consortium for Advanced Batteries, June 2021), p. 10, https://www.energy.gov/sites/default/files/2021-06/FCAB%20National%20Blueprint%20Lithium%20Batteries%200621_0.pdf

46 Ibid., p. 12.

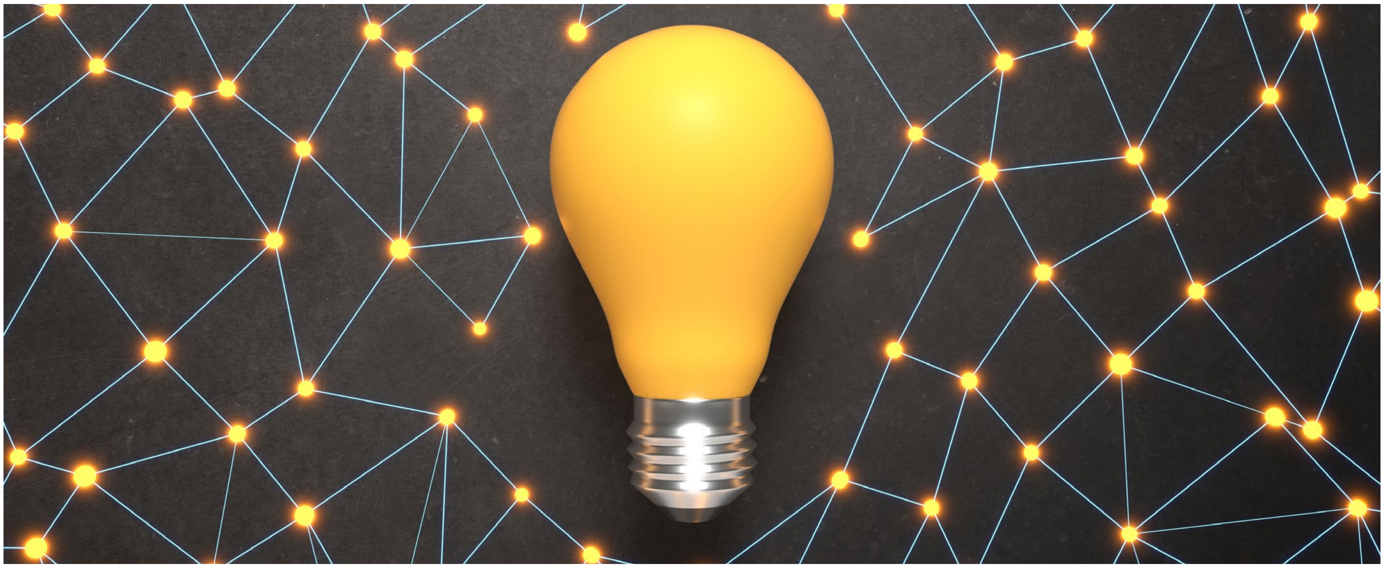
47 Ibid., p. 15.

48 Baltazar Tabelin et al., p. 12.

49 Ibid.

50 "The Raw-Materials Challenge."

ELECTRIFICATION AND THE FUTURE GRID



Aside from the cost of converting technologies and finding the material to buttress electrification efforts, another significant cost will be in adapting the grid to meet increased demand from these resources. An NREL study of future electrification projected that electricity demand could increase from 4,000 terawatt-hours (TWh) in 2020 to 5,000 TWh by 2050 in its reference case, or as much as 7,000 TWh in its high electrification scenario. In the higher-use forecast, electricity would be as much as 35% of all energy end use.[51]

If the high-end or even middle-of-the-road scenarios are realized, this will impact the grid in meaningful ways. First, this increased demand, if it also increases overall system peaks, could necessitate the development of new capacity, above and beyond what is already being planned. This, in and of itself, has complicating factors.

First, there are studies suggesting that increased electrification is already leading to increased marginal CO_2 emissions, which are distinct from average total emissions. While total average emissions have decreased by 28% over the past decade, marginal emissions have increased by 7%, according to one study.[52] This is because coal is increasingly now being used as the marginal fuel for generation. As the study authors put it, "Higher marginal emissions means that adding new EVs to the stock of vehicles now causes more CO2 emissions on the electricity grid than it did 10 y[ears] ago."[53]

51 Ella Zhou and Trieu Mai, *Electrification Futures Study: Operational Analysis of U.S. Power Systems with Increased Electrification and Demand-Side Flexibility* (NREL/TP-6A20-79094, Golden, CO: National Renewable Energy Laboratory, 2021), p. 6, https://www.nrel.gov/docs/fy21osti/79094.pdf

52 Stephen P. Holland, Matthew J. Kotchen, Erin T. Mansur, and Andrew J. Yates, "Why Marginal CO2 Emissions Are Not Decreasing for US Electricity: Estimates and Implications for Climate Policy," PNAS 119, no. 8 (2022): e2116632119, https://resources.environment.yale.edu/kotchen/pubs/margemit.pdf

53 Ibid.

Other authors note, however, that these models rely on short-run marginal emissions rates, and thus their projections of increased marginal emissions are based on a static forecast of the nation's generation portfolio. Long-run marginal emissions rates, on the other hand, consider the potential that this new load would prompt more low-emissions generation to be constructed, thereby leading to lower marginal emission rates.[54]

Indeed, future projections of generation capacity show an increasing number of renewable resources, particularly wind and solar, as shown in Table 5. As of January 2022, nearly 113,000 MW of generating capacity were under construction or had been permitted to begin construction. Of this amount, just under 95% were solar, natural gas, and wind, of which 70% were wind and solar alone.[55]

54 Pieter Gagnon and Wesley Cole, "Planning for the Evolution of the Electric Grid with a Long-Run Marginal Emission Rate," iScience 25, no. 3 (2022): 103915, https://www.sciencedirect.com/science/article/pii/S2589004222001857

Table 5: Permitted plants and plants under construction, by fuel type

Fuel type	Nameplate capacity (MW)	Share (%)
Solar	54,372.91	48.18
Natural gas	26,900.76	23.84
Wind	25,683.23	22.76
Hydro	2,910.19	2.58
Nuclear	2,560.00	2.27
Geothermal	238.00	0.21
Agriculture by-product	49.90	0.04
Biomass solids	36.50	0.03
Biomass gases	30.50	0.03
Waste heat	28.60	0.03
Other	26.40	0.02
Landfill gas	12.08	0.01
Distillate fuel oil	7.60	0.01
Biomass other	2.00	0.00
Grand total	**112,858.67**	

A review of electrification and current and future generation capacity can help paint a picture of the potential environmental impacts of electrification. The states with the highest levels of electricity as a share of end-use energy tend to be predominantly fueled by natural gas, as shown in Table 6. Forty-four percent of operating capacity[56] in the United States is currently fueled by natural gas, and all states in the top 10 in terms of electrification except one exceed the national average. Hawaii is the only outlier as most of its generation capacity is oil-fired, though it also has higher shares of non-hydro renewable capacity than any state in the top 10 except Nevada.

Conversely, many states in the bottom half of electrification have higher than average rates of hydro and renewable capacity. Adding nuclear to the mix, 34% of U.S. generation capacity is composed of nuclear, renewable, and hydro, the 10 least electrified states average 41% of such capacity, as compared to 27% for states in the top 10. This suggests that as low-electrification states increase the amount of electrified end uses, they will be doing so with a higher base of non-carbon-emitting forms of generation.

Despite having higher shares of non-CO2-emitting generation capacity, the states with lower rates of electrification have higher per capita CO2 emission rates than states with high rates of electrification, even though they are similar in the carbon intensity of the energy supply, as can be seen in Tables 7a and 7b.

Although there are discrepancies and outliers in Tables 7a and 7b — Louisiana has the fifth highest rate of per capita CO_2 emissions, while low-electrification states like Massachusetts, New Hampshire, Vermont, and Maine are among the lowest per capita emission states — overall, higher electrification states tend to have lower per capita emission rates. Moving beyond the top and bottom 10, states in the upper half of the electrification percentage have average per capita emissions of 16 metric tons per person, while states in the lower half average 24 metric tons per person.

55 As summarized in American Public Power Association, *America's Electricity Generation Capacity: 2022 Update*, March 2022, https://www.publicpower.org/system/files/documents/Americas_Electricity_Generation_Capacity_2022_Update.pdf

56 While actual generation (MWh) is a better measure of how resources are actually deployed, capacity is used here to better contrast with future scenarios. It should also be noted that capacity and generation within a state border are often exported over state lines, so this may not accurately capture the fuel profile of each state. This is the closest approximation available at this time.

Table 6: Share of generation fuel capacity in 10 most electrified states

State	Electricity usage percentage (%)	Coal (%)	Gas (%)	Other (%)	Nuclear (%)	Renewable (%)	Hydro (%)
Hawaii	90.1	5.8	1.6	62.2	0.0	29.3	1.2
Florida	85.1	8.8	69.7	6.8	5.7	8.9	0.1
Arizona	80.6	10.3	54.5	0.4	12.7	12.8	9.3
Texas	76.0	13.0	54.0	0.2	3.5	28.9	0.5
Louisiana	72.0	14.3	73.8	1.4	8.0	1.9	0.7
Mississippi	71.7	9.8	77.4	0.1	9.6	3.0	0.0
Nevada	71.0	5.4	56.2	0.1	0.0	31.2	7.1
Virginia	67.1	9.0	48.2	6.7	12.8	10.7	12.6
Alabama	66.1	16.1	50.1	0.1	18.8	4.7	10.1
Georgia	65.7	21.8	45.0	2.7	10.1	11.0	9.3

Table 7a: Emissions and carbon intensity levels for top 10 electrified states

State	Electricity usage percentage (%)	2019 CO_2 emissions per capita (metric tons per person)	Carbon intensity of energy supply (kg of energy-related CO_2 per million Btu)
Hawaii	90.1	14.5	66.7
Florida	85.1	10.9	55.1
Arizona	80.6	12.7	49.8
Texas	76.0	23.6	48.4
Louisiana	72.0	41.8	47.7
Mississippi	71.7	21.0	52.0
Nevada	71.0	13.5	53.2
Virginia	67.1	12.5	49.5
Alabama	66.1	21.6	45.2
Georgia	65.7	12.8	50.1

Table 7b: Emissions and carbon intensity levels for bottom 10 electrified states

State	Electricity usage percentage (%)	2019 CO_2 emissions per capita (metric tons per person)	Carbon intensity of energy supply (kg of energy-related CO_2 per million Btu)
Massachusetts	39.2	9.2	55.7
Illinois	38.5	16.1	47.1
Wyoming	38.3	101.9	74.2
Wisconsin	37.0	16.3	54.9
Montana	35.6	30.2	57.7
Michigan	35.2	15.9	53.4
Alaska	34.2	46.7	56.6
New Hampshire	33.4	10.2	35.9
Vermont	30.3	9.6	32.8
Maine	29.5	10.7	37.6

The data suggest that as we move toward a more electrified economy, relative CO_2 emissions will continue to fall because electrified end uses generally emit less CO_2 on a Btu equivalent basis. Because many of the states with lower rates of electrification have relatively higher shares of non-CO_2-emitting generation capacity, and all states are developing more of such capacity, then emissions should decline even further. That being said, utilities will need to assess the most economic and efficient portfolio for future planning. Whatever is added to the grid to ensure a reliable power supply will incur costs ultimately borne by customers; therefore, stakeholders should consider all options for accommodating an increasingly electrified load.

OTHER OPTIONS FOR OFFSETTING DEMAND IMPACTS OF ELECTRIFICATION

Additional generation capacity will certainly be developed, and there are strategies that can be used to mitigate the total amount needed, including shifting demand through energy efficiency, demand response programs, and other means of load shifting. A Brattle Group study of a Pepco pilot found that energy efficiency and load flexibility could reduce peak demand in the Pepco territory by 14% and reduce the annual peak demand growth rate to 0.9%.[57] In total, 40% of load growth between 2021 and 2050 would be reduced by load flexibility.

Electrification and increased renewable generation can also work in tandem. As Jim Lazar observes, most residential water heating use is in the morning and evening hours. If this load could be moved to the mid-afternoon period when solar is at its peak, or overnight when wind and other thermal generation are underutilized, this could maximize generation capacity and mitigate the need to increase peak capacity.[58]

This could apply to EV charging as well. Many utilities offer customers with EVs time-of-use rates.[59] Under this rate design, usage is charged at a higher rate during system peak periods, but usage during off-peak hours is priced at a reduced rate. Typically, these programs are designed to encourage drivers to charge overnight. These rates could also be designed to encourage charging during the middle of the day, especially as more solar is added to the grid as a source of primary generation.

57 Ryan Hledik, Sanem Sergici, Michael Hagerty, and Julia Olszewski, *An Assessment of Electrification Impacts on the Pepco DC System* (The Brattle Group, prepared for Pepco, August 2021), https://www.pepco.com/Documents/1167%20%20Pepco%27s%20Electrification%20Study%20%20082721.pdf

58 Jim Lazar, *Teaching the "Duck" to Fly*, 2nd ed. (Montpelier, VT: The Regulatory Assistance Project, 2016), p. 10, https://www.raponline.org/wp-content/uploads/2016/05/rap-lazar-teachingtheduck2-2016-feb-2.pdf

59 See APPA, *Exploring Electric Vehicle Rates for Public Power* (2021), https://www.publicpower.org/resource/exploring-electric-vehicle-rates-public-power

Even if load is distributed more evenly throughout the day, there will need to be major upgrades to both the distribution and transmission grids. The National Academy of Sciences estimates that $2.1 trillion in capital investments will be needed just by 2030 to put the United States on a path to a near-zero-emission economy. Of that total, a significant amount will be needed to accommodate increased electricity load due to EVs and space heating.[60] Among the investment needed in EVs, for example, are investment in a ubiquitous EV charging infrastructure and investment in vehicle connectivity and real-time control infrastructure.[61]

60 National Academies of Sciences, Engineering, and Medicine, *Accelerating Decarbonization of the U.S. Energy System* (Washington, DC: The National Academies Press, 2021), https://doi.org/10.17226/25932

61 Ibid., p. 87

If the transition to EVs is achieved on any meaningful scale, this will require utility investment in local distribution infrastructure. Some pockets of service territories, particularly in California, are already being strained by the deployment of EVs. Multiple cars on a feeder charging at the same time can max out the capacity of those feeders, not to mention what may happen when more families begin to have more than one EV in their household. While load flexibility, as previously discussed, can help, there will almost certainly be a need to be upgrade these networks as not every driver will be willing to (or able to) curtail their usage and charge only at specific times of the day.

Similarly, as large companies like Home Depot, Amazon, and others electrify their fleets, including medium- and heavy-duty vehicles, they will look to install chargers in their locations. This load will be on a magnitude of multiple megawatts. Utilities may be able to identify locations where this added load can be more easily accommodated, but there are few places where adding 5, 10, or 15 MW of load at once will not incur substantial costs.

CONCLUSION

This report is meant to paint a picture of the current landscape for electrification and to ponder some of the implications for a widespread reliance on electrified end uses. None of the preceding should be taken to imply that this is an impossible, unachievable goal. The United States has already steadily increased the amount of electrified heating as a proportion of energy use and has done so without dramatically increasing electricity prices or sacrificing reliability. Indeed, as the data indicate, homes with high levels of electrification have lower than average energy bills. Moreover, EV sales have steadily increased over the past decade, and manufacturers have signaled their intent to focus on this segment of the market.

At the same time, we cannot ignore some of the challenges and implications of increased electrification. Utilities, customers, policy makers, and every other conceivable stakeholder need to assess where they are and the best path forward toward electrification. For those in locations much farther along the path, it may be as simple as forging ahead with minimal disruption. For many others, though, electrification will require massive shifts in their current infrastructure. This can be done economically, but it will also require careful study, and it may necessitate waiting for technology to improve to ensure that adoption will not be disruptive to customers.

It will also require policy makers to balance competing needs. If electrification is part of an overall process of achieving emissions reductions, then any electrification efforts that could create environmental harm or deplete resources must be weighed against the potential benefits. It should also spur investment into research and development in new mining and resource extraction technologies as well as new types of battery technology that require reliance on less scarce resources available domestically.

APPENDIX 1:

STATES RANKED BY ELECTRICITY PERCENTAGE

State	Percentage of homes heated by electricity (%)	Average annual temperature	Residential RpkWh (2020)	Average electric monthly bill ($)	Household electric use (kWh)	Electricity usage percentage (%)
Hawaii	33.4	70.0	30.28	162.65	6,445.93	90.1
Florida	91.9	70.7	11.27	128.65	13,698.04	85.1
Arizona	60.5	60.3	12.27	136.65	13,364.26	80.6
Texas	60.4	64.8	11.71	132.55	13,583.19	76.0
Louisiana	63.7	66.4	9.67	116.10	14,406.92	72.0
Mississippi	57.3	63.4	11.17	128.04	13,755.95	71.7
Nevada	35.9	49.9	11.34	110.34	11,676.18	71.0
Virginia	55.4	55.1	12.03	131.75	13,142.54	67.1
Alabama	65.8	62.8	12.57	143.90	13,737.23	66.1
Georgia	55.1	63.5	12.02	129.96	12,974.09	65.7
North Carolina	63.8	59.0	11.38	118.45	12,489.98	64.3
California	27.1	59.4	20.45	116.94	6,862.05	63.5
South Carolina	71.5	62.4	12.78	138.11	12,968.35	62.5
Tennessee	62.3	57.6	10.76	125.71	14,019.85	62.3
Oregon	51.6	48.4	11.17	102.35	10,995.29	61.9
Washington	56.2	48.3	9.87	95.69	11,633.85	60.9
Maryland	42.4	54.2	13.01	124.55	11,487.84	60.3
Oklahoma	39.7	59.6	10.12	109.11	12,938.41	58.5
Arkansas	51.5	60.4	10.41	110.35	12,720.42	57.8
Delaware	35.1	55.3	12.56	117.06	11,183.98	56.8
Kentucky	52.8	55.6	10.87	116.65	12,877.99	55.8
Utah	14.2	48.6	10.44	80.27	9,226.21	53.7
District of Columbia	43.2	57.8	12.63	88.87	8,443.63	51.9

State	Percentage of homes heated by electricity (%)	Average annual temperature	Residential RpkWh (2020)	Average electric monthly bill ($)	Household electric use (kWh)	Electricity usage percentage (%)
Idaho	34.1	44.4	9.95	95.05	11,463.37	51.1
South Dakota	32.2	45.2	11.75	121.82	12,440.99	50.8
Pennsylvania	23.5	48.8	13.58	114.88	10,151.62	49.7
West Virginia	44.6	51.8	11.8	124.05	12,614.85	49.5
Missouri	36.8	54.5	11.22	115.31	12,332.92	48.7
Indiana	29.9	51.7	12.83	120.37	11,258.71	48.2
Ohio	24.3	50.7	12.29	107.32	10,479.21	47.7
Nebraska	31.0	48.8	10.80	109.42	12,158.33	47.4
Kansas	25.3	54.3	12.85	113.49	10,598.24	46.0
Iowa	23.3	47.8	12.46	107.78	10,380.30	45.1
Colorado	23.2	45.1	12.36	87.89	8,533.12	44.2
New Jersey	13.9	52.7	16.03	109.55	8,201.23	44.2
New Mexico	21.1	53.4	12.94	86.68	8,038.63	43.5
Connecticut	16.8	49.0	22.71	161.51	8,534.44	43.3
North Dakota	40.9	40.4	10.44	113.30	13,023.21	43.0
Minnesota	18.1	41.2	13.17	102.13	9,305.48	42.8
Rhode Island	10.6	50.1	22.01	130.76	7,129.12	42.2
New York	12.5	45.4	18.36	110.45	7,218.68	42.1
Massachusetts	16.4	47.9	21.97	132.20	7,220.88	39.2
Illinois	17.1	51.8	13.04	93.96	8,646.80	38.5
Wyoming	22.6	42.0	11.11	96.58	10,431.95	38.3
Wisconsin	16.3	43.1	14.32	99.42	8,330.87	37.0
Montana	24.8	42.7	11.24	96.47	10,298.98	35.6
Michigan	10.1	44.4	16.26	109.85	8,107.19	35.2
Alaska	13.1	26.6	22.57	124.65	6,627.55	34.2
New Hampshire	9.9	43.8	19.04	120.03	7,564.93	33.4
Vermont	5.9	42.9	19.54	110.82	6,805.53	30.3
Maine	7.4	41.0	16.81	95.76	6,836.04	29.5

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