PECAN STREET

Addressing an Electrification Roadblock: Residential Electric Panel Capacity

Analysis and Policy Recommendations on Electric Panel Sizing

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PECAN STREET

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Electrification is an Imperative for Addressing Climate Change

The August 2021 Intergovernmental Panel on Climate Change (IPCC) report yet again illustrates the need for urgent action to decrease greenhouse gas emissions (GHGs) if we are to keep average global temperatures from rising beyond 1.5 degrees. The electrification of homes that use natural gas and other combustion fuels is a critical step in achieving meaningful emissions cuts that will help to avoid the worst impacts of climate change. With social and political will aligning behind energy sector decarbonization policies, including building electrification, it is critical to understand the technical considerations for developing effective policies that also avoid placing unintended burdens on low-to-moderate-income (LMI) households. Here we take a closer look at how updated building and energy codes and targeted incentive programs for upgraded residential electric panel capacity can clear the path for full electrification. Our policy recommendations for achieving full electrification include:

- Electrify all homes with sufficient electric panel capacity as rapidly as possible.
- Update building and energy codes to require a minimum 200A panel size for all new construction.
- Make electrification the least cost option for homeowners by offering equitable incentives for existing homes that need an electric panel upgrade to electrify. Incentives should be prioritized for LMI households.

To undertake this analysis, Pecan Street built a model using its residential research network data that shows how much electricity individual appliances and homes use. The model allows us to simulate the incremental additions of individual electric appliances and compares them to the minimum electric panel size required by the electric code. The modeling tool is available on Pecan Street's website [https://www.pecanstreet.org/electrification-tool] and can aid local policymakers and home builders in calculating the electric panel sizing needs for their region.

Our analysis found that 35-45 million homes can fully electrify now without a panel upgrade - Pecan Street's research and policy advocacy strongly supports electrification of these homes as quickly as possible. There are also millions of homes that will need a panel upgrade before they can transition away from combustion fuels, including natural gas, propane, heating oil and gasoline. This is an opportunity for policymakers, building and energy code officials, and utilities to act proactively by deploying clear electrification policy and incentive programs. Incentives should be offered for upgrading electric panels for existing homes, and codes for new construction homes should be updated to require panel capacity sufficient for full building and transportation electrification. These policy changes would clear the path to full electrification and avoid combustion fuel technology lock-in, which would result in continued GHG emissions from these fuels for decades to come. Research has shown that all-electric homes will also enjoy lower lifetime costs and improved indoor air quality.

Why Electric Panel Capacity Plays a Critical Role in Home Electrification

As of 2015, one in four households in the United States was fully electrified. This leaves approximately 65 million single family homes that will need to transition at least some of their energy sources to electricity. Additionally, only 2% of automobiles in the US are powered by electricity. If all vehicles are going to become electric, a large percentage of the nation's 86 million single family homes will need to add electric vehicle charging systems. These transitions will require millions of households to upgrade to higher capacity electric panels.

Residential electric service panels are where a home's electricity is distributed throughout the house from a single set of wires that connects to the utility grid. The main breaker distributes power to other smaller breakers that power individual circuits or appliances in a home. Electric panel size is determined by the current rating of the main breaker and typically ranges between 100 - 400A. A panel is required to be an adequate size for a home based on a formula in the National Fire Protection Association's (NFPA) National Electric Code (NEC).

The NEC electric panel size calculation considers a home's specific electrical loads and their typical use patterns to ensure the main breaker can provide enough electricity to meet the home's demand. As a general rule, the more electric loads there are in a home, the larger its electric service panel must be. The specific formula used to calculate electric service size is found in Article 220 of the NEC and is described in the analysis section below. The main factors that contribute to the electric panel size of a home are:

- The home's square footage, which is used to estimate lighting and plug loads
- The nameplate electric load of the appliances in the home
- The number of dedicated branch circuits

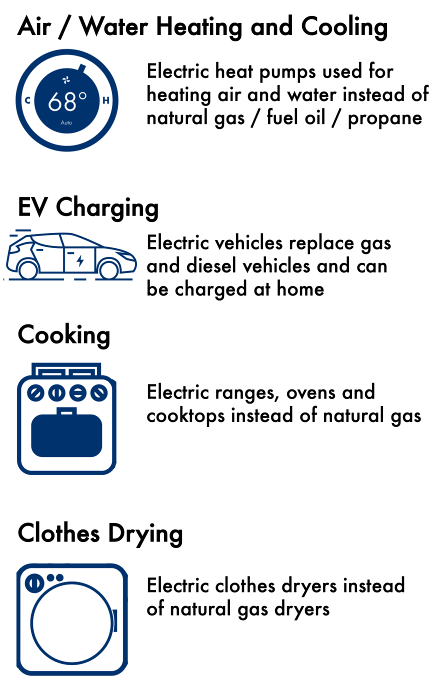

Figure 1: Electrification examples

Due to the cost increase to install a larger electric panel, builders generally install the smallest amperage panel required by the NEC. During construction, the difference in cost between installing a 100A and 200A panel is only a few hundred dollars, but large builders can realize savings from installing the minimum size electric panel at scale across all their new builds. If a home is fossil fuel-assisted (i.e. uses combustion fueled appliances) the code minimum electric service panel requirement is lower and may make future electrification impossible without a panel upgrade. Regardless of the age of a home, our analysis shows that an electric panel below 200A will likely require an electric panel upgrade or other load management system before it can fully electrify with current building codes and technology. Our results point to as many as 48 million households that may require such an upgrade in order to electrify. If an electric panel upgrade is assumed to cost $2,000 on average, this is as much as a $100 billion impediment to residential electrification in America. Policymakers should see this as an opportunity to enact electrification policies and incentive programs that ensure homeowners, especially LMI homeowners, are not left with the bill during the transition to full electrification.

Greenhouse Gas Emissions Impact and Technology Lock-In

The driving force behind residential electrification is the reduction of greenhouse gas emissions. A 2020 research paper by the Rocky Mountain Institute found that in seven cities across the United States an all-electric home had lower lifetime costs and GHG emissions than a home with combustion fuel appliances or a mix of both. GHG emissions from electricity generation are rapidly declining in the United States, which will translate to lower lifetime GHG emissions from electric appliances. In contrast, lifetime GHG emissions from combustion fuel powered appliances are essentially fixed. For example, a two-way electric heat pump may only slightly outperform a natural gas furnace over its lifetime with the current GHG intensity of electricity generation, but if GHG emissions from electricity generation are reduced over the next decade, the electric heat pump will significantly outperform the gas furnace.

Another important concept for electrification is technology lock-in. When a homeowner replaces an appliance with a combustion fuel appliance, future GHG emissions are locked in from the production and burning of fossil fuels. Most natural gas appliances last for 10-20 years, so it is essential that all new appliance replacements are electric.

Research Results

The goal of this analysis is to understand the role that electric panel sizing may play as electrification accelerates. By evaluating the electric panel size and other characteristics of the homes in our sample, we can better understand the impacts of panel capacity upgrades and develop policy recommendations on a national scale to remove roadblocks to residential electrification.

Our sample includes 263 homes from Pecan Street's research testbed. Most homes are located in Austin, Texas, largely in the Mueller neighborhood, and were built after 2007. Twelve homes are townhomes, and the remaining 251 are single family homes.

Electric Panel Size Calculation Methods

The National Electric Code provides two different methods for calculating the minimum size of residential electric panels, the Standard Method (NEC 220.40) and the Optional Method (NEC 220.80). The Optional Method generally allows a smaller electric panel size when compared to the Standard Method calculation for the same project. All analysis in this paper assumes that the NEC Optional Method for calculating electric service panel size is used. If the Standard Method were used instead, the analysis would show more electrical panel upgrades would be required at lower levels of home electrification.

Home Characteristics that Contribute to Electric Panel Size

Listed below are the four main factors that affect the minimum residential electric service panel size using the Optional Method in the 2020 NEC.

- **Electric vs. combustion fuel appliances:** The most important factor when sizing a residential electrical service panel is how many electric appliances are in the home. If a house is built with natural gas service and appliances, it reduces the home's maximum electrical load and thus the minimum required size of the electric panel. Space heaters, water heaters, ovens, cooktops and dryers can all be powered by either combustion fuels or electricity.

- **Nameplate electric load of appliances in the home:** There is often a significant range of nameplate electric load across appliances of different brands and sizes. For example, an electric induction cooktop with six high powered burners may use double the power of a smaller cooktop.

- **The square footage of a home:** The size of a home is used as a proxy to determine the electric capacity required for lighting and plug loads. The larger a home is, the larger an electrical service panel must be.

- **The number of dedicated branch circuits:** Small appliances and the outlets that serve them are fed by dedicated circuits to ensure reliability. A high number of dedicated circuits will increase the required panel size. Typical branch circuits include washing machines and refrigerators.

Table 1 shows three configurations for a 2,000 square foot home that results in three different electric panel sizes. The primary differences between these scenarios are the number of electric appliances, the heating and cooling systems used, and the nameplate loads of each appliance. These calculations show that when homes are built with natural gas assistance and the electric appliances have low to moderate loads, 100A-150A electric panels are sufficient per the NEC code, but would not allow for full electrification of the home in the future.

Table 1: NEC 220.80 Panel Calculation Example

NEC 220.80 Panel Calculation Example

Electric loads are calculated in Volt-Amps

	Natural Gas	Mixed Gas and Electric	All Electric
Lighting and Plug Loads			
Lighting and Plug Loads	6.0K	6.0K	6.0K
Dedicated Circuits			
Dishwasher	1.5K	1.5K	1.5K
Garbage Disposal	1.5K	1.5K	1.5K
Microwave	1.5K	1.5K	1.5K
Washing Machine	1.5K	1.5K	1.5K
Appliance Loads			
Dryer	5.0K	5.0K	5.0K
Oven		5.0K	5.0K
Cooktop		7.0K	7.0K
Water Heater			4.5K
EV Charger			18.0K
Intermediate Calculation			
First 10K @ 100%	10.0K	10.0K	10.0K
After 10K @ 40%	2.8K	7.6K	16.6K
Intermediate Total	12.8K	17.6K	26.6K
Heating and Cooling			
100% of Heating / Cooling	4.0K	4.0K	4.0K
65% of Backup Heat		6.5K	6.5K
Panel Size Calculation			
Final Total	16.8K	28.1K	37.1K
Convert to Amps	70 Amps	117 Amps	155 Amps
Minimum Panel Size	**100 Amps**	**125 Amps**	**200 Amps**

Common Electric Panel Upgrade Triggers

Homes built with combustion fuel assistance – i.e., natural gas heating and/or cooking, or oil-based heating - will often have an electric panel below 200A. As households electrify or add loads like EV chargers, they will likely need to upgrade their electric panel along the way. It's important to understand how and when an electric panel upgrade will be triggered and how triggers can be avoided to create the best policy environment for residential electrification.

Figure 2 shows that electric vehicles have the largest range and the highest potential nameplate load of any electrical load in the home. This combined with the coming wave of EV adoption means they are likely to be one of the most common triggers for an electric panel upgrade.

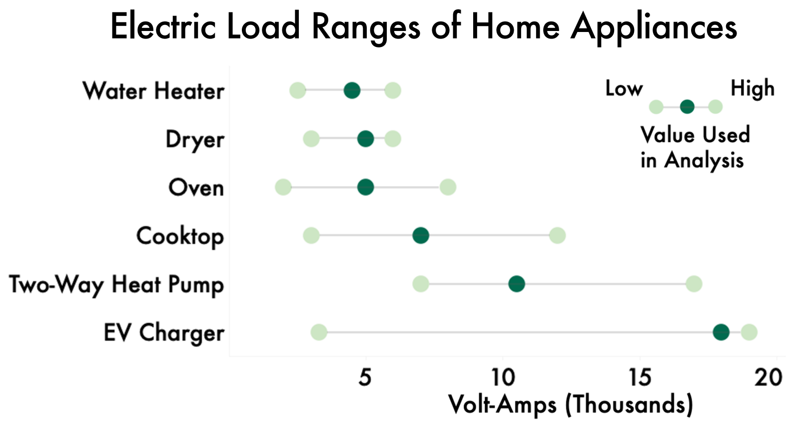

Figure 2: Nameplate Load Range of Home Appliances

HVAC systems have the second highest load impact, partly because the NEC formula treats it differently than other appliance loads. Because HVAC systems are a continuous load, they are rated at 100% of nameplate and / or 65% of backup heating kVa depending on the equipment. Since most other loads are rated at 40% of their nameplate value, a two-way heat pump system has an outsized impact on the size of the electric panel compared to other nameplate loads. Importantly, a two-way heat pump is more likely to be rated at 65% of its backup resistance heat load than 100% of continuous load. Another major trigger for panel upgrades is the replacement of an oven/cooktop combination (range). Ovens and cooktops have high nameplate loads on their own, but because they are often part of a single unit and are replaced together, they are more likely than a dryer or water heater to trigger a panel upgrade. Any new home appliance or circuit can trigger an electric panel replacement, but the purchase of electric vehicles, two-way heat pumps and oven / cooktop combinations are the most likely to trigger one.

Another significant factor when identifying loads that will trigger an electric service panel upgrade is the current adoption level of an electric appliance. An electric dryer for example is the least likely appliance to trigger a panel upgrade because 64% of homes in the United States already have electric dryers. Similarly, 60% of homes have electric ranges. Conversely, 10% of homes have two-way electric heat pumps, and only 2% of homes own an electric vehicle. Thus, there will be far fewer people adding electric dryers and ranges for the first time compared to electric vehicles or two-way heat pumps for the first time.

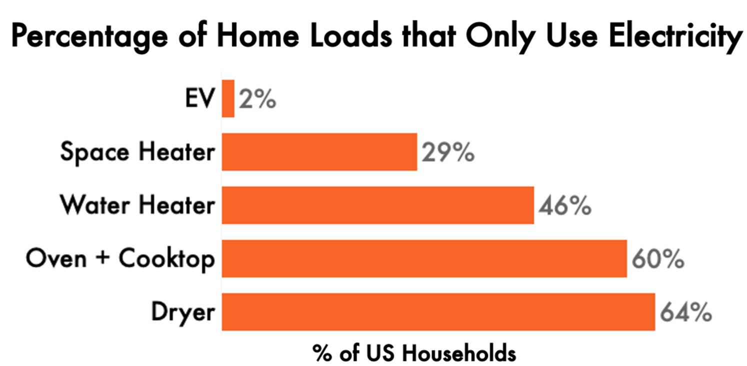

Figure 3: Percentage of home loads that only use electricity

Figure 4 shows the cumulative effect of adding electric appliances to the homes in our sample and the effect on the NEC calculation for minimum panel size. Note that these calculations only focus on home appliances that are required to be considered by NEC. If other discretionary loads, such as hot tubs or pool pumps were included in the calculations, an even larger portion of homes would require a panel upgrade for electrification.

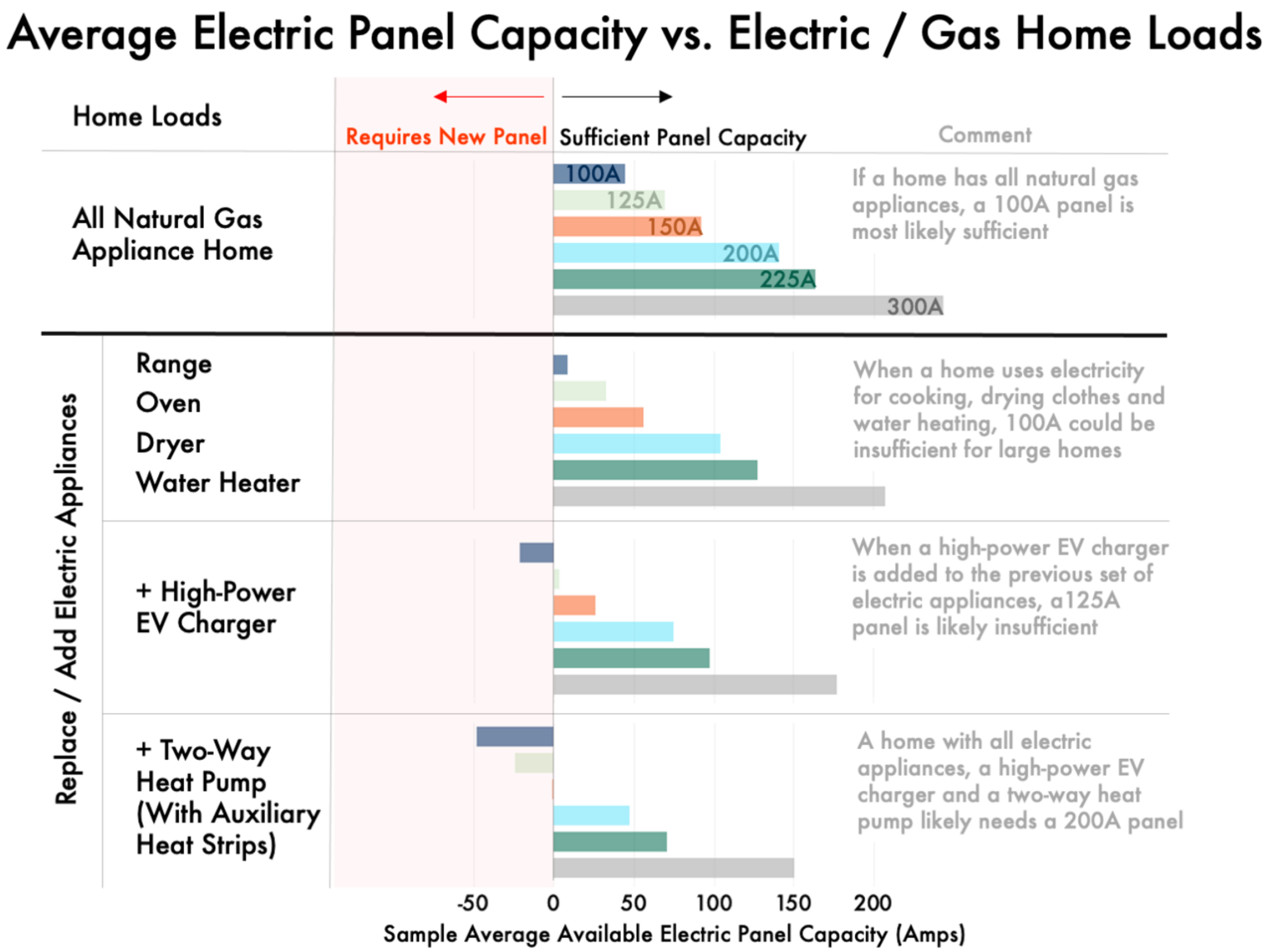

Figure 4: Average electric panel capacity vs electric / gas home loads

Generalizability of Results

To understand how the results of our study could be generalized for applicability to other regions, we used U.S. Census Data to assess how representative the homes in our sample were to the average American home. We then performed a regression analysis to assess the relationship between panel size and age of home, and to compare panel size and home square footage.

Surprisingly, there wasn't a significant relationship between the age of the homes in our sample and their electric service panel size. It's intuitive to think that older homes would be more likely to have smaller electric panels because residential electric demand has grown steadily over the past century. When older homes are renovated, it is routine to upgrade the electric panel. A relationship more likely exists between the panel size and the year of the last major home renovation, but unfortunately that data is not available. Interestingly, homes in the sample that were built after 2007 were more likely to have electric panels under 200A than homes that were built before 2007.

There is, however, a positive correlation between the size of the homes in our sample and the size of its electric panel. The bottom pane in Figure 5 shows a steadily rising median square footage and interquartile range as electric panel size increases. This effect is not surprising for two reasons. First, the square footage of a home directly impacts the NEC electric service panel size calculation in the form of lighting and plug loads, although that effect is relatively minor. The greater effect stems from the fact that larger homes generally have larger HVAC systems, more branch circuits and larger appliances to serve the needs of more people. For example, a 1,000 square foot difference in home size requires an additional 3,000 Volt-Amps of service capacity to account for plug loads and lighting. While more HVAC system tonnage and additional auxiliary heat strips can add 6,000 Volt-Amps of service capacity to the calculation even before larger appliances like water heaters and clothes dryers are considered.

Figure 6 shows that while the distribution of home square footage in our sample is characteristic of the rest of the country, the age distribution is skewed towards newer homes. We did not observe a relationship between the age of the homes in our sample and electric panel size, but this could be a possible source of sample bias when applying our findings to the U.S. housing stock.

Since 96% of the homes sampled were in Texas, there is a strong regional bias. Figure 7 shows that southern states are more likely to be all-electric compared to other regions of the country, due to the mild winter temperatures. This means homes in Texas and, thus, our sample, likely have larger electric panels on average than homes in other regions of the country. Home builders, combustion fuel infrastructure and fuel pricing all also vary by region, but their effect on electric panel size is difficult to predict.

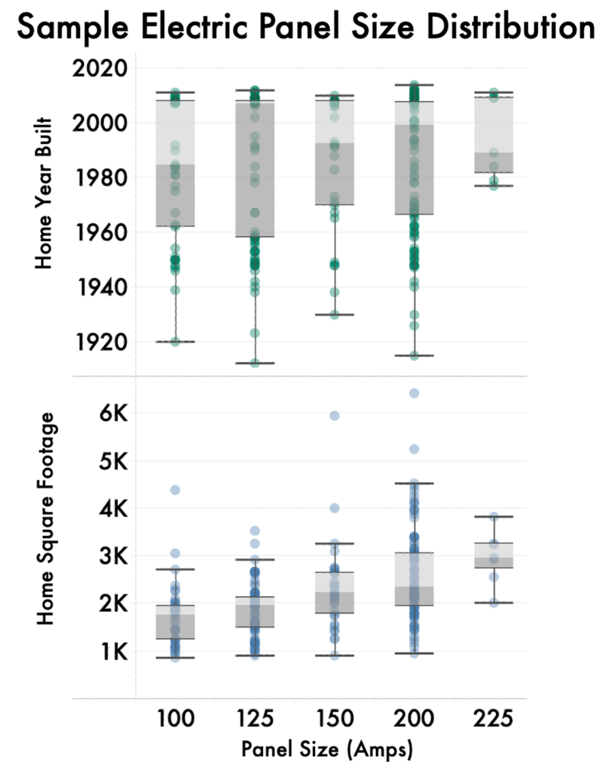

Figure 5: Electric panel size vs year built & square footage

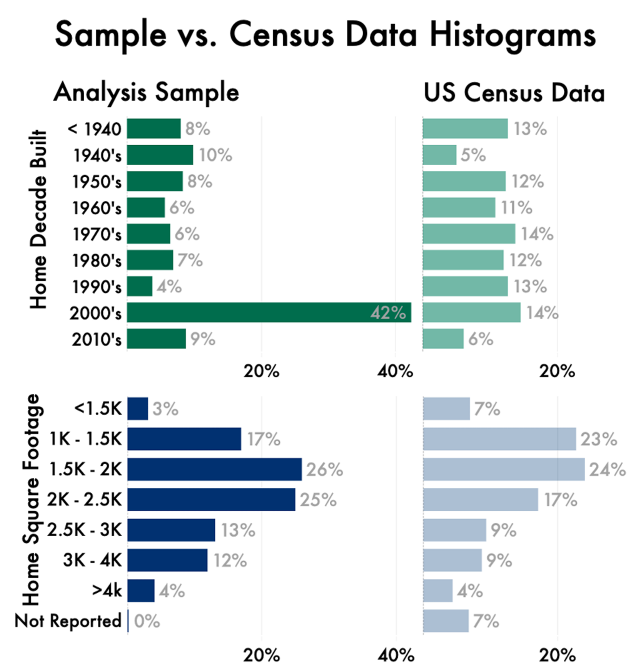

Figure 6: Analysis sample vs U.S. Census data for year built and square footage

All Electric vs Multiple Fuel Households By Region 1993 - 2015

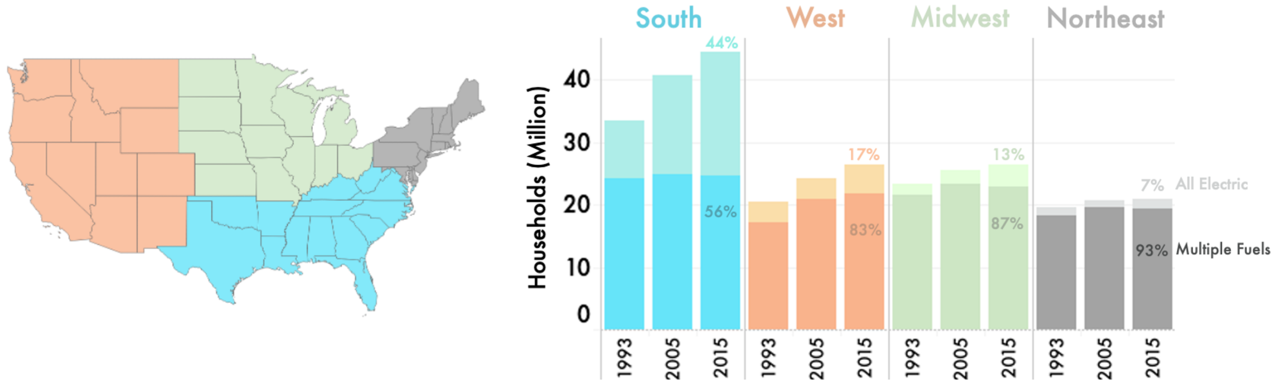

Figure 7: All-electric homes by region 1993-2015; all-electric in light shading, multiple fuels in dark shading

Our analysis of the current electric panel sizing formulas in the NEC combined with market trends in home appliances show that 200A panels are the recommended minimum size required for total home electrification. It is possible to fully electrify a home with a 150A electric panel, but this is highly dependent on EV charger size and the amount of heat pump auxiliary resistance heat. Auxiliary resistance heat varies regionally with colder climates needing more than warmer climates. Figure 8 shows that 59% of the homes in our sample are below the critical size of 200A. Also, 80% of the homes below 200A are 125A or lower which means that an electric panel upgrade will likely come before the last combustion fuel appliance is replaced. This means electric panel upgrades will be required sooner, which may make them more likely to choose combustion fuel appliances in the absence of sufficient incentives.

Electrification with an Electric Panel Below 200A

Some key factors affect whether a home is able to electrify with panels of 100A - 150A:

- Electric Vehicles and residential electric vehicle supply equipment (EVSE) have a wide range of potential charging levels. Level 1 EVSE's plug into a normal 120V outlet and charge from 1.3kW - 2.4kW, while some Level 2 EVSE's can reach 19 kW and require an 80A or 100A breaker. The size of the breaker serving a home's EVSE is an impactful variable when trying to electrify a home with an electric panel below 200A.

- Smart plug splitters can be a lower cost solution for renters or home-owners who want to add an electric vehicle. Dryers, water heaters and EV's are commonly colocated in garages. A smart splitter can be used to charge an EV on the same 240V circuit as another appliance without costly panel upgrades.

- Smaller homes often have smaller appliances with smaller nameplate loads. If electric appliances have small nameplate loads compared to the normal range of that appliance, it may be possible to fully electrify with a smaller electric panel.

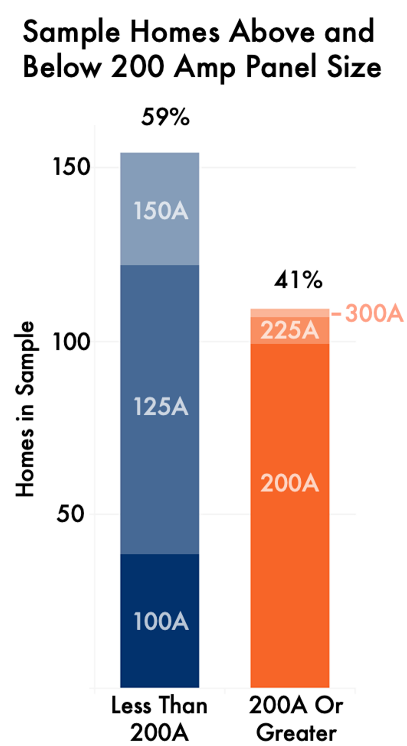

Figure 8: Breakdown of sample above and below 200A panel size

Policy Recommendations & Examples

Policymakers need to act to remove the significant infrastructure, cost and logistical challenges to home electrification if we are to achieve the ambitious GHG emissions reductions required to avoid the worst-case climate scenarios described by the IPCC. Electric panel capacity has been a little-known electrification issue but one that presents a substantial roadblock to full electrification. This analysis is intended to draw attention to the scale of impact and necessity of addressing this issue, and to guide policymakers towards solutions that allow for full electrification.

Require a Minimum of 200A Electric Service Panels for New Construction

Electric panels with 100A capacity installed in homes today will almost certainly need an upgrade for the home to fully electrify, and homes with 125-150A panels will likely need a panel upgrade or other smart load management solution to fully electrify. If newly built homes directly mirror our sample, 59% will be built with electric panels under 200A. That means of the almost 1 million single family homes built in the US in 2020, approximately 550,000 were built with electric panels that are too small for the home to fully electrify. This could add between one and two billion dollars a year to the cost of upgrading homes for full electrification. Every day that passes without these changes to the building or energy code makes residential electrification more difficult.

Building and Energy Code Updates

In the United States, building and energy codes are adopted at the state and local levels of government so they can be tailored to regional climates and laws. Every three years, the International Code Council (ICC) releases the International Energy Conservation Code (IECC) and the International Residential Code (IRC), which serve as the model codes for state and municipal governments to adopt. At least one version of both the IECC and IRC have been adopted by 48 and 49 states respectively. However, state and local governments don't always adopt the latest code every three years, so there is a wide range of IECC and IRC code versions in place across the country.

Both the IRC and IECC could increase the minimum electric panel size for new residential buildings. Importantly, the IRC directly uses the NEC for its chapters on electrical codes and they both currently require a minimum electric panel size of 100A in a single-family dwelling. For new construction, this minimum should be increased to 200A. The marginal cost of installation between a 100A and 200A panel is minimal, and a 200A panel ensures the home can fully electrify.

The 2021 IECC has several appendices that give guidance on solar and electric readiness in homes but are not part of the base code. Solar readiness refers to homes that are built to avoid major impediments to solar system installation in the future. A larger electric panel makes a home more solar ready because it has more space for additional breakers which solar systems need to connect to a home's electric system. Solar readiness is yet another reason 200A panels should be made standard in energy codes across the country.

The 2021 IECC process deemed several solar and electric readiness provisions outside of its scope, but this does not preclude them from being considered for the 2024 IECC. Furthermore, the New Buildings Institute (NBI) and Natural Resources Defense Council (NRDC) created solar and electric readiness stretch codes that are compatible with the 2021 IECC and can be adopted along with the base code by state and local governments who wish to improve their jurisdiction's solar and electric readiness.

Create Incentives for Existing Homes to Upgrade Panels to 200A or Higher

Most homeowners and property managers will use cost as the main criterion for choosing an appliance. Simply put, if switching to an electric appliance requires an electric panel upgrade, the additional cost and effort may favor the purchase of another combustion fuel appliance. This scenario would lead to combustion fuel technology lock-in and more GHG emissions for decades to come.

We recommend subsidies for upgrading electric panels to 200A or higher to help homeowners overcome the financial barrier to full electrification. These subsidies could be offered from federal, state or local governments, or could be offered by utilities that support customer electrification. To help ensure a just energy transition, we recommend that these subsidies be based on income and slide with household income levels, rather than being made available on a first-come, first-serve basis to all residents. A recent report from The Center for American Progress and Rewiring America details the need for appliance incentives for electrification, including specifically for electric panel upgrades. The report recommends an average incentive of $4,200 to participating households and an average of $6,000 to participating low-to-moderate-income (LMI) households.

It is crucial to appropriately target incentives so that all households, including LMI households, can take advantage of these financial incentives. For example, a tax-based incentive that requires tax liability would not be a favorable model for supporting electrification of LMI households. Rather, financial incentives should be created at multiple points in the purchase and installation process to provide the most convenient and immediate impact to consumers. Rebates at the point-of-sale can ensure electric appliances are the cheapest option, and rebates for installation costs can ensure the additional costs that can accompany residential electrification will not deter consumers.

Model Electrification Policy Examples

California Energy Code

The California Energy Code is developed independent of the IECC and is known for leading on energy conservation issues, particularly in relation to reducing GHG emissions from buildings. The latest California energy code adopted in 2020 requires 200A electric panels in new homes and renovations as part of its solar readiness requirements. The Code's 2022 revision is under development and its current language will require 225A electric panels to be installed in new homes along with many other electric readiness measures. The California Energy Code is recognized for its energy conservation measures and innovative policy implementation for reducing GHG emissions from buildings that other jurisdictions can look to as a model.

NEC Electric Code Article 625.42: Enabling EV Automatic Load Management Systems

Article 625 of the NEC governs electric vehicle charging. A key provision in this section is Article 625.42 which states:

> "Where an automatic load management system is used, the maximum equipment load on a service and feeder shall be the maximum load permitted by the automatic load management system."

This has significant implications for the required electric panel size to serve multiple electric vehicles. Level 2 EV chargers can have large nameplate charge values up to 19kW. If two or more chargers are installed at a home, they can be connected to a load management system which throttles the current draw to remain below the circuit's maximum output when both are charging at the same time. With this system in place, a circuit can be rated at the maximum load permitted by the automatic load management system. Article 625.42 is important because with the proper load management systems, homes will be able to serve two or more electric vehicles comfortably with a 200A electric service panel. Without Article 625.42 there could be a potential need for even larger panel upgrades to 225A, 300A or 400A panels as home add multiple electric vehicles.

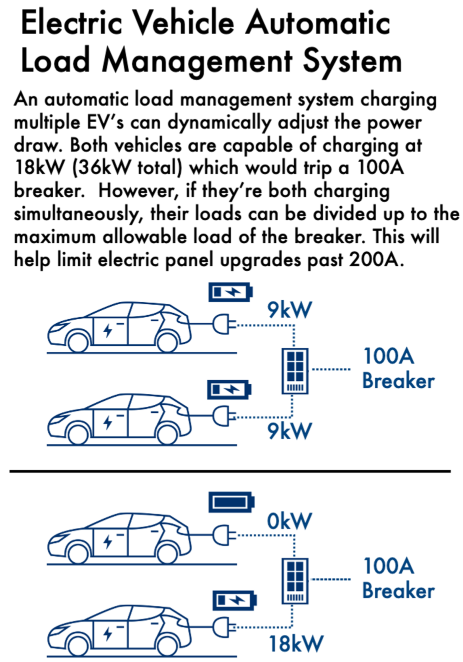

Figure 9: Example of EV loads managed by an automatic load management system

Electrifying the Residential Sector is Critical – Policy and Incentives that Remove Roadblocks to Full Electrification Should be, Too

The residential building sector uses 17% of the total energy consumed in the United States and transportation accounts for an additional 35%. Residential electrification will play a major role in reducing greenhouse gas emissions and avoiding the worst impacts of climate change. We need to rapidly electrify the residential sector and power it with carbon free electricity. To accomplish this we need to update building and energy codes and provide strong financial incentives to make all homes, new and existing, electric ready - including electric panel capacity requirements.

If we are to achieve the ambitious GHG emissions reductions required to avoid the worst-case climate scenarios described by the IPCC, policymakers and utilities should support the rapid electrification of the 35 - 45 million homes that can electrify with their existing electric panels. Further, they need to act to remove the significant infrastructure, cost and logistical challenges to homes that need a panel upgrade to electrify. Electric panel capacity has been a little-known electrification issue but one that presents a substantial roadblock to full electrification. This analysis is intended to draw attention to the scale of impact and necessity of addressing this issue, and to guide policymakers towards solutions that allow for full electrification. Our policy recommendations include:

- Adopt codes that require a minimum of 200A electric service panels for new construction.
- Update national model codes with a 200A minimum panel size, such as the 2023 NEC, 2024 IRC or 2024 IECC
- Create equitable incentives for existing homes to upgrade panels to 200A or higher

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