Zero Net Energy Modular Home, Vermont

Reynold's Landing, Georgia

Alberta, Canada

A Zero Emissions All-Electric Single-Family Construction Guide

The Cottages at Fort Bragg, California

Stanford, California

Post wildfire rebuild in Sonoma County, California

Savoy House, Massachusetts

REDWOOD ENERGY

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Check out Redwood Energy's Commercial and Multifamily Zero Carbon and All-Electric Guides at their website: *https://www.redwoodenergy.tech/*

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This report was produced for Menlo Spark, a non-profit, community-based organization that unites businesses, residents, and government partners to achieve a climate-neutral Menlo Park by 2025. Menlo Spark weaves together transformational energy, transportation, land use and building policies that promote community prosperity, bolster economic vitality, and protect civic heritage. The intent of this report is to help cities and developers everywhere embrace healthier, lower cost all-electric building construction practices.

Introduction

The news of climate change is unquestionably grim—increasing extreme weather events are burning, blowing down, and flooding communities on every continent and island. These extreme weather events are unarguably linked to man-made carbon pollution. To address this, many cities and nations have identified smart building electrification, paired with renewable energy, as the primary solution to 28% of carbon emissions from building operations (Figure 1).[1]

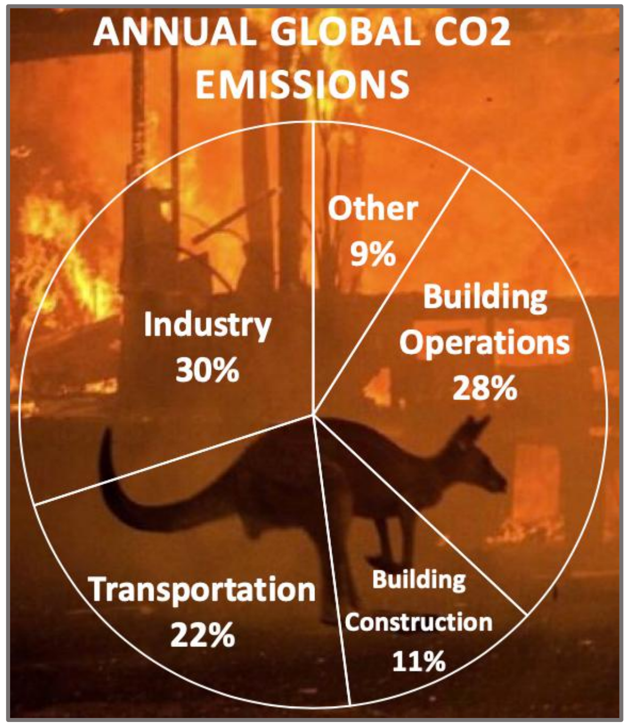


Figure 1: Construction and Operation of Buildings totals 49% of annual CO2 pollution. Photo credit-Matthew Abbot, NYT. Analysis by Architecture 2030 using UN Environment Global Status Report 2017; EIA International Energy Outlook 2017.

This document aims to guide every homeowner, builder, contractor, policy maker and any other interested party to fully realize the benefits of building all-electric homes. Building all-electric homes saves money and energy, creates heathier, pollution-free and safer living spaces, and helps lead the way to a stable climate.

Building new homes without fossil fuels to address climate change has been innovated by architects and home builders, codified for 2020 by dozens of California cities, the suburbs of Boston, New York City, and even countries like Britain[2] by 2025. Many of these new electrification policies also require electric car chargers in each new home to address greenhouse gas emissions from transportation (see p. 40 for a guide to 2020 model electric vehicles). Because the process of constructing new buildings represents 11% of climate change pollution each year, our manufacturing and use of building materials, such as cement and iron[3] (p. 20), must also change. One such innovation, introduced by Marin County, CA, effective January 1, 2020, is a low-carbon concrete building code that can be adopted by jurisdictions anywhere.[4]

Building homes with natural gas service – factoring in design, permitting, infrastructure, pipes, and labor – adds an average of more than $20,000 per California home (p. 7). This is why all-electric housing began regaining market share in 1993, following a 20-year hiatus resulting from the two 1970s oil crises—they're less expensive to build, sell and rent at the same market value, and can be upsold as Zero Net Energy with a 100% offset solar array.

In 1933 Government programs such as the Rural Electrification Administration provided loans to organizations like the Tennessee Valley Authority, which began connecting households to the electric grid for free, providing electric lighting and labor-saving appliances. Electric utilities created a media campaign from 1953-1975 that showcased Ronal Reagan's all-electric mansion and every big star of the era, from Judy Garland to Sammy Davis Jr. to advertise the luxury and class of the all-electric lifestyle (Figure 2). The twenty years between 1973 and 1993 was the only period since the 1933 when all-electric houses didn't gain market share.

Figure 2: From 1953-1963 Ronald Reagan directed an electric utility-sponsored top 10 TV show with A-list guest stars. The show's tagline and jingle: "Live Better Electrically."

In 2015, the most recent data available, all-electric homes accounted for 1 in 4 homes nation-wide and is growing.[5]

The market transition to all-electric has accelerated since 2010 due to the improvements of electric "heat pump" space and water heating, which can now efficiently heat at temperatures as low as -30°F. The 2016 Propane Market Outlook put it succinctly, *"As heat pump technology continues to advance, conventional heat pumps will be a growing threat to the propane heating market."*[6]

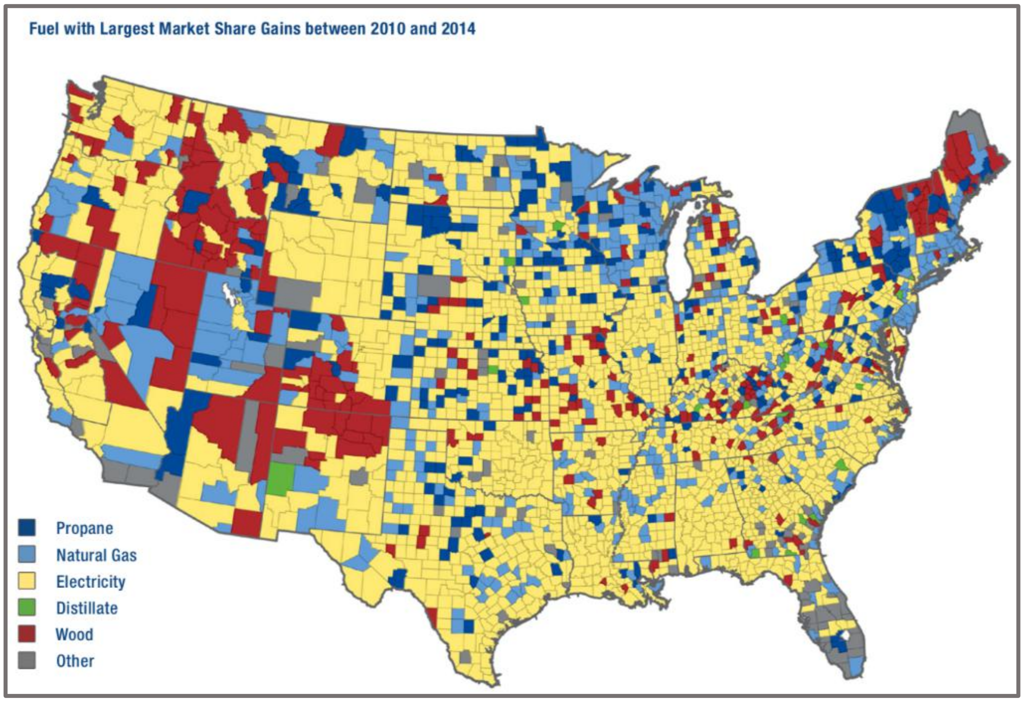


Figure 3: Electric heating, both heat pumps and resistance as the main source of heating in the home has increased from 30% in 2005 to 35% in 2015. Figure from ICF's 2016 Propane Market Outlook.[6]

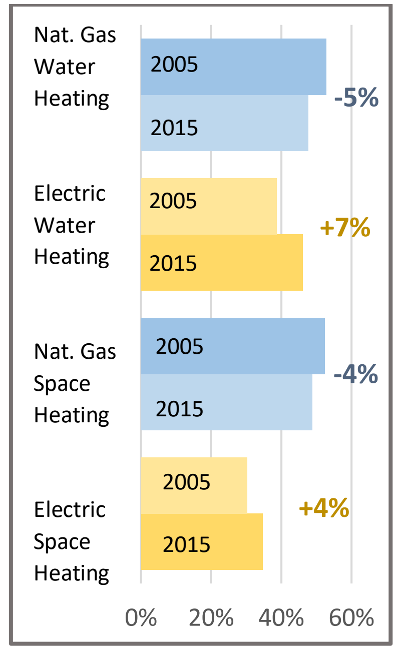


Figure 4: Percent change of all residential homes that use electric or natural gas space and water heating between 2005 and 2015.

Massachusetts has moved faster than many states to electrify buildings, in part because of a September 2018 explosion in the Merrimack Valley caused by an over-pressurized gas main. The explosion killed one person, injured dozens of others, required the evacuation of 30,000, and destroyed 130 buildings. After this catastrophe, thousands of homes in the affected towns permanently abandoned gas service and Columbia Gas has been barred from future work in the entire state.[7] Brookline was the first Massachusetts town to ban gas citywide in response, with Cambridge and Boston announcing their interest in following suit.[8]

Figure 5: A 207-to-3 vote in Brookline, MA, banned fossil fuels in new buildings and gut rehabs beginning in 2021.[9]

Figure 6: A large home in Lawrence, MA was among the 130 destroyed by gas explosions in 2018 when maintenance workers accidentally over-pressurized the gas main, turning gas-using homes into bombs. All-electric homes are safer.[10]

In places with aged infrastructure, gas system upgrades are being found to be more expensive; for example, Boston, Chicago, and Philadelphia are pursuing electrification as the more financially viable solution. The 38 electric utility co-ops of Georgia are using market mechanisms rather than regulations to support that state's majority all-electric housing market,[11] with the same phenomenon in Alabama[12] and Florida,[13] where utilities like The Southern Company and Gulf Power are accelerating the market demand for all-electric housing.

In another important trend, electric utilities are recognizing the value of doubling their sales with all-electric homes and tripling sales with electric cars. In the Midwest 88% of electric co-ops pay customers to switch their space heating and other appliances from gas to electric. In 2018, the National Rural Electric Cooperative Association (NRECA) Board unanimously approved a resolution supporting beneficial electrification programs; NRECA supports 900 co-ops representing nearly half of the land area in the US and serves almost 50 million people.[15]

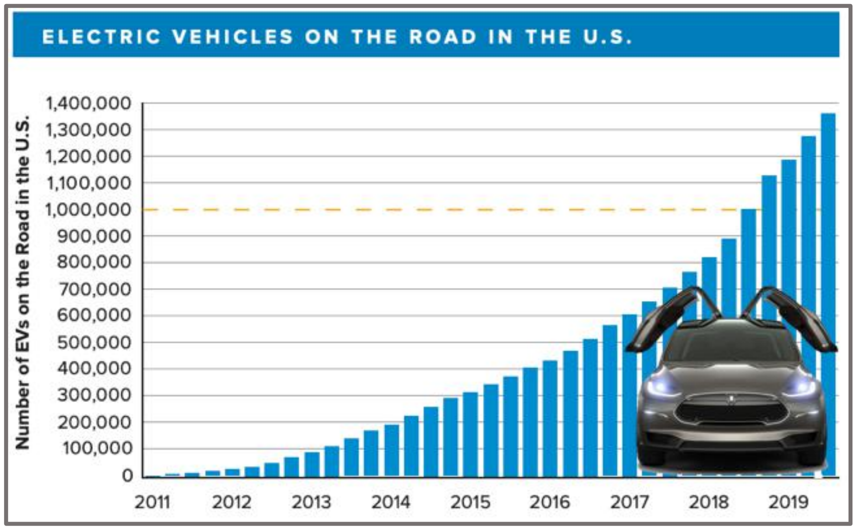


Figure 7: Led by Tesla, U.S. electric vehicle sales are growing rapidly and sold more than a million by 2019. They are a solution to one of the largest sources of climate change.[14]

Adding Rooftop Solar to Offset Electricity

Today 94% of solar powered homes are built by developers, not visionary homeowners.[16] The Zero Energy Residential Buildings Study found that there was a dramatic 59% increase between 2018 to 2019 in growth in solar homes.[16] 2020 will be remembered as the year the world's 5th largest economy, California, required every new home to have a solar array, covering roughly 60% of the home's predicted energy use.[17] Nationally, LBNL labs found the 1.1 million solar powered homes in 2015 in the U.S. were valued at $17,000 higher than homes without solar arrays,[18] with the solar installation value recouped in sale. On average in the U.S. a solar array will repay itself in 7.4 years, with a 25-year warranty.[19]


The New York Times

California Will Require Solar Power for New Homes

By Ivan Penn May 9, 2018

Celebrities and Solar

Celebrities from Dr. Dre, Puff Diddy, Brad Pitt and Scarlett Johansson have endorsed solar power and installed arrays on their own homes, many sized for 100% solar offset. Oprah Winfrey, Prince and Dusty Baker, among others, have used their star power and personal wealth to promote solar power initiatives in disadvantaged communities from Oakland (Prince) to New Orleans (Brad Pitt), from rural America (Mark Ruffalo, Don Cheadle) to Africa (Oprah, Akon).

President Barak Obama:
The White House Solar Electric Array

President Jimmy Carter:
The White House Solar Thermal Array

CA Governor Arnold Schwarzenegger
initiated solar rebates state-wide.

Oprah Winfrey

Oprah Winfrey's Leadership Academy for Girls in South Africa has solar power, as does Vele Secondary School in Limpopo, which has won many awards for sustainability.[20]

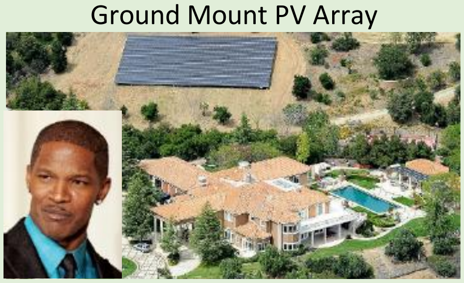
Akon

Akon Lighting Africa has provided power to 14 African countries and is rapidly expanding to supply solar power throughout the continent.[21]

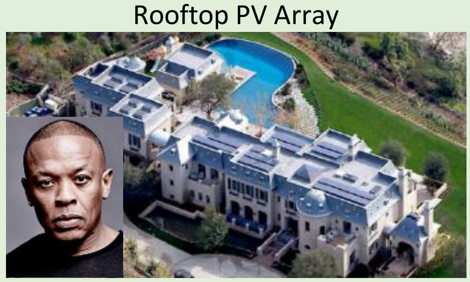
Dusty Baker

Dusty Baker showed the world its first "high five" in 1977 after slugging his 30th home run of the season for the Dodgers and started a national celebratory tradition. After a career of managing the Giants, Cubs, Reds, and Nationals, his third career is in developing large solar projects for historically black universities, tribal reservations, and commercial businesses.[22] The entrepreneurial opportunities of solar are real—according to the U.S. government, 370,000 people were employed in solar nation-wide in 2016 compared to 160,000 in coal—2.3x more.[23]

Jamie Foxx's
Ground Mount PV Array



Dr. Dre's
Rooftop PV Array



Best Practices in Solar Ready Roof Design

The key to achieving zero net carbon is matching the renewable energy production of the onsite solar (photovoltaic, or PV) array to the household's electricity demand. Without paying attention to this energy balance, the risk is that the roof will not accommodate a solar array large enough to meet the energy usage of the home's occupants. There are two fundamental factors that determine success – **form** and **efficiency**. **A solar friendly roof form is often overlooked yet needs attention earlier than any other aspect of design or construction. Solar panels range in efficiency from 6% to 21.5%, and a challenging roofline can be partially addressed by using higher efficiency panels.**

To achieve success with a 100% offset solar array, adhere to these principles during **early design**:

- The fewer roof planes, the better. While planning departments may encourage designers to 'make it more interesting,' complicated roofs are the enemy of energy performance; you may need to educate local regulators. (Complicated roofs are also the enemy of moisture-proofing, durability, thermal comfort, and affordability! This may help persuade planners to accept simpler designs.)
- Preserve the largest possible *unobstructed* expanse(s) of south- and/or west-facing roof area. South-facing solar arrays generate more energy, while west-facing arrays collect more energy during high utility rate periods, and thus may prove to be more economically beneficial. (A solar vendor can evaluate this for you.)

- To avoid obstructions, design floor plans to concentrate roof penetrations, such as plumbing and mechanical vent stacks, on roof areas that are not intended for solar production (e.g., north- and east-facing planes).
- Run energy models ***early and often*** during design to compare your energy production potential with anticipated energy usage. Adjustments can be made easily and inexpensively early in design, but at much greater expense and difficulty later in the design process.

In addition to solar on rooftops, solar can also be added as canopies and carports that add other benefits to the home, like creating a shaded courtyard and protecting cars from the elements.

The Benefits of All-Electric Design

The following section details the benefits of building all-electric: lower construction costs, lower carbon emissions, improved public safety, improved indoor health, higher efficiency, the lowest utility bills when paired with PV panels, and a simplified building process.

Lower Construction Costs

A study prepared for the Pacific Gas and Electric Company found that the gas-related construction costs for a mixed-fuel home can be up to $30,800 for an average single-family home, all paid by the buyer; this includes the difference between gas and electric appliances, in-house gas piping and infrastructure, and onsite gas infrastructure.[24] Other cost estimates from California's gas and electric utilities are shown below in Figure 8. Avoided gas infrastructure costs include $140-360 per foot for low-pressure distribution lines,[25] $16,570 for the meter and lateral,[26] and $200-1,000 piping cost per fixture.[27]

*"**All-electric is a no brainer**. The cost of bringing gas to a building site is expensive. In our developments all-electric is less expensive to build and just as efficient, or more efficient, in operations. And you can't generate gas onsite, but you can generate electricity with solar electric panels to lower bills."*

*- **Chris Dart, President of Danco Communities**, a large single- family and multifamily affordable housing developer in Northern CA*

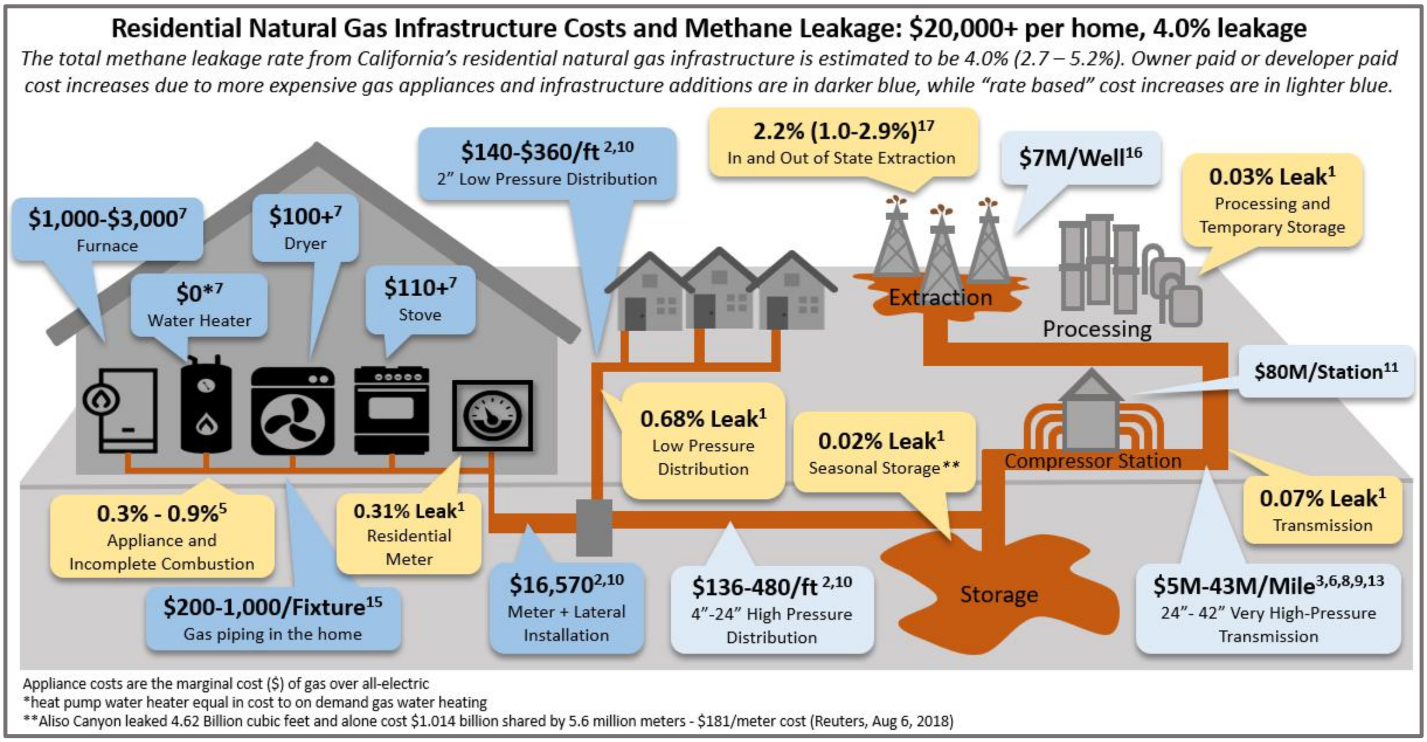


Figure 8: Studies submitted to the regulatory agencies by SoCalGas and PG&E show the high hidden costs of building with gas, particularly gas plumbing in the building and gas laterals from the street. Additional studies illustrate the significant leaks at each stage.

Lower Utility Bills

Energy affordability is a critical issue for many American households – utility bills are the number one use of payday loans in the US; those loans are carried an average of 150 days at 400% interest, furthering the cycle of poverty.[28] Due to rapid gains in electric appliance efficiency, utility bills for all-electric homes can be up to $800/year less than for comparable mixed-fuel homes.[29] The US Department of Energy (DOE) produces "yellow tags" for every appliance on the market, showing the national average annual utility cost. As shown in Figure 9, an electric heat pump water heater is $70 less per year to operate which corresponds to a savings of about 40% compared to one of the most efficient gas water heaters. Additionally, some electric utilities charges are high enough to make rooftop solar a potential solution to cost-effectively lowering utility bills for the entire house.

Figure 9: US Dept of Energy labels show with average U.S. energy prices, heat pump water heaters cost $70 per year less to operate than the most efficient gas water heaters on the market.

When is Electricity Cheaper than Gas?

One misconception commonly heard is that "gas is cheap." In fact, even in the high-cost state of California, replacing gas appliance with electric can save money. Ken Rider, Senior Advisor to the Chair of the California Energy Commission, developed these graphs (Figure 10) to illustrate the utility bills savings of heat pump water heaters compared to equivalent gas water heaters. Savings are small with low-efficiency heat pumps, large with high efficiency heat pumps, and dramatic when solar electric panels are included. Adding solar reduces the cost of operating a water heater by one half to two thirds compared to both low and high efficiency gas water heaters.

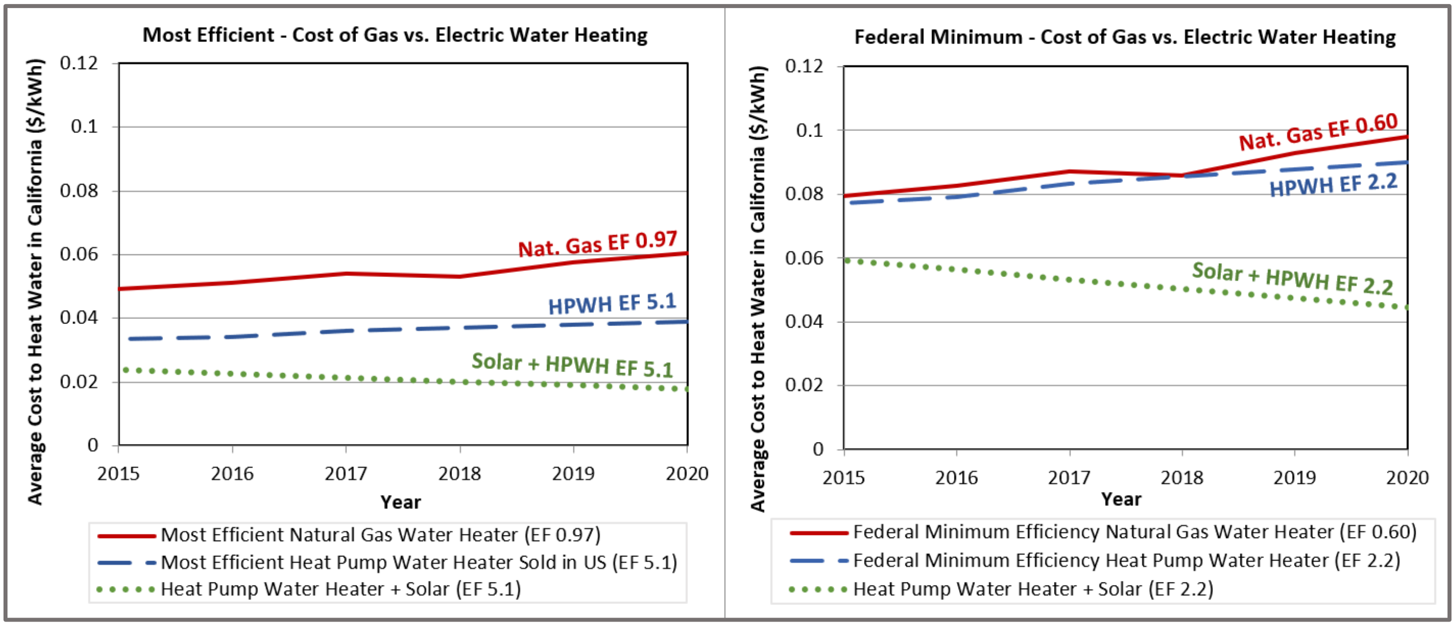


Figure 10: A comparison of the utility bill costs of heating water with gas versus electricity in California, both with the most efficient water heaters and the least efficient.[30]

Reduced Greenhouse Gas Emissions

Buildings currently contribute roughly 28% of global greenhouse gas (GHG) pollution from energy use. Housing construction can rapidly make a large reduction in carbon pollution by avoiding or replacing fossil fuels like gas, fuel oil, and propane with efficient all-electric construction. Additionally, methane leaked from the fracking, storage and delivery of "natural" gas is an exceptionally strong GHG pollutant, and according to the Environmental Defense Fund, "about 25% of the human-made global warming we're experiencing is caused by methane emissions."[31] Even when the electricity in the grid comes from coal or gas power plants, households with efficient electric space and water heating appliances produce much less total air pollution than those with the most efficient gas furnaces and water heaters.[32] Forty-eight utilities nationwide have made commitments to shift to renewable energy, and many states have mandated renewable energy. New York, Washington, Oregon, and California have committed to having 100% carbon-free power grids by 2045.[33]

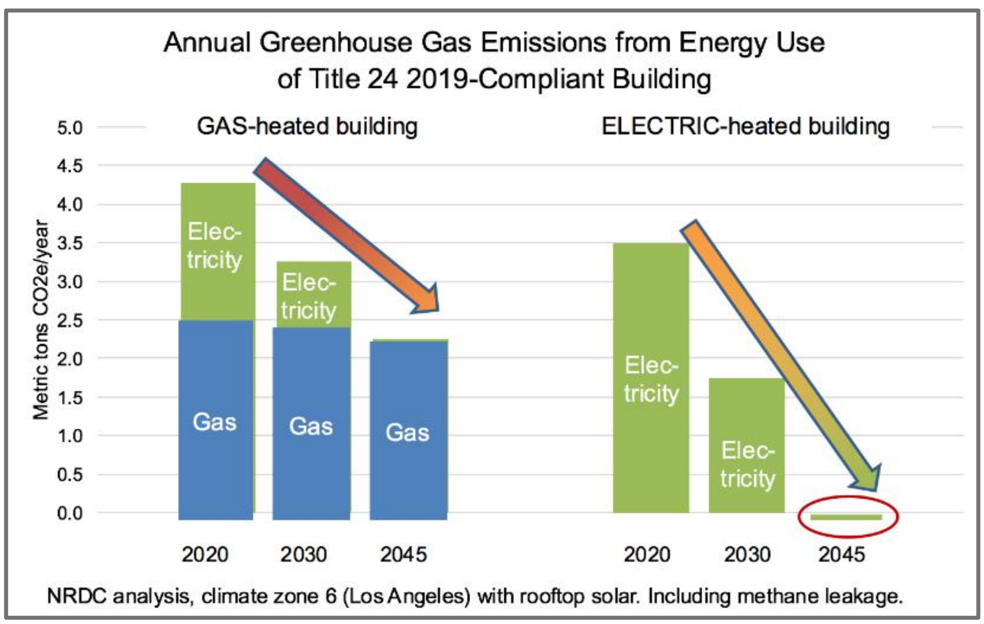


Figure 11: Buildings using gas cannot meet California's 2045 legal commitments, while all-electric buildings can. (Delforge, NRDC)

Figure 12: Burning gas at home increases childhood asthma. (Photo by Gateway Health)

Improved Indoor Health

Dozens of studies[34] show gas combustion in homes causes asthma in children. A gas stove doubles the odds a home chef of have lung and heart disease, and triples the chances that a home chef will need asthma medication.[35] Burning gas in household appliances produces damaging levels of pollutants like carbon monoxide, formaldehyde, nitrogen dioxide, acetaldehyde, and ultrafine particles.[36] The California Air Resources Board warns that "cooking emissions, especially from gas stoves, have been associated with increased respiratory disease." (*see Smog in Your Kitchen* sidebar). The carbon monoxide produced by burning gas in appliances can be lethal; carbon monoxide poisoning in the US kills 500 people and sends 15,000 people to the emergency room every year.[37]

Improved Public Safety

Nationwide since 2010 the natural gas system has caused 236 public safety incidents and $198 million in damages per year.[38] The toll includes causing half of the fires after both the 1994 Los Angeles earthquake and the 1989 San Francisco earthquake. [39, 40] Even in the absence of an earthquake, natural gas accidents have killed 548 people and broken more than 9,000 pipelines between 1986 and 2016 in the U.S. (nearly one a day).[41] In 2010 a major gas main in San Bruno, CA, exploded into flames 1,000 feet high, killing eight people, destroying 38 homes and damaging 70 others, and leaving behind a crater 40 feet deep.[42]

Figure 13: Methane leakage from a Colorado gas well 150' away caused this explosion that killed two brothers. (Photo by CBS)

Better for Builders

Beyond construction cost savings, all-electric design benefits builders by:

1. Reducing the many hassles of working with a Utility to provide new services in the street and to the building
2. Reducing construction labor—road closure, trenching, laying pipe, safety inspections, backfilling and road repair
3. Reducing the design costs, construction time and permitting of gas meters, internal gas plumbing, disposal piping for acidic condensate and venting to remove combustion exhaust that is hot enough to start a house fire and polluted enough that it must vent at least 10 feet distant from an openable window or door.
4. Reducing construction hazards—construction workers are killed every year by hitting gas pipelines with earth moving equipment and construction tools. For instance, in Ohio construction workers hit gas mainlines 410 times in 2015 alone.[44]
5. Eliminates the need for combustion safety testing of gas appliances for leaks, complete fuel combustion, and carbon monoxide back drafting.

Figure 14: An improperly marked gas line by the utility killed a plumber and destroyed neighboring buildings.[43]

The Smog in Your Kitchen

This sidebar summarizes the results of interviews by Redwood Energy's Sean Armstrong with Dr. Brett Singer of the Lawrence Berkeley National Laboratories, and Bruce Nilles of the Rocky Mountain Institute.

Armstrong: An April 2019 *New Yorker* article about the hidden air pollution in our homes said that there is actual smog formation in kitchens after 20 to 30 minutes of cooking on a gas stove. [47] Was that an exaggeration?

Singer: If you add pollutants like NO_2 from gas stoves to the cooking emissions, it is a mixture deserving of a name like "smog," although that name is already taken by outdoor air pollution.

Armstrong: Bruce, you wrote in the *New York Times*[48] in May 2019 that NO_2 "can easily reach levels that would be illegal outdoors."

Nilles: NO_2 is one of the main pollutants from gas stoves, and it is both linked to childhood asthma in otherwise healthy children, and worsens pre-existing breathing problems.[49] That is why the EPA sets outdoor health-based standards for NO_2, but gas stoves cause indoor NO_2 levels that can be worse than the outdoor air next to gas power plants and highways.

Singer: In our research the issue is most acute in smaller homes. Just using a couple of gas burners got to problematic levels of NO_2 in all the smaller homes.

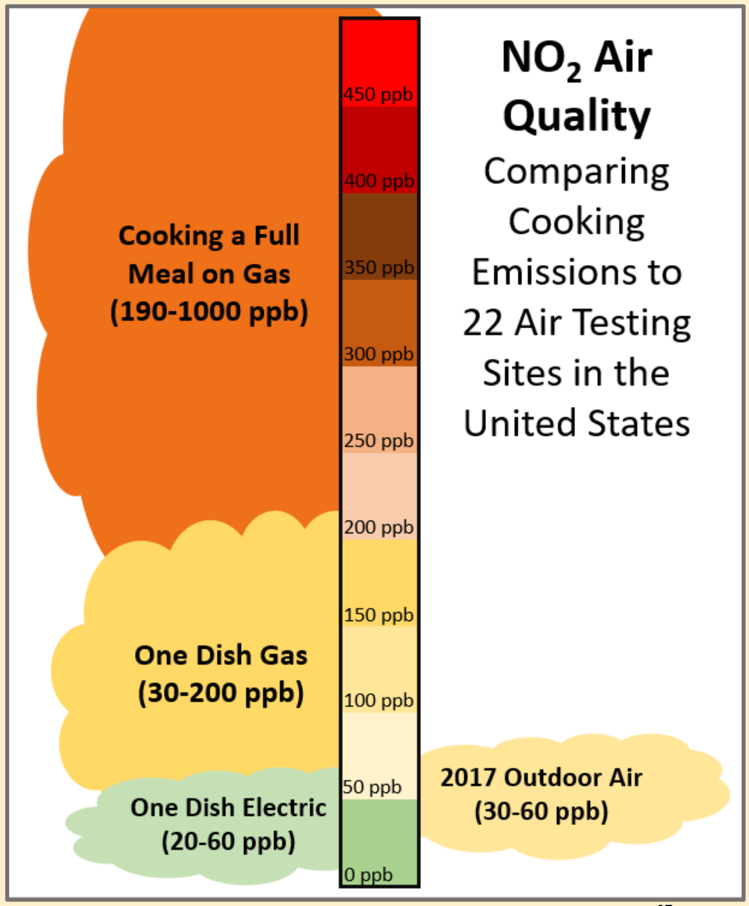


Figure 15: Comparison of 2017 outdoor air NO_2 data[45] and cooking NO_2 emissions[46].

Armstrong: How bad is it? Are indoor levels of NO_2 from a gas stove as high as those found outside on LA-style smoggy days?

Nilles: Yes, the levels of NO_2 in your kitchen are often higher than the EPA's outdoor threshold of 100 ppb. The California Air Resources Board found gas stoves that were producing 190 to 1,000 ppb of NO_2 in the kitchen after cooking a full meal, and even cooking individual dishes on gas stoves produced air quality that would be illegal outdoors.[50]

Armstrong: So, cooking on a gas stove produces NO_2 pollution as bad as the outdoor air in a city?

Nilles: Or worse. Every county in the US today is in compliance with the EPA health based NO_2 standards outdoors, but not our kitchens if we have a gas stove.

Resilience

Energy disruptions challenge our resilience, depriving our home of refrigeration, light, hot water, air conditioning and more. Disruptions are often caused by extreme weather events like heat waves, hurricanes and ice storms, and in the worst events both gas and electricity are shut down. These energy disruptions are threats to commerce, comfort, safety, and health. Below we make the case for a resilient and decarbonized grid and present a number of solutions.

Figure 16: Climate change-fueled natural disasters impact the resilience of the electric grid in the US. These photos are (above) a fire in Sylmar, CA, October 10th, 2019[51] and (below) the aftermath of hurricane Sandy in Ortley Beach, NJ, in 2012.[52]

Public Safety Power Shutoffs

With the goal of avoiding catastrophic fires, in California utilities have begun to conduct "public safety power shutoffs" during high wind events over the next ten years.[53] In October 2019, roughly 3 million customers experienced these preventative power outages in PG&E, Southern California Edison (SCE), and San Diego Gas and Electric (SDG&E) utility areas.[54] Gas, groceries, and generators sold out as a frenzy of people throughout California rushed to prepare. Lacking electricity to operate gasoline pumps, most gas stations were closed and access to gasoline was limited during the power shutoffs. Lines for gas stretched down streets, empty cars were pushed to gas stations, and gas stations began rationing sales to ensure public safety.

Figure 17: Access to gas was strained during the 2019 Public Safety Power Shutoffs in California. Left, a man pushes his car to the gas station;[55] center, a line of cars waits to get gas;[56] and right, a gas station was inoperable during the outage.[57]

Resilience with PV and Batteries Avoid the Dangers with Gas

With the right design, critical loads in a home can run on a battery that is charged by a solar array more or less indefinitely. With home batteries becoming affordable, and reversible car chargers making electric cars available for emergency power (see p.40), a home can now operate uninterrupted during power outages for days, and with a solar array a house can be off-grid for 2/3rds of the year without residents needing to conserve energy. Typically, critical loads during an outage are about 10% of a house's total electrical load.

Proposals to eliminate fossil fuel use in buildings—propane, fuel oil and natural gas—are sometimes met with concerns about how one heats and cooks in an all-electric home during a power outage, as if gas fueled homes were exempt from this concern. However, electric-start gas stoves, furnaces, water heaters and dryers are also vulnerable to a power outage and forcing them to light can result in an explosive leak. During California's planned power outages to prevent wildfire in 2019, residential back-up generators became a daily source of fires[58].

Figure 18: Example of residential battery storage.[59]

Solar-plus-battery systems are the better way to supply backup power. Solar electric systems with batteries provide an emergency power option that is less dangerous, less polluting, less noisy, does not have to be refueled and can pay for itself over time. Even without solar panels to recharge, battery systems can provide hours or days of backup power for necessary loads. The initial cost of a solar-plus-battery system is more than the price of a generator but burning down one's house with a generator or dying of accidental carbon monoxide poisoning are causes of death every year in the United States. Aside from resilience, an energy storage system means the battery can be charged by the solar array during times of lowest energy cost, and then the stored energy can be used when electricity rates are highest, e.g., 4 to 9 p.m. The savings accrued using this strategy will offset some of the initial battery investment over time. The average payback period of a solar array is 4 to 8 years,[60] but while a battery can earn a modest income, it does not earn a "profit"—it is a safety device. A generator will never have the possibility to pay for itself and carries with it the cost and danger of storing combustible fuel at your home.

Modern gas appliances need electricity to operate. Today most gas water heaters, gas stoves, and gas furnaces have an electric igniter and controls that won't function when the grid is down, and it can be life-threateningly dangerous to forcibly light gas appliances. Appliances with old-fashioned pilot lights still exist but are rare in new construction. They are not efficient due to the gas wasted keeping the pilot light burning.

Figure 19: Cindy King, upon returning to her home in October 2019 after the Kincade Fire in Northern California, found that while the electricity had been restored, she had no gas to heat the house.[61]

Gas takes longer to restore after shutoffs and disasters. In the late fall of 2019, roughly 24,000 customers in California's Sonoma County did not have power *or* gas for about a week. They were unable to cook or to heat their homes, leaving them exposed to freezing nighttime temperatures.[61] In most cases, electricity was restored many days before gas service was reestablished. According to a PG&E representative, turning on gas lines is more complex than restoring electricity, as utility workers must visit each customer's home or business, inspect the gas meter for leaks, and clear gas lines before restoring service and re-lighting pilot lights.[61]

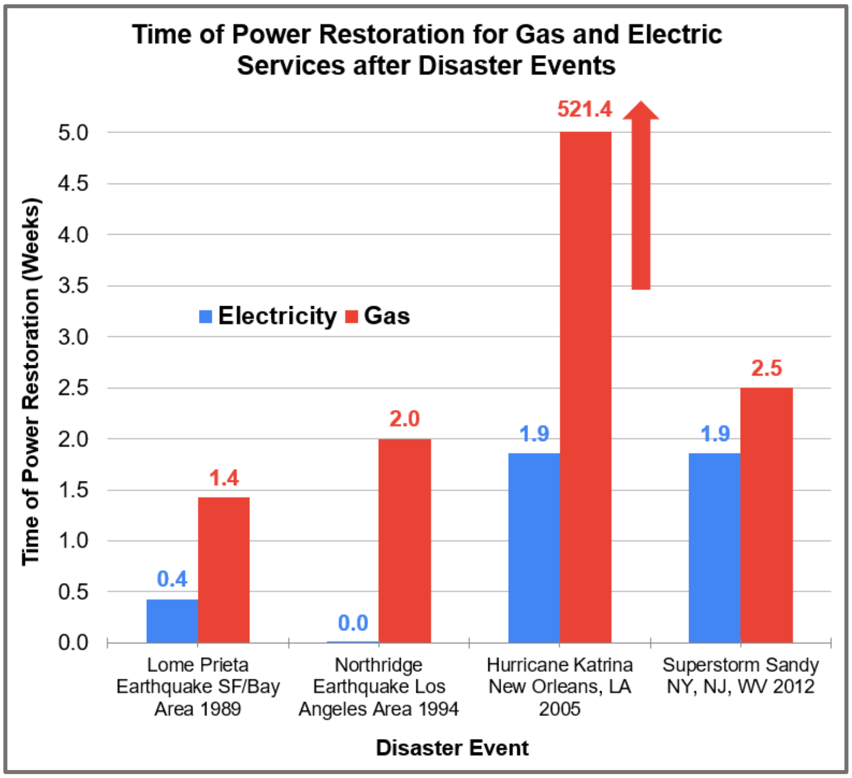


Figure 20: the time of power restoration for various natural disaster events. The time to restore the natural gas system was much longer compared to the electric grid.[62]

In other disaster events across the US, gas also has taken longer to restore than electricity. In the aftermath of Hurricane Katrina, 28,900 utility poles were destroyed and only 75% of the grid was restored after 23 days. Restoring the gas system in New Orleans, however, took over 10 years – 162 miles of corroded cast iron pipes had to be replaced because of salt water intrusion.[63] After the 1989 earthquake in the San Francisco Bay Area, one of the most labor-intensive parts of restoration of the gas system was relighting pilot lights, at a cost of $7 million dollars.[64] The earthquake also destroyed portions of the gas distribution system; three low pressure systems were so heavily damaged that 1,000 pipeline leaks were reported and insertion of plastic pipe was required.[64] The electric grid is more resilient after natural disasters – it is less damaged by water intrusion and earthquakes and takes less time to restore. The time of power restoration after natural disasters is essential to making sure the public is safe and normal life can resume.

Gas generators are dangerous and pollute the air. Most generators have only enough fuel to provide power for two days, and more fuel isn't always available during a major disaster—gas stations run out. In addition, gas stations cannot pump without electricity and often do not have a power back-up system like solar and a battery. Generators can also be hazardous – for example, in the recent PSPS events in California, a generator ignited a commercial building in Arcata, CA, causing substantial structural, electrical, and interior damage, along with loss of merchandise. Although widely used, diesel and propane generators are expensive to operate and maintain. They require monthly testing to properly maintain.

Figure 21: A generator fire broke out in Arcata, CA, during a PSPS in October 2019, resulting in three businesses being temporarily condemned until repairs ensure their safety.[65]

The value of resilience is important for homeowners to understand – what are your financial risks due to potential hotel stays or food spoilage? How much productivity or income may be lost during an outage, and how long do you want to be prepared for? The Clean Coalition[66] is developing a "value of resilience" methodology[67] to help individuals and businesses answer this question. The myriad benefits of resilience in the face of power outages are hard to quantify; however, see more on this under *Battery Storage* in the *All-Electric Product Guides section*.

Lack of resilience comes with high costs:

- $119 billion: The annual cost of power outages to the U.S.
- $20 – $55 billion: The annual cost to Americans of extreme weather and related power outages
- $243 billion – $1 trillion: Potential cost of a cyber-attack that shuts down New York and D.C. areas.

(source: Clean Coalition 2019)

Passive Building Measures

The most cost-effective passive resilience solution– that is, to keep building occupants healthy and comfortable *without* power – is to improve the envelope. There are various passive strategies, including air sealing, adding insulation, and/or installing more efficient windows, that can shield residents from extreme temperatures while minimizing the need for power and mechanical systems. There are numerous excellent resources on passive design strategies, one of which is the *Zero Net Energy Primer* published by the American Institute of Architects California Council.[68]

Microgrids and Nanogrids

Our centralized energy infrastructure is costly, aging, and can be a fire risk in hot, dry weather. Advanced energy buildings that are designed to provide for most of their own energy needs can be called ***nanogrids***, and a community of them which interconnects locally and can disconnect and "island" from the larger grid is called a ***microgrid***. Microgrids are a solution to decentralizing the grid and provide resilience, from home systems that can operate off-grid, to community-scale microgrids. Microgrids can be powered by stationary or mobile energy storage facilities. Nanogrids and microgrids enhance resilience in our communities and homes by allowing priority loads, or even ALL electrical loads, to remain fully powered in a grid outage event.

Blue Lake Rancheria Community Microgrid During the 2019 PSPS

The Blue Lake Rancheria microgrid offered a safe and warm place for the local community to charge their devices during the PG&E PSPSs. Located in Blue Lake, CA, it serves tribal government offices, EV charging, a convenience store and gas station, a hotel, a casino and a water treatment system – and is an American Red Cross emergency evacuation site. The project utilizes a 420kW solar array, a 500kW / 950 kWh battery energy storage system, and a 1 MW backup diesel generator. The microgrid can seamlessly transition from being grid-connected to islanding. The annual savings from the solar array are approximately $150,000 in annual electricity costs. During the power shutoffs the Rancheria was a refuge for eight people with critical medical needs for power and was credited by the Department of Health and Human Services with saving the lives of four of these individuals.[69] It is estimated that this project will save 175 MT of CO_{2e} per year. This project was designed with the idea of being reproduceable – research suggests that there are sites throughout California that could benefit from this kind of design, offsetting 5.2 billion kWh, reducing about 1.5 million metric tons of greenhouse gas emissions per year.[70]

Figure 22: Aerial view of the Blue Lake Rancheria microgrid.

Vehicle to Home (V2H) and Vehicle to Grid (V2G) Charging

The island of Maui, with its constrained grid, and the Los Angeles Air Force Base[73], with its need for resilience during emergencies, began using Nissans for Vehicle-to-Building and Vehicle-to-Grid chargers in 2014.[74] Honda, Mitsubishi, Toyota and other car manufacturers with standard CHAdeMO certified Level 2 charging plugs can now support bi-directional charging. Tesla is also expected to release a V2H charging system for its cars in early 2020.

Figure 23: Nissan unveils the U.S. commercial offering of V2H charging in LA for 2019 deployment in the U.S., using battery-powered Leaf cars and Fermata Energy bi-directional charging.[71]

Figure 24: Clean energy enthusiasts observe a Nissan EV as part of the JUMPSmartMaui program.[72]

Figure 25: The LA Air Force Base increasing its resiliency with the largest EV fleet on a federal facility, 42 vehicles of Nissan Leafs, VIA plug-in hybrid vans, Ford C-MAXs, and Chevy Volts with all these cars use V2G technology.[73]

V2H During Disaster Events

In Japan, V2H systems provide resiliency during extreme climate events. Typhoon number 15 ripped through Japan in early September and as a result, 931,000 homes lost power.[75] One vehicle owner, Mr. N, has the Leaf to Home system that includes an EV power station, with a DC connection to solar, EV batteries and the home batteries – coined the “tribrid energy storage system” by Nichicon Corporation. The Nissan leaf battery and with its 15amp circuit was able to power the lights, refrigerator and eco-cute heat pump water heater for two and a half days.[76] During the day his 4.5kW solar array was able to charge the car batteries, but it was not enough to fill them. Mr. N was able to drive to the closest Nissan dealer, which was outside of the outage zone, charge his EV and come back home – free of charge from Nissan. During the power outage, Nissan also sent out a fleet of 30 EVs to assist people with no power with a system called the Power Mover, which is a small, suit case sized mobile battery system with 4.5kW capacity that can power AC appliances and be connected to the Leaf.[77]

Figure 26: Mr. N’s Nissan Leaf being used during the Chiba power outage in Japan.[76]

Figure 27: The “Power Mover” a 4.5kW portable EV power station that can also supply typical AC appliances.[77]

Electric and Zero Carbon Building Policies

Efficient electrification paired with cheap renewable energy is on a path to policy permanency, a practice driven **historically in most of the nation by cost savings,[78] but being embraced by municipalities to meet climate targets**. California is an example of a leading state in climate policy[1] including these four noteworthy laws:

- The Global Warming Solutions Act of 2006 (**AB 32**) required the state of California to reduce its GHG emissions to 1990 levels by 2020; in 2016, **SB 32**, further required the state to reduce GHG emissions 40 percent below 1990 levels by 2030.
- California Renewables Portfolio Standards of 2018 (**SB 100**) requiring 100% carbon free electricity by 2045.
- The Low Emissions Buildings and Sources of Heat Energy Act of 2018 (**SB 1477**) providing direction to State energy agencies to pursue electrification of buildings as an essential strategy to curb climate and air pollution.[79]

Cities and Counties within California often provide early environmental leadership. Examples of local leadership electrification codes include:

- The City of Berkeley was the first in the nation to ban gas in all new construction, including homes, beginning in 2020;[80]
- The City of Arcata is planning for a complete moratorium on gas hook-ups in all new construction and municipal rehabs in 2020;
- The City of Los Angeles policy will no longer permit gas in new construction starting in 2030;[81]
- The City of Carlsbad requires either an inexpensive electric heat pump water heater or a solar hot water array;[82]
- In 2016 the City of Palo Alto and the County of Marin adopted Green Building Ordinances that support electrification.[83]
- Over 20 other California jurisdictions have adopted reach codes for 2020 that support electrification; and many more cities and counties are actively exploring reach codes.[84]

Decarbonization Goals

The efficiency of high-performance heat pumps (e.g. greater than 310% efficient) is an opportunity to reduce greenhouse gas pollution even when electrical power is created exclusively with fossil fuels, although many cities are swiftly moving towards carbon free power. The City of Vancouver, which uses clean hydro power, has a carbon standard for buildings that will effectively require all electric buildings by 2030,[85] while the City of San Jose is already promoting Zero Net Carbon (ZNC) new construction that sources energy through their clean grid through its recently approved Climate Smart San José.[86] San Jose adopted a package of incentives for electric buildings through "Reach Codes" in September 2019, followed up in October 2019 by an explicit ban on gas use in new homes, accessory dwellings ("ADUs"), small apartment and condo buildings of 3 stories or less, and municipal buildings. The decades of energy efficiency codes, policies and programs have always been for the benefit of reducing energy costs and the upstream generation costs and environmental impacts. But it is the growing spotlight on the relationship between building's energy use and carbon, and the efficiency gains and cost reductions in renewable generation, that is making electrification the policy trend and our future.

Single Family Building Code

Some states and cities are beginning to implement mandatory zero energy policies. The leading states and local governments working to advance the cleanest energy policies for new homes include California, Washington State, New York, Massachusetts, and Vermont.[87] In California, for example, all homes built in 2020 and beyond will be highly efficient meeting zero-net-energy standards that include solar panels to generate enough power to meet each home's expected annual electric needs.[88] In the 2019 Energy Code Section 110.10- The main electrical service panel shall have a minimum busbar rating of 200 amps.[89] This requirement will meet needs for full electrification of a home in the future even if it is dual fuel today.

1 See https://www.climatechange.ca.gov/state/legislation.html for a more comprehensive list of California's climate legislation.

Reach Code

Reach Codes and additional standards are starting to move in the direction to address carbon. We have seen this in work completed by Zero Code,[90] ASHRAE standards and state building code standards. California's state building code has a trajectory to mitigate carbon coupled with 100% renewable generation by 2045. Across the nation, we are witnessing local governments leading the way for a fossil free future, demonstrating not only feasibility but also community and environmental benefits of clean energy buildings. Cities are adopting varying types of reach code to achieve emission reduction and clean energy goals targeting their specific building stock. Examples include (exemption and exceptions exist but are not included here):

- Prohibition of gas infrastructure in new buildings
- Higher performance requirements for mixed fuel buildings and code minimum for all electric buildings.
- All electric new construction building code
- Single measure requirements like a heat pump water heater in all new residential construction.

Jurisdiction	Approach			Systems			Buildling Types								Add-Ons		
	Natural Gas Infrastructure Moratorium	All-Electric Reach	Electric-Preferred	Whole Building	Water Heating	Space Heating	Low Rise Residential	City-Owned Properties	High Rise Residential	Hotel	Retail	Office	Restaurant	Life Sciences	Additional Solar	Electric Vehicles	Natural Gas In Lieu Fee
Alameda	X			X				X									
Berkeley	X		X	X			X	X	X	X	X	X	X	X			
Brisbane*		X			X	X	X	X	X	X	X	X	X				
Campbell		X			X	X	X									X	
Carlsbad		X			X		X								X		
Cupertino		X		X			X	X	X	X	X	X	X			X	
Davis			X	X			X										
Hayward		X	X	X			X	X	X	X	X	X	X	X	X		
Healdsburg		X			X	X	X	X	X	X	X	X	X	X			
Los Altos Hills		X			X	X	X	X	X	X	X	X	X				
Los Gatos		X		X			X									X	
Marin County			X	X			X	X	X	X	X	X	X	X		X	
Menlo Park*		X			X	X	X	X	X	X	X	X	X		X	X	
Mill Valley			X	X			X		X							X	
Milpitas			X	X			X	X	X	X	X	X	X	X			
Morgan Hill	X			X			X	X	X	X	X	X	X	X			
Mountain View*		X		X			X	X	X	X	X	X	X		X	X	
Pacifica		X			X	X	X	X	X	X	X	X	X		X	X	
Palo Alto*		X	X	X			X	X	X	X	X	X	X	X		X	
Richmond		X		X	X	X	X	X	X	X	X	X				X	
San Francisco	X		X	X			X	X	X	X	X	X	X		X	X	
San Jose*	X		X	X			X	X	X	X	X	X	X	X	X	X	
San Luis Obispo			X	X			X	X	X	X	X	X	X	X	X		X
San Mateo			X	X			X					X			X	X	
San Mateo County		X		X			X	X	X	X	X	X	X			X	
Santa Cruz	X			X			X	X	X	X	X	X		X			
Santa Monica			X	X			X	X	X	X	X	X	X	X	X		
Santa Rosa		X		X			X										
Saratoga		X			X	X	X	X	X	X	X	X	X	X		X	
Windsor		X		X			X										
*City Council opted to go beyond staff recommendation.																	

Figure 28: Building decarbonization efforts in California as of 2/13/2020.[91]

Over 50 California municipalities are studying new limits on natural gas in buildings, with at least 24 cities already adopting policies this year that prohibit gas or strongly favor all-electric homes (*and often include other sectors a well*) beginning in 2020. These cities including San Jose, the nation's 10th most populous city, are listed in Figure 28 with the specific type of policy and additional requirements such as solar, electric vehicle chagrins, battery energy storage, and in lieu fees for natural gas use in new construction.[91] Other cities across the nation that are looking at adopting legislation to limit natural gas include: Cambridge, Minnesota, Seattle, and New York City. Brookline, Massachusetts recently adopted a "Prohibition on New Fossil Fuel Infrastructure in Major Construction."[9] This encompasses a gas ban for new homes, and other cities in Massachusetts including Cambridge, Newton, and Lawrence, are expected to adopt similar policies.

Embodied Carbon

By 2030, a building erected in 2020 will have polluted more from its construction than its operation—only by 2050 will its "embodied carbon" equal its pollution from operating energy consumption. Green building certifications such as LEED, GreenPoint Rated and the Living Building Challenge address embodied carbon in their certifications. The two greatest contributors to climate change from construction include.[92]

- **Concrete**. Using less cement is the most effective way to reduce the carbon footprint of concrete, because Portland cement is high in embodied energy and produces significant greenhouse gases through production. Simply allowing for a slower drying period saves cement. Several mixing strategies and supplementary materials can reduce cement, such as recycled glass and rice husk ash.[93] Even better, a new method of creating concrete actually pulls CO_2 out of the air, or directly out of industrial exhaust pipes, and turns it into synthetic limestone. This carbon negative concrete, which has been demonstrated in pilot project at San Francisco Airport, will soon be available for commercial sale from a company called Blue Planet.[94,95]

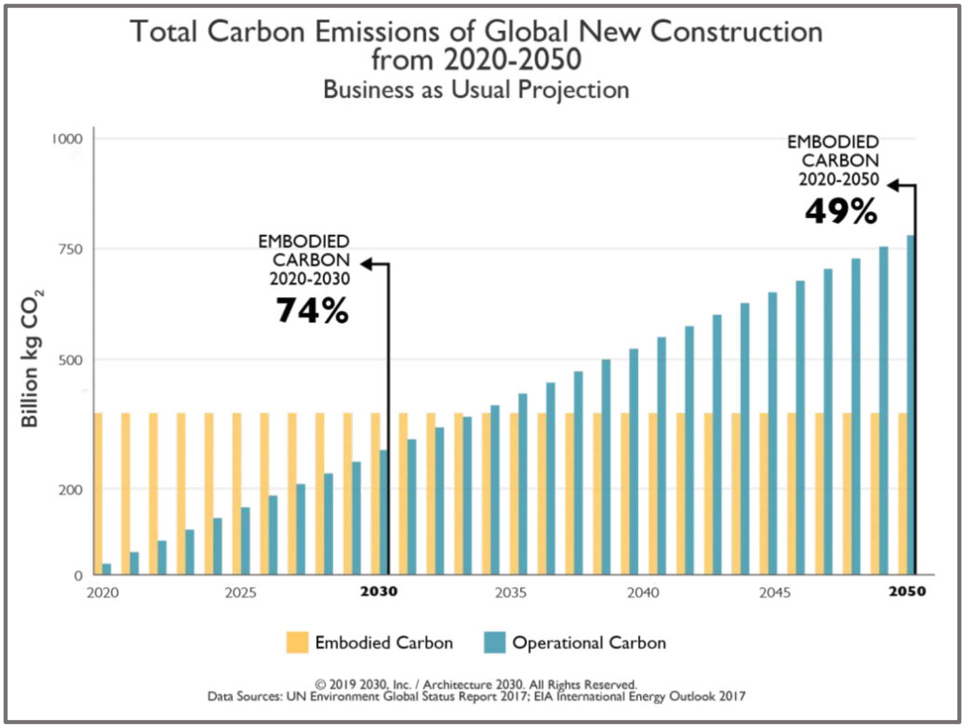


Figure 29: The CO2 pollution from a building will be constructed in 2020 will still be 74% due to its construction in 2030, not its operations. Only in 2050 are the two sources of pollution equal.

- **Steel**. Refining steel is the source of 7% of global climate change. Structural steel can be replaced with wooden cross-laminated timbers, and wooden skyscrapers are being built world-wide—the tallest is now 345'. Rather than requiring a steel smelter and a mountain of coal, wood buildings sequester carbon in their structure.

- **Refrigerants**. Current refrigerants include HFCs which have no ozone depletion potential (ODP) but have global warming potential (GWP) when released into the atmosphere. Ideal refrigerants have zero ODP, zero GWP, non-toxic, non-flammable, acceptable operating pressures, and volumetric capacity appropriate to the application. While standards and products continue to advance, there are considerations for today. Select HVAC systems with lower volume of refrigerants such as ductless mini splits which have 14% of refrigerants as a conventional split system. Look for low GWP products in heat pump waters heaters of 150GWP. For low GWP refrigerants to be used in direct space conditioning systems, there may need to be some adjustments to other building standards, but 750 GWP could be a good target. Select equipment not just by efficiency but consider refrigerants as well.

- **Insulation.** Different insulations have varying global warming potential (GWP) and ozone depletion potential levels. Closed cell spray foam and extruded polystyrene (XPS) have high GWP over 1.4 lifetime GWP/sqft*R as well as halogenated flame retardants. Use insulations such as cellulose, fiberglass, open cell water-blown, expanded polystyrene, or mineral wool that have a lifetime GWP potential greater than .05 GWP/ sq.ft.* R. In addition to R-value for greater thermal performance, look at GWP for greater environmental performance.

Case Studies

Developers generally pursue all-electric construction first because it lowers construction costs to avoid gas infrastructure. To date thousands of homes have been built without gas, and major home builders such as KB Homes and City Ventures offer all-electric homes as a standard choice.[96,97] Below are notable all-electric case study examples from across the United States with a brief explanation of their electrification strategy.

Taft School, Connecticut

Elia Jones House, Washington

Savoy House, Massachusetts

Custer Custom, Washington

ZED 2, Colorado

Fishers Circle, Minnesota

Project 15-580, Stanford, CA

Mark Jacobson is a professor at Sanford University and is leading the Solutions Project – a movement to switch the world over to 100% renewable energy. In accordance with the Solutions Project, his new 3,200 square foot home is all-electric and zero net energy. The home has a rooftop solar array with a Tesla Powerwall for storage and charging electric vehicles, Nest appliances, heat pumps for heating and cooling, and an induction stove – with no gas lines at the property.[98] The home was designed and built by the Canadian company BONE Structure that uses prefabricated steel framed walls that are 90% recycled steel, which made the home faster to build, more sustainable because steel is recyclable, seismically resilient and safe from damage from termites and mold. After a year of living in the home, it produced as much energy as was used, and the family got a $530 dollar check from their energy provider for roughly producing 20% more than used.[99]

Figure 30: Sanford professor Mark Jacobson's passive house and the four tesla power walls that provide backup power and EV charging.

Zero Energy Modular Home - The Wallace's Story, Waterbury, VT

Wally Wallace found the perfect home when visiting Efficiency Vermont's zero energy model home showing. Wally and his sister Rosina had lost both of their houses on their Waterbury farm in a fire in the summer, but that winter Wally was staying warm in his new ZEM home. Previously, he faced $300/month fuel bills during colder months. Now, Wally will produce enough solar credits during the sunny spring and summer months to cover his year-round electric usage. In his new, super-insulated home, Wally stayed in a t-shirt during a recent 7-hour outage, while a snowstorm raged, and outdoor temperatures were below freezing. The features of the zero energy modular homes include healthy material choices, high levels of insulation, tight air sealing, triple pained windows, a fresh-air ventilation system, heat pump space heating and cooling, heat pump water heating, and rooftop solar designed to offset the home's energy use.

Figure 31: ZEM On Tour in Waitsfield, May 2018.[100]

Reynold's Landing Smart Neighborhood, Birmingham, AL

Reynolds Landing is a community-scale microgrid project by Alabama Power, a subsidiary of Southern Company. Located in Birmingham, Alabama, the project is the first of a series of "Smart Neighborhood" projects undertaken by Alabama Power and Southern Company. Smart Neighborhoods are an initiative by Southern Company and their subsidiaries to get their customers on innovative, reliable, and affordable energy systems. The Reynolds Landing project, constructed in December 2017, consists of 62 single-family homes with a community-scale microgrid. These homes have a HERS score between 40 and 50, employing technologies like heat pump water heaters and variable capacity HVAC systems and insulations. The homes were built by Signature Homes, a residential real-estate company operating in Alabama and Tennessee. The community-scale microgrid at Reynolds Landing consists of the following distributed energy resources (DERs): a 330kW PV array, 300kW / 680kWh lithium-ion battery for energy storage, and a 360kW natural gas generator. The Reynolds Landing neighborhood is connected to the existing electrical grid, but has the capability to "island" from the grid and rely solely on DER generation from its microgrid. The microgrid is equipped with energy management software tools developed by the US Department of Energy Oak Ridge National Laboratory (ORNL) that can autonomously manage the distributed generation assets.

Figure 32: Alabama Power's Reynolds Landing Smart Neighborhood in Birmingham, Alabama, the housing tract and the solar array.[101]

Veterans Village, Sonoma County, CA

Veterans Village by Sonoma County Community House is a tiny home village for homeless veterans sprouted in response to the wild fires that ripped through Santa Rosa, and the first development in the city to be streamlined for temporary housing. This project will be 100% zero net energy. There are 14 single resident units total. Each unit has its own heating and cooling and every four units shares a water heater. Providing the heating and cooling to the space will be the Mitsubishi Arama packaged terminal heat pump (HSPF=8.608, SEER=12) and the domestic hot water system will be the NEEA Rated heat pump water heater Sanden 83 gallon.

Figure 33: Sonoma County tiny home village for homeless veterans.[102]

Modular Lifestyles Tiny Homes

Modular Lifestyles, Inc. was founded in 1988, in California, as a dealer for HUD code manufactured homes. The company has expanded to be a leader of tiny home and modular home markets. Homes that concentrate on both on- and off-the-grid factory-built housing. Products from Modular Lifestyles have been endorsed as Zero Energy Ready Homes by the U.S. Department of Energy. Their home designs incorporate into their homes energy efficiency that stands above 15% of the average Californian home. Modular Lifestyles designs their homes with custom specifications that can include: BIPV solar roof shingles, Wind Energy utilizing wind turbines scaled for the home, 2020 standards for ZNE for new construction of under 3200 kwh annually, and a battery bank system can be added to support off-grid living. By focusing on balancing house performance to the surrounding climate they achieve close to zero utility costs. They also offer certifications to their clients: Energy Star, HERS Rated, and Green Point Rated.

Figure 34: Two examples of the Modular Lifestyle Tiny Homes.

Figure 35: The Third Residential Ecovillage Experience located in Ithaca, New York.

Third Residential Ecovillage Experience (TREE), Ithaca, NY

The Third Residential Ecovillage Experience at Ecovillage Ithaca is an all-electric, DOE Zero Energy Ready Home and passive house certified development in upstate New York. The community has 17 single family units, 4 duplexes and 15 multifamily units. Each single-family unit is 2 floors with 3 bedrooms and 2 bathrooms. TREE is the newest addition to the largest co-housing project in the world and is also certified EPA Indoor Air PLUS, WaterSense and LEED Platinum. Each single-family residence is equipped with rooftop solar, solar hot water heating, energy recovery ventilation, tripled glazed windows, R45 walls, R-90 attics and an R36 slab.[103]

North Avenue Co-Op, Burlington, VT

When the residents of Burlington's only affordably priced single-family neighborhood purchased their mobile home park from the long-time owners they had an immediate need to fill all the vacant lots. The problem that had bedeviled this 75-year-old mobile home park for decades was making it hard for the new cooperative to generate the income needed to service the park mortgage: lots built for the small mobile homes of the 1950's couldn't accommodate a modern manufactured home up to 76' long. The solution came packaged in a healthy home with no energy bills. A mobile home replacement program helped the North Ave Co-Op develop a small lot with a custom-built zero energy modular home (ZEM). Efficiency Vermont and Burlington Electric Department supported the project with technical services and a substantial incentive to make sure the home was affordable to someone at 80% AMI. ZEMs aren't as cheap as a mobile home, but the extra quality, comfort and healthy environment are "paid" for with the energy savings. Fully electrified with solar array to cover the annual energy consumption, this home is helping the North Ave Co-Op be financially sustainable, and helping Burlington, VT meet its long-term energy- and climate goals. The features of this ZEB include balanced high efficiency ventilation (1 ACH50), U 0.21 windows, R-40 wall assembly, cold climate heat pump, and a net metered 4.5 kW solar array.

Figure 4: Photo of the outside and inside of the zero energy modular homes (by Peter Schneider, Efficiency Vermont).

Independence and Juniper Developments in Sacramento, CA

The Sacramento Municipal Utility District will partner with national homebuilder DR Horton to build 104 all-electric homes in Sacramento in the "Independence" and "Juniper" communities. The homes consist of heat pump space heating and cooling, heat pump water heating, and induction stoves. Construction for these homes are motivated by the Sacramento Municipality District's ambitious climates goals aiming to reduce their utility GHG emissions by 90% from 1990 levels by 2050. To reach these goals the utility is incentivizing the new all-electric construction by offering rebate packages. The Smart Home program offers rebates of different amounts, depending on if the project is single-family or multi-family, or a gas-to-electric conversion.

Figure 36: The Juniper development by Meritage Homes in Sacramento, California.[104]

Tubbs Fire Rebuild Homes, Sonoma County, California

Park Family Home, Santa Rosa

Figure 37: The Park Family's home, rebuilt all-electric after the Tubbs Fire in 2017.[105]

The Tubbs fire in 2017, the Kincade fire and intermittent power outages to prevent fires in 2019 has left Santa Rosa in a frenzy. Many families need to not only rebuild homes, but to build their homes safe, resilient and that invest in the future. Cameron Park has built an elegant, efficient and environmentally minded all-electric 4-bedroom, 2.5 bath, 1,940 square feet, single story home in the Coffey Park community in Santa Rosa. The home is built with modern efficient appliances, high-tech skylights, super-insulated walls and triple-pane windows. All of this allows the homeowners to be warm in the winters and cool in the summers, despite intensifying seasons. The total energy efficiency is 20% higher than the requirements of Title 24 energy code. Whether it be a power outage or natural disaster, this home's owners will be prepared. Rooftop solar panels and 9.8-kilowatt storage battery in the garage make possible to operate without relying on the grid for power, providing the residents with confidence in an uninterrupted power supply. The home is connected to the main grid, giving the option for the homeowner to sell excess power back to the utility.

Figure 38: Barry Hirsch's home, rebuilt all-electric in Sonoma County after the 2017 Tubbs Fire.

Hirsch Family Home

Barry Hirsch, after losing his home in the Tubbs fire in October 2017, took advantage of the "All Electric Home with Solar + Storage" incentive packaged offered by Sonoma Clean Power (SCP) as part of their Advanced Energy Rebuild program. Barry used the full $17,500 incentive offered to upgrade his home and made the decision not to install any natural gas because, as he stated, "it's the right thing to do."

The house uses a mini-split heat pump, a ventilation system, and a heat pump water heater with a rooftop solar array that is projected to fully power the entire home. Left over solar energy can be used for EV charging or sold back to the SCP program. The LG battery systems enables the family to use extra energy generated during the day to power the home at night, and for critical loads to be continuously maintained, adding a resiliency component in cases of natural disaster and grid disruptions. The solar and battery systems include 360-watt LG panels, SolarEgde inverters, a LG Chem 9.8 kWh AC-coupled battery, and a JuiceBox Pro 40 EV charger.

Habitat Studio, Edmonton, Alberta, Canada

Northern Canada has long, cold, dark winters, and yield from solar arrays is low to non-existent in the darkest months. Habitat Studios focuses on the design and implementation of custom zero net energy homes in these conditions. A majority of these homes fall into their determined net zero “sweet spot” using the following envelope specifications: R37-4”EPS + R22 Frost Wall for the foundation, R-18-4” Type 2 EPS for under slab insulation, R40-12” Double 2x4, 24” OC for walls, and R-80 cellulose for the ceiling. Their envelopes are tightly sealed to 0.5 ACH achieved with caulked poly and siga tape. Heating and cooling loads are met with Fujitsu Ducted Mini Split Air Source Heat Pumps to live comfortably in the extremely cold climate. For ventilation, the Air Pohoda Ultima 240E Heat Recovery Ventilator (HRV) is used. Hot water needs are met with a heat pump water heater. Below is a few of Habitat Studios case studies. All presented are examples of all electric or NetZero housing. The NetZero home “SweetSpot” constructed in 2016 was the first home in all of Canada to receive an EnerGuide rating of Zero on the new EnerGuide Rating System. Since then Habitat Studios has added 4 more NetZero homes to their portfolio.

Maverick

Windsor Park NetZero

MillCreek NetZero

Alpha Wolf

Parkland NetZero

DeLux

NetZero SweetSpot 2016

Riverdale NetZero

Corporation for Better Housing, Central Valley, California

Located in the Central Valley farming towns of Selma, McFarland and Williams, the Corporation for Better Housing has developed 156 zero net energy homes as part of a strategy to win scarce funding from the USDA Rural Development Division. The homes for low-income farmworker families are modest in size—about 1400sf—but built to the LEED Platinum standard for efficiency and occupant health. Designed to be a Net Positive Energy development,[106] the all-electric homes have 4kW to 5kW solar arrays paired with efficient ducted HVAC, heat pump water heaters located in the garage, all LED lighting and Energy Star appliances.

Figure 39: The typical solar powered house farmworker families by the Corporation for Better Housing, and an aerial view of the 40 Green Valley Homes in Williams, CA near the olive and almond orchards of the northern Central Valley of California.

The Cottages at Cypress, Fort Bragg, CA

Figure 40: ***The Cottages at Cypress in Fort Brag, California.***[107]

The Cottages at Cypress in Fort Bragg was difficult to permit—the multifamily zoning was unpopular with neighbors, and the political solution was to build twenty-six 600-800sf homes on the single parcel. The cottages each have a 4kW (DC) solar array, although two homes in the shade of cypress trees are credited via "virtual net metering" from an array on the community building. With the frugal senior tenants using, on average, only half of their solar array's energy, each resident has enough extra energy to drive 5,000 miles per year for free in an electric car.[30] The community building and laundry facility are offset with a 20kW array. The houses are equipped with high efficiency mechanical systems: a 25 SEER Fujitsu 9RLQ air source mini-split for heating, a GE GeoSpring air source heat pump water heater with an energy factor of 2.35, and 100% LED lighting.[30] The solar array subsidies brought the net cost down to just $20,000, which was paid back in less than a year with net revenue supporting social programs. The 2007 Energy Independence and Security Act was a bipartisan law that the USDA Rural Development implemented in their 514/516 loan program with competitive points for Zero Net Energy. With California and Federal subsidies committing to this goal was a net financial gain, not a burden, to the development. In addition, it was found that senior citizens use less significantly less energy cooking and showering, which resulted in a 100% solar offset design performing at 180% annual offset.

Shingled Tiny Home, Arcata, CA

Figure 41: The Power Efficient Tiny Home in Arcata, California on Sean Armstrong's property--two 1000W water heaters, a 1400W induction cooktop and a 1200W toaster oven and 500W space heater with an ERV keep power demands below 30Amps for both the tiny house and adjacent tiny bathroom.

Arcata, California. Behind the "Redwood Curtain" in Northern California is Sean Armstrong's tiny home, a demonstration of power-efficient design and sourcing of sustainable materials. The 150 sf home sits on farmland that is home to both Tule Fog Farm and Redwood Energy (the authors of this booklet), and is rented to purpose-driven people who want to milk a cow in the morning and drink their hot cocoa in the evening in an all-electric, all-local-wood home sealed with beeswax and olive oil, and insulated with wool. The power-efficient solutions use only 120V appliances that use less than 1400W--two water heaters, a two-burner induction stove, a large toaster oven, electric space heater and Panasonic Whisper Energy Recovery Ventilator. The separate bathroom is insulated with 2 inches of cork siding and heated with an overhead heat lamp, so heat is instant and used only when occupied. Sean is pointing at the Japanese "Shou Sugi Ban" method of lightly burning the surface of wood, rather than using pressure treated wood.

Teaser: A Zero Emissions All-Electric Single-Family Retrofit Guide

The next phase of this document series will be ***A Zero Emissions All-Electric Single Family Retrofit Guide***. This section gives a teaser to what will be included: case studies, a in depth discussion on the "Amp Diet" in the home and how to choose the right products, along with an updated product guide specifically for retrofits.

The All-Electric Home "Amp Diet"

You can electrify without needing an oversized expensive electric panel and upsized service-drop wire from the grid. Also you can electrify in ways that are grid friendly and make it cheaper for you and everyone else to do the same. It's analogous to wanting low carbon building materials and low global warming potential refrigerants. We've been developing ideas, tools, strategies and guidance for the "Amp Diet" to help you live larger on a smaller panel. Think of it as Amp Diet for a small friendly grid. The Amp Diet is especially important when it comes to fuel switching a home, you want to make sure all new electric appliances and loads fit on the various circuits and panel in the home. Efficiency measures can double as amp saving measures – like installing better insulation, getting rid of ductwork, and choosing higher efficiency heat pumps. Also choosing specific lower amp products helps to reduce the amp diet - like a cooking range that combines the stovetop and oven into one appliance or a low amp heat pump water heater. Some choices may have more than one good option that have amp savings – like choosing a combined condensing washer and dryer versus a separate heat pump clothes dryer. Other options include energy management systems, which may be desired if you have particularly high energy or high amp loads that may be running at the same time, like an electric vehicle and a dryer. A common example of this is when an EV charging station is installed on the 30-amp dedicated circuit where the dryer is in a typical home. (See the Energy Storage and Management Systems section below). Designing all-electric retrofits can require careful attention to the Amp Diet. To aid this process an Amp Diet spreadsheet tool will be available in the upcoming Retrofit Guide.

Perlita Passive House, Los Angeles, CA

When Xavier Gaucher became Passive House certified, he vowed that his next home would meet this highly efficient standard. The home he eventually bought and retrofitted became the first Passive House certified home in Southern California. When his home was being designed to meet California building specifications, he noticed that his energy use was going to be more than what a potential solar array could offset for his roof size. So, in order to meet zero net energy standards, Gaucher pursued the passive house standard. This means high amounts of insulation, no thermal bridging, high performance windows and appropriate shading, a very tight envelope, and continuous ventilation to reduce heating and cooling loads.[108] With these extra measures the all-electric home, will produce more than it uses with only 12 solar panels on a 2,000 sf house.

Figure 42: The Perlita Passive House: the beginning, a complete to-the-stud strip, an impressive amount of insulation, and the finished product.[109]

All-Electric Product Guides

The following product guides provide an overview of electric products on the market as guidance to electrify all the end uses in single-family homes. This guide includes the basics – space heating and cooling and domestic hot water – as well as cooking, laundry drying, and accessory end uses like electric fireplaces, electric cars, electric car chargers, landscaping and pool heating. A snapshot of technical specifications as well as the retail price of each product is provided in the tables below. It is suggested to find the most up to date specifications online, exact numbers may change as newer product versions are available and costs may vary.

Heat pumps are the solution to meeting our largest energy demands in buildings. Heat pumps go by many names depending on their applications like “refrigerators,” “air conditioners,” “air source heat pumps,” and “reverse chillers.” The history of chemical refrigeration dates to the 1550’s when saltpeter baths were first used to chill wine. Ice manufacturing was a booming business by the late 1700’s, and the first true “refrigerator” was built to chill beer at the nation’s largest brewery, S. Liebmann’s Sons Brewery in Brooklyn, New York in 1870. Willis Carrier is credited with inventing the air conditioner compressor in 1902 also in Brooklyn, NY. Residential refrigerators were common by the 1920’s, and reversible air conditioners (aka “heat pumps”) came on the market in the 1950’s.

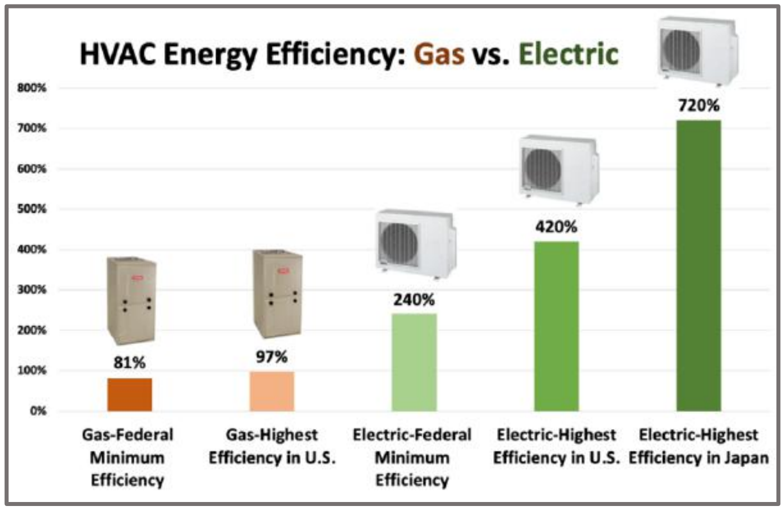


Figure 43: Air source heat pumps collect more energy from the air than they use to gather it. (Image by Redwood Energy).

Heat pumps can draw their energy from three main sources --the air, the ground and water - this energy is then moved into either air, water, or refrigerants which are cycled through the building to meet heating and cooling needs. The most common and flexible heat pumps are “air source”, like that in your refrigerator or your air conditioner. Ground source and water source are a little less common and are usually used on larger scale and use the soil or bodies of water as heat sources. Sometimes, “Air to water heat pump” refers to a two-stage process, where there is a central air source heat pump that chills or heats water, then that water circulates through the building instead of air.

Heat pumps can move heat from one substance to another so well because of the compression and expansion of fluids called refrigerants. There are many types of refrigerants, but the most common for heating and cooling are the Hydrofluorocarbons r410 and r134a which are newer versions of refrigerants like R22 but do not contribute to ozone depletion. However, the industry has been moving toward “natural” refrigerants like CO2 (R744), Ammonia (R717) and Propane (R290) that do not deplete the ozone and contribute many orders of magnitude less to global warming.

Figure 44: Fujitsu heat pump in the snow.[110]

Cold Climate Heat Pumps can now collect heat from outside air down to Arctic temperatures (-20°F)[111], where early models were limited to warmer climates. With the use of inverters, heat pumps can now accelerate their compressor pump so they can operate in below freezing temperatures. In addition to inverter technology, cold climate heat pumps have a heating element to defrost the outside unit to keep ice from forming on it.

Cold climate products are indicated by a blue highlighted cell and bold text in the tables below.

Domestic Hot Water

The following section provides electric alternatives to gas water heaters for single family applications. The most common options are individual tank water heaters and on demand water heaters. Heat pump water heaters deliver hot water at high efficiencies and typically come with electric resistance back up for peak loads.

Individual Heat Pump Water Heaters

The water heaters below all rely upon heat pumps. Typical electric water heaters that use electric resistance are not shown due to their inefficiency. The products shown collect 2.4 – 3.8 units of heat for every one unit of electricity powering the air source heat pump and provide 30-80 gallons of water storage. Some have a 4,000 BTU compressor integrated on top of the tank, others use a 12,000-36,000 BTU separate compressor outside that produces more BTUs at a higher efficiency. These models can be used as either serving one dwelling unit or can be combined in a distributed central plant to feed multiple units.

Figure 45: Jane Fisher decided to install an energy saving heat pump water heater at her investment property in Melbourne.[112]

Figure 46: A Sanden CO2 heat pump water heater compressor working outside in 5°F (-15°C) weather.[113]

<table>
<tr><th></th><th>Sanden CO2
</th><th>GE
GeoSpring
</th><th>Rheem
Prestige Hybrid
</th><th>AO Smith
Voltex Hybrid
</th><th>Bradford White
AeroTherm
</th><th>Steilbel Eltron
Accelera
</th></tr>
<tr><td>Description</td><td>Split HPWH</td><td>Low Power Heat Pump Water Heater (announced soon)</td><td>Hybrid</td><td>Hybrid</td><td>Hybrid</td><td>Hybrid</td></tr>
<tr><td>Gallons</td><td>43, 83</td><td>(40), 50, 80</td><td>50, 65, 80</td><td>50, 66, 80</td><td>50, 80</td><td>58, 80</td></tr>
<tr><td>Voltage (V)</td><td>208/230</td><td>120V, 208/240V</td><td>208/240</td><td>208/240</td><td>208/240</td><td>220/240</td></tr>
<tr><td>Dimension (in)</td><td>27.5H x 35W x 11D</td><td rowspan="9">TBA 2020</td><td>74H x 24Diam.</td><td>69H x 27Diam.</td><td>71H x 25Diam.</td><td>60H x 27Diam.</td></tr>
<tr><td>Ref. Type</td><td>R744 (CO2)</td><td>R134a</td><td>R134a</td><td>R134a</td><td>R134a</td></tr>
<tr><td>Ambient Temp. Range (F)</td><td>-20 – 110 (cold climate)</td><td>37 – 145</td><td>45 - 109</td><td>35 – 120</td><td>42 – 108 / 6 – 42</td></tr>
<tr><td>Power (W)</td><td></td><td></td><td>4,500</td><td>550 – 4,500</td><td>650 - 1500</td></tr>
<tr><td>Max Amps (A)</td><td>13</td><td>15 – 30</td><td>30</td><td>30</td><td>15</td></tr>
<tr><td>Heating (BTUh)</td><td>15,400</td><td>4,200</td><td>-</td><td>-</td><td>5,800</td></tr>
<tr><td>Heating (COP)</td><td>5.0</td><td>-</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>Energy Factor</td><td>3.09 – 3.84</td><td>3.55 – 3.70</td><td>3.06 – 3.61</td><td>2.40 – 3.39</td><td>3.05 – 3.39</td></tr>
<tr><td>Price ($)</td><td>$ 3,400-3,500</td><td>$ 1,200-1,400-1,700</td><td>$ 1,400-1,500-1,900</td><td>$ 1,400-1,600</td><td>$ 2,300-2,600</td></tr>
</table>

Small Demand and Low Voltage Applications (120V)

Electric resistance water heaters are best used where hot water is needed in small amounts or when a project requires strict voltage limitations. Tankless water heaters can be used in a bathroom, or a 120sf tiny house that has no room for a 50-gallon tank or that is not sharing water system with other tiny homes. Electric resistance uses 2-4 times more energy than a heat pump but can be the right size for the right demand and they are helpful when there is no 220V electricity available. The 2 to 7-gallon tanks on the market use 120V, while anything larger uses 240V for more heating capability.

	Stiebel Eltron Mini-E Series 	**Stiebel Eltron** SHC Series 	**Bosch Tronic** 3000 Series 
Description	Tankless, Point of use	Mini tank, Point of use	Mini tank, Point of use
Gallons	0.21 (gpm)	6, 4, 2.7	7, 4, 2.7
Voltage (V)	120/110	110/120	120
Dimension (in)	6H x 7W x 3D	20H x 15W x 15D	17H x 17W x 14D
Power (W)	1,800	1,300	1,440
Max Amps (A)	15	11.3	12
Heating (COP)	0.98	0.98	0.98
Price ($)	$ 160	$ 230	$ 210

Heating, Ventilation and Air Conditioning

The following guide gives an overview of heating and cooling electric systems that are used in single-family buildings. The sample of products shown includes central heat pumps, mini-split heat pumps, packaged terminal heat pumps and vertical terminal heat pumps.

Resources for Finding HVAC Products

Air-Conditioning, Heating and Refrigeration Institute (AHRI) Directory of Certified Product Performance
https://www.ahridirectory.org/Search/SearchHome

Northeast Energy Efficiency Partnerships (NEEA) - Cold Climate Air Source Heat Pump List
https://neep-ashp-prod.herokuapp.com/#!/product_list/

Energy Star Product Finder
https://www.energystar.gov/productfinder/

Large Application Heat Pumps (240V – 480V)

Larger application heat pumps are most typically used for central air and water systems. The Mitsubishi PWFY and the Spacepak products shown below can be applied to a variety of applications. They are air to water heat pumps so they can be used for radiant heating, hot water preheating, warming pools, collecting waste heating from a cooling process, and other applications. They can also be stacked in series to get extra capacity for larger building applications. The Mitsubishi City Multi series is a variable refrigerant flow heating and cooling system just like mini-splits but bigger. The compressor sits outside and lines of refrigerant run through the home with fan units that blow air over the lines to provide heating and cooling to the space.

	Stiebel Eltron WPL(15,20,25) (AS, ACS) 	**Arctic** Heat Pump 020A 	**Spacepak** Solstice (Extreme) 	**Mitsubishi** City Multi S-Series PUMY(P36,P48)NHMU 	**Mitsubishi** PWFY Series 
Description	Air-to-water heat pump outdoor unit, combined DHW and HVAC	Hydronic Heating, Domestic Hot Water, Pools and hot tubs	Air to water, hydronic heating and cooling	Air source heat pump	Air to Water Can be paired with City Multi Series
Voltage (V)	230	220-240V	230	460	208 / 230
Dimension (in) (HxWxD)	-	33 x 18.5 x 45	4.0 x 4.5 x 1.5	-	31 x 17 x 11
Ref. Type	R410a	R410a	R410a	R410a	R134a
Ambient Temp. Range (H/C) (F)	**-4 (Air) – 140 (Water)**	**-15**	**-8 – 105 (cold climate)**	**0 – 60 (cold climate)**	**-13- 90 / 23 – 115 (cold climate)**
Power (W)	1,090 -7,530	2,710 - 3,000	3,880 – 5,963	12,000 – 16,100	15
Max Amps (A)	7.9 - 30	15	23.5 - 31	-	25
Heating Cap. (BTUh)	8,525 – 46,500	35,826	42,240 – 66,480	42,000 – 66,000	36,000 – 72,000
Cooling Cap. (BTUh)	7,330 – 58,000	25,600	40,000	36,000 – 60,000	39,000 – 79,800
Heating (COP)	1.85-5.09	3.14	2.12 – 3.26	3.30 – 3.90	-
Cooling (COP)	2.39-3.76	2.5	2.43	3.25 – 4.16	-
Price ($)		$ 4,060	$ 6,900	-	-

Mini-Splits (240V)

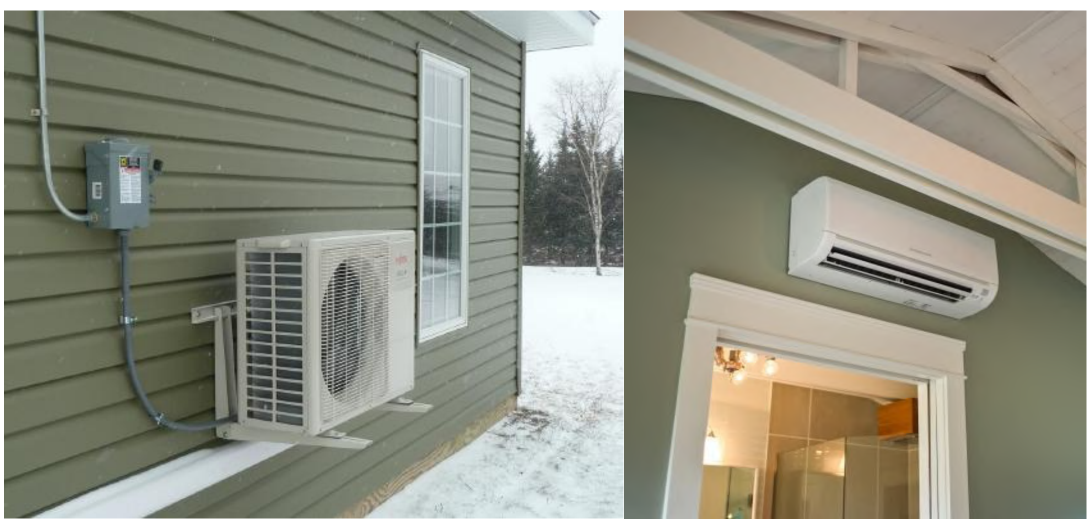


Figure 47: An example of a ductless mini-split heat pump outdoor compressor unit[114] and indoor fan unit[115].

Mini split systems are comprised of a compressor outside the building and a fan inside the building. Mini split systems can also have many fans inside the building, commonly referred to as multi split systems, where one outside unit serves multiple fans or zones inside the building. Having multiple zones in the building allows for a more controlled, versatile arrangement of installations and temperature settings compared to a typical split HVAC system. Zones can be at different temperature settings while still being served by one outside unit. Multi/mini split systems can be ductless (where refrigerant lines move heat around the building) or they can have mini ducts where air is moved around the building. Having no ducts prevents duct leakage energy losses but having many refrigerant lines running through the building can cause problems if they leak. In general, mini/multi split systems are more efficient than typical HVAC systems. No ducting also has an advantage because of reduced fan loads.

	Fujitsu Halcyon Series 	**Mitsubishi** HyperCore FH50 	**LG** LMU18CHV 	**Gree** TERRA 	**Chilltrix** CX34 
Description	2 – 4 indoor units, XLTH models		2 zones	1 zone	Air to Water Heat Pump
Dimension (ft) (HxWxD)	39 x 38 x 14	36 x 9 x 12	24 x 24 x 12	27 x 35 x 14.3	3.1 x 3.6 x 1.4
Ref. Type	R410a	R410a	R410a	R410a	R410a
Ambient Temp. Range (H/C) (F)	**-15 – 75 / 14 – 115 (cold climate)**	**-15 / 115 (cold climate)**	**-4 – 64 F / 14 – 118 C (cold climate)**	5 – 75 / 5 - 118	-4 – 122 (cold climate)
Power (W)	1,330 – 2,700	1,380 – 1,480	1,300 – 2,660	200 – 1,000	360 - 2,360
Max Amps (A)	16.4 - 26	13.6	11.09	7.0	15
Heating Cap. (BTUh)	22,000 – 36,400	10,900 – 30,700	22,000	2,000 – 11,000	4,000-33,800
Cooling Cap. (BTUh)	18,000 – 35,200	8,500 – 26,600	17,000	9,000	4,000 – 30,000
Heating (COP)	3.60 – 4.04	3.07 - 4.85	3.0	3.2 - 3.8	3.92
Cooling (COP)	3.52 – 3.60	3.31 – 5.10		3.66 – 4.25	6.75
Price ($)	$ 1,600	-	$ 1,240	$ 900	$ 4,300

Ducted Minisplit Heat Pumps

	Senville SENA/18HF/ID 	**Carrier** 38MGQC183 	**Gree** MULTI18HP230V1BO 	**Mitsubishi** MXZ3C24NAHZ2 
Indoor Unit Dimension (in)	34.7 x 28.5 x 8.27	36.2 x 8.3 x 25.0	35.4 x 7.9 x 24.2	37.4 x 16.4
Outdoor Unit Dimension (in)	33.3 x 14.3 x 27.64	33.3 x 27.6 x 12.6	38.0 x 27.6 x 15.6	41.3 x 37.4 x 13.0
Ref. Type	R410A	R410A	R410A	R410A
Ambient Temp. Range (F)	**-22 (cold climate)**	4 - 122	**-4 – 118 (cold climate)**	**-13 – 115 (cold climate)**
Max Amps (A)	25	20	25	40
Heating Cap. (BTUh)	18,000	18,500	19,000	25,000
Cooling Cap. (BTUh)	17,000	17,500	18,000	22,000
Heating (COP)	3.0	2.8	2.6	2.6
Cooling (COP)	5.9	5.7	4.1	4.5
Per Indoor Unit Piping Length (ft)	98	98	65	82
Price for Outdoor Unit ($)	$ 1,400 (includes 50 ft refrigerant line)	$ 1,760 (no refrigerant lines)	$ 1,930 (no indoor units or refrigerant lines)	$ 3,110 (no ducting or refrigerant lines)

	Pioneer YN012GMFI22RPD	**Mitsubishi** MXZ2C20NAHZ2	**LG** LD127HV4	**Fujitsu** 12RLFCD
				
Indoor Unit Dim. (in)	27.5 x 17.8 x 7.9	16.4 x 37.4	7.5 x 27.6 x 38.3	7.8 x 27.6 x 24.4
Outdoor Unit Dim. (in) (HxWxD)	27.5 x 17.8 x 7.9	41.3 x 37.4 x 13.0	33.0 x 21.5 x 12.6	24.5 x 31.1 x 11.3
Ref. Type	R410A	R410A	R410A	R410A
Ambient Temp Range (F)	**-13 – 122 (cold climate)**	**-13 – 115 (cold climate)**	**-4 – 118 (cold climate)**	**-5 – 115 (cold climate)**
Max Amps (A)	15	29.5	15	15
Heating Cap. (BTUh)	12,000	13,700	16,000	16,000
Cooling Cap. (BTUh)	12,000	18,000	11,600	12,000
Heating (COP)	11.5	9.5	10.5	11.5
Cooling (COP)	21.5	15	19.6	20
Per Indoor Unit Piping Length (ft)	82	82	66	66
Price for Outdoor Unit	$ 1,050 (includes refrigerant lines)	$ 2,780 (no refrigerant lines)	$ 2,050 (no refrigerant lines)	$ 1,660 (no refrigerant lines)

The Cost of Mini-Split Systems

The following section gives an overview of the costs associated with ductless heat pumps. The first table show the pricing for leading manufacturers for single-head and multi-head systems. Below is an interview with Jonathan Moscatello of the Heat Pump Store in Portland, Oregon, a description of the mark up on heat pump prices, and a description of costs for short ducted or mini-duct systems. Minisplit cost information is courtesy of Jonathan Moscatello of the Heat Pump Water Heater Store in Portland, Oregon.

Single-Head					
	9k BTU	**12k BTU**	**15k BTU**	**18k BTU**	**24k BTU**
Daikin	$4,200	$4,450	$5,000	n/a	n/a
LG	$4,400	$4,500	$4,800	$5,000	$5,200
Panasonic	$4,400	$4,600	$5,800	n/a	n/a
Fujitsu	$4,600	$4,800	$5,100	$5,700	$5,900
Mitsubishi	$4,900	$5,400	$5,800	$6,100	$6,400

Multi-Head				
	2 Zone	**3 Zone**	**4 Zone**	**5 Zone**
Daikin	$6,800[a]	$8,500[a]	$10,500[a]	n/a
LG	$6,200[a]	$7,800[a]	$9,400[a]	n/a
Panasonic	$6,200	$7,100	$8,100	$10,200
Fujitsu	$7,400[a]	$9,000[a]	$11,200[a]	$12,500
Mitsubishi	$8,500[a]	$10,500[a]	$12,900[a]	$15,500[a]

- Multifamily installations, where the labor is onsite all day and able to accomplish 4-6 installations, cost ~30% less
- Indoor units involving simple installation method, the outdoor and indoor unit sharing an exterior wall with 15' of interconnecting line sets and electrical
- Indoor unit is of the high-wall mounted type
- $500 increase per indoor unit is typical when the refrigerant line set length increases to 25' or longer to cover the additional labor and materials to add refrigerant to the system
- Up to $1,000 increase per indoor unit when the indoor unit is located on an interior wall, necessitating that the refrigerant line set be installed through an attic or crawlspace
- [a] Indicates "cold climate" model

Interview on Heat Pump Pricing with Jonathan Moscatello of the Heat Pump Store in Portland, Oregon

The following section summarizes the correspondence between Sean Armstrong of Redwood Energy and Jonathan Moscatello of the Heat Pump Store in Portland, Oregon. Jonathan had just returned from China, where he has direct import relationships for ductless mini-split heat pumps, with decades in the business.

A lot of people are not clear about how heat pumps are sold in the market. Could you explain to us?

Sure, it's not that complicated, but it's true that most people aren't exactly sure how it works. The process starts with the Manufacturer--they sell to Distributors. I don't know what the Manufacturer pricing is, and generally it's not possible to buy directly from the Manufacturer. When you are a Contractor who wants to install a heat pump, you buy from the Distributor. Then you sell it the Client, and at each step there is a markup of 25 to 50%.

If the contractor is fair and the labor is well-trained and fairly paid, what is the total cost of installing a ductless mini split with one fan coil?

The lowest cost for a 1 ton, with one fan coil, that you'll see where someone can stay in business is $4,200 to do an individual house. For a 2-ton, $5,500 is the lowest price you would see. In multifamily, where a contractor could have a property owner or a general paying for electrical AND where the installers could be onsite for a week (operating in a highly productive installation - 4 to 6 systems per day) - we regularly see $3,000 per system installation—about 30% less than an individual home. I did this business for a number of years, and contractors take a lot of risks and work hard in difficult work environments.

How much does it cost to buy just the materials for a 1-ton mini split heat pump?

What the Contractor pays from the Distributor is $800 to $1,400 a ton, with the average around $1,200. Mitsubishi is an example of a $1,400 per ton product, while $1,200 a ton is found in products from Daikin, Panasonic, LG, and Aurora. What the contractor charges a client is 40% to 50% more than their price. So $800-$1400 to the Contractor is $1100--$2100 to the Client, plus labor and additional materials.

Can you tell us about the cost for buying and installing a heat pump with multi-zone system, where there are 2-5 fan coils scattered in different rooms?

Well, if a 1-ton mini-split cost about $1,200, a 1.5 ton with two fan coils cost $1,600 to $1,800, and a 2-ton compressor with three fan coils cost about $3,200. Of course, this is marked up 40%-50% when sold to a client. The inside fan coils each cost about $450, while the compressor goes up in cost at about $800/ton.

What about the Labor costs for installing a ductless mini split?

Labor is a constrained resource. For a full-time job, labor is paid $25 an hour to $35 an hour, and sold to the client at $42 an hour to $60 an hour. To install a 1-ton heat pump by market leading contractors takes 2 to 4 hours, and for contractors who do not typically install ductless systems - that same work takes 4 to 8 hours because of contractor inefficiency, likely due to their relative inexperience.

Cost Breakdown of Overhead Minisplit Heat Pumps

Pricing of ductless heat pump installations vary widely due in large part to the margin goals of the installation company involved. Typically, installation companies fall into three margin categories based on attributes relating to their overhead and size. Below is an example of marked up costs and the breakdown of overhead pricing.

Table 1: Example of "Marked Up Costs" Pricing Model of Simple Installation of a Single Zone System.

Labor	$300 (5 hours x $60 per hour)
Equipment	40% of sale price or $1,200 (and up to $2,400 depending on equipment)
Materials	Approximately 5% of sale, roughly $300
Subcontractor (electrical)	$600-1000
Permits	$100-150
Subtotal	$2,500 /.6 (40% Margin)
Total	$4,166

Table 2: Cost breakdown of how overhead costs for mini split heat pumps.

Margin Categories	Attributes related to Overhead and Size	Gross Profit
Low	Staff size: less than 5 Business location: Work out of home Years in business: "New Entrants", less than 5. Type of work: Almost all installation sales. Annual revenue: under $1.5 million.	25-35%
Medium	Staff size: 5 to 15 Business location: Small shop with limited office space. Years in business: 5 to 15. Type of work: installation, with limited service and maintenance sales. Annual revenues: $1.5 to $3.5 million.	35-45%
High	Staff size: 15 to 50+ Business location: Professional office space, warehouse, loading dock. Years in business: over 15 years, often multi-generational. Type of work: Commercial and residential, installation, sales and service. Annual revenue: over $3.5 million	>45%

Short Ducted (aka Mini-Ducted), Low Static Heat Pump Installation Costs

The pricing of so-called short run ducted split systems varies widely, due in large part to the unique requirements of each installation. In general, the cost of equipment (only) used in short-run ducted split systems is comparable in cost to ductless split systems (when the comparing the cost of equipment per unit of BTU of output). The variability in installed cost comes from the labor and materials needed to install a ductwork system. In most installations, the ductwork system is newly installed instead of being reused from an older installation. In this way, the new ductwork system will satisfy the engineering requirements of the equipment and the space being conditioned.

The labor and materials involved in ductwork, insulation, air sealing and grills/registers should not be discounted. When ductwork is installed in attics and crawlspaces, the labor costs can increase when conditions make these spaces difficult to work in. When ductwork is installed within the conditioned space by attaching to the existing ceiling, there will be additional costs to install a "drop ceiling" to hide the ductwork. Many installers have found that when pricing short-run ducted systems, the ductwork materials can cost much more than the wholesale cost of the equipment.

Given all the variability in labor and materials required to install a short-run ducted split system, most contractors price each installation as the opportunity arises. They do this by estimating the labor hours required in the prospective job, ask their distribution partner to provide a quote for all the materials and equipment needed, ask subcontractors for a quote, and finally enter all these costs into a spreadsheet whereby they apply a mark-up to satisfy their companies margin goals.

This method of marking up all the unique costs has many benefits to the installation company: it provides the installers with a materials and equipment list, and the company with a proforma model that they can manage by within should the company win the job. However, this pricing system doesn't provide government and utility programs with any simple pricing model to use.

Ducted Heat Pumps (240V)

Ducted heat pump and air conditioning systems are usually driven by a central compressor that pumps air through ducts to vents in different areas throughout the building. These systems pair an outdoor air to air heat pump unit with an indoor evaporator coil and air handler unit.

	Goodman GSZC180481C 	**Pioneer** DYC036GMFI18RT 	**Daikin** DZ14SA0483 	**York** YZH02412C 	**Carrier** Infinity 25VNA036A003 
Dimension (in) (WxDxH)	35 x 35 x 38	29 × 29 x 24	29 x 29 x 34	42 x 23 x 34	35 x 28 x 44
Ref. Type	R410a	R410a	R410a	R410a	R410a
Ambient Temp. Range (H/C) (F)	**-5 – 115 (cold climate)**	5-118	**-10 – 65 (cold climate)**	**-10 – 115 (cold climate)**	**-4 – 68 (cold climate)**
Power (W)	4,830 – 4,840	2200	3300	2,500 – 3,412	1,050 – 1,240
Heating Cap. (BTUh)	22,000 – 59,500	33,600	44,500	18,000 - 59,000	25,000
Cooling Cap. (BTUh)	23,000 – 56,500	34,600	45,000	19,000 – 58,000	36,000
Heating (COP)	1.47 – 6.77	2.8	3.95	2 -4	2.3 - 4
Cooling (COP)	3.66 – 4.10	5.1	4.1	4 – 4.4	4 – 4.4
Price ($)	$ 2,500	$ 3,000	$ 2,000	$ 2,000	$ 6,800

Vertical Terminal Air Conditioner

VTAC's are a type of ducted heat pump like the products listed above except they sit vertically in a closest and provide heating and cooling to a space without having visible units hanging on the wall or outside the building.

	Amana AVH123H 25A,35A,50A 	**GE** AZ75H (09,12,18)EAC 	**Islandaire** EZ (09,12,15,18) 	**LG** LVN361HV4 
Voltage (V)	208 / 230	208 / 230 or 265	208/230	230
Dimension (in) (HxWxD)	32 x 23 x 23	32 x 23 x 23	31 x 23 x 23	48 ¾ x 18 x 21 1/4
Ref. Type	R410a	-	-	410a
Ambient Temp. Range (H/C) (F)	*Indoor: 115 max *Outdoor: 80 max	25 Degrees switches to electric resistance heat	*Indoor: 115 max *Outdoor: 80 max	Indoor: 57-81 Outdoor: -4 - 118
Power (W)	2,100 – 5,000	-	620 - 1950	6,100
Max Amps (A)	15 - 29	-	12 – 24	32
Heating Cap. (BTUh)	7,000 – 17,000	8,400 – 15,700	8,400 – 15,500	40,000
Cooling Cap. (BTUh)	-	9,500 – 17,500	8,900 – 17,500	36,000
Heating (COP)	3.0	2.5 – 3.6	3.0	2.9
Cooling (COP)	-	2.9 – 3.1	3.0	3.2
Price ($)	$ 1,900	$ 1,800-1,900-2,400	-	$ 1,700

Packaged Terminal Air Conditioners and Heat Pumps

PTACs and PTHPs are all-in-one HVAC units that are used to heat and cool 1 to 3 rooms. These types of units are ductless and can be hung from a wall and ducted through (e.g. Innova, Sakura), mounted in a window or placed into a cutout in the wall. Packaged units deliver heating or cooling directly to the space, avoiding energy losses from ductwork but introducing potential leaks around the product if it is not sealed.

(120V) Packaged Terminal Heat Pumps

	Innova (8,10,10DC,12DC, 12DC Elect) 	**Frigidaire** FFRH0822Q1 	**Friedrich** YS10N10C 	**Gree** 26TTW09HP115V1A 
Description	Twin ducts through the wall, dehumidification, ER back-up	Noise 50.2 dB (low) Heat pump with ER	Heat pump model – no back up ER	Heat pump model with ER + dehumidification
Voltage (V)	230	115	115	115
Dimension (in)	1.8H x 3.3W x 0.5D	15H X 22W x 23D	15H x 25W x 29D	15H x 26W x 16D
Ref. Type	R410a	R410a	R410a	R410a
Ambient Temp. Range (H/C) (F)	**14 – 64 / 23 – 109 (cold climate)**	**-5 – 75 / 5 – 110 (cold climate)**	40 – 115	29 - 125
Power (W)	545 – 730	780 – 1,290	917 - 978	830 – 1,150
Heating Cap. (BTUh)	0.7 – 3.05 kw @-7 (0.79 – 1.11) kw	3,500 (ER) 7,000 (HP)	8,000	3,900 (ER) 6,600 (HP)
Cooling Cap. (BTUh)	0.8 – 3.1 kw	8,000	10,000	9,000
Heating (COP)	2.84 – 3.22	2.63	2.6	3
Cooling (COP)	3.12 – 3.28	2.87	3.19	2.87
Price ($)	-	$ 770	$ 750	$ 840

*ER = electric resistance, HP = heat pump

(240V) Packaged Terminal Heat Pumps

	Amana (AH093E35AX, AH123G35AX, AH183E35AX) 	**Friedrich** (YS12N33C, YM18N34C, YL2N35C) 	**Gree** (W07HP230V1A, W09HP230V1A, W12HP230V1A) 	**LG** (LP073HDUC, LP093HDUC1, LP123HDUC1, LP153HDUC) 
Description	Heat pump model	Heat pump model – no back up ER	Heat pump model with ER + dehumidification	Smaller inverter - cold climate ready for tiny homes
Voltage (V)	208/230	230/208	230	208/230
Dimension (in)	16H x 26W x 27D	20H x 28W x 35D	15H x 26W x 16D	16H x 42W x 21D in
Ref. Type	R410a	R410a	R410a	R410a
Ambient Temp. Range (H/C) (F)	61 - 86	60 - 115	29 - 125	**-4 - 75 / 54 – 115 (cold climate)**
Power (W)	920 – 3,680	1,100 – 2,400	680 – 3,500	2,300 - 4,700
Amps (A)	4.2 – 16.0	4.9 – 19.5	3.0 – 15.2	15,20, 30-amp cord
Heating Cap. (BTUh)	10,700 – 9,000 (ER) 8,100 – 16,00 (HP)	11,300 – 22,000	3,900 – 11,000 (ER) 6,600 – 11,400 (HP)	1,250 - 13,400
Cooling Cap. (BTUh)	9,200 – 17,300	12,000 – 24,00	7,200 – 11,700	7,100 – 14,900
Heating (COP)	2.6 - 2.9	2.6 -2.7	2.9 – 3.1	3.1 – 3.5
Cooling (COP)	2.63 – 2.93	3.02 – 3.19	2.81 – 3.11	3.28 – 3.90
Price ($)	$ 1,250	$ 1,700-2,100	$ 930	$ 840

Electric Vehicles

In California the greatest percentage of smog and greenhouse gas emissions in the state come from fuel burning vehicles. Electric vehicles create no direct air pollution, rely on a grid in California that is 50% renewables, use just 1/3rd the energy of gas engines. Electric vehicles are the key to reducing the carbon impact of driving, and their battery systems can provide resilience to your home by running critical electric loads when the power goes out—see below discussion of Vehicle to Home charging. The below section provides a list of 2019 model electric vehicles with their specifications, provided by Menlo Spark.[2] For inspiration is also an example of a 1946 pickup truck electrification.

Manufacturer	BMW	BMW	Chevrolet	Fiat	Honda	Hyundai	Hyundai
Model	i3	i3s	Bolt EV	2019 500e	Clarity Electric	Ioniq EV	Kona Electric
Passengers	4	4	5	4	5	5	5
Doors	4	4	4	2	4	4	4
MSRP (from)	$44,450	$47,650	$36,620	$33,460	$33,400	$30,315	$36,950
Car Body	Hatchback	Hatchback	Wagon	Hatchback	Sedan	Compact Hatcback	SUV
Range	153 miles	153 miles	238 miles	84 miles	89 miles	124 miles	258 miles
MPGe City / Highway	124/102	124/102	128/110	121/103	126/103	150/122	132/108
MPGe Combined	118 miles	112 miles	128 miles	112 miles	114	136	120
Battery Capacity	42 kWh	42 kWh	60 kWh	24 kWh	25.5 kWh	28 kWh	64 kWh
Horsepower	170	181	200	111	161	118	201
0-60 Speed	7.2 seconds	6.8 seconds	6.5 seconds	8.4 seconds	7.7 seconds	10.2 seconds	6.4 seconds
Top Speed	93 mph	99 mph	91 mph	85 mph	110 mph	102.5 mph	103.8 mph
Charge Time (120 volt)	13-16 hours (3-4 miles/hour)	13-16 hours (3-4 miles/hour)	4 miles/hour	24 hours	19 hours	24 hours	60 hours
Charge Time (240 volt)	4.9 hours (26 miles/hour)	4.9 hours (26 miles/hour)	25 miles/hour	4 hours	3.5 hours	4 hours 25 min	9 hours 35 min
Quick Charge Option	80% in 42 min	80% in 42 min	90 miles in 30 min	not available	80% in 30 min	80% in 23 min	80% in 54 min
Max Cargo	15.1 - 36.9 cu ft (depending on seat configuration)	15.1 - 36.9 cu ft (depending on seat configuration)	16.9 cu ft (56.6 cu ft max volume)	7 cu ft	14.3 cu ft	23 cu ft	19.2 cu ft (45.8 cu ft with seat space)

Kia	Kia	Nissan	Nissan	Tesla	Tesla	Tesla	Jaguar	Smart
Soul EV	Niro EV	Leaf S	Leaf Plus	Model S	Model X	Model 3 (standard range)	I-pace	ForTwo EQ
5	5	5	5	5	7	5	5	2
4	4	4	4	4	4	4	5	2
$33,950	$38,500	$29,990	$37,445	$79,990	$84,990	$38,990	$69,500	$26,740
Hatchback	Hatchback	Hatchback	Hatchback	Hatchback	SUV	Sedan	SUV	Hatchback
111 miles	239 miles	151 miles	226 miles	370 miles	325 miles	240 miles	234 miles	58 miles
124/93	123/102	124/99	114/94	101/102	83/89	138/124	80/72	124/94
108	112	112	104	102	85	131	76	108
30 kWh	64 kWh	40 kWh	62 kWh	75-100 kWh	75 - 100kWh	50 kWh	90 kWh	17.6 kWh
109	201	147	214	518	518	258	394	80
11.5 seconds	6.5	7.4 seconds	6.8 seconds	2.4 seconds	4.4 seconds	5.3 seconds	4.5 seconds	11.4 seconds
90 mph	108 mph	90 mph	106 mph	163 mph	155 mph	140 mph	124 mph	81 mph
33 hours	60 hours		2.5 days	79 - 96 hours	72 - 89 hours	3 miles/hour	2+ days	13 hours
5 hours	9-10 hours	8 hours	11 hours	8.8 - 10.7 hours	7.75 - 9.66 hours	12 hours	13 hours	3 hours
80% in 30 min	80% in 1 hour	80% in 40 min	80% in 45 minutes	130 miles in 15 minutes	115 miles in 15 minutes	180 miles in 15 minutes	80% in 45 - 85 minutes	-
18.8 cu ft (49.5 cu ft with seat space)	19 cu ft	23.6 cu ft (30.0 with rear seats down)	23.6 cu ft (30.0 with rear seats down)	30 cu ft	88 cu ft	15 cu ft	25.3 cu ft	9 cu ft

[2] Go to www.menlospark.org to learn more.

Volkswagon	Porsche	Tesla	Tesla	Kia	Volkswagon	Rivian	BMW	Byton	Mercedes	Ford	Volvo
e-Golf	**Taycan**	**Model Y**	**Roadster**	**Soul EV**	**ID3**	**R1T Truck**	**iX3**	**M Byte**	**EQC**	**Mustang Electric SUV**	**XC40 Electric**
5		7	4	5	5	5	5	5	5	5	5
5		4	2	4	4	4	4	4	4	4	4
$31,895	**$150,900**	**$48,000**	**$200,000**	**$17,490**	**<$30,000**	**$69,000**	**$56,000**	**$45,000**	**$70,000**	**$40,000**	
Hatchback		SUV	Sedan	Hatchback	Hatchback	Truck	SUV	SUV	Hatchback		SUV
125 miles	280 miles	300 miles	620 miles	243 miles	205 miles	230-400 miles	250 miles	224 miles	200 miles	300 miles	
126/111									80/70		
119									75		
35.8 kWh	83.7 kWh	kwh	200 kwh	64 kwh	45, 58, 77 kwh	105, 135, 180	75 kwh	71 and 95 kwh	80 kWh	100 kWh	
134	616		"almost 1000"	147		700		270	402		
8.5 seconds	3.0 seconds	3.5 seconds	1.9 seconds	8.3 seconds	8.0 seconds	3 seconds	5 seconds		4.9 seconds		
93 mph	161 mph	150 mph	over 250 mph	114 mph	99 mph	125 mph	124 mph		112 mph		
26 hours		26 hours		59 hours							
6 hours	9 hours	8 hours		< 5 hours							
80% in an hour	80% in 21 minutes				80% in 44 minutes		80% in 28 minutes	80% in 30 minutes	10%-80% in 40 minutes		
23 cu ft		66 cu ft		24.2 cu ft	35.3 cu ft	24.2 cu ft					

1946 Ford Pickup Truck Gas to Electric Conversion

Story from Amy Dryden of Franklin Energy

"Commuting by bike in Oakland and inhaling the exhaust of a 1950s Chevy made it crystal clear I could not put our fixer-up dream truck, a classic 1946 Ford pickup, back on the road with a gas engine. The climate friendly solution? Electrify it! After a couple of years of puttering and painting, we have an all-electric antique with a maximum cruising and parading range of 30 miles—plenty enough. The Motor went from 400lb flat V-8 engine with 160lbs of fuel, 560 total, to a 60lb motor with 300lbs of batteries—360lbs, 200lbs lighter than before. Level 1 charging is accessed under gas tank cap and Level 2 at front of truck. The battery design includes handmade battery racks, hood latch, and weatherproofing -- a labor of love that can share the road with bicyclists."

Figure 48: Electrified 1946 Fork Pickup truck.[116]

Vehicle to Home and Vehicle to Grid Charging

Vehicle-to-Home Charging was developed in Japan after the 2011 tsunami closed the nation's nuclear power plants. Nissan pioneered the concept of **"Vehicle-to-Home" (V2H)** which uses a charger to isolate a home from the grid and draws on the vehicle's battery power for its electrical needs when utility grid power is not available. T Nissan estimates that its all-electric Leaf can power an average home in Japan for two to four days without solar,[117] and with rooftop solar the system is sufficient for off grid living most of the year.

The term **"Vehicle-to-Grid" (V2G)** describes the situation where the car's excess electricity is provided to the utility grid. The International Energy Agency estimated that in 2030 there will be 130 million electric vehicles on the road, which will contain almost ten times the amount of energy storage needed for a renewably powered grid.[118]

One company, Ossiaco Inc., has developed dcbel™, North America's first Vehicle to Home electric vehicle charger, which also operates as a solar inverter and home energy management system.[119] Ossiaco's energy management system gives homeowners a view of the electricity flowing between the electric vehicle(s), solar panels, stationary batteries and the grid. Other companies such as Nuvve and Fermata Energy are currently working with EV manufacturers to place V2H/V2G capabilities in the vehicles themselves. The release date of these in-vehicle products are dependent on OEM integration and certification timelines.

Vehicle to Building (V2B) Chargers

Honda	Mitsubishi	Nissan
		

Vehicle to Grid (V2G) Chargers

Nissan	Endesa	OVO	Princeton Power Systems
			

Energy Management Systems

This section focuses on products that can monitor energy in the home as well as control it. The smart panels and smart circuit splitters shown below can avoid power upgrades by prioritizing different electric loads, like pausing EV charging, allowing the dryer to run, the restarting EV charging. Other products allow scheduling loads, connecting with solar PV, and home battery charging optimization, among many other features. See above for the Ossiaco product.

Whole House Panels

Thermolec[120] DCC-9	**Span**[121]	**Eaton**[122] Pow-R-Command	**Koben**[123] GENIUS Smart Panel
			
• Connects EV charger to panel to manage energy loads • real-time reading of total power consumption of electrical panel; if panel exceeds 80% rated load, then temporarily de-energizes the vehicle charger. Reconnects automatically when other loads allow	• Replaces traditional electrical panel in the home • Can monitor and control electrical usage at the circuit level • Puts control into the hands of the homeowner with intuitive smartphone app • Plug in play solution for rooftop solar, battery storage and EV charging	• Control lighting and plug loads with time and space occupancy schedules to maximize energy savings • 15 A, 20 A and 30 A configurations in single- and two-pole models suitable for voltage systems up to 480V • Can add expansion panels up to 168 controllable circuit breakers	• Replaces old electrical panel and allows home to become "Smart Grid" ready • integrates EV Charging, Solar, Battery Storage, Generator and your utility whether you are planning for the new energy era or have already installed your new energy technology.

Subpanels

Eaton[124] Energy Management Circuit Breaker (EMCB) 	• Programmable breakers to prioritize loads in power outage scenarios, control shedding of lighting and plug loads • Remote cycling of HVAC, WH, to offset energy demands and save money • Can connect with solar monitoring, home networks and demand response • In the future could simplify EV charging	**Lumin**[125] Smart Panel 	• real time balancing of battery use and charging • manages renewable generation, energy use and storage • Dynamic switching of loads based on time of use rates • off grid mode sheds non-critical loads and islands • can pair with batteries to create an integrated energy management system, removes requirement of a subpanel or protected loads panel • programmable schedules to automatically control loads • Max size: (x6) 60A, (x6) 30A

Smart Circuit Splitters

BSA Electronics[126] Dryer Buddy 	• plugs into a 30A circuit (common dryer plug) and allows for vehicle charging while dryer is not in use. • It has a digital display that shows the draw of each load.	**Neo Charge**[127] Smart Splitter 	• Level 2 charging without rewiring or panel upgrade • Pauses EV charging for other large loads then resumes charging • Also have a "dual car" option – charge two EVS at half power, or fully charge one then the other

Electric Battery Storage

Battery storage provides resiliency during disasters and shorter power outages, can be sold to utilities as a resource for their grid management, or allow you to go off-grid in more rural regions. Solar electric panels, with rare examples of residential wind turbines and micro hydro dams, are paired with batteries and often an energy management system to make it easy for occupants to live within their energy budget. An innovation discussed above, vehicle to home charging, gives the possibility of delivering more power to a home with an electric car, a needed alternative to the too-common practice of using gas generators to meet loads during the least sunny parts of a winter. Owners and builders can include the full solar plus energy storage when they build or remodel, or pre-wire for the capability to add these systems later. The Clean Coalition has developed the "Electrification and Community Microgrid Ready" (ECMR) document to guide the easy and inexpensive installation of prewiring for grid interactive solar plus energy storage systems.[128]

Battery Systems

Battery systems have dropped 87% in price over the last decade, from $1100/kWh in 2010 to $156/kWh in 2019, helping explain the rapid international growth in affordable electric vehicles and home batteries.[129] Home batteries can be modest and scaled to a reduced set of power needs during outages, or large and able to take your home "off--grid" altogether. Home batteries are now so common that you can pick up a Yeti battery power pack as an alternative to a home generator at Home Depot.[130] Sunshine is roughly 1/5th as strong on Winter Solstice as Summer Solstice, which makes powering a home off grid with just solar panels a challenge without significant efficiency efforts, resorting to fossil fuel generators, or getting power from a grid-charged electric car (see below Vehicle to Home section). Home batteries are made with a variety of chemicals and minerals, but leading products currently all incorporate Lithium, which is highly reactive, light-weight and relatively common, found on every continent in rocks of volcanic origin and mined heavily in Chile, Australia and China.

	DC Batteries			AC Batteries		
DC Battery	**Blue Planet** Energy	**LG** RESU 10H	**SimpliPhi** Power 2.4	**Tesla** Powerwall	**Panasonic** EVDC-105	**Sonnen** EcoLinx
						
Capacity (kWh)	8, 12, 16	9.3	2.4	13.5 (up to 135)	5.7, 11.4, 17.1	10, 12, 14, 16, 18, 20
Round Trip Eff.	98%	94.5%	98.0%	98%	89%	86%
Chemistry	Lithium Iron Phosphate	Lithium-ion	Lithium Iron Phosphate	Lithium Nickel Manganese Cobalt Oxide	Lithium-ion	Lithium Iron Phosphate

Electric Cooking

The LED "flame" of a Samsung induction stove (at left) is an example of how intuitive it can be to transition to cleaner, faster and safer all-electric cooking. Gas stoves cause unhealthy levels of Nitrous Oxides that would be illegal if it were from a gas power plant. After just twenty minutes of cooking and a sunny window, a kitchen can have actual smog and trigger asthma and lung ailments. Gas cooking appliances are 25-40% efficient, while electric cooking appliances are 70-95% efficient, meaning electric kitchens use 1/3rd as much energy and require only 1/3rd as much cooling. Using electric appliances avoids the construction costs and costs to run extra gas venting equipment. In addition to being more efficient, induction cooking appliances are faster, provide more temperature control and cause less kitchen fires than gas or radiant electric stoves.[131] Below are products that facilitate both retrofits and new construction with high performance cooking equipment. Countertop products do not require any installation retrofits and plug into a standard wall outlet. Drop-in cooktops, on the other hand, are installed into a cut-out of the countertop and hard-wired to a 120V or 240V outlet. Electric cooking comes in a variety of technologies, standard electric, glass top radiant electric, and induction.

Consumer Reports Prefers Induction

Top 6 of 8 Ranges for 2020 were electric, top 2 were Induction

Fuel	Model	Consumer Reports Rating	Cost
Induction	GE Profile PHS930SLSS	86	$2,432
Induction	Kenmore Elite 95073	84	$1,525
Gas	LG Signature LUTD4919SN	84	$3,000
Induction	LG LSE4617ST	82	$2,500
Induction	LG LSE4616ST	82	$1,700
Smoothtop	Whirlpool WGE745c0FS	82	$1,000
Gas	Samsung NY58J9850WS	81	$2,725
Induction	Frigidaire Gallery FGIF3036TF	81	$1,035

Figure 49: Consumer Reports prefer induction, the top 6 of 8 ranges for 2020 were induction.

Glass Top Radiant Range (Less than $550)

Make/Model	**Amana** AER6303MFS 	**Whirlpool** WFE320M0ES 	**Frigidaire** FFEF3052TS 	**GE Appliances** JBS60DKBB 
Wattage	1,800	3,000	100-3,000	3,100
Price	$450	$500	$500	$510
Oven space (cu. ft)	4.8	4.8	4.9	5.3

Glass Top Radiant Range (Greater than $500) (9600W, 240V using a 40amp circuit)

Make/Model	**Kenmore** 92612 	**Frigidaire** Gallery FGIF3036TF 	**Samsung** NE58K9560WS 	**LG** LSSE3026ST 	**Bosch** 800 Series 
Price	$700	$ 1,075	$1,400	$1,700	$2,500

Slide-In Induction Range (9600W, 240V using a 40amp circuit)

Make/Model	**Frigidaire** Gallery FGIS3065PF	**Bertazzoni** Professional PROF304INSROT	**GE** Profile PHS930SLSS	**Café** CHS985SELSS	**Fisher & Paykel** Series 9 OR36SCI6R1
					
Price	$2,760	$4990	$2,440	$3,420	$7499 (50 amp)

Single Burner Countertop Induction (1800W, 120V and using a 15amp circuit)

Make/ Model	**Avantco** ICBTM-20 Light Duty	**Avantco** IC1800 Heavy Duty	**Eurodib** C1823	**NuWave** PIC Platinum	**Vollrath** Mirage Cadet 59300
					
Price	$50	$120	$160	$200	$270
Temp. Range	140°F - 460°F	140°F - 460°F	150°F - 450°F	100°F-575°F	100°F - 400°F

Single Burner Drop-In Induction (1800W, 120V and using a 15amp circuit)

Make/Model	**True Induction** TI-1B	**Avantco** DC1800	**Adcraft** IND-DR120V	**Spring** SM-651R	**Bon Chef** 12083
					
Price	$140	$170	$190	$440	$500
Temp. Range	150°F-450°F	140°F-464°F	Up to 464°F	145°F-185°F	150°F-450°F

Double Burner Countertop Induction (1800W, 120V and using a 15amp circuit)

Make/Model	**Eurodib** S2F1	**Duxtop** 9620LS	**Inducto**	**Avantco** IC18DB	**NuWave** PIC Double
					
Price	$200	$190	$150	$150	$200
Temp. Range	150°F -450°F	140°F -460°F	176°F -460°F	140°F -460°F	100°F – 575°F

Multi Burner Induction Stovetops (9600W, 240V using a 40amp circuit)

Make/Model	**Empava** IDC-36 36”	**KitchenAid** KCES556 HSS 36”	**Bosch** NETP068SUC 30”	**Samsung** NZ36K7880UG 36”	**Frigidaire** FPIC3677RF 36"
					
Price	$900	$1,300	$1,300	$2,300	$2,500

Electric Laundry Dryers

As our building systems become more efficient, the energy use of appliances becomes more apparent. Laundry loads can sometimes be the largest load, so ensuring that the most efficient equipment is used is important. More surprising may be that the first cause of high consumption is convenience—households with in-unit laundry run twice as many loads as households with only access to a central laundromat.[132] While washing machines and clothes dryers use about the same amount of motor energy per load, boiling the water out of wet laundry uses 81% of all the energy in an average laundry load in 2010,[133] assuming one is using a standard ~30% efficient gas dryer, rather than a ~250% efficient electric heat pump dryer.

Energy Star, a program led by the US Environmental Protection Agency (EPA), aims to inform consumers and businesses on how to cut down on operating costs by listing and ranking energy efficient products[134]. Until recently, both residential and commercial/coin-operated clothes drying machines were excluded from the list of Energy Star rated appliances because of their consistently high-power demand between all products available on the market. Innovative technologies like moisture sensors, heat pump drying and condensation drying have led to a rise in the availability of residential-grade Energy Star rated dryers.[135] Some examples of residential-grade Energy Star washers and dryers are shown below: standard, combined condensing washer and dryers and heat pump dryers.

Standard Electric Dryers

Energy Star ranked Laundry Dryers use a variety of strategies to better eliminate water from clothes, such as fans, humidity sensors and heating technologies. Electric resistance dryers require a vent, while condensing dryers do not. The following products use electric resistance to dry clothes.

	Samsung DV45K76E	LG DLE1501	GE GTD65EB	Maytag MED3500W	Whirlpool WED75HEFW	Electrolux EFME417
						
Price	$400	$450	$500	$650	$650	$700
Drum Capacity (cu. ft)	7.4	7.4	7.4	7.4	7.4	8.0
kWh/year	607	607	608	608	608	608

Combination Condensing Washer & Dryer

Condensing Washer/Dryer combine both space and energy efficiency and are ventless—laundry water instead goes down the drain. They are most common in retrofitted apartments in Europe, and run on 120V outlets, using as much energy as a hair dryer on medium and stresses fabrics less. After washing the clothes, the same machine dries the laundry using a condenser.
A laundry cycle, from loading to unloading, takes 2-3 hours.

"Oh my God, it's a dream come true. Set it and forget it is best thing since sliced bread… we throw our laundry in when we go to bed and wake up to a fresh ready batch. I'll never go back to the disappointment of opening up to wet laundry." – ***Sierra Martinez, a satisfied condensing dryer user***

	Magic Chef MCSCWD20W3 	**Haier** HLC1700AXW 	**Summit** SPWD2201SS 	**Deco** DC4400CV 	**LG** WM3488HW 	**Whirlpool** WFC8090GX 
Price	$720	$1,000	$1,000	$1,200	$1,300	$1,500
kWh/year	85 kWh/year	65kWh/year	65kWh/year	96kWh/year	120 kWh/year	180kWh/year
Drum Capacity (cu. ft.)	-	2.0	2.0	3.5	2.3	2.8
Volts/Amps	-	120V/10A	115V/12A	110V/15A	120V/15A	240V/30A

Heat Pump Dryers

Heat pump dryers are also ventless but maintain a higher temperature than a condensing dryer and lower than that of electric resistance, and therefore dry clothing at a rate between the two. Note that smaller drum sizes hold less clothes, and consequently take less time to dry.

	Samsung DV22N685H 	**Blomberg** DHP24400W 	**Kenmore** Elite 81783 	**Beko** HPD24412W 	**Whirlpool** WED9290FC 	**Miele** TWI180WP 
Price	$1,000	$1,100	$1,100	$1,300	$1,700	$1,900
kWh/year	145kWh/year	149kWh/year	-	149kWh/year	531kWh/year	133kWh/year
Drum Capacity (cu. ft.)	4.0	4.1	7.4	4.1	7.4	4.1
Cycle Time (min)	60	46	-	46	75	35

Electric Landscaping



Powerful electric landscaping equipment uses lightweight batteries and efficient motors that are half as loud as gas equivalents, produce no local air pollution, and are easier to maintain. Modern batteries now offer comparable length of operating time to gas tanks, and batteries are safer to store than gasoline, oil and rags.

	Blower	**Chain Saw**	**Pole Pruner**	**Trimmer**	**Hedge Trimmer**	
STIHL[136]	BGA 45 ($130) 	MSA 120C ($350) 	HTA 65 ($660) 	FSA 56 ($150) 	HAS 56 ($280) 	RMA 460 ($420) 
Husqvarna[137]	320iB ($230) 	120i ($260) 	536LiP4 ($400) 	336LiLC ($250) 	115iHD55 ($230) 	LE121P ($450) 
RYOBI[138]	RY40411 ($170) 	RY40530 ($200) 	P4361 ($140) 	P2080 ($130) 	P2660 ($130) 	RY48110 ($2700) 

*Prices will vary – visit retailers for the most current cost information.

Electric Fireplaces

Swirling, fire-like mist lit with LEDs and a log fire's worth of heat: these are the new electric fireplaces. They're less expensive than gas stoves, safer, cleaner, and plug into a normal 120V wall outlet. They provide heat in a more efficient and smokeless way – a 3,000-Watt electric fireplace can warm spaces up to 800 feet and look great doing it. From convincing to dramatic, electric fireplaces are ready to match the tastes of any owner. Outdoor electric space heaters are similarly versatile and ready to replace headache-inducing propane burners

	Modern Flames LFV2-12015-SH 	**Amantii** Panorama XT 88 	**Dimplex** IgniteXL 100” 
Size (inches)	134.75" W x 11.5" x 22"	88" W x 30" x 12"	100.63" x 15.63" x 5.88"
Install Type	Recessed Wall Insert	Built-In, Indoor/Outdoor	Recessed Wall Insert
Price	$5000	$3400	$2900
Voltage/Amps	110V / 15A	120V / 12.5A	120V or 240V / 15A dedicated
Heat Output	5000 BTU	4800 BTU	8530 BTU
	Touchstone Sideline 45” 	**Touchstone** Sideline Elite 60 	**Amantii** Zero Clearance 
Size (inches)	45" W x 21.4" x 5.5"	59.75” W x 19.25” x 5.5”	30.25” W x 26.75” x 10.13”
Install Type	Recessed Wall-Mounted	Recessed Wall-Mounted	Built-In
Price	$500	$1200	$1200
Voltage/Amps	120V / 11+ A	120V / 12.5 A	120V / 12.5A
Heat Output	5118 BTU	750/1500W	1500W
	Puraflame Western Series EF45D-FGF 	**Dimplex** Revillusion 25” 	**Dimplex** Linwood, GDS33HL-1310RG 
Size (inches)	35" W x 8.8" x 27"	25 5⁄8" W x 19" x 13"	65.3" W x 50" x 10.8"
Install Type	Fireplace Insert	Plug-In, Insert	Mantle-Set
Price	$350	$500	$1350
Voltage/Amps	120V / 12.5A	120V / 12.5A	120V / 12.5 A
Heat Output	5000 BTU/hr, 1500W	5118 BTU	5118 BTU/hr, 1500W

Electric Barbeques

Electric BBQ grills heat up much more quickly than charcoal or gas grills and distribute heat more evenly over the entire grill area. With no charcoal fumes and no propane gas burning, they are safer and can be used indoors in inclement weather. Electric grills are cheaper to operate, clean up easier, need little maintenance and can also be used in high rise buildings where typical combustion grills are not allowed due to fire code restrictions.

	Electri Chef The Safire 115V 	**Electri Chef** Emerald 24" 	**Electri Chef** Ruby 32" Built-in 	**Kenyon** B70590 	**Kenyon** B70060 
Cooking Surface (sq. in.)	224	336	448	115	115
Price	$700	$3,600	$3,500	$1200	$650
Voltage	115V	220V	220V	120V	120V

	Weber 55020001 	**Char-Broil** 804142 	**Kuma** Profile 150 	**Americana** 9359U8.181 	**Maverick** E-50S 
Cooking Surface (sq. in.)	280	240	145	200	173
Price	$320	$200	$220	$245	$180
Voltage	120V	120V	110	120V	120V

	Fire Magic E250S-1Z1E-P6 	**Char-Broil** Patio Bistro 240 	**Weber** Q 2400 	**Meco** Easy Street 	**Kenyon** Floridian 
Cooking Surface (sq. in.)	240	240	280	200	240
Price	$1400	$190	$246	$248	$710
Type	Patio Post	Mobile	Mobile	Mobile	Built-in
Voltage/ Amp	120V / 20A	120V / 15A	120V / 13A	120V / 12.5A	240V / 5.5A
Heat Output	1800W	1750W	1560W	1500W	1300W

Electrically Heated Swimming Pools and Hot Tubs

Utilizing a heat pump can be an efficient way to address the energy demands of heating a pool. To size a heat pump pool heater, assume the heat pump must produce 4 to 6 BTUs/Hour for each gallon of heated pool water, with higher productivity needed when the incoming water is colder in the winter. In addition, solar thermal can an efficient way to heat pools or supplement pool heating.

Figure 50: Pacific Companies Zero Net Energy apartment complexes built in 2014 with heat pumps for the hot tub and swimming pools. (left King Station Apartments, King City, CA and right Belle Vista Senior Apartments, Lakeport, CA.)

Pool and Hot Tub Heat Pumps

Listed briefly below are heat pump specifically designed for pools and cost $2400-$4200 for 90,000 BTUs/Hr to 140,000 BTUs/Hr of heating, about 1/10th the price of a similar-sized solar thermal pool heater. Heat pumps significantly reduce construction costs compared to solar thermal while providing the same ~80% offset of energy use by using ambient heat in the air, while working all 12 months of a year, compared to 5 to 8 months of renewable pool heating with solar thermal panels.

	Hayward HeatPro Electric Heater	**Pentair** UltraTemp 110 Heat Pump	**PHNIX**	**AquaCal HeatWave** SuperQuiet SQ120R
				
Price	$3,000	$3,270	Patented technology in China – price unavailable	$4,200
Heating Capacity (BTU)	140,000	108,000	117,000	110,000
Heating COP	6.0	5.8	12.4	5.5
Temp. Range	50-104°F	45-104°F	50-110°F	55-100°F

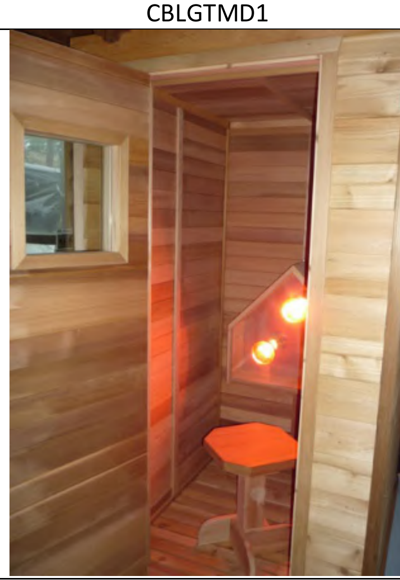
Electric Sauna Heaters

The following section offers alternatives to gas powered saunas: electric resistance and infrared. Electric resistance saunas offer an experience just like traditional saunas – electric resistance coils warm up rocks so that water can be poured over them to create steam. Infrared saunas are very different from traditional steam saunas. This style of products uses low intensity infrared lights to increase body temperature, which is better for the lifetime of the wood rooms and creates an enjoyable experience comparable to steam.

240V: Electric Resistance, heater unit only

Model	**Finlandia** FLB30-ESH	**Finlandia** FLB80-ESH	**Harvia** HPC-HTR61	**Harvia** HNC-HTR105	**Polar** HNVR 45SC
Picture					
Capacity (kW)	3.0	8.0	6.8	10.5	4.5
Price	$627.00	$782.00	$1,065.00	$2,040.00	$914.00

120V: Infrared, Full Room

Model	**JNH Lifestyles** MG217HB	**Cedarbrook** CBLGTMD1	**Radiant Saunas** BSA2409
Picture			
Price	$1,100	$2,040	$1,400

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