



*Sean Armstrong's House in Arcata, CA*



*The Heat Pump Store in Portland, Oregon*



*Jon and Kelly's Electrified Home in Cleveland, OH*

## A Pocket Guide to All-Electric *Retrofits* of Single-Family Homes



*A Big Chill Retro Induction Range*



*A Water Vapor Fireplace by Nero Fire Design*



*A NeoCharge Smart Circuit Splitter*

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Check out Redwood Energy's Commercial, Multifamily and Single-Family Home Zero Carbon All-Electric Guides at their website: <https://redwoodenergy.net/research/>

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# Table of Contents

- INTRODUCTION ..... 4
- THE BUSINESS OF ELECTRIFYING HOMES..... 5
  - CLEAN ENERGY COMPANY HIGHLIGHT: BLOCPOWER..... 5
  - A LIST OF CALIFORNIA CONTRACTORS WHO PERFORM BUILDING ELECTRIFICATION..... 5
  - ELECTRIFICATION TECHNICAL ASSISTANCE PROGRAM ..... 5
- THE BENEFITS OF AN ALL-ELECTRIC HOME RETROFIT ..... 6
  - HEALTH ..... 6
  - SAFETY ..... 6
  - WEALTH ..... 6
  - COMFORT ..... 6
  - CLIMATE ..... 6
- DESIGN FACTORS WHEN ELECTRIFYING YOUR HOME ..... 7
- ELECTRIFYING ON A TIGHT BUDGET ..... 8
  - PLUG-IN COOKTOPS ..... 8
  - PLUG-IN COOKING APPLIANCES..... 8
  - PLUG-IN SPACE HEATERS..... 9
  - WATER HEATERS ..... 9
- WHAT DOES IT COST TO ELECTRIFY YOUR ENTIRE HOME? ..... 10
  - WHAT DOES IT COST TO ELECTRIFY YOUR HOME’S KITCHEN? ..... 11
  - WHAT DOES IT COST TO ELECTRIFY YOUR HOME’S LAUNDRY DRYER?..... 12
  - WHAT DOES IT COST TO ELECTRIFY YOUR HOME’S WATER HEATING? ..... 13
  - WHAT DOES IT COST TO ELECTRIFY YOUR SPACE HEATING? ..... 14
- THE “WATT DIET” - AVOID A NEW ELECTRICAL PANEL AND REDUCE WIRING ..... 18
  - A 100-AMP PANEL HAS ENOUGH POWER FOR COMPLETE ELECTRIFICATION OF A 3,000 SQUARE FOOT HOME..... 18
  - HOW INSULATING AND AIR SEALING REDUCE THE NECESSARY SPACE HEATING POWER..... 20
  - POWER TRADE-OFFS FOR THE WATT DIET ..... 21
- SIMPLE “BOX-SWAPPING” RETROFITS..... 24
  - BOX SWAPPING THE HEATING, VENTILATION AND AIR CONDITIONING (HVAC) SYSTEM..... 24
  - BOX SWAPPING A WATER HEATER..... 25
  - BOX SWAPPING A STOVE ..... 27
  - BOX SWAPPING A GAS CLOTHES DRYER ..... 27
  - BOX SWAPPING A GAS GENERATOR ..... 28
  - BOX SWAPPING A GAS GENERATOR WITH AN ELECTRIC CAR ..... 29
- ELECTRIC RETROFIT INCENTIVES AND REBATES ..... 30
- CASE STUDIES OF COMPLETE ELECTRIFICATION RETROFITS ..... 31
  - 1890 RANCH, RAVENNA, OH ..... 31



BEN AND SARA SHALVA’S HOME, BALTIMORE, MD .....	31
STEVE AND LISA SCHMIDT’S HOME, LOS ALTOS, CA: ELECTRIFYING WITHOUT INCREASING THE POWER SUPPLY .....	32
WEI-TAI KWOK’S HOME, LAFAYETTE, CA.....	33
PETER AND MARGARET DARBY’S HOME IN HAMILTON, NY .....	33
CAMPUS CENTER FOR APPROPRIATE TECHNOLOGY (CCAT) AT HUMBOLDT STATE UNIVERSITY, ARCATA, CA .....	34
PERLITA PASSIVE HOUSE, LOS ANGELES, CA .....	34
JON AND KELLY’S HOME, CLEVELAND HEIGHTS, OH .....	35
COLONIAL SOLAR HOUSE, URBANA, IL.....	35
THE BINDLEY CARBON NEUTRAL RENOVATION, HOLDERNESS, NH .....	36
ROSS RESIDENCE, AMHERST, MA.....	36
ERIKA REINHARDT’S FAMILY RESIDENCE, BAY AREA, CA .....	37
MODEST MANOR, SAN FRANCISCO, CA.....	37
<b>ADDITIONAL ALL-ELECTRIC CASE STUDIES .....</b>	<b>39</b>
<b>ALL-ELECTRIC PRODUCT GUIDES .....</b>	<b>40</b>
ELECTRIC COOKING .....	41
KITCHEN HOODS (LOW SOUND, HIGH AIR FLOW) .....	45
HEATING, VENTILATION AND AIR CONDITIONING .....	46
DOMESTIC HOT WATER .....	60
ELECTRIC LAUNDRY DRYERS.....	64
HEAT PUMPS FOR SWIMMING POOLS AND HOT TUBS .....	66
ELECTRIC FIREPLACES.....	68
ELECTRIC SAUNA HEATERS .....	69
ELECTRIC OUTDOOR HEATERS.....	70
ELECTRIC BARBEQUES .....	71
ELECTRIC LANDSCAPING .....	72
ELECTRIC SNOWBLOWERS .....	74
ENERGY MANAGEMENT SYSTEMS.....	75
SOLAR PHOTOVOLTAIC PANELS .....	77
SOLAR INVERTERS AND SOLAR ARRAY SIZING.....	78
ELECTRIC BATTERY STORAGE .....	80
LOW-COST RESILIENCE.....	81
ELECTRIC VEHICLE SUPPLY EQUIPMENT (EVSE) .....	83
VEHICLE TO HOME AND VEHICLE TO GRID CHARGING.....	84
ELECTRIC VEHICLES.....	85
ELECTRIC SNOWMOBILES .....	87
<b>REFERENCES.....</b>	<b>88</b>

# Product Guide Quick Reference



Electric Cooking	Heat Pump Water Heaters	Electric Dryers	Heat Pump Space Heating and Cooling	Electric Vehicles	Energy Management Systems	Solar PV Panels	Back-up Batteries
p. 41	p. 60	p. 64	p. 46	p. 85	p. 75	p. 78	p. 80



Heat Pump Pool and Spa Heating	Electric Saunas	Electric Fireplaces	Electric Outdoor Heating	Electric Landscaping	Electric Barbeques
p. 66	p. 69	p. 68	p. 70	p. 72	p. 71

## Introduction

Welcome! This booklet is intended to be a simple “how-to” guide to help homeowners, home renters, utilities and policy makers who want to replace existing gas appliances with efficient electric alternatives, many of which are simple and require no home modifications (e.g., countertop induction ranges, condensing washer/dryers, portable space conditioning heat pumps). This booklet has three sections, the first to explain the costs, benefits and strategies for electrifying a home, the second section is lessons learned from case studies of retrofitted homes, and the third section is an extensive product guide to help choose your electrification appliances.

You are not alone in this project of electrifying your home! And it can be affordable and easy—see our discussion of the Watt Diet and how one can avoid electrical upgrades. Since 1993 Americans have been progressively using more electric appliances, and 1 in 4 homes nationwide are now all-electric<sup>1</sup>: electric stoves are now 61% of annual sales in the U.S.<sup>2</sup> and electric laundry dryers are 88% of annual sales,<sup>3</sup> while the majority of homes built since 1950 have been built with electric water heaters, and since 1970 the majority of homes have been built with electric space heating.<sup>4</sup> Electrifying existing buildings, often paired with low-cost solar power, is a growing industry nation-wide.

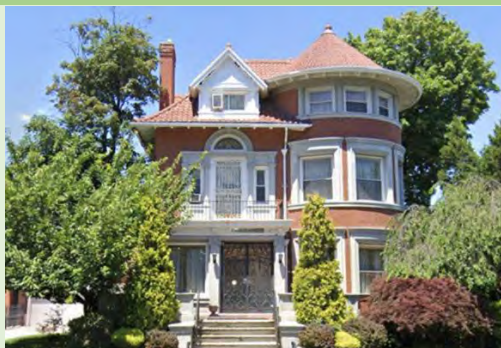
This guide was written to accelerate this existing trend to use electric appliances because the scientific consensus is that fossil fuels burned in homes and buildings in the U.S. are contributing to at least 28% of climate change<sup>5</sup>, with natural gas leaks upstream of our appliances responsible for a substantial amount of additional global climate change.<sup>6</sup> As our grid power grows cleaner by including more clean, renewable energy, a concerted effort is underway globally to use cleaner grid electricity to replace polluting fossil fuel appliances.<sup>7</sup>

# The Business of Electrifying Homes

This section is just a sampling of the thousands of clean energy companies that are making buildings better for people and the planet with heat pumps, electric appliances, and solar arrays.

## *Clean Energy Company Highlight: BlocPower*

Cornerstone Baptist Church, a historic Black Church in Brooklyn, NY, owns a landmark parsonage on President Street. Until 2020 the Reverend Lawrence Aker and his family suffered from a common fuel oil (aka diesel) boiler problem: dramatic overheating, requiring AC use even in the winter.<sup>8</sup> The solution, a heat pump system, was designed, financed and installed by **BlocPower**, founded by CEO Donnel Baird. Like a growing number of businesses nation-wide, BlocPower installs efficient heat pumps, often paired with solar arrays, to dramatically increase comfort, reduce energy bills, and stop contributing to smog and asthma. BlocPower's CEO, Donnel Baird, [speaks movingly](#) about how in 2012 he channeled his opposition to racial unfairness into a business model for clean energy that benefitted communities of color. As a Black founder, Donnel was turned down 200 times before any venture firms were willing to back his vision, but BlocPower is now funded by some of the world's largest investors.<sup>9</sup> Other contractors who were early adopters of heat pump + solar retrofits in the U.S. include Building Doctors in Los Angeles, Electrify My Home and emeraldECO serving the San Francisco Bay Area, Energy Smart Ohio, and The Heat Pump Store in Oregon.



**Figure 1: Cornerstone Baptist Parsonage and BlocPower CEO Donnel Baird.**

## *A List of California Contractors who Perform Building Electrification*

When electrifying your home, it is important to find a skilled and knowledgeable contractor. The Clean Energy Connection has put together an online searchable database of California contractors with positive customer references and at least 2.5 Stars on Yelp that is free to use for all.<sup>10</sup> The contractors are experts in heat pump water heaters, heat pumps for space heating, electric appliances, electric vehicle chargers, solar arrays, and battery storage. In addition, [The Switch is On](#) has a contractor look up tool on their website.

CLEAN ENERGY CONNECTION

OUR PROCESS ABOUT US RESOURCES FIND A CONTRACTOR

FIND A CONTRACTOR

Contractor Name Category Services Offered

Zipcode Distance from Zip SEARCH CLEAR ALL

## *Electrification Technical Assistance Program*

An example for utilities nation-wide, Silicon Valley Clean Energy has free technical experts on-call in their Electrification Technical Assistance Program. Any architect, engineer, builder or developer is eligible for all-electric design assistance that would usually cost thousands of dollars, for buildings of any type or size. The reports are then shared for free to accelerate community competence in all-electric design.<sup>11</sup>

Electrification Technical Assistance Program

TRC DNV-GL

Interest Form

Thank you for your interest in designing a low carbon building!

# The Benefits of an All-Electric Home Retrofit

## Health



Children in homes with gas stoves are 42% more likely to develop asthma<sup>12</sup> than those with electric stoves and asthma kills ten Americans a day<sup>13</sup> and costs on average \$3,266 per year for medications. The health impacts of air pollution from fossil fuels fall disproportionately on people of color - African Americans are three times more likely to suffer from asthma than the general population.<sup>14</sup> In addition, home chefs using gas stoves have twice the risk of lung and heart disease, and are three times as likely to need asthma medication as people cooking on electric stoves.<sup>15</sup> These health impacts are tied to the many pollutants released when gas is burned, such as nitrogen dioxide, cancer-causing formaldehyde and acetaldehyde, and ultra-fine particulates.<sup>16</sup> Gas stoves and other gas appliances are also dangerous due to carbon monoxide, an odorless gas that kills 500 people a year in the U.S. and sends 15,000 people to the emergency room.<sup>17</sup>

## Safety



Electric cooktops, water heating, space heating and clothes drying all present lower fire risks and lower explosion risks than their gas fired alternatives. Just having electricity as the one utility service eliminates the risk of having both gas and electric services – and reduces the dangers that come with a pressurized and combustible network of fuel going to homes. Nationwide since 2010 the natural gas system has caused 236 public safety incidents and \$198 million in damages per year.<sup>18</sup> 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).<sup>19</sup> Additionally, construction risks are reduced by not having the threat of hitting gas pipelines when digging trenches, doing road work, etc. For instance, in Ohio construction workers hit gas mainlines 410 times in 2015 alone.<sup>20</sup>

## Wealth



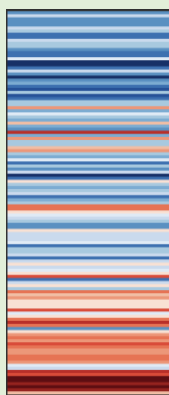
Utility bills for efficient all-electric homes can be up to \$800/year less than for comparable homes using fossil fuels due to recent rapid gains in electric appliance efficiency and the low cost electricity available in most of the U.S.<sup>21,22</sup> Utility bills are the #1 use of payday loans in the U.S., with annual interest rates as high as 400% and an average repayment period of five months.<sup>23</sup> Replacing gas appliances with electric appliances also allows homeowners to lower bills with solar power—in the U.S. the average repayment period is 8 years<sup>24</sup> into the warranted 25 year lifespan of the solar panels and inverter, producing a net profit three times greater than the installation cost. (e.g. producing power at 1/3 the average retail electric rate.)

## Comfort



Heating your home with a heat pump can dramatically improve comfort due to quieter and more consistent warmth. While a furnace continuously turns off-and-on, blowing heat noisily through the ductwork at high speed, a heat pump fan stays always on continuously at a lower, quieter speed and evenly heats your home. Cooking with electric equipment can also be much more comfortable, especially during warm weather since electric stoves produce half as much waste heat in the kitchen. In 2020, Consumer Reports ranked the top 8 stoves, and the best stoves were electric induction stoves, ranked #1-2, #4-5, and #8, with a smooth top electric resistance stove at #6. Cooking with electricity means one has access to the best stoves on the market—the fastest, easiest to clean and most controllable stoves made.

## Climate



A recent analysis found big climate and clean air benefits from replacing gas appliances with electric in every state across the U.S.<sup>25</sup> This is due to two key factors: Heat pump appliances are three to four times more efficient than gas, and also because grid electricity is sourced with more renewable energy every year. The global community of cities, states and nations have identified building electrification as the fastest, least expensive, and most likely to succeed solution to the building sector's 28% of global greenhouse gases.<sup>26</sup> One of the largest sources of greenhouse gases is not from burning gas, but instead its leaking Methane ("natural gas"), which is an exceptionally strong greenhouse gas. Methane leaks at each stage--fracking, storage, delivery piping and in the appliance--and "about 25% of the human-made global warming we're experiencing is caused by methane emissions,"<sup>27</sup> according to the Environmental Defense Fund. Differently put, eliminating gas service to one's home doubles the positive impact of not burning gas.



# Design Factors When Electrifying Your Home

This guide organizes the discussion of retrofits in two main categories, “box swapping” when only the appliances themselves are upgraded and there’s enough power to replace a gas appliance with an electric one, and “deep retrofits” when additional building shell improvements, duct and air sealing improvements are combined for added comfort. Either of these types of retrofits can be done quickly, or phased in over the course of years, depending on the owner’s needs. Below are questions to consider, when considering electric retrofits for your home.

	<b>Up-Front Costs and available funds</b>	What is your budget for electric retrofit? While there can be savings from electrifying all at once, most people can only afford retrofitting in steps. Consider the most pressing needs first, like an old water heater that may soon give out; and the least expensive options, like a two-burner induction range which can plug into existing 120V wiring and provides immediate health benefits of avoided combustion in your kitchen.
	<b>Utility Bills</b>	Do you want lower utility bills? Heat pump space heaters are at least four times more efficient than comparable gas models and can now operate at –30°F. Avoiding electric resistance, which is not very efficient, and the use heat pumps for laundry drying, hot water and space heating will keep electric bills low.
	<b>Solar Power</b>	Would you like to generate your own clean power? Solar power in the U.S. has an average payback of 8 years <sup>28</sup> , and the cost of solar panels has dropped by 89% since 2006 <sup>29</sup> . Electrifying your home and installing a solar array can eliminate your utility bills.
	<b>Location</b>	What climate are you in, and how old is your home? Weather, existing insulation and regional building practices (e.g., radiators vs. ducts) will influence what type and size of heating and cooling equipment best meets your needs.
	<b>Power Supply</b>	How much power is supplied to your home? Electrifying all the gas loads in an older home may require more power from the utility, but you can likely avoid this by choosing power-efficient appliances and using power sharing plugs ( <i>See the <b>Home Watt Diet</b> Section for more information</i> ). Many modern homes already have enough power to support an all-electric transition, especially if you already have air conditioning—that same power can be used for space heating in the winter.
	<b>Electric Vehicle Charging</b>	How much power do you need for electric vehicles? Investing in efficiency in the home can free-up capacity for faster charging and more car chargers. Also, power-sharing chargers can eliminate the need for upgrades, by sharing a circuit with things like laundry, car charging automatically resumes when the dryer is finished.
	<b>Product Choice</b>	What do you value? As you review the product guides in this booklet, note the differences in efficiency, aesthetics, cleanability, cost, and comfort.
	<b>Health and Environment</b>	How concerned are you about indoor air pollution and health? Gas stove release pollution that contributes to asthma and other respiratory and cardiac health impacts, but they use relatively little gas compared to a furnace or water heater that “only” pollutes outdoor air. If you are going to electrify your home in steps, consider your health when prioritizing retrofits.



# Electrifying on a Tight Budget

Many of the co-authors of this booklet have limited means--we have young families, or graduated from college with student loans, or are living in rental homes, and found these electrification options out of necessity, but we use them because they're satisfying and effective. All of these products allow DIY/self-installation, which cuts total costs by half or more. For example, a **comfortable, high-quality electric lifestyle can cost less than \$2000** with a True Induction range (\$140), an Oster oven (\$160), a Whynter portable heat pump (\$440) and a DIY "retrofit ready" heat pump water heater from Rheem (\$1200).

## Plug-In Cooktops

These 120V cooktops can plug into any outlet in your home. Countertop resistance ranges cost less than \$20 for one burner and \$30 for two burners. A countertop induction range can cost as little as \$50 for one burner and \$140 for two burners.

			
Brentwood resistance plate	Brentwood resistance plates	IKEA induction	DrinkPod True Induction
<b>\$18</b>	<b>\$30</b>	<b>\$50</b>	<b>\$140</b>





## Plug-In Cooking Appliances

These 120V models can plug into any outlet in your home and can fry, stew, bake, roast, rotisserie, steam and air fry, using the versatility and controllability of electricity to provide more services than larger, standard ovens. The largest models can accommodate a small-medium size turkey.

				
Crockpot 2 Quart Insulated Slow Cooker	Instant Pot 3 Quart Insulated Multi-Function Cooker	Presto Stainless Steel Electric Wok	Elite Combination Oven/Griddle/ Steamer	Oster French Doors, XL Capacity Convection Oven ( <i>Staff Favorite</i> )
<b>\$10</b>	<b>\$60</b>	<b>\$80</b>	<b>\$40</b>	<b>\$160</b>
Insulated cookware uses 1/4 <sup>th</sup> as much electricity to get the same job done, regardless of whether it's slow or fast.	This insulated multi-function vessel can slowly make yogurt, pressure cook beans and rice, steam vegetables and stew meats.	Electric woks can steam, bake and stir-fry, spreading heat evenly through the wok.	Many small oven appliances are multi-function—this one is unusual in having a griddle/steamer on top.	This oven can bake a modest Thanksgiving turkey and is controllable for high performance baking.

## Plug-In Space Heaters

An electric resistance heater is silent and low-cost for a bedroom, but a heat pump produces 2-4 times as much heat with the same amount of electricity, enough to heat and cool multiple rooms.

			
Electric Resistance Heaters	Toshiba Mobile Heat Pump	Mr. Cool DIY-12-HP-115B Ductless Minisplit	Ephoca HPAC 2.0 Through-wall heat pump via two 6" ducts
<b>\$50+</b>	<b>\$440</b>	<b>\$1450</b>	<b>\$2000</b>
For one room. Enclosed heating elements are safest.	10,000 BTUs/Hr is enough for a big living room down to ~20F. 120V, audible fan, for a warmer climate.	12,000 BTUs/Hr heat pump works down to 5F. 120V, quiet, designed for self-installation, but needs dedicated circuit. <i>(Note that the ugly fan coil box sits outside, just like an A/C unit.)</i>	10,000 BTUs/Hr heat pump works down to -5F, has supplemental resistance heating. 120V, can plug into any circuit (doesn't require a dedicated circuit), quiet, designed for self-installation.

## Water Heaters

An electric resistance model can come in smaller sizes and fits the smallest construction budgets. Heat pump water heaters start at 40 gallons (although 20-gallon models in Eurasia are coming to the U.S. market), cost 3x as much to buy but use only 1/3<sup>rd</sup> as much electricity as a resistance water heater.

			
Bosch ES8 Resistance 7 Gallons	Reliance Resistance 19 Gallons	Rheem Resistance 30 Gallons	120V Rheem Heat Pump 40 Gallons
<b>\$215</b>	<b>\$380</b>	<b>\$380</b>	<b>\$1200</b>
This 7-gallon tank is right sized for a <b>single</b> 6-8 min showers with a 1.5gpm showerhead. 120V wiring, but 1440W still requires a dedicated circuit. 17" square, 15" deep, stores at up to 145F to provide a longer shower.	This 19-gallon tank is right sized for <b>two</b> consecutive 6-8 min showers with a 1.5gpm showerhead. 18" round, 24" high. 120V, but 1650W element requires a dedicated circuit.	This 30-gallon tank is right sized for <b>three</b> consecutive 6-8 min showers with a 1.5gpm showerhead. 19" round and 48" high. 240V wiring, 16Amp draw goes on a 20Amp circuit.	This "retrofit ready" 40-gallon tank is right sized for <b>four</b> consecutive 6-8 min showers with a 1.5gpm showerhead, more if stored at 130F-140F. Comes in 120V, 900W for plugging into a shared circuit, and 240V using 2250W or 4500W requiring a dedicated circuit.

# What Does it Cost to Electrify Your Entire Home?

This section is intended to help you make a realistic budget for electrifying your house. One way to approach home electrification is incrementally, when an appliance is ready for replacement. Often there is no cost difference between gas and electric appliances, just a one-time wiring cost, and some of those can be avoided (see Lisa and Steve Schmidt’s case study).

Electrifying your house with new appliances can cost **\$2,000** if you self-install, as you saw in the above “Electrifying on a Tight Budget.” But if you’re hiring contractors, going with higher end products and putting them in a larger home, the budget starts at \$10,000. If the house is being thoroughly re-insulated for more comfort (note the grey part of the bars below) and broken ductwork is being replaced, then the cost doubles or triples. Every house is different, and people have different tastes and desires, so unsurprisingly there are a wide range of costs that you will see in the discussion below.



Figure 2: An all-electric retrofitted home in Cleveland, Ohio whose total home comfort and electrification retrofit costs were \$31,000 (House 9 in the figure below).

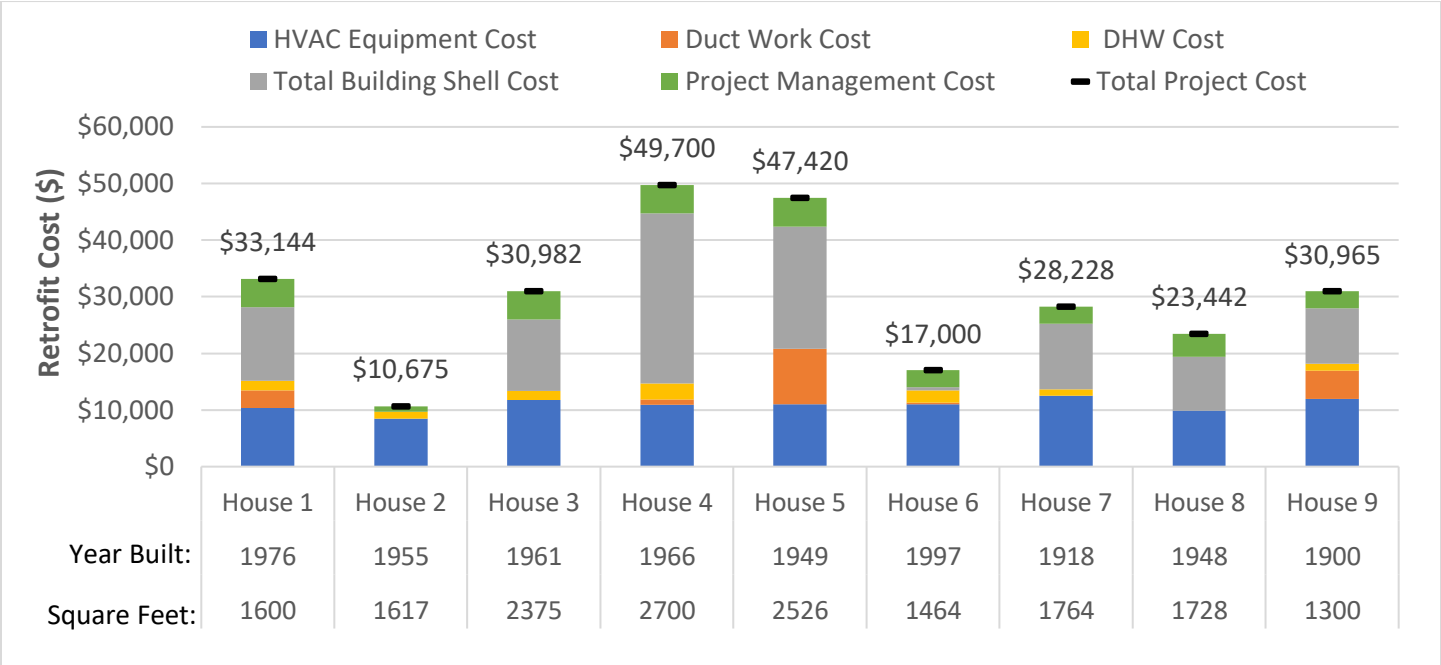


Figure 3: A summary of Energy Smart Ohio's case studies, showing the range of costs of home comfort and electrification retrofits. An important thing to note is that the heat pump cost reflects cold climate heat pumps, and the water heater costs reflect a mix of electric resistance and heat pump tanks for most homes, most of which were self-installed by the homeowners.

To help keep you on budget when hiring contractors, below you will find suggestions for “**box swapping**,” what we playfully call replacing existing gas appliances with nearly identical electric appliances, which avoids retrofit costs. You can also avoid wiring costs by using **power-efficient equipment**, such as condensing washer/dryers, and/or by using **power-sharing plugs**, which can share power between two high-power appliances like electric car chargers, laundry dryers, electric ranges and electric water heaters. In the “**Watt Diet**” discussion below you will find a comprehensive set of strategies to help you avoid rewiring your house or adding more power service to your home, while still electrifying all your loads.



## What Does It Cost to Electrify Your Home’s Kitchen?

Cooking with electricity means one has access to the best stoves on the market—the fastest, easiest to clean and most controllable stoves made. In 2020, Consumer Reports ranked induction stoves as the #1, 2, 4, 5, and 8 best stoves for sale, with a smooth top electric resistance stove at #6 of the top 10. Replacing a gas stove with an electric one generally has two costs—wiring a new 240V plug (averaging \$300<sup>30</sup>) and purchasing the stove (\$500-\$2,500).

However, one of the co-authors of this booklet happily cooks with two 120V\* countertop induction units (\$150-\$250 each) and a Thanksgiving turkey-friendly 120V countertop oven (\$150), avoiding the expense of adding a 240V\*\* plug and adding the convenience of two cooking stations in the kitchen, so the spouses can have some elbow room when cooking at the same time.



Figure 4: An induction wok is featured in David Kaneda’s kitchen in Cupertino, CA<sup>31</sup> and Erika Reinhardt loves that her toddler can now safely make pancakes with their new induction stove—learn more below in her case study.



Figure 5: A double oven KitchenAid induction stove; the cost of electric induction cooktops at Home Depot in August of 2020, ranging in size from 24 inch (5 products), 30 inch (14 products), 36 inch (17 products). X marks the average, the middle line is the median, the box surrounds 50% of cases, and the “whiskers” illustrate the lowest 25% and the highest 25% of cost data.

\*120V electricity is delivered between 110V and 127V, and appliances are sometimes alternatively described as “115V”

\*\*Similarly, 240V refers to appliances that use delivered voltage that ranges between 208V and 250V, and one finds appliances are listed at 220V or 230V, depending on the whims of the manufacturer, but they all plug into the same outlet.

## What Does It Cost to Electrify Your Home's Laundry Dryer?

You likely already have an electric laundry dryer—88% of laundry dryers sold in the U.S. are electric. But when replacing a gas dryer, the simplest upgrade is to a 120V condensing washer/dryer (\$800-\$1600), which is a single appliance rather than two machines, and is popular world-wide. Using a 120V condensing washer/dryer avoids the expense of adding a 240V plug (averaging \$300<sup>32</sup>), and adds the convenience of not having to move damp laundry from the washer to the dryer. Should you wish to install your own 240V plug, [here](#) is a DIY video.

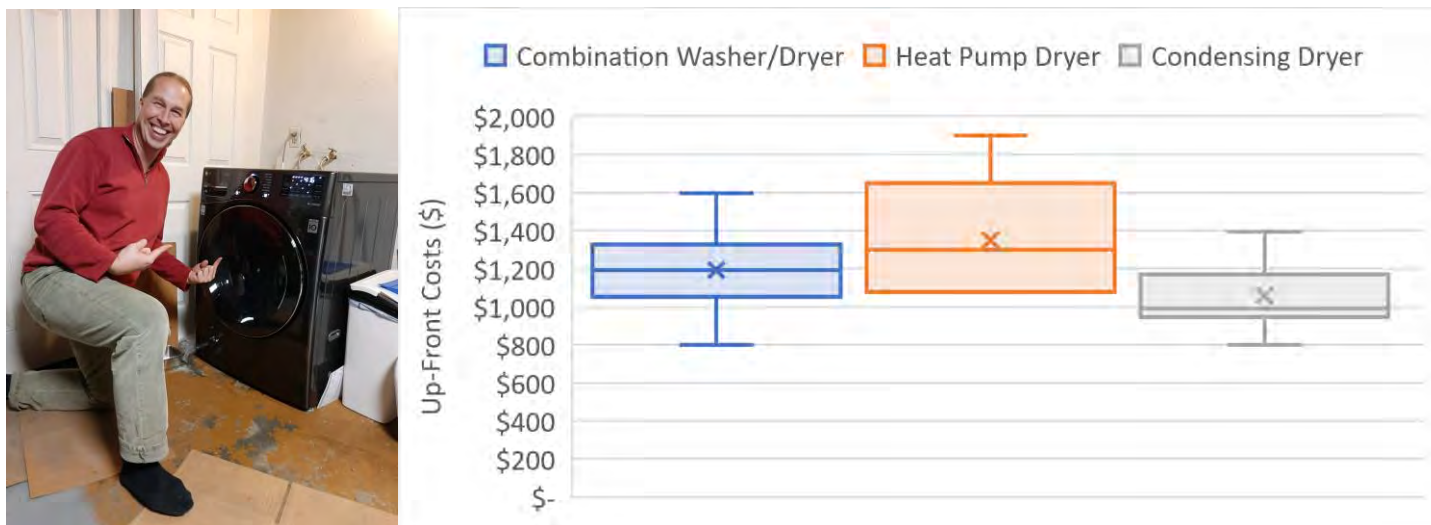


Figure 6: At left, one of the authors celebrating his first laundry load in an all-in-one, condensing washer/dryer, which he loves. At right, the cost of 22 Energy Star laundry dryers of various types at Home Depot in August of 2020.

Electric Resistance and Heat Pump dryers both use 240V power, but electric resistance dryers use roughly twice as much electricity as a heat pump or condensing dryer (figure below).<sup>33</sup> Also, electric resistance dryers blow out hot, lint-filled air through a vent, while heat pump and condensing dryers are ventless: the water they extract from the wet laundry goes down a drain and the lint is caught in a filter.

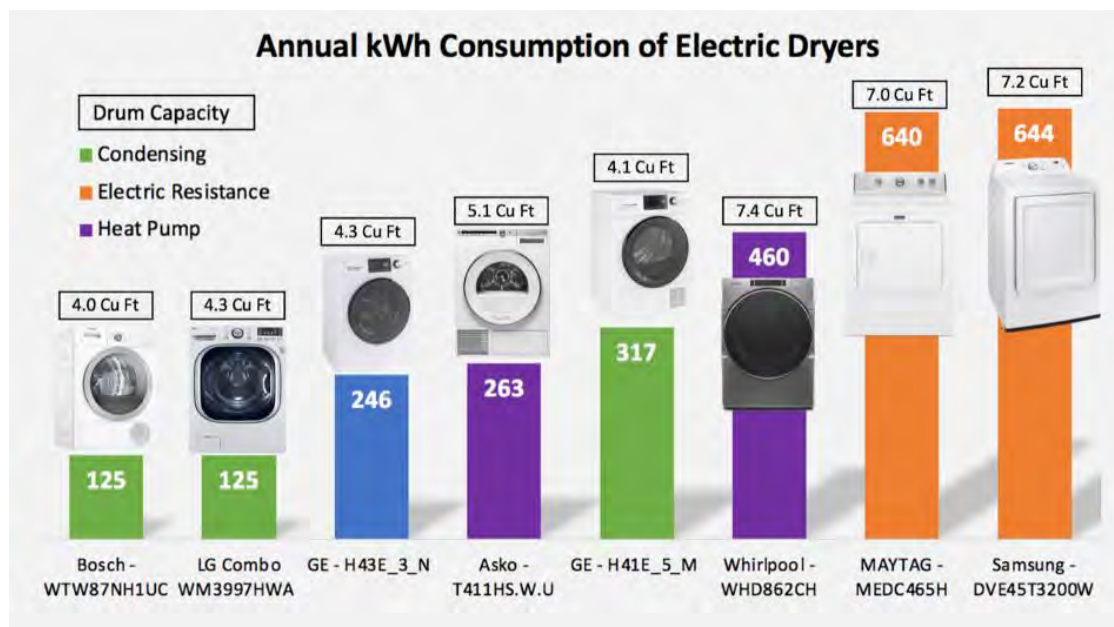


Figure 7: Relative dryer energy use, condensing dryers and heat pump dryers use roughly half the energy of a standard electric resistance dryer.



## What Does It Cost to Electrify Your Home's Water Heating?

There are two common types of electric water heaters—electric resistance and heat pump. Electric resistance, what one sees happening inside of a toaster when the wires get hot, uses 3-5 times as much energy as a heat pump, which collects existing heat from the air. The energy savings of using a heat pump water heater over the course of a year is equal to the amount of energy to drive an electric car about 12,000 miles. However, a heat pump water heater is a larger investment, costing up to 3 times as much as a resistance water heater but using only 1/3 as much electricity. Resistance water heaters also come in smaller sizes: they come as small as 2 gallons for a sink, or 7 gallons for a single shower. The smallest heat pump water heater in the U.S. is a 40 gallon, while models as small as 20 gallons are sold in Eurasia.



Figure 8: Rheem heat pump water heater.

### California: The Sacramento Municipal Utility District (SMUD)

The municipal utility serving Sacramento, California rebated 1650 gas-to-heat pump water heater conversions over two years. Roughly 70% of all installations ranged between \$3,000 and \$5,000, with another 15% below and 15% above that price range. A 50-gallon heat pump tanks cost about \$1,200 before installation, so the rest is labor, materials and profit, with self-installations costing \$1500-\$2000.

The range of prices illustrates the value of getting multiple bids or learning to do it yourself ("DIY"). Instruction videos for DIY installation can be found [here](#) and [here](#).

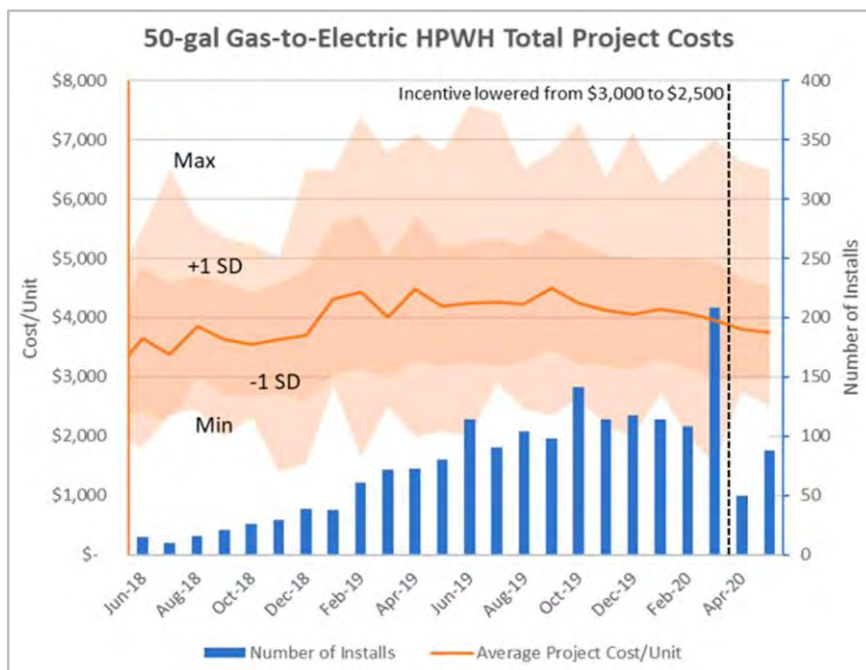


Figure 9: The retrofit pricing from 1650 installations of 50-gallon heat pump water heater replacements in Sacramento over two years.<sup>34</sup>

SMUD Residential Heat Pump Water Heater Total Project Costs									
Technology		2018		2019		2020		Total	
		Cost/Unit	Count	Cost/Unit	Count	Cost/Unit	Count	Cost/Unit	Count
50-gal	Gas to Electric	\$ 3,763	114	\$ 4,291	1,005	\$ 3,983	531	\$ 4,155	1,650
	Electric to Electric	\$ 3,299	51	\$ 3,747	99	\$ 3,769	37	\$ 3,629	187
	All	\$ 3,619	165	\$ 4,242	1,104	\$ 3,969	568	\$ 4,101	1,837
65/80-gal	Gas to Electric	\$ 3,781	9	\$ 4,578	25	\$ 4,381	30	\$ 4,374	64
	Electric to Electric	\$ 3,813	3	\$ 3,806	12	\$ 4,003	6	\$ 3,863	21
	All	\$ 3,789	12	\$ 4,328	37	\$ 4,318	36	\$ 4,247	85

<sup>1</sup>Total project costs are assumed to include equipment, labor, permits, and profit, but these items are not collected by SMUD - some total costs may include additional costs or exclude some items.

<sup>2</sup>SMUD gas-to-electric HPWH incentive level of \$3,000/unit began in May 2018 and went down to \$2,500 in April 2020; the electric-to-electric incentive level is currently \$500/unit.

Figure 10: The pricing of 1912 heat pump water heater replacements, both of gas and electric tanks, in Sacramento. Note that gas to electric costs about \$500 more than electric to electric due to wiring costs and plumbing a condensate drain. (SMUD, 2020).



## What Does It Cost to Electrify Your Space Heating?

If you have gas heat, getting rid of it will likely be the largest benefit to the environment and your utility bills. Leading contractors from different parts of the U.S. shared their bidded costs to help us write this section. Details are below, but to summarize, a house usually needs 1-3 “tons” (1 ton is 12,000 BTUs/hr) of heating capacity; each “ton” costs \$3,200 to \$6,000 with Energy Smart Ohio, between \$4,650 to \$5,950 in Sacramento, CA, and \$3,100-\$4,300 in Oregon for ductless mini splits installed by The Heat Pump Store in Portland and Eugene. From this cost data you can assume that your next heat pump will cost between \$3,100 and \$18,000, depending on how big and insulated your house is, and how good a bid you got. Fixing a furnace’s ducting often isn’t necessary, but we can see from Energy Smart Ohio’s pricing that when there are minor problems it will cost a few hundred dollars to fix, and \$3,000-\$10,000 for completely replacing old ducting.

However, there are \$500-\$700 portable, quiet heat pumps that work when its 10F outside, and they can be self-installed in a window, which works for home renters and homeowners on a strict budget.



Figure 11: The Heat Pump Store staff installing in Portland, OR.



Figure 12: Daiken’s 96-acre heat pump factory in Houston, TX.

### California: The Sacramento Municipal Utility District (SMUD)

The electric utility that serves Sacramento, CA rebated almost 800 heat pumps used for space conditioning (heating and cooling) in 2020. SMUD organizes heat pump installation costs by efficiency (HSPF means “Heating Seasonal Performance Factor,” and the higher the number, the more efficient) and type (Packaged, Mini Split, Standard Split), with pricing for each “ton” of heating capacity. This historical unit refers to one ton of ice melting in one day, which absorbs 12,000 British Thermal Units (BTUs) per hour. A 400-1,000 sf house likely needs only 1 ton of heating/cooling capacity (\$4,650 to \$5,950), while a 2,000 - 3,000 sf house might use 3 tons (\$13,500 to \$17,860).<sup>35</sup>

SMUD Residential Space Heating Heat Pump Total Project Costs/Ton					
Technology		Gas-to-Electric		Electric-to-Electric	
		Cost/Ton	Count	Cost/Ton	Count
HSPF 8 to 10, 2-stage	Package HP	\$5,194	119	\$4,279	49
	Split HP	\$4,652	206	\$4,706	88
HSPF ≥ 10, 2-stage	Split HP	\$5,198	32	\$4,713	11
HSPF 8 to 10, Variable	Split HP	\$5,953	79	\$5,331	18
	Minisplit HP	\$5,395	12	\$5,007	3
HSPF ≥ 10, Variable	Split HP	\$5,691	78	\$6,085	12
	Minisplit HP	\$5,464	54	\$5,319	3

<sup>1</sup> SMUD HP program requirements for split/minisplit: ≥2-stage (or variable), HSPF 8.2 or greater, must service entire home. Package: ≥2-stage (or variable), HSPF 8 or greater. These exceed Title 24 standards, and thus costs may not be comparable to other program/statewide estimates.

<sup>2</sup> Total project costs are assumed to include equipment, labor, permits, and profit, but these items are not collected by SMUD - some total costs may include additional costs or exclude some items.

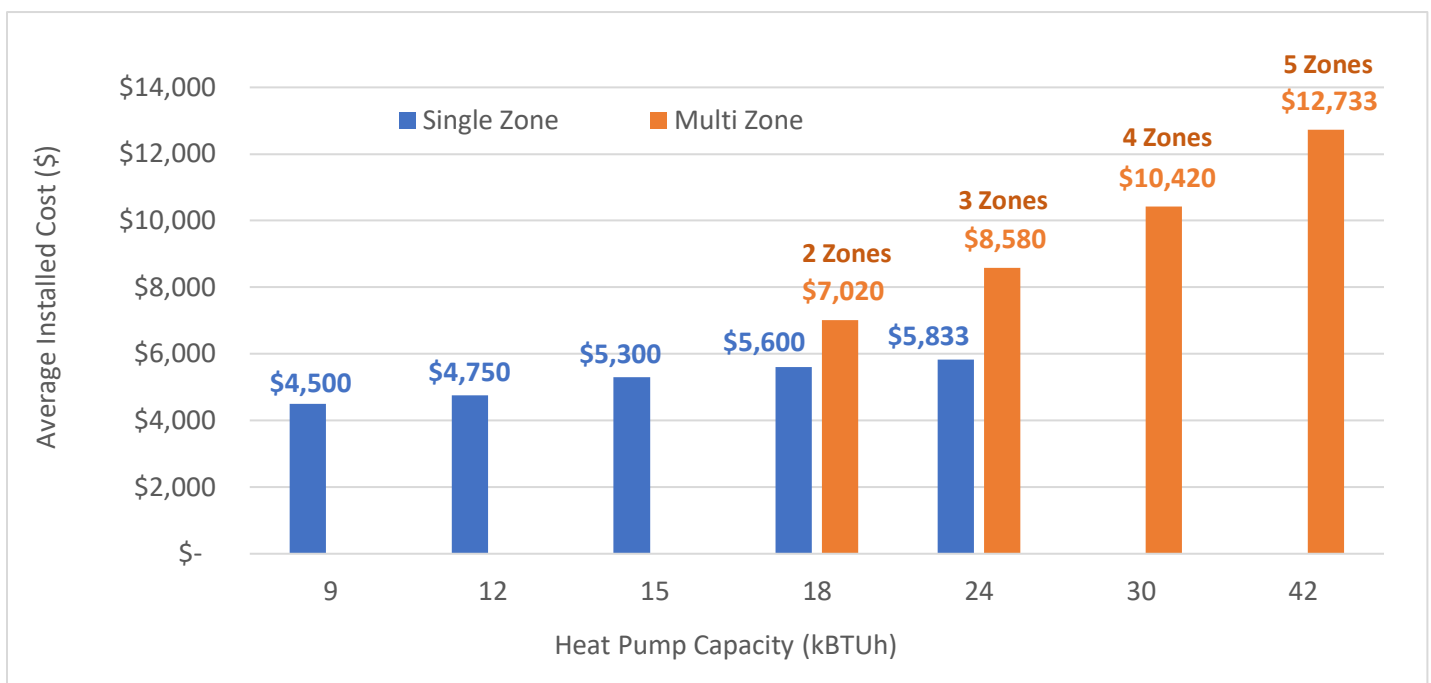
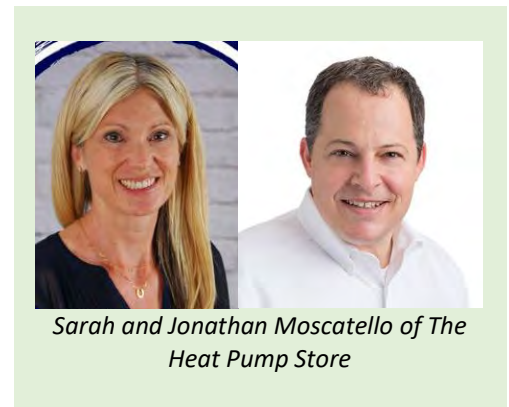
<sup>3</sup> Gas-to-electric rebate is \$2,500 and electric-to-electric is \$750. \$2,000 in additional rebates for AC & airflow have been reduced to \$500 as of Aug. 2020 due to COVID-19 economic considerations.

**Figure 13: From the SMUD data, selecting a variable speed inverter drive over “two stage” appears to cost an extra \$1,300/ton in lower efficiency units (HSPFs under 10) to select Variable Speed Inverter drive vs. “Two stage”. The same up-selecting in more efficient heat pumps has a \$500/ton premium. There appears to be almost no premium for selecting higher HSPF when selecting variable speed drive units. HSPF = Heating Seasonal Performance Factor (higher is better) is a seasonal energy efficiency measurement of heat delivered per kWh of electricity used.**

## Oregon: The Heat Pump Store

Below are the standard installed costs for ductless mini split heat pumps kindly provided by Sarah and Jonathan Moscatello, who keep their 50 staff busy installing thousands of Heating/AC heat pumps each year from Eugene to Portland, OR. Sarah and Jonathan only install ductless mini split HVAC heat pumps, which are the most efficient type and let residents choose a comfortable temperature in each zone in the home with a remote control. A single wall-mounted fan coil will condition a 500sf-1,200sf zone, depending on the climate and how well insulated the house is.

The cost of a ductless mini split system varies by the space conditioning capacity of the system as well as by the number of zones of the system. The manufacturer's wholesale pricing also impacts retail pricing—there is a roughly 30% price difference between leading brands like Daikin, LG, Panasonic, Fujitsu, and Mitsubishi due to the manufacturer's investment in product quality and marketing. Should you wish to self-install, [here](#) is a DIY instructional video.



**Figure 14: Average installed cost of ductless mini-split systems, the blue showing the prices for a single zone systems of different capacity sizes, and the orange shows the average costs for multi zone systems.<sup>36</sup> Pricing was provided under contract by The Heat Pump Store in 2019.**

Note that these costs assume the outdoor and indoor components share a wall within 15' of each other, because 25' or more separation adds \$500 more per zone, and placing the inside Heater/AC on an interior partition wall costs \$1000 more per zone—because interior wall locations require that wiring and refrigerant lines must be installed in a crawlspace or attic, rather than inexpensively on the building's exterior.



## Ohio: Energy Smart Home Performance

Nate Adams is an electrification consultant in Ohio, proudly removing gas lines during the day and running the Electrify Everything and HVAC 2.0 Facebook sites at night (“HVAC” stands for Heating, Ventilation and Air Conditioning). Nate’s focus on client comfort to address Ohio’s muggy summers and frigid winters means a ducted heat pump also comes with humidity management and a thick air filter to reduce pollen and other allergens.



Nate Adams of Energy Smart Ohio

Replacing the existing gas furnace and air conditioner with a ducted heat pump costs an average of \$10,951 while making the homeowners more comfortable. Additional insulation and air sealing to get rid of drafts also helps provide the comfort people are seeking in Ohio’s tough climate and it allows the use of smaller heat pumps and can avoid the need for large ducts. But it becomes about half of the project cost and a critical part of providing true comfort in a touch climate. Consequently, Nate considers his job to be providing “home comfort,” and heat pumps simply provide the most comfort with quiet, evenly heated and cooled homes, but homeowners often also want more insulation, less draftiness and repaired ductwork to reduce energy waste.<sup>37</sup> The costs below were provided under contract by Nate Adams and are intended to help you set a realistic budget for both electrifying your ducted HVAC system and making your house more comfortable and efficient.

Table 1: Cost breakdown of Energy Smart’s projects in Ohio.<sup>37</sup>

Energy Smart Ohio Comfort Upgrade Costs											
Client	Zip Code	Square Feet of House	Year Built	Job Date	Heat Pump Equipment+ Install Cost	Duct Work Cost	Insulation and Air Tightness Costs	Project Management Cost	Total Project Cost	HVAC Capacity Before (BTU/hr)	HVAC Capacity After (BTU/hr)
Peter A.	44256	1600	1976	10/19	\$10,400	\$3,100	\$12,994	\$5,000	\$31,494	140,000	36,000
Ryan A.	44233	1617	1955	11/17	\$8,500	\$0	\$0	\$1,000	\$9,500	100,000	24,000
Hallie B.	44313	2375	1961	12/17	\$11,800	\$0	\$12,582	\$5,000	\$29,382	120,000	36,000
Brad M.	44202	2700	1966	10/16	\$10,950	\$950	\$30,000	\$5,000	\$46,900	90,000	36,000
David F.	44236	2526	1949	7/19	\$11,000	\$9,850	\$21,570	\$5,000	\$47,420	60,000	36,000
Cindy W.	44410	1464	1997	3/19	\$11,050	\$250	\$500	\$3,000	\$14,800	57,000	24,000
Carole P.	44255	1700	2000	7/20	\$11,460	\$0	\$300	\$2,000	\$13,760	10,000	36,000
Jon N.	44118	1764	1918	10/14	\$12,498	\$0	\$11,530	\$3,000	\$27,028	80,000	36,000
John P.	44231	1728	1948	5/19	\$9,850	\$0	\$9,592	\$4,000	\$23,442	85,000	36,000
Paul S.	44103	1300	1900	8/15	\$12,000	\$4,995	\$9,770	\$3,000	\$29,765	120,000	24,000
Average Costs					\$10,951	\$1,915	\$10,884	\$3,600	\$27,349	86,200	32,400

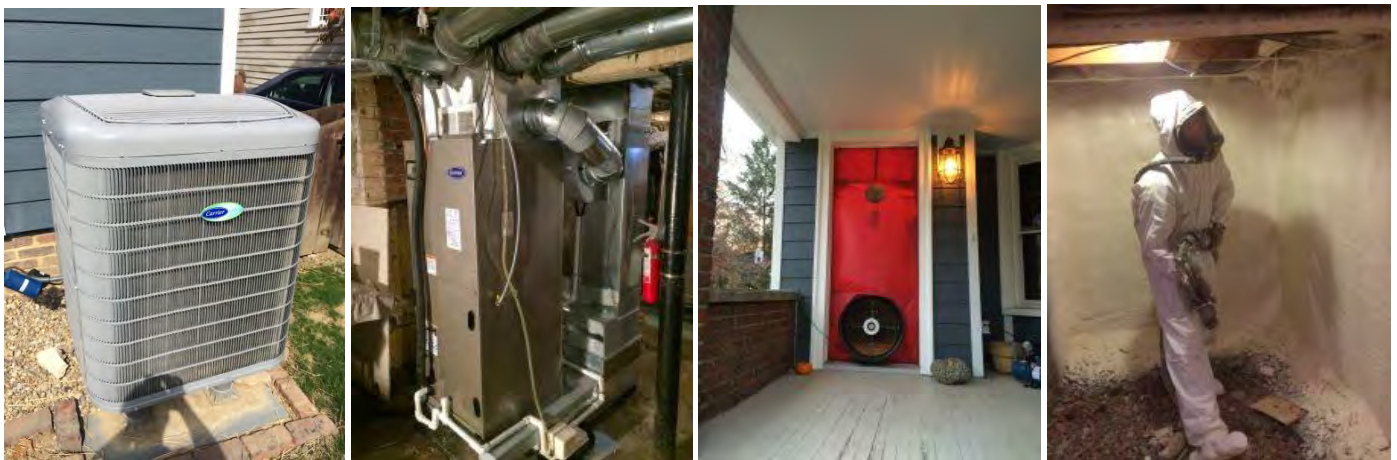


Figure 15: A few images from Energy Smart Ohio’s retrofit project 1918 House of the Future in Cleveland Heights. Left to right: Carrier Greenspeed heat pump, air handler in the basement, blower door test, and insulating the basement.



### Vermont and New York: The Vermont Energy Investment Corporation (VEIC)<sup>38</sup>

VEIC builds all-electric modular homes and helps low-income residents of Vermont and New York retrofit their homes with heat pumps. Li Ling Young, VEIC's Senior Energy Consultant, sees heat pump retrofits costing \$7,000-\$20,000, similar to what we saw in the data from nearby Ohio. Li Ling notes that many homes could use another \$10,000 of insulation and air tightness work for greater comfort. VEIC found that in the milder, coastal region of New York state, even without extra insulation or sealing air leaks, HVAC contractors are installing ductless heat pumps and confidently removing the fuel fired heating systems.



Unlike standard ducted and ductless air-to-air heat pumps, the relatively uncommon air-to-water heat pumps that make hot water for radiant floors in wealthier people's homes can be quite expensive—Li Ling saw two recent installation bids for \$35,000. Radiant floors don't provide air conditioning, so it can make sense to downsize the radiant floor heat pump while adding a ductless mini-split, which provides more control over heating (radiant floors can take 8-24 hours to significantly change temperature) and air conditioning during the summer.

### Massachusetts: State-Wide Rebate Data<sup>39</sup>

The electric utilities of Massachusetts have tracked installation costs on more than 600 rebated heat pumps used for Heat and Air Conditioning between 2014 and 2019. Most retrofitted systems, including ductwork, permitting and design, cost between \$10,000 and \$30,000 in homes that range between 800 square feet to 2,500 square feet. Note that costs are both significantly lower or higher than the averages—getting a lower price is often the result of getting more than one bid.

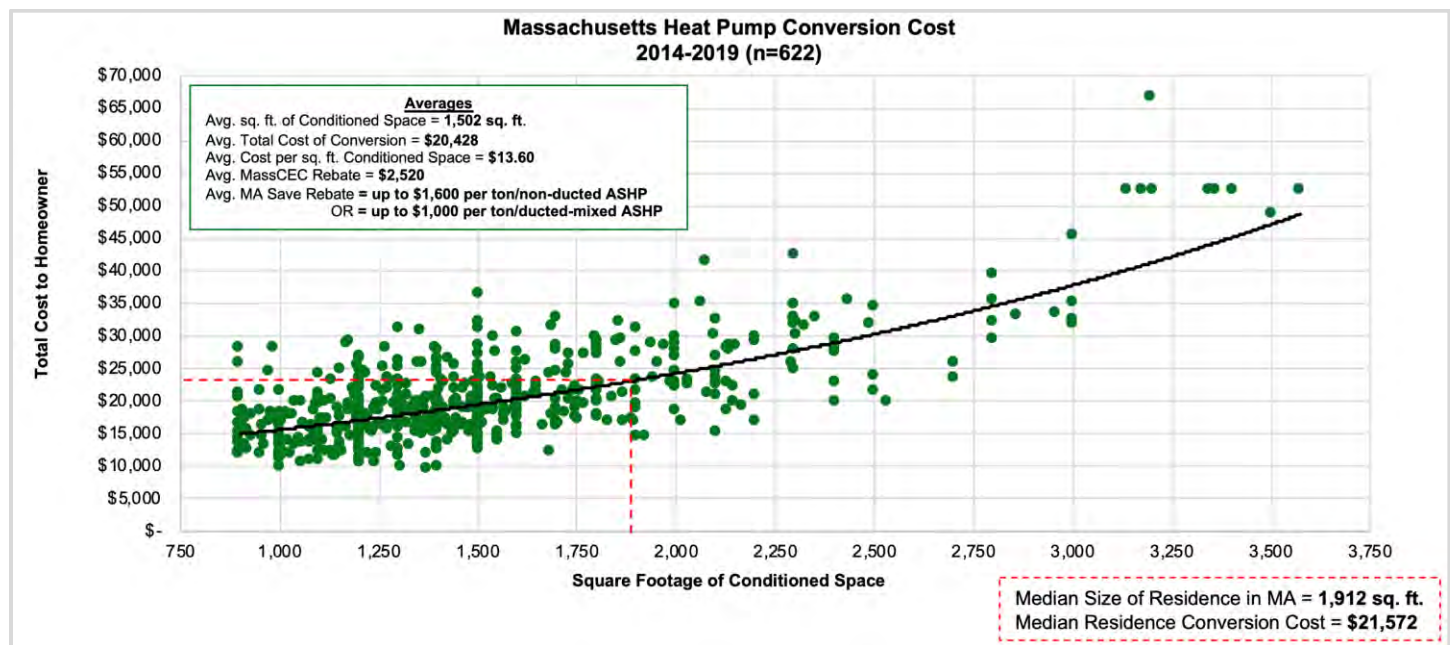



Figure 16: Heat pump conversion cost data from Massachusetts rebate program. Keep in mind the heat pump costs shown are for cold climates, meaning they are likely to have variable speed drives and high capacities, thus increasing their cost.

# The “Watt Diet” - Avoid a New Electrical Panel and Reduce Wiring

Retrofitting with 240V electric stoves, water heaters, laundry dryers and space heating creates the expense of running new wires to each appliance, ranging from \$85 to \$600 per circuit and averaging \$300<sup>40</sup>, and sometimes this new demand for electricity can trigger the need for a new circuit breaker panel and service upgrade. A new circuit breaker panel costs at least \$450, averaging \$1,475 and as much as \$4,000.<sup>41</sup> However, there are many ways to stay on budget and using the existing power supply of your home by following the National Electrical Code (NEC). We call this process of avoiding power upgrades a “Watt Diet,” which involves power efficient appliances and sometimes power balancing plugs. If you’d like to learn more, the authors offer a 30-minute training [here](#).

## *A 100-Amp panel has enough power for complete electrification of a 3,000 square foot home*

The above statement will surprise some readers, but it’s true—most homes don’t need more than the minimum the National Electrical Code requires, which is at least a 100 Amp, 3-wire service for every single-family home (see the full page panel diagram figure below- Example 2).<sup>42</sup> Below is an example of a set of appliances that can fit into an all-electric 100-amp home, including a “high power” 21 Amp heat pump water heater and a 3 ton [36,000 BTUs/hr] heat pump for space conditioning. These appliances pair with a 2,000 square foot home in the relatively mild climate of Northern California (e.g. Sacramento, Bay Area), but could also support a larger house or a house of a similar size in a colder climate. See the additional two full page Watt Diet examples below, the first is a “typical” 2,000 square foot home and the second is a power efficient 3,000 square foot home.



Brand and Type	Frigidaire Fridge	Waste King Garbage Disposal	Frigidaire Dishwasher	Broan Kitchen Exhaust Fan	Amana Radiant Electric Range	Heat Pump Water Heater	LG Combined Washer/Dryer	Fujitsu Heat Pump (heating and cooling)	Plug Loads and Lighting
Cost (\$)	\$650	\$50	\$440	\$350	\$650	\$1,300	\$1,500	\$11,000*	3,000W (kitchen plugs) +
Power	720W	480W	1,200W	168W	9,600W	4500W	1,200W	5,760W (heat pump at design T) + 840W (air handler)	6,000W (plugs and lighting)**
Amps	6A	4A	10A	1.4A	40A	21A	10A		
Volts	120V	120V	120V	120V	240V	240V	120V		

\* Average cost of a ducted heat pump, from Energy Smart Ohio’s case studies (see What Does it Cost to Electrify Your Space Heating? section above)

\*\* 3,000 Watts for kitchen plugs and 3 Watts per square foot for plugs and lighting as defined by the National Electrical Code, assuming a 2,000 square foot home.

### Here are several more Code compliant ways to keep your house on its current panel with the Watt Diet:

- 1) **Use efficient heat pumps**—electric resistance heating uses 3-5 times as much power as heat pumps. Higher efficiency heat pumps (like those with inverter controls and omitting resistance back-up heating) use less electricity and power to heat and cool.
- 2) **Use a condensing, combined washer/dryer** (also called ventless washer/dryer), which are popular world-wide and designed specifically for retrofits: they use so little power they can plug into any 120V outlet in a house, while 240V dryers (resistance, heat pump and condensing) require a larger, 240V dedicated circuit.
- 3) **Use a combined range and oven**--the NEC requires twice as much power allocated to a separate oven and range (19,200W) as a combined range and oven (9,600W). Similarly, avoid attaching a microwave oven to the wall, which triggers an extra, dedicated circuit—just place the microwave *on* the countertop or cabinet.

- 4) **Insulate and air seal the home** to select smaller heat pumps for the reduced space heating power needs. Most houses do not need more than 3 tons (36,000 BTUs/hr) if they are reasonably insulated, regardless of the climate. Keeping the heat pump capacity smaller allows the reuse of existing ducts, while ductless designs save even more energy by not losing heat through ducting.
- 5) **Use circuit-sharing plugs** (e.g. NeoCharge, Dryer Buddy, SplitVolt, or hard wired SimpleSwitch) so one existing high voltage (240V) outlet can power both a car charger and a laundry dryer, or a water heater and a range (See Lisa and Steve Schmidt’s case study).
- 6) **Analyze a year of the home’s history of hourly power usage**—it may be low enough to allow added electrical devices even if some NEC panel calculation methods indicate otherwise. Code allows you to multiply last year’s hourly peak kW use by 1.25 and add new nameplate power (kW) loads up to the main panel rating (e.g. 24 kW for 100A panel or 48 kW for 200A panel. section 220.87). However, this option is only for homes without solar. Knowing your home’s max power use can be helpful to see if you are under capacity, but also if you are at capacity - you may want to consider upsizing your panel for nuisance tripping reduction or possible safety improvement reasons.
- 7) **Check to see if you need to free up panel spaces for new circuits or if you can share poles.** In older homes when less efficient appliances were common; the circuits were upsized appropriately to fit these appliances. One way to utilize old wide breaker spaces is to replace them with “tandem breakers” that are thin and can serve two circuits from one breaker space (AKA single pole space) or you can combine circuits in a sub panel that then lands on only one pair of poles in the main panel. Automatic Circuit Sharing (ACS) devices also make double-use of a breaker space by serving two devices that take turns using the power. If things are really tight, gathering several small circuits onto a sub panel is a way to create more panel pole spaces. Keep in mind that a 100 Amp Sub Panel can be served by a smaller circuit like a 50 Amp circuit serving up to 80 Amps of loads because of their already counted diversity.

Below is a summary of the National Electrical Code requirements for wiring a house. General lighting and plug loads have a watts per square foot requirement, and kitchen counter circuits and bathrooms require circuits of a certain size. Various appliances require dedicated circuits as well, like exhaust hoods, garbage disposals and ranges.

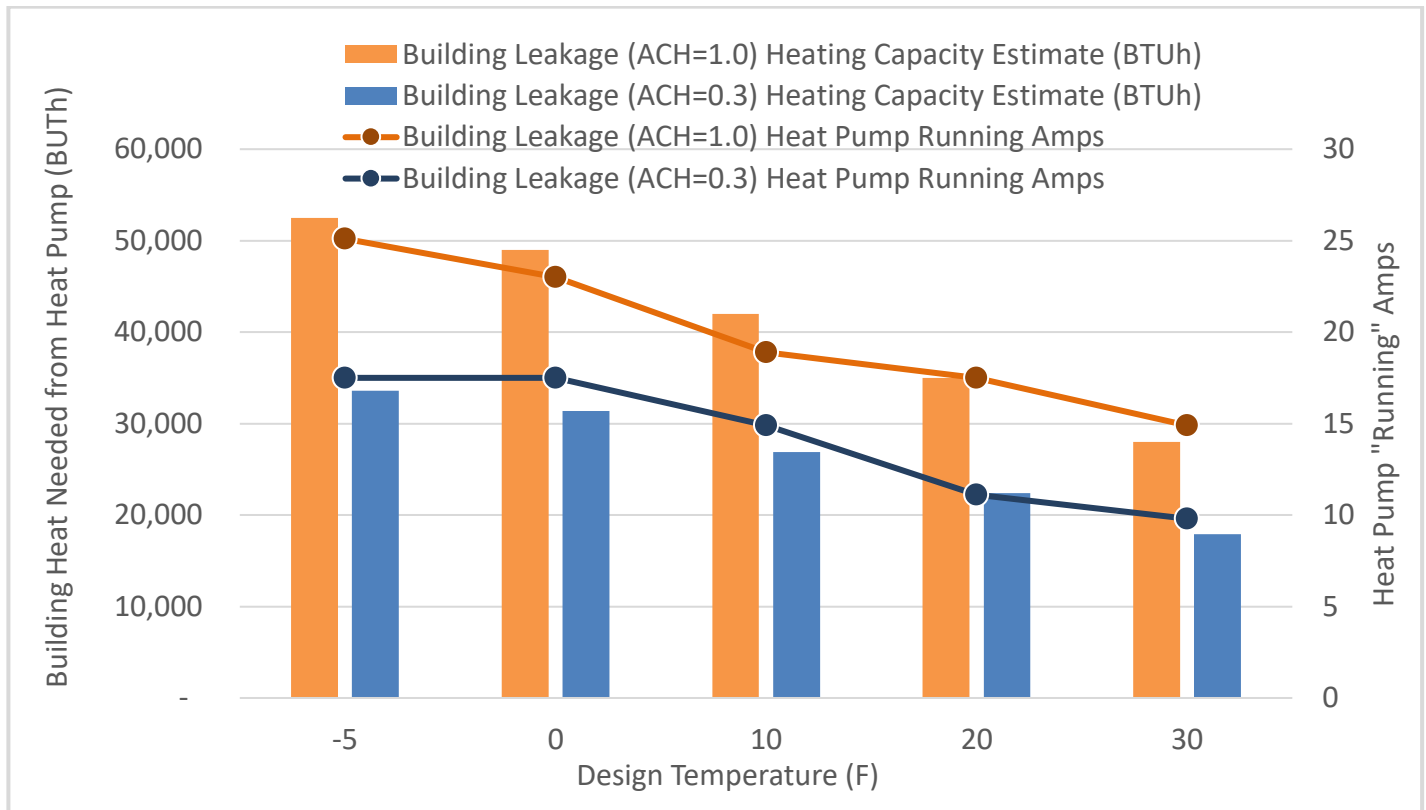
**Table 2: The required circuits in a single-family home.**

<b>Appliance</b>	<b>National Circuit Requirements and Guidelines (NEC required)<sup>43</sup></b>
<b>Kitchen Counter Circuits</b>	Two dedicated 20-Amp circuits NEC 210.52 (B)(1) 120V
<b>Kitchen Small Appliances</b>	One or more additional circuit(s) are required for small, hard wired appliances (kitchen exhaust hoods, garbage disposals, dishwashers, trash compactors and other motor loads and shall not be on the same circuit as either of the two) NEC 210.52(B)(1) 120V
<b>Bathroom Circuits</b>	At least one 20-Amp circuit 120V if circuits serve a single bathroom, lights may be on the same circuit. NEC 210.11(C)(3)
<b>Range Circuit</b>	Minimum of 40 Amps NEC 210.19 (3) 240V
<b>General Lighting</b>	General lighting circuit shall be provided for 3 Watts per square foot (NEC 220.12) 120V
<b>Other Large Appliances</b>	Required dedicated circuit of 15-50 Amps. Often 240 V



## How Insulating and Air Sealing Reduce the Necessary Space Heating Power

Most climates are heating dominated, so the power required to heat your home will be higher than the power to cool your home. The difference in air leakage rates, or air changes per hour (ACH) (orange vs. blue bars) makes a large difference in the necessary heating power. We show this impact at progressively warmer heating “design temperatures,” and the corresponding reduced power/ampere needs. Your house’s heating “*Design Temperature*” is defined as the coldest outdoor temperature the house will see in its climate, except for 0.2% of the hours of a typical weather year, or 18 total hours a year. Example “design temperatures” in CA include: Los Angeles is 43F, Sacramento is 37F, Yosemite National Park is 20F, South Lake Tahoe is 10F, Truckee is -4F. In cooling dominated climates, window overhangs and shades, window film or low heat gain windows, heat reflective house paints or “cool roofs” may reduce heat pump sizing and power use. One author plants hop vines on his home’s west side for seasonal shade and home brewing.



**Figure 17: The heating requirements at various heating design temperatures and two leakage rates with the corresponding “running” amps for the heat pump (based on the Fujitsu FO\*14R ducted heat pumps<sup>44</sup>) and a 2,000 square foot house with modest insulation (R13 walls, R38 attic).**

## Power Trade-Offs for the Watt Diet

Homes have a set amount of power access through the service wire from a nearby power pole. For example, a service wire may provide 24,000 Watts (100 Amps at 240V). This graph illustrates options to save 13,900 Watts just from choosing more efficient appliances and avoid upgrading the utility service wire and your circuit breaker panel. The graph at right compares the power demand of various appliances using the National Electrical Code (NEC) calculation method. The NEC takes an appliance's rated power use and reduces it by 50%-

60%, based on the likelihood the appliance will be in use. So, a 24,000-Watt service wire might have 35,000 Watts of appliances on it and still be Code compliant.

Some notable power saving options in this graph are that the difference between ductless and ducted space heating (up to 6,300 W savings), different types of laundry dryers (up to 2,880 W savings), different power levels of water heaters (up to 1,650 W savings) and different level of car chargers (up to 3,072 W savings). There are also large savings (up to 3,072 W) from using Power Sharing devices (this can be achieved by sharing a circuit between the car charger and the range for example, see the Product Guide below for more information on these devices). Using this table one can count 13,900 Watts of potential savings, which equals 50 Amps at 240V—enough to power a second, smaller house (e.g. “mother-in-law” or “ADU” home) next to the main house. Or those 13,900 Watts of potential savings can prevent a house from having to upsize its service wire, breaker panel and circuits within the house. Or they can be reallocated into your favorite enhancements of devices or new amenities.

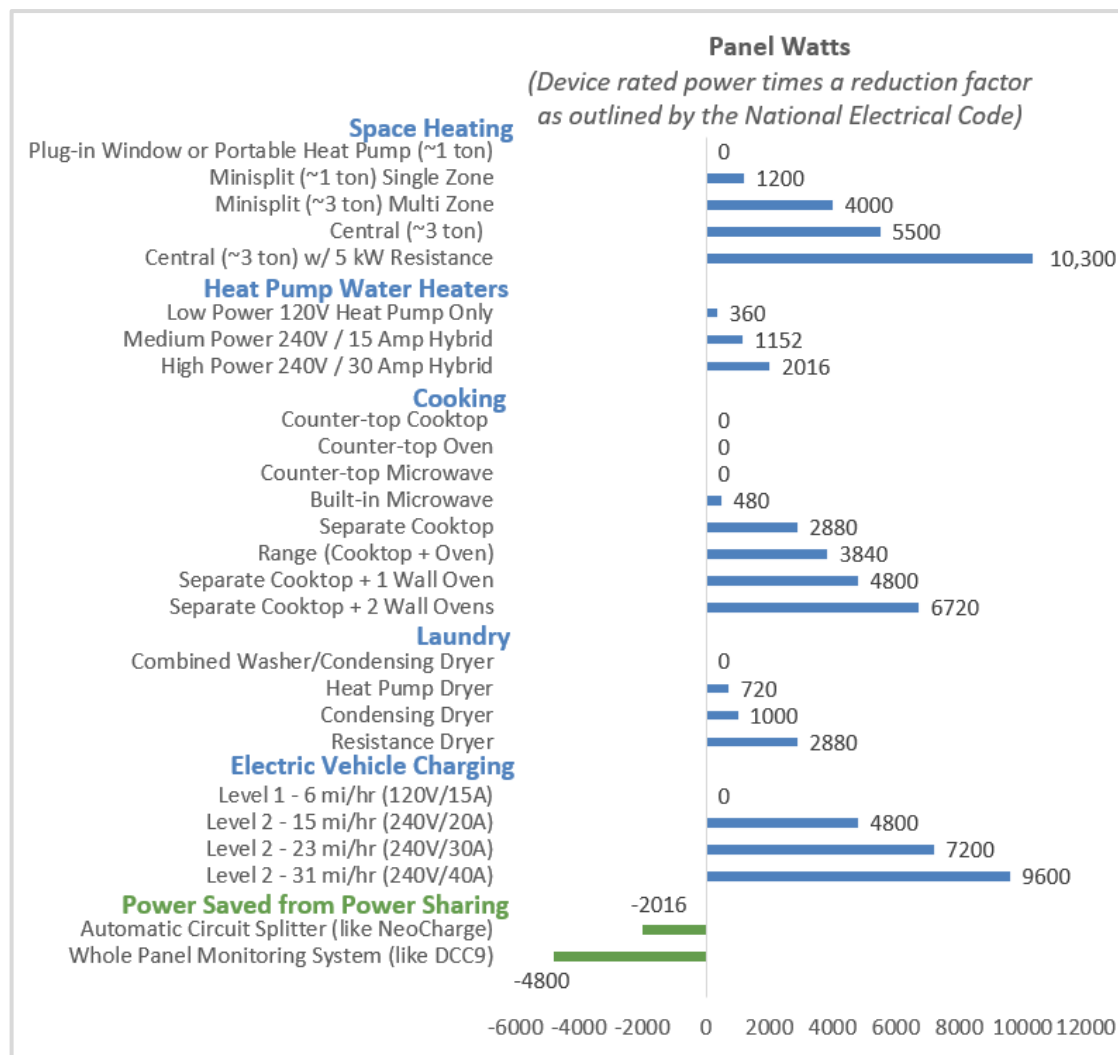


Figure 18: Panel watts of various space heating and appliances in the home.

Calculate the Watt Diet for your own home! **Download the Watt Diet Calculator at Redwood Energy's Website:**

<https://redwoodenergy.net/research/#calculator>

## All Electric 100 Amp Home (2,000 square feet)

Ducted heat pump, medium power heat pump water heater, hybrid heat pump dryer

Device Volts	Device Amps	100 Amp Panel		Device Amps	Device Volts
120	8	Lights/Plug 15	51	Lights/Plug 8	120
120	8	Lights/Plug 15	51	Lights/Plug 8	120
120	8	Lights/Plug 15	51	Lights/Plug 8	120
120	5	Garbage Disposal 15	20	Kitchen Outlets 13	120
120	7	Refrigerator 20	20	Kitchen Outlets 13	120
120	5	Stove Hood 15	20	Dishwasher 12	120
120	0	Furnace (removed) 15	20	Clothes Washer 10	120
240	11	Heat Pump Centrally Ducted 25	20	Hybrid Heat Pump Dryer 14	240
240	15	EV Charger 20	50	Range (cooktop + oven) 40	240
240	16	Solar Input 20	20	Heat Pump Water Heater 12	240



House square footage = 2000

Total Counted Panel Amps = 99.7

### Additional House Information

- 4 occupants
- EV charging up to 14 miles/hr
- Located in California climate zone 3 (SF Peninsula)
- Some insulation
- 23,000 Btuh heating and cooling
- 60-80 gallon heat pump water heater
- 4-burner induction or standard electric range
- 7.4 cu. foot hybrid heat pump dryer
- A 20-amp circuit will support a 3.8 kW inverter. (Many 3.8 kW inverters can support up to a 5.8 kW solar array depending on inverter load ratio)

Diagram creation  
and design by:  
Josie Gaillard,  
Courtney Beyer,  
and Tom Kabat

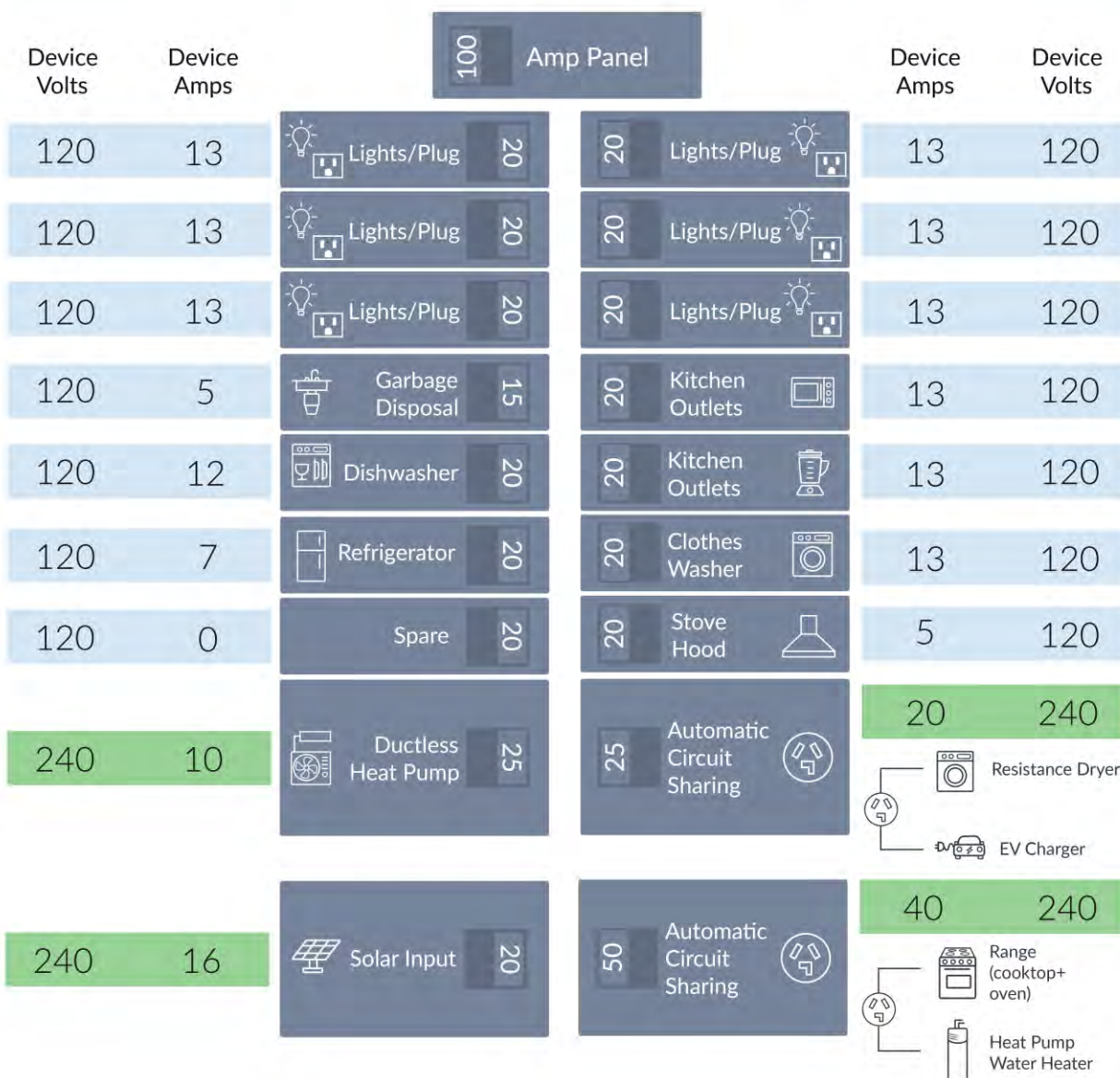
Load calculations per the National Electrical Code Section 220.82(B) and 220.83(B)

April 9, 2022



## All Electric 100 Amp Home (3,000 square feet)

Two “automatic sharing” circuits, ductless mini split heat pump, resistance dryer, high power heat pump water heater



House square feet = 3000

Total Counted Panel Amps = 99.7

### Additional House Information

- 4-6 occupants
- EV charging up to 19 miles/hr
- Located in California climate zone 3 (SF Peninsula)
- Some insulation
- 30,000 BTU heating and cooling
- 40-80 gallon heat pump water heater
- 4-burner induction or standard electric range
- 7.4 cu. foot standard resistance dryer
- A 20-amp circuit will support a 3.8 kW inverter. (Many 3.8 kW inverters can support up to a 5.8 kW solar array depending on inverter load ratio)

Diagram creation and design by:  
Josie Gaillard,  
Courtney Beyer,  
and Tom Kabat

Load calculations per the National Electrical Code Section 220.82(B) and 220.83(B)

April 8, 2022

# Simple “Box-Swapping” Retrofits


Box-swapping describes the relatively quick and painless process of switching out gas appliances with similar electric appliance, such as a ducted heat pump replacing a ducted air conditioner. An example of what is *not* box swapping is abandoning your home’s ductwork and installing a radiant floor—changing systems may be more comfortable, but it is rarely the low-cost option. Each “box swap” has items to consider that are discussed below. Contact your local contractor to get specific cost estimates and design strategies.

## *Box Swapping the Heating, Ventilation and Air Conditioning (HVAC) System*

Heating, Ventilation and Air Conditioning can come in many forms—ducted, ductless and radiant are the most common types, and each has an analogue heat pump product. There are also electric resistance products that can be swapped in place of gas space heating, but they are not discussed here in detail due to their low efficiency.

### Box Swapping a Ducted HVAC System

In a typical ducted heating and cooling system, there is a furnace for heating and an air conditioner for cooling. One strategy to retrofit this type of system is to replace the outdoor unit of the air conditioner with a heat pump, placed in the same location. A heat pump outdoor unit looks just like an air conditioner outdoor unit. Since a furnace typically has a large fan within it that blows hot air through the ductwork, the furnace is replaced with a similar dimension “air handler” containing a coil that is connected to the outdoor heat pump via refrigerant lines. In a furnace-only home, the same ducts can be used for a heat pump, and you get the added benefit of getting heating and cooling. One easy way to accomdate both space and water heating conversions is with an “umbilical” wire from the indoor air handler to the outdoor heat pump (this is a work around some manufacturers provide because air handlers are typically 240V, where furnaces are only 120V). This frees up the old 120V 15-20 Amp furnace blower circuit for now powering a 120V retrofit ready heat pump water heater.

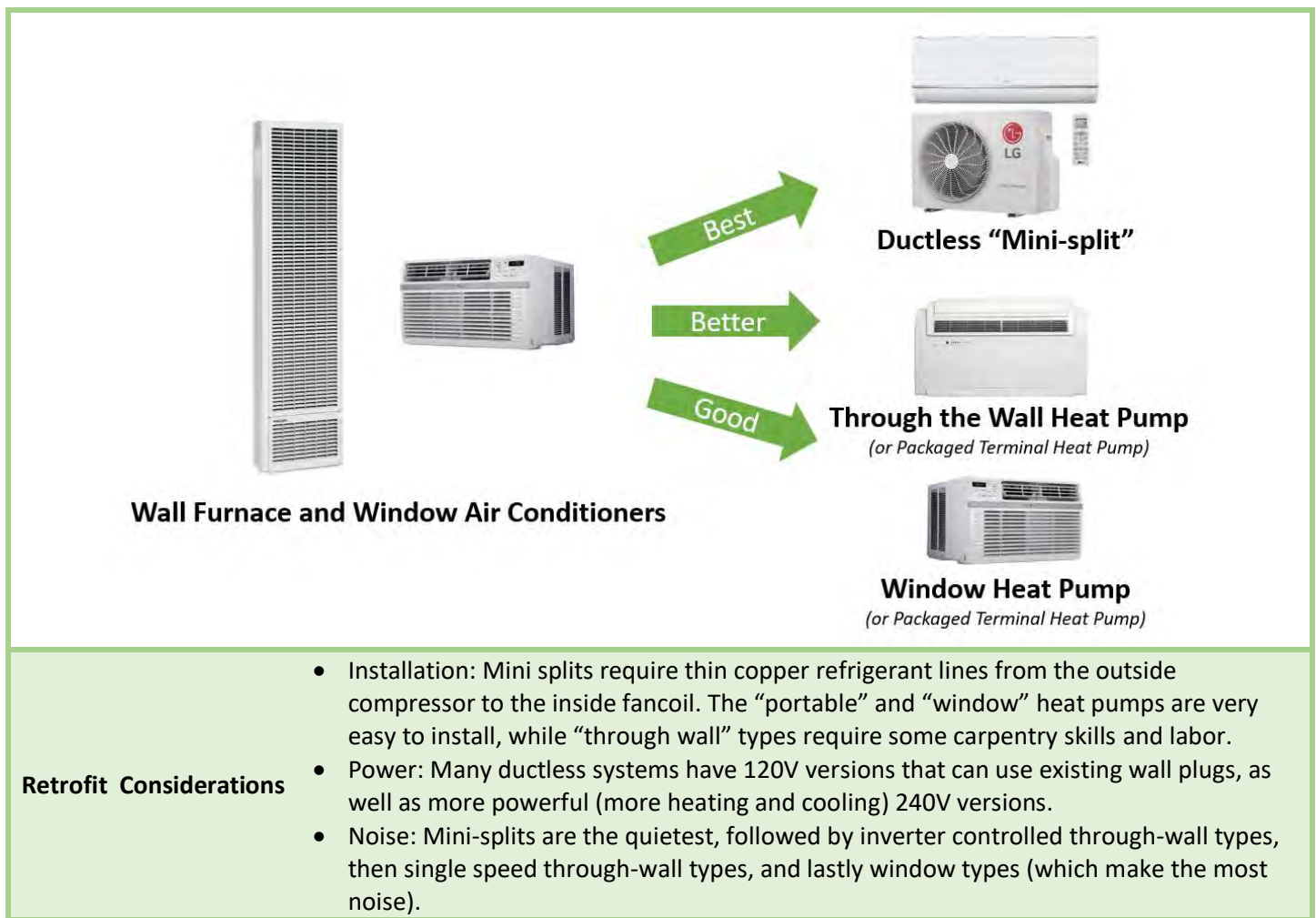


**Retrofit Considerations**

- Typically, air handlers for heat pumps are 240 volts and air handlers for furnaces are 120 volts so it is important to note the circuit that the air handler uses. However, a common work around is to connect the heat pump and the air handler with an “umbilical cord” wire, bypassing this issue.

### Box Swapping a Ductless System

In this scenario, where there is no existing ductwork, ductless heat pumps can be a good fit. Not having ducts reduces energy losses, and ductless mini splits are the most efficient heat pumps on the market. Smaller, older homes will sometimes have gas wall furnaces with the addition of window air conditioners. Even if you have one or the other, getting a mini-split or packaged terminal heat pump (reversible window air conditioner) is a great choice because they both provide heating and cooling out of just one box. If aesthetics is your strongest driver, mini-splits can also be installed to have mini-ducts (or horizontal ducts) which are shorter than typical ducts and can be packaged away in attic space out of sight.



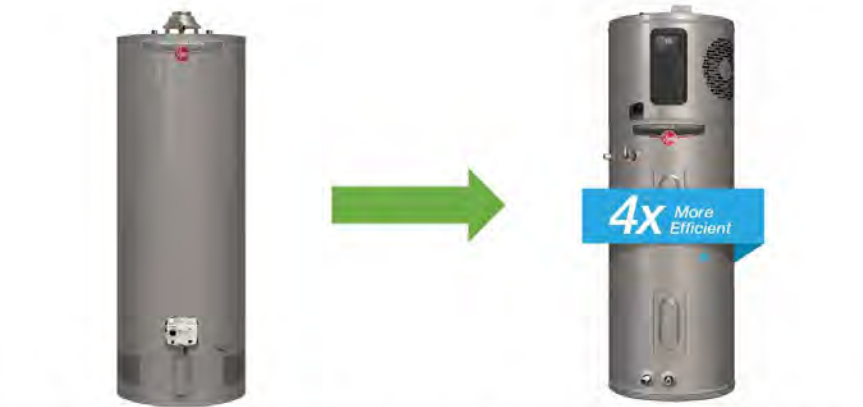
## Box Swapping a Water Heater

Retrofitting your gas tank water heating can be done with either an electric resistance type water heater or by using a more efficient heat pump water heater. It is not feasible yet to do a simple swap-out of an on-demand gas water heater with a heat pump water heater—wall-hung heat pump water heaters are just coming on the market in the U.S., although sold widely overseas. Note that some heat pump water heaters are referred to as “hybrid” because they have back-up electric resistance, which is needed sometimes with refrigerants (e.g. R-134a) but not others (e.g. CO<sub>2</sub>). This is true because the refrigerant R-134a does not produce as much heat at lower outdoor temperatures, however electric resistance back up can be avoided by increasing storage volume and increasing the temperature setting of the tank.

### Gas Tank Water Heater to Heat Pump Water Heater (HPWH)

Gas tank water heaters are typical in many homes. They can be box swapped with electric heat pump water heaters (HPWHs) of the same size or larger. Common heat pump water heaters come in various volumes-- 40, 50, 65 and 80 gallons--but require 240 volts of power because they were initially developed to “box swap” with 240V electric resistance water heaters.





**Gas Tank Water Heater**

**Heat Pump Water Heater**

**Retrofit Considerations**

- Most existing models require 240V electricity and can share the 240V outlet for the laundry dryer with a circuit-sharing plug (see product guide section for options), although a 120V version by Rheem has come out.
- The heat pump water heater can use indoor heat or be vented to the outdoors
- A small condensate water pipe needs to be routed either outdoors or it can be routed down an existing washer standpipe line, or into a laundry sink or floor drain
- They are fairly quiet at 50 decibels of fan and electric motor noise, like that of a laundry dryer

Gas water heaters in most garages have a nearby 240-volt plug for the electric clothes dryer. One solution would be to wire a new circuit 30-amp circuit to power the HPWH, or another solution is to use a power sharing device that splits the circuit between the heat pump water heater and dryer. An example of an automatic power sharing device would be that once the dryer is done running, it automatically switches power back to the water heater. Because the power sharing device takes turns powering either the water heater or the dryer, it avoids overloading the circuit. Another solution would be to get a combined washer and dryer that can plug into a normal 120-volt socket, leaving the 240-volt plug for the heat pump water heater.

Also, currently out from Rheem and soon to be released by GE under the name Haier are “retrofit ready” heat pump water heaters, that plug into a typical 120-volt typical outlet. These new retrofit ready water heaters are expected to draw only around 7.5 amps. So, instead of wiring a new 240V circuit or replacing your standard electric dryer, you can use a 120V retrofit ready heat pump water heater.

### Three ways to get more hot water – which one is right for you?

The more people in the home, the more hot water you will use. If you have two people in your home you will probably want a 40-gallon water heater, for three people would use 50 gallons, 4 people would use 65 gallons, and 5+ people use 80 gallon tanks.<sup>45</sup> Current (no pun intended) Heat pump water heaters are generally either 30-amp or 15-amp machines based on the Amperage of the electric resistance backup elements they use to supplement the heat pump. The 15-amp products put less power into the water during the course of the first hour test so all else being equal, they would deliver slightly less hot water in the first hour test and thereby have a lower **first hour rating**.

#### Three ways to get more hot water:

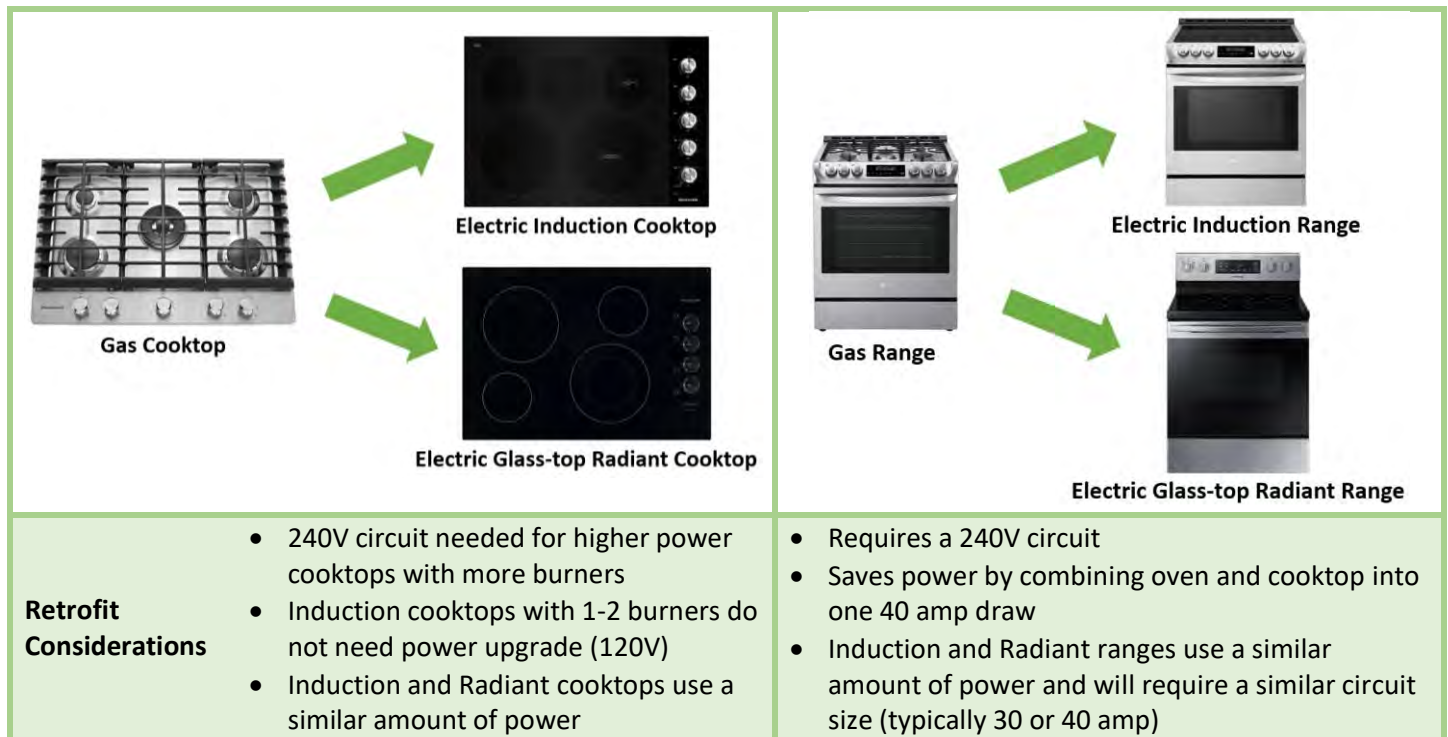
1. Set the tank to a higher temperature (and use a mixing valve to avoid scalding if you are setting it above 130F)
2. Select a larger volume tank
3. Select a higher power heat pump water heater that is 30-amps

## Box Swapping a Stove

Electric stoves use the same amount of space as gas stoves, and come in every fashion—sleek, antique or simple. Most require 240V power though, requiring a few hundred dollars of electrical work before it can plug in. Induction cooktops are favored by many professional chefs and they are easier to clean, faster to cook with, and they create less indoor air pollution. However, electric radiant stoves are roughly half as expensive, also come with easy-to-clean glass tops, but are less controllable, slower and about 10% less efficient than induction. Electric radiant cooktops allow you to use aluminum and other non-ferrous pans, while induction requires cookware with iron content, like cast iron or some types of stainless-steel pans. Any pan that a magnet can stick to works well for induction cooking. You can continue using glass and aluminum pots with induction if you put a steel disk beneath it—they are commonly sold for induction retrofits. A lower cost retrofit is to use countertop induction cooktops that are smaller (1 – 2 burners) and use 120V electricity, so they can use any of the kitchen plugs, paired with 120V countertop ovens.



**Figure 19: A stainless steel disk used to convert your favorite pan to be compatible with an induction cooktop, called a "heat diffuser" or "Induction adapter plate".**



If you have a gas oven and gas cooktop, then you might lack a dedicated, high power circuit required for electric stoves (40-50 Amps at 240V). The no-circuit upgrade solution would be to use one or two countertop induction cooktops. The other option is to run an additional, dedicated 240V circuit for 40-50 Amps. If the cooktop and oven are separated, they count as needing more power, and both require a dedicated circuit. Double ovens tend to need double the power of single ovens (40 amps vs. 20 amps).

## Box Swapping a Gas Clothes Dryer

As discussed above, about 12% of homes have gas fired clothes dryers. You don't need to have a high power (240V) outlet available, you can retrofit with a combined "All-in-one" condensing washer-dryer that can plug into any outlet in the home (120V). However, the washer-dryer still needs to have a supply water pipe and a drainage pipe, so its easiest to locate it where the existing washing machine was.



**Standard Washer and Dryer**

**Combined Washer and Dryer**







**Retrofit Considerations**

- Combined washer/dryers can plug into a 120V / 15-amp circuit
- Needs a place to drain water
- Does not require venting

Heat pump dryers come in both 120V or 240V versions and are similarly as energy efficient as the combined washer/dryers. Some of them come with electric resistance back-up, so while they are more efficient they still require as much power as a standard electric dryer—30 Amps at 240V—which will necessitate a new 240V circuit to where you are replacing the gas dryer. Condensing washer/dryers come in sizes up to 4.5 cubic feet, while heat pump dryers come in sizes up to 7 cubic feet and resistance dryers can be as large as 9 cubic feet.

### Box Swapping a Gas Generator

During California’s planned power outages to prevent wildfire in 2019, residential back-up generators tragically became a daily source of fires.<sup>46</sup> Unfortunately most generators run out of fuel after two days, and more fuel is often unavailable or rationed during a major disaster—even gas stations run out or just can’t pump. To replace a gas generator requires a battery, ideally paired with a solar array so it refills itself every day. Below are examples of mobile electric generators—batteries with plugs—and their price closely matches the amount of energy they can deliver without recharging. The batteries go up in cost as their capacity increases which is measured in Watt-hours. For example, the Goal Zero Yeti 500X could power a 10-Watt lightbulb for 50 hours or could charge a 12W smart phone 42 times. As another example, the Goal Zero Yeti 6000X could run an average full-sized fridge (100W) for 60 hours. Further below are miniature examples of this—single light bulbs with battery back-up, which is Code mandated for commercial new construction and is now available for homes. *(See more Low-Cost Resilience solutions in the product guide at the end of the document.)*

						
<b>Model</b>	S200	Rockpals	RIVER 600	Goal Zero Yeti 500X	Goal Zero Yeti 1500X	Goal Zero Yeti 6000X
<b>Price</b>	\$170	\$220	\$350	\$700	\$2000	\$5000
<b>Solar charging</b>	Yes	Yes	Yes	Yes	Yes	Yes
<b>Battery Capacity (Wh)</b>	193	288	288	500	1500	6000
<b>Output Voltage (V)</b>	5, 12 (VDC) 120 (VAC)	5, 12 (VDC) 120 (VAC)	5, 12 (VDC) 120 (VAC)	5, 9, 12, 20 (VDC) 120 (VAC) / 2.5A	5, 12, 20 (VDC) 120 (VAC) / 16.5A	5, 12, 20 (VDC) 120 (VAC) / 16.5A
<b>Full charge time with 120VAC input (hrs)</b>	6-7	6-7	1.6	4.5 (120V/1A)	7 (120V/2A)	12 (120V/5A)



Below are examples of light bulbs with a battery built into their base. They screw into standard outlets and are as bright as 40–60-Watt incandescent bulbs, appropriate for day-to-day use, but during an outage they will stay on for 3-5 hours, enough to get through a night or two without electricity.

Picture of the LED Light Bulb + Battery				
Model	GE - A21	YKDtronics	JacksonLux	Neporal
Lighting Hours on Battery Power (hrs)	5	3-4	3-4	4-5
Wattage (W)	8	5	9	15
Lumens	760	500	850	800
Lumens/Watt	95	100	94.44	53.33
Price	\$15	\$8	\$9	\$11

### Box Swapping a Gas Generator with an Electric Car

In the wake of the 2010 tsunami in Japan that shut down all nuclear power plants, 1/3<sup>rd</sup> of Japan's electricity supply, in 2011 Nissan began promoting their electric cars as a resiliency resource that can power a house or small commercial building. In our product guides you'll find products that perform this work in the U.S. The island of Maui, with its constrained grid, and the Los Angeles Air Force Base<sup>47</sup>, with its need for resilience during emergencies, began using Nissans for Vehicle-to-Building and Vehicle-to-Grid chargers in 2014.<sup>48</sup> Honda, Mitsubishi, Toyota and other car manufacturers with standard CHAdeMO certified Level 2 charging plugs can now support bi-directional charging.

#### The Value of Resilience:

- \$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)

September 2020, Typhoon Faxai ripped through Japan resulting in 934,000 homes losing power.<sup>49</sup> To help during the crisis, Nissan dealerships outside of the power outage zone invited Leaf owner to come and charge for free, and those with vehicle-to-home chargers were able to also power their homes. One vehicle owner, Mr. N, blogged about how his Nissan Leaf's was able to power the lights, refrigerator and heat pump water heater for two and a half days.<sup>50</sup> His first resource was a 4.5kW solar array, which was able to meet most of the loads, and Mr. N was able to drive to the closest Nissan dealer outside of the outage zone and bring back a full charge to meet the rest of his needs.



Figure 20: Nissan unveils the U.S. commercial offering of Vehicle-to-Home charging for the U.S., using battery-powered Leaf cars and Fermata Energy bi-directional charging.<sup>51</sup>



Figure 21: A Nissan Leaf charging the grid as part of the Hawaii's JUMPSmartMaui program.<sup>52</sup>

Figure 22: The LA Air Force Base increasing its resiliency with the largest EV fleet on a federal facility, 42 vehicles of Nissan Leafs, KIA plug-in hybrid vans, Ford C-MAXs, and Chevy Volts with all these cars using Vehicle-to-Grid technology.



# Electric Retrofit Incentives and Rebates

Several different incentives and rebates are available for clean, electric heat pumps appliances and structural building efficiency upgrades. These are usually offered through utilities, local government, or states, and vary widely depending on your location. Taking the time to check with local utilities and agencies for discounts and incentives can save you thousands of dollars. PG&E, for example, has a marketplace with deep discounts and up to \$500 in rebates on some heat pump models.<sup>53</sup> Other utilities offer even larger incentives summarized in the Table below. The Sacramento Municipal Utility District (SMUD) has one of the nation’s most aggressive initiatives to encourage all-electric homes, offering incentives worth up to \$13,500 toward the gas-to-electric conversion of existing homes.<sup>54</sup> The federal government also has various incentives, one good resource is the [DSIRE Database of State Incentives for Renewables and Efficiency](#), which has state and federal incentive information. In addition, [The Switch is On](#) website has a incentive look up tool.

SMUD is also helping low-income customers by embedding electrification in its existing low-income energy efficiency program.<sup>60</sup> Roughly 80 percent of homes in the program receive electric heat pump heaters. Other energy providers are creating similar programs to assist low-income customers in the transition from gas to electric. Peninsula Clean Energy is launching a Low-Income Healthy Homes and Electrification Program in 2021, offering “turn-key” home upgrades that provide both energy efficiency and electrification at no cost to low-income residents in San Mateo County.

In California at least 16 different cities, community choice energy providers, and agencies offer additional rebates and incentives to replace gas appliances with electric. In the San Francisco Bay Area, the BayREN program gives \$1,000 in incentives to the installing contractor for Heat Pump Water Heaters as well as rebates for other electric conversions in their Home Plus program.<sup>62</sup> Some area community choice energy providers layer additional rebates onto the BayREN discount, however these discount programs are not always “stackable” with other utility discounts.

**Table 3: Just a few rebates and incentives for electric appliances.**

<b>SoCal Edison<sup>55</sup></b>	<ul style="list-style-type: none"> <li>Up to \$1,000 for Electric Water Heaters</li> <li>Up to \$300 for Central HVAC Heat Pumps</li> <li>Up to \$600 for Mini Split HVAC Heat Pumps</li> </ul>
<b>SMUD<sup>56</sup> which has the nation’s largest “beneficial electrification” rebate program</b>	<ul style="list-style-type: none"> <li>Up to \$750 for Induction cooktops</li> <li>Up to \$2500 for Heat pump HVAC</li> <li>Up to \$2500 for Heat Pump Water Heaters</li> <li>Up to \$2500 for Electrical Panel Upgrades</li> </ul>
<b>Great Northwest Installations, Oregon<sup>57</sup></b>	<ul style="list-style-type: none"> <li>Deep discounts on Heat Pump Water Heaters of roughly \$1300 for a total installed cost of \$800-\$1550 (for 40 gallon to 80 gallon sizes)</li> </ul>
<b>Peninsula Clean Energy<sup>58</sup></b>	<ul style="list-style-type: none"> <li>\$1,500 for HPWH on top of BayREN’s \$1,000</li> <li>Electrical Panel Upgrade to 100 amps \$1,500</li> <li>Electrical Panel Upgrade to 200 amps \$750</li> </ul>
<b>City of Palo Alto<sup>59</sup></b>	<ul style="list-style-type: none"> <li>\$1,500 for heat pump water heater</li> </ul>
<b>Federal – Residential Energy Efficiency Tax Credit</b>	<ul style="list-style-type: none"> <li>Up to \$500 for water heaters, heat pumps, air conditioners, building insulation, windows, roofs</li> </ul>



**Figure 23: Summary of the incentives offered by BayREN.<sup>61</sup>**

In addition, some local agencies, such as Silicon Valley Clean Energy, have developed online customer assistance programs to help customers replace gas appliances with electric; their eHUB helps customers find the best electric appliance including the discounts, as well as local installers.<sup>63</sup> Other agencies offer discounts on heat pump water heaters replacing gas water heaters as a means of reducing peak energy use (or “demand response”). Sonoma Clean Power offers incentives for smart thermostats and heat pump water heaters, in addition to free electric car chargers.<sup>64</sup> They have partnered with GridSavvy to offer a \$5 per month bill credit on top of appliance discounts for customers that enroll in the demand response program.



## Case Studies of Complete Electrification Retrofits

Below are all electric retrofits from across the United States - whether it be in the coldest climates of the mid-west or in the temperature forests of northern California, all-electric designs are the desired choice for comfortable, efficient and environmentally conscious homes.

### *1890 Ranch, Ravenna, OH*

The region around Lake Erie has blizzards in the winter and humid heat in the summer, and older houses are rarely comfortable in all seasons. Habitat for Humanity volunteers in this small Ohio town near Cleveland retrofitted a very old home to help a disabled community member. The first step was reducing household moisture by sealing the basement's dirt floor with plastic sheeting. They then replaced the broken gas furnace and ductwork with a cold climate heat pump and new ductwork, paired with a dehumidifier on the fresh air supply. The heat pump water heater also does a small amount of dehumidification, along with reducing energy bills. With a final wrap of insulation and caulking all the cracks, the house is warm in winter, dry during the summer and supplied with clean, fresh air year-round. Retrofit design by Energy Smart Ohio.<sup>65</sup>



**Figure 24:** This 1890 home near Lake Erie was retrofitted by Habitat for Humanity volunteers to be all-electric and comfortable in all seasons.<sup>66</sup>

### *Ben and Sara Shalva's Home, Baltimore, MD*

Ben and Sara moved into their Baltimore, 1950s home in the fall of 2019. Rather than refill the tank of fuel oil for their furnace, they joined their neighbors and electrified the old heating system by replacing the existing air conditioner with a heat pump of the same size. Because it snows in Baltimore, they selected a "cold climate" heat pump that still heats during extreme cold weather (e.g. -20F). Cold climate heat pumps use small computers to control the heat pump, so it works well at any temperature, while old-fashioned heat pumps lack a computer that allows sub-freezing functionality.



**Figure 25:** Ben and Sara Shalva replaced their fuel oil furnace with a heat pump for a more comfortable, fossil fuel free house. Multiple neighbors recommended a local installer who had already replaced their fuel oil furnaces with heat pumps, saving utility costs every winter and adding AC to an old house for comfortable summers.<sup>67</sup>



### *Steve and Lisa Schmidt's Home, Los Altos, CA: Electrifying Without Increasing the Power Supply*

Lisa and Steve Schmidt, two “early adopters” in Silicon Valley’s all-electric retrofit program and well-known energy consultants, run their large 4,000 square foot Los Altos family home on a standard 200 Amp panel, even as they have retrofitted chargers for two electric cars, an electric motorcycle, an induction range, a combined washer-condensing dryer, a heat pump water heater and a heat pump for space heating and cooling.



**Figure 26: At the Schmidt’s home, the Bosch electric induction stovetop<sup>68</sup> is shared on the same circuit as the Rheem heat pump water heater<sup>69</sup> using the NeoCharge (middle) (Images courtesy of Steve and Lisa Schmidt).**

The trick to avoiding upsizing their power supply from 200 Amps to more (e.g. 400 Amps) was using NeoCharge plugs, which are similar to the SimpleSwitch, Dryer Buddy, Splitvolt and EV-PowerShare plugs. These plugs are designed to share power between two 240V devices using one plug. The NeoCharge controls power



**Figure 27: The NeoCharge allows two electric vehicles to be plugged in at the same time at the Schmidt’s home, where one car is charged completely then it automatically switches over to the other car to charge (Images courtesy of Steve Schmidt).<sup>70</sup>**

use, so one electric car waits for the other to charge, or the water heater waits while the induction stove cooks, then resumes heating the water in the storage tank when the stove is done. This power sharing strategy avoided the need for an expensive panel and service line wire upsize.

Their other strategy was efficiency--rather than using a 7000 Watt electric resistance laundry dryer and triggering a wiring upgrade, they bought 700 Watt condensing washer/dryer, so efficient with its power demand that it can plug into any existing 120V outlet. Lisa loves it-- *“The condensing Washer/Dryer is just outstanding. It washes quickly and does a better job than my old washer and dryer—the clothes come out cleaner and very dry. I’m thoroughly impressed.”*



## Wei-Tai

### Kwok's Home, Lafayette, CA

Wei-Tai Kwok, a solar energy executive with construction skills, electrified his house to be part of the solution to global climate change.<sup>72</sup> "I've seen and used ductless mini-split heat pumps countless times during my Asia travels, with each room having a remote control and the ability to adjust the fan levels. It didn't really register in my head that the reason was because it's simply the most cost-effective way for them to get modern day comfort, and that someday my house would benefit from this same technology."



Figure 28: Out with gas and in with electric mini-splits and induction cooking!<sup>71</sup>

## Peter and Margaret Darby's Home in Hamilton, NY

This all-electric home called Newbridge Farm was built in 1830 and has seen many transitions over 190 years, first burning wood, then coal, and next was fuel oil until Peter Darby completely electrified it, installing a water-source heat pump that uses heat from groundwater.<sup>73</sup> The chilled groundwater is then discharged into a lovely backyard stream. Peter is a City Councilmember in Hamilton and has helped lead political efforts to prevent new natural gas fracking within the town boundaries while educating his neighbors about how to completely electrify their homes.



Figure 29: Peter Darby's home that was built in 1830 was retrofitted to be zero emissions and all-electric, including a water source heat pump that uses well water as the heat source, and discharges the water into the adjacent creek.<sup>74</sup>



### *Campus Center for Appropriate Technology (CCAT) at Humboldt State University, Arcata, CA*

This campus home to three student Co-Directors is the nation's last demonstration house from the 1970s, outliving hundreds of others founded by the Carter Administration because student funding made it immune to federal funding cut-backs. Tens of thousands students have toured, while hundreds have built and maintained a back yard wind turbine, pedal powered appliances, rooftop solar panels and even a French fry grease biodiesel refinery. Nightly meals are cooked on an induction range, and showers are heated with a heat pump water heater. The organization's unique student leadership model has led to students founding related groups, like Earth First! Humboldt that taught and organized tree sits to challenge local illegal logging of old growth redwood forests; Arcata's "Bayside Farm Park," which has started many professional organic farming careers; HSU's nearly first-in-the-nation Environmental Science degree program, and many more campus clubs that collect campus recyclables, compost cafeteria food waste, fix students' bicycles, and grow food for the homeless.



**Figure 30: The Campus Center for Appropriate Technology: outside image of green house and garden, bike power generation, Julia Butterfly Hill an environmentalist activist, and the student staff.<sup>75</sup>**



**Figure 31: The Perlita Passive House: the original house was stripped to the studs, re-insulated, tested and made into an LA modern masterpiece of efficiency.<sup>76</sup>**

### *Perlita Passive House, Los Angeles, CA*

The Gaucher Family retrofitted their home to be the first Passive House certified home in Southern California, removing the gas service and installing a 100% offset solar array. Significant amounts of insulation, both inside and wrapping the building, prevent thermal bridging, while high performance windows and a very tight envelope almost eliminate heating and cooling loads.<sup>77</sup> With these extra measures the all-electric home uses a modest 4kW array to power an entire 2,000 sf house, two thirds of what a similar house would require without deep efficiency measures.



### *Jon and Kelly's Home, Cleveland Heights, OH*

Jon and Kelly wanted to turn their 100-year-old house into a zero-emissions home to reduce their impact on the climate while also making the house more comfortable. Also, after living through several power outages, they wanted to make their home as off-grid as possible. A 3-ton Carrier Greenspeed heat pump was all that was needed to heat and cool their home and the resulting cost to heat their home is on par with other gas systems in the area.<sup>78</sup> The air sealing and insulated was extensive – special attention was paid to the attic, which was insulated with spray foam and finished with dry wall creating a workout room with AC. The end result of the envelope was R-13 walls and R-25 attic with an electric resistance water heater and electric stove. Kelly and Jon are happy they retrofitted – the value of their home increased, it is highly efficient and comfortable, their cost of living went down, and most importantly they are reducing their carbon footprint. Read the full detailed case study at [Energy Smart's website](#).



Figure 32: Jon and Kelly's retrofit snap shots, new siding (left), adding insulation, and their Carrier Greenspeed heat pump.<sup>79</sup>

### *Colonial Solar House, Urbana, IL*

Upon becoming increasingly concerned about the impacts of climate change and attending a presentation on net-positive energy housing, Scott Willenbrock made the decision to completely retrofit his colonial home to provide all its own energy. First, he installed solar



Figure 33: All electric retrofit in Heartland (Building Performance Journal)<sup>80</sup>

photovoltaics on top of his garage and roof that have microinverters attached to the back. The microinverters allow for each of the modules to operate even if one of them is shaded. Next his natural gas furnace was replaced with a ground-source heat pump. Previously, the house was built with no insulation; however, after running an energy audit he was able to insulate with closed-cell foam. Paul and his family have been enjoying his all-electric retrofit for the past 3 years.<sup>81</sup>

### *The Bindley Carbon Neutral Renovation, Holderness, NH*

After attending a seminar about the effects of climate change, Jane Bindley, owner of the original 70's ranch house, enlisted the help of Ben Southworth to curate a carbon neutral renovation. Ben and Marc Rosenbaum (the energy engineer) installed a 7.5-kilowatt solar array on top of the roof to produce all the power the house would consume over the course of a year. Next, a ground source heat pump was installed and replaced the old oil boiler system. High performance Thermotech windows and doors were installed for better insulation. CFL lights bulbs were switched out for LEDs for efficiency and durability.<sup>82</sup> Lastly, the envelope is tightly sealed with lots of insulation to keep its residents comfortable: wall R-52, roof R-72, basement wall R-40, basement Floor R-25. Combining thermal comfort and all-electric devices with solar meets Jane's goal of being carbon neutral.



Figure 34: The 1970's Ranch Home (left), during the renovation (top right) and Jane Bindley.<sup>83</sup>

### *Ross Residence, Amherst, MA*

This old home built in 1884 was in need of a deep retrofit. The new homeowners, the Ross's, came to Coldham&Hartman Architects with a completely new design in mind. The first order of business was to completely redo the existing roof. The bay roofs were torn off and a new roof was installed, accompanied with 12.4 kW of photovoltaics. Moving towards a no combustion household, the Ross's decided to install a 15 Amp Steibel Eltron heat pump water heater and an induction cooktop. To heat and cool the house a Mitsubishi CityMulti Multi-port air source heat pump was installed. The Ross's are now enjoying their completely renovated home. Due to the well-insulated envelope, even during a snowstorm with no power for two and half days, and outside temperatures being 20 degrees, their home never went below 67 degrees.<sup>84</sup> Read the full case study at the [1000 Home Challenge](#) Website!



Figure 35: The Ross Residence newly renovated home.<sup>85</sup>



### *Erika Reinhardt's Family Residence, Bay Area, CA*

To address the urgency of climate change, Erika Reinhardt and her family replaced their 2018 gas appliances— a gas stove, a gas dryer, and a gas boiler for radiant floor heating and domestic hot water. The replacements were a new induction range, an Energy Star efficient electric laundry dryer, and a Chiltrix CX34 air-to-water heat pump with tanks to provide hot water for both radiant heating and domestic hot water. A natural gas fireplace and outdoor grill were turned off— neither were used enough to justify replacement. Each of the appliances required a new 240V circuit, but the existing circuit breaker panel was right sized already for their new all-electric home.

The induction range and laundry dryer were easy to install because contractors are familiar with this process. The most challenging element of this renovation was finding a Bay Area contractor familiar with heat pumps that support radiant floor heating. Many interviews were necessary before finding an experienced crew, and Bay Area construction prices are double those of lower cost communities in the U.S.



Figure 36: Erika Reinhardt's electrified home in California (images and description courtesy of Erika Reinhardt).

### *Modest Manor, San Francisco, CA*

A pair of shy do-it-yourself sorts electrified their 2,200 square foot two story home on a budget in little experimental stages. The original 1940's home had been remodeled in the late 1990's with a 150 Amp underground service line and has R-38 insulation in the roof and R-13 in walls. The first floor has about 900 square feet that is uninsulated over the "half dirt basement" where the old furnace and water heater used to sit. Watching a few plumbing and electrical videos, reading a how-to book on wiring and volunteering with **SunWork.org**, the homeowners built up skills and confidence to pair up with their buddies to take turns in electrifying each other's homes. They realized it's not rocket science and it can be a fun hobby that saves thousands of dollars.

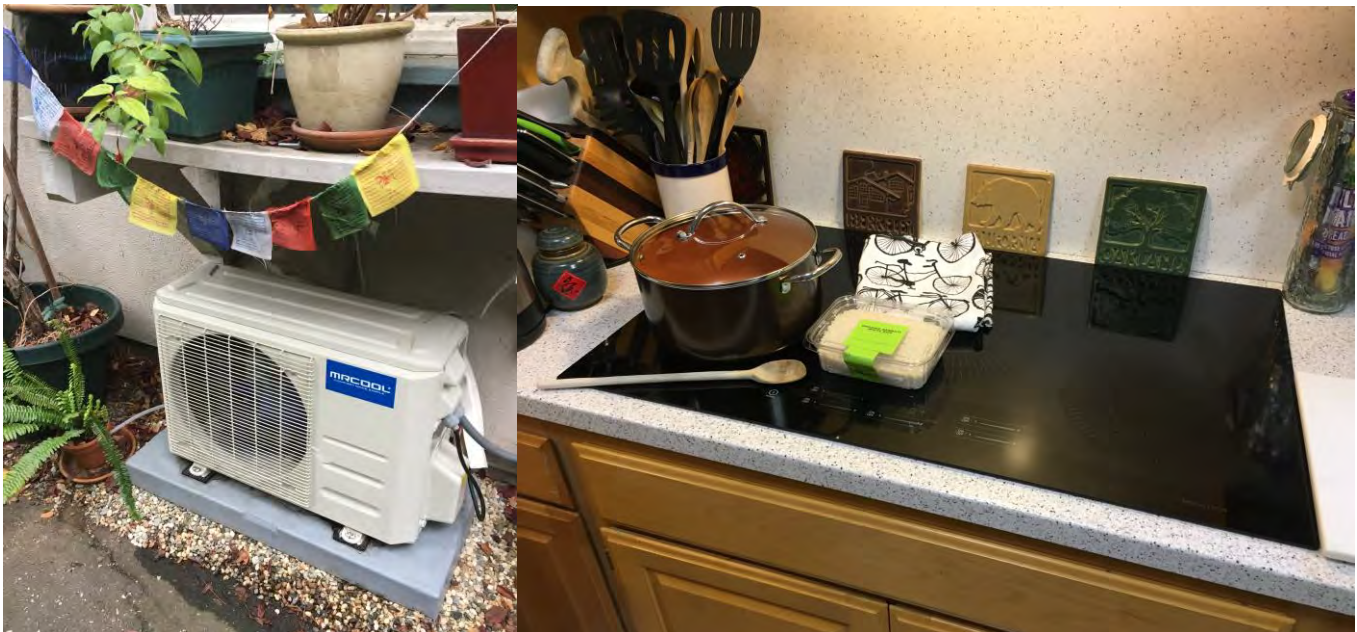


Figure 37: The Modest Manor's Mr. Cool Minisplits heat pump and induction cooktop.



We started with the heat pump water heater and included a couple of tee and ball valves to accommodate a future hydronic heating system. Next was the window heat pump – it was so easy that even renters can pop them in and take them out when they move. The third project was the pre-charged DIY version of “Mr. Cool” brand mini-split that can easily be installed on an exterior wall by passing the pre-charged sealed “line-set” through a 3 inch hole. The most recent project was a 36 inch five “burner” Frigidaire Gallery induction cooktop replacing our 20-year-old gas cooktop.

The homeowners love the new benefits of zoned heating and cooling as well as a gas-free kitchen. They may install another DIY mini split or a simpler \$600 portable dual hose heat pump placed in and vented up the old brick fireplace and chimney. They plan to plug the old ductwork and abandon it in place and to remove the 35 year old gas furnace to free up some space.

The gross cost of purchasing and installation has been \$6,400 all together and it avoided the cost of gas fired replacements. The gas cost alternatives would have cost at least \$5,000 for the gas furnace, gas water heater, gas cooktop and gas dryer – so the net cost was only about \$1,400. When any of the electric units burn out, the second replacement will be quick and easy because the new circuits are all in place now.

**Table 4: Summary of costs for the Modest Manor DIY retrofit.**

Appliance	Type of Cost	Cost	DIY Labor Hours	Specifications
<b>Heat Pump Water Heater</b>	Appliance	\$1,200	4	50 Gal. Discontinued HPWH from Lowe’s
	Materials Electrical	\$150	5	New 240V 30A circuit in flexible armored conduit
	Pipes and fittings	\$190 for materials & lunch for my buddy	10	Connectors and ball valves for future hydronic heating coil plus condensate pump and line
<b>Window Heat Pump</b>	Appliance	\$390	1/2	Frigidaire 8,000 Btuh 120V plug-in window heat pump. # FFRH0822R1
<b>Mini-Split Heat Pump</b>	Appliance + shipping	\$1,600	1	Mr. Cool DIY 12,000 Btuh variable speed 120V
	Electrical Materials	\$120	5	New dedicated 120V 20 Amp outdoor outlet serving as “disconnecting means”
	Head Installation	Free with my buddy after we did hers	9	Watch video, mount bracket, drill hole, pass line-set through it
	Compressor Installation	\$40	3	Bolt to plastic base on gravel bed
<b>Induction Cooktop</b>	Appliance	\$900	1	Frigidaire Gallery “36
	Materials Electrical	\$190	5	Crawling under house to run new 240V 40A circuit
<b>Combined Washer/Condensing Dryer</b>	Appliance	\$1,600	1	It just plugs in where the prior washer was and replaces washer and dryer.
<b>Total</b>	Gross Cost	\$6,400	45	Net Incremental Cost \$1,400 if we subtract out the cost of new gas machines.



# Additional All-Electric Case Studies

Mackey Deep Energy Retrofit, PA<sup>1</sup>



Dateo Family Home, CA<sup>2</sup>



Willowbrook House, TX<sup>3</sup>



Swanson Family Home, CA<sup>4</sup>



Fink-Simo Family Home, MA<sup>5</sup>



Cinnamon Family Home, CA<sup>6</sup>



Delforge Family Home, CA<sup>7</sup>



Markiewicz and Ahrens Home, CA<sup>8</sup>



A Retrofit by emeraldECO, CA<sup>9</sup>



Ron and Lee's Family Home, ME<sup>10</sup>



Byron Family Home, CA<sup>11</sup>



Road to Energy Independence Retrofit, WI<sup>12</sup>



Ghosh Family Home, CA<sup>13</sup>

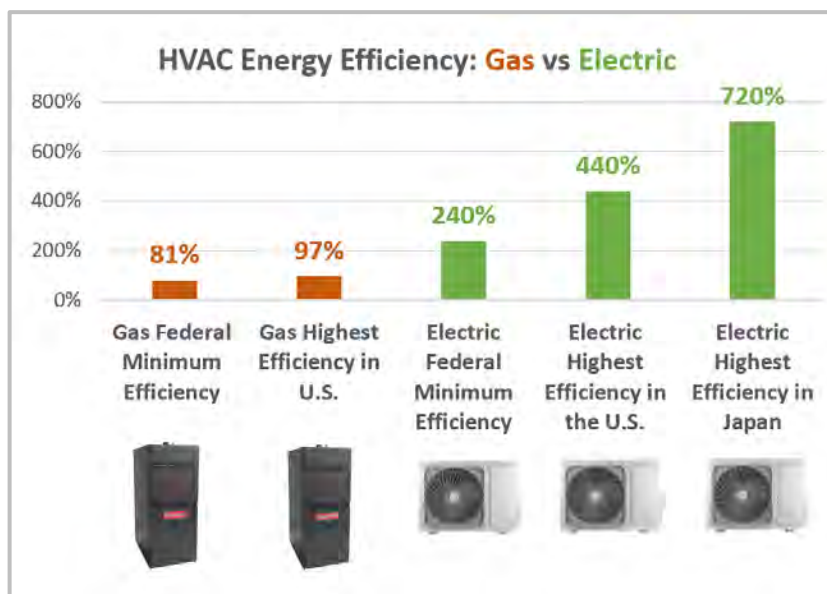




## All-Electric Product Guides

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 a key solution to meeting our largest energy demands in buildings—space heating and water heating. 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 38: 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.



**Figure 39: Fujitsu heat pump in the snow.<sup>86</sup>**

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.

Cold Climate Heat Pumps can now collect heat from outside air down to Arctic temperatures (-20°F)<sup>87</sup>, 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.



## 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 1/3<sup>rd</sup> as much energy and require only 1/3<sup>rd</sup> 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 gasstoves.<sup>88</sup> 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.



**Figure 40: Consumer Reports prefer induction, the top 6 of 8 ranges for 2020 were induction.**

### Glass Top Radiant Range (\$550 or less)

Manufacturer and Product Image	Amana AER6303MFS	Whirlpool WFE320MOES	Frigidaire FFEF3052TS	GE Appliances JBS60DKBB
				
<b>Max Power (Watts)</b>	1,800	3,000	100-3,000	3,100
<b>Price</b>	\$450	\$550	\$550	\$550
<b>Oven space (cu. ft)</b>	4.8	4.8	4.9	5.3

### Glass Top Radiant Range (Greater than \$500) (240V using a 40amp circuit)

Manufacturer and Product Image	Samsung NE59M4310SS/AA	GE JB480DMBB	LG LSSE3026ST	Bosch 800 Series
				
<b>Max Power (Watts)</b>	9,600	10,500	13,500	14,800
<b>Price</b>	\$700	\$950	\$1,800	\$2,200
<b>Oven Space (cu. ft)</b>	5.9	5.0	6.3	4.6






### Slide-In Induction Ranges (240V, 40 amp)

Manufacturer and Product Image	<b>Frigidaire</b> FFIF3054TS 	<b>LG</b> LSE4616ST 	<b>Frigidaire</b> Gallery FGIH3047VF 	<b>Samsung</b> Virtual Flame NE58K9560WS 	<b>GE</b> Profile PHS930SLSS 
Price	\$1,000	\$1,900	\$2,000	\$2,400	\$2,440

### Slide-In Induction Range (240V, 40 amp)

Manufacturer and Product Image	<b>KitchenAid</b> KSIB900ESS 	<b>Bosch</b> HII8056U 	<b>Café</b> CHS900P2MS1 	<b>Bertazzoni</b> Professional PROF304INSROT 	<b>Fisher &amp; Paykel</b> Series 9 OR36SCI6R1 
Price	\$2,970	\$3,400	\$3,420	\$4,990	\$7499

### Retro Induction Ranges

Manufacturer and Product Image	<b>Smeg Range Cooker</b> Victoria TR4110IPG 	<b>Retro Collection</b> BCRI30 	<b>Elmira Northstar</b> 1954P 	<b>Ilve Majestic II Collection</b> UMDI10NS3MBP 	<b>AGA Classic</b> ATC3 
Price	\$3,500	\$5,100	\$5,800	\$9,100	\$22,000
Max Power (W)	8,400	2,500	2,500	12,000	9,600
Oven space (cu. ft)	-	4.0	4.3	3.82	1.4 per oven






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

Manufacturer and Product Image	<b>True Induction</b> TI-1B 	<b>Avantco</b> DC1800 	<b>Adcraft</b> IND-DR120V 	<b>Spring</b> SM-651R 	<b>Bon Chef</b> 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


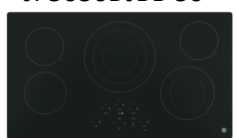



### Single Burner Countertop Induction (1800W, 120V and using a 15amp circuit)

Manufacturer and Product Image	<b>Aicok</b> 	<b>Avantco</b> ICBTM-20 Light Duty 	<b>Avantco</b> IC1800 Heavy Duty 	<b>NuWave</b> PIC Platinum 	<b>Vollrath</b> Mirage Cadet 59300 
Price	\$40	\$50	\$120	\$200	\$270
Temp. Range	140°F - 460°F	140°F - 460°F	140°F - 460°F	100°F-575°F	100°F - 400°F

### Double and Triple Burner Countertop Induction (1800W, 120V and using a 20 amp circuit)

Manufacturer and Product Image	<b>Eurodib</b> S2F1 	<b>True Induction</b> TI-3B 	<b>NuWave</b> PIC Double 	<b>Inducto</b> 	<b>Duxtop</b> 9620LS 
Price	\$200	\$525	\$200	\$150	\$190
Temp. Range	150°F -450°F	140°F -460°F <i>(Three Burners!)</i>	100°F – 575°F	176°F -460°F	140°F -460°F

### Four+ Burner Induction Stovetops (9600W, 240V using a 40amp circuit)





Manufacturer and Product Image	<b>Empava</b> B07VVYN2PV 36" 	<b>GE</b> JP5036DJBB 36" 	<b>Frigidaire</b> FPIC3677RF 36" 	<b>Samsung</b> NZ36K7880UG 36" 	<b>Elica</b> ENS436BL 36" 
Price (\$)	\$550	\$1,090	\$1,750	\$2,250	\$4,410

### Energy Efficient Cooking

Redwood Energy tested five types of cooking equipment to find the lowest possible use of cooking energy. We found that using insulated cooking appliances, or insulated pots, saves energy by dramatically reducing heat loss during cooking. Three test appliances were insulated--a Crock-Pot slow cooker, a COSORI pressure cooker and an Air Core insulated pot. The other two were not insulated--a SUNAVO electric hotplate and a Avantco countertop induction range. Our test was cooking a cup of dried chickpeas were soaked for 8 hours and drained of water. The beans were then added to the cookware with 4 cups of room temperature water. The chickpeas were fully cooked when the color change was consistent all the way through, but not so cooked that the chickpea would lose its structure. For both stovetop methods the pot of water was brought to a boil then left to simmer until the chickpeas cooked to the required texture. Time and energy use in kWh were taken from a P3 P4400 Kill A Watt Electricity Usage Monitor.

This study concluded that the ideal cookware to reduce energy consumption are the pressure cooker or slow cooker. Time is always a factor when it comes to the convenience of cooking, so pressure cooker is a great way to limit cooking time while getting similar low energy use as a slow cooker. For a traditional cooking experience, the induction stove top is a great alternative to the electric resistance cooktop. This method saves about 40 minutes in cooking time and uses about 22% less energy.











Manufacturer and Product Image	Crock-Pot SCR200-R slow cooker	COSORI C3120-PC pressure cooker	Avantco IC1800 countertop induction range	SUNAVO 1500W electric resistance cooktop	Air Core insulated pot w/ SUNAVO electric resistance
					
Price	\$10	\$70	\$110	\$50	\$50
Cooking time (hours)	2.76	0.34	1.21	1.87	0.34
Energy use (kWh)	0.19	0.19	0.64	0.82	0.31
Cost (cents)	3.2¢	3.2¢	10.7¢	13.7¢	5.2¢

\*Cost is calculated from the Californian 2019 average of 16.7 cents per kWh.

### Countertop Ovens (120V)

Are you looking to cook a full rotisserie chicken, but live in a tiny home or small electrified apartment? Well look no further, you can live large on a small circuit - countertop kitchen ovens are widely popular and can satisfy your oven cooking needs. The collection below represents the largest countertop ovens on the market that have various functions like convection and air fry technology.

Manufacturer and Product Image	Luby Large Toaster Oven	Aobosi Convection Toaster Oven	Galanz Airfry Toaster Oven	Oster Countertop Oven
				
Oven Size (ft <sup>3</sup> )	1.9	1.6	1.5	1.3
Dimensions (DxWxH) (in)	16.1 x 22.0 x 14.4	26.2 x 19 x 18.5	19.3 x 21.8 x 13.0	22.0 x 19.5 x 13.0
Power (W)	1800	1500	1800	1525
Price	\$133	\$169	\$199	\$220
Remarks	The shelving is poorly supported for heavy dishes.	Rotisserie option is nice for those who cook that way.	The timer and temperature settings are imprecise.	Our favorite: Controls, shelves and options all work well.

Manufacturer and Product Image	Black and Decker Toaster Oven	KitchenAid Dual Convection Countertop Oven	Breville BOV900BSS Smart Oven Air	Hamilton Beach Convection Oven
				
Oven Size (ft <sup>3</sup> )	1.1	1	1	-
Dimensions (DxWxH) (in)	21.5 x 14.5 x 11.2	16.4 x 18.5 x 13.0	17.5 x 21.5 x 12.7	20.6 x 16.5 x 13.1
Power (W)	1500	1800	1800	1500
Price	\$105	\$280	\$400	\$130
Remarks	Airfry setting Can fit a 9"x 13" pan	Built in temperature probe "Can bake 2 whole chickens (based on 3.6 lb. weight)"	14 lb. turkey, LCD display, 6 independent heating elements, 13 cooking functions	Rotisserie, convection

## Kitchen Hoods (Low Sound, High Air Flow)


To evacuate pollution from cooking properly, a quiet yet high air flow kitchen hood is essential. The effectiveness of kitchen hoods is so important that California is instituting a new policy in their building energy code - kitchen hoods for electric stoves must have a flow rate of 110 to 160 cfm and gas stoves must have a flow rate of 180 to 280 cfm, depending on the size of the unit. Venting pollution from gas cooking requires a higher flow rate because gas creates more pollutants when burned (like NO<sub>2</sub>, which is regulated by the EPA to maintain high outdoor air quality). The kitchen hood must also be at a sound level of 3 sones or less, so residents can use them comfortably. The following kitchen hoods meet this requirement in California, and are considered products for best practices for efficient, comfortable, and all-electric buildings.

Proposed minimum range hood capture efficiency (CE) requirements, and proposed alternative airflow compliance requirements for demand-controlled range hoods






Dwelling Unit Floor Area (ft <sup>2</sup> )	Hood Over Electric Range	Hood Over Natural Gas Range
>1500	50% CE or 110 cfm	70% CE or 180 cfm
1000 - 1500	50% CE or 110 cfm	80% CE or 250 cfm
750 - 1000	55% CE or 130 cfm	85% CE or 280 cfm
<750	65% CE or 160 cfm	85% CE or 280 cfm

Or  
Downdraft exhaust with minimum of 300 cfm (no change from 2019 requirements)  
Or  
Continuous exhaust at 5 kitchen ACH50 (applies to enclosed kitchens only – no change from 2019 requirements)

### Quiet Kitchen Hoods

Manufacturer and Product Image	ProLine PLJW 125 series 	Zephyr Power Typhoon Series AK2100BS 	KOBE Brillia CHX91 SQB-1 	KOBE Premium RA38 SQB-1 	FOTILE JQG7501 
Noise (sones)	1.5 @ 385 CFM 7.5 @ 900 CFM	2.5 @ 300 CFM	3 @ 300 CFM	3 @ 300 CFM	2.64 @ 510 CFM
Air Flow (CFM)	900	850	680	680	850
Width (inches)	30, 36	30, 36, 42, 48	30, 36	30, 36	30
Cost (\$)	\$719 (30 in) \$740 (36 in)	\$679 (30 in) \$629 - \$709 (36 in)	\$593 (30 in) \$600 (36 in)	\$539 (30 in) \$575 (36 in)	\$1,099.00

### Quiet, Low-Cost Ducted Hoods Compliant with California 2022 Code

Manufacturer and Product Image	Broan RP136WW 	Broan 	Whirlpool WVU57UC0FS 	KitchenAid KVUB400GSS 30" 	BV Range Hood 
Noise (sones) @ an Airflow Rate (Cubic Feet Per Minute)	0.5 @ 120 CFM* 7.0 @ 440 CFM	1.2 @ 150 CFM 3.0 @ 200 CFM 5.5 @ 280 CFM	0.5 @ low speed 5.2 @ 350 CFM	0.1 @ low speed 5.2 @ 400 CFM	1.5 @ 200 CFM 7.5 @ 750 CFM
Air Flow (CFM)	440	300	350	400	750
Width (inches)	36"	30"	30"	30"	30"
Exhaust Method	Ducted	Ducted	Ducted	Ducted	Ducted
Cost	\$170	\$200	\$220	\$365	\$340

\*compliant airflow for a dwelling unit of 1500 ft<sup>2</sup> or less floor area

## Heating, Ventilation and Air Conditioning

The following guide gives an overview of heating and cooling electric systems that are used in single-family and multifamily buildings. The sample of heat pumps shown are in three major categories – air source, geothermal, and hydronic. They range in size from 9,000 BTU/h to 600,000 BTU/h and include central heat pumps, mini-split heat pumps, packaged terminal heat pump, vertical terminal heat pumps, “all-in-one” HRV heat pumps, geothermal heat pumps, and hydronic 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

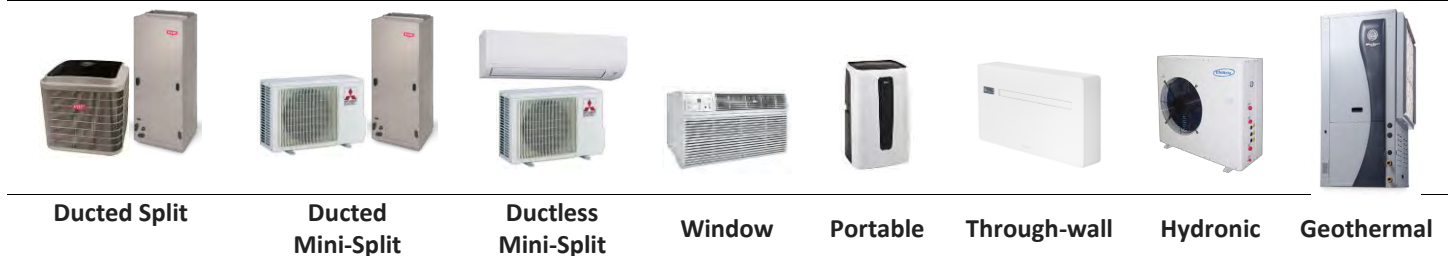
[https://neep-ashp-prod.herokuapp.com/#!/product\\_list/](https://neep-ashp-prod.herokuapp.com/#!/product_list/)

Energy Star Product Finder

<https://www.energystar.gov/productfinder/>

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

### Overview of Single-Family HVAC



### What is considered “high efficiency” for space conditioning air-to-air heat pump?

SEER is used to rate air conditioner efficiency, while HSPF is used to rate heating efficiency. Typical efficiencies for a heat pump range from 14 SEER / 8.2 HSPF on the low end for ducted systems up to 38 SEER / 15 HSPF on the high end for ductless systems. If your home is striving for high performance goals, then seek a system above 20 SEER and above 10 HSPF. An important thing to note is that the most efficient furnace is only 97% percent efficient at converting fuel to heat, while the most efficient mini-split heat pump is 410% efficient at heating (HSPF ~ 14).<sup>89</sup>

SEER: (Seasonal Energy Efficiency Rating) has units of Cooling BTUs provided per Watt-hour of electric use ( $SEER/3.412 = \text{Seasonal cooling COP}^{90}$ ) HSPF: (Heating Season Performance Factor) has units of Heating BTUs provided per Watt-hour of electric use ( $HSPF/3.412 = \text{Seasonal heating COP}^{91}$ )

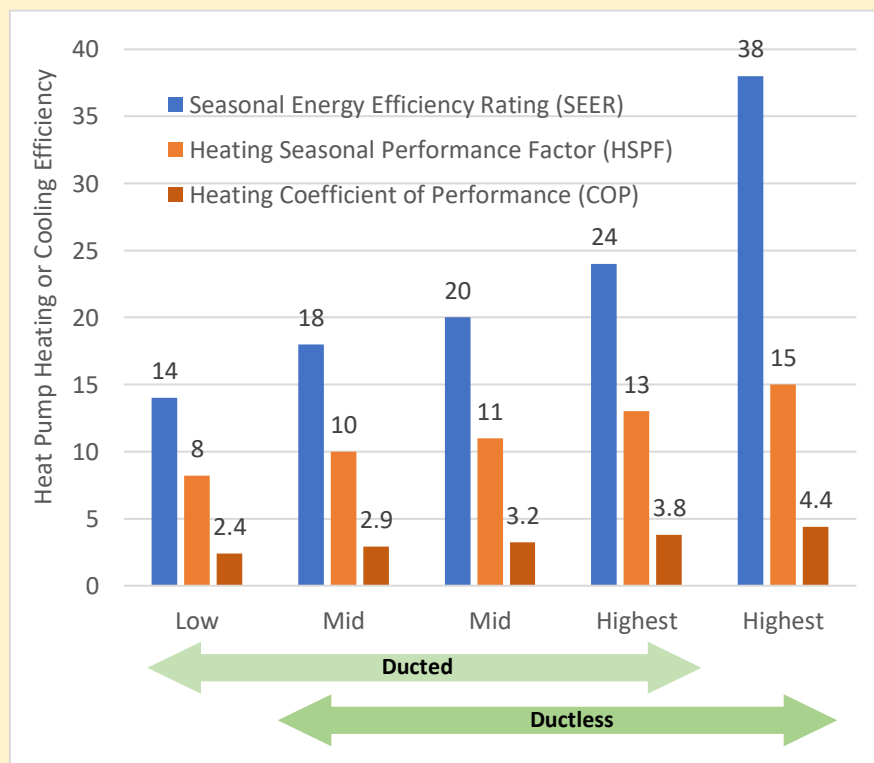


Figure 41: Typical heating and cooling efficiencies of heat pumps.







## Air Source Heat Pumps (Air-to-Air)

Using a reversible air conditioner – a “heat pump” – to heat people’s homes began in the 1930s, grew in popularity in the 1950s when they became smaller and more affordable, and has grown exponentially world-wide. Air source heat pumps that heat air do so with fan coils that may be mounted on the wall or ceiling or hidden in the ceiling or a closet and connected to ducts. Starting in 2001, computers began to be added to heat pumps—these small computers calculate in real-time the heat available outdoors vs. the heat requested indoors and speed up the internal parts to collect more heat as the outdoor temperature drops, even down to  $-31^{\circ}\text{F}/-35^{\circ}\text{C}$ . They have the side benefit of being much quieter than single-speed heat pumps. Heat pumps with these computerized controls are often advertised as having “inverter drives,” “variable speed” or “variable refrigerant flow,” phrases which all have the same meaning.

## Central 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.

Manufacturer and Product Image	<b>York</b> YZH02412C 	<b>Goodman</b> GSZC180481C 	<b>Daikin</b> DZ14SA0483 	<b>Carrier</b> Infinity 25VNA036A003 
<b>Dimension (in) (WxDxH)</b>	42 x 23 x 34	35 x 35 x 38	29 x 29 x 34	35 x 28 x 44
<b>Crankcase Heater</b>	No	Yes, with switch	Factory-installed	Internal, Factory Installed
<b>Ref. Type</b>	R410a	R410a	R410a	R410a
<b>Ambient Temp. Range (H/C) (F)</b>	<b>-10 – 115</b> <b>(cold climate)</b>	<b>-5 – 115</b> <b>(cold climate)</b>	<b>-10 – 65</b> <b>(cold climate)</b>	<b>-4 – 68</b> <b>(cold climate)</b>
<b>Power (W)</b>	2,500 – 3,412	4,830 – 4,840	3300	1,050 – 1,240
<b>Heating Capacity (BTU/h)</b>	18,000 - 59,000	22,000 – 59,500	44,500	25,000
<b>Cooling Cap. (BTU/h)</b>	19,000 – 58,000	23,000 – 56,500	45,000	36,000
<b>Heating (COP)</b>	2 -4	1.47 – 6.77	3.95	2.3 - 4
<b>Cooling (COP)</b>	4 – 4.4	3.66 – 4.10	4.1	4 – 4.4
<b>Price (\$)</b>	\$ 2,000	\$ 2,500	\$ 2,000	\$ 3,200

## Energy Consequences of Uncontrolled Crank Case Heaters

Traditional ducted Heat Pump and Air Conditioner Compressors are often heated with a crank case heater (or sump heater), which keeps the lubricant warm enough to not mix with refrigerant – preventing it from becoming “milky” and resulting in a noisy, inefficient heat pump. These can use a significant amount of electricity if uncontrolled (e.g., 100W on 24/7/365 becomes **876 kWh/year which can double the energy use of a smaller home**), but can be designed to use much less energy, and only when needed. Some HVAC heat pumps do not use them *at all* due to different lubricants or modified design. One should consider this non-rated, but real, energy use when choosing a heat pump.



Figure 5: “Belly Band” crankcase heater (heating wire wrapped around compressor).



Figure 6: Insertion crankcase heater (heating element inside compressor).

Many manufacturers have devised strategies to avoid or reduce the use of a crank case heater:

- Using lubricant that does not mix with refrigerant
- A recycling pump that stores refrigerant away from the compressor lubricant during shut down
- Temperature sensors that only turn on the crank case heater when the refrigerant gases are approaching liquid state and could mix with lubricant

While crank case heaters are not always clearly identified in product specification sheets, asking for information from the Contractor or their Distributor will clarify whether you may have a heat pump that performs as advertised or an unidentified, potentially large “phantom load.”

## 120V Air Handlers

Typical air handlers for furnaces are 120V, but typical air handlers for heat pumps are 240V. Supplying 240V electricity for a fan is overkill, and a relic of the era before 2009 inverter-controlled heat pumps allowed heat pumps to avoid resistance heat when the temperature dropped below freezing. This is no longer needed and some manufacturers, like Mitsubishi<sup>1</sup>, Mr. Cool, and Fujitsu supply 240V power via wiring wire from the outdoor 240V compressor/condenser. However, below are 120V heat pump air handlers that can use the existing furnace fan wiring, avoiding the need to run a new wire.

Manufacturer and Product Image	Advanced Distributor Products B Series Air Handler <sup>92</sup>	Stelpro SCV-P-1411 <sup>93</sup>	King Electrical Mfg. Co. AH1/5-120V <sup>94</sup>
			
Price (\$)	Not public	\$925	\$965
CFM	800	1400	1000
Size (in) LxWxH	22 x 15 x 44	24.75 x 22 x 22	20 x 16 x 30.5

<sup>1</sup> Page 44, shows the multi-position air handling unit that pairs with the Mitsubishi outdoor compressor heat pump <<https://www.mitsubishi-pro.com/pdfs/m-series-catalog.pdf>>

## Mini-Split Heat Pumps (240V)

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



**Figure 42: An example of a ductless mini-split heat pump outdoor compressor<sup>95</sup> mounted to stay above the snow and a wall-mounted indoor fan coil<sup>96</sup>.**

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.

## The Complete Cost of Mini-Split Systems

The following section gives an overview of the costs associated with hiring a contractor to install ductless heat pumps. The first table show the pricing for leading manufacturers for single-head and multi-head systems. Below is a 2019 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.

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 <sup>a</sup>	\$8,500 <sup>a</sup>	\$10,500 <sup>a</sup>	n/a	
LG	\$6,200 <sup>a</sup>	\$7,800 <sup>a</sup>	\$9,400 <sup>a</sup>	n/a	
Panasonic	\$6,200	\$7,100	\$8,100	\$10,200	
Fujitsu	\$7,400 <sup>a</sup>	\$9,000 <sup>a</sup>	\$11,200 <sup>a</sup>	\$12,500	
Mitsubishi	\$8,500 <sup>a</sup>	\$10,500 <sup>a</sup>	\$12,900 <sup>a</sup>	\$15,500 <sup>a</sup>	
<ul style="list-style-type: none"> <li>• Multifamily installations, where the labor is onsite all day and able to accomplish 4-6 installations, cost ~30% less</li> <li>• Indoor units involving simple installation method, the outdoor and indoor unit sharing an exterior wall with 15' of interconnecting line sets and electrical</li> <li>• Indoor unit is of the high-wall mounted type</li> <li>• \$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</li> <li>• 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</li> <li>• <sup>a</sup> Indicates "cold climate" model</li> </ul>					



## 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 to 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.**

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

### What can you tell us about the installation costs of Short Ducted Heat Pumps?

The pricing of so-called short run ducted mini-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 comparing the cost of equipment per unit of BTU 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.

### Ductless Mini-Split Heat Pumps (120V)






Interior Wall-Mounted Fan Coil	GE Caliber Series AS12CRA	Mitsubishi MZ-JP12WA	Gree LIV (09,12) HP115V1B	Carrier 38MAR	Haier
					
<b>Description</b>	1 Indoor Fan Coil	1 Indoor Fan Coil	1 Indoor Fan Coil	1 Indoor Fan Coil	1 Indoor Fan Coil
<b>Dimension (in) (HxWxD)</b>	21 x 31 x 10	22 x 32 x 11	33 x 21 x 13	32 x 21 x 13	28 x 35 x 14
<b>Ref. Type</b>	R410a	R410a	R410a	R410a	R410a
<b>Ambient Temp. Range (H/C) (F)</b>	-4 - 115	-4 - 115	0 - 115	-13 - 122	-4 - 115
<b>Crankcase Heater</b>	Not Indicated		Not Indicated	Not Indicated	Not Indicated
<b>Power (W)</b>		800 – 1,300	1,955	1,725	2,100
<b>Max Amps (A)</b>		11.8	17	15	18
<b>Heating Cap. (BTU/h)</b>	12,000	12,200	9,600; 12,500	12,000	16,000
<b>Cooling Cap. (BTU/h)</b>	12,000	12,000	9,000; 12,000	12,000	12,000
<b>Heating (COP)</b>	2.92	2.9	3.3	2.03 - 3.80	3.2
<b>Cooling (COP)</b>	2.92	2.9	4.67	3.8	3.75
<b>Price (\$)</b>	\$860	\$1200	\$790	\$1800	






### Ductless Mini-Split Heat Pumps (240V)

Interior Wall-Mounted Fan Coil	HAIER Arctic Next Gen	Fujitsu Halcyon Series	Mitsubishi HyperCore FH50	MrCool MDUO180(24-60)	LG <sup>97</sup> Multi F MAX LGRED
					
<b>Description</b>	1 Indoor Fan Coil	1 – 4 indoor Fan Coils	1 – 4 indoor Fan Coils	Pre-charged, 2 - 5 Fan Coils	2 - 5 Fan Coils
<b>Dimension (in) (HxWxD)</b>		39 x 38 x 14	36 x 9 x 12	56 x 38 x 13	54 x 24 x 15
<b>Ref. Type</b>	R410a	R410a	R410a	R410a	R410a
<b>Ambient Temp. Range (H/C) (F)</b>	-31 / 95	-15 – 75 / 14 – 115	-13 / 115	-22 / 110	-13 – 64 / 14 – 118
<b>Crankcase Heater</b>	Not Indicated	Not Indicated	Not Indicated	Not Indicated	Not Indicated
<b>Power (W)</b>	230 – 2,160	1,330 – 2,700	1,380 – 1,480	1090 – 3070	970 – 6,020
<b>Max Amps (A)</b>		16.4 - 26	13.6	14.8	23
<b>Heating Cap. (BTU/h)</b>	23,000	9,000 – 36,400	10,900 – 30,700	24,000 – 54,000	15,840 – 61,000
<b>Cooling Cap. (BTU/h)</b>	14,000	9,000 – 35,200	8,500 – 26,600	24,000 – 54,000	14,400 – 58,000
<b>Heating (COP)</b>	1.94 - 4.21	3.60 – 4.04	3.07 - 4.85	3.65	3.4
<b>Cooling (COP)</b>	2.74 - 4.46	3.52 – 3.60	3.31 – 4.11	4.12	4.1
<b>Price (\$)</b>	\$1,900	\$ 2,000 - \$5,000	\$2,000 - \$3,500	\$3,000	\$2,400 – 5,100



## Ducted Mini-Split Heat Pumps






Attic Fan Coil and Ductwork	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)
Crankcase Heater	Not Indicated	Not Indicated	Not Indicated	Not Indicated
Max Amps (A)	25	20	25	40
Heating Cap. (BTU/h)	18,000	18,500	19,000	25,000
Cooling Cap. (BTU/h)	17,000	17,500	18,000	22,000
Heating (COP)	3.0	2.8	2.6	2.6
Cooling (COP)	4.2	4.2	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)

Attic Fan Coil and Ductwork	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)
Crankcase Heater	Not Indicated	Not Indicated	Not Indicated	Not Indicated
Max Amps (A)	15	29.5	15	15
Heating Cap. (BTU/h)	12,000	13,700	16,000	16,000
Cooling Cap. (BTU/h)	12,000	18,000	11,600	12,000
Heating (COP)	3.37	2.79	3.1	3.4
Cooling (COP)	4.35	3.6	4.18	4.2
Per Indoor Unit Piping Length (ft)	82	82	66	66
Price for Outdoor Unit	\$ 1,200 (includes 25ft refrigerant lines)	\$ 2,780 (no refrigerant lines)	\$ 2,050 (no refrigerant lines)	\$ 1,660 (no refrigerant lines)





## Packaged Terminal Heat Pumps (240V and 120V)

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

Manufacturer and Product Image	Innova HPAC 2.0 	Olimpia Maestro 	Frigidaire FFRH1122UE 	Friedrich YS10N10C 	Gree 26TTW09HP115V1A 
Description	Twin ducts through the wall, dehumidification, Resistance back-up	Twin ducts through the wall, dehumidification	Heat pump with Resistance (ER)	Heat pump model – no back up Resistance	Heat pump model with Resistance (ER)
Voltage (V)	120	120	120	120	120
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	R410a
Min. Heat Pump Operating Temp (F)	<b>-14 (cold climate)</b>	<b>5 (cold climate)</b>	40	40	29
Power (W)	545 – 730	830-850	780 – 1,290	917 - 978	830 – 1,150
Heating Capacity (BTU/h)	3,100 - 10,000	10,600 (Heat Pump only)	9,900 (HP) 3,500 (ER)	8,000	6,600 (HP) 3,900 (ER)
Cooling Cap. (BTU/h)	2,600 - 10,000	11,600	11,000	10,000	9,000
Heating (COP)	2.84 – 3.22	3.8	2.63	2.6	3
Cooling (COP)	3.12 – 3.28	3.8	2.87	3.19	2.87
Price (\$)	\$1950	\$1700-\$2300	\$ 700	\$ 1000	\$ 700

### (240V) Packaged Terminal Heat Pumps

Manufacturer and Product Image	Amana AH (093,123,183) 	Friedrich Y (S12, M18, L2) 	Gree W (07,09,12) 	LG LP (073,093,123,153) 
Description	Heat pump model	Heat pump model – no back up ER	Heat pump model with ER + dehumidification	Heat Pump with ER, but HP functions in cold climates
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	<b>-4 - 75 / 54 – 115 (cold climate)</b>
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 Capacity (BTU/h)	10,700 – 9,000 (ER) 8,100 – 16,00 (HP)	11,300 – 22,000	3,900 – 11,000 (ER) 6,600 – 11,400 (HP)	6200- 13,400
Cooling Cap. (BTU/h)	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 (\$)	\$ 700 - 1,250	\$ 1,000 - 1,500	\$ 930	\$ 1,000 – 2,000

### Portable Air Source Heat Pumps (120V)

Heat pumps can come on wheels for those who want to electrify their space heating but may not have the budget or permission from the landlord to install a permanent, whole house solution.

These retrofit-ready heat pumps can plug into any outlet in a home and come with ducts that fit into an open window. The ducts allow outside air to be pulled in as a heat source or sink and then exhausted while the heat pump heats or cools the inside air. They can do additional work as powerful dehumidifiers, with a storage tank and/or condensate drain line.



Figure 43: A “two-pipe” portable heat pump.

Manufacturer and Product Image	Edge Star	Black + Decker BPACT12HWT	Whynter ARC-14SH	Haier HPND14XHT
				
<b>Voltage</b>	120V	120V	120V	120V
<b>Power (W)</b>	1250W (cool)/ 1200W (heat)	-	1250W	1260W (cooling)
<b>Max Amps (A)</b>	-	9A	10.8A	11.4A
<b>Dehumidifying Capacity</b>	85 pints/day	-	101 pints/day	88.8 pints/day
<b>Heating Capacity (BTU/h)</b>	14,000	10,000 and 11,000	13,000	10,000
<b>Cooling Capacity (BTU/h)</b>	14,000	14,000	14,000	14,000
<b>Temperature Range F (Output)</b>	61 - 89	55 - 81F	61 - 89	61 – 100 (can go below freezing at lower capacities)
<b>Refrigerant</b>	R410a	R410a	R32	R410a
<b>Dimensions (in) (HxWxD)</b>	35 x 19 x 16	28 x 17 x 14	36 x 19 x 16	29 x 15 x 17
<b>Price</b>	TBA	\$697	\$575	\$670

A short study was conducted by Redwood Energy to compare the leading brands of portable heat pumps, for roughly a month in Arcata, CA during the months February and March. In summary the Whynter performed the best, however it discharged a large amount of water each day which became a hassle to dump every few hours (keep in mind the weather in Arcata is very humid). The Whynter used roughly 15 kwh/day and was so effective at heating the space the gas furnace was not turned on during its test period and the homeowner decided to keep it after the test period was over.

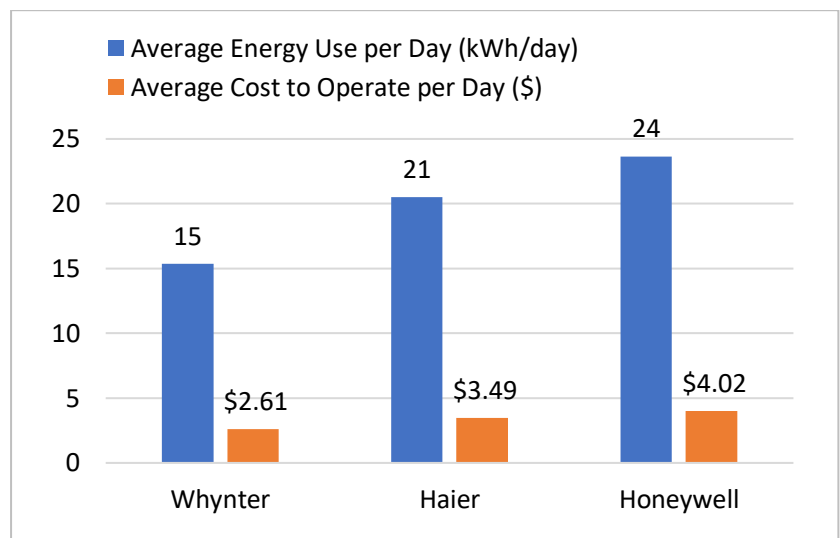












Figure 44: Test results comparing three leading brands of portable heat pumps, tested for a few weeks in Arcata, CA during February-March.



## Hydronic Heat Pumps (Air-to-Water) (240V)






The air to water (aka hydronic) heat pumps are used in radiant floor heating, domestic hot water and swimming pools and hot tubs in cold climates—note in blue the ambient temperatures in which they can operate.

Manufacturer and Product Image	Stiebel Eltron WPL (15,20,25) (AS, ACS) 	Arctic 020A 	Spacepak Split System Inverter 	Aermec ANK (030,045,050) 	Chiltrix CX34 	Nordic ATW 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, heating and cooling, inverter compressor	HVAC and DHW combination	Air to Water Heat Pump	Hydronic heating, fan coils air-conditioning
Voltage (V)	230	220-240V	240	208/230	220	208/230
Dimension (in) (HxWxD)	-	33 x 18.5 x 45	55H x 35W x 15D	50H x 58W x 18D	38.15 x 43.9 x 16.74	34 x 34 x 35
Ref. Type	R410a	R410a	R410a	R134a	R410a	R410a
Ambient Temp. Range (H/C) (F)	<b>-4 (Air) – 140 (Water)</b>	<b>-15 (cold climate)</b>	<b>-22 – 105 (cold climate)</b>	<b>-4 – 107 (cold climate)</b>	<b>-4 – 122 (cold climate)</b>	<b>-7 – 120</b>
Power (W)	1,090 - 7,530	2,710 - 3,000	5,200 – 9,500	2,810 – 4,520	360 - 2,360	1,190 – 2,500
Max Amps (A)	7.9 - 30	15	32	45	15	15 - 30
Heating Cap. (BTU/h)	8,525 – 46,500	35,826	21,000 – 68,000	37,670 – 57,598	4,000 - 33,800	4,280 – 22,700
Cooling Cap. (BTU/h)	7,330 – 58,000	25,600	20,400 – 51,600	30,120 – 48,240	4,000 – 30,000	17,400
Heating (COP)	1.85-5.09	3.14	4.23	3.1 – 4.4	3.92	1.38 - 4.94
Cooling (COP)	2.39-3.76	2.5	4.09	-	6.75	1.57 - 5.84
Price		\$3750	\$7500	\$5500-\$7500	\$4300	\$5000

Manufacturer and Product Image	Stiebel Eltron WPL (15,20,25) (AS, ACS) 	Stiebel Eltron WPL (19A, 23A) 	Chiltrix CX34 	Nyle C25A – C250A 
Description	Air-to-water heat pump outdoor unit, combined DHW and HVAC	Air-to-water heat pump outdoor unit, combined DHW and HVAC	Air to Water Heat Pump	Air to Water Heat Pump
Voltage (V)	230	230	220	208/230/440-480/575
Dimension (in) (HxWxD)	41 x 59 x 23	55 x 49 x 50	38.15 x 43.9 x 16.74	-
Ref. Type	R410a	R410a	R410a	R134a
Ambient Temp. Range (H/C) (F)	<b>-4 (Air) – 140 (Water) (cold climate)</b>	<b>-4 (Air) – 149 (Water) (cold climate)</b>	<b>-4 – 122 (cold climate)</b>	<b>35 – 120</b>
Power (W)	1,090 - 7,530	2,900	360 - 2,360	5,500 - 24,000
Max Amps (A)	7.9 - 30	15	15	(@ 240V) 28 - 150
Heating Cap. (BTU/h)	8,525 – 46,500	25,000; 31,000	4,000 - 33,800	27,500 – 272,500
Cooling Cap. (BTU/h)	7,330 – 58,000	-	4,000 – 30,000	21,200 – 218,000
Heating (COP)	1.85-5.09	3.0 - 4.12	3.92	(max) 4.58 – 5.33
Cooling (COP)	2.39-3.76	-	6.75	(max) 3.88 – 4.33
Price	-	-	\$4300	-

## Geothermal Heat Pumps (Ground/Water-to-Air/Water) (240V)

Geothermal Heat Pumps rely on the constant temperature in the ground or a large body of water to deliver conditioned air to a home year-round, typically their coils are buried in the ground and can have various configurations (vertical, horizontal, etc.). In the winter when the temperature above ground is lower than the temperature below the ground, the heat from the ground is transferred into the building for space heating, and vice versa in the summer for cooling. Geothermal heat pumps can provide space heating, space cooling, domestic hot water heating and/or pool heating. For domestic hot water, a desuperheater (which is a small heat exchanger) uses the heat generated from the compressor to heat water for the home. For pool heating, either the heat from the ground can be transferred directly to the pool, or the heat from the ground can be transferred to a compressor (with refrigerant lines) to then heat the water further. Each unit pictured works with ground loops, water loops or ground water loops with optional hot water.

Manufacturer and Product Image	Nordic R Series Residential	Water Furnace 7 Series - 700A11	York York Affinity YAF	Geostar Aston Series	Bosch Green Source ES Model
					
<b>Voltage (V)</b>	208/230	208/230	208/230	208-230	208-230
<b>Dimension (in) (HxWxD)</b>	66 x 36 x 44	58 x 32 x 26	25x31x58	25x31x58	21x26x54
<b>Ref. Type</b>	R410a	R-410a	R-410A	R_410A	R-410a
<b>Ambient Temp. Range (H/C) (F)</b>	23 - 110	45 – 85 / 45 – 100 (air) 20 – 90 / 30 – 120 (water)	45-100/45-85(air) 30-120/20-90(water)	(45-100) air (30-120) water	50-100
<b>Power (W)</b>	1203- 1,764	-	-	-	-
<b>Max - Amps (A)</b>	7.8	32 - 46	-	-	-
<b>Heating Cap. (BTU/h)</b>	15,200 – 23,000	13,000 – 78,000	14,000-85,000	16400-19500	20,500-80,000
<b>Cooling Cap. (BTU/h)</b>	20,100 – 26,800	11,000 – 60,000	11,000-66,000	21000-26000	18,000-72000
<b>Heating (COP)</b>	3.7 - 4.9	3.5 - 7.6	4.6-5.9	3.4-5.88	3.6-4.1
<b>Cooling (COP)</b>	5.7 - 9.6	4.7 – 15.6	3.8-5.2	4.8-7.032	41-7.6

## Heat and Energy Recovery Ventilation (HRV and ERVs)

Heat Recovery Ventilators (HRV) and Energy Recovery Ventilators (ERV) are the same systems but with a different heat exchanger core. The ERVs heat exchanger allows water droplets to be transferred with the heat. The key difference is that an ERV will make your home more humid in winter, and less humid in summer, compared with an HRV.<sup>98</sup> The goal with an HRV is rid the house of its stale, moist air while transferring the maximum amount of heat into the clean incoming air. This keeps your heat and money inside while filtering contaminated air out. The location of the project will generally determine need for an HRV or ERV.

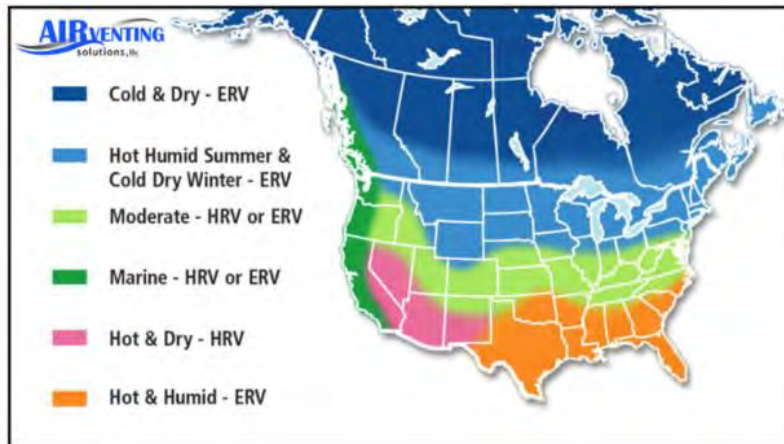


Figure 45: Choosing an HRV or ERV system based on location map.<sup>99</sup>

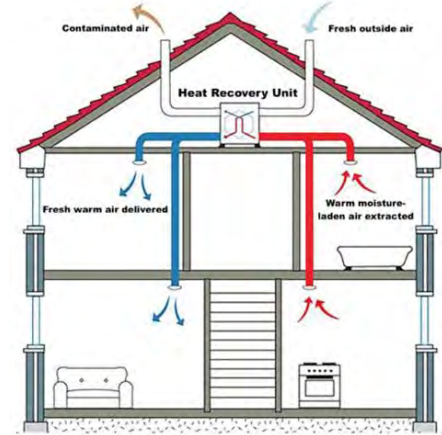


Figure 46: Heat Recovery ventilation system example.<sup>100</sup>




The unit operates continuously, sucking air through ducts that are positioned in prime generation locations of moisture and odor ex. bathrooms and kitchen. As the air flows out to an exterior vent, it passes through a metal box containing a matrix of crimped aluminum plates, full of air channels. At the same time, fresh outdoor air is being sucked into the building, passing through the same box on its way to outlets located in two central locations. The two airstreams never mix, but as they pass each other, heat migrates from the warm outbound stream to the cool inbound, preheating it and reducing load on the heating plant. There is no running cost to this process as all of its operations are done by the laws of physics. In the summer, the system works in reverse, using the house's cooler conditioned air to strip off some of the incoming fresh air's heat, precooling it and reducing load on the air-conditioning system.

Manufacturer and Product Image	Fantech VHR70 Fresh Air Appliance	Fantech FLEX 100H ES Fr. Air Appliance	BLAUGER ERV EC D(R) 150	Zehnder ComfoAir Q350	BLAUGEG KOMFORT EC D5B180(-E)	BLAUBERG KOMFORT EC SB5506
Max air flow	57 CFM	104 CFM	181 CFM	206 CFM	220 CFM	441 CFM
Home size	1-to-3-bedroom homes	3 to 4 bedrooms homes	Apartments to small homes	Medium to large homes	Large apartments and homes	Large homes
Ambient / Transported air temp [°F]	-13 to 32 heating	-12 to 32 heating	-13 to 32 heating	-4 to 104	-13 to 140	-13 to 140
Voltage	120	120	120	240	120	120
Max Amps (A)	0.4	1.6	2.5	1.42	0.71	2.3
Sensible Recovery Efficiency (%)	61-72% from -13°F to 32°F	62% - 65% from -12°F to 32°F	77% - 82% from -13°F to 32°F	86.5%	88-98%	88-98%



## ERV, HRV, and Heat Pump Combined Products

The products shown below are all-in-one systems that provide filtered ventilation as well as heat pump heating. They are most applicable to small apartments but could also be used for tiny homes and smaller zones within a larger home. The CERV-2 for example, is used by VEIC for their zero net energy highly efficient modular homes.

Manufacturer and Product Image	CERV-2	Minotair Pentacare V12	Ephoca xK92NSGx
			
Description	Ducted Ventilation and Heat Pump – HRV Combo	Ducted Heat Pump, HRV, and Ventilation (MERV-15) Combo with 5kW resistance heat	Ducted Ventilation, Heat Pump, ERV, MERV-13 filtration
Unit Dim. (in) (HxWxD)	38 x 25.5 x 40	16 x 18 x 40	39 x 38 x 10
Refrigerant	R410a	R410a	R410a
Ambient Temp Range (F)	No low temperature cutoff	No Low Temperature cutoff, resistance heater is controlled for efficiency	-5F
Voltage	120V	120V / 240V	240V (120V available)
Max Amps (A)	12A	6.6A (HP-only), 27A Max	15
Heating Cap. (BTU/h)	9,720 (17F) – 11,262 (47F)	5,600 (17F) – 8,700 (47F)	10,300 – 16,600 (47F)
Cooling Cap. (BTU/h)	7,544 (95F)	11,200 (95F)	3,100 – 10,500
Heating (COP)	2.8 – 3.6	2.4 (17F) – 3.0 (47F)	4.0
Cooling (COP)	3.2	3.3 (95F)	3.6
Price for Unit	\$6000	\$6000	\$4000 Wholesale, \$6000 Retail

## 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.

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

### Individual Heat Pump Water Heaters (240V and 120V)

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. Installing these units indoors especially in basements can provide dehumidification as well as avoid low ambient temperatures. Another way to think of it is they provide free hot water and dehumidification for half the year by offsetting a small amount of cooling load. New systems using CO2 as a refrigerant (R744) can handle brutal winter climates.



Figure 47: A Steibel Eltron heat pump water heater installed in a basement in the Northeast.<sup>101</sup>



Figure 48: A Sanden CO2 heat pump water heater compressor working outside in 5°F (-15°C) weather.<sup>102</sup>

### Heat Pump Water Heaters on US Market (240V)

Manufacturer and Product Image	Eco2 Systems	Steibel Eltron Accelera	Rheem Prestige Hybrid	AO Smith Voltex Hybrid	Bradford White AeroTherm
<b>Description</b>	Large Volume Cold Climate CO2 Refrigerant	Hybrid: Heat Pump and Resistance	Hybrid: Heat Pump and Resistance	Hybrid: Heat Pump and Resistance	Hybrid: Heat Pump and Resistance
<b>Gallons</b>	43, 83	58, 80	50, 65, 80	50, 66, 80	50, 80
<b>Voltage (V)</b>	208/230	220/240	208/240	208/240	208/240
<b>Dimension (in)</b>	27.5H x 35W x 11D	60H x 27Diam.	74H x 24Diam.	69H x 27Diam.	71H x 25Diam.
<b>Ref. Type</b>	R744 (CO2)	R134a	R134a	R134a	R134a
<b>Ambient Temp. Range (F)</b>	<b>-30 – 110 (cold climate)</b>	42 – 108 / 6 – 42	37 – 145	45 - 109	35 – 120
<b>Power (W)</b>	2200W peak	650 – 1500W	2250W and 5000W	4,500W	550 – 4,500W
<b>Max Amps (A)</b>	13	15	15 – 30	30	30
<b>Heating (BTU/h)</b>	15,400	5,800	4,200	-	-
<b>Heating (COP)</b>	5.0	-	-	-	-
<b>Energy Factor</b>	3.09 – 3.84	3.05 – 3.39	3.55 – 3.70	3.06 – 3.61	2.40 – 3.39
<b>Price (\$)</b>	\$ 3,400	\$ 2,300-2,600	\$ 1,200-1,400-1,700	\$ 1,400-1,500-1,900	\$ 1,400-1,600

### Retrofit Ready Heat Pump Water Heaters (120V)

There has been a market demand for heat pump water heaters that are “retrofit ready” meaning, they can plug into a 120V typical electrical socket, to rapidly electrify water heating. Both Rheem and GE have announced they will be releasing retrofit ready heat pump water heaters to the U.S. soon.

### Product Highlight – Eco2 Heat Pump Water Heater

The Eco2 uses CO<sub>2</sub> as a refrigerant (which does not contribute to global warming, like other typically used refrigerants) and allows the heat pump to have no “hard stop” of operation even at very low outdoor air temperatures.<sup>103</sup> At low outdoor air (-15°F) and low inlet water temperatures (Figure below) it can make hot water up to 145 degrees Fahrenheit, and it is still more efficient than the top-of-the-line natural gas hot water heater (COP of 1.9 vs. COP of 0.95). At warm outdoor air temperatures (above 70°F) the COP, or efficiency of the Eco2 heat pump water heater, increases to above a 5.0 COP, where a comparable natural gas water heater is still at a 0.95 COP.



Manufacturer and Product Image	GE GeoSpring	Rheem Prestige Hybrid
		
Description	Heat Pump Only	Heat Pump Only
Gallons	40, 50	40
Voltage (V)	120V	120V
Dimension (in)	More Specifications Coming Soon	66H x 23 Diameter
Ref. Type		R134a
Ambient Temp. Range (F)		45 - 140
Power (W)		2,400
Breaker Size (A)		20A
Heating (BTU/h)		12,000
Energy Factor		3.0



Figure 49: The Eco2 heat pump water heater compressor working outside in 5°F (-15°C) weather.<sup>104</sup>

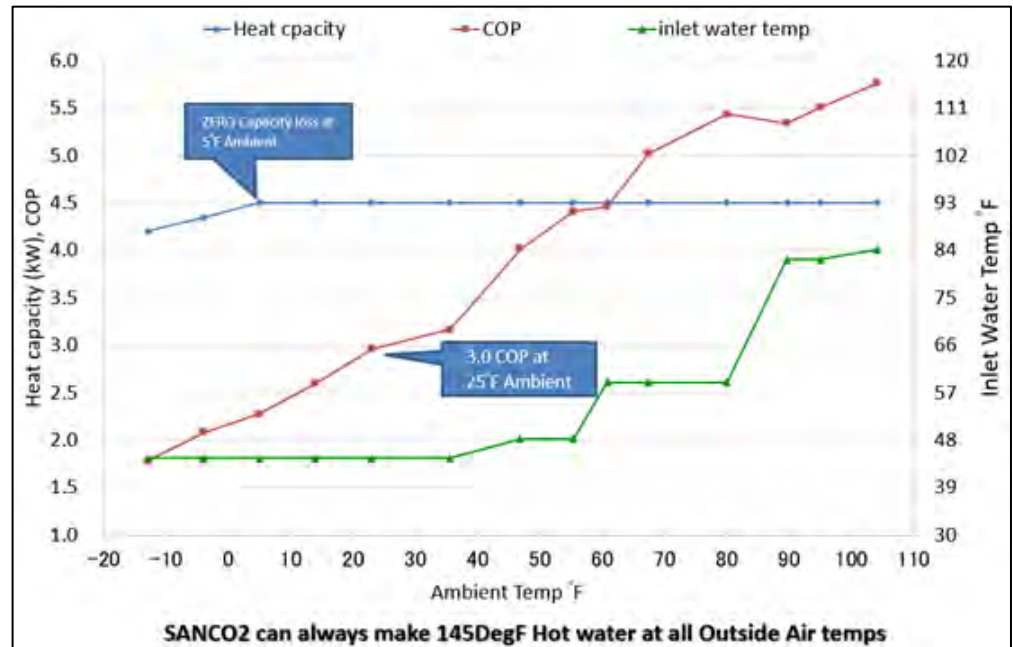





Figure 50: Eco2 heat pump water heater heating capacity, COP, and inlet water temperatures at various ambient air temperatures.<sup>105</sup>



## On-Demand Water Heaters (120V and 240V)




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.

### Small Demand and Low Power Applications (120V)

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

## Hybrid Heat Pump and Electric Resistance On-Demand Water Heaters

One specialty product is a hybrid heat pump and electric resistance back up water heater by Nulite. This product is meant to replace on-demand gas water heater systems and are more efficient than a typical electric resistance and gas on-demand water heaters. Created in China, they are now available in the United States.

Manufacturer and Product Image	Nulite NERS-FR1.5F 	Nulite NE-BZ2/W200 	Rheem EGSP2 – EGSP30 
<b>Description</b>	Hybrid Heat Pump with Resistance	DC Inverter Heat Pump Water Heater	Electric Resistance Tank
<b>Gallons</b>	18.5 (70L)	53 (200L)	2.5 – 30 Gal
<b>Voltage (V)</b>	220 @ 50 Hz	220V @ 50 Hz	120, 208, 240, 277, 480V
<b>Ref. Type</b>	R134A	R410A	Electric Resistance
<b>Ambient Temp. Range (F)</b>	5 – 68 (cold climate)	-13 – 118 (cold climate)	<b>Delivered Hot Water:</b> <b>110-170F</b>
<b>Power (W)</b>	860 – 1500	5,000	1,500 – 6,000
<b>Max Amps (A)</b>	Pending	20	25A @ 240
<b>Heating (BTU/h)</b>	12,500	27,000	5,000 – 20,000
<b>Heating (COP)</b>	1.36 - 5.34	Pending, Approx. 5.4	>1
<b>Energy Factor</b>	Pending	Pending	-
<b>Price (\$)</b>	UL Certification Pending	UL Certification Pending	\$400 - \$2,000

### Three ways to get more hot water – which one is right for you?

The more people in the home, the more hot water you will use. If you have two people in your home you will probably want a 40 gallon water heater, for three people would use 50 gallons, 4 people would use 65 gallons, and 5+ people use 80 gallon tanks.<sup>106</sup> Current (no pun intended) Heat pump water heaters are generally either 30-amp or 15-amp machines based on the Amperage of the electric resistance backup elements they use to supplement the heat pump. The 15-amp products put less power into the water during the course of the first hour test so all else being equal, they would deliver slightly less hot water in the first hour test and thereby have a lower **first hour rating**.

Below is a figure that estimates the hypothetical first hour rating for the various power levels of heat pump water heaters (High Power, Half Power, and 120V Retrofit Ready) and for the size of the tank (40-80 gal). For example, in a three-person home, the first hour rating would be around 55 gallons, so a 120 V “retrofit ready” heat pump water heater or a 240V / 15-amp “half power” heat pump water heater that is 40 gallons would be adequate. Also, it’s important to note that the more hot water storage you have, the more hot water you can deliver in the first hour.

#### Three ways to get more hot water:

1. Set the tank to a higher temperature (and use a mixing valve to avoid scalding if you are setting it above 130F)
2. Select a larger volume tank
3. Select a higher power heat pump water heater that is 30-amps

#### Interpreting the graph below, there are nine ways to get a 70 gallon first hour rating:

1. A full power 40 gal tank at 130F (no mixing valve needed).
2. A full power 50 gal tank at 120F
3. A half power 50 gal tank at 150F with mixing valve
4. A 120V 50 gal tank at 155F with mixing valve
5. A full power 60 Gal tank at 120F
6. A half power 60 gal tank at 135F
7. A 120V 60 gal tank at 145F with mixing valve
8. A half power 80 gal tank at 120F
9. A 120V 80 gal tank at 122 F

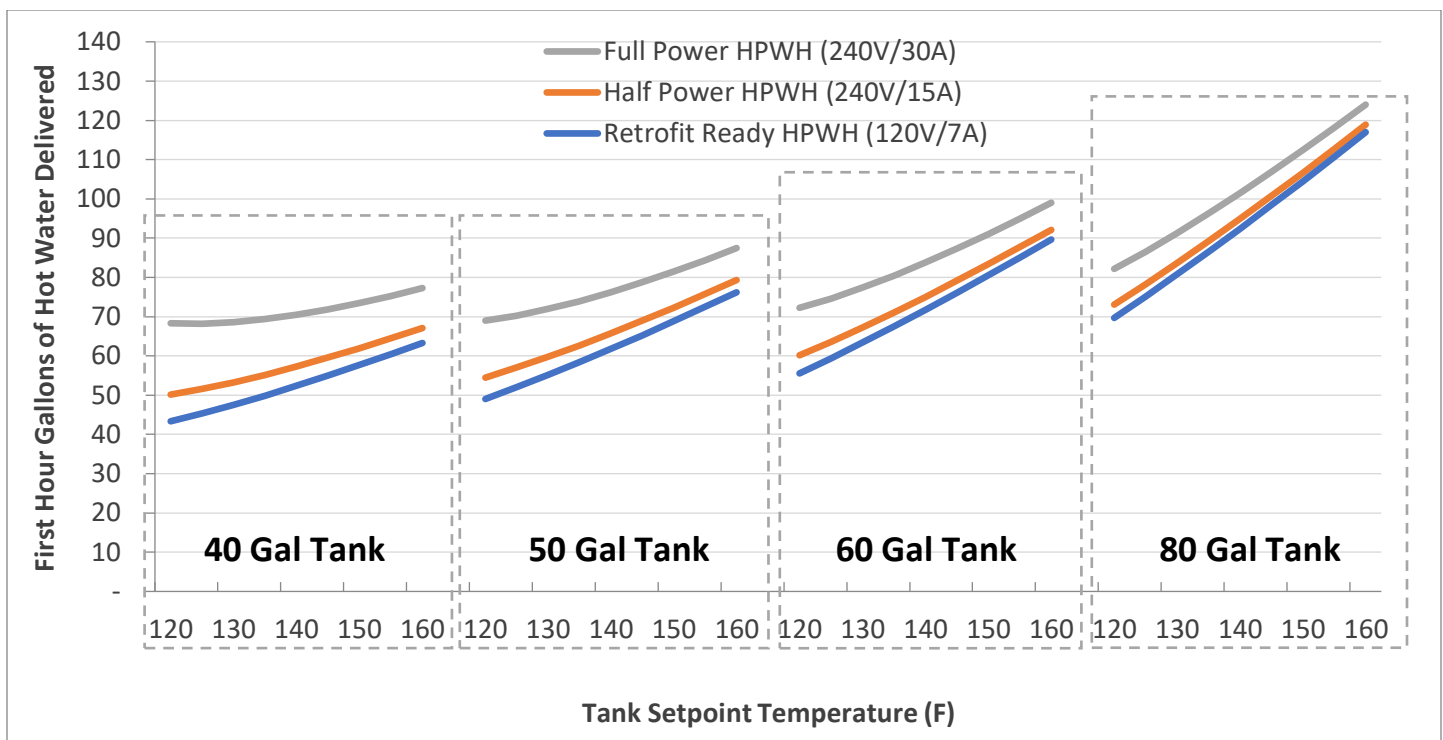
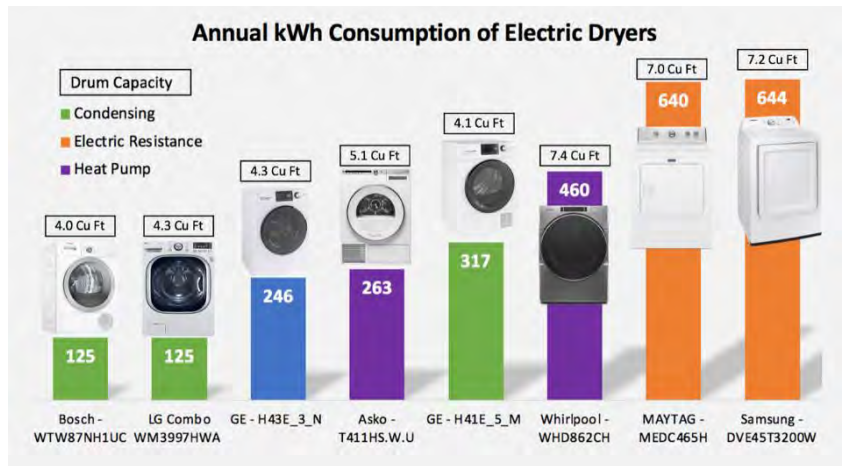


Figure 51: Approximate “first hour rating” (with a rate of 3 gpm until the hot water runs out) based on the power of heat pump water heater, tank size and temperature setting.

## 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.<sup>107</sup> 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,<sup>108</sup> assuming one is using a standard ~30% efficient gas dryer, rather than a ~250% efficient electric heat pump dryer.



**Figure 52: Relative dryer energy use, condensing dryers and heat pump dryers use roughly half the energy of a standard electric resistance 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<sup>109</sup>. 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.<sup>110</sup>

### Condensing Washer & Dryer—A combined appliance

Condensing Washer/Dryers 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 2-4 hours, depending on the fabric and load size.

*“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 combined washer/dryer user***

### Combination Condensing Washer & Dryer (120V)







Manufacturer and Product Image	Magic Chef MCSCWD20W3	Haier HLC1700AXW	Summit SPWD2201SS	Deco DC4400CV	Whirlpool WFC8090GX	LG WM3998HBA	
							
	Price	\$720	\$1,000	\$1,000	\$1,200	\$1,500	\$2,000
	Energy Use (kWh/year)	85	65	65	96	180	120
	Drum Capacity (cu. ft.)	2.0	2.0	2.0	3.5	2.8	4.5
Volts/Amps	120V/12A	120V/10A	115V/12A	110V/15A	240V/30A	120V/10A	



## 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. Hybrid heat pump dryers combine resistance elements and heat pump technology to improve overall energy efficiency.






### Heat Pump Dryers (240V)

Manufacturer and Product Image	Samsung DV22N685H	Blomberg DHP24400W	Kenmore Elite 81783	Beko HPD24412W	Whirlpool Hybrid WHD560CHW	Miele TWI180WP
						
Price	\$1,000	\$1,100	\$1,100	\$1,300	\$1,250	\$1,900
kWh/year	145kWh/year	149kWh/year	-	149kWh/year	460kWh/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	70	35

## 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.

### Standard Electric Dryers (240V)

Manufacturer and Product Image	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

## Heat Pumps for Swimming Pools and Hot Tubs

Utilizing a heat pump can be an efficient way to address the energy demands of heating a pool. In addition, solar thermal can be an efficient way to heat pools or supplement pool heating.

### Contractor perspectives on heat pump pools:

- **They are simpler:** Heat pump pool heaters are relatively new to most contractors on the market in the Bay Area, but a common consensus is that heat pump pool heaters are simpler to install than gas pool heaters in new single-family construction because of the challenges of running gas lines compared to the simplicity of a 40-Amp electrical wire in residential settings.
- **They work well:** Heat pump pool heaters work well year-round, and Hayward and AquaCal are the locally favored brands due to their contractor technical support. AquaCal is especially favored for integration into automatic of pool covers. The AquaCal HeatWave SuperQuiet lives up to its name and is especially quiet.
- **They cost less to operate:** Heat pump pool heaters save pool owners on their utility bills compared to gas because they collect 5 or more units of heat for every 1 unit of electricity, while gas pool heaters use 6 times as much energy, collecting only 0.8 to 0.9 units of heat for every 1 unit that is burned.<sup>111</sup> See cost calculations in the Appendix for further detail.
- **Winter pools should be paired with efficiency measures:** Pool covers dramatically reduce heat loss, and contractors also advocate for automatic pool covers. Floor return lines, which prevent stratification (cold water at the bottom of the pool and hot water at the top) are common in older pool designs and are an important efficiency measure. See the schematic in the Appendices. Large outdoor pools that are kept warm during the winter can use multiple standard heat pumps that are designed to be integrated together to meet the higher heating demand. Generally these are plumbed in parallel, with a logic system for automation such as Hayward Omnilogic<sup>112</sup>, and no storage tank.
- **More skilled contractors are needed in the pool industry:** EPA 608 Technician<sup>113</sup> Certification is recommended for pool contractors to service the refrigeration components of heat pump pool heaters, and indicates a level of training similar to HVAC professionals. There are workarounds, including partnering with an HVAC professional who has the certification, but that can add additional delays to the repair due to scheduling. EPA 608 is not necessary to install most new construction heat



Figure 53: Pacific Companies Zero Net Energy apartment complexes built in 2014 with heat pumps for the hot tub and swimming pools (left) and one of the author's brother enjoying a heat pump pool in New York.

### Sizing a heat pump pool heater

To right-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. Most heat pumps are sized for back yard pools (10' x 20' x 5.5' = 8,228 gallons, 15' x 30' x 5.5' = 18,513 gallons, 20' x 40' x 5.5' = 32,912 gallons).

Right-sized heat pump pool heaters are designed to run without interruption and can modulate their heat output to match both large and small demands. By contrast, gas-fueled pool heaters will cycle on and off rather than overheat, particularly during summer weather when only a small amount of heat is needed to maintain the pool temperature relative to winter use. In addition, a heat pump can also cool the water in your pool where a gas heater cannot. A well-sized pool heat pump can raise and maintain the temperature of the water +30 degrees above the source water temperature. The source water temperature depends on where you live – the ground temperature is roughly equal to the last months average air temperature. For example, if the previous month’s average air temperature was 50 degrees you can assume this month’s ground temperature is 50 degrees and you can heat the water in your pool up to around 80 degrees. Aquacal provides an excellent heat pump pool heater sizing estimator that also performs cost-of-use estimates: <https://www.aquacal.com/sizing-and-savings-calculator/>

#### The benefit of using pool covers:

- Reduces the need for pool cleaning and can help reduce energy bills
- Using a pool cover properly can halve your pool heat pump sizing by preventing heat from escaping.
- Pick a dark-colored, solid material for improved solar heat absorption.<sup>114</sup>
- Automatic pool covers are a convenient and aesthetic option.
- A traditional, manual pool cover made of vinyl will achieve the same efficiency benefit as an automatic pool cover if used properly.

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. The key technology involved in heat pump operation at low temperatures is pairing an **inverter** with the compressor, which allows the compressor to operate at multiple speeds depending on the output needed due to environmental conditions. Inverter-compressor units are often called “Variable Speed” or “VS”. Below is a sample of heat pump pool heaters.

	<b>Hayward</b> HeatPro VS Variable Speed 	<b>Pentair</b> UltraTemp 110 Heat Pump 	<b>AquaCal</b> HeatWave SuperQuiet SQ166R ICEBREAKER 	<b>AquaCal</b> Heatwave SuperQuiet Variable Speed SQ150VS 	<b>AquaCal</b> Great Big Bopper 	<b>Arctic</b> 060ZA/B 
<b>Price</b>	\$3,000	\$3,270	\$4,800	\$5,700	\$40,000	\$4,400
<b>Heating Capacity (BTUh)</b>	90,000	108,000	126,000	115,000	527,000	88,030
<b>Inverter Driven?</b>	<u><b>YES</b></u>	<u><b>NO</b></u>	<u><b>YES</b></u>	<u><b>YES</b></u>	unknown	<u><b>YES</b></u>
<b>Heating COP</b>	5.1	5.8	5.6	5.0	6.6	6.2
<b>Temp. Range</b>	30°F Air*	45°F Water*	25°F Air*	25°F Air*	40°F	-4°F

*\*The lowest operating weather condition specification is based on conversations with manufacturers but has not been verified by AHRI or other third-party testing programs, and operating any pool heater (including gas) below freezing will produce inconsistent results.*



## Electric Fireplaces

Swirling, fire-like mist lit with LEDs and a campfire's worth of heat: these are electric fireplaces. They are less expensive to purchase and install than gas stoves, safer, cleaner, and plug into a normal 120V wall outlet. They provide heat in a more efficient and smokeless way – an electric fireplace can warm a room and look great doing it. From convincing to dramatic, electric fireplaces are ready to match the tastes



Figure 54: A Dimplex Opti-Myst cassette within a commercial space.<sup>115</sup>



Figure 55: AFireWater fireplace in a home.






of any owner. Outdoor electric space heaters are similarly versatile and ready to replace headache-inducing propane burners.

### What is a water vapor fireplace?

An ultrasound vibrator breaks water into ultra-fine water vapor, with small fans and LED lights producing extremely realistic mist “flames.” The LED lighting allows for both natural and artistic colors of flames. The height of the flames can be customized as well by adjusting the opening where the water vapor comes out. Opti-Myst and AFireWater have many different styles of LED water vapor fireplaces to provide ambiance in residential, commercial, and high-rise buildings.

### Why buy a water vapor and LED fireplace?

These mist-and-LED are the safest and cleanest electric technologies to put within a home or office. Unlike real fireplaces, they are not emitting soot, smoke, carbon monoxide or other combustion byproducts into a space, and can be controlled via a smart phone for optimal aesthetics. Fireplaces can now be safely enjoyed by pregnant mothers and small children without worry about health impacts from air pollution.

Manufacturer and Product Image	Dimplex Opti-Myst With Logs (CDFI 500-PRO)	Dimplex Opti-Myst (CDFI 1000-PRO)	AFireWater Prestige	Dimplex Opti-Myst (GBF 1000-PRO)	Dimplex Opti-Myst (GBF 1500-PRO)
					
Price (\$)	\$1,430	\$2,640	\$3,460	\$3,630	\$5,640
Power (Watt)	230	460	60-180	1400	1460
Amps	1.91	3.8	Not Available	11.67	12.17
Voltage (V)	120	120	120	120	120
Heating (BTU)	785	Not Available	Not Available	4981	4981




## 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 have made improvements to traditional steam saunas. This style of products uses low intensity infrared lights to increase body and air 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	Polar HNVR 45SC	Harvia HPC-HTR61	Harvia HNC-HTR105
Picture					
Capacity (kW)	3.0	8.0	4.5	6.8	10.5
Price	\$630	\$780	\$910	\$1,070	\$2,040

### (120V) Infrared, Full Room

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




## Electric Outdoor Heaters

Keeping warm outside does not need to come from odorous and polluting propane outdoor heaters, there are many electric equivalents that range from wall mounted high power 240V to free standing 120V options for your outdoor heating needs.

### Wall Mounted

Manufacturer and Product Image	Bronic	Sunheat	Heatstrip
			
Power (W)	2300	4500	6000
Voltage (V)	240	240	240
Price	\$985	\$450	\$800
Manufacturer and Product Image	Infratrech	RADtec	Heatstrip
			
Power (W)	6000	1500	1500
Voltage (V)	240	120	120
Price	\$800	\$150	\$200



### Free Standing

Manufacturer and Product Image	Ener-G+	Fire sense	Aura
			
Power (W)	1400	1500	1500
Voltage (V)	120	120	120
Price	\$300	\$300	\$400



## 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.

Manufacturer and Product Image	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

Manufacturer and Product Image	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

Manufacturer and Product Image	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



















## 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.

### Residential Grade

These products are designed for weekly use at a residence, and are somewhat less expensive (but also less durable) than the commercial grade equipment shown further below. You'll love how quiet they are.

	Blower	Chain Saw	Pole Pruner	Trimmer	Hedge Trimmer	
STIHL <sup>116</sup>	BGA 45 (\$130) 	MSA 120C (\$350) 	HTA 65 (\$660) 	FSA 56 (\$150) 	HAS 56 (\$280) 	RMA 460 (\$420) 
Husqvarna <sup>117</sup>	320iB (\$230) 	120i (\$260) 	536LiP4 (\$400) 	336LiLC (\$250) 	115iHD55 (\$230) 	LE121P (\$450) 
RYOBI <sup>118</sup>	RY40411 (\$170) 	RY40530 (\$200) 	P4361 (\$140) 	P2080 (\$130) 	P2660 (\$130) 	RY48110 (\$2700) 

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

### Commercial Grade

These products are designed for durability so they can sustain constant use by landscaping crews. If you're tired of the noise from a "mow and blow" landscaper, encourage them to switch to these dramatically quieter electric equivalents to their equipment.

	Blower	Chain Saw	Pole Pruner	Trimmer	Hedge Trimmer	
STIHL <sup>119</sup>	BGA 100 (\$350) 	MSA 160 C-BQ (\$350) 	HTA 85 (\$490) 	FSA 130 R (\$400) 	HAS 94 R (\$500) 	RMA 510 (\$520) 
Husqvarna <sup>120</sup>	550iBTX (\$500) 	T536Li XP (\$400) 	536LiPT5 (\$500) 	536LiLX (\$300) 	536LiHD60X (\$430) 	LE221R (\$430) 
RYOBI <sup>121</sup>	RY40440 (\$270) 	P549 (\$200) 	RY40561 (\$200) 	RY40250 (\$160) 	RY40610A (\$150) 	RY48ZTR100 (\$4100) 

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



## Electric Snowblowers

There is a wide range of electric snowblowers on the market ranging from a few hundred up to about 800 USD. Their lack of a need for maintenance makes them extremely convenient. This equipment does not require oil changes, filter changes, new spark plugs, or any gasoline. This also makes storage and usage safer for the operator.

Electric snowblowers, on average, are significantly quieter than their gasoline counterparts making blowing before work in the morning much more bearable for you and your neighbors. This clean, quiet, and efficient alternative to gas now also is readily available as battery powered rather than corded, giving you all the freedom of a gas-powered engine without the hassle.






Manufacturer and Product Image	EGO SNT2102	Snow Joe iON18SB	PowerSmart DB2401	Earthwise SN74018	Toro 38381	Snow Joe Ultra SJ620
Lbs. of snow/minute	1500	500	700	500	700	650
Terrain conditions	Paved & Gravel	Flat/Paved	Flat/Paved	Flat/Paved	Flat/paved	Flat/paved
Snow handling	Heavy wet to fluffy light	Heavy wet to fluffy light	Moderate dry to fluffy light	Heavy wet to fluffy light	Fluffy light	Fluffy light
Battery requirements	(2) 56-Volt 5.0Ah Lithium- Ion	40-Volt 4.0-Ah Lithium-Ion	40-Volt 4.0 Ah Lithium- Ion	40-Volt 4.0 Ah Lithium- Ion		
Run time	15 minutes	65 minutes	25 minuets	30 minuets		
Motor Type					15 Amp Series Wound Electric	13.5 Amp
Throwing distance	35ft	20ft	30ft	30ft	30ft	20ft
Clearance	21" wide & 10" deep	18" wide & 8" deep	18" wide & 11" deep	18" wide & 12" deep	18" wide & 8" deep	18" wide & 10" deep
Weight	70 lbs.	32 lbs.	18.5 lbs.	35 lbs.	25 lbs.	31.5 lbs.
Price	\$604*	\$300*	\$270*	\$250*	\$280	\$150

\*batteries and charger included



## 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, then 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







	<b>Span<sup>122</sup></b> 	<b>Eaton<sup>123</sup></b> <b>Pow-R-Command</b> 	<b>Koben<sup>124</sup></b> <b>GENIUS Smart Panel</b> 
<b>Cost</b>	\$2,500 including installation costs	TBA	TBA
<b>Description</b>	<ul style="list-style-type: none"> <li>Can monitor and control electrical usage at the circuit level</li> <li>Puts control into the hands of the homeowner with intuitive smartphone app</li> <li>Plug-in-play solution for rooftop solar, battery storage and EV charging</li> </ul>	<ul style="list-style-type: none"> <li>Control lighting and plug loads with time and space occupancy schedules to maximize energy savings</li> <li>15 A, 20 A and 30 A configurations in single- and two-pole models suitable for voltage systems up to 480V</li> <li>Can add expansion panels up to 168 controllable circuit breakers</li> </ul>	<ul style="list-style-type: none"> <li>Allows home to become “Smart Grid” ready</li> <li>Can integrate 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.</li> </ul>

### Subpanels

<b>Eaton<sup>125</sup></b> <b>Energy Management Circuit Breaker (EMCB)</b> 	<ul style="list-style-type: none"> <li>Programmable breakers to prioritize loads in power outage scenarios, control shedding of lighting and plug loads</li> <li>Remote cycling of HVAC, WH, to offset energy demands and save money</li> <li>Can connect with solar monitoring, home networks and demand response</li> <li>In the future could simplify EV charging</li> </ul>	<b>Lumin<sup>126</sup></b> <b>Smart Panel</b> 	<ul style="list-style-type: none"> <li>Real time balancing of battery use and EV charging</li> <li>Manages renewable generation, energy use and storage</li> <li>Dynamic switching of loads based on time of use rates</li> <li>Off-grid mode sheds non-critical loads and islands</li> <li>Can pair with batteries to create an integrated energy management system, removes requirement of a subpanel or protected loads panel</li> <li>Programmable schedules to automatically control loads</li> <li>Max size: (x6) 60A, (x6) 30A</li> </ul>
<b>Available for purchase</b>		<b>\$2,500 – 4,000 Single Family home Install</b>	

## Smart Circuit Splitters (EV Charging and Appliances)


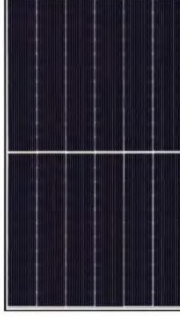
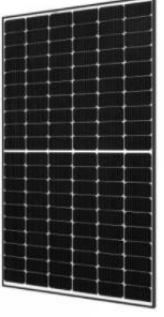


There are a few types of smart circuit splitters shown in the table below. Smart circuit breakers allow two devices (typically high power) to share a circuit, which can avoid an electrical panel upgrade (For example, like an EV charger and a Dryer). A more sophisticated version of this (DCC and EVDuty) will actually monitor the whole home's power consumption then adjust EV charging accordingly. The Neo Charge and the Dryer Buddy both come with built in plugs for attaching to the wall and two appliances, so they are easy to install. Both products also have two options for power sharing – the first, power is supplied to one device or another, and the second, power is supplied to two devices simultaneously. The SimpleSwitch is typically hardwired and just has the first option of powering one device at a time. The Thermolec DCC products and the EVDuty will both monitor a whole homes power consumption – however the DCC products will turn EV charging off when the load on the home panel exceeds 80% of its rated capacity, versus the EVDuty that will determine the left-over power space on the panel, then supply this to the EV for continuous charging.



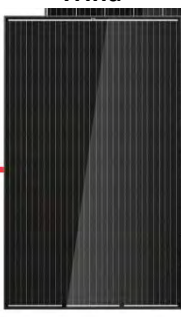

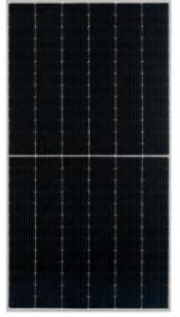
	<b>Neo Charge</b> <sup>127</sup> Smart Splitter 	<b>BSA Electronics</b> <sup>128</sup> Dryer Buddy 	<b>SimpleSwitch</b> <sup>129</sup> 240V Circuit Switch 	<b>Splitvolt</b> <sup>130</sup> Splitter Switch 	<b>Thermolec</b> <sup>131</sup> DCC 	<b>EVDuty</b> <sup>132</sup> Smart Current Sensor 
Cost (\$)	\$500 (Appliance) \$550 (Dual Car)	\$200 – 365 (several outlet versions)	\$550 (240V) \$650 (EV) \$550 (120V)	\$319	\$1,050 (DCC-9), \$945 (DCC-10)	\$500
Switch On/Off Between Two Devices	Yes	Yes	Yes	Yes	NA	NA
Continuous Power to Two Devices	Yes	Yes	No	No	NA	Yes, shares power between appliance circuit and EV circuit
Monitors Whole House Loads	No	No	No	No	Yes, if total panel exceeds 80% rated load, turns off EV charging. Reconnects automatically	Yes, monitors a unit/home's current draw, left over current will be used to charge EV
NEMA Outlet (NEMA-Amps)	10-30, 14-30, 14-50, (10-50 for portable))	10-30 to 10-30, 10-30 to 14-50, 14-30 to 14-30)	Hardwired, Optional Plugin	10-30, 14-30, 14-50	Hardwired	Hardwired, or NEMA 6-50, 14-50 outlet
Additional Notes		digital display that shows the draw of each load.	120V version as well	Full color display screen	Multifamily and Single Family, DCC-10 uses one double pole breaker slot	Multifamily and Single Family.



## Solar Photovoltaic Panels

The cost of installing solar on a home depends on the amount of electricity a homeowner wants to generate. In addition, the state you are in, how much energy you use, your roof's sunlight exposure and complexity, panel manufacturer, and size of the system all contribute to the costs of a solar array. Over the last 10 years residential photovoltaic systems have dropped more than 60% for a commonly used 6 kW system from \$50,000 to about \$20,000 or less before incentives. There is a 22% tax credit from the Federal Government on installing solar in homes in the year 2021 and by the year 2022 there will only be available tax credit of 10% to commercial buildings. About 47% of the cost of solar systems is solar equipment, 35% of cost on installation and permits, and 18% of cost is operation and maintenance. Below are some of the leading manufacturers of solar panels with their associated cost from August 2020. Unshaded good exposure solar arrays produce power that ends up costing only 6-8 cents per kWh over the life of the system. It pays to own the system and to maximize the power output by going **large** and **efficient** to decrease the amount of grid power you need to buy. Think of solar panels as the way to make electrification extremely cost effective and saving hundreds of dollars over the course of the solar array's lifetime.

	<b>SunPower</b> Maxeon® Gen5 	<b>Q Cells</b> Q. Peak DUO ML-G9 	<b>REC</b> Alpha 	<b>LG</b> Neon 2 	<b>Winaico</b> WSP-340MX 
Type	Monocrystalline	Monocrystalline	Monocrystalline	Monocrystalline	Monocrystalline
Power Output (W)	400	390	370	345	340
Efficiency	22.3%	20.8%	21.2%	20.1%	19.4%
Size (in) (LxWxD)	Contact	72.4 x 40.6 x 1.3	67.8 x 40 x 1.2	66.9 x 40 x 1.6	67.2 x 40.5 x 1.4
Price (\$)	SunPower	\$240	\$360	\$310	Contact Winaico

	<b>Solaria</b> PowerXT-370R-PD 	<b>Panasonic</b> HIT 	<b>Trina</b> 	<b>Canadian Solar</b> 	<b>Jinko Solar</b> 
Type	Monocrystalline	Monocrystalline	Monocrystalline	monocrystalline	monocrystalline
Power Output (W)	370	340	275-315	237-255	455
Efficiency	19.4%	20.3%	19.2%	19.9%	20.6%
Size (in) (LxWxD)	63.8 x 43.9 x 1.6	62.6 x 41.5 x 1.6	65.0x 39.1x 1.38	81.8x39.1x1.38	85.91x40.51x1.59
Price (\$)	\$360	\$340	contact	contact	Contact

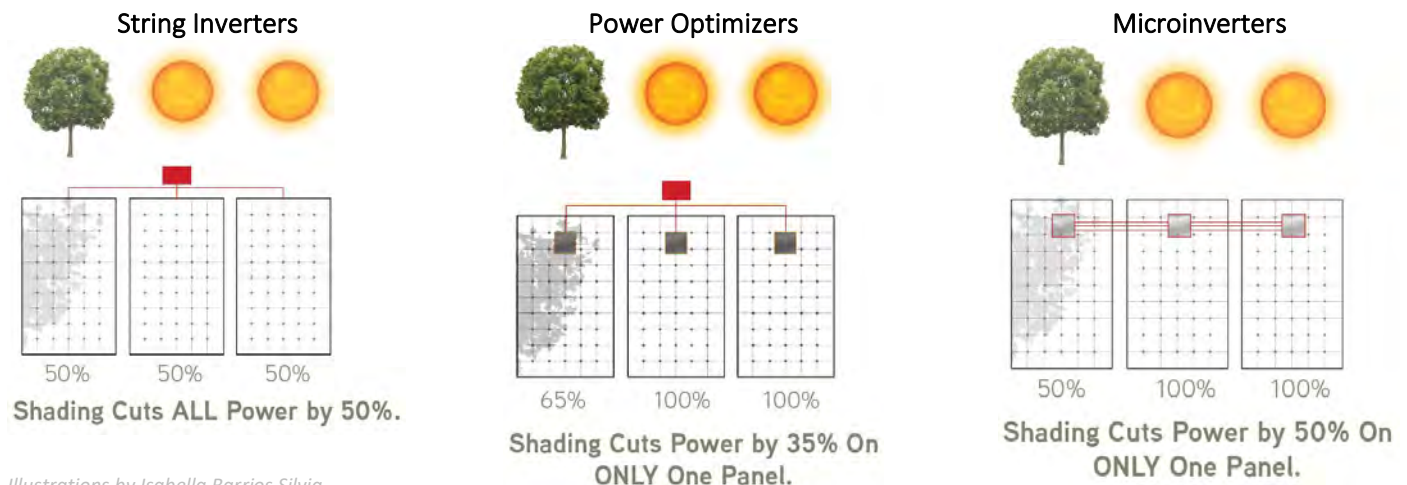
## Solar Inverters and Solar Array Sizing

Solar inverters are one of the most important parts of a solar panel system - they take energy from solar panels and convert it from DC power to AC power to use within a building. To offset the average energy use of a typical 1,200 square foot house, the solar array will



Figure 56: A typical 1,200 sq. ft. and 2,000 sq. ft. home. Illustration by Isabella Barrios Silva.

be about 200 square feet and 4 kW of DC power. For an average 2,000 square foot house, the solar array will be about 400 square feet and about 8 kW of DC power. Each panel is about 20 square feet and about 400 Watts per panel. To power an average electric car for a year (12,000 miles), it requires an additional 2 kW solar array using 100 square feet of roof space.



Illustrations by Isabella Barrios Silva

Solar string inverters use **one central inverter** connected to all solar panels in a **single circuit**, such that one panel's shading affects the power produced by all panels. The circuit may have multiple wired ("strings") connecting the panels.

**Advantages:** lower installation and maintenance costs

**Disadvantages:** warranty will be shorter (10-12 years) compared to micro-inverters (25-year warranty).

A solar array with power optimizers has **one central circuit / inverter** making wiring easier to install, and **multiple system optimizers** on each solar panel allows **each panel to provide maximum power** without being affected by other panels negatively.

**Advantages:** similar advantages as micro-inverters but at a lower cost and have a 20–25-year warranty.

**Disadvantages:** higher maintenance costs since they are exposed to the environment on the roof. Central inverters only have a 10-12-year warranty.

Microinverters are an **individual inverter and circuit on each solar panel**, allowing them to operate independently to provide maximum power and to **not be negatively affected by other panels**.


**Advantages:** can track production of each panel individually, making it easier to detect if panels need maintenance.

**Disadvantages:** more hardware the on roof requires more maintenance compared to a string inverter.





## Solar Array Size and the Watt Diet

The size of your electrical panel will cap the size of your solar array – because the code limits the maximum solar circuit to 20% of the size of the panel, a 100 Amp electric panel is limited to 20-amp solar circuits. Because long duration loaded circuits cannot be loaded to their maximum for safety reasons, this means only 16-amps are available (the “80%” rule). A typical solar array for a home is 240 volts, so this multiplied by 16-amps gives you a 3.8 kW max of AC power. However, most inverters allow for “clipping” which means you can install a solar array that is larger than 3.8 kW DC. Each inverter company allows a different “inverter load ratio” or how much an inverter can be overloaded. For the state-of-the-art Solar Edge and Enphase inverters, this ratio is 1.6, meaning you can have a max solar array DC size of 6.0 kWdc. When the solar array is producing more than the 3.8 kW AC the inverter can process, the excess energy is “clipped”. However, this allows for the max amount of energy allowed by the inverter for more hours of the day, instead of just at around noon. Using DC coupled battery storage can also mitigate clipping by moving excess energy into storage instead of clipping it. With today’s low solar panel prices and comparatively higher grid power prices it often makes good sense to install solar panels up to the inverter’s load ratio, which can result in a cost less than 8 cents per kWh.


## Enphase - Microinverters

	Model	IQ7	IQ7X	IQ7	IQ7A
	Price (\$)	147	175	155	179
	Max Output AC Power (VA)	295	320	250	366
	DC Input Power (W)	235 - 440	320 - 460	235 - 350	350 - 460
	Max DC input Voltage (V)	60	79.5	48	58

## Solar Edge – Single Phase Inverters

	SE3800H-US	SE5000A-US	SE6000H-US	SE11400H-US	SE10000A-US
					
Maximum Ac Power Output (VA)	3,800 @ 240V	5,450 @ 240 V	6,000 @ 240V	11,400 @ 240 V	10,950 @ 240 V
AC Output Voltage Range (Vac)	240	240	240	240	240
AC Frequency (Hz)	59.3-60-60.5	59.3-60-60.5	59.3-60-60.5	59.3-60-60.5	59.3-60-60.5
Max. Input Current @ 240V (dc)	10.5 A / 2520 W	15.5 / 3720 W	16.5 A / 3960 W	30.5 A / 7320 W	30.5 A / 7320 W

## Solar Edge – Combined EV Charger and Solar Inverter








	Model	SE3800H-US	SE7600H-US
	Maximum Ac Power Output (VA)	3,800 @ 240V	7,600 @ 240V
	AC Output Voltage Range (Vac)	240	240
	AC Frequency (Hz)	59.3-60-60.5	59.3-60-60.5
	Max DC Charger Power (W)	9,600	
	EV Charger Connector Type	SAE-J1772-2009, aka CCS	
	Maximum DC Power (W)	5,900	11,800



## 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 turbines, 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.<sup>133</sup>

Battery system prices have dropped 87% in price over the last decade, from \$1100/kWh in 2010 to \$156/kWh in 2019, helping drive the rapid international growth in affordable electric vehicles and home batteries.<sup>134</sup> 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.<sup>135</sup> 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, lightweight, and relatively common, found on every continent in rocks of volcanic origin and mined heavily in Chile, Australia, and China. Some manufacturers such as Sonnen include inverter Wi-Fi integration and off products that are standalone units.







	DC Batteries			AC Batteries			
DC Battery	Blue Planet Energy	LG RESU 10H	SimpliPhi Power 2.4	Tesla Powerwall	Panasonic EVDC-105	Sonnen Eco	Sonnen EcoLinx
							
Capacity (kWh)	8, 12, 16	9.3	2.4	13.5 (combinations up to 135)	5.7, 11.4, 17.1	5 – 20 (2.5 kWh steps)	10, 12, 14, 16, 18, 20
Round Trip Eff.	98%	94.5%	98.0%	98%	89%	90%	86%
Chemistry	Lithium Iron Phosphate	Lithium-ion	Lithium Iron Phosphate	Lithium Nickel Manganese Cobalt Oxide	Lithium-ion	Lithium Iron Phosphate	Lithium Iron Phosphate
Price		\$5,520		\$7,600 (+ \$2,500 install)	\$12,700, \$15,300, \$18,500	\$9,000 (5kwh)	

## Low-Cost Resilience

A full home sized solar array and battery system can be costly, so this section aims to provide a few products that can help improve your home's resilience, but for an affordable cost. When the power grid goes down, having a back up power for lighting and phone charging at a minimum is essential. This section also provides a solution to propane fueled camp stoves.

### Electric Generators

Electric generators are high-capacity batteries that can provide power to a range of devices (devices with 12V car ports that use DC power or devices with 120V plugs typical in a home). To recharge the internal battery, power may be input from various sources such as solar, car batteries, or directly from the grid. Electric generators that have solar charging available directly connect to solar panels and draw power from them to recharge. The batteries go up in cost as their capacity increases which is measured in Watt-hours. For example, the Goal Zero Yeti 500X could power a 10-Watt lightbulb for 50 hours or could charge a 12W smart phone 42 times. The largest two batteries shown below, have a higher rate of power supply which enables them to power more energy consuming devices. As another example, the Goal Zero Yeti 6000X could run an average full-sized fridge (100W) for 60 hours.

Picture	Pecron S200	Rockpals	RIVER 600	Goal Zero Yeti 500X	Goal Zero Yeti 1500X	Goal Zero Yeti 6000X
						
Price	\$170	\$220	\$350	\$700	\$2000	\$5000
Solar charging	Yes	Yes	Yes	Yes	Yes	Yes
Battery Capacity (Wh)	193	288	288	500	1500	6000
Output Voltage (V)	5, 12 (VDC) 120 (VAC)	5, 12 (VDC) 120 (VAC)	5, 12 (VDC) 120 (VAC)	5, 9, 12, 20 (VDC) 120 (VAC) / 2.5A	5, 12, 20 (VDC) 120 (VAC) / 16.5A	5, 12, 20 (VDC) 120 (VAC) / 16.5A
Full charge time with 120VAC input (hrs)	6-7	6-7	1.6	4.5 (120V/1A)	7 (120V/2A)	12 (120V/5A)

### Electric Cooking on Small Batteries

Electric cooking devices such as induction stovetops are viable alternatives to natural gas cooking options because they eliminate the risks of burning natural gas. However, typical induction stoves require a lot of power and can use up battery storage quickly. The alternative cooking devices shown below can be powered by electric generators more efficiently and use a typical car outlet (which are in all electric vehicles as well). For example, the RoadPro car frying pan can run for 8.3 hours using the Goal Zero Yeti 1500X. Keep in mind only the larger electric generators will pair with these cooking devices because of their amperage draw.

Picture	RoadPro Car Frying Pan	RoadPro Car Oven	RoadPro Crock Pot
			
Price	\$30	\$35	\$50
Watts	180	144	150
Voltage	12V DC	12V DC	12V DC
Amps	15	12	12
Run time with Goal Zero Yeti 1500X (hr)	8.3	10.4	10

## Back-up Battery Light Bulbs

These light bulbs are equipped with backup batteries that stay charged while power is being supplied as normal and get discharged when power goes out. This is a viable option for areas that require constant lighting and cannot be disturbed even during power outages.

Picture of the LED Light Bulb + Battery				
Model	GE - A21	YKDtronics	JacksonLux	Neporal
Lighting Hours on Battery Power (hrs)	5	3-4	3-4	4-5
Wattage (W)	8	5	9	15
Lumens	760	500	850	800
Lumens/Watt	95	100	94.44	53.33
Price	\$15	\$8	\$9	\$11

## Electric Camp Stoves and Grills

**Biolite CampStove 2** is a camp stove that burns twigs found at any campsite with a battery-powered fan that creates a vortex of hot, smokeless fire. Biolite cooks food quickly while simultaneously recharging the battery from the heat, which is transformed into electricity and can additionally charge a headlamp or cellphone. This Biolite is perfect for backpacking because it is lighter than the average butane canister. An additional grill attachment also available, shown in the image on the right above, for cooking small meals. This model also provides the option of USB charging for small electronics. The specs for the stove are below:

- Charge phones, lights, and more with 3W generated power
- Burn twigs, sticks, wood scraps, or [pellets](#)
- Boil Time: 1L in 4.5 min
- Battery Capacity: 2600 mAh
- Packs down to size of a 32oz wide mouth water bottle
- Weight: 2.06 lbs



**BioLite FirePit:** Enjoy the warmth, smell, crackle, and feel of a wood campfire, but fan-assisted to reduce smoke. With capacity for up to 4 standard firewood logs, the BioLite FirePit creates hyper-efficient flames with patented airflow technology and gives you a front-row seat to the magic thanks to the X-Ray mesh body, enabling 360 views. Lift the fuel rack and toss in charcoal to transform it from a fire pit to a portable hibachi style grill, complete with an included grill grate. Control the size of your flames manually or remotely with the free Bluetooth app.






- Fuel: Burns firewood or charcoal
- Burn time: 24hr on low, 10hr on medium, 5hr on High
- Dimensions: 27" x 13" x 15.8"
- Weight: 19.8 lbs







## Electric Vehicle Supply Equipment (EVSE)

EV Charging standards have been developed under the EVSE protocol. There are three levels, Level 1, Level 2, and Level 3 (aka DC Fast Charging). These levels are associated with how much power can be delivered to your car. The EV charger can be connected to the grid via a hardwired connection to an electrical panel, done by an electrician, or a NEMA (National Electrical Manufacturer's Association) standardized outlet. For Level 1 this will be the standard 120-volt and 15 to 20-amp socket found on your kitchen counter, bathroom, or bedroom outlet. For Level 2 chargers, depending on the power requirement you may see a typical 30-amp electric clothes dryer outlet, also called NEMA 14-30, or a typical 50-amp electric oven outlet, called NEMA 14-50; or else the charger may be hardwired by an electrician. DC Fast Chargers use DC power, as opposed to AC power coming from the grid, to charge the battery of your car. Level 3 chargers are almost never found in single-family homes, due to the amount of power needed.

	Level 1 <sup>136</sup>	Level 2 <sup>137</sup>	Level 3
			
<b>Electrical Specifications</b>	120 Volts, 15 to 20 Amps maximum	240 Volts, 20 to 40 Amps, 30 Amps is common	DC Fast Charging, 12kW or greater
<b>Grid Connection, NEMA Receptacle</b>	NEMA 5-15, NEMA 5-20 	NEMA 14-30, NEMA 14-50, Hardwired 	Always Hardwired, very rare outside of Multifamily and Commercial applications
<b>Connector Types</b>	SAE J1772	SAE J1772	CHAdEMO, SAE J1772 aka CCS + 2 pins, Tesla proprietary





### Level 2 EV Chargers

	SolarEdge LJ40P-KIT-SA-EV-S	Juicebox <sup>138</sup> JuiceBox 40	Chargepoint <sup>139</sup> ChargePoint Home Flex	Siemens VersiCharge
				
<b>Connector</b>	SAE J1772	SAE J1772	SAE J1772	SAE J1772
<b>NEMA Types<sup>140</sup></b>	NEMA 6-50	Hardwired or Plug (NEMA14-50)	Hardwired or Plug (NEMA 6-50 or 14-50)	Hardwired or Plug (NEMA 6-50)
<b>Output Amps</b>	40	40	50	30
<b>Output Power (kW)</b>	Up to 9.6	Up to 9.6	3.8 - 12	1.8 - 7.2
<b>Mounting Method</b>	Wall-mounted	Wall, Column, or Pedestal	Wall, Column, or Pedestal	Wall-mounted
<b>Input Amps (240V)</b>	40A	40A	50A, 40A continuous	32
<b>Breaker Size (Amps)</b>	50, 2-phase	50, 2-pole	50, 2-pole	40, 2-pole
<b>Input Voltage</b>	240 AC	208-240 VAC, 1-phase	208-240 VAC, 1-phase	208-240 VAC
<b>Input Power</b>	-	10,000W	10,000W	7,700W
<b>Price</b>	\$550	\$599 (base)	\$699	\$730

## 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. Nissan estimates that its all-electric Leaf can power an average home in Japan for two to four days without solar,<sup>141</sup> 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.<sup>142</sup>

### Nuvve Available Now, Others Available Soon in the United States

	Wallbox <sup>143</sup> Quasar	Ossiaco <sup>144</sup> dcbel	Nuvve <sup>145</sup> PowerPort	Fermata Energy <sup>146</sup>
				
<b>Vehicle-to-Home</b>	X	X	X	X
<b>Vehicle-to-Grid</b>			X	X
<b>Other Capabilities</b>	<ul style="list-style-type: none"> <li>It charges and discharges through a CHAdeMO vehicle connector</li> <li>Max power of 7.4 kW</li> </ul>	<ul style="list-style-type: none"> <li>Also operates as a solar inverter and home energy management system</li> <li>Coming to market in 2021/2022</li> </ul>	<ul style="list-style-type: none"> <li>6-80 Amps of Single Phase AC charging</li> <li>6-120 Amps of Three Phase AC Commercial Charging</li> </ul>	<ul style="list-style-type: none"> <li>Commercial and residential capabilities</li> <li>Coming to the US market in 2021</li> </ul>



### Not Available in the United States

Since at least 1996 there have been a plethora of companies outside the United States have V2H and V2G chargers. They are used during power outages and to provide grid services. Using a car's battery to power your home or to sell back to the grid is an essential service in our all-electric future.

Vehicle to Building (V2B) Chargers			Vehicle to Grid (V2G) Chargers			
Honda	Mitsubishi	Nissan	Nissan	Endesa	OVO	Princeton Power Systems
						

## 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 1/3<sup>rd</sup> 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. The below section provides a list of 2022 model electric vehicles with their specifications, provided by Menlo Spark.<sup>2</sup>

	 <h3>ELECTRIC VEHICLE BUYER'S GUIDE* MARCH 2022</h3> 							
Manufacturer	Audi	BMW	BMW	Chevrolet	Chevrolet	Ford	Hyundai	Hyundai
Model	e-tron	i4	iX Drive 50	Bolt EV	Bolt EUV	F-150 Lightning	Ioniq EV	Kona Electric
Passengers	5	5	5	5	5	4	5	5
Doors	5	5	5	5	5	2	4	4
MSRP (from) <sup>1</sup>	\$43,900	\$55,400	\$83,200	\$37,495	\$37,495	\$52,974	\$39,700	\$34,000
Car Body	Hatchback/SUV	Coupe	SUV	Hatchback	Hatchback	Truck	Hatchback	SUV
EPA Range (miles)	241	270	324	259	247	230	220	258
MPGe City / Highway	100/89			257/309	270/324		132/98	132/108
MPGe Combined	95			281	293		114	120
Battery Capacity (from)	82 kWh	83.9 kWh	111.5 kWh	65 kWh	66 kWh	98 kWh	58.2 kWh	64 kWh
Horsepower	295	170	181	200	200	563	139	195
0-60 Speed	7.9 seconds	5.5 seconds	4.4 seconds	6.5 seconds	7 seconds	4.5 seconds	5	7.9
Charge Time (240 volt)	7.5 hours	11-15 hours	9-12 hours	7 hours	7 hours		6 hours, 5 minutes	6 hours, 10 minutes
DC Fast Charge Time <sup>3</sup>	5%-80% in 38 min	80% in 31 min	80% in 35 min	100 miles in 30 min	100 miles in 30 min	15%-80% in 1:31	80% in 54 min	80% in 54 min
Max Cargo	53.1 cu ft	45.56 cu ft	61.8 cu ft	56.9 cu ft	57 cu ft	52.8 cu ft	56.2 cu ft	39.3 cu ft
Federal Tax Credit <sup>2</sup>	\$7,500	\$7,500	\$7,500	N/A	N/A	\$7,500	N/A	\$7,500
Additional Notes						production to start in Spring 2022 on 2023 model		

								
Manufacturer	Jaguar	Kia	Kia	Lucid	Mercedes Benz	Mini	Nissan	Nissan
Model	I-Pace S	Niro EV	EV6	Air Grand Touring	EQS	Cooper SE	Leaf S	Leaf e+ S
Passengers	5	5	5	5	5	4	5	5
Doors	5	4	4	4	4	2	4	4
MSRP (from) <sup>1</sup>	\$69,900	\$40,900	\$39,990	\$139,000	\$102,310	\$29,900	\$29,900	\$36,550
Car Body	SUV	Crossover	SUV	Sedan	SUV	Hatchback	Hatchback	Hatchback
EPA Range (miles)	234	239	232	469	340	114	149	226
MPGe City / Highway	80/72	136/100	123/102	121/122	92/99	119/100	123/99	118/97
MPGe Combined	76	117	112	121	95	110	111	108
Battery Capacity (from)	90 kWh	58kWh	64 kWh	112 kWh	115 kWh	32.6 kWh	40 kWh	62 kWh
Horsepower	197				329	181	147	215
0-60 Speed	4.5 seconds	7.5 seconds	8 seconds	3.0 seconds	5.9 seconds	6.9 seconds	7.4 seconds	
Charge Time (240 volt)	13 hours	9 hours	7.5 hours		8 hours	4.25 hours	8 hours	10 hours
DC Fast Charge Time <sup>3</sup>	80% in 45 - 85 minutes	80% in <1 hour	80% in <1 hour		80% in 23 minutes	80% in 39 min	80% in 40 min	80% in 43 min
Max Cargo	25.3 cu ft	49.6 cu ft	45.9 cu ft		62.5 cu ft	7.45 cu ft	30 cu ft	30 cu ft
Federal Tax Credit <sup>2</sup>	\$7,500	\$7,500	\$7,500	Unknown	\$7,500	\$7,500	\$7,500	\$7,500
Additional Notes	2020 model							

<sup>2</sup> Go to [www.menlospark.org](http://www.menlospark.org) to learn more.






									
Manufacturer	Polestar	Porsche	Rivian	Tesla	Tesla	Tesla	Tesla	Volkswagen	Volvo
Model	Polestar 2	Taycan	R1T	Model S	Model X	Model 3	Model Y	ID.4 Pro	C40 Recharge
Passengers	5	4	4	5	5 to 7	5	5 to 7	5	
Doors	5	4	5 or 7	4	4	4	4	5	
MSRP (from) <sup>1</sup>	\$45,900	\$82,700	\$67,500	\$94,990	\$104,990	\$44,990	\$58,990	\$40,760	\$58,750
Car Body	Sedan	Sedan	Truck	Sedan	SUV	Sedan	SUV	SUV	SUV
EPA Range (miles)	270	200	314	405	348	272	330	260	226
MPGe City / Highway		76/84	74/66	124/115	107/97	138/126	127/117		94/80
MPGe Combined		79	70	120	102	132	122		87
Battery Capacity (from)	100 kWh	79.2 kWh	135 kWh	100 kWh	100kWh	60 kWh	80 kWh	82 kWh	80 kWh
Horsepower				518	502.9+258.8	283			
0-60 Speed	7 seconds	5.1 seconds	3 seconds	3.1 seconds	3.8 seconds	5.8 seconds	4.8 seconds	7.7 seconds	4.7 seconds
Charge Time (240 volt)	7 hours			8.75 hours	5.75 - 8.75 hours	5.75 hours			
DC Fast Charge Time <sup>3</sup>	80% in 31 min		80% in 41 min	80% in 40 min at Supercharger	80% in 50 min at Supercharger	80% in 30 min at Supercharger			
Max Cargo	14.27 cu ft	14.37 cu ft	11.65 cu ft	58.1 cu ft	81.21 cu ft	12 cu ft	66 cu ft	55.6 cu ft	
Federal Tax Credit <sup>2</sup>	\$7,500	\$7,500	\$7,500	N/A	N/A	N/A	N/A	\$7,500	\$7,500
Additional Notes		other models with higher range/power		other models with higher ranges	other models with higher ranges	other models with higher ranges	other models with higher ranges		

## EVs and Outdoor Recreation Inspiration



## Electric Snowmobiles

Cold weather transportation is a sector that has not regularly been in the spotlight of renewable energy, but it is in desperate needs of clean solutions. This rapidly improving technology has many benefits over its gas counterparts. Gas-powered snowmobiles have little to no emissions standards and many have two stroke engines causing them to be sometimes as much as 50 times more polluting than the average car.<sup>1</sup> Less emissions and pollution is an obvious plus, but financially these machines also have the huge advantage of needing practically no maintenance, which reduces cost of ownership. There is no fuel, no oil, no transmission, and no drive belts, so the cost of operation is much lower and that means more time can be spent out riding rather than doing costly fixes back at home. These snowmobiles are compatible with and can charge anywhere with automotive standard equipment. The average charging time with the AC 240V Level 2 charger is about 2 hours, but now there exists a DC fast charger which can bring the battery up to 80% in just 20 minutes.<sup>147</sup>

Manufacturer and Product Image	Taiga Motors Ekko TS3	Taiga Motors Atlas	Taiga Motors Nomad
			
Range	131km	140km	134km
0-100km/h	3.3s	2.9s	NA
Towing (1,124lbs)	NA	NA	510kg
Engine Package	180hp	180hp	120hp
Battery	27 kWh	27 kWh	27 kWh
Weight (ride ready)	265kg / 586lbs	271kg / 597lbs	275kg / 607lbs
Track	154"x 15"x 2.5" 165"x 15"x 2.5"	137"x15"x1.6"	Studded 154"x16"x1.6"
Front Suspension	Double wishbone Travel: 220mm / 8.66"	Double wishbone Travel: 220mm / 9.05"	Double wishbone Travel: 224mm / 8.82"
Rear Suspension	Rad-M multilink Travel: 270mm / 10.6"	Rad-X multilink Travel: 300mm / 11.8"	Rad-u multilink Travel: 300mm / 11.8"
Stance	950mm / 37.4in	1074mm / 42.3in	1074mm / 42.3in
Dimensions	Height: 1482mm / 58.2in Length: 3360mm / 132.3in	Height: 1278mm / 50.3in Length: 3158mm / 124.3in	Height: 1550mm / 61.0in Length: 3275mm / 128.9in
Features	HD display with GPS mapping Custom terrain profiles Powder flow package	HD display with GPS mapping Custom terrain profiles Click adjustable shocks	HD display with GPS mapping 2-up seating Active stability management



# References

## Cover Page Citations

Top left: Ross Residence, Amherst, MA: 1000 Home Challenge. (2012). Deep Energy Retrofit Goes for Zero. <https://1000homechallenge.com/case-studies/>  
Middle left: Darby Residence, Hamilton, NY: Jay Egg (2019) 1830 Home in Hamilton, New York is an all-electric Geothermal Masterpiece. Green Builder. <https://www.greenbuildermedia.com/energy-solutions/1830-home-in-hamilton-ny-is-an-all-electric-geothermal-masterpiece>  
Top right: 1918 House of the Future, Cleveland Heights, OH: [https://energysmartohio.com/case\\_studies/1917-net-zero-ready/](https://energysmartohio.com/case_studies/1917-net-zero-ready/)  
Bottom left: Big Chill Retro Induction Stove: <https://bigchill.com/>  
Middle right: Neo Charge Smart Circuit Splitter: <https://www.getneocharge.com/>  
Bottom right: Water Vapor Fireplace, Nero Fire Design: <https://www.nerofiredesign.com/gallery>

## Additional All-Electric Case Studies

- 1: 1000 Home Challenge. (2012). Mackey Deep Energy Reduction Case Study. Accessed: [https://jhn.e94.myftpupload.com/wp-content/uploads/2020/10/Mackey\\_THC\\_Case\\_Study.pdf](https://jhn.e94.myftpupload.com/wp-content/uploads/2020/10/Mackey_THC_Case_Study.pdf)
- 2: Image Courtesy of Mary Dateo.
- 3: International Living Future Institute. (2021). Willowbrook House. Accessed: <https://living-future.org/lbc/case-studies/willowbrook-house/> (Image by Sunshine Mathon)
- 4: Image Courtesy of Dick Swanson.
- 5: Northeast Sustainable Energy Association. (2021). Fink-Simko Zero Net Energy Deep Energy Retrofit. Accessed: <https://nesea.org/project-case-study/fink-simko-zero-net-energy-deep-energy-retrofit/general>
- 6: Image Courtesy of Barry Cinnamon.
- 7: Image Courtesy of Pierre Delforge.
- 8: Image Courtesy of Eva Markiewicz and Spencer Ahrens.
- 9: Image Courtesy of Diane Sweet of EmeraldECO.
- 10: Earth Mother News. (2015). A Renewable Home Energy Retrofit: How We Did It. Accessed: <https://www.motherearthnews.com/renewable-energy/other-renewables/home-energy-retrofit-zm0z15jzhir>
- 11: Image Courtesy of Jeff and Debbie Byron.
- 12: 1000 Home Challenge. (2010). Road to Energy Independence. Accessed: <https://jhn.e94.myftpupload.com/wp-content/uploads/2020/10/Joann-Olson-Wisconsin-Case-Study.pdf>
- 13: Image Courtesy of Indra Ghosh.

- 1 Federal Energy Information Administration. (2019). "One in four U.S. homes is all-electric." <https://www.eia.gov/todayinenergy/detail.php?id=39293>
- 2 Statista (2020). "Unit shipments of electric/gas cooking appliances in the U.S. from 2007 to 2017." <https://www.statista.com/statistics/295477/unit-shipments-of-electric-gas-cooking-appliances/>
- 3 Statista (2020) "Gas dryer unit shipments in the United States from 2005 to 2017." <https://www.statista.com/statistics/322357/gas-dryers-shipments-united-states/>
- 4 Engelberg, Jeremy and Brassell, Evan. (2019). "Differences in Fuel Usage in the United States Housing Stock: American Housing Survey Report." U.S. Census Bureau. <https://www.census.gov/content/dam/Census/library/publications/2019/demo/h150-19.pdf>
- 5 UN Environment Global Status Report 2017; EIA International Energy Outlook 2017
- 6 Environmental Defense Fund. (2020). Methane, The Other Important Greenhouse Gas. EDF calculation based on IPCC AR5 WGI Chapter 8." <[www.edf.org/climate/methane-other-important-greenhouse-gas](http://www.edf.org/climate/methane-other-important-greenhouse-gas)> Note that other sources like livestock (e.g. cows) contribute to methane emissions also.
- 7 Griffith, Saul. (2020). Rewiring America: A Field Manual for the Climate Fight. Accessed: [static1.squarespace.com/static/5e540e7fb9d1816038da0314/t/5f21eda94f7832d9b1a31bf/1596059082636/Rewiring\\_America\\_Field\\_Manual.pdf](https://static1.squarespace.com/static/5e540e7fb9d1816038da0314/t/5f21eda94f7832d9b1a31bf/1596059082636/Rewiring_America_Field_Manual.pdf)
- Roberts, David, Vox Explainer, <https://www.vox.com/2016/9/19/12938086/electrify-everything>
- 8 Marketplace Tech. (2020). Podcast: Making old building resilient to climate change requires new financial tools. <https://www.marketplace.org/shows/marketplace-tech/making-old-buildings-resilient-to-climate-change-requires-new-financial-tools/>
- 99 Lacey, S. (2021). Watt It Takes: BlocPower CEO Donnel Baird Wants to Electrify Buildings for Everyone. <https://www.greentechmedia.com/articles/read/watt-it-takes-blocpower-ceo-donnel-baird-wants-to-electrify-buildings-for-everyone>
- 10 Clean Energy Connection. (2021). Find a Contactor. Accessed: <https://www.cleanenergyconnection.org/find-contractor>
- 11 TRC. (2021). Building Electrification Technical Assistance. Accessed: <https://allelectricdesign.org/>
- 12 Weiwei Lin, Bert Brunekreef, and Ulrike Gehring, "Meta-analysis of the effects of indoor nitrogen dioxide and gas cooking on asthma and wheeze in children," International Journal of Epidemiology, Volume 42, Issue 6, (December 2013): 1724–1737, <https://doi.org/10.1093/ije/dyt150>.
- 13 Asthma and Allergy Foundation of America. "Asthma Facts and Figures." Accessed July 23, 2020. [www.aafa.org/asthma-facts/](http://www.aafa.org/asthma-facts/).
- 14 Tursynbek Nurmagambetov, Robin Kuwahara, and Paul Garbe. "The Economic Burden of Asthma in the United States 2008–2013." Annals of the American Thoracic Society.
- 15 Jarvis et al. (1996) "Evaluation of asthma prescription measures and health system performance based on emergency department utilization." <<https://www.ncbi.nlm.nih.gov/pubmed/8618483>>
- 16 Singer, B. (2018). Healthy Efficient Homes: Research Findings. ACEEE 2018 Conference on Health, Environment and Energy. <<https://aceee.org/sites/default/files/pdf/conferences/chee/2018/1b.singer.pdf>>
- 17 Environmental Protection Agency. (2009). Preventing Carbon Monoxide Poisoning. <[https://www.epa.gov/sites/production/files/2015-08/documents/pcmp\\_english\\_100-f-09-001.pdf](https://www.epa.gov/sites/production/files/2015-08/documents/pcmp_english_100-f-09-001.pdf)>
- 18 San Francisco Department of the Environment. (2017). Methane Math: How Cities Can Rethink Emissions from Natural Gas. <[https://sfenvironment.org/sites/default/files/fliers/files/methane\\_math\\_natural-gas-report\\_final.pdf](https://sfenvironment.org/sites/default/files/fliers/files/methane_math_natural-gas-report_final.pdf)>
- 19 Joseph, G. (2016). "30 Years of Oil and Gas Pipeline Accidents, Mapped." Citylab.
- 20 Jarosz, Brooks. "Construction worker called in gas line rupture before explosion." Dec 22, 2016. ABC 6 News, Columbus, Ohio. <<https://abc6onyourside.com/investigators/construction-worker-called-in-gas-line-rupture-before-explosion>>
- 21 Synapse Energy. (2018). Economics, Decarbonization of Heating Energy Use in California Buildings at 2, 39. <<http://www.synapse-energy.com/sites/default/files/Decarbonization-Heating-CA-Buildings-17-092-1.pdf>>
- 22 Billimoria et al. "The Economic of Electrifying Buildings." Rocky Mountain Institute. 2018. [rmi.org/insight/the-economics-of-electrifying-buildings/](http://rmi.org/insight/the-economics-of-electrifying-buildings/)
- 23 Levy, R. and Sledge, J. (2012) A Complex Portrait: An Examination of Small-Dollar Credit Consumers. Center for Financial Services Innovation.
- 24 Energy Sage. "How to calculate solar panel payback period (ROI)." Accessed Dec. 28, 2020. <https://news.energysage.com/understanding-your-solar-panel-payback-period/#:~:text=The%20typical%20solar%20payback%20period,20%2C000%2F%242%2C500%20%3D%208>.
- 25 Sierra Club. (2020). New Analysis: Heat Pumps Slow Climate Change in Every Corner of the County. Accessed: <https://www.sierraclub.org/articles/2020/04/new-analysis-heat-pumps-slow-climate-change-every-corner-country>
- 26 Architecture 2030. (2020). Why the Building Sector? <[https://architecture2030.org/buildings\\_problem\\_why/](https://architecture2030.org/buildings_problem_why/)>
- 27 Environmental Defense Fund. (2020). Methane, The Other Important Greenhouse Gas. \*EDF calculation based on IPCC AR5 WGI Chapter 8." <[www.edf.org/climate/methane-other-important-greenhouse-gas](http://www.edf.org/climate/methane-other-important-greenhouse-gas)> Note that other sources like livestock (e.g. cows) contribute to methane emissions also.
- 28 Energy Sage. "How to calculate solar panel payback period (ROI)." Accessed Dec. 28, 2020. <https://news.energysage.com/understanding-your-solar-panel-payback-period/#:~:text=The%20typical%20solar%20payback%20period,20%2C000%2F%242%2C500%20%3D%208>.
- 29 U.S. Energy Information Administration. "U.S. Shipments of Solar Photovoltaic Modules Increase as Prices Continue to Fall." August 19, 2020. <https://www.eia.gov/todayinenergy/detail.php?id=44816#:~:text=The%20average%20value%20of%20solar,per%20peak%20watt%20in%202019>.
- 30 Thiele, Timothy. "Average Costs for 12 Common Electrical Projects." Dec 21, 2020. The Spruce. <https://www.thespruce.com/electrical-project-costs-1152463>



- 31 Silicon Valley Clean Energy. "Award Winning All-Electric Living." <https://www.svcleanenergy.org/all-electric-award/>
- 32 Thiele, Timothy. "Average Costs for 12 Common Electrical Projects." Dec 21, 2020. The Spruce. <https://www.thespruce.com/electrical-project-costs-1152463>
- 33 Environmental Protection Agency. "Energy Star Product Finder." Searched Nov 29, 2020. <https://www.energystar.gov/productfinder/product/certified-clothes-dryers/results>
- 34 Sacramento Municipal Utility District. "SMUD Residential Electrification Project Costs." CEC TN # 234862, Docket Number 19-DECARB-01. 9/22/2020.
- 35 Sacramento Municipal Utility District. "SMUD Residential Electrification Project Costs." September 22, 2020. Docketed to California Energy Commission #19-DECARB-01, TN 2348620.
- 36 Mini-split costs courtesy of Jonathan and Sarah Moscatello, owners of the Heat Pump Store in Portland, Oregon.
- 37 Electrification cost data courtesy of Nate Adams of Energy Smart Ohio.
- 38 Personal communication from Li Ling Young, VEIC, on September 15, 2020.
- 39 Diversified Energy Specialists for MEMA. "Case Study: Massachusetts Air-Source Heat Pump Installations 2014-2019." November 25, 2019. [https://massenergymarketers.org/files/3115/7858/1868/DES\\_-\\_Heat\\_Pump\\_Study.pdf](https://massenergymarketers.org/files/3115/7858/1868/DES_-_Heat_Pump_Study.pdf)
- 40 Thiele, Timothy. "Average Costs for 12 Common Electrical Projects." Dec 21, 2020. The Spruce. <https://www.thespruce.com/electrical-project-costs-1152463>
- 41 Homeguide.com. "How Much Does It Cost to Upgrade Or Replace An Electrical Panel?" Accessed Jan 2, 2021. <https://homeguide.com/costs/cost-to-replace-electrical-panel#:~:text=Cost%20to%20Replace%20Circuit%20Breaker,of%20circuits%2C%20and%20the%20amperage.>
- 42 Sioux Center (n.d.) General Electrical Requirements for Single Family Dwellings. Accessed: <https://www.siouxcenter.org/DocumentCenter/View/246/GENERAL-ELECTRICAL-REQUIREMENTS-?bidd=>
- 43 Sioux Center (n.d.) General Electrical Requirements for Single Family Dwellings. Accessed: <https://www.siouxcenter.org/DocumentCenter/View/246/GENERAL-ELECTRICAL-REQUIREMENTS-?bidd=>
- 44 Fujitsu (2021). Downloads. Accessed: <https://www.fujitsu-general.com/us/resources/pdf/support/downloads/specification-sheets/pdf-fo-14r-pfj-806-04.pdf>
- 45 Water Heater Timer. (n.d.) What size indirect water heater do you need? Accessed: <http://waterheatertimer.org/What-size-indirect-heater.html>
- 46 Resnik, Max. (2019). "Nevada County crews battle generator fires during planned outages." KCRA 3, Nevada County, California.< <https://www.kcra.com/article/nevada-county-generator-fires-pg-e-outages-california/29256051>>
- 47 Pappalardo, J. (2014). The World's Biggest Vehicle-to-Grid Experiment Is Happening at a California Air Force Base. Popular Mechanics. <<https://www.popularmechanics.com/cars/hybrid-electric/a13460/electric-vehicles-to-grid-experiment-us-air-force/>>
- 48 Hawaiiian Electric (2018). Electrification of Transportation: Strategic Roadmap. Retrieved from Energy and Environmental Economics: < [https://www.ethree.com/wp-content/uploads/2018/04/201803\\_EOT\\_roadmap.pdf](https://www.ethree.com/wp-content/uploads/2018/04/201803_EOT_roadmap.pdf)>
- 49 Asahi Shimbun Digital. (2019). The power transmission tower is tilted in Chiba. <<https://www.asahi.com/articles/ASM991F7RM98UTILQ1M.html>>
- 50 EVsmartBlog. 2019. Experiences of victims who survived the Chiba power outage of 2019 with electric cars and V2H. <<https://blog.evsmart.net/electric-vehicles/report-from-2019-chiba-power-outage/?>>
- 51 Lambert, F. (2018). "Nissan launches 'Nissan Energy' to commercialize vehicle-to-home/building with the Leaf. Electrek. <<https://electrek.co/2018/11/28/nissan-energy-leaf-vehicle-to-home-building/>>
- 52 Maui Now (2017). JUMPSmartMaui Announces Successful Completion of Project. Maui Now. <<https://mauiNOW.com/2017/05/05/jumpsmautmaui-announces-successful-completion-of-project/>>
- 53 PG&E (2021). Marketplace. Accessed: [marketplace.pge.com/](https://marketplace.pge.com/)
- 54 Sacramento Municipal Utility District (2021). A whole house approach to energy efficiency. Accessed: <https://www.smud.org/en/Rebates-and-Savings-Tips/Improve-Home-Efficiency>
- 55 SoCal Edison (2021). Marketplace. Accessed: [https://www.sce.com/sites/default/files/2019-07/Marketplace%20Fact%20Sheet%200719%20r5\\_WCAG.pdf](https://www.sce.com/sites/default/files/2019-07/Marketplace%20Fact%20Sheet%200719%20r5_WCAG.pdf)
- 56 Sacramento Municipal Utility District. (2021). SMUD Go electric With rebates up to \$2,500. Accessed: <https://www.smud.org/en/Rebates-and-Savings-Tips/Go-electric>
- 57 Great Northwest Installations (2020). Portland Area Water Heater Promos. Accessed: [www.greatnorthwestinstallations.com/waterheaterpromo](http://www.greatnorthwestinstallations.com/waterheaterpromo)
- 58 Peninsula Clean Energy. (2020). Residential Programs and Rebates <<https://www.peniculacleanenergy.com/heat-pump-water-heater/>>
- 59 City of Palo Alto (2020). Heat Pump Water Heater Program Details. Accessed: [https://www.cityofpaloalto.org/gov/depts/utl/residents/save\\_energy\\_n\\_water/rebates/heat\\_pump\\_water\\_heater/program\\_details.asp](https://www.cityofpaloalto.org/gov/depts/utl/residents/save_energy_n_water/rebates/heat_pump_water_heater/program_details.asp)
- 60 Note that these services are free for customers who qualify for energy assistance.
- 61 BayREN. (2021). Electrification: Programs to Electrify Homes. Accessed: <https://www.bayren.org/electrification>
- 62 BAYREN Home (2021). "Bring Out the Best in Your Home." BayREN Residential. Accessed: <https://bayrenresidential.org>
- 63 Silicon Valley Clean Energy. (2021). Electric Appliances at Home. Accessed: <https://www.svcleanenergy.org/electric-home/>
- 64 Sonoma Clean Power (2021). Accessed: <https://sonomacleanpower.org/news/incentives-for-smart-thermostats-and-heat-pump-water-heaters-now-available>
- 65 Energy Smart Home Performance (2016) 1890 Ranch – Habitat for Humanity Deep Energy Retrofit. Energy Smart Home Performance <[http://energysmartohio.com/case\\_studies/1890-ranch-habitat-humanity-deep-energy-retrofit/](http://energysmartohio.com/case_studies/1890-ranch-habitat-humanity-deep-energy-retrofit/)>
- 66 Energy Smart Home Performance (2016) 1890 Ranch – Habitat for Humanity Deep Energy Retrofit. Energy Smart Home Performance <[http://energysmartohio.com/case\\_studies/1890-ranch-habitat-humanity-deep-energy-retrofit/](http://energysmartohio.com/case_studies/1890-ranch-habitat-humanity-deep-energy-retrofit/)>
- 67 Photos courtesy of Ben and Sara Shalva
- 68 Best Buy. (2020). Bosch-Benchmark Series 30" Electric Induction Cooktop. Accessed: <https://www.bestbuy.com/site/bosch-benchmark-series-30-electric-induction-cooktop/6335504.p>
- 69 Photos courtesy of Steve Schmidt
- 70 Photos courtesy of Steve Schmidt
- 71 Sustainable Lafayette. (2021). Home Electrification Part 1: Why We are Removing Gas from our Home and Going All Electric. Accessed: <https://www.sustainablelafayette.org/post/why-we-are-removing-gas-from-our-home-and-going-all-electric>
- 72 Sustainable Lafayette. (2021). Home Electrification Part 1: Why We are Removing Gas from our Home and Going All Electric. Accessed: <https://www.sustainablelafayette.org/post/why-we-are-removing-gas-from-our-home-and-going-all-electric>
- 73 Jay Egg (2019) 1830 Home in Hamilton, New York is an all-electric Geothermal Masterpiece. Green Builder. <<https://www.greenbuildermedia.com/energy-solutions/1830-home-in-hamilton-ny-is-an-all-electric-geothermal-masterpiece>>
- 74 Jay Egg (2019) 1830 Home in Hamilton, New York is an all-electric Geothermal Masterpiece. Green Builder. <<https://www.greenbuildermedia.com/energy-solutions/1830-home-in-hamilton-ny-is-an-all-electric-geothermal-masterpiece>>
- 75 Campus Center for Appropriate Technology. (2021). Accessed: <https://ccat.humboldt.edu/>
- 76 Photographs courtesy of Xavier Gaucher. Personal Communication.
- 77 Gaucher, X. (n.d.) The Perlita Passive House Journey. Builder and Developer. <<https://bdmag.com/perlita-passive-house-journey/>>
- 78 Energy Smart Ohio. (2016). 1918 House of the Future in Cleveland Heights. Accessed: [https://energysmartohio.com/case\\_studies/1917-net-zero-ready/](https://energysmartohio.com/case_studies/1917-net-zero-ready/)
- 79 Energy Smart Ohio. (2016). 1918 House of the Future in Cleveland Heights. Accessed: [https://energysmartohio.com/case\\_studies/1917-net-zero-ready/](https://energysmartohio.com/case_studies/1917-net-zero-ready/)
- 80 Willenbrook, Scott. (2020). Colonial Solar House. <https://ws.engr.illinois.edu/blogs/getfile/37/40688>
- 81 Willenbrook, Scott. (2020). Colonial Solar House. <https://ws.engr.illinois.edu/blogs/getfile/37/40688>
- 82 1000 Home Challenge. (2010). The Bindley Carbon Neutral Renovation. Accessed: <https://jhn.e94.myftpupload.com/wp-content/uploads/2020/10/Bindley-Carbon-Neutral-Renovation-Case-Study.pdf>
- 83 1000 Home Challenge. (2010). The Bindley Carbon Neutral Renovation. Accessed: <https://jhn.e94.myftpupload.com/wp-content/uploads/2020/10/Bindley-Carbon-Neutral-Renovation-Case-Study.pdf>
- 84 1000 Home Challenge. (2012). Deep Energy Retrofit Goes for Zero. Accessed: <https://jhn.e94.myftpupload.com/wp-content/uploads/2020/10/Ross-Residence-Case-Study.pdf>
- 85 Northeast Sustainable Energy Association. (2021). Ross Residence. Accessed: <https://nesea.org/project-case-study/ross-residence/general>
- 86 Refrigeration Kings. (2019). "Protect Your Heat Pump From the Harsh Atlantic Weather" <<https://www.kingsrefrigeration.com/residential/heat-pump-accessories>>
- 87 Sanden. (n.d.) Heat Pump Water Heater. <[https://www.sandenwaterheater.com/sanden/assets/File/SANDEN\\_CO2WaterHeaterG3\\_3\\_17.pdf](https://www.sandenwaterheater.com/sanden/assets/File/SANDEN_CO2WaterHeaterG3_3_17.pdf)>
- 88 See the Induction Cooking Fact Sheet by Tom Lent: <[https://docs.google.com/document/d/1qIGX6-tFdawfA6Nq8SYifRbtucX9RzqAdjZ\\_5NdWBE/edit](https://docs.google.com/document/d/1qIGX6-tFdawfA6Nq8SYifRbtucX9RzqAdjZ_5NdWBE/edit)>

- 89 The Carrier Infinity 24 Heat Pump with Greenspeed Intelligence (25VNA4) is being marketed with a cooling efficiency up to 24 SEER and a heating efficiency up to 13 HSPF. This heating efficiency corresponds to 3.8 COP. Although gas and electric efficiency differ on a more technical level, this simplified version of comparison is considered effective at communicating the difference in efficiencies of the two heating technologies.
- 90 <[https://en.wikipedia.org/wiki/Seasonal\\_energy\\_efficiency\\_ratio](https://en.wikipedia.org/wiki/Seasonal_energy_efficiency_ratio)>
- 91 <[https://en.wikipedia.org/wiki/Heating\\_seasonal\\_performance\\_factor](https://en.wikipedia.org/wiki/Heating_seasonal_performance_factor)>
- 92 Advanced Distributer Products Air Handler <<https://www.carrierenterprise.com/b-series-air-handler-2-ton-cu-multi-position-cased-painted-r-410a-ac-txv-hot-water-heat-with-pump-120v-bcrma3624s3p3>>
- 93 Stelpro Air Handler <<https://www.homeelectrical.com/120v-air-handler-psc-built-control-1400-cfm-62-amp-stp-scvp1411.1.html>>
- 94 King Electrical Mfg. Co. <<https://www.gordonelectricsupply.com/p/King-Ah1-2-120V-Air-Handler-1-2-Hp-120V-Job-Htr/6499432?ID=/King-Electrical-Mfg-Co/mfr-11FU>>
- 95 Quadomated. (2012). Fujitsu 15RLS2 Heat Pump Installed – My Initial Thoughts. <<http://www.quadomated.com/house/fujitsu-15rls2-heat-pump-installed-my-initial-thoughts/>>
- 96 Beuerlein, K. Is Ductless Heating and Cooling Right for You? HGTV. <<https://www.hgtv.com/remodel/mechanical-systems/is-ductless-heating-and-cooling-right-for-you>>
- 97 LG (2019). Residential/Light Commercial Systems Counter Quick Reference Guide. < [https://www.victordist.com/content/PI\\_Home\\_Comfort\\_Solutions\\_Reference.pdf](https://www.victordist.com/content/PI_Home_Comfort_Solutions_Reference.pdf)>
- 98 <https://www.thisoldhouse.com/milton-house/21015136/the-case-for-installing-a-heat-recovery-ventilator>
- 99 The difference between an HRV and an ERV - AVS - the Best Choice. (2020). < <http://www.airventingsolutions.com/how-to-choose-between-hrv-erv-home-ventilation-systems-usa-canada>>
- 100 How Do Heat Recovery Systems Work?. (2017). < <https://www.bpcventilation.com/blog/do-heat-recovery-systems-work>>
- 101 Revision Energy. (2021) <https://www.revisionenergy.com/solar-power-for-your-home/solar-powered-water-heating/>
- 102 SANCO2 Water Heater. (2020). Twitter, <<https://twitter.com/sandenco2hphwh?lang=en>>
- 103 John Miles. SANCO2 performance curves at cold temperatures [email correspondence]. Message to: Sean Armstrong. 2020 Oct 29.
- 104 SANCO2 Water Heater. (2020). Twitter, <<https://twitter.com/sandenco2hphwh?lang=en>>
- 105 SANCO2 Water Heater. (2020). Twitter, <<https://twitter.com/sandenco2hphwh?lang=en>>
- 106 Water Heater Timer. (n.d.) What size indirect water heater do you need? Accessed: <http://waterheatertimer.org/What-size-indirect-heater.html>
- 107 Baylon et al. (2013). "Residential Building Stock Assessment: Multifamily Characteristics and Energy Use." Ecotope, Inc. for NEEA.
- 108 Korn & Dimetrosky. (2010). "Do the Savings Come Out in the Wash? A Large-Scale Study of In-Situ Residential Laundry Systems." The Cadmus Group. ACEEE Summer Study on Energy Efficiency in Buildings
- 109 U.S. Department of Energy. (2017). "Saving Energy and Money with Appliance and Equipment Standards in the United States" <[https://www.energy.gov/sites/prod/files/2017/01/f34/Appliance%20and%20Equipment%20Standards%20Fact%20Sheet-011917\\_0.pdf](https://www.energy.gov/sites/prod/files/2017/01/f34/Appliance%20and%20Equipment%20Standards%20Fact%20Sheet-011917_0.pdf)>
- 110 Janeway, K. (2014). "Finally, the lowly dryer can reach for Energy Star" <<https://www.consumerreports.org/cro/news/2014/05/finally-the-humble-dryer-can-reach-for-energy-star/index.htm>>
- 111 Raypak Heat Pump Pool and Spa Heater Installation and Operation Manual <https://s3.amazonaws.com/AWSProd/sites/raypakcom/documents/6000.56.pdf>
- 112 Hayward Omni Logic Smart Pool and Spa Control <https://www.hayward-pool.com/shop/en/pools/omnilogic-i-aumoni-1>
- 113 EPA (2021) Section 608 Technician Certification <https://www.epa.gov/section608/section-608-technician-certification-0>
- 114 River Pools. Swimming Pool Covers: The Good, the Bad, and the Ugly <https://www.riverpoolsandspas.com/blog/swimming-pool-covers-the-good-the-bad-the-ugly>
- 115 Modern Blaze (2020). Commercial electric fireplace. <<https://www.google.com/maps/uv?pb=!1s0x88137ddbda180241%3A0xd2a0ba797ab5122b!3m1!7e115!>>>
- 116 STIHL. (2019) "AP Series" <<https://www.stihlusa.com/products/battery-products/ap-series/>>
- 117 Husqvarna. (2019). "Battery Series" <<https://www.husqvarna.com/us/products/battery/>>
- 118 RYOBI. (2019). "Lawn and Garden" <<https://www.ryobitools.com/outdoor>>
- 119 STIHL. (2019) "AP Series" <<https://www.stihlusa.com/products/battery-products/ap-series/>>
- 120 Husqvarna. (2019). "Battery Series" <https://www.husqvarna.com/us/products/battery/>
- 121 RYOBI. (2019). "Lawn and Garden" <https://www.ryobitools.com/outdoor>
- 122 Span. (2019). Flexible energy for the modern home <<https://www.span.io/>>
- 123 Eaton. (2017). Eaton Pow-R-Command intelligent panelboard. <<https://www.eaton.com/ecm/groups/public/@pub/@electrical/documents/content/pa144001en.pdf>>
- 124 Koben. (2020). Energy Management. The GENIUS Smart Panel. <<https://kobensystems.com/energy-management/>>
- 125 Eaton. (2019). Energy management circuit breaker <<https://www.eaton.com/us/en-us/markets/innovation-stories/energy-management-circuit-breaker.html>>
- 126 Lumin. (2019). Lumin energy management platform <<https://www.luminsmart.com/platform>>
- 127 NeoCharge. (2019). NeoCharge Smart Splitter <<https://www.getneocharge.com/>>
- 128 BSA Electronics. (2019). Dryer Buddy <<https://www.bsaelectronics.com/collections/dryer-buddys>>
- 129 SimpleSwitch. (2020). <https://simpleswitch.io/products/simple-switch>
- 130 SpitVolt (2020). <https://www.splitvolt.com/splitter-switches/>
- 131 DCC. (2018). DCC-9 <<https://dcc.technology/dcc-9/>>
- 132 EVduty. (2019) EVduty Smart Current Sensor. <<https://evdutystore.elmec.ca/blogs/news/b-new-evduty-product-smart-current-sensor-b>>
- 133 Contact Clean Coalition for more information. <<https://clean-coalition.org/>>
- 134 Bandyk, Matthew. "Battery prices fall nearly 50% in 3 years, spurring more electrification: BNEF." Utility Dive. Dec. 3, 2019. <<https://www.utilitydive.com/news/battery-prices-fall-nearly-50-in-3-years-spurring-more-electrification-b/568363/>>
- 135 Goal Zero. Discover Power Station. <<https://www.goalzero.com/product-features/portable-power-stations/>>
- 136 Lectron Level 1 EV Charger (n.d.) < [https://ev-lectron.com/products/lectron-portable-electric-car-charger-16a?variant=31869379477550&currency=USD&utm\\_medium=product\\_sync&utm\\_source=google&utm\\_content=sag\\_organic&utm\\_campaign=sag\\_organic&gclid=Cj0KCQJw8rT8BRcBARisALWiOvTPOzVj9F1DMDM8zMMz6K8Sfk3-kREz2Cr7Y62B\\_OpG2ewdtcmFhhUaAkjMEALw\\_wcB](https://ev-lectron.com/products/lectron-portable-electric-car-charger-16a?variant=31869379477550&currency=USD&utm_medium=product_sync&utm_source=google&utm_content=sag_organic&utm_campaign=sag_organic&gclid=Cj0KCQJw8rT8BRcBARisALWiOvTPOzVj9F1DMDM8zMMz6K8Sfk3-kREz2Cr7Y62B_OpG2ewdtcmFhhUaAkjMEALw_wcB) >
- 137 <[https://ev-lectron.com/products/lectron-portable-electric-car-charger-40a?variant=31879961313326&currency=USD&utm\\_medium=product\\_sync&utm\\_source=google&utm\\_content=sag\\_organic&utm\\_campaign=sag\\_organic&gclid=CjwKCAiAi\\_DBRApEiwASslbJ9axEuKodVZMhOuDFAEcGTcxjY1jFlZhxISmfrd9u1wulj5zTRkeRoCOAQQAAd\\_BwE](https://ev-lectron.com/products/lectron-portable-electric-car-charger-40a?variant=31879961313326&currency=USD&utm_medium=product_sync&utm_source=google&utm_content=sag_organic&utm_campaign=sag_organic&gclid=CjwKCAiAi_DBRApEiwASslbJ9axEuKodVZMhOuDFAEcGTcxjY1jFlZhxISmfrd9u1wulj5zTRkeRoCOAQQAAd_BwE)>
- 138 Inside EVs. (2021). "Enelx Juicebox Smart EV Charger Review" <<https://insideevs.com/news/402950/enelx-juicebox-smart-ev-charger-review/>>
- 139 Chargepoint Home Flex. (2021). "Chargepoint Home Flex" <[https://www.chargepoint.com/drivers/home/chargepoint-home-flex/?gclid=Cj0KCQKQIA5vb-BRCRARisAJBkC6KZWl3-tz92cM3FqHwL9J70Tj4G3k6UvqOcmMCRmQzN59JrCARydfSaAmaoEALw\\_wcB](https://www.chargepoint.com/drivers/home/chargepoint-home-flex/?gclid=Cj0KCQKQIA5vb-BRCRARisAJBkC6KZWl3-tz92cM3FqHwL9J70Tj4G3k6UvqOcmMCRmQzN59JrCARydfSaAmaoEALw_wcB)>
- 140 NEMA Sockets For EV Charging (n.d) < <https://www.splitvolt.com/nema-sockets-for-ev-charging-at-home/> >
- 141 Gerdes, J. (2019). Will Your EV Keep the Lights On When the Grid Goes Down? Green Tech Media. <<https://www.greentechmedia.com/articles/read/will-your-ev-keep-the-lights-on-when-the-grid-goes-down>>
- 142 McMahon, J. (2019). All The Energy Storage The Grid Needs Will Soon Be Under Our Noses. Forbes. <<https://www.forbes.com/sites/jeffmcmahon/2019/11/12/all-the-grid-batteries-we-need-and-more-will-soon-be-under-our-noses/#696c61f136e3>>
- 143 Wallbox. (2020). [https://wallbox.com/en\\_us/](https://wallbox.com/en_us/)
- 144 Ossiaco. (2020) Dcbel. Your Energy Without Compromise. <<https://dcbel.ossiaco.com/>>
- 145 Nuvve. (2020). <https://nuvve.com/2019/05/01/nuvve-powerport/>
- 146 Fermenta Energy. (2020). <https://www.fermentaenergy.com/homeowners>
- 147 Taiga Electric /snowmobile - 100% electric high torque sleds. (2020). Retrieved 29 October 2020, from <https://taigamotors.ca/snowmobiles/>