Hydronic Air-Source Heat Pumps

Zero Carbon Commercial Construction:
An Electrification Guide for Large Commercial Buildings and Campuses

REDWOOD ENERGY

By Sean Armstrong, Jenna Bader, Emily Higbee, Lynn Brown, Richard Thompson IV, Roger Hess, Harlo Pippenger, Cheyenna Burrows and Wyatt Kozelka

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Introduction

As new reports roll out with greater frequency detailing the urgency of addressing climate change, with clear recommendations to accelerate a transition from fossil fuel use and advance all efforts to reduce climate pollution, it has become a top priority to ensure that new buildings are designed to use renewable, zero carbon energy.[1] This report focuses on how large commercial developments can go carbon free with standard all electric designs that save money and create more comfortable spaces.

Buildings are one of the largest sources of carbon or climate pollution, contributing 28% of global emissions due to energy used for power, heating and cooling, second only to industry (30%) and before transportation (22%). While many buildings can generate on-site renewable power or purchase it at an affordable cost, natural gas – a fossil fuel – is still widely used for heating and cooking. Replacing natural gas in buildings with all electric designs is the single most impactful climate mitigation step that can be taken in most areas.[2] Natural gas has exceptionally high carbon emissions when the lifecycle of the fuel, including leaks, are considered. In California, roughly 5% of methane - the chemical name for natural gas - is leaking[3], and this is more damaging to our climate than the 95% that is released as CO2 when burned, because methane is a more potent greenhouse gas with 100 times the warming impact of CO2 in the short term.[4]

Natural gas also poses direct safety hazards and can create health impacts inside buildings that are not well ventilated. For example, The National Fire Protection Association found that natural gas use in homes is responsible for roughly 7,900 residential house fires per year, directly causing 51 deaths and 194 injuries on average. The carbon monoxide produced by burning gas indoors can be even more lethal; according to the US EPA, carbon monoxide poisoning results in roughly 15,000 emergency room visits and 500 more deaths every year.[5]

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[1] Intergovernmental Panel on Climate Change (2018). *Global Warming of 1.5° C: An IPCC Special Report on the impacts of global warming of 1.5° C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty*. Retrieved from IPCC: https://report.ipcc.ch/sr15/pdf/sr15_spm_final.pdf

[2] There are plenty of exceptions here where there are large industrial or freight sources, or where the use of renewable power may still be challenging, however, most developments are in areas where renewable power can be obtained and where building energy use is substantial.

[3] Wentworth, Naomi (2017). *Natural Gas Methane Leakage and the Potential of Renewable Natural Gas*. Retrieved from ZNE Retreat Youtube Presentation: https://www.youtube.com/watch?v=3tcBhaoL7Uo

[4] Environmental Protection Agency (2018). *Understanding Global Warming Potentials*. Retrieved from US EPA: https://www.epa.gov/ghgemissions/understanding-global-warming-potentials

[5] San Francisco Dept. of the Environment (2017). *Methane Math: How Cities Can Rethink Emissions from Natural Gas*. Retrieved from Urban Sustainability Directors Network: https://www.usdn.org/uploads/cms/documents/methane-math_natural-gas-report_final.pdf
https://www.epa.gov/sites/production/files/2015-08/documents/pcmp_english_100-f-09-001.pdf

The global consensus is that in order to solve climate change, buildings must be powered electrically by blending a continuous supply of renewable energy (e.g. solar, wind, water, supported by energy storage) and delivering it through the electrical grid. A note of optimism is that nationally one in four homes are built all-electric, led by the South[6] with more than one in two homes built all-electric in 2018. The electrification trend is growing rapidly because all-electric construction is more affordable to build.

The following guide contains examples of large new commercial developments that have avoided natural gas and other fossil fuel use in favor of all electric designs. The examples show that in most cases with careful planning, developers have saved money by avoiding natural gas for new construction. This is because electric heating, water heating, and cooking equipment has advanced significantly in recent years with greater efficiency, more products on the market to choose from, and declining costs as this equipment builds market share. A list of the best all electric equipment with technical specifications follows the example projects.

All-Electric Construction: From Zero to Hero

Figure 1. Advertisement in the Better Homes and Gardens Magazine, October 1958, promoting the "Live Better Electrically" Medallion for New Construction Homes.[7]

California "Reach Codes" and utility rebates are encouraging all-electric construction in order to reduce carbon, air pollution, and costs. Some of California's top tech companies, like Google, Tesla, LinkedIn and SpaceX are leading the effort with new all-electric campuses. However, California's leadership of the all-electric movement dates back to the 1950s, when Ronald Reagan directed A-List actors like James Dean and Judy Garland in the General Electric Theater, a Top 10 TV show from 1953-1963 that encouraged viewers to "Live Better Electrically" and buy a "Gold Medallion Home."

[6] Sloan, M. (2016). *2016 Propane Market Outlook: Key Market Trends, Opportunities and Threats Facing the Consumer Propane Industry Through 2025*. (Propane Education and Research Council) Retrieved from ICF International: https://www.afdc.energy.gov/uploads/publication/2016_propane_market_outlook.pdf

[7] SMECC (2007). *Live Better Electrically Medallion Home*. Retrieved from SMECC Archives: https://www.smecc.org/live_better_electrically_medallion_home.htm

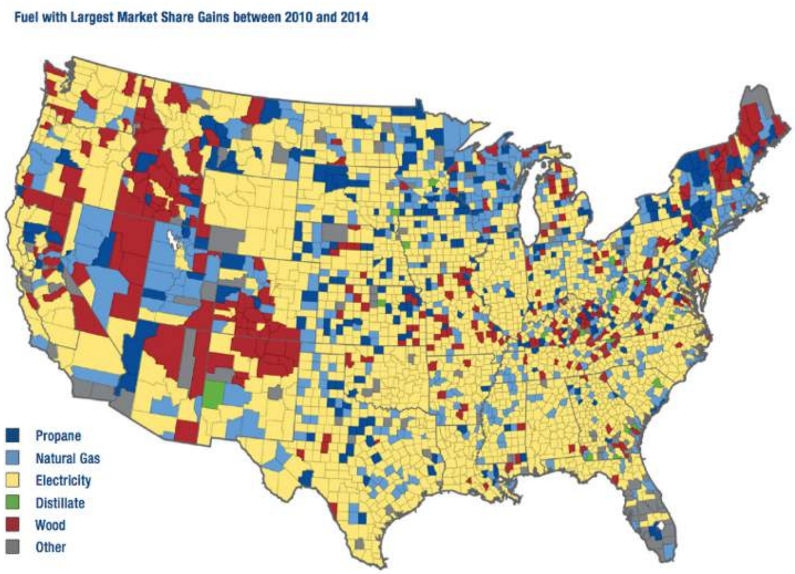

Figure 2. All-Electric construction has been growing since 1993, and are now the market share growth leader across the US.

Although Reagan was later Governor of California during the OPEC Oil Embargo of 1973, he could not stop the cost of electricity from quadrupling overnight, even in his all-electric Palisades mansion. Frustrated with high energy prices, among Reagan's first acts as President in 1981 was the deregulation of American oil drilling and coal mining, leading to a fossil fuel boom that continues to this day. It was not until 1993 that all-electric construction began a resurgence, becoming a national phenomena in 2010 and the market share growth leader in almost every state because of the inherent lower construction cost of all-electric buildings. According to the Rocky Mountain Institute's 2018 Electrification Study, not only is all-electric construction already cost-effective for new construction, but upcoming building codes and carbon pricing increases will make it even more economically compelling to build all-electric.[8]

Case Studies

Fine Dining at the All-Electric Space X, Tesla and Boring Company Campus

Elon Musk's 1 million square foot all-electric campus for designing Space X rockets, Tesla cars and the Boring Company underground "hyperloops".

Their all-electric cafeteria kitchen is led by Chef Ted Cizma, whose professional ambition is to someday serve Elon Musk his meals on Mars. Elon Musk is an international leader in technology design, including on-line payment processing, long distance electric cars, reusable rockets, solar rooftop shingles and electric high-speed subways. His buildings use air source heat pumps.

Figure 3. All-electric Space X and Tesla Design Center and Elon Musk.

Figure 4. Ted Cizma, Head Chef: Space X's all-electric free staff cafeteria.

[8] Billimoria, Sherri (2018). *Report Release: Electrifying Buildings for Decarbonization: The Role of Electric Space and Water Heating*. Retrieved from Rocky Mountain Institute: https://rmi.org/report-release-electrifying-buildings-for-decarbonization/

The University of California and Stanford University

In 2019 the 137 million square feet of University of California buildings will no longer use fossil fuels in major retrofits, nor in new construction at any of the ten campuses. By 2025 the entire UC system will be carbon neutral—6000 buildings. Silicon Valley's Stanford University has already electrified most of their campus of 12 million square feet of buildings with a central water source heat pump with one hot storage tank and two cold water tanks. The heat exchanger produces hot water by pulling heat from groundwater, reducing heating energy needs by 93%, and the combined efficiencies of the new system reduce water use by 70%.[9]

Figure 5. Stanford University's Central Energy Facility.

All-Electric Google Bay View Campus

When it opens in 2019, Larry Page and Sergey Brin's new Google headquarters will be a 1.1 million square foot, all-electric campus with a signature accomplishment -North America's largest ground-source heat pump will meet their heating and cooling loads.[10] A network of 69 miles of pipes and 2,500 holes will connect to heat pump compressors that use 1/4th as much energy as the most efficient gas burning equipment. Ground source heat pumps also will save 8 million gallons of water a year that would normally be evaporated in a chiller tower to make chilled water for Air Conditioning.[11]

Figure 6. Google's Bay View campus, artist rendering, with Larry Page and Sergey Brin.

Google's all-electric commercial kitchens will serve about 5,000 staff their meals in a mix of outdoor and sheltered dining areas. Google, like Apple, Facebook and other large companies pursuing their corporate greenhouse gas reduction goals, purchases solar and wind power installed remotely from their campus to offset their energy demands.

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[9] Stagner, J. (n.d.). *Stanford Energy System Innovations (general overview - Silicon Valley Clean Energy).*

[10] Note that Google used a *ground-source* heat pump rather than the *air-source* heat pumps that are much more common and cheaper to install for the mild climate of the Bay Area. This may be due in part to interest in testing new technology for ground-source heat pumps.

[11] Noack, M. (2017,10 27). *Google's unbuilt Bay View campus already claims breakthrough*. Retrieved from Mountain View Voice: https://www.mv-voice.com/news/2017/10/27/googles-unbuilt-bay-view-campus-already-claims-breakthrough

The Exploratorium, San Francisco

Figure 7. Bird's eye view of the Exploratorium, San Francisco, CA.

The Exploratorium's extraordinary 1.4 MW solar array supplies energy equaling 100% of annual site energy use, including 600 displays and 28 miles of radiant piping for heating and cooling the building. The San Francisco Bay is the source of both hot and cold water via eight 50-ton water-source heat pumps. This system results in a seven-year payback compared to a conventional chiller, cooling tower and boiler system.[12]

LAX International Terminal: 29 All-Electric Restaurants Feed the World

Figure 8. Restaurants of all types feed 10 million travelers a year at LAX's all-electric international terminal.

The 1.5M square foot all-electric Tom Bradley International Terminal at LAX opened in 2014 to showcase modern American design, both aesthetic and functional, and all-electric design. Eliminating gas pipelines in the terminal saved hundreds of thousands of dollars in 4"-6" diameter gas piping for the 29 restaurants.[13] Electric cooking also transfers heat at ~80% efficiency, compared to gas at ~30% efficiency, which means less than half as much waste heat in the kitchen. The large efficiency gain means cooler kitchens for worker productivity, smaller and less expensive AC and ventilation equipment, half the air conditioning bills and fewer kitchen fires.

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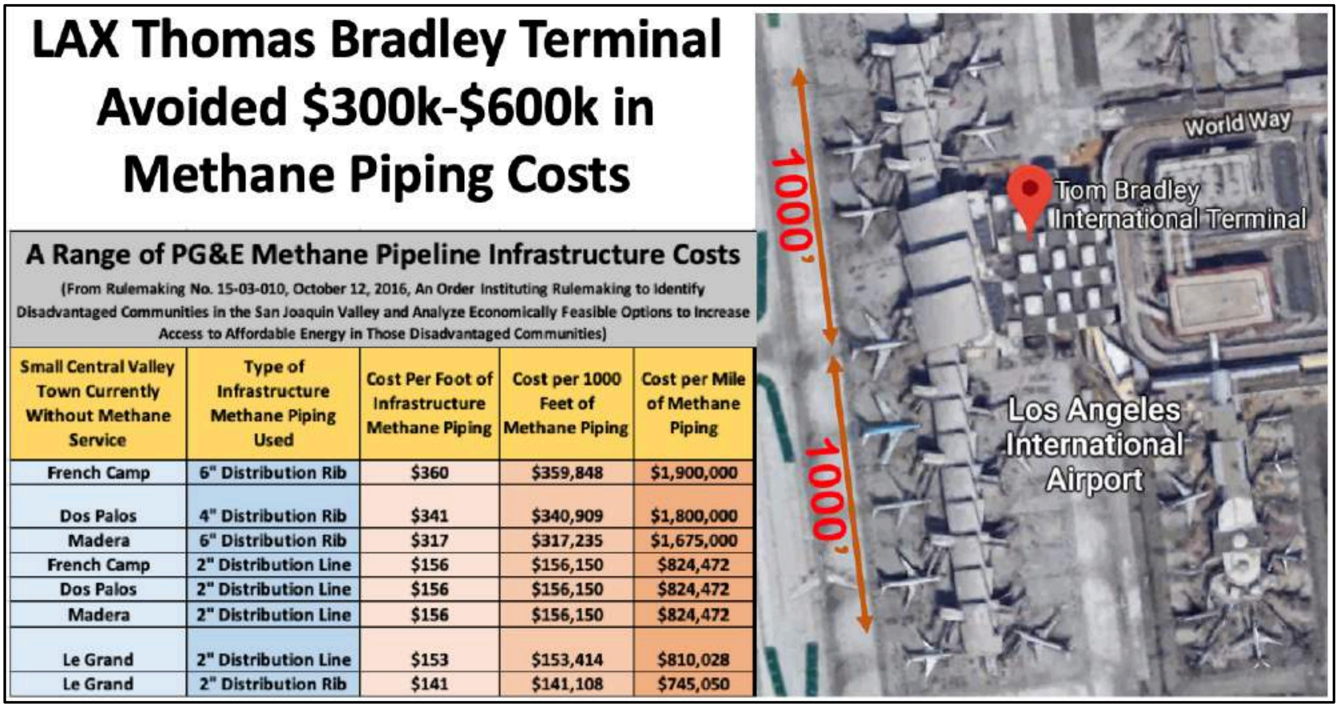
[12] Exploratorium. (2015). *About Us*. Retrieved from Exploratorium: https://www.exploratorium.edu/annual-report-2014/

[13] Estimates from *Figure 9* below.



A Range of PG&E Methane Pipeline Infrastructure Costs

(From Rulemaking No. 15-03-010, October 12, 2016, An Order Instituting Rulemaking to Identify Disadvantaged Communities in the San Joaquin Valley and Analyze Economically Feasible Options to Increase Access to Affordable Energy in Those Disadvantaged Communities)

Small Central Valley Town Currently Without Methane Service	Type of Infrastructure Methane Piping Used	Cost Per Foot of Infrastructure Methane Piping	Cost per 1000 Feet of Methane Piping	Cost per Mile of Methane Piping
French Camp	6" Distribution Rib	$360	$359,848	$1,900,000
Dos Palos	4" Distribution Rib	$341	$340,909	$1,800,000
Madera	6" Distribution Rib	$317	$317,235	$1,675,000
French Camp	2" Distribution Line	$156	$156,150	$824,472
Dos Palos	2" Distribution Line	$156	$156,150	$824,472
Madera	2" Distribution Line	$156	$156,150	$824,472
Le Grand	2" Distribution Line	$153	$153,414	$810,028
Le Grand	2" Distribution Rib	$141	$141,108	$745,050

Figure 9. Gas infrastructure for a wide range of commercial end uses requires 2" or greater gas lines.[14] LAX is in LADWP territory, not PG&E, so costs are indicative but not directly comparable.

J. Craig Venter Institute Laboratory

Figure 10. The zero carbon J. Craig Venter Institute Laboratory.

Craig Venter shares credit for being first to decode the human genome and was the first to transplant new DNA into a cell. His 44,600 square foot Research Institute in La Jolla, California was the world's first zero-emissions, 100% solar powered research facility. The hyper-efficient laboratory utilizes air source heat pumps for hydronic heating and cooling, and uses thermal storage to reduce and control heating and cooling loads. Even the heat rejected by their intensely cold genetic material freezers is recaptured for heating the building's water.

[14] Commission, C.P. (2016). *Rulemaking 15-030-010*. Sacramento: Governor Edmund G. Brown, Jr. Note that the example cost data shown here is for PG&E, whereas LAX is served by a different utility, but the relative gas infrastructure costs are expected to be similar.

National Renewable Energy Lab Research Support Facility, Golden, Colorado

Figure 11. NREL's Research Support Facility in Golden, Colorado.

The National Renewable Energy Laboratory (NREL) in Colorado is a 100% solar powered research facility, pairing a long list of technical innovations with traditional passive solar design. Daylighting and efficient office equipment are key, but most impressive is that the buildings are heated with waste heat from the data center that is supplemented with solar thermal collectors on the south side of each building. A "labyrinth" of heat exchangers and thermal mass in the basements of the 360,000 square foot campus provide thermal energy storage.[15]

David and Lucile Packard Foundation, Los Altos

Figure 12. The David and Lucile Packard Foundation Headquarters.

Lucile and David Packard were leading designers and business people, and their 49,000 square foot David & Lucile Packard Foundation campus was an early success of 100% solar powered commercial construction. Employees are kept comfortable with water-chilled radiant panels and an air source heat pump that heats water for ducted hot air distribution. Window light shelf panels do double duty by managing light and heat gain. An integrated design process was performed to optimize the building shape, natural light, natural ventilation, motorized sun shades and a 303 kW PV system.[16]

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[15] Pence, L. (2013). *National Renewable Energy Lab (NREL).* Retrieved from There and Back Again: https://drpence.wordpress.com/2013/05/07/national-renewable-energy-lab-nrel/

[16] Rumsey, P., Soladay, E., & Murphree, A. (2015). *Graceful Inspiration* - David and Lucile Packard Foundation Headquarters. High Performance Buildings.

Zero Net Energy Center, San Leandro, Retrofit

Figure 13. The ribbon cutting ceremony officiants included 13th District Congresswoman Barbara Lee and Training Director Byron Benton celebrating a win-win for local green jobs at the solar, wind and battery powered San Leandro union hall retrofit, and Governor Jerry Brown supporting action on Climate Change.

In 2012, the International Brotherhood of Electrical Workers #595 union hall needed a deep retrofit, so the electricians removed the gas service, covered the rooftop with solar arrays, caught the Bay winds with micro-turbines, and installed back-up batteries. 13th District Congresswoman Barbara Lee said at the ribbon cutting, "I'm thrilled… to see Labor take a stand for renewable energy use and good jobs. This ZNE center will provide state-of-the-art training for electrical workers.[17]" The 45,000 square foot retrofit uses an air source variable refrigerant flow (VRF) system to make co-incident heating and cooling more efficient with a heat exchanger, similar to Stanford's system but without thermal storage tanks. Waste heat from the air conditioning mode of the VRF at the ZNE Center is used to make domestic hot water, supplemented with solar thermal panels and an electric resistance back-up element.[18] Including the comprehensive efficiency efforts, total site energy dropped 75% after the retrofit.

A Wide Range of Noteworthy All-Electric Buildings

The New Buildings Institute (NBI) develops high efficiency building codes for states and have tracked the rapid growth of all-electric design among their database of highest performing buildings. The following list is a sample of the fossil-fuel free commercial buildings submitted to NBI, varying in purpose, size and location.

State	Building Type (General)	Name	City	Energy Use Intensity (kBtu/sf-yr)	Gross Area (sq. ft)
AZ	Office	DPR Construction Phoenix Net Zero Office	Phoenix	26.8	16,533
CA	Education	Bishop O'Dowd High School, Environmental Science Center	Oakland	18.0	3,275
		Environmental Nature Center	Newport Beach	17.6	8,535
		IBEW Local 595 Zero Net Energy Center	San Leandro	15.0	45,001
		Sacred Heart Schools Stevens Family Library	Atherton	13.2	6,800

[17] Alameda Building and Trades Council (2013). IBEW Zero Net Energy Training Center Celebrates Grand Opening. Retrieved from BTC Alameda: http://www.btcalameda.org/ibew-zero-net-energy-training-center-celebrates-grand-opening/
[18] Hummel, M., Grant, G., Benton, B., & Desmond, K. (2015). Working Example - Zero Net Energy Center. High Performing Buildings.

	Multifamily	Plaza Point	Arcata	15.3	20,283
	Office	435 Indio Ave	Sunnyvale	13.5	31,800
		AP+I Design	Mountain View	17.9	14,300
		David and Lucile Packard Foundation	Los Altos	24.4	49,161
		DPR San Francisco Office	San Francisco	21.6	24,010
		IDeAs Z2 Design Facility	San Jose	22.6	6,557
	Other	Audubon Center at Debs Park (off grid)	Los Angeles	17.1	5,020
		Bagatelos Architectural Glass Solutions	Sacramento	17.1	63,000
	Public Assembly	Diamond X Ranch Student Intern Center-Malibu	Calabasas	31.5	3,500
		West Berkeley Public Library	Berkeley	21.7	9,399
CO	Office	NREL Research Support Facility	Golden	46.1	222,000
DE	Public Assembly	Camden Friends Meeting Social Hall	Camden	17.9	3,121
FL	Education	Sarasota Audubon Nature Center	Sarasota	10.3	2,500
	Mercantile (Enclosed and Strip Malls)	PNC Net-Zero Branch - Ft. Lauderdale	Ft Lauderdale	59.1	4,766
	Office	Leon County Cooperative Extension	Tallahassee	19.4	13,000
		TD Bank Branch - Ft. Lauderdale	Fort Lauderdale	91.8	3,970
	Other	Anna Maria Historic Green Village	Anna Maria	28.2	9,797
HI	Other	Hawaii Gateway Energy Center	Kailua-Kona	28.0	5,600
IN	Public Assembly	Chrisney Library	Chrisney	16.7	2,413
KY	Education	Locust Trace AgriScience Campus (High School)	Lexington	9.9	70,000
		Richardsville Elementary School	Bowling Green	19.0	72,285
MA	Education	Smith College Bechtel Environmental Classroom	Northampton	11.5	2,500
MD	Education	Potomac Watershed Center	Accokeek	44.2	3,971
ME	Education	Coastal Maine Botanical Gardens Bosarge Family Education Center	Boothbay	19.2	8,200
MI	Education	Lenawee Intermediate School District Center for a Sustainable Future	Adrian Township	7.7	8,750
MN	Other	Science House	St. Paul	18.0	1,532
NC	Education	Sandy Grove Middle School	Lumber Bridge	20.6	74,000
NJ	Education	Willow School	Gladstone	21.8	20,000
NV	Public Assembly	Pahranagat National Wildlife Refuge Administrative Office and Visitor Contact Station	Alamo	27.8	5,000
NY	Other	Hudson Valley Clean Energy HQ	Rhinebeck	9.8	5,470
		Omega Center for Sustainable Living	Rhinebeck	13.2	6,200
OH	Education	Oberlin College Lewis Center	Oberlin	31.4	13,600
OR	Education	Durham Education Center	Tigard	19.0	17,000
		Hood River Middle School Net-Zero Addition	Hood River	26.8	5,331
PA	Public Assembly	Phipps Center for Sustainable Landscapes	Pittsburgh	18.2	24,350
VA	Education	Brock Environmental Center	Virginia Beach	14.6	10,500
VT	Education	Putney Field House	Putney	9.7	16,800
WA	Education	Bertschi School Science Wing	Seattle	48.0	1,425
	Multifamily	zHome - Issaquah	Issaquah	21.0	5,813
	Office	Bullitt Foundation Cascadia Center for Sustainable Design and Construction	Seattle	9.7	52,000

Key Electrification Findings for Commercial Buildings

1. All-electric commercial buildings are ***valuable***—they save hundreds of thousands of dollars in gas line connections to buildings.
2. All-electric commercial buildings are ***safer***--they avoid the destructive costs of 7,900 residential fires a year started by gas uses in the U.S., including hundreds of deaths and life changing injuries.[19]
3. All-electric commercial buildings are ***efficient***, using ½ to 1/5th the energy of a gas burning building, with even greater efficiency possible with heat exchangers when there are overlapping needs for Heating and Cooling.
4. All electric ***kitchens are cooler***, cleaner and safer. Cooking with gas triples the AC bill, the 3400F flame increases accidental burns, poisonous combustion biproducts like formaldehyde cause cancer, while carbon monoxide causes 500 accidental deaths per year in U.S.[20]
5. All-electric buildings ***can operate with cheap storage***—fleets of vehicle batteries and storing thermal energy (e.g. tank of hot water, block of ice) can shift consumption to the sunny hours of the day and provide renewable energy later at night.[21]
6. All-electric buildings ***can be 100% renewably powered***, giving building owners access to the least cost energy for sale—large-scale solar power.

Figure 14: Bullitt Center in Seattle Washington, known as the world's greenest building.

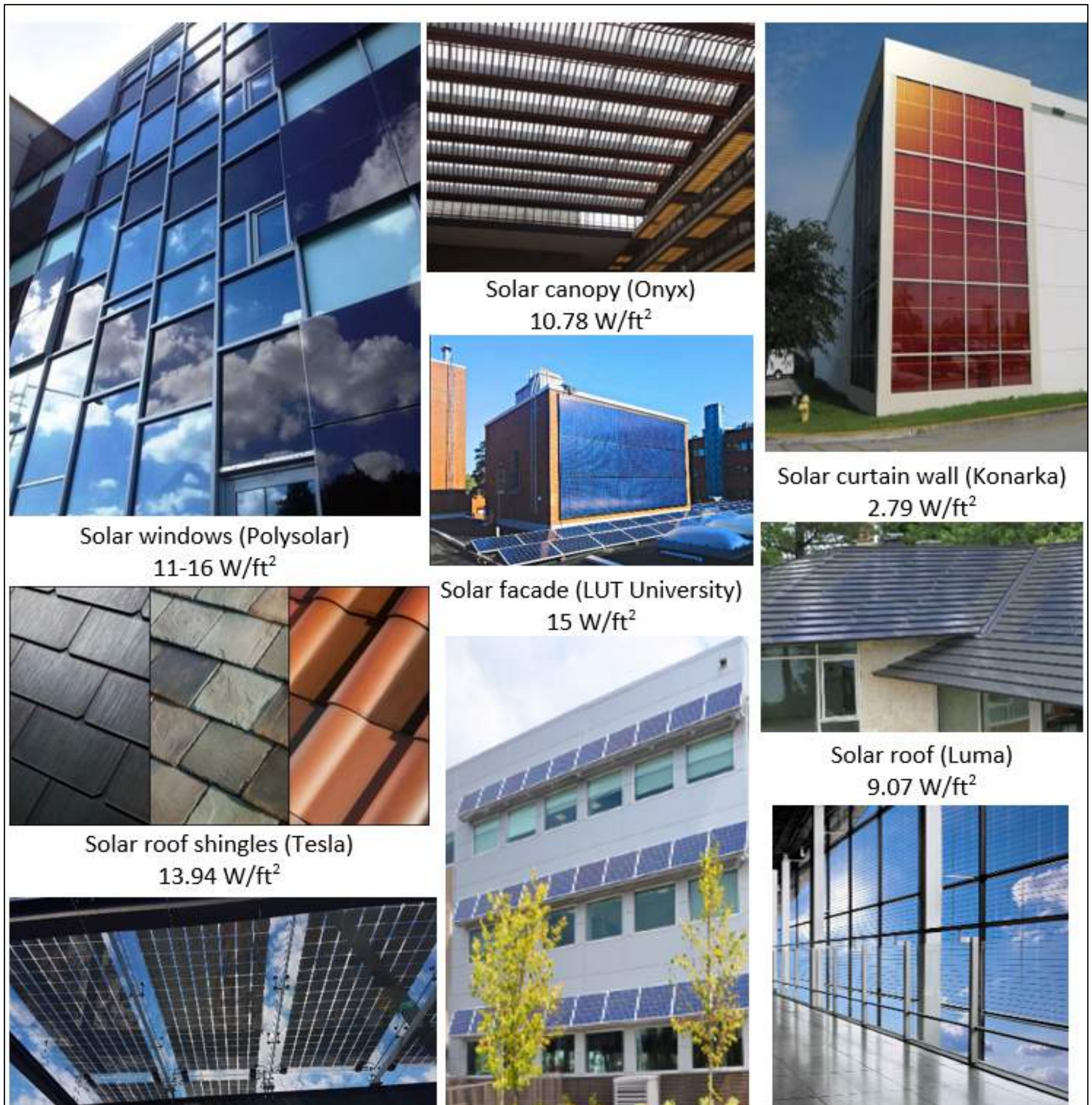
[19] San Francisco Dept. of the Environment (2017). *Methane Math: How Cities Can Rethink Emissions from Natural Gas*. Retrieved from Urban Sustainability Directors Network: https://www.usdn.org/uploads/cms/documents/methane-math_natural-gas-report_final.pdf
[20] United States Environmental Protection Agency (2009). *Preventing Carbon Monoxide Poisoning: Information for Older Adults and Their Caregivers*. Retrieved from US. EPA: https://www.epa.gov/sites/production/files/2015-08/documents/pcmp_english_100-f-09-001.pdf
[21] Nicolette, Brenden (2017). *Peak Load Management Primer* –Blog Post June 27, 2017. Retrieved from Energy Watch: https://energywatch-inc.com/category/blog-post/page/5/

All-Electric Product Guide

The following guides provide examples of the most energy efficient and trusted products that are available on the market now. Products include building integrated solar panels, commercial kitchen gear, heat pumps for space and water heating and air conditioning, pool and hot tub heaters, electric fireplaces and electric vehicles that can work in reverse and charge a commercial building or the connected grid.

Building Integrated Solar

As of November 2018 commercial-scale rooftop solar costs between $2000/kW and $2600/kW, while carport and canopy solar installs for $3200/kW. When buildings do not have sufficient rooftop and carport space, integrated photovoltaic shingles, skylights, canopies, wall panels and windows can make on-site renewable generation a feasible goal for the biggest of buildings. They range widely in efficiency, aesthetics and price, but at best they are a cost-effective replacement for conventional shingles, windows and wall paneling.



Solar windows (Polysolar) 11-16 W/ft²

Solar canopy (Onyx) 10.78 W/ft²

Solar curtain wall (Konarka) 2.79 W/ft²

Solar facade (LUT University) 15 W/ft²

Solar roof (Luma) 9.07 W/ft²

Solar roof shingles (Tesla) 13.94 W/ft²

Solar canopy (Onyx) 10.78 W/ft²

Solar awnings SkyFireEnergy) 18.58 W/ft²

Solar windows (Pythagoras) 13 W/ft²

Commercial Kitchen Appliances

The modern electric kitchen provides chefs with more control, speed, safety and cooler working environments than gas. Julia Child cooked only on electric stoves, while modern Michelin stars Wolfgang Puck (of Spago), and Thomas Keller (of The French Laundry) are devotees of the all-electric kitchen for productivity, speed, control and safety. Wolfgang Puck even has his own line of residential electric induction ranges for sale.

Vollrath Ultra Series Dual Hob
($2,516)

Vollrath Cayenne Dual Hob Heavy Duty
($2,319)

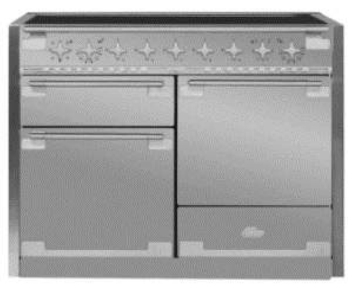
Vollrath Induction Wok
($2,215)

Garland Heavy Duty Electric Range
($9,093)

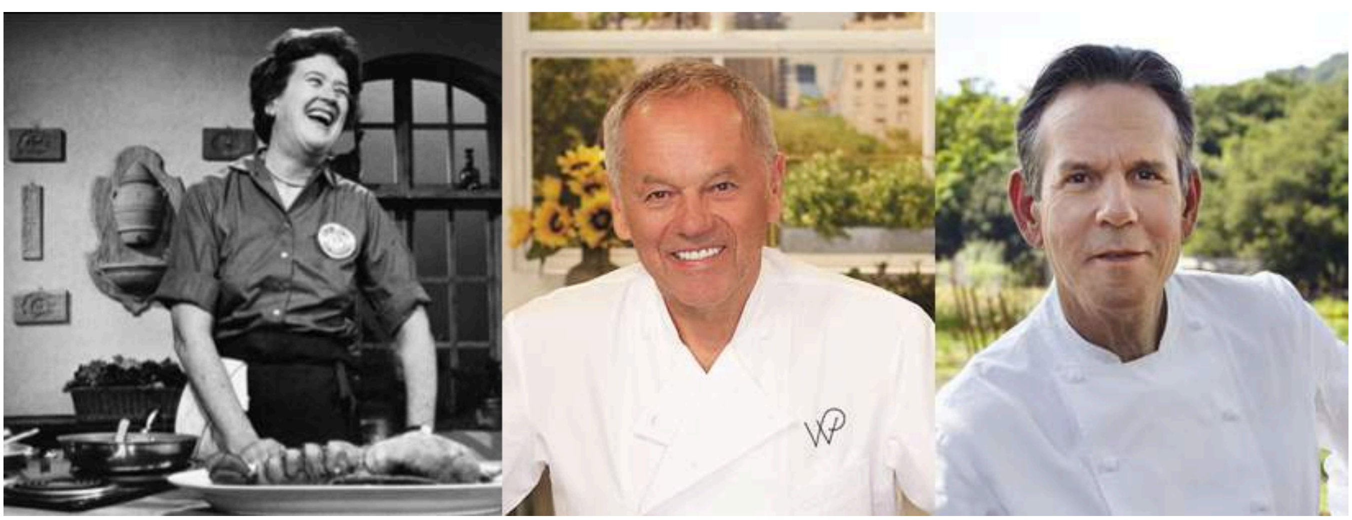
Vulcan Endurance
($8,333)

Bertazzoni Professional Series
($4,400)

AGA Elise Induction
($11,335)



AGA Companion Induction
($6,499)



Julia Child, Wolfgang Puck and Thomas Keller: globally famous chefs in favor of electric cooking.

Domestic Hot Water (DHW) and Heating, Ventilation and Air Conditioning (HVAC)

The following guide offers an overview of electric compressor technologies available to meet hot water, space heating and air conditioning loads. Compressors have many different names, depending on their applications, with names like “refrigerators,” “air conditioners,” “air source heat pumps,” and “reverse chillers.” There are compressors sized to meet the needs of cooling or heating almost anything—from cars to high rise buildings.

The history of chemical refrigeration dates back 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 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. Early heat pumps could heat down to about 2°C (35°F), which limited the product to warmer climates, but modern “inverter” controls now accelerate the compressor pump so they can collect heat down to -34°C (-30°F) --“cold climate” compressors now heat all-electric homes above the Arctic Circle.

Compressors can draw their energy from three main sources --the air, the ground and water-- and the energy is used to condition water or the air. The most common and flexible technology is the “air source” compressor, like that in your refrigerator or your air conditioner (used at Space X). “Ground source” compressors use the soil (e.g. Google’s new campus), while “water source” compressors use ponds and bays (e.g. the Exploratorium). Sometimes, “water source heat pump” refers to two-stage process, where there is a central air source heat pump that chill or heat recirculating water with heat, and then small water-source heat pump in the apartment or office pull out the heat for space heating, or add heat to the chilled water for air conditioning.

Using a compressor allows a building owner to eliminate gas infrastructure—mainline extensions, laterals, interior plumbing and combustion venting--which lowers the cost of construction. The following section offers a sampling of the biggest heat pumps available on the market in 2018. These products provide space heating and cooling, domestic hot water, or all three. All products shown are widely adopted world-wide, although currently less common in California, one of the most gas-reliant states in the U.S. Most of the products shown deliver energy via hot and cold water, but some use conventional refrigerants. All products shown are widely adopted in the North American market.

Design Guidance for Heat Pump Central Domestic Hot Water Systems

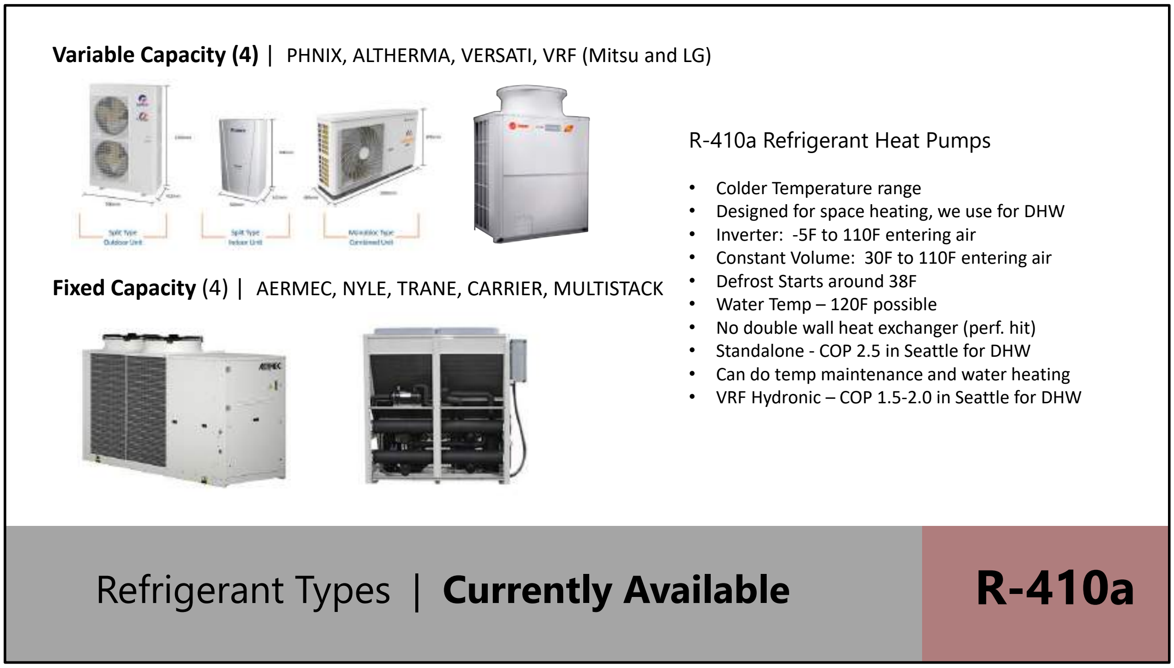
Using compressors/heat pumps to provide Space Cooling dates to the 1920s, for Space Heating since the 1940s, but using compressors to heat domestic hot water for cafeterias, apartment complexes, dairies[22] and other large uses dates only to the 1970s, and has advanced further in Asia where efficiency is more valued. Consequently, there is less familiarity among North American designers of both the products and practice of designing commercial hot water systems using heat pumps. Below is helpful guidance from the engineers at Ecotope of Seattle, the most experienced designers (25 systems so far) of central domestic hot water heat pumps in North America.

1. ***Heat pumps are not boilers***. Do not oversize the central heat pump for faster recovery, which leads to both higher construction costs and equipment failure. Instead use a series of dispatchable 5-15 ton heat pumps, rather than one larger (e.g. 60 ton) heat pump, and favor hot water storage over hot water production.
2. When recirculating hot water, ***split the pipe heat loss load from the usage load***. Temperature maintenance of recirculating water is ideal for "multi-pass" heat pumps that handle 110F incoming water (e.g. Aermec, Daiken) and perform 10F temperature bump-ups, while meeting peak loads is best done with a "single pass" heat pump (e.g. Sanden, Colmac) that uses cold incoming water, not recirc water, to efficiently lift temperatures from 50F to 150F.
3. ***Install "heat traps"*** on both hot and cold water sides of storage tanks to prevent migration and mixing.
4. ***Reduce pipe surface area*** to greatest extent possible. Insulate remaining pipes with 1"-4" of foam, depending on space availability. Insulate tanks to at least to R-19, same as an outside wall, due to the even more extreme heat loss than found in a wall.
5. ***Design diagnostics into crucial points in the heat plant and distribution system***—electrical gauges to measure power quality, temperature gauges to monitor heat gain and loss, and control valves on the discharge side of pumps to measure pump flow
6. ***Provide redundancy in heat pumps and choose electric resistance storage tanks*** for a durable, dependable design for the eventuality that system components need maintenance.
7. ***Consider adding drain line heat recovery*** to save energy while improving the hot water delivery capacity.

Figure 15: Ecotope Case Study "RCC" system for 194 unit Multifamily building, using best practices in central heat pumps for domestic hot water, from ACEEE presentation by Shawn Oram.

[22] C&I Case Studies in Beneficial Electrification (2018): *Agribusiness: Dairy Water Heating*. Retrieved from: www.cooperative.com/programs-services/bts/documents/techsurveillance/ts-beneficial-electrification-dairy-water-heating-april-2018.pdf

Central DHW Products, Organized by Refrigerant and Function *(Courtesy of Ecotope)*



Design Guidance for Heat Pump HVAC Systems

Using compressors/heat pumps to provide Space Heating and Space Cooling is well-understood, and widely available products are designed to heat and cool commercial buildings by variety of mechanisms, using either water, refrigerants or ducted air to deliver thermal comfort to occupants. Some products can additionally heat domestic hot water, but combining Space Heating with Domestic Hot Water decreases net performance from a COP of 2.5-2.8 down to a COP of 1.2-1.8, primarily due to destratification of the storage tanks. It is best to dedicate a heat pump system to HVAC, and another to domestic hot water.

3-in-1 Products: Domestic Hot Water, Space Heating and Space Cooling

		Aermec Air to Water		**PHNIX** Air to Water		**Aermec** Water to Water	
		 NRP (800,900,1000,1250, 1404,1504,1655,1800)		 PASHW (030S-PS, 050S-PS, 100S-PS, 150S-PS, 300S-PS)		 NXW (500,550,600,650,700, 750,800,900,1000,1250,1400)	
Heating Capacity Range	KW	216	495	10	100	121	457
	BTUh	738,278	1,689,276	35,145	341,212	412,000	1,560,000
	Ton	62	141	3	28	34	130
Cooling Capacity Range	KW	182	423	7	59	113	457
	BTUh	620,400	1,444,200	23,066	201,315	384,000	1,560,000
	Ton	52	120	2	17	32	130
Heating Efficiency	COP	10.42	10.66	2.96	4.68	3.94	4.24
	EER	35.58	36.40	10.11	15.98	13.46	14.48
Cooling Efficiency	COP	2.80	2.84	2.70	2.84	4.52	5.80
	EER	9.56	9.70	9.20	9.70	15.43	19.81

Heating and Cooling Only

		Swegon Air to Water		**Carrier** Air to Air		**Mitsubishi** Air to Refrigerant	
		 Cobalt Pro		 WeatherMaker 50TCQ (17,24)		 Y-Series - City Multi Series	
Heating Capacity Range	KW	303	2007	49	64	23	119
	BTUh	1,033,874	6,848,133	166,000	220,000	80,000	405,000
	Ton	86	571	14	18	7	34
Cooling Capacity Range	KW	302	1983	53	70	21	106
	BTUh	1,030,461	6,766,242	180,000	240000	72,000	360,000
	Ton	86	564	15	20	6	30
Heating Efficiency	COP	3.10	3.23	2.30	3.30	3.56	4.22
	EER	10.59	11.03	7.85	11.27	12.16	14.41
Cooling Efficiency	COP	2.70	3.05	3.10	3.16	3.40	4.16
	EER	9.22	10.42	10.60	10.80	11.60	14.20

Electrically Heated Swimming Pools and Hot Tubs

Google's Dublin Headquarters includes a staff pool.

Many commercial buildings (e.g. hotels, corporate campuses) have swimming pools and hot tubs. To size a heat pump pool heater, assume the heat pump must produce 4 to 6 BTUs/Hour for each gallon of heated pool water, with higher productivity needed when the incoming water is colder in the winter.

 Hayward Heat Pro	 Pentair	 Aquacal Heatwave

***Pool and Hot Tub Heat Pumps**: Hayward Heat Pro, Pentair and Aquacal Heatwave are three high-performance air source heat pumps used to heat swimming pools and jacuzzies.*

Electric Fireplaces

Swirling, fire-like mist lit with LEDs and a log fire's worth of heat: these are the new electric fireplaces for use in outdoor recreational spaces, restaurants and hotel lobbies, as well as replacing gas hearths in luxury condos like those on the 35th floor of the Salesforce tower[23]. They're less expensive than gas stoves, safer, cleaner, and plug into a normal 120V wall outlet. From convincing to dramatic, electric fireplaces are ready to match the tastes of any owner. Outdoor electric space heaters are similarly versatile and ready to replace headache-inducing propane burners.

Dimplex Opti-Myst Pro 1000 ($2099)

Napoleon See-thru ($2,008)

Dynasty DY-BT79 ($1,299)

Amantii Zero Clearance ($1,308)

Amantii BI-40-SLIM (In/Out) ($1,618)

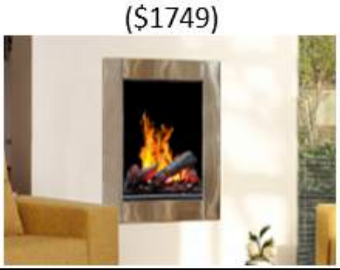
Modern Flames CLX Series ($7,449)

Dimplex Opti-Myst Pro 500 (outdoor) ($1300)

EnerG+ Patio Heater (outdoor) ($186.99)

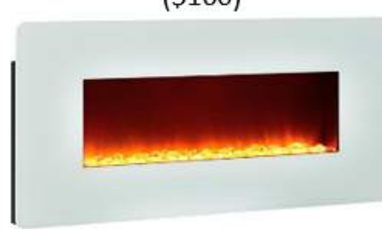
Touchstone Sideline (outdoor) ($574)

Dimplex Opti-Myst Pro 400 ($1749)



ClassicFlame Felicity ($349.77)

Altra Furniture ($160)



[23] Heller, Nathan (2018). *The Bright Lights of the Salesforce Tower*. Retrieved from the New Yorker: www.newyorker.com/culture/culture-desk/the-bright-lights-of-the-salesforce-tower

Electrifying Vehicles for Building and Grid Back-Up

A 2019 Honda electric sport car (left) and a fleet of Chinese electric buses (right).

Fleets of electric buses, trucks and cars can now provide back-up for homes, commercial buildings and the electrical grid. The practice of using vehicle batteries for other uses accelerated in 2012 in Japan after the 2011 tsunami closed the nation's nuclear power plants. Nissan first began supporting Vehicle to House (V2H) and Vehicle to Grid (V2G) charging with their electric Leaf. The island of Maui, with its constricted grid, and the LA Air Force Base[24], are more recent adopters in the United States.[25] Honda, Mitsubishi, Toyota and other car manufacturers with standard CHAdeMO-certified Tier II charging plugs can now support V2H and V2G charging. At larger scale, China is rapidly electrifying the nation's fleet of hundreds of thousands of buses and using them for battery-back up of the grid and buildings.

The LA Air Force Base is increasing its resiliency and readiness with a fleet of bi-directional Nissan Leafs.

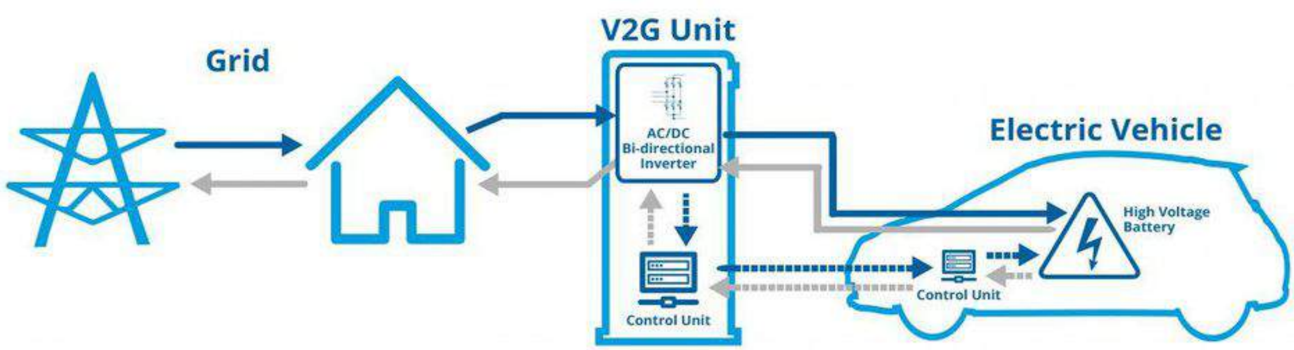
Nissan has partnered with Maui's utility since 2012 to help manage their island grid with Nissan car batteries, implemented through the Evohana by JumpStartMaui program.

[24] Princeton Power Systems (2014). *Case Study, L.A. Air Force Base EV Charging Stations*. Retrieved from Princeton Power: https://www.princetonpower.com/pdf-new/LAAFB_Case_StudyC.pdf
[25] Hawaiian 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

Vehicle to Building (V2B) Chargers: V2B chargers has been increasing in popularity since Nissan first began offering their Leaf for building back-up in 2012. An electric car can provide hours or days of backup power for an electric building, depending on the battery and consumption behavior. With a right-sized solar array and a V2B electric car or cars, a building could survive indefinitely for about 2/3rds of the year when the sunshine is strong enough to offset daily consumption. Honda, Mitsubishi and Nissan are a few of the top manufacturers that offer Vehicle to Building chargers.

		
Honda	Mitsubishi	Nissan

Vehicle to Grid (V2G) Chargers: V2G chargers allow the electric vehicle batteries to provide supplemental power to the electric grid and help maintain grid frequency to improve grid harmonization. Nissan, Endesa, OVO and Princeton Power Systems are a few examples of V2G chargers available today.



			
Nissan	Endesa	OVO	Princeton Power Systems

Electric Fleet: Electric fleet vehicles are available in all sizes and types, and due to their lower operating costs they have been widely adopted world-wide. These large commercial vehicles have significant battery storage both for travel and possible vehicle-to-building or grid battery use.












The entire fleet of 16,500 buses serving 12,000,000 people in Shenzhen, China are electric. Every five weeks, China adds 9,500 electric buses to its national fleet. Electrification projects of this magnitude can be felt around the world, causing the global demand for fuel to drop by about 500 barrels a day for every 1,000 EV buses.[26]

[26] Poon, L. (2018). *How China Took Charge of the Electric Bus Revolution*. Retrieved from City Lab: https://www.citylab.com/transportation/2018/05/how-china-charged-into-the-electric-bus-revolution/559571/

This report was written by Redwood Energy, a purpose-driven building science consultancy dedicated since 2011 to mitigating climate change and supporting lower income households. Redwood Energy leads the world in designing Zero Carbon developments, and has been acknowledged with Grand Prizes in design by the United Nations (2017) and the PCBA Gold Nuggets (2016), with additional awards from the Department of Energy (2015) and the Southern California Building Industry Association (2017).

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

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