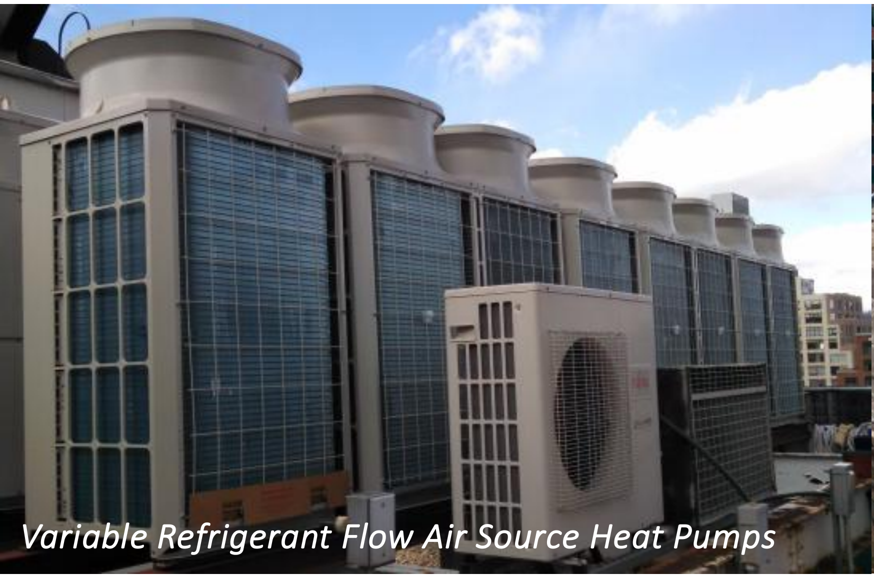

Zero Carbon Commercial Construction:

An Electrification Guide for Large Commercial Buildings and Campuses

2nd Edition

REDWOOD ENERGY

By Sean Armstrong, Jenna Bader, Emily Higbee, Lynn Brown, Richard Thompson IV, Roger Hess, Harlo Pippenger, Cheyenna Burrows, Wyatt Kozelka, Jonathan Sander, Nicholas Brandi, and Scott Shell, Principal at EHDD

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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, hot water 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 CO_2 when burned, because methane is a more potent greenhouse gas with 100 times the warming impact of CO_2 in the short term.[4]

Leaks from gas pipelines are also a serious public hazard, with a gas pipeline explosion 8 out of every 10 days between 1986 and 2016, with 548 fatalities.[5] The carbon monoxide produced by burning gas indoors can be even more lethal; according to the U.S. Centers for Disease Control, carbon monoxide poisoning results in roughly 15,000 emergency room visits and 500 deaths every year.[6]

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[7] 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.*

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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] Joseph, George. "30 Years of Oil and Gas Pipeline Accidents, Mapped." Citylab. November 30, 2016

[6] Centers for Disease Control and Policy. Carbon Monoxide-Related Deaths – United States, 1999-2004. Morbidity and Mortality Weekly Report. December 21, 2007; 56(50):1309-12.

[7] 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

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.[1]

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."

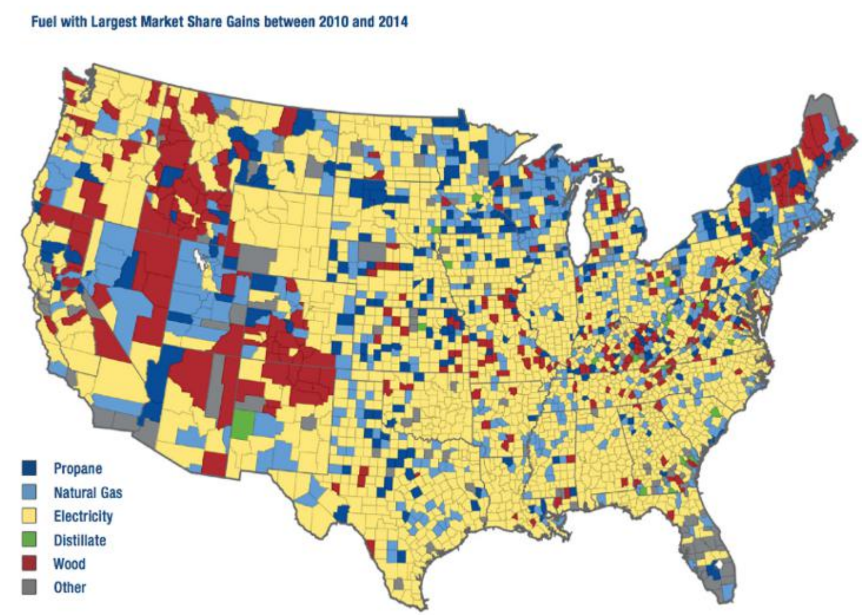

Figure 2: All-Electric construction has been growing since 1993, and are now the market share growth leader across the US.

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

The following case studies provide an ample selection of commercial projects that have chosen to go all electric or are leaders in efficient design. The projects below include campus facilities, large residential buildings and commercial all-electric kitchens. Only a few of these cutting-edge projects are explained in detail, so additional case studies as well as a list of other noteworthy buildings are also provided.

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.

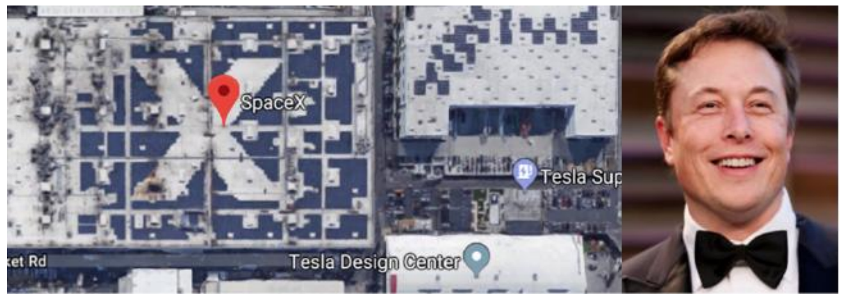

Figure 3: All-electric Space X and Tesla Design Center and Elon Musk.

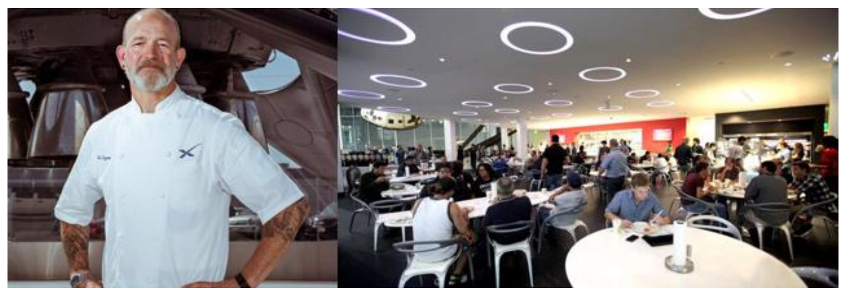
Figure 4: Ted Cizma, Head Chef: Space X's all-electric free staff cafeteria.

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 of water source heat pumps and heat exchangers.

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[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/

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

Zero Net Energy Center, San Leandro, Retrofit

Figure 6: 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.[10]" 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.[11] Including the comprehensive efficiency efforts, total site energy dropped 75% after the retrofit.

Google Bay View Campus

When it opens in 2019, Sergey Brin and Larry Page'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.[12] 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

Figure 7: Google's all-electric Bay View campus will open in 2019

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[10] 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/

[11] Hummel, M., Grant, G., Benton, B., & Desmond, K. (2015). Working Example - Zero Net Energy Center. High Performing Buildings.

[12] 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.

water for Air Conditioning.[13] Google, like Apple, Facebook[14] 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.

The Exploratorium, San Francisco

Listed as one of "The Ten Coolest Museums in the World" by the New York Times Magazine in 2018[15], San Francisco's coastal Exploratorium has an extraordinary 1.4 MW solar array that supplies energy equaling 100% of annual site energy use, including 600 educational displays used by and 28 miles of radiant piping in the floor 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.[16]

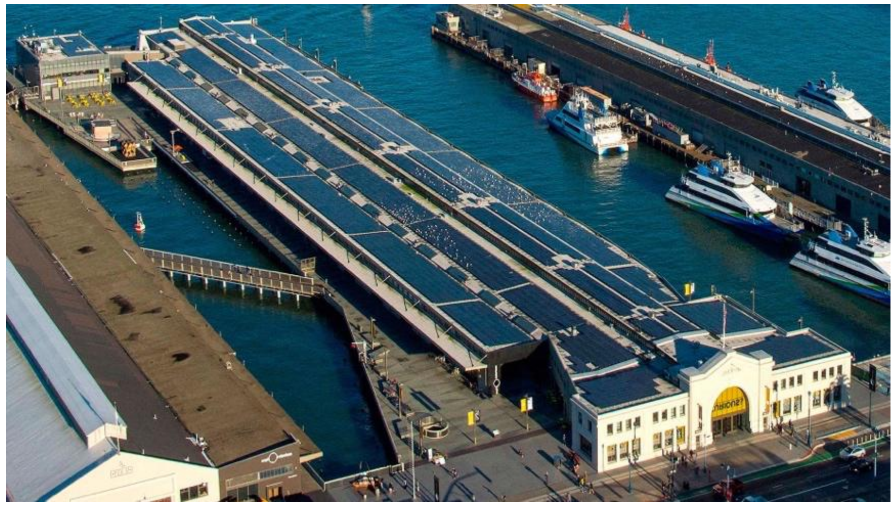

Figure 8: Bird's eye view of the Exploratorium, San Francisco, CA.

Hyatt Regency Waikiki Beach Resort and Spa, Hawaii

The Hyatt Regency at Waikiki Beach offers a luxurious all-electric lifestyle: all electric condos and hotel rooms, conference halls, an outdoor mall, heated pools, hot tubs and an array of high-end restaurants.[17] Hawaii's resorts are frequently all-electric due to limited gas infrastructure on the islands, which lack fossil fuel deposits but are rich in solar and wind electricity resources.

Figure 9: The various all-electric amenities of the Hyatt Regency of Waikiki Beach Resort: Ocean view rooms, a shopping mall, a pool and spa, and restaurants.

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[13] 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

[14] Shieber, J. (2018). Facebook has committed to using 100% renewable power for global operations by 2020. https://techcrunch.com/2018/08/28/facebook-has-committed-to-using-100-renewable-power-for-global-operations-by-2020/

[15] Exploratorium Facts and Figures. https://www.exploratorium.edu/support/facts-figures

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

[17] Hyatt Regency Waikiki Beach Resort and Spa. <https://www.hyatt.com/en-US/hotel/hawaii/hyatt-regency-waikiki-beach-resort-and-spa/hnlrw>

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.

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

National Renewable Energy Lab Research Support Facility, Golden, CO

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.[18]

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

David and Lucile Packard Foundation, Los Altos, CA

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 in the summer with water-chilled radiant panels and warm in the winter with an air source heat pump for hydronic (where heat is transported with piped water), ducted hot air distribution system. 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.[19]

Figure 12: The David and Lucile Packard Foundation Headquarters.

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[18] 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/

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

Additional All-Electric Case Studies[20]

Alexander Valley Medical Center
Guttmann & Blaevoet

Goldman School of Public Policy
Guttmann & Blaevoet

Pier 70, Building 12
Point Energy Innovation

700 Santana Row
Interface Engineering

500 Santana Row
WRNS Architects
Interface Engineering

Lawrence Berkley National Laboratory - Genomics Lab
Smith Group/ JJR and Integral Group

Sacramento Municipal Utility District Office & Operations Building
Guttmann & Blaevoet

Silver Oak Winery
Guttmann & Blaevoet

SFO Consolidated Admin Facility
Integral Group

American Geophysical Union
Interface Engineering

415 Mathilda
Integral Group

380 N. Pastoria
Integral Group

[20] Additional all-electric case studies are from the presentation "The Cost Effectiveness of Building Electrification." by Scott Shell, Principal of EHDD Architecture.

All-Electric Schools[21]

Lick Wilmerding High School
55,000 SF
Architect: EHDD
MEP: Integral Group

Mark Day School
14,574 SF
Architect: EHDD
MEP: Integral Group

Marin Country Day School Sciences
11,500 SF
Architect: EHDD
MEP: Integral Group

Sonoma Academy
19,500 SF
Architect: WRNS
Mechanical: Interface Engineering
Electrical: Integral Group

Sacred Heart Academic & Arts
79,000 SF
Architect: WRNS
Mechanical: Interface
Electrical: Integral Group

White Hill Campus- Ross Valley USD
42,000 SF
Architect: WRNS
Engineer: Interface Engineering

Sacred Heart School Library
6,800 SF
Architect: WRNS
MEP: Interface Engineering

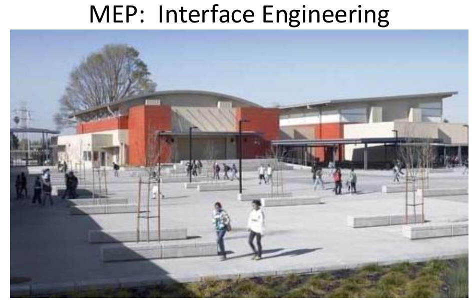
CES- Bishop O'Dowd
3,700 SF + 1,500 SF outdoor classroom
Architect: Siegel & Strain Architects
MEP: Integral Group

Albany High School
10,500 SF
Architect: LCA Architects
MEP: Guttmann & Blaevoet

Blue Oak Middle School
36,500 SF
Ratcliff

Clair Lilienthal Elementary
Architect: Lionakis

MLK Middle School
Architect: Hibser Yamauchi Architects
MEP: Interface Engineering



[21] All the electric school case studies are taken from the presentation "All Electric Schools Sep 3, 2019." by Scott Shell, Principal of EHDD Architecture.

All-Electric New York Restaurants

Below is a sample of fine dining restaurants in New York City that have chosen to go all-electric for greater speed, better control, lower construction cost and reduced danger to the chefs. Culinary traditions from around the world are improved by high performance electric kitchen equipment, from tossing fine pasta with delicate sauces in temperature-controlled induction woks at SOLA, to charring octopus leg and baking goat cheese crème at the Grand Army oyster bar.

Figure 13: All-Electric Culinary leaders in New York City include many diners, an upscale oyster bar, induction ranges for each customer's Mongolian hot pot and fine Italian dining made with induction woks.

All-Electric Commercial Kitchens [22]

Troisgros Grande Maison, Roane, France[23]

Chatham University

[22] Brad Jacobson and Scott Shell of EHDD, Tarah Schroeder of RICCA, Richard Young of Frontier Energy, Chef Christopher Galarza of Chatham University, and Hormoz Janssens of Interface Engineers. (2019). All Electric Commercial Kitchens.

[23] Loire Le Departement. Premier service a Ouches pour la Mainson Troisgros <https://www.loire.fr/jcms/lw_1169100/premier-service-a-ouches-pour-la-maison-troisgros>

Porter Academy

Blue Cross Blue Shield

RE Farm

Princess Cruises - La Mer and Harmony Restaurants (Michelin star chefs Emmanuel Renaut and Richard Chen)

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/sq ft/year)	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
	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.[24]
3. All-electric commercial buildings are ***efficient***, using 1/2 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.[25]
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.[26]
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: Neighbors flee an out-of-control fire in San Bruno fueled by a damaged high-pressure gas pipeline.[27]

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[24] 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

[25] 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

[26] 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/

[27] National Transportation Safety Board. (2011). Accident Report – San Bruno Pipeline Rupture. American Gas Association. https://www.aga.org/research/reports/ntsb-accident-report---san-bruno-pipeline-rupture---sept-2011/

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 appliances, 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/ft^2

Solar canopy (Onyx)
10.78 W/ft^2

Solar curtain wall (Konarka)
2.79 W/ft^2

Solar facade (LUT University)
15 W/ft^2

Solar roof shingles (Tesla)
13.94 W/ft^2

Solar roof (Luma)
9.07 W/ft^2

Solar canopy (Onyx)
10.78 W/ft^2

Solar awnings SkyFireEnergy)
18.58 W/ft^2

Solar windows (Pythagoras)
13 W/ft^2

Commercial Kitchen Appliances

Figure 15: Julia Child, Wolfgang Puck and Thomas Keller: globally famous chefs in favor of electric cooking.

The modern electric kitchen provides chefs with more control, speed, safety and cooler working environments than gas. [28] 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.

- Electric cooking equipment delivers heat three times as effectively than gas equipment—heat delivery efficiency is between 60% and 90%, compared to gas equipment at 25-35% efficient. [29] In addition, energy star commercial electric cooking equipment can reduce loads.
- Faster heat delivery is important during rush hours—at a fast food restaurant an electric fryer produces six more baskets of fries per hour than a gas fryer, directly impacting sales, labor efficiency and profitability.
- Gas inefficiency triples kitchen air conditioning and ventilation loads, and gas combustion pollution (NO2, Formaldehyde) makes kitchens inherently less healthy for chefs.
- Induction electric cooking offers precise temperature control, while gas burns at 3400F and then relies upon inefficiencies in heat transfer, or liquids in the pan to cool it. Induction stoves protect chefs from high temperature burns when they bump cookware.

Commercial Electric Ranges

Make/Model	**Bertazzoni** PRO304INMXE	**Garland** SS686	**Vulcan** EV36S4FP1HT2	**AGA Elise** AEL48IN-SS	**Lang** R36C-APA	**Garland** SS684
						
Price	$3,000	$6,490	$8,440	$8,930	$10,100	$10,400
Amp/Wattage	45.5 / 12.4	78 /19	13kW	50 / 14.9	103.8/21.6	33kW
Volts	240	240	208	240	208-240	208-240
Heating Type	Induction	Radiant	Radiant	Induction	Radiant	Radiant
Temp. Range	NA	150°F - 550°F	200°F-500°F	NA	150°F - 450°F	150°F - 550°F
Burner Diameter	7”(2x)/ 5”/ 8”	6 ½”(x3)/ 8 ½”(x3)	NA	Flattop	24” griddle/8” element(x4)	NA

Commercial Ovens (208V)

Make/Model	**Bakers Pride** BCO-E1	**Vulcan** VC5ED-11D1	**Blodgett** BDO-100-E	**Garland** SUME-100
				
Price	$3,324	$3,715	$3,810	$4,630
Kilowatts	10.5kW	12kW	11kW	10.4kW

[28] Kostuch Media Ltd. (2017). Why Induction Cooking is the Hottest Trend to Hit Restaurant Kitchens. Food Service and Hospitality. <https://www.foodserviceandhospitality.com/why-induction-cooking-is-the-hottest-trend-to-hit-restaurant-kitchens/>

[29] Source: Andre Saldivar, Foodservice Technology Center, Southern California Edison

Commercial Single Burner Countertop Induction Cooktops (1800 W / 15 Amps / 120V)

Make/Model	**Update** International IC	**Eurodib** C1813	**Waring** WIH200	**ChangBERT**	**Vollrath** 6950020
					
Price	$200	$90	$150	$250	$610
Temp. Range	140°F-460°F	150°F-450°F	Up to 450°F	NA	NA

Electric Induction Woks (240V / 15A)

Make/Model	**Spring** SM-351WCR-8	**Garland** GI-SH	**APW** Wyott IWK	**Vollrath** 6958301	**Garland** GI-SH/WO/IN
					
Price	$1,470	$1,760	$1,950	$2,200	$2,440
kW	3.5	3.5	3.0	3.0	5.0

Electric Fryers

Make/Model	**Dean** SR114E	**Imperial Range** IFS-40-E	**Frymaster** RE14C-SD	**Anets** AEH14X	**Garland** 36ES11	**Vulcan** CEF40
						
Amp/Wattage	14kW	14kW	39A/14kW	58.3A/14kW	51A/12kW	47A/17kW
Volts	208V	208-240V	208V	240V	240V	208V
Price	$1,650	$1,820	$5,280	$4,140	$5,960	$4,340

Induction Catering / Buffet Equipment

Make/Model	**Garland** GI-HO 1500 Induction Warmer	**Spring USA** QS7230 Warming table	**Vollrath** 7552280 60" Buffet Table	**Bon Chef** 50120 Induction Buffet Case	**Bon Chef** 50102 96" Buffet Table
					
Price	$2,250	$5,700	$6,520	$11,630	$16,120
Amp/ Wattage	NA / 1500W	20A/650W	11.25A / 1350W	50A/NA	30A / 3200W
Voltage	120V	120V	120V	220V	110 V

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.

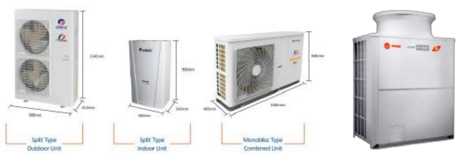
Low Global Warming Potential Refrigerants

Heat pumps can move heat from one substance to another so well because of the compression and expansion of chemicals 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. In addition, the industry has been moving toward “natural” refrigerants like CO_2 (R744), Ammonia (R717) and Propane (R290) that do not deplete the ozone and have a low global warming potential (GWP).[30]

The following table (Courtesy of Ecotope) provides a summary of domestic hot water products and their refrigerant types and gives a description of how each group of products work. There are few CO_2 refrigerant products on the market

[30] Accelerate Magazine. (2015). Guide to Natural Refrigerants in North America, the State of the Industry. http://www.r744.com/files/1811_Guide_america_2015_online-compressed.pdf

today, and essentially only one product in the United States (Sanden, see below). But since CO_2 has a GWP of 0, this makes it a viable refrigerant for future products. Beyond HVAC and DHW, commercial refrigeration, like in grocery stores, has been moving towards using low GWP refrigerants.

R-410a Currently Available	**Variable Capacity (4)** | PHNIX, ALTHERMA, VERSATI, VRF (Mitsu and LG)  **Fixed Capacity** (4) | AERMEC, NYLE, TRANE, CARRIER, MULTISTACK 	• Colder Temperature range • Designed for space heating, we use for DHW • Inverter: -5F to 110F entering air • Constant Volume: 30F to 110F entering air • Defrost Starts around 38F • Water Temp – 120F possible • No double wall heat exchanger (perf. hit) • Standalone - COP 2.5 in Seattle for DHW • Can do temp maintenance and water heating • VRF Hydronic – COP 1.5-2.0 in Seattle for DHW
R-134a Currently Available	**Fixed Capacity** | Most Integrated HPWH ("hipwa") COLMAC, AO SMITH, NYLE 	• Warmer Temperature range • Designed for DHW • Constant Volume: 40F to 110F entering air • Defrost Starts around 45F EA • Water Temp – 130-160F possible • Includes Double Wall Heat Exchanger • Single Pass Water Heating in BG Garage- COP 2.7 Seattle • Temperature Maintenance in BG Garage – COP 2.5 Seattle • Available as Single or Multi-pass • Temperature maintenance with single • Available with communicating controls
R-744 (CO_2) Currently Available	**CO_2 Variable Capacity** SANDEN (1.25 Ton) 	• Entering Air Range -25 to 110 F • Inverter Driven Compressors • Available as Single Pass only • Designed for DHW • Water Temp – 150F and 190F possible • Technically does NOT require double wall (CO2) • Water Heating COP 3.2 • Temperature Maintenance Challenging
R-744 (CO_2) Currently Unavailable	**CO_2 Variable Capacity (Available Internationally)** Mayekawa (22T), Mitsubishi (11T), MHI (8T), Itomic (3, 7, 22T), Sanden (larger 4.2T) 	• Entering Air Range -25 to 110 F • Inverter Driven Compressors • Available as Single Pass only • Designed for DHW • Water Temp – 150F and 190F possible • Technically does NOT require double wall (CO2) • Water Heating COP 3.2 • Temperature Maintenance Challenging • No UL on any of these products yet (field test possible)

Commercial Refrigeration Using Low Global Warming Potential Refrigerants

Commercial refrigerators and freezers are a growing problem—they often leak 50% of their refrigerant fluids a year, which are among the strongest climate change chemicals made by humans, causing 3,500 to 11,000 times more climate change per molecule than CO_2. Sales of low GWP_{20} refrigerant chillers using CO_2, Propane and Ammonia have been booming in the American market due to better chilling functionality and lower operating expenses in grocery stores, data centers, ice rinks, etc. This natural market shift is also strengthened by policy measures like California's announced phase-out by 2023 of high GWP_{20} refrigerants and the EPA's GreenChill Partnership.[31] CO_2 refrigerant products for various applications are being adopted world-wide--in China, Russia, Germany, Norway, the Middle East and more.[31] Stores around North America have been adapting low GWP refrigeration systems, and a few are listed below.

Sprouts in Dunwoody, Georgia[32]

- First CO_2-based supermarket refrigeration systems in a warm-weather market in North America.
- The key to Sprouts' new system is a proprietary TrilliumSeries hybrid evaporative condenser designed for Hillphoenix by Baltimore Air to operate in ambient temperatures above 85 degrees
- Developed a new product that's a hybrid evaporative condenser adapted for use with CO_2 – provides lower system condensing temperatures than conventional air-cooled or water-cooled condensing systems.

Sobeys, Canada[33]

- Canada's second largest food retailer with 1,778 stores
- Adopted carbon dioxide refrigeration as its standard system for new stores and major renovations
- Over 63 stores using a CO_2 system in 2018. 15-20 stores opening every year with CO_2, and 10 more renovations.
- Manufacturers Carnot and CSC are both focused on developing CO_2 technology and worked closely with Sobeys to develop CO_2 solutions

Whole Foods[34]

- 22 of its 465 stores utilize all-natural refrigerant systems most with R-290 (Propane) for self-contained cases
- AHT Cooling Systems USA – adoption of propane systems has increased so much in the US AHT will transition its entire equipment platform to R-290 (2017)
- Santa Clara, CA location - features what's arguably the most environmentally friendly refrigeration system in the U.S. that uses a R-290/CO2 cascade system

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[31] Williams, A. (2018). Year in Review: The Best of R744.com in 2018. R744.com <http://www.r744.com/articles/8749/year_in_review_the_best_of_r744_com_in_2018>

[32] The Produce News. (2014). Sprouts Farmers Market and Hillphoenix push sustainable alternative. <http://www.producenews.com/more-what-s-new/13449-sprouts-farmers-market-and-hillphoenix-push-sustainable-alternative>

[33] R744.com (2015). Sobeys set for life with CO2-only refrigeration system. <http://www.r744.com/articles/6044/sobeys_set_for_life_with_co_sub_2_sub_-only_refrigeration_system>

[34] Wicher, A. (2017). Pioneering Natural Refrigeration. Whole Foods Market makes R-290 a cornerstone of its refrigeration strategy. <https://climate.emerson.com/documents/9760-issue9-pioneering-natural-refrigeration-lr-en-us-1732146.pdf>

High Temperature Heat Pumps

High temperature loads like brewing, canning fruit, and bottling plants require high temperature equipment. Recent innovations have given heat pumps the ability to boost waste heat from industrial processes – making them ideal for processes like drying, sterilization and pasteurization as well as other heat demanding processes.[35] Some high temperature heat pump products are listed in the table below.

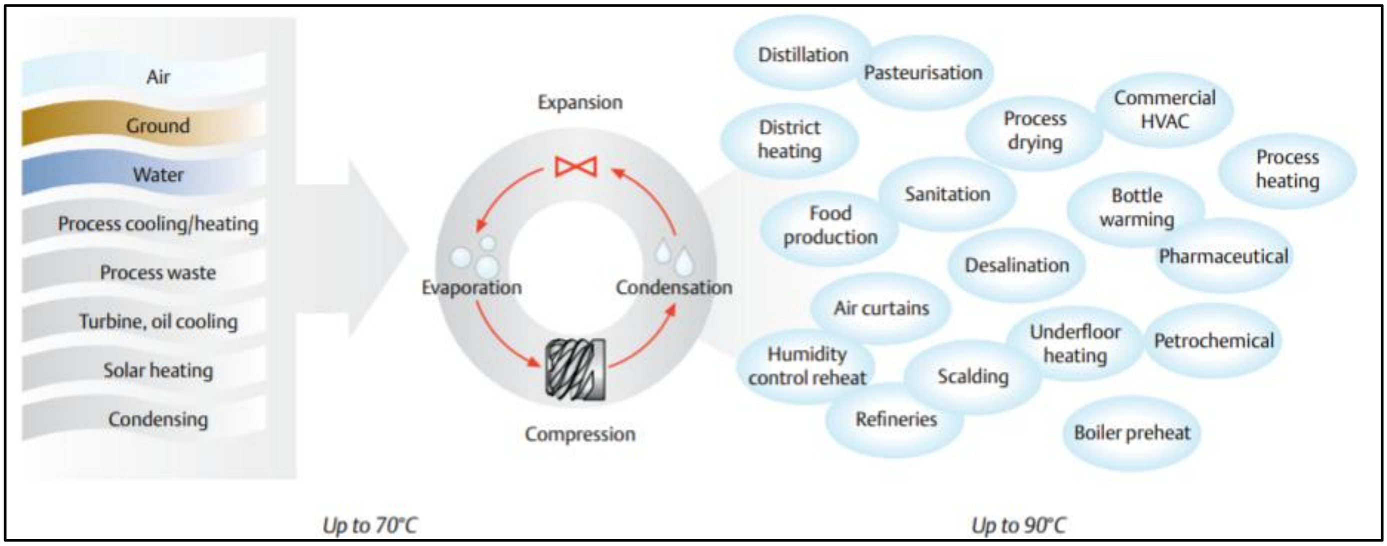


Figure 16: An example of the sources and sinks for an industrial heat pump.[36]

High Temperature Heat Pump Products

	**Viking Heat Engines[35]** **The HeatBooster - High temperature heat pump** • Designed to boost waste heat up to 165C (329F) • Highly flexible – adaptable to fluctuation of supply and demand of heat • High coefficient of performance at high temperature lifts • Piston compressor developed together with AVL is heavy duty with a long service life and little maintenance and can operated on all common refrigerants • 90C heat source with 120C (248F) heat since results in COP of 5 using R1336mzz-Z
	**Emerson Climate Technologies[36]** **Neatpump - High temperature ammonia heat pump** • Evaporator temperature from -10C (14F) to 20C (68F) results in hot water temperature from 73C (163F) to 90C (194F). COPs ranging from 3 to 10. • Vilter single screw compressors – diverse applications with different capacities

[35] Viking Heat Engines. HeatBooster HBS4 Industrial heat pump for sustainable heat production.
[36] Emerson Climate Technologies. Neatpump The High Temperature Ammonia Heat Pump. <http://ammonia21.com/files/448_dvi143_neatpump_en_1209.pdf>

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	700,000	1,700,00	35,000	340,000	412,000	1,560,000
	Ton	62	141	3	28	34	130
Cooling Capacity Range	KW	182	423	7	59	113	457
	BTUh	620,000	1,400,000	23,000	200,000	384,000	1,600,000
	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	1,000,000	6,800,000	160,000	220,000	80,000	405,000
	Ton	86	571	14	18	7	34
Cooling Capacity Range	KW	302	1983	53	70	21	106
	BTUh	1,000,000	6,800,000	180,000	240,000	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

Figure 17: 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

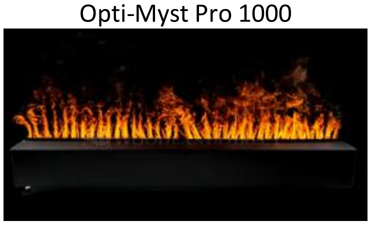
Pool and Hot Tub Heat Pumps*: Hayward Heat Pro, Pentair and Aquacal Heatwave are three high-performance air source heat pumps used to heat swimming pools and jacuzzies.*

Electric Fireplaces

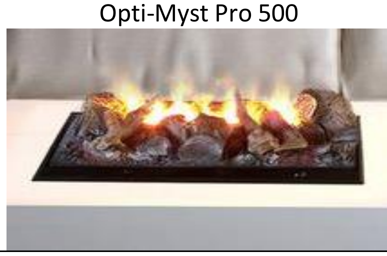
Swirling, fire-like mist lit with LEDs and a log fire's worth of heat: these are the new electric fireplaces for use in outdoor recreational spaces, restaurants and hotel lobbies, as well as replacing gas hearths in luxury condos like those on the 35th floor of the Salesforce tower[37]. They're less 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.

Indoor Electric Fireplaces

	ClassicFlame Felicity 	**Amantii** Zero Clearance 	**Modern Flames** CLX Series 
Size	46.6"W, 19.75"H,5"D	29.5"W, 38.75"H, 8.5" D	144" W,25.5" H, 5.3" D
Price	$350	$1,300	$7,500
Voltage/Amps	120V/12.5A	120V/12.5A	120V
Heat Output	1,500W	1,500W	1,500W

	Dimplex Opti-Myst Pro 1000 	**Napoleon** See-thru 	**Dynasty** DY-BT79 
Size	40.1" W, 9.5"H, 12" D	50"W, 18.4"H, 9"D	80"W, 19.3" H, 7" D
Price	$2100	$2,000	$1,300
Voltage/Amps	120V	120V/240V	120V/10.8A
Heat Output	460W	3,000W	1,300W

Outdoor Electric Fireplaces/Heaters

	Dimplex Opti-Myst Pro 500 	**Touchstone** Sideline 	**EnerG+** Patio Heater 
Size	20" W, 9.5"H, 12" D	50"W,17.9"H ,6"D	11" W, 4'3"H,11"D
Price	$1300	$574	$186.99
Voltage/Amps	120V/3.83A	120V/11A	110V/13A
Heat Output	230W	1,500W	1,500W

[37] 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

Figure 18: A 2019 Honda electric sport car (left) and a fleet of Chinese electric buses (right).

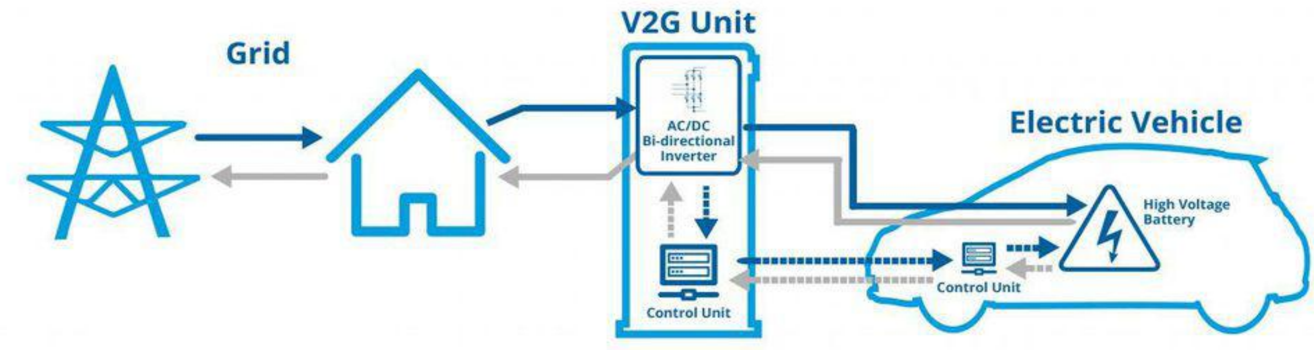
Fleets of electric buses, trucks and cars can now provide back-up for homes, commercial buildings and the electrical grid. The practice of using vehicle batteries for other uses accelerated in 2012 in Japan after the 2011 tsunami closed the nation's nuclear power plants. Nissan first began supporting 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[38], are more recent adopters in the United States.[39] 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.

Figure 19: The LA Air Force Base is increasing its resiliency and readiness with a fleet of bi-directional Nissan Leafs.

Figure 20: 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.

[38] 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

[39] 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 Fleets: 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.[40]

[40] 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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