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The Building Electrification Technology Roadmap (BETR)

Summary

A companion document to the full BETR Report: A Path to Decarbonization for California Efficiency Programs

Technical status, barriers, and paths to advancing electrification technologies in residential and commercial buildings.

Prepared By:

Alexi Miller and Cathy Higgins
New Buildings Institute

January 2021

In Partnership with:

BUILDING DECARBONIZATION COALITION

With Sponsorship From:

EPRI ELECTRIC POWER RESEARCH INSTITUTE
LA DWP Los Angeles Department of Water & Power
PG&E Pacific Gas and Electric Company
SOUTHERN CALIFORNIA EDISON
SMUD

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New Buildings Institute is a 501(c)(3) nonprofit organization whose mission is to push for better buildings that achieve zero energy, zero carbon, and beyond to protect people and the planet. Learn more at www.newbuildings.org.

The Building Decarbonization Coalition unites building industry stakeholders with energy providers, environmental organizations and local governments to help electrify California's homes and workspaces with clean energy. www.buildingdecarb.org

Acknowledgements

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Purpose

The Building Electrification Technology Roadmap (BETR) supports increased adoption of highly efficient electric technologies that displace natural gas technologies. BETR addresses this in three ways: 1) characterizing existing and up-and-coming electrification technologies; 2) identifying barriers to adoption, and 3) providing targeted near- and long-term actions to support building electrification. While this study does not address the complicated topic of cost, other resources on cost studies are cited in the Full Study.

This roadmap is primarily a guide for utilities and organizations working to advance building electrification programs and decarbonization policies in the state of California. It can also inform manufacturers, the design community, building owners, and policymakers throughout North America.

The research conducted for this roadmap recognizes, leverages, and builds on existing studies and efforts underway on assessing and advancing electric technologies that improve both energy and emissions performance in buildings. BETR is a collective representation of the lead and contributing authors' research and professional judgments regarding the findings, rather than an account of every author's position on each technology. Different interpretations are likely within the diversity of the parties working on, or impacted by, electrification. Errors and omissions are the responsibility of the authors. BETR stands as a unique report containing valuable insights about the full set of technologies necessary for building electrification.

This Summary is a companion document to the Full BETR Study of over 100 pages which is described and linked on page 7.

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Introduction

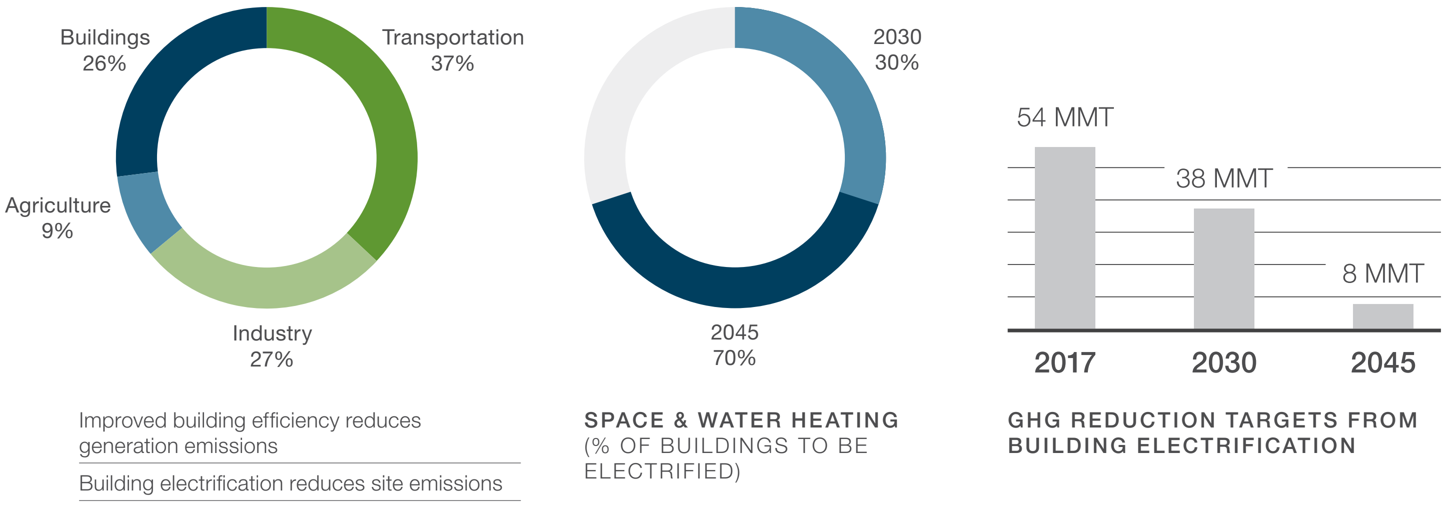
This study was prepared in 2020 while the year was on course to break the record for hottest annual global and U.S. temperatures. The changing snowpack increases risk of floods and water shortages; drier forests are more vulnerable to fires; and hotter temperatures lead to more smog, which can damage lungs.

California's Fourth Climate Change Assessment further highlights serious impacts expected from climate change if greenhouse gas emissions are not dramatically reduced.[1] While climate change often feels like an intractable dilemma many solutions for addressing buildings' role in climate change are readily available and accessible today. Building electrification, or the shift from gas appliances to all-electric appliances and technologies powered by an increasingly clean grid, is widely recognized as a critical pathway for achieving significant greenhouse gas (GHG) emission reduction.

In order to meet its landmark 2045 carbon neutrality goal, the State of California has set ambitious targets necessary to reduce and avoid existing emissions across all sectors, and proactively pursue negative emission pathways.[2] Cities, industries, and companies, along with large public institutions, are following suit, adopting electrification reach codes and climate action plans to reduce emissions. This is one reason why within the building sector we have experienced a purposeful shift from energy use (kWh) reductions to greenhouse gas emission (GHG) reductions. Although the use of multiple fuels in homes and buildings has a long history of meeting our comfort and technical needs, on-site natural gas combustion has a limited future. We must electrify buildings to meet the state's climate action goals.[3]

Electrify 70% of California buildings by 2045

Buildings share of California GHG Emissions and Targets to Electrify Buildings.
Source: NBI 2020, based on SCE 2019, Pathway 2045



SPACE & WATER HEATING
(% OF BUILDINGS TO BE ELECTRIFIED)

GHG REDUCTION TARGETS FROM BUILDING ELECTRIFICATION

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1 California's Fourth Climate Change Assessment
2 State of California 2018, Executive Order B-55-19 to Achieve Carbon Neutrality | Baker, S. et. al. Lawrence Livermore National Laboratory 2020, Getting to Neutral
3 Billimoria, S. et. al. Rocky Mountain Institute 2018, The Economics of Electrifying Buildings

A Greener Grid is Not Good Enough

Using renewable energy to power buildings is already an effective way to reduce carbon emissions in the state of California, where renewables reached more than 32% of energy production in 2018. By 2045, 100% of the state's retail electricity sales are targeted to be met by renewables. As grid-delivered electricity gets cleaner, the importance of building technologies grows. Transitioning away from direct use of fossil fuels (i.e. natural gas, propane) on-site is the next step in the energy transformation.

Keeping the grid reliable requires a continuous balancing act between supply (power plants) and demand (mostly at buildings). Because of their central role in the energy system, buildings have the potential to either act as grid decarbonization accelerators, or to slow and limit progress. As more of the grid mix comes from variable resources like wind and solar the balance becomes harder to maintain. *When* energy is used is becoming nearly as important as *how much* energy is used. 'Smart' electrification, leveraging digital technology to enable two-way communication between the utility and its customers, will allow buildings to enable and accelerate the transformation to a carbon-neutral economy.

Because of their central role in the energy system, buildings have the potential to either act as grid decarbonization accelerators, or to slow and limit progress.

Electrification's Multiple Benefits

Direct site natural gas use, combined with leakage in delivery, can be responsible for as much as 60% of the CO_2 emissions of a mixed-fuel home.[4] Through this study, we found that replacing fossil fuel-based systems in four categories—space and water heating, cooking, and laundry systems—with efficient electric technologies cuts energy use by over 40% and carbon emissions by over 75% for those four end-uses across multiple major California climate zones (see **Full Report**).

Through this study, we found that replacing fossil fuel-based systems in four categories—space and water heating, cooking, and laundry systems—with efficient electric technologies cuts energy use by over 40% and carbon emissions by over 75% for those four end-uses in all cases in multiple California climate zones.

Health and Equitable Electrification

The natural gas supply chain contributes to air pollution in several ways including leaking, venting, and combustion of natural gas. Just a few of gas's many pollutants include particulates, methane, volatile organic compounds (VOCs), nitrogen oxides (NOx), and sulfur oxides (SOx). Strong attention is now turning to indoor air quality associated with internal gas appliances and the outdoor exposure to air pollution that communities living near gas power plants experience—often in lower-income neighborhoods.[5]

Recently the California Air Resources Board (CARB) adopted a groundbreaking resolution that commits action on emissions from gas appliances in buildings from both a climate and a public health perspective (NOx emissions).[6] The resolution states that CARB will support the California Energy Commission (CEC) and other agencies to adopt standards in the 2022 code cycle that will result in stronger gas stove ventilation standards and electrification of appliances for all new buildings. This is the clearest commitment that CARB has made to date to address the climate and health impacts from gas appliance emissions in the buildings sector.

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[4] E3 2019, **California Residential Building Electrification Market Assessment**

[5] American Public Health Association 2019, **Public Health Impact of Energy Policy in the United States**

[6] CARB 2020, **California Indoor Air Quality Program Update**

Electrifying homes will have a huge positive impact on the people who live in communities that have long suffered the negative effects of climate change.[7] Electrification also creates opportunities for expansion of clean and green technology companies providing paths for people to learn new skills and to access living wage jobs.

The Road to Building Electrification

The BETR is a guide for utilities and other organizations developing, implementing, and supporting electrification programs as a way to advance high efficiency technologies, reduce GHG emissions and improve public health. It's the first study to characterize the industry status of all electrification technologies that replace traditional combustion technologies, site barriers to adoption, and the road to accelerate adoption.

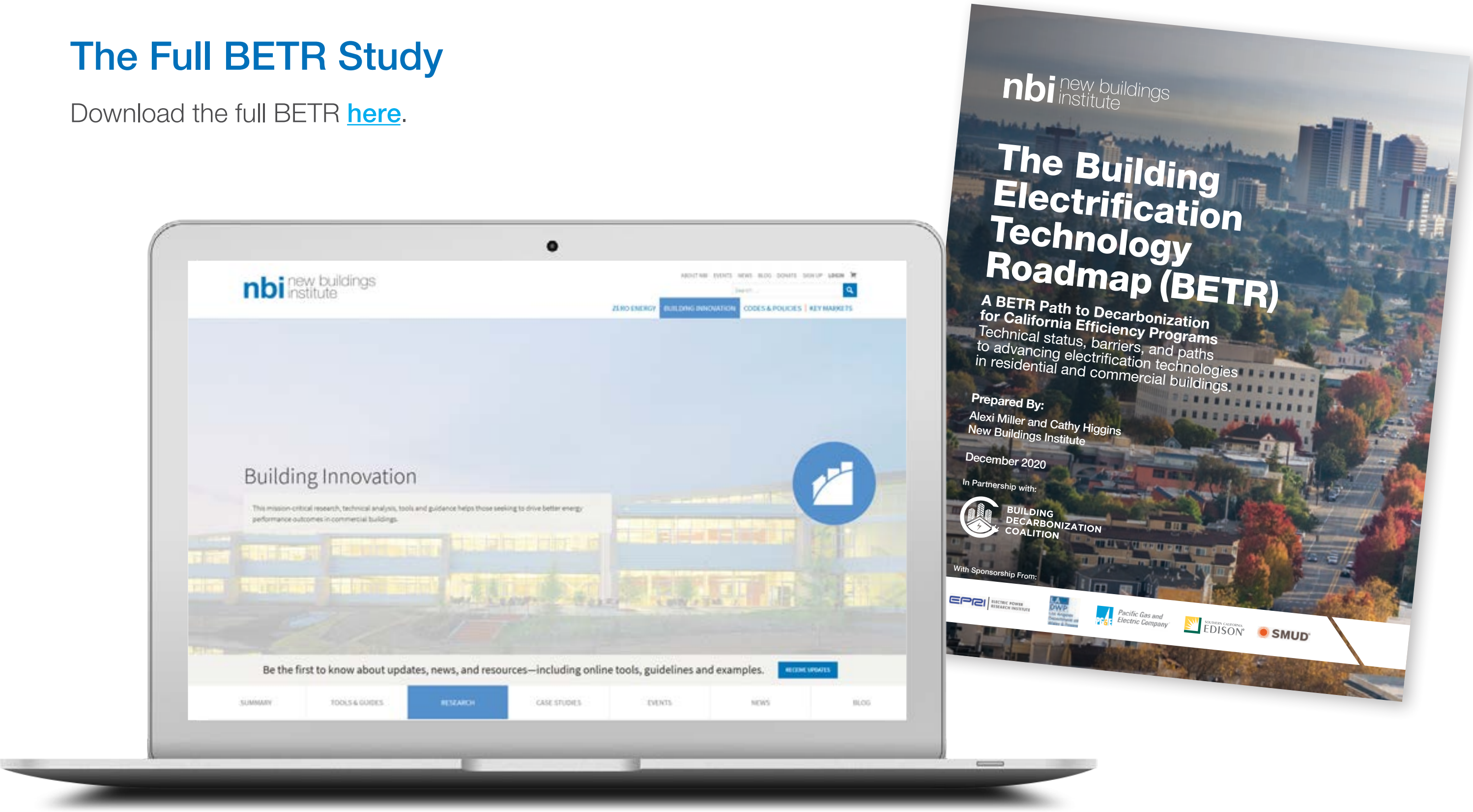
Although developed and written to guide efficiency programs, the recommended actions can also inform manufacturers, the design community, owners, and policymakers. "The sooner the BETR" should be our motto moving forward.

This Summary is an overview of the BETR research team's key technology findings and recommendations for overcoming barriers. However, the full BETR study of more than 100 pages offers:

- a detailed representation of the status, roadblocks, and recommendations for each efficient electrification technology.
- examples of electrification applied by residential building types and packages.
- references and resources such as the literature search list, electrification studies, and manufacturer survey results.

The Full BETR Study

Download the full BETR here.



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The Building Electrification Technology Roadmap (BETR)

A BETR Path to Decarbonization for California Efficiency Programs
Technical status, barriers, and paths to advancing electrification technologies in residential and commercial buildings.

Prepared By:
Alexi Miller and Cathy Higgins
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December 2020

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With Sponsorship From:

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[7] Greenlining Institute 2019, **Equitable Building Electrification**

Methodology

The research team conducted extensive literature reviews, consulted with industry allies, and created a master matrix and Technology Assessment Graphic (TAG) tool to enable scoring and assumption variations or electrification technologies. The TAG tool also provides the funders a tool for their use in varying the assumptions and making alternative program scenarios.

Assessing Status

The assessment resulted in 38 technologies across four end-uses that are frequently met by natural gas technologies in California. The team also identified a selection of internationally available and upcoming technologies across the same end-uses that are identified in the full BETR report.

Qualitative characterizations were made across:

- A data set of 38 technologies
- Four end-uses (space heating, water heating, cooking, and clothes drying and laundry)
- Five sectors (multifamily, single family, small commercial, large commercial, and higher education/institutional)
- Vintages (new construction and existing building retrofits).

THE 38 ELECTRIFICATION MEASURES ACROSS THE FOUR END-USE AREAS

SPACE HEATING

- 240V ASHP, Split System, conventional refrigerant
- 240V ASHP, Split System, low-GWP refrigerant
- Packaged Terminal Heat Pump
- 240V ASHP Packaged RTU, conventional refrigerant
- 240V ASHP Packaged RTU, low-GWP refrigerant
- Heat Recovery Chiller
- Mini-Split ASHP
- 120V ASHP, Split System, <5 ton, conventional refrigerant
- 120V ASHP, Split System, <5 ton, low-GWP refrigerant
- Variable Refrigerant Flow
- Electric Resistance Boiler
- Ground (and Water) Source Heat Pump
- Combo Small Packaged ASHP+DHW
- Integrated Heat Pump Boiler and Domestic Water Heater
- Non-Vapor Compression Heat Pump

WATER HEATING

- Unitary 240V HPWH, conventional refrigerant
- Central HPWH, conventional refrigerant
- Central HPWH, low-GWP refrigerant
- Unitary 240V HPWH, low-GWP refrigerant
- Unitary 120V HPWH, conventional refrigerant
- Unitary 120V HPWH, low-GWP refrigerant
- Solar Thermal Assisted WH
- Electric Resistance WH: Point of Use Distributed, Tankless

COOKING

- Commercial Electric Cooking Equipment: Oven, Fryer, etc.
- Commercial Induction Range
- Commercial Electric Cooking Equipment: Combination Oven
- Residential Drop-In/Slide-in/Stand-Alone Induction Range
- Commercial Induction Full Size Wok Range
- Commercial Electric Cooking Equipment: Chain Broiler
- Commercial Countertop Induction Hob/Wok
- Residential Countertop Induction Hob
- Commercial Electric Resistance Range
- Residential Electric Resistance Range

CLOTHES DRYING AND LAUNDRY

- Heat Pump Dryer
- Combo Washer-Dryer (Condenser Dryer)
- CO_2 Laundry System
- Electric Resistance Dryer
- Ultrasonic Dryer

The technologies were scored in each variation with a ‘low, ‘moderate’, or ‘high’ across five parameters that most inform their viability for electrification. The Matrix scoring resulted in 145 unique characterizations of existing and emerging electrification technologies, across four end-uses with the greatest potential to reduce overall GHG emissions.[8] The scores were used in the write ups per technology on status, each technology scoring table and informed the roadblocks and recommendations.

FIVE SCORING PARAMETERS FOR THE ELECTRIFICATION TECHNOLOGIES

RANKING	PARAMETERS				
	Technology Readiness	**U.S. Product Availability**	**Ease of Application**	**Awareness**	**GHG Reductions** (compared to other electric measures)
High	Technically ready	Readily available	Few-to-no site barriers	Technology is familiar and in use	High reductions
Moderate	Ready in 1-5 years	Moderate availability	Some site barriers	Technology is familiar; not widely used	Moderate reductions
Low	Ready in 6-10 years	Low or no availability	Significant site barriers	Technology is generally unknown	Low reductions

Characterizing the Roadblocks and Recommendations

For the characterization of Roadblocks and Recommendations (R&R) the research team used an effective framework from technology logic models to group the roadblocks (barriers) into four primary solution channels with targeted entities to engage for market transformation. These channels also mirror the California Emerging Technology Council (ETCC) paths for market advancement. Each end-use has a table of R&R followed by the Roadmap of Recommendations graphic which identifies activities for efficiency programs across the channels and in the near term (2020-2025) and next term (2026-2030) to provide a 10-year guide of priority actions to building electrification.

Most electrification technologies share a core set of R&R and these are summarized in Conclusions and Commonalities rather than repeated for each end-use.

FOUR SOLUTION CHANNELS FOR ELECTRIFICATION TECHNOLOGY ADVANCEMENT

	SOLUTION CHANNEL			
	Technology	Market	Programs	Policies – Standards
SOLUTION TARGET	• Product Manufacturers • Researchers • Demonstration Partners	• Suppliers, distributors, installers • Designers • Retailers • Consumers: building owners, facility managers	• Utilities • Government (city) • Collaborations and national programs	• State policies • City policies • Public utility commissions (PUC)

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[8] For the purpose of this study electrification technologies are those that can provide equal or improved building services normally delivered by combustion technologies or appliances and do not represent every electric technology.

Technology Status and Recommendations

This BETR Summary presents a section for each end-use with the high-level findings. The full BETR report includes detailed narrative by technology across status, roadblocks and recommendations.

END-USES

Space Heating

Water Heating

Cooking

Clothes Drying and Laundry

Space Heating

Space heating is the largest overall driver of fossil fuel use in California buildings, with wide variations by building type. Space heating averages nearly one-third of total residential building energy use in California, and natural gas accounts for the vast majority (82%) of all home heating fuel.[9] Nearly all (96%) residential forced air furnaces in California burn natural gas, which was an increase of almost 10% from 2013 to 2019.[10, 11]

Efforts to electrify space heating systems center on heat pump technologies, which are 3-5 times more efficient that standard electric or gas heating systems. Heat pump technology has been around for decades and is well-suited to the generally moderate California climate, with recent advancement in cold climate models applicable to Northeast California and the high Sierra regions. However, heat pumps represent a low percentage of current home heating systems (only 2% of heated California homes use heat pumps as their primary heat source), and their use in commercial buildings varies from approximately 16% in Northern to 40% in Southern California.[12]

Efforts to electrify space heating systems center on heat pump technologies, which are 3-5 times more efficient that standard electric or gas heating systems.

Status of Electrification Space Heating Technologies

A wide variety of technologies fall into the heat pump category—they use heat transfer from various sources such as outside air, water, the ground, refrigerant loops inside a building, and waste heat. In the residential sector, air source heat pumps offer the most promise to displace gas-fueled forced-air furnaces. A premium-efficiency air source heat pump operating in a typical Southern California home uses 36% less energy and is responsible for 71% less GHG emissions compared to a high-efficiency condensing gas furnace. Furthermore, heat pumps can achieve efficiencies of greater than 100% (efficiencies of 300%-400% are typical), while combustion technologies cannot.

Today's heat pumps rely on the vapor compression cycle, which necessarily uses refrigerants. Concerns around the global warming impact and safety use of refrigerants have spawned new technology concepts.[13] Starting in 2025, many space heating technologies sold in California will be required to use lower global warming potential (GWP) refrigerants, which will reduce greenhouse gas emissions.[14, 15]

The Space Heating Electrification Technologies Scoring Table summarizes the status of electric space heating technologies and the applicable building types and vintages.

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[9] EIA 2015, **EIA RECS table CE3.5**

[10] Calmac 2012, **California Lighting and Appliance Study**

[11] EIA 2009, **RECS**

[12] Synapse 2018, **Decarbonization of Heating Energy Use in California Buildings**

[13] DOE 2014, **Non-Vapor Compression HVAC Technologies Report**

[14] California Air Resources Board 2020, **Proposed Amendments to HFC Regulations**

[15] The Global Warming Potential (GWP) was developed to allow comparisons of the global warming impacts of different gases: **EPA explanation**.

SPACE HEATING ELECTRIFICATION TECHNOLOGIES SCORING OF STATUS AND APPLICATIONS

SPACE HEATING TECHNOLOGY	MATRIX SCORES					BUILDING TYPE APPLICABILITY					VINTAGE APPLICABILITY	
	Technology Readiness	Product Availability	Ease of Application	Awareness	Scale of GHG Reductions	Single Family	Multifamily	Small Comm	Large Comm	Higher Ed/Inst	New Construction	Retrofit
240V ASHP, Split System†	●	●	◒	●	◒	✔	✔	✔	✔	✔	●	◒
Packaged Terminal Heat Pump†	●	●	◒	●	●		✔	✔		✔	●	●
240V ASHP Packaged RTU†	●	●	◒	●	●	✔	✔	✔	✔	✔	●	●
Heat Recovery Chiller	●	●	○	●	◒				✔	✔	◒	◒
Mini-Split ASHP†	●	●	●	●	◒	✔	✔	✔	✔	✔	●	●
120V ASHP, Split System, <5 ton†	●	◒	●	◒	◒	✔	✔	✔			○	●
Variable Refrigerant Flow††	●	●	◒	●	◒		✔	✔	✔	✔	●	◒
Electric Resistance Boiler	●	●	◒	●	○		✔	✔	✔	✔	●	◒
Ground (and Water) Source Heat Pump	●	●	○	●	◒	✔	✔	✔	✔	✔	◒	○
Combo Small Packaged ASHP+DHW *emerging*	◒	○	○	○	●	✔	✔	✔			●	●
Integrated Heat Pump Boiler and Domestic Water Heater *next gen*	○	○	○	○		✔	✔	✔	✔	✔		
Non-Vapor Compression Heat Pump *next gen*	○	○		○		✔	✔	✔	✔	✔		

Refrigerant GWP must be below 750 (i.e. to be mid-GWP or low-GWP) in California beginning in 2025 for this product (†) and 2026 for this product (††). In general, HVAC products meeting this requirement are in development and are not available today.

● High (3) ◒ Moderate (2) ○ Low (1)

Technology Status Key Takeaways

Various forms of heat pump systems are technically ready and available to address new construction, some retrofits, and commercial space heating needs.

Heat pumps stand out when it comes to electrifying space heating due to their mature technology, high market awareness, and high efficiency. Within the residential sector, the most mature and readily available technologies are 240V split and mini-split air source heat pumps (ASHPs) using conventional (typically HFC) refrigerants. For the commercial sector, a large diversity of products are available to address different building types and sizes. Heat recovery chillers, split and mini-split 240V ASHPs, variable refrigerant flow (VRF) systems, packaged thermal heat pumps (PTHPs), and packaged 240V ASHP rooftop units are readily available and mature all-electric technologies that can be implemented in both new and retrofit applications.

Electric resistance boilers and electric reheat coils are technically ready and available to address niche space heating needs but don't offer the high efficiency and GHG reduction benefits that heat pumps do.

Electric resistance works but it is 3-4x less efficient than heat pumps. To meet the three key beneficial electrification goals of energy efficiency, emission reductions, and operating cost savings, electric resistance heat should not be used where a heat pump could do the job. When installed in tandem with sufficient thermal energy storage, electric resistance boilers can be well suited where high penetrations of variable renewable resources result in over-production at peak hours, providing abundant low-cost, clean electricity.

Emerging products offer lower GHG, targeted applications, and increased retrofits.

'Combination' heat pumps are designed to provide both space and water heat but are relatively uncommon in the U.S. They have been piloted in both new construction and retrofit programs abroad, such as the Energiesprong program in the Netherlands and in California through a CEC demonstration project following the Energiesprong model of scalable home retrofits.[16]

Window-mounted heat pumps are an emerging product in the U.S. and considered a good solution for multifamily retrofits.

Roadblocks and Recommendations

Two key technology barriers common to heat pumps of all types are cold-climate performance and the upcoming transition to mid- and low-GWP refrigerants. Manufacturers have made great strides in improving cold-climate heat pump performance, but there is room for improvement. Other roadblocks, and ways to overcome them, vary by building type and vintage (existing or new construction). Single-family homes and smaller buildings are most likely to use air-to-air split systems or mini-split heat pumps; many commercial buildings of all sizes use packaged air-to-air rooftop units; larger buildings may use central systems either with air or water heat distribution.

In all sectors, electrifying existing gas-fired heating systems comes with unique retrofit barriers related to site considerations, such as wiring, ducting, and building configuration. Another shared barrier is the business models of the supply chain and installers whose typical practices, recommendations, and revenues are tied to a gas-burning product line. Addressing this mid-stream influencer group with business rationale and training is critical to increase adoption of space heating electrification technologies.

Addressing the mid-stream influencer group (supply chain and installers) with business rationale and training is critical to increase adoption of space heating electrification technologies.

A 2013 study stated that ongoing research and development activities were expected to increase heat pump efficiency by 30-50% for heating services and to reduce costs by 20-30% by 2030.[17] These continual improvements and cost reductions will help accelerate heat pumps deeply into the market.

The Summary of Space Heating Electrification Technologies Roadblocks and Recommendations shows key roadblocks in advancing the electrification of space heating technologies, followed by near-term recommendations for actions.

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[16] Rocky Mountain Institute's **REALIZE** initiative in California and the **RetrofitNY** program in New York are building on the **Energiesprong** model to scale zero energy retrofits across the U.S.

[17] IRENA 2013, **Heat Pumps Technology Brief**

Summary of Space Heating Electrification Technologies Roadblocks and Recommendations

SPACE HEATING ELECTRIFICATION TECHNOLOGIES ROADMAP OF RECOMMENDATIONS

SPACE HEATING

	2020									2025								2030
	Increase Availability	Product Research & Development	Testing & Validation	Workforce Development & Tools	Build Awareness, Confidence, & Demand	Work with Supply Chains & Retailers	Incentives & Financing	Coordinated & Partner Programs	Pilot Programs & Bulk Purchases	Increase Availability	Product Research & Development	Testing & Validation	Workforce Development & Tools	Build Awareness, Confidence, & Demand	Work with Supply Chains & Retailers	Incentives & Financing	Coordinated & Partner Programs	Pilot Programs & Bulk Purchases
READY NOW																		
240V ASHP, Split System†				⬢	⬢		●	●	●					⬢		●	●	●
Packaged Terminal Heat Pump†					⬢	⬢	●	●	●					⬢		●	●	●
240V ASHP, Packaged RTU†					⬢		●		●					⬢		●		●
Heat Recovery Chiller				⬢	⬢		●	●					⬢			●	●	
Mini-Split ASHP†				⬢	⬢		●	●	●					⬢		●	●	●
120V ASHP Split System <5 Ton†	■	■	■	⬢	⬢	⬢	●	●	●					⬢	⬢	●		●
Variable Refrigerant Flow				⬢			●											
Ground (and Water) Source Heat Pump							●									●		
Electric Resistance Boiler	no activities																	
EMERGING																		
Combo Small Packaged ASHP+DHW		■	■	⬢	⬢	⬢	●			■	■					●		●
EMERGING OR INTERNATIONAL*																		
Integrated Heat Pump Boiler and Domestic Water Heater		■	■	⬢	⬢					■	■		⬢	⬢	⬢	●	●	
Non-vapor Compression Heat Pump		■									■	■	⬢	⬢	⬢	●	●	

■ **Technology**
MANUFACTURERS
RESEARCHERS
PARTNERS

⬢ **Market**
DISTRIBUTORS
INSTALLERS
CONSUMERS

● **Programs**
UTILITIES
CITIES/GOV'T
COLLABORATIONS

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*Activities after 2025 depend on technology development and market availability progress during 2020-2025.

†2025 CA Req. for <750 GWP.

Water Heating

Nothing says comfort like hot water. But combustion water heaters burning gas or propane account for 90% of water heating—and 40% of natural gas use—in California single-family homes.[18] For California to meet its climate goals at least 30% of the state's residential gas water heaters must be electrified by 2030.[19]

In commercial buildings, hot water use varies widely by building type, with minor use in offices for handwashing, dishwashing, and occasional on-site showers, while higher education and institutional facilities include housing and food service with large hot water needs. Restaurants and commercial laundry also demand high quantities of hot water. Electrification technologies are available to support those uses as well.

90% of California residential water heaters are gas or propane.

Status of Electrification Water Heating Technologies

Water heating electrification focuses on heat pump water heaters (HPWHs)—a decades-old, reliable technology now undergoing a renaissance in technological optimization for both single and multi-family homes. HPWH products are generally either 'unitary' (50-100 gallon storage tank with integrated heat pump) or 'central' (one or multiple heat pumps serving a water heating plant). A conventional refrigerant unitary HPWH operating in a typical Southern California home uses half the energy and is responsible for 77% lower emissions compared to a conventional gas-powered storage tank water heater. In multifamily, where water heating is often the largest energy use, central HPWHs can readily be used in larger water plant facilities.

There are three key components of beneficial electrification: energy efficiency, emissions reductions, and cost savings. Smart HPWHs hit the three criteria: They are super-efficient and displace gas technologies, they help keep utility bills low for occupants of all-electric buildings, and the new California demand management standard (JA13), ensures that they can be smart and flexible, reducing electricity costs for all Californians.[20]

New grid-integrated controls on HPWHs are key to unlocking a decarbonized energy supply.

The Water Heating Electrification Technology Scoring Table summarizes the status of electric water heating technologies and the applicable building types and vintages.

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[18] **UC Davis for CEC 2019**

[19] **CA Executive Order** | The Advanced Water Heating Initiative (**AWHI**) has a goal of 50% adoption by 2030.

[20] JA13 **Qualification Requirements** for Heat Pump Water Heater Demand Management Systems is a performance compliance requirement for California to shift water heater loads to reduce peak load and enable renewable energy integration. A national requirement for this capability—CTA 2045—has been tested and is under consideration as a product requirement.

WATER HEATING ELECTRIFICATION TECHNOLOGY SCORING OF STATUS AND APPLICATIONS

	MATRIX SCORES					BUILDING TYPE APPLICABILITY					VINTAGE APPLICABILITY	
WATER HEATING TECHNOLOGY	Technology Readiness	Product Availability	Ease of Application	Awareness	Scale of GHG Reductions	Single Family	Multifamily	Small Comm*	Large Comm*	Higher Ed/Inst	New Construction	Retrofit
Unitary 240V HPWH, conventional refrigerant	●	●	◒	◒	◒	✔	✔				●	◒
Central HPWH, conventional refrigerant	●	●	◒	◒	◒		✔			✔	●	◒
Central HPWH, low-GWP refrigerant	◒	◒	◒	◒	●		✔			✔	●	◒
Unitary 240V HPWH, low-GWP refrigerant	◒	○	◒	○	●	✔	✔			✔	●	◒
Unitary 120V HPWH, conventional refrigerant *emerging*	◒		○	○	◒	✔	✔					◒
Unitary 120V HPWH, low-GWP refrigerant *emerging*	○		◒	○	●	✔	✔					◒
Solar Thermal Assisted WH	◒	◒	○	◒	◒	✔	✔				●	◒
Electric Resistance WH: **Point of Use Distributed, Tankless**	●	●	◒	●	○	✔	✔	✔	✔	✔	●	◒

*HPWHs are not marked as "applicable" in Small and Large Commercial buildings because water heating needs are minimal in most offices. HPWHs are valuable in commercial buildings with higher water heating needs such as restaurants, health care, and lodging.

● High (3) ◒ Moderate (2) ○ Low (1)

Technology Status Key Takeaways

Heat pump water heaters (HPWH)s are technically ready and available to address residential new construction, some retrofits, and multifamily hot water needs with demand control capability.

HPWHs are the most promising water heating technology and the highest priority to pursue immediately. The unitary 240V HPWH is a highly reliable technology immediately ready for single-family, multifamily, and commercial new construction. The technology is widely available for retrofit situations with adequate panel ampacity, a dedicated circuit, and 240V wiring. Most of today's unitary HPWHs have integrated demand control capability, allowing them to serve as a giant battery—generating and storing hot water when price or carbon signals are attractive, then providing the stored hot water as needed to the building. Electric resistance tankless, or instantaneous, water heaters also score high in terms of technology readiness, availability, and awareness. Yet the energy savings and GHG reductions from HPWHs are significantly greater, making them a clear leader in building electrification.

Across commercial products, central HPWHs for multifamily and institutional applications are technically ready with a couple of product and configuration options that fully address new and most retrofit applications. More products are anticipated in central HPWH systems, and demand controls are a growing part of this product line as well. Small electric resistance point-of-use water heaters for office washrooms are ready, available, and well known for these specific applications. HPWHs face moderate-to-low trade and customer awareness and ease of application in retrofit applications.

Solar thermal and electric resistance water heaters are technically ready but have drawbacks.

Solar thermal and electric resistance water heaters are both technically ready and available. But electric resistance is inefficient and scores low on GHG impact value compared to HPWH systems. Solar thermal has excellent niche applications and a long history but is not as scalable and can be labor intensive, requires more maintenance, and can have performance issues. These technologies are thus a lower priority for electrification of hot water systems in buildings.

Emerging products set the stage for retrofits and further emission reductions.

The 120V unit, a game-changer for the residential retrofit market, is expected in 2021. While one unit is market ready there is a need for field validation of these emerging products before program, customer, and contractor acceptance can increase. This plug-in unit will more easily meet the space requirements of existing gas tanks without requiring wiring upgrades. Its more modest rate of hot water supply can be offset by a slightly larger tank and mixing valve.

For optimum emission reductions there are many international products that use ‘natural refrigerant’ systems and qualify as ‘low-GWP’. Just two models are readily available in the U.S. at this time—both of which use CO_2, which is both low-GWP and highly effective if the unit has to be placed outdoors in cold climates.[21] One is a residential (5 ton) HPWH with extensive installations for single and multifamily applications, and the other is a new central HPWH (10 ton). Other manufacturers are planning low-GWP units, but immediate attention is on advancing the market-ready and available standard refrigerant U.S. HPWH products.

Roadblocks and Recommendations

HPWHs face challenges including but not limited to supply chain market confidence, consumer, installer and designer technology awareness, low product availability (120V and low-GWP), lack of emerging technology field validated data, reluctance to displace existing electric resistance and gas product lines, and outdated federal specifications, labelling and misaligned connectivity criteria. Retrofit applications in all cases have lower ‘ease of application’ scores due to venting and space requirements and panel constraints.

Increasing consumer, installer and designer technology awareness and confidence will build demand for HPWHs.

The Summary of Water Heating Electrification Technologies Roadblocks and Recommendations shows key roadblocks in advancing the electrification of water heating technologies, followed by near-term recommendations for actions.

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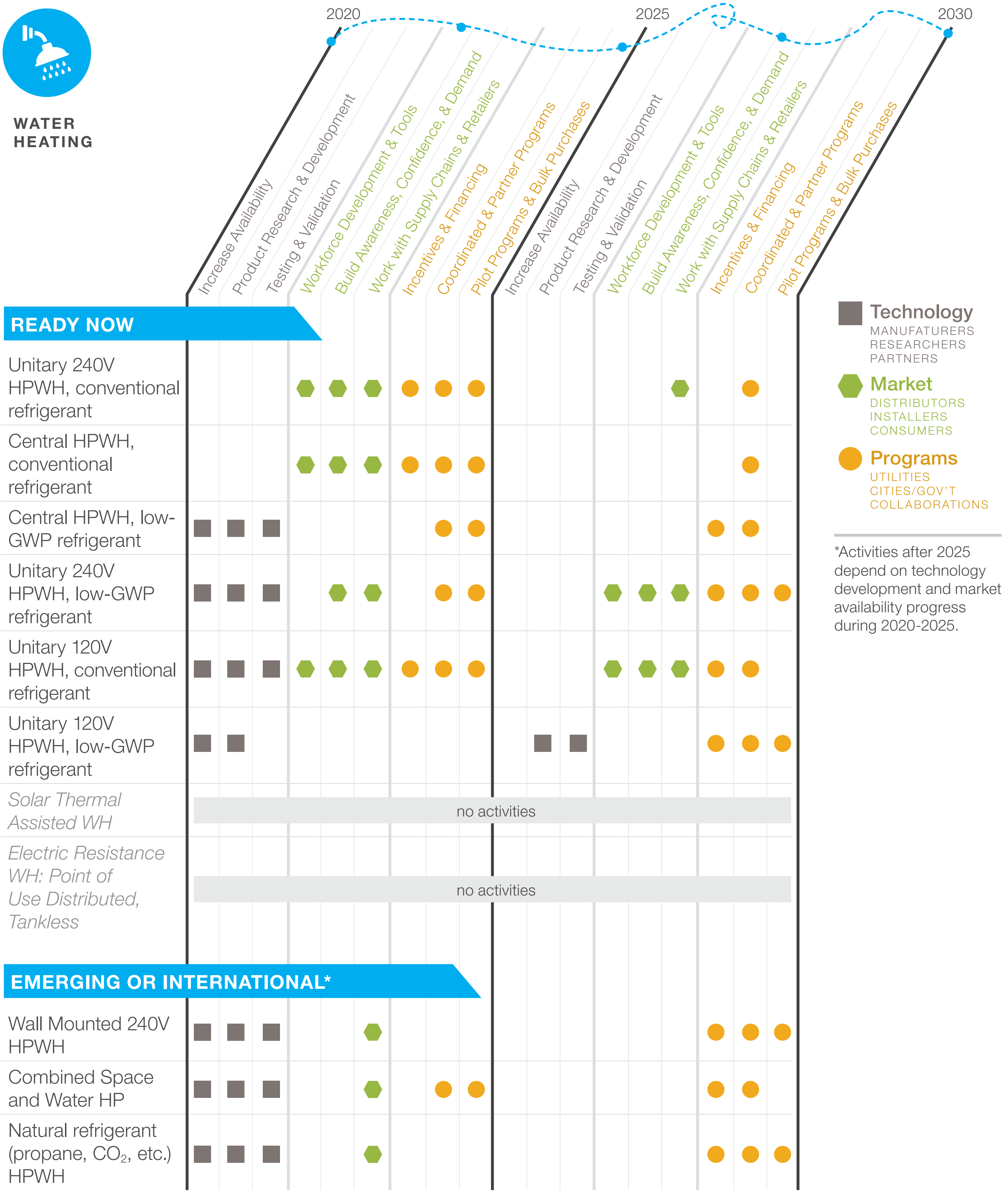
[21] See footnote 15

Summary of Water Heating Electrification Technologies Roadblocks and Recommendations

WATER HEATING ELECTRIFICATION TECHNOLOGIES ROADMAP OF RECOMMENDATIONS



WATER HEATING

READY NOW

	2020									2025								
	Increase Availability	Product Research & Development	Testing & Validation	Workforce Development & Tools	Build Awareness, Confidence, & Demand	Work with Supply Chains & Retailers	Incentives & Financing	Coordinated & Partner Programs	Pilot Programs & Bulk Purchases	Increase Availability	Product Research & Development	Testing & Validation	Workforce Development & Tools	Build Awareness, Confidence, & Demand	Work with Supply Chains & Retailers	Incentives & Financing	Coordinated & Partner Programs	Pilot Programs & Bulk Purchases
Unitary 240V HPWH, conventional refrigerant				⬢	⬢	⬢	●	●	●						⬢		●	
Central HPWH, conventional refrigerant				⬢	⬢	⬢	●	●	●								●	
Central HPWH, low-GWP refrigerant	■	■	■					●	●							●	●	
Unitary 240V HPWH, low-GWP refrigerant	■	■	■		⬢	⬢		●	●				⬢	⬢	⬢	●	●	●
Unitary 120V HPWH, conventional refrigerant	■	■	■	⬢	⬢	⬢	●	●	●				⬢	⬢	⬢	●	●	
Unitary 120V HPWH, low-GWP refrigerant	■	■									■	■				●	●	●
Solar Thermal Assisted WH	no activities																	
Electric Resistance WH: Point of Use Distributed, Tankless	no activities																	

EMERGING OR INTERNATIONAL*

	Increase Availability	Product Research & Development	Testing & Validation	Workforce Development & Tools	Build Awareness, Confidence, & Demand	Work with Supply Chains & Retailers	Incentives & Financing	Coordinated & Partner Programs	Pilot Programs & Bulk Purchases	Increase Availability	Product Research & Development	Testing & Validation	Workforce Development & Tools	Build Awareness, Confidence, & Demand	Work with Supply Chains & Retailers	Incentives & Financing	Coordinated & Partner Programs	Pilot Programs & Bulk Purchases
Wall Mounted 240V HPWH	■	■	■			⬢										●	●	●
Combined Space and Water HP	■	■	■			⬢		●	●							●	●	
Natural refrigerant (propane, CO_2, etc.) HPWH	■	■	■			⬢										●	●	●

■ **Technology**
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RESEARCHERS
PARTNERS

⬢ **Market**
DISTRIBUTORS
INSTALLERS
CONSUMERS

● **Programs**
UTILITIES
CITIES/GOV'T
COLLABORATIONS

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*Activities after 2025 depend on technology development and market availability progress during 2020-2025.

Cooking

Cooking represents a small proportion of total residential energy and gas use: about 5% of energy and 7% of total gas use statewide.[22] Cooking with gas-fired appliances is associated with adverse indoor health effects in California homes, including elevated risk of asthma, cardiovascular disease, and cancer.[23] In the commercial sector, cooking represents a great opportunity for reducing energy use while cutting emissions and improving performance, indoor air quality, and workspace comfort. Restaurants and other buildings with commercial cooking use 5-7 times more energy per square foot than other types of commercial buildings.[24]

Cooking is not only a core function of many built environments; it is also a difficult task and an act that elicits strong opinions and deep emotions about how to achieve the right outcome. Residential and commercial cooking cannot be ignored in getting to carbon neutrality. However, unlike other more utilitarian applications such as space and water heating, replacing gas cooking appliances in buildings with electric equipment will require a much deeper education and outreach campaign.

Status of Electrification Cooking Technologies

Currently available off-the-shelf electrification cooking equipment can replace almost every piece of gas equipment in both residential and commercial kitchens, offering the same or better performance.[25] All technologies for the electrification of residential and commercial cooking score high for technology readiness and high or moderate for product availability.

Induction technology has recently revolutionized electric cooktop cooking by changing the way heat is transferred to cookware. Using a magnetic field, induction cooktops excite the molecules in a pot or pan, generating heat for cooking. Induction technology results in a near complete energy transfer to the cooking vessel, making induction cooktops incredibly energy efficient relative to other modes of cooking. Other benefits of induction cooktops, in comparison to gas burners and traditional resistance heating elements, include faster cook times, more precise temperature control, and improved safety.

The Cooking Electrification Technology Scoring Table summarizes the status of residential and commercial cooking technologies and the applicable building types and vintages.

Currently available off-the-shelf electrification cooking equipment can replace almost every piece of gas equipment in both residential and commercial kitchens, offering the same or better performance.

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[22] CEC 2015, References for Calculating Energy End-Use, Electricity Demand and GHG Emissions

[23] LBNL 2015, Results of the California Healthy Homes…: *Impact of Natural Gas Appliances on Air Pollutant Concentrations* found the use of natural gas cooking burners substantially increases the risk of elevated CO, NOx and NO_2 consistent with prior studies.

[24] EPA ENERGYSTAR 2015, **Guide for Cafes, Restaurants and Kitchens**

[25] The underfired open gas broiler is the one piece of commercial cooking equipment that does not currently have a true electric equivalent from a taste and cooking performance standpoint; however, electric chain broilers and other process changes can facilitate the replacement of a gas broiler with electric equipment.

COOKING ELECTRIFICATION TECHNOLOGY SCORING OF STATUS AND APPLICATIONS

COOKING TECHNOLOGY	MATRIX SCORES					BUILDING TYPE APPLICABILITY		VINTAGE APPLICABILITY	
	Technology Readiness	Product Availability	Ease of Application	Awareness	Scale of GHG Reductions	Residential Kitchens	Commercial Kitchens	New Construction	Retrofit
Commercial Electric Cooking Equipment: Oven, Fryer, etc.	●	●	●	●	●		✔	●	◒
Commercial Induction Range	●	◒	◒	◒	●		✔	●	◒
Commercial Electric Cooking Equipment: Combination Oven	●	●	●	●	●		✔	●	◒
Residential Drop-In/Slide-in/Stand-Alone Induction Range	●	●	◒	◒	●	✔		●	◒
Commercial Induction Full Size Wok Range	●	○	◒	◒	●		✔	●	◒
Commercial Electric Cooking Equipment: Chain Broiler	●	●	●	◒	●		✔	●	◒
Commercial Countertop Induction Hob/Wok	●	●	●	◒	◒		✔	●	●
Residential Countertop Induction Hob	●	●	●	◒	◒	✔		●	●
Commercial Electric Resistance Range	●	●	◒	●	◒		✔	●	◒
Residential Electric Resistance Range	●	●	◒	●	◒	✔		●	◒

● High (3) ◒ Moderate (2) ○ Low (1)

Technology Status Key Takeaways

Induction cooktops and electric resistance ovens are technically ready and available to address residential new construction, some retrofits, and commercial cooking needs.

Moving from a mixed-fuel residential kitchen to an all-electric kitchen is fully achievable in new construction today with available induction range tops and electric resistance ovens. Moving from a mixed-fuel commercial kitchen to an all-electric kitchen is also achievable with available technologies, including induction, but this transition requires an integrated system approach to the kitchen design that is not currently being employed in most cases. Induction range tops for both residential and commercial applications are available to consumers in single-hob, multi-hob, and traditional “6-burner” configurations (hob is the generic term for a stovetop burner or element). These induction ranges outperform the equivalent gas and electric resistance range tops in energy efficiency, heat up and boil tests, and simmer tests.[26, 27] And, relative to other cooking technologies, the GHG reduction impacts are high.

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[26] Livchak, D., et. al. Frontier Energy for SMUD 2019, **Residential Cooktop Performance and Energy Comparison Study**

[27] Ruan, E., Frontier Energy for CEC 2020, **Induction Cooktop Analysis**

Residential glass top radiant is technically ready and widely available but lacks good applications, performance experience, and GHG impacts.

Glass top radiant, because of its low upfront cost, is often the builder's choice for use in an all-electric kitchen. However, the performance of radiant cooktops is significantly worse than that of induction cooktops, in terms of controllability, cooking time, and safety. Induction offers significant improvement in both efficiency and cooking performance. Poor consumer experiences with glass top radiant could lead to a dismissal of all forms of electric cooking. Efficiency programs should prioritize induction technologies over glass top radiant technologies.

Roadblocks and Recommendations

The end-user is one of the major roadblocks to a fully electrified kitchen. When comparing electric-resistance coil and glass top radiant cooktops with gas cooktops, consumer surveys indicate that people tend to prefer the familiarity and quick response time of gas burners. Some also like having the option to charbroil on the flame. There is a lack of knowledge by customers about the performance and safety benefits of induction cook tops, leading people to stick with the tried-and-true gas stove. Economics are also a roadblock, as induction cooktops are typically more expensive than gas stoves and require ferrous pots and pans, which may require a separate investment. Therefore, consumer awareness campaigns must target technology and economics as well as emotions, opinions, habit, and prejudice.

There is a lack of knowledge by customers about the performance and safety benefits of induction cook tops, leading people to stick with the tried-and-true gas stove.

Site conditions, primarily existing wiring limitations, are a potentially significant barrier to the electrification of other kitchen equipment such as ovens, griddles, broilers, and fryers. Drop-in/slide-in induction and countertop induction options are recommended for retrofit applications in both residential and commercial settings given the ease of installation. These are also much less expensive compared to multi-burner induction stovetops.

The Summary of Cooking Electrification Technologies Roadblocks and Recommendations shows key roadblocks separately for residential and commercial in advancing the electrification of cooking technologies, followed by near-term recommendations for actions.

Summary of Residential Cooking Electrification Technologies Roadblocks and Recommendations

COOKING ELECTRIFICATION TECHNOLOGIES ROADMAP OF RECOMMENDATIONS

COOKING

	2020									2025									2030
	Increase Availability	Product Research & Development	Testing & Validation	Workforce Development & Tools	Build Awareness, Confidence, & Demand	Work with Supply Chains & Retailers	Incentives & Financing	Coordinated & Partner Programs	Pilot Programs & Bulk Purchases	Increase Availability	Product Research & Development	Testing & Validation	Workforce Development & Tools	Build Awareness, Confidence, & Demand	Work with Supply Chains & Retailers	Incentives & Financing	Coordinated & Partner Programs	Pilot Programs & Bulk Purchases	
READY NOW																			
Commercial Electric Cooking Equipment: Oven, Fryer, etc.						⬢	●	●	●						⬢	●	●	●	
Commercial Induction Range	■			⬢	⬢	⬢	●	●	●						⬢	●	●	●	
Commercial Electric Cooking Equipment: Combination Oven				⬢	⬢	⬢	●	●	●						⬢	●	●	●	
Residential Drop-In/ Slide-in/Stand-Alone Induction Range	■			⬢	⬢	⬢	●	●	●						⬢	●		●	
Commercial Electric Cooking Equipment: Chain Broiler				⬢	⬢	⬢	●	●	●						⬢	●	●	●	
Commercial Countertop Induction Hob/Wok					⬢	⬢	●	●	●						⬢	●	●	●	
Residential Countertop Induction Hob	■			⬢	⬢	⬢	●	●	●						⬢	●			
Residential Electric Resistance Range	no activities																		
Commercial Electric Resistance Range	no activities																		
EMERGING OR INTERNATIONAL*																			
Commercial Induction Full Size Wok Range	■			⬢	⬢	⬢		●		■					⬢	●	●	●	

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RESEARCHERS
PARTNERS

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COLLABORATIONS

*Activities after 2025 depend on technology development and market availability progress during 2020-2025.

Clothes Drying and Laundry

Clothes drying and laundry represent a small proportion of residential gas use in California (approximately 4%).[28] Yet in some commercial and multifamily buildings, laundry systems can be the greatest energy hog. Large clothes dryers use huge amounts of energy to remove water out of heavy, wet clothing—a process that represents up to 81% of the total energy used to complete an average load of laundry.[29]

For this study, the baseline is the standard gas dryer. However, many buildings have already installed electric resistance dryers as the standard. Of the electric clothes drying technologies analyzed, the electric resistance dryer is the least efficient, representing a big opportunity for energy and emission reduction efforts. Also, the 30-amp resistance element in standard electric resistance clothes dryers puts stress on the electrical grid, as it runs far longer than most other appliances, as well as taking up precious capacity in lower amp panels.

Of the electric clothes drying technologies analyzed, the electric resistance dryer is the least efficient, representing a big opportunity for energy and emission reduction efforts.

Status of Electrification Clothes Drying and Laundry Technologies

For this study, we looked at four electric clothes dryer types and one integrated laundry system, as shown in the table below. All of the technologies included in this study are technically ready and available in the U.S. but have very low adoption.

The Clothes Drying and Laundry Electrification Technology Scoring Table summarizes the status laundry (clothes drying) technologies and the applicable building types and vintages.

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[28] CEC 2015, References for Calculating Energy End-Use, Electricity Demand and GHG Emissions *(enter title to access pdf—not linkable)*

[29] Redwood Energy 2019, **Electric Multifamily Guide**

CLOTHES DRYING AND LAUNDRY ELECTRIFICATION TECHNOLOGY SCORING OF STATUS AND APPLICATIONS

CLOTHES DRYING AND LAUNDRY TECHNOLOGY	MATRIX SCORES					BUILDING TYPE APPLICABILITY				VINTAGE APPLICABILITY	
	Technology Readiness	Product Availability	Ease of Application	Awareness	Scale of GHG Reductions	Single Family	Multifamily	Institutional	Laundry	New Construction	Retrofit
Heat Pump Dryer	●	●	◒	◒	●	✔	✔			●	●
Combo Washer-Dryer (Condenser Dryer)	●	●	◒	◒	◒	✔	✔			●	●
CO_2 Laundry System	●	●	◒	○	◒			✔	✔	●	●
Electric Resistance Dryer	●	●	●	●	○	✔	✔	✔	✔	●	◒
Ultrasonic Dryer	○	○	●	●	●	✔	✔			●	●

● High (3) ◒ Moderate (2) ○ Low (1)

Technology Status Key Takeaways

Heat pump dryers and combo washer/dryers (condensing dryers) are the recommended technologies to focus electrification efforts for residential buildings right now.

Both are technically ready to address residential laundry needs, and condensing washer/dryers are relatively easy to install (120V and no exhaust ducting). Heat pump dryers use about 60% less energy than a standard resistance dryer and 30-40% less electricity than efficient ENERGY STAR-rated electric resistance clothes dryers.[30] They are newly available in the U.S. and use 240V and require no ducting.

Combo washer/dryers (condensing dryers), which combine washing and drying in one appliance, are the most promising technology for energy efficiency and GHG reductions. They are available but uncommon in the U.S. Worldwide they are popular due to their space efficiency and convenience: the combined unit eliminates the need to shift clothes between two appliances.

Electric resistance dryers are technically ready and available to address residential new construction and commercial laundry needs.

ENERGY STAR electric resistance dryers, which use humidity sensors to prevent over-drying, can deliver 20% energy savings over standard electric resistance dryers due to shorter run times. This technology requires both electrical connections and venting, so it scores lower for ease of application for existing buildings. It also scores lower for emission reductions compared to the more efficient heat pump and combo washer/dryer options.

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[30] CPUC 2018, Energy Efficiency Potential and Goals Study for 2018 and Beyond and Martin, E. et. al ACEEE Summer Study 2016, Measured Performance of Heat Pump Clothes Dryers

Roadblocks and Recommendations

The main roadblocks for clothes drying technology are research and development of larger commercial-grade systems, and a need for further growth in the U.S. market. U.S. consumer expectations for large-capacity clothes dryers have impeded market growth for comparatively smaller combination condensing clothes washer/dryers and heat pump clothes dryers, both of which are more common in Europe and Asia. Typically, U.S. clothes dryers are 7 cubic feet but today's condensing dryers range from 2-4 cubic feet.

From an application perspective, the main roadblock for clothes drying technologies is in retrofit scenarios where a new electric resistance dryer is replacing a gas dryer: it will need a 240V electrical outlet.

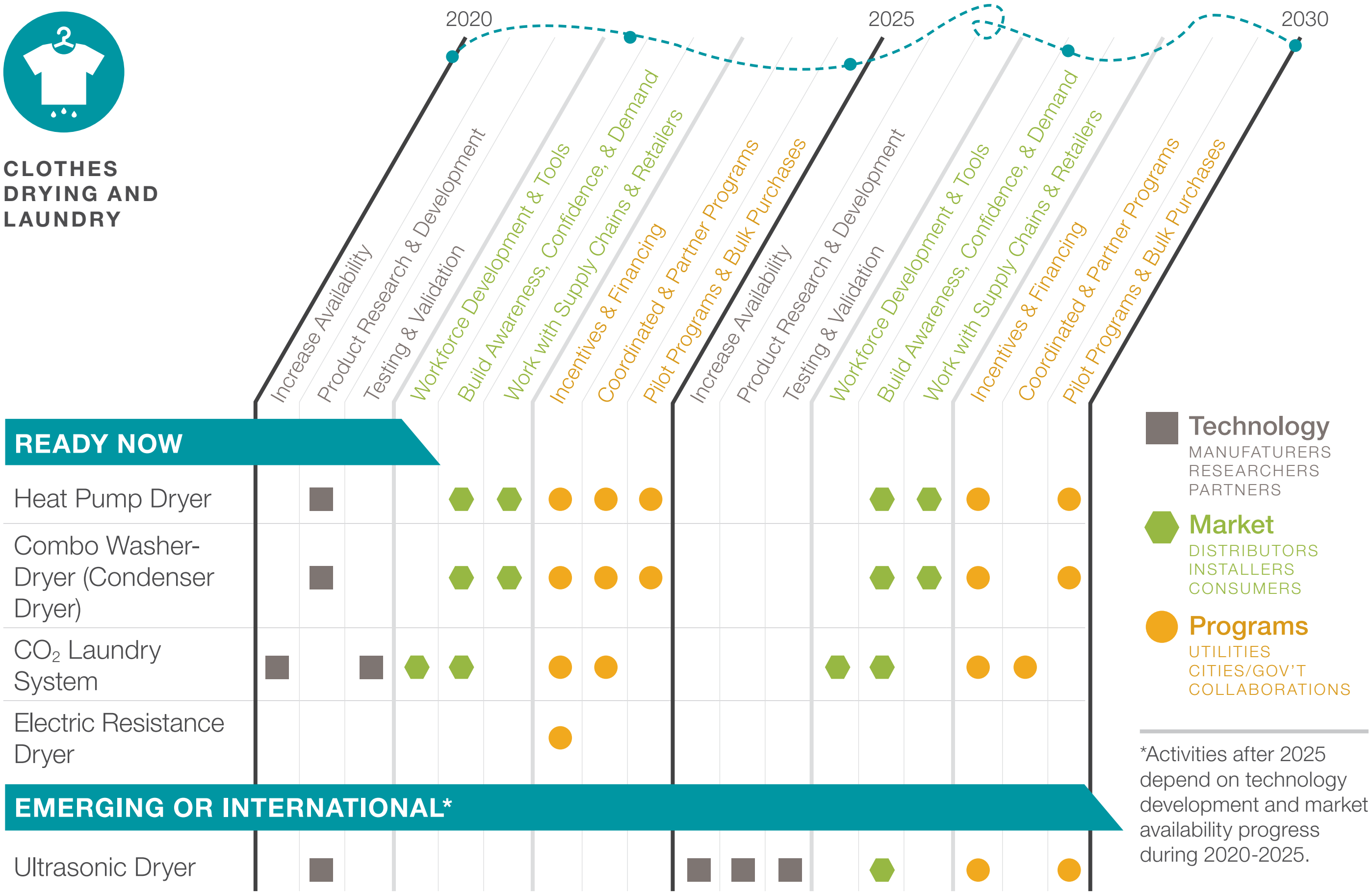
As momentum grows for building electrification in North America, many international manufacturers are working to bring their existing and upcoming products here. Focusing efforts around growing the combo washer/dryer (condensing dryer) market in the U.S. is a top recommendation. Today's combo units, however, are smaller than U.S. customer expectations for residential units. The smaller units are appropriately sized for rentals or multifamily buildings.

The Summary of Clothes Drying and Laundry Electrification Technologies Roadblocks and Recommendations shows key roadblocks for advancing the electrification of laundry (clothes drying) technologies, followed by near-term recommendations for actions.

> Increasing electrification trends is getting the attention of international manufacturers.

Summary of Clothes Drying and Laundry Electrification Technologies Roadblocks and Recommendations

CLOTHES DRYING AND LAUNDRY ELECTRIFICATION TECHNOLOGIES ROADMAP OF RECOMMENDATIONS



CLOTHES DRYING AND LAUNDRY

	2020									2025									2030
	Increase Availability	Product Research & Development	Testing & Validation	Workforce Development & Tools	Build Awareness, Confidence, & Demand	Work with Supply Chains & Retailers	Incentives & Financing	Coordinated & Partner Programs	Pilot Programs & Bulk Purchases	Increase Availability	Product Research & Development	Testing & Validation	Workforce Development & Tools	Build Awareness, Confidence, & Demand	Work with Supply Chains & Retailers	Incentives & Financing	Coordinated & Partner Programs	Pilot Programs & Bulk Purchases	
READY NOW																			
Heat Pump Dryer		■			⬢	⬢	●	●	●					⬢	⬢	●		●	
Combo Washer-Dryer (Condenser Dryer)		■			⬢	⬢	●	●	●					⬢	⬢	●		●	
CO_2 Laundry System	■		■	⬢	⬢		●	●					⬢	⬢		●	●		
Electric Resistance Dryer							●												
EMERGING OR INTERNATIONAL*																			
Ultrasonic Dryer		■								■	■	■		⬢		●		●	

■ **Technology**
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COLLABORATIONS

*Activities after 2025 depend on technology development and market availability progress during 2020-2025.

Residential Package Examples

Electrifying homes is a natural starting place for building electrification programs. In new construction this is an easy lift technically and results in lifecycle occupant benefits in almost all scenarios.[31] For single-family and low-rise multifamily the variety of technologies and the building type variations are less than in the commercial sector, which eases the selection and application learning curve. Residential electrification can also serve to inform small and medium commercial sector designers and contractors. All-electric developments already exist in parts of California in both market-rate and affordable housing projects, where developers recognized that not installing gas infrastructure freed up capital for higher efficiency strategies and appliances.

To provide a lens into a whole-building electrification strategy and estimate typical energy and emission savings over an all-gas-fired baseline, the research team created packages of technologies appropriate to each residential building type. The packages were used in a 3-tiered modeling analysis of energy and emission savings for different combinations. The packages are not in all cases the ideal recommendation, as that is dependent on site and economic considerations. The packages for the two residential building types include a baseline with gas appliances, a 'better' all-electric package representing immediately available and mature technologies, and a 'best' all-electric package high-efficiency equipment, representing a max-tech combination.

Technology-level Analysis

In addition, the research team modeled a mid and highest efficiency product for two 'workhorses of electrification'—space and water heat pumps—as shown below.[32] A mid-efficiency air source heat pump and HPWH reduce energy use by 21% and 50% and emissions by 80% and 77% respectively for those end-uses in a Southern California home with gas technologies. Together, space and water heat pumps are responsible for a large majority of the dramatic energy and emission savings shown in the package impact estimates.

Electrifying the four main gas-using technologies of space and water heating, cooking, and clothes drying in homes or multifamily buildings cuts energy use by over 40% and GHG emissions by over 75% for those four end-uses in multiple California climate zones.

A mid-efficiency air source heat pump and HPWH reduce energy use by 21% and 50% and emissions by 80% and 77% respectively for those end-uses in a Southern California home with gas technologies.

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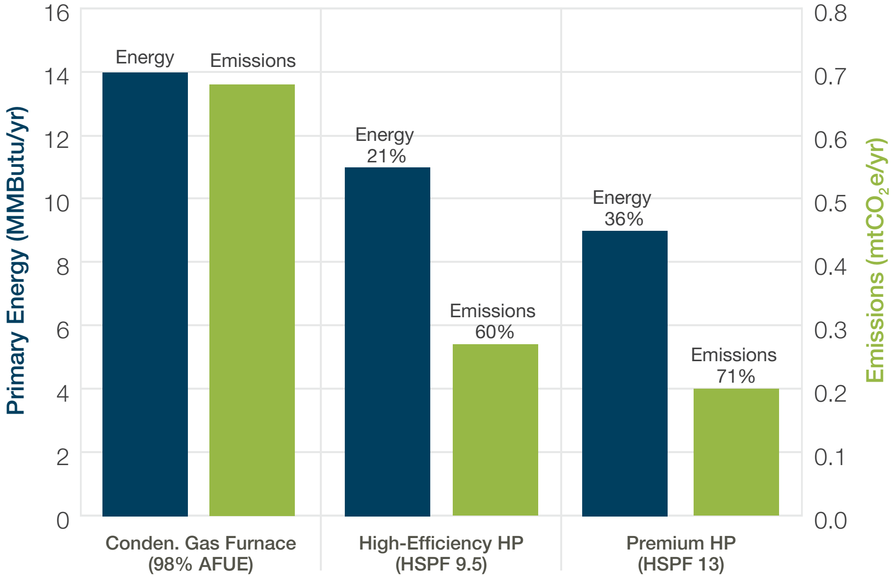
[31] E3 2019, **Residential Building Electrification in California**

[32] Modeled in California Climate Zone 8 (ASHRAE/IECC climate zone 3B)

RESIDENTIAL AIR SOURCE HEAT PUMP ENERGY AND EMISSION SAVINGS COMPARED TO HIGH-EFFICIENCY GAS FURNACE IN SOUTHERN CALIFORNIA

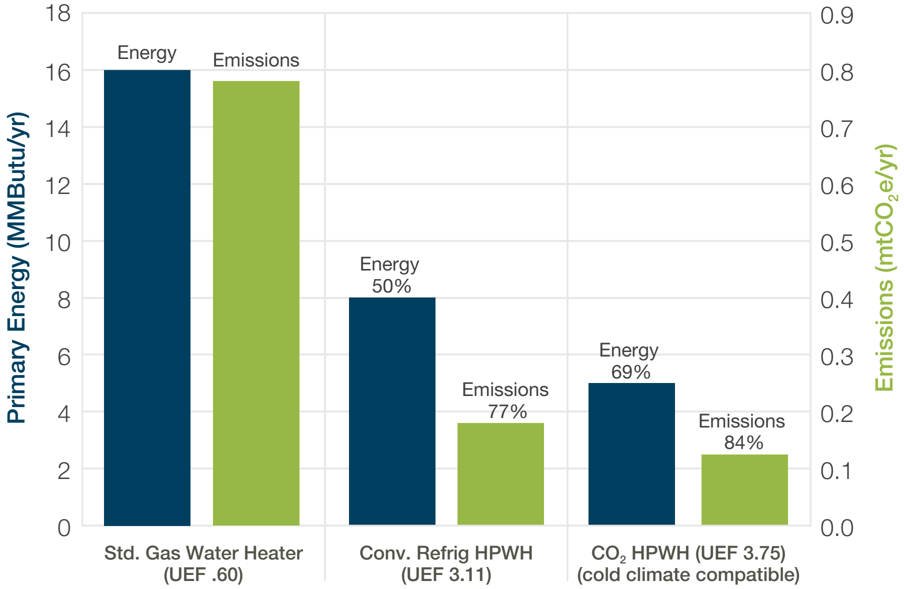
Source: NBI 2020. Based on 2018 modeling and data from EPRI



Heat pumps for space and water heating in homes are technically ready today and have major reductions in energy and emissions.

RESIDENTIAL HPWH ENERGY AND EMISSION SAVINGS COMPARED WITH STANDARD GAS WATER HEATER IN SOUTHERN CALIFORNIA

Source: NBI 2020 Based on 2018 modeling and data from EPRI



Primary source energy only, includes gas distribution losses and electric generation, transmission and distribution losses. Does not include emissions from gas delivery or refrigerant leakage.

Single-Family Home Packages

In single-family homes, both space heating and water heating account for a high proportion of total home energy use and GHG emissions. The gas baseline, all-electric 'better,' and all-electric 'best' packages are described in the figure below.

SINGLE FAMILY TECHNOLOGY PACKAGE FOR MODELING ENERGY AND EMISSION ANALYSIS MODELING[33]

	GAS BASELINE	BETTER	BEST
WATER HEATING	Gas Storage Tank, UEF=0.60	Unitary 240V HPWH, UEF=3.11	Unitary 240V HPWH, low-GWP refrigerant, UEF=3.75
SPACE HEATING	Gas Furnace, AFUE=80%	240V split ASHP, SEER=16, HSPF=8.6	Mini-Split ASHP, SEER=23, HSPF=10.5
COOKING	Gas Range + Gas Oven	Electric Resistance Range, Electric Oven	Induction Range, Electric Oven
CLOTHES DRYING	Gas Standard Dryer	Electric Resistance Dryer	Heat Pump Dryer

Electrifying these four systems yields high savings in terms of energy and GHG emissions, as shown in the charts below. In all cases modeled, the 'better' all-electric package cuts baseline energy use roughly in half and cuts emissions by more than 75%, while the 'best' case cuts energy use by nearly 2/3 and emissions more than 80% as seen in the table below.[34]

SINGLE FAMILY ENERGY AND EMISSION SAVINGS FOR ELECTRIFICATION OF THE FOUR END-USES

		Single Family – Gas Base vs Better Package				**Single Family – Gas Base vs Best Package**			
		Site Energy Savings		Emissions Savings		Site Energy Savings		Emissions Savings	
City	**CA CZ**	**kWh**	**%**	**Lbs CO_2**	**%**	**kWh**	**%**	**Lbs CO_2**	**%**
San Francisco	3	6,852	49%	4,249	78%	8,711	63%	4,553	84%
Los Angeles	9	4,049	43%	2,804	76%	5,895	62%	3,103	84%
Sacramento	12	7,931	51%	4,775	79%	9,981	65%	5,124	85%
Lake Tahoe	16	18,357	65%	9,402	85%	18,674	66%	9,469	85%

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[33] Electric Resistance range was modeled because it has 'Better' emission reductions compared to a gas range. But it is ineffective at cooking compared to gas and to induction. We do not recommend introducing an inferior product to homeowners that may result in a return to gas technologies for cooking but rather advocate for the high satisfaction of induction stove tops.

[34] Energy and CO_2 reductions represent the change from baseline to all-electric package for the sum of the four end-uses, not the whole building. Energy and CO_2 emissions associated with end-uses that are unchanged between baseline and all-electric packages, such as plug loads or lighting, is not represented.

Multifamily Housing Packages

For most multifamily buildings hot water use represents the No.1 energy demand, often followed by space heating. Tenant energy burden most be considered in tandem with upfront electrification costs, especially in low-income and affordable multifamily buildings. The variability in size and design of multifamily buildings greatly affects the technology options available to them. For example, low-rise multifamily buildings are more like single-family homes in many ways; whereas high-rise apartment/condo buildings are often designed and built more like commercial buildings and may include commercial spaces at the street-level.

End-uses such as water heating are addressed differently based on the size of the building: a larger multifamily building will more likely have a central water heating plant served by gas boilers, while townhomes and low-rise multifamily are more likely to use unitary water heaters.

LOW-RISE MULTIFAMILY TECHNOLOGY PACKAGE FOR MODELING ENERGY AND EMISSION ANALYSIS MODELING

	GAS BASELINE	BETTER	BEST
WATER HEATING	Gas Storage Tank, UEF=0.60	Unitary 240V HPWH, UEF=3.11	Unitary 240V HPWH, low-GWP refrigerant, UEF=3.75
SPACE HEATING	Gas Furnace, AFUE=80%	Packaged Terminal Heat Pump, EER=11, COP=3.3	Variable Refrigerant Flow
COOKING	Gas Range + Gas Oven	Electric Resistance Range, Electric Oven	Induction Range, Electric Oven
CLOTHES DRYING	Gas Standard Dryer	Electric Resistance Dryer	Heat Pump Dryer

Electrifying these systems yields high savings both in terms of energy and emissions. In all cases modeled, the ‘better’ all-electric package cuts baseline energy use by 40% or more and cuts emissions by 77% or more, while the ‘best’ case cuts energy use by nearly 2/3 and emissions by 84% or more as shown in the chart below.

LOW-RISE MULTIFAMILY ENERGY AND EMISSIONS SAVINGS FOR ELECTRIFICATION OF THE FOUR END-USES

		Multifamily – Gas Base vs Better Package				**Single Family – Gas Base vs Best Package**			
		Site Energy Savings		Emissions Savings		Site Energy Savings		Emissions Savings	
City	**CA CZ**	**kWh**	**%**	**Lbs CO_2**	**%**	**kWh**	**%**	**Lbs CO_2**	**%**
San Francisco	3	3,236	45%	2,166	77%	4,434	62%	2,352	84%
Los Angeles	9	2,324	40%	3,153	85%	3,587	61%	3,353	90%
Sacramento	12	4,206	51%	2,563	80%	5,316	64%	2,733	85%
Lake Tahoe	16	7,445	57%	4,147	82%	8,433	65%	4,308	85%

Conclusions and Commonalities

California efficiency programs and organizations have a 40-year history of transforming markets for the reduction of energy use in buildings. The industry is now widening the focus to include GHG emission reductions to benefit community and public health. We can leverage our history to develop a new generation of programs that catalyze a larger set of societal and economic benefits. The findings in the BETR are fundamental as well as monumental, clearly describing technologies role in building electrification.

> We can leverage our history to develop a new generation of programs that catalyze a larger set of societal and economic benefits.

While the focus of the BETR is on end-uses and technology status, the energy and emission reductions are compelling and serve as critical data drivers for the recommendations laid out in the Roadmap. Specifically, the BETR took a deeper dive analyzing residential impacts of building electrification compared to other building types, due to available modeling resources.

BETR ANALYSIS ON RESIDENTIAL ENERGY AND EMISSIONS IMPACTS FROM BUILDING ELECTRIFICATION

Topic	Some of the Residential Findings
Space Heating	A high-performance heat pump in a single family Southern California home saves **36% energy and 71% emissions** compared to a condensing gas furnace.
Water Heating	A conventional refrigerant HPWH heater in a single family Southern California home **saves 50% energy and 77% emissions** compared to a standard gas tank water.
End-Use Packages	Electrifying the four main gas-using technologies of space and water heating, cooking, and clothes drying in homes or multifamily buildings **cuts energy use by over 40% and GHG emissions by over 75% for those four end-uses in multiple California climate zones.**

The full BETR study provides details at each technology within its end-use application. However, the technologies share common roadblocks and a set of recommended activities for rapidly advancing them together in the market. The five collective strategies to advance all the technologies are seen in the figure below.

FIVE COLLECTIVE STRATEGIES TO ADVANCE ELECTRIFICATION TECHNOLOGIES

Source: NBI 2020

- **1 Build Demand** Create Compelling Value
- **2 Support Supply Chain** Make the Business Case
- **3 Partner with Production** Manufacturers are Motivated
- **4 Close the Cost Gap** Invest Heavily Now
- **5 Align Programs and Policies** Make the Path Easy

The extent of research and findings in BETR is extensive. For this reason, this BETR Summary serves as a companion document to the full 100 page study. The full BETR study has detailed and layered information on each technology, market channel and recommendations and can be accessed **here**.

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The Building Electrification Technology Roadmap (BETR)

A BETR Path to Decarbonization for California Efficiency Programs

Technical status, barriers, and paths to advancing electrification technologies in residential and commercial buildings.

Prepared By:
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New Buildings Institute

December 2020

In Partnership with:
BUILDING DECARBONIZATION COALITION

With Sponsorship From:

The funders of this study are committed to helping the state of California meet its 2045 carbon neutrality goal. If one thing is clear from this Roadmap, it's that we must act with greater urgency to accelerate building electrification technologies. By working together to take the recommendations into concrete actions, we can make great progress toward reducing the energy use and GHG emissions of all buildings across the state of California over the next 10 years.


California efficiency programs and organizations have a 40-year history of transforming markets for the reduction of energy use in buildings. We can leverage our history to develop a new generation of programs that catalyze a larger set of societal and economic benefits. The findings in the BETR are fundamental as well as monumental, clearly describing California's technology path to building electrification.

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New Buildings Institute (NBI) is a nonprofit organization driving better energy performance in buildings to make them better for people and the environment. We work collaboratively with industry market players—governments, utilities, energy efficiency advocates, and building professionals—to promote advanced design practices, innovative technologies, public policies, and programs that improve energy efficiency. The Getting to Zero website houses over 300 curated resources including guidance, educational webinars, policy models, research, case studies, and more to help all buildings achieve zero energy. Visit gettingtozeroleadership.org to learn more.

BUILDING DECARBONIZATION COALITION

buildingdecarb.org

The Building Decarbonization Coalition (BDC) unites building industry stakeholders with energy providers, environmental organizations and local governments to help electrify California's homes and workspaces with clean energy. Through research, policy development, and consumer inspiration, the BDC is pursuing fast, fair action to accelerate the development of zero-emission homes and buildings that will help California cut one of its largest sources of climate pollution, while creating safe, healthy and affordable communities.

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