Opinion Dynamics

RESIDENTIAL BUILDING DECARBONIZATION TECHNOLOGY AND POLICY BRIEF

THIS IS THE FIRST IN A SERIES OF BRIEFS DESIGNED TO SUMMARIZE AND SYNTHESIZE MARKET TRENDS.

JANUARY 2022

The information presented herein is part of the BUILD Program and TECH Initiative Evaluations currently underway in CA on behalf of SCE and the CPUC.

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Guidehouse

3 Major end-uses of focus:

- space
- water
- cooking

Several product options in the market today and growing.

SPACE HEATING & COOLING

Heat pumps represent the most efficient electric space heating option on the market today. Increased adoption of heat pumps can contribute to significant system-wide decarbonization of residential heating and cooling. Heat pumps are capable of being installed with or without ducts and as a split or packaged system. Heat pumps can be air-source, which transfers heat air-to-air, or ground-source, which uses geothermal heat exchange loops. Air source heat pumps are the most common type of heat pump on the market today. Recent heat pump innovations include applications for ancillary load flexibility and technological advances like absorption heat pumps.

Technology/ Feature	Benefits	Drawbacks
Air-Source Heat Pump	Significant energy and cost savings over time as compared to electric resistance heating	Can be significantly less efficient in colder climates; may cost more upfront; contractors less familiar with ASHPs
Ground-Source Heat Pump	Highest efficiency, less maintenance, longer lifetimes, and less dependency on outdoor temperature than ASHPs	Very high capital expenditures when compared to most other system alternatives; complex and labor-intensive installation
Hybrid Heat Pumps with Gas Furnace Backups	Eliminates electric resistance backup systems; cold climate effectiveness; can be operationally economical	Upfront cost of both heat pump and gas infrastructure. Using gas as fuel still produces point-of-combustion emissions
Absorption Heat Pumps (typically gas-fired)	Models on the market recover combustion heat; synergy with zone control; flexibility of heat source	Mainly used in industrial or commercial settings, despite availability for large homes
Feature: Load shifting to align clean and cheap supply and demand	Reduced system-wide costs; greater renewable consumption; reduced grid congestion	Impacts customer comfort; manual shifting is impractical; insufficient customer incentives
Feature: Zone control systems	Useful for larger homes; heat pump can keep different rooms at different temperatures	High initial cost; somewhat more complicated to design
Feature: Desuperheater add-on to GSHP for water heating	Recovers waste heat from cooling mode for 2–3x more efficient water heating than traditional systems	Requires backup water heating system when GSHP is inactive
Feature: Multi-stage compressors for enhanced efficiency	Air flow velocity has multiple intensity levels; saves energy; reduces on/off operation and compressor wear; generally quieter	Associated with higher cost models
Feature: Non-vapor compression (solid state, mechanical, thermally driven)	Efficiency gains; lower global warming potential (GWP); thermal options may offer peak load reduction	Significant R&D funding needed; few options commercialized; some safety concerns still need to be addressed; greater noise potential

WATER HEATING

Water heaters are appliances that provide a continual supply of hot water by using an energy source to heat water above its initial temperature. Water heaters can be segmented by fuel type (electric, solar, gas) and by storage type (storage tank, tankless, or heat pump). HPWHs are the new standard-bearer for efficiency among electric water heaters. The most efficient HPWHs today are up to three times more efficient than a electric resistance (ER) water heater in mild climates. When electricity comes from clean sources, HPWHs can provide a significant opportunity for decarbonization. They can be purchased as an integrated system with a co-located water storage tank and heat pump with electric resistance elements as backup, or as a split system as an outdoor unit placement separate from the water tank. Split system HPWHs do not have an option for electric resistance backup, which can be helpful in a wider range of ambient conditions. HPWHs are significantly more efficient in warmer climates.

Technology/Feature	Benefits	Drawbacks
ASHPWHs	Higher efficiency than ER and traditional gas water heating	Ineffective in cold climates; more considerations for installation, price
Integrated HPWH	Greater product optionality, electric resistance backup which maintains small temperature differentials	Generally smaller compressor, generates hot water slower than split system
Split System HPWH	Enables heat pump location flexibility	Less frequently incorporate ER backup; heat pump is only input source
Geothermal HPWH desuperheater	Very high efficiency, especially in warmer locations	High CAPEX for geothermal heat pump; less viable residentially
Drain-water heat recovery technology	Recover heat from already-used hot water; payback ranges from 2.5–7 years	Installation more expensive in older homes
CTA-2045 port enabling load shifting	Reduced system-wide costs; greater renewable consumption; reduced grid congestion; advanced communication capabilities	Port supply chain issues with pandemic; impacts customer comfort; manual shifting is impractical; insufficient customer incentives
Ability to use 120V outlet	May enable space-constrained installations using existing electrical wiring	Requires planning to avoid overloading of existing circuits
Electric Tankless Water Heaters	Can be paired for use with specific appliances	Limited flowrate may not support simultaneous hot water demand from multiple end uses, upfront cost & not always more efficient

 3

INDUCTION COOKTOPS

Induction cooktops are cooking vessels that use flat glass surfaces equipped with heating coils that are powered by electromagnetic energy activated by the iron in cookware. These are the most efficient electric cooktops. Inductions use magnetic fields to achieve nearly complete energy transfer to ferrous cooking equipment; cookware made of copper, aluminum, and glass are incompatible with induction cooktops. Although more expensive upfront than ER, and generally more expensive to operate than gas, induction cooktops offer lifetime financial and energy savings and an opportunity to reduce carbon emissions. Induction technology offers unmatched heat-up times, easier cleaning ability, and several health, comfort, and safety benefits compared to alternatives. Additionally, conduction cooktop prototypes are under development; they leverage thick metallic film layers to heat a ceramic silicon nitride hotplate, which directs heat to the specialized cookware via conduction. These offer opportunities for further efficiency gains and more precise temperature control if lab results hold true at a larger scale.

Technology/Feature	Benefits	Drawbacks
Power-boost mode (Induction)	Increases power by up to 50%, quicker heat up	N/A
Convection	Reduces cooking time	Typically found on mid to high priced cooktops
Wifi Connectivity	Customer convenience, remote cooktop controls	Typically found on mid to high priced cooktops

Product	Efficiency	Upfront Affordability	Cooking Quality	Heat-up Speed	Appearance
Smooth Electric Resistance Stove	◔	◕	◑	◔	◕
Electric Coil Resistance Stove	◑	◕	◔	◑	◔
Induction Stove	◕	◔	◑	●	◕
Conduction Stove Prototype	●	N/A	●	◕	N/A

Most efficient electric space heating option on the market today

Can reduce heating energy consumption by **~50%**

EFFICIENCY PERFORMANCE

Heat Pump HVAC Efficiency:

- The technology in the marketplace now can reduce heating energy consumption by ~50% compared to electric resistance heating options.
- ASHP can deliver up to three times more heat to a home than the electrical energy it consumes.
- Purchasing the best available ASHP or GSHP results in ~$5,000 worth of lifetime savings when compared to the least efficient ASHP or GSHP on the market.

Quantifying Efficiency:

- ASHP efficiency is measured using SEER and HSPF. SEER represents efficiency for cooling mode, while HSPF measures heating mode efficiency. Both incorporate the variable temperatures throughout cooling and heating seasons.
- ASHP efficiency rises significantly with warmer climates. On average the COP of a tested heat pump rose from 2.2 to 3.5 COP (~60% increase) as the outside temperature rose from -5°C to 15°C. In 15°C weather, some trials saw COPs higher than 5, while the COP didn't break 3 for any test at -5°C (Figure 3).
- GSHP efficiency is measured using EER and COP. EER also represents efficiency for cooling but is specific to one temperature, as underground temperatures generally remain more stable seasonally. Similarly, COP represents efficiency for heating but is specific to one temperature.
  - The Less Efficient column in Figures 1 and 2 show the minimum allowable efficiencies by the DOE: 14 SEER / 8.2 HSPF for ASHPs and 15.0 EER / 3.1 COP for GSHPs.
  - While the best ASHPs can reach 33.1 SEER and 14 HSPF, values greater than 18 SEER and 10 HSPF should be considered high efficiency.
  - The most efficient GSHPs can reach 30.5 EER (Figure 2).
  - The least efficient GSHPs consume 12% to 16% less energy annually than equivalent ASHPs.
- 'Cold Climate' ASHPs yield annual operational savings of ~$1500 and ~$250 when replacing propane and oil systems respectively in the Northeast, but don't yield monetary savings for customers that use natural gas systems (Figure 4). The simple payback periods for replacing propane and oil systems in this region are 6–9 years and 25 years respectively (Figure 5). Savings are likely to be even greater in warmer climates.

Figure 1: ASHP Efficiency and Savings

Lifetime Savings for Efficient Residential Air-source Heat Pump Models

Performance Metric	Best Available	ENERGY Star®	Less Efficient
SEER	33.1	15.0	14.0
HSPF	14.0	8.5	8.2
Annual Energy Use-Heating and Cooling (kWh)	5,123	9,289	9,746
Annual Energy Cost-Heating and Cooling ($)	$ 449	$ 814	$ 854
Lifetime Energy Cost (15 years)	$ 5,338	$ 9,680	$ 10,157
Lifetime Cost Savings (Over Less efficient)	$ 4,818	$ 476	N/A

Source: DOE, 2021

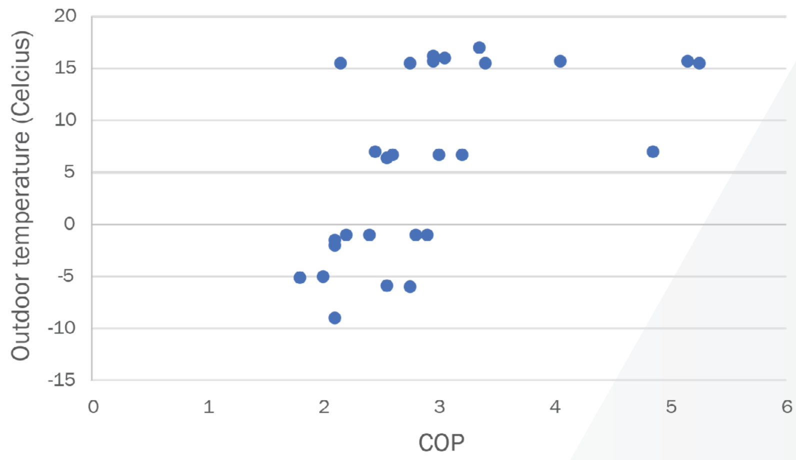
Figure 2: Geothermal Heat Pump Efficiency and Savings

Lifetime Savings for Efficient Residential Ground-source Heat Pump Models

Performance Metric	Best Available	ENERGY Star®	Less Efficient
EER	30.5	17.1	15.0
COP	N/A	3.6	3.1
Annual Energy Use-Heating and Cooling (kWh)	4,493	7,050	8,125
Annual Energy Cost-Heating and Cooling ($)	$ 394	$ 618	$ 712
Lifetime Energy Cost (15 years)	$ 6,761	$ 10,610	$ 12,227
Lifetime Cost Savings (Over Less efficient)	$ 5,465	$ 1,617	N/A

Source: DOE, 2021

Figure 3: ASHP Efficiency by Temperature



Source: BRANZ, 2018

Figure 4: Cold Climate ASHP Operational Savings Per Year

ccASHP Savings from the following system types	Annual Savings
Propane System	$1,462
Oil System	$255
Natural Gas System	$261

Source: Synapse Energy, 2018

Figure 5: Cold Climate ASHP Payback Period

Heating Scenario	Payback Period (Years)
Replace Existing Eqpt. On Failure	
Propane System	9
Oil System	25+
Natural Gas System	No Payback
Keep Existing Eqpt. as supplemental heating	
Propane System	6
Oil System	24
Natural Gas System	4

Source: Synapse Energy, 2018

Source: https://d39d3mj7qio96p.cloudfront.net/media/documents/SR414_Heat_pump_performance.pdf | https://www.nrel.gov/docs/fy18osti/70485.pdf | https://nailor.com/corporate/news/how-water-source-heat-pumps-work

Pricing ranges from **$5K - $15K**

PRICING

- Depending on home modifications and the differences in regional cost, the capital expenditure for ASHPs in the U.S. typically ranges from $5,500 to $14,500/project.

- Over 4,000 customer-submitted data points indicate that total installation costs are more variable for geothermal, mini-split, and hybrid than for ASHPs (Figure 6).

Figure 6: Price Range by Technology Type

Type	Total Installation Costs
Air Source	$4,500 - $8,000
Geothermal	$6,000 - $20,000
Mini-split	$2,000 - $14,500
Hybrid	$2,500 - $10,000

Source: HomeAdvisor, Angi, 2021

- ASHP installed costs are expected to decline from ~$1600/ton to ~$1200 /ton on average across three advancement scenarios with 0.7%, 1%, and 1.5% annual cost reductions. The 1.5% reduction case is in line with IEA's technology road map by 2050 (Figure7).

Figure 7: ASHP Installed Cost Projections

Scenario	Installed Cost ($/ton)	Year
Slow Advancement	$ 1,720	2015
Slow Advancement	$ 1,680	2020
Slow Advancement	$ 1,580	2030
Slow Advancement	$ 1,480	2040
Slow Advancement	$ 1,400	2050

Scenario	Installed Cost ($/ton)	Year
Moderate Advancement	$ 1,720	2015
Moderate Advancement	$ 1,670	2020
Moderate Advancement	$ 1,500	2030
Moderate Advancement	$ 1,375	2040
Moderate Advancement	$ 1,275	2050

Scenario	Installed Cost ($/ton)	Year
Rapid Advancement	$ 1,720	2015
Rapid Advancement	$ 1,650	2020
Rapid Advancement	$ 1,400	2030
Rapid Advancement	$ 1,200	2040
Rapid Advancement	$ 1,020	2050

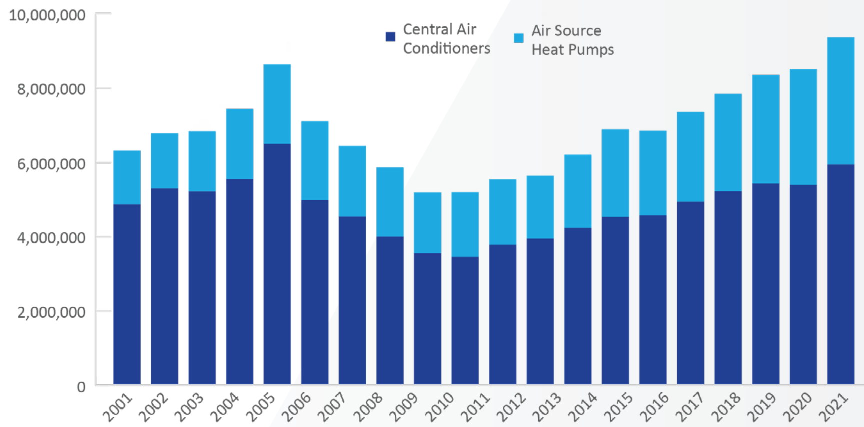
Source: NREL, 2017

Market size was $13.5B in 2020 and projected to be **$22.2B** by 2030

MARKET SIZE

- Strengthening demand for energy efficiency and more stringent policy goals for reducing carbon emissions are the largest growth drivers for residential heat pumps.
- ASHP shipments from U.S. manufacturers have risen in most years from 2010–2020, peaking in 2020 with nearly 3.5 million shipments (Figure 8).
- In 2020, 165,588 ASHPs were shipped to CA and 50,000 GSHPs are installed in the U.S. each year (Source: Opinion Dynamics, 2021).
- The market share of ASHPs has risen from ~34% in 2010 to ~37% in 2020, indicating strong ASHP growth compared to traditional space cooling, whose sales grew more modestly (Figure 8).
- From 2021–2030, the U.S. residential heat pump market is projected to see 5% CAGR, reaching $22.2B by 2030.

Figure 8: U.S. Manufacturing Central AC vs. ASHP Shipments



Source: AHRI, 2020

- Since 2018, the majority of space heating growth has come from systems under 65,000 BTUH, likely for residences and small businesses. Unit sales for those under 65,000 BTUH increased by 13%, while sales decreased by 15% for units larger than 65,000 BTUH (Figure 9).

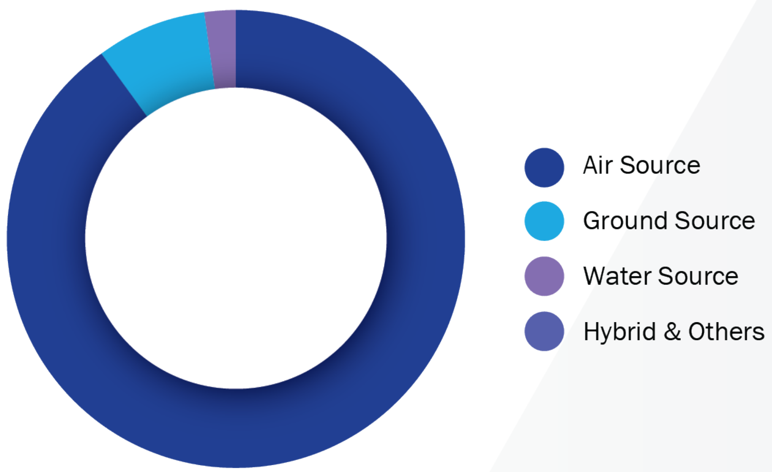
Figure 9: Sales of Space Heating & Cooling Systems by Size

Size in Thousands of BTUH	2018	2019	2020
Under 16.5	253,836	303,780	357,759
16.5-21.9	676,927	739,928	864,142
22-26.9	1,581,830	1,635,309	1,830,740
27-32.9	1,307,088	1,332,524	1,483,746
33-38.9	1,781,400	1,793,488	1,984,554
39-43.9	663,503	651,503	717,084
44-53.9	967,998	948,059	1,040,749
54-64.9	773,391	757,653	787,593
65-96.9	109,986	109,606	92,770
97-134.9	84,261	83,717	69,076
135-184.9	57,590	56,986	46,644
185-249.9	24,673	25,109	20,780
250-319.5	16,838	16,054	17,257
320-379.9	4,208	4,222	3,892
380-539.9	4,322	4,393	4,141
540-639.9	3,406	3,117	3,112
>640	4,736	5,215	4,723

Source: AHRI, 2020

- ASHPs constituted ~90% of the residential U.S. heat pump market, with GSHPs covering most of the remaining 10% (Figure 10).

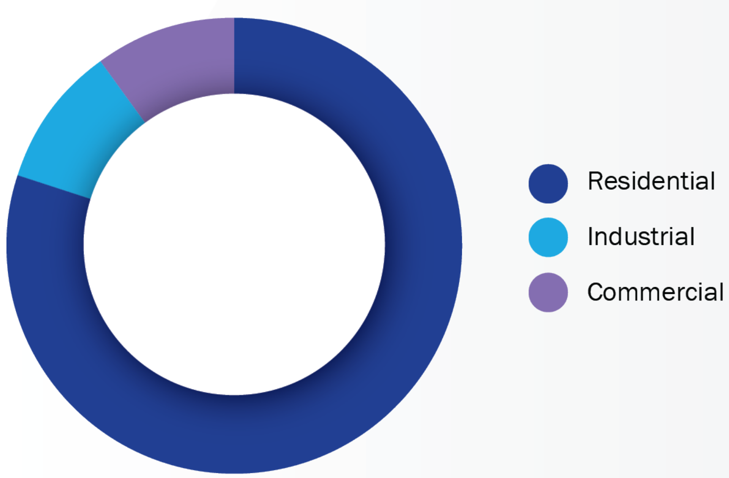
Figure 10: U.S. Residential Heat Pump Market Size



Source: [Global Market Insights, 2021]

- The residential sector dominated the industry, capturing nearly 80% of heat pump market share globally (Figure 11).

Figure 11: Global Heat Pump Market Size



Source: [Grandview Research, 2021]

Advancements in refrigerants and compressors will increase environmental benefits

INNOVATION

- ASHP efficiencies will improve with advancements in refrigerants and the expanded use of variable speed compressors (Figure 12).
- Heat pumps can be leveraged for load shifting, which reduces fossil fuel use and stress on the grid, while capturing more renewable energy at peak hours.
  - Residential load flexibility could reduce peak demand consumption associated with space cooling by 35–40GW and by ~10GW for heating by 2030 (Figure 13).
  - Customer discomfort from load shifting can be mitigated to an average of 2.5 minutes of unsatisfactory time per day and a max temperature drop of 2.3°C with constant capacity reservation in thermal energy storage supplements. Multi-stage heat pumps can also switch to less intrusive low-power draw.
- R-410A and R407C refrigerants will be phased out by 2024, increasing R&D need for low-GWP refrigerants.
  - R-452B is an ideal interim replacement of R-410A with a ~66% reduction in GWP, improved overall efficiency, and similar pressure design and capacity match that avoids equipment re-design.
  - Other promising refrigerants being considered for heat pump applications include R455A (GWP <150) and R290.

Figure 12: Residential Heat Pump Efficency Projections

Scenario	Seasonal COP (SCOP)	Year
Slow Advancement	2.5	2015
Slow Advancement	2.7	2020
Slow Advancement	2.9	2030
Slow Advancement	3.0	2040
Slow Advancement	3.0	2050
Moderate Advancement	2.5	2015
Moderate Advancement	3.0	2020
Moderate Advancement	3.8	2030
Moderate Advancement	4.3	2040
Moderate Advancement	4.6	2050
Rapid advancement	2.5	2015
Rapid advancement	3.0	2020
Rapid advancement	4.0	2030
Rapid advancement	5.0	2040
Rapid advancement	5.3	2050

Source: NREL, 2017

Figure 13: Load Flexibility Peak Demand, Resiential U.S.

Winter Load Flexibility Peak Load Reduction Potential by Technology

Technology	Peak Demand avoided residential (GW)
Heating	10
Cooling	1
Water Heating	7
Home Electronics	2
Washing/Drying	12

Summer Load Flexibility Peak Load Reduction Potential by Technology

Technology	Peak Demand avoided residential (GW)
Heating	0
Cooling	38
Water Heating	8
Home Electronics	1
Washing/Drying	14

Source: Joule, 2021

Efficiency varies by climate, volume of water, and location in the residence

EFFICIENCY PERFORMANCE

Factors influencing HPWH efficiency:

- ER water heaters are significantly less efficient in all climates than both hybrid HPWHs (with ER backup) and pure heat pumps.
- COPs for hybrid and pure HPWHs were 36% and 24% greater for FL than ND, illustrating HPWH efficiency gains with warmer climates (Figure 16).
- Any form of electric water heating, even ER, can reduce emissions compared to gas alternatives. ER water heating (COP 0.96) results in fewer emissions than gas storage, gas tankless, and gas HPWH given renewable grid energy mixes of ~30%, ~55%, and ~70%; renewable penetration thresholds are even lower for HPWHs.
- Split system HPWHs had higher COPs, greater split system power (kW) and significantly lower heat up times compared to their integrated system counterparts. (Figure 14).
- HPWH efficiency also increases meaningfully with the volume of water drawn.
  - Increasing water drawn off by 200% (50L to 150L) results in an average increase of time by 108% and 115% and average increase of COP by 17% and 10% for integrated and split system HPWHs respectively (Figure 14).
- Basement HPWH locations yield greater cold/intermediate climate efficiency; garage/vented closet locations are better for warm climates (Figure 16).

Figure 14: HPWH Performance by System Types

	Water Drawn-off	Time	Power	Electrical Energy	Thermal Energy	COP
Percent Increase (50 to 150 L)	200%	108%	-1%	105%	140%	17%
Average Split Percent Increase (50 to 150 L)	200%	115%	1%	117%	140%	10%
ASHP	**Water Drawn-off**	**Time**	**Power**	**Electrical Energy**	**Thermal Energy**	**COP**
Integrated	50	69.88	0.85	0.99	2.19	2.19
Split	50	34.81	1.31	0.76	2.19	2.87
Integrated	50	60.71	0.85	0.86	2.32	2.70
Split	50	40.00	1.14	0.76	2.32	3.04
Integrated	50	70.47	0.86	1.01	2.45	2.42
Split	50	40.00	1.35	0.90	2.45	2.72
Integrated (Average)	50	67.02	0.85	0.95	2.32	2.44
Split (Average)	50	38.27	1.27	0.81	2.32	2.88
Integrated	100	110.82	0.85	1.57	4.20	2.68
Split	100	67.56	1.19	1.34	4.20	3.01
Integrated	100	100.91	0.88	1.48	3.92	2.64
Split	100	60.00	1.30	1.30	3.92	3.01
Integrated	100	111.03	0.87	1.61	4.23	2.63
Split	100	65.12	1.29	1.40	4.23	3.02
Integrated (Average)	100	107.59	0.87	1.55	4.12	2.65
Split (Average)	100	64.23	1.26	1.35	4.12	3.01
Integrated	150	146.02	0.83	2.02	6.16	3.05
Split	150	85.44	1.25	1.78	6.16	3.46
Integrated	150	126.35	0.85	1.79	4.78	2.67
Split	150	74.88	1.33	1.66	4.78	2.87
Integrated	150	145.41	0.85	2.06	5.79	2.80
Split	150	85.98	1.27	1.82	5.79	3.19
Integrated (Average)	150	139.26	0.84	1.96	5.58	2.84
Split (Average)	150	82.10	1.28	1.75	5.58	3.17

Source: Journal of Energy in South Africa, 2018

Figure 15 & 16: HPWH Performance by Climate and Location

Annual COP for Cold, Intermediate, and Hot Climates (50-gal)

State	Heating System	COP
ND	Electric Resistence	0.96
ND	Hybrid Heat Pump	2.03
ND	Pure Heat Pump	2.80
NY	Electric Resistence	0.95
NY	Hybrid Heat Pump	2.22
NY	Pure Heat Pump	3.11
FL	Electric Resistence	0.96
FL	Hybrid Heat Pump	2.77
FL	Pure Heat Pump	3.47

Annual COP by Installation Location in Homes (50-gal)

State	Heating System	COP
ND	Vented Closet	1.18
ND	Garage	1.48
ND	Basement	2.02
NY	Vented Closet	1.57
NY	Garage	2.06
NY	Basement	2.22
FL	Vented Closet	2.72
FL	Garage	2.75
FL	Basement	2.47

Source: NRDC, 2017

Median cost of HPWH ranges from **$2,800-$3,900** with infrastructure

PRICING

Current Installed Costs:

- HPWHs can be favorable from an installed-cost perspective, especially when considering negated gas distribution infrastructure (including main extension, service extension, meters, in-home infrastructure and plan reviews (Figures 17 & 18).
  - Individual gas systems w/ infrastructure included have median installed cost of ~$3,600.
  - Individual HPWH systems w/ infrastructure included have median installed cost of ~$2,800.
  - National data shows individual gas systems w/ infrastructure included have median installed cost of ~$3,600. The median cost of tankless systems in CA is ~$3,500.(Source: Opinion Dynamics, 2021).
  - National data shows individual HPWH systems w/ infrastructure included have median installed cost of ~$2,800. The median cost of HPWH in CA is ~3,900. (Source: Opinion Dynamics, 2021).

2018-2020 Growth Rate (Under 65,000 BTUH)	2018-2020 Growth Rate (Over 65,000 BTUH)
13.2%	-15.4%

Source: NREL, 2017

Figure 17 & 18 : Installed Costs (Gas Infrastructure costs included & not included)

Gas Infr. Costs Included

	Central Heat Pump	Central Gas	Individual Heat Pump	Individual Gas	Multi-Central Heat Pump
Whisker max	4450	5450	N/A	N/A	N/A
Box max	3250	4450	3500	4150	2400
Median	2450	1850	2750	3600	1850
Box min	1600	1600	1850	3100	1650
Whisker min	730	1450	1650	N/A	N/A

Gas Infr. Costs Not Included

	Central Heat Pump	Central Gas	Individual Heat Pump	Individual Gas	Multi-Central Heat Pump
Whisker max	4650	3300	N/A	N/A	N/A
Box max	3050	3000	3700	2050	2400
Median	2350	1650	3000	1700	1850
Box min	1600	1250	2050	1250	1650
Whisker min	1000	1100	1850	N/A	N/A

Source: RMI, 2020

Gas units are currently more popular than electric but HPWH market expected to see CAGR of 2.6% through 2026

MARKET SIZE

- Retailers sell more electric than gas units, while distributors sell more gas than electric based on end-users & installation difficulty.
- Customers with gas water heaters ~2x more likely to switch to electric than electric to gas.
- Only 20% of customers purchase same brand as their existing water heater.
- ENERGY STAR® marketing and promotions have proven to increase HPWH trust and sales rates.
- In 2021, only 2/9 recorded months saw residential sales for electric greater than gas (Figure 19 & 20).
- Electric sales dropped by nearly 20% (residential) from March to April in 2020 compared to ~12% in 2021. COVID-19 resulted in less construction, and thereby less demand for water heaters (Figure 19).

Source: https://neea.org/img/documents/water-heater-market-characterization-report.pdf

Figure 19: 2021 U.S. Residential Water Heater Shipments

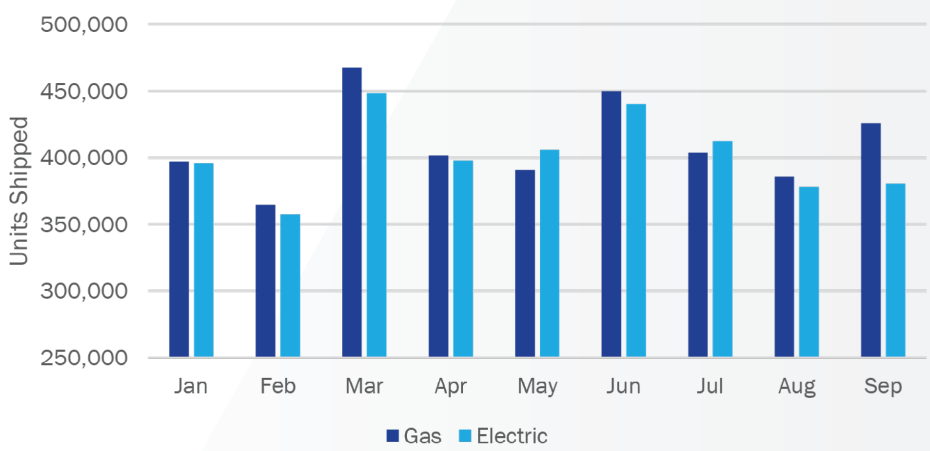
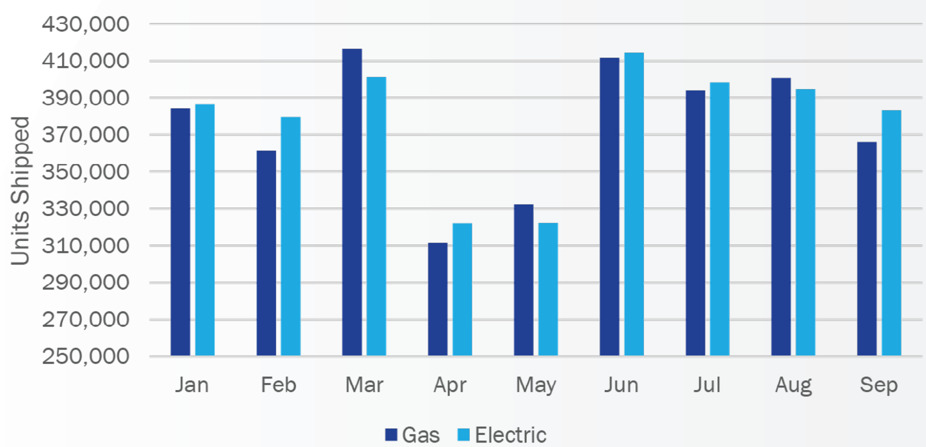


Figure 20: 2020 U.S. Residential Water Heater Shipments



Source: Industry Research, 2021

HPWHs can be used as a tool to lessen peak demand

INNOVATION

- Hot topics within the industry range from shifting load during peak for minimizing energy costs and emissions to replacing refrigerants from the standard R134a fluid to alternatives such as R1234yf, which offers significant efficiency improvements and drastically lower GWP, but is currently not cost effective.
- Load flexibility programs are emerging for HPWHs (e.g., National Grid Connected Solutions). These programs incentivize customers to shift water heater energy consumption to off-peak periods, using behavioral, automated, or direct utility control mechanisms. This can increase customer motivation for a HPWH purchase.
- Residential load flexibility could reduce peak demand consumption by ~10 GW from water heating by 2030 (Figure 21).
- The water heating market in the Northeast is split across brands, but over 1/3 of customers considered a Rheem®/Ruud® product.
- Supply chain shortages from the pandemic have made producing CTA-2045 modules difficult; higher NEEA HPWH tiers have temporarily removed DR capabilities as a requirement since load shifting is difficult without communication from these modules.

Figure 21: Load Flexibility Peak Demand, Residential U.S.

Summer Load Flexibility Peak Load Reduction Potential by Technology

Technology	Peak Demand avoided residential (GW)
Heating	10
Cooling	1
Water Heating	7
Home Electronics	2
Washing/Drying	12

Winter Load Flexibility Peak Load Reduction Potential by Technology

Technology	Peak Demand avoided residential (GW)
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Source: Joule, 2021

Induction cooktop efficiency is **85%** better than gas and electric resistance options

DOE recently amended the conventional cooktop test methodology to include induction compatibility

INDUCTION EFFICIENCY AND PERFORMANCE

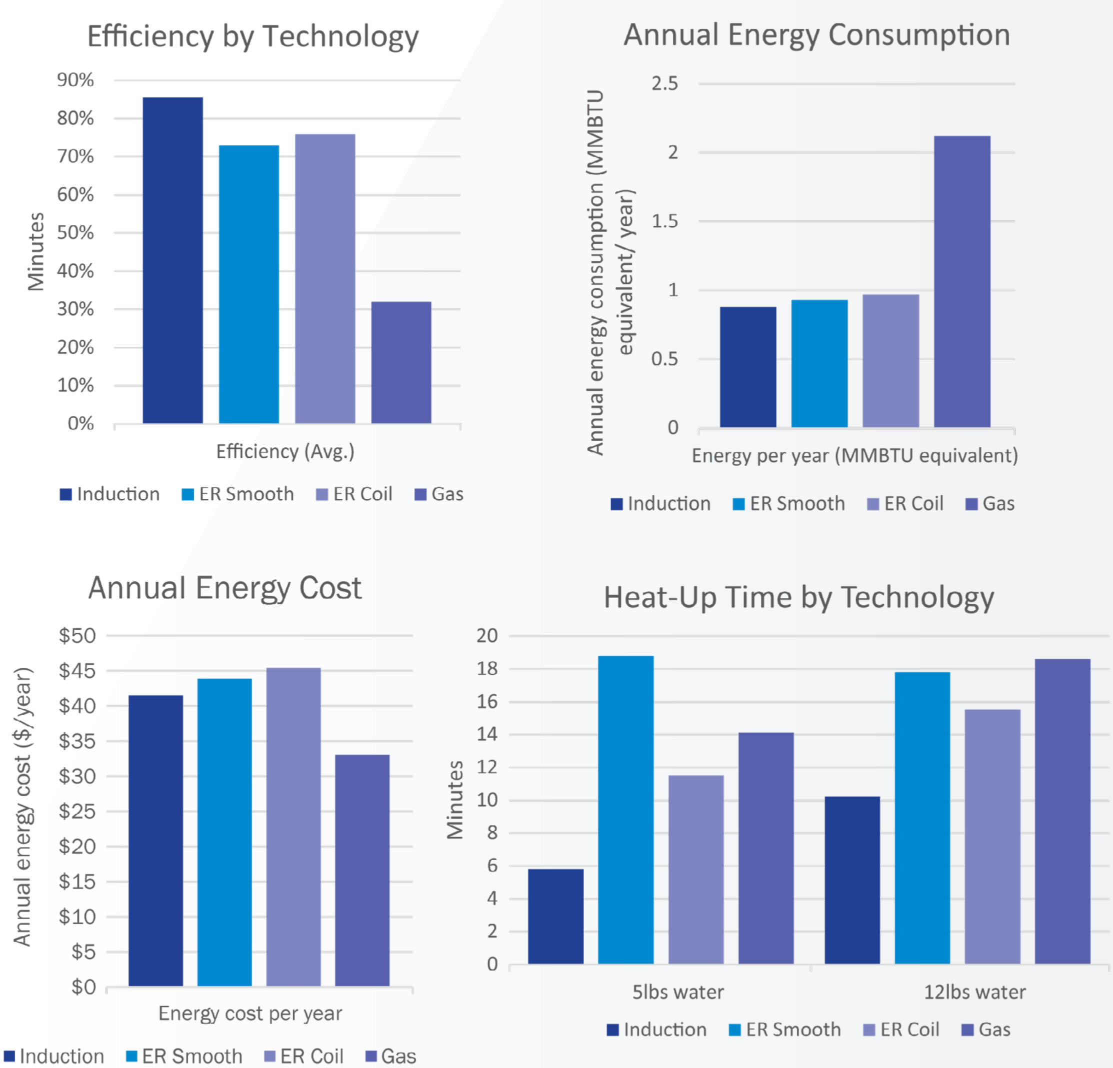
Technology Efficiency Comparisons:

- Cooktop efficiencies for induction are 85%, 70-80% for ER, and 32% for gas. Cooktop energy input rates are greatest for gas, followed by induction then ER. Annual gas consumption is over twice as high as electric alternatives when converted to MMBTU (Figure 22). Emissions levels depend on the grid's energy mix of electricity.
- Induction cooktops boast the fastest heat-up times for commercialized options, averaging 10.2 mins to heat 12-lbs of water compared to 16.7 and 18.6 for ER and gas (Figure 22).

Technology Savings Comparisons:

- Annual energy costs for gas cooktops are still cheaper with one FRONTIER Energy study finding they cost ~$33/year, while induction and ER options average at ~$41.50/year and ~$44.50/year (Figure 22).
- If all cooktops sold in 2021 in the U.S. used induction technology, energy savings would exceed 1,000 GWh and associated cost savings would exceed $125M according to ENERGY STAR®.

Figure 22: Cooktop Performance by Technology



Source: Frontier Energy, 2019

For induction cooking, the largest barrier is higher upfront cost than ER and gas

INDUCTION PRICING

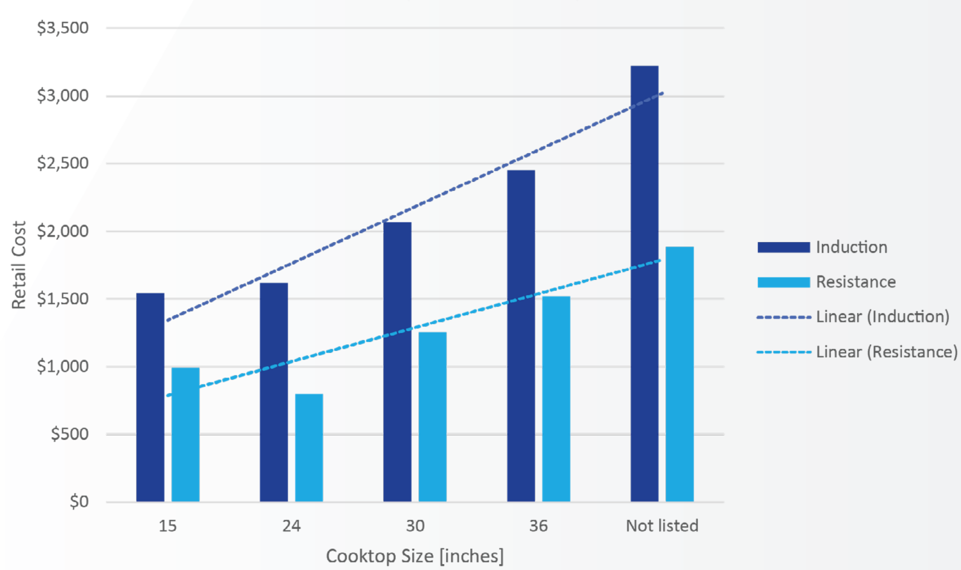
- Installing an inductive cooktop requires incremental installation costs ranging from $210–$280 depending on existing electrical infrastructure.
- Compared to the highest tier resistance option, equipment price increases by ~72% and installation cost increases by ~180% (Figure 23) as they include the price of the required ferrous cooking equipment.
- Market analysis from eight leading brands indicates induction and resistance retail prices increase with cooktop size relatively linearly. 30- and 36-inch cooktops covered over 70% of the models analyzed (Figure 24).
- Retail prices for induction cooktops for the eight market players analyzed were around $2,000, with Miele® and Whirlpool® units standing out as more and less expensive, respectively. Resistance retail prices were more variable, with Sub-Zero®, Wolf®, and Miele® emerging as more expensive and Whirlpool® & Electrolux® as cheaper on average.

Figure 23: Electric Smooth Element Cooktop Costs

EL	Equipment Price (2018$)	Installation Cost (2018$)	Total Installed Cost (2018$)
Baseline	$ 407.78	$ 131.36	$ 539.14
1	$ 408.81	$ 131.36	$ 540.18
2	$ 410.49	$ 131.36	$ 541.86
3 (induction)	$ 704.73	$ 367.40	$ 1,072.12

Source: DOE, 2020

Figure 24: Retail Pricing by Cooktop Size



Source: Leading Brand Websites, 2021

Induction cooktop growth is expected to outpace electric cooktop market growth despite cost

INDUCTION MARKET SIZE

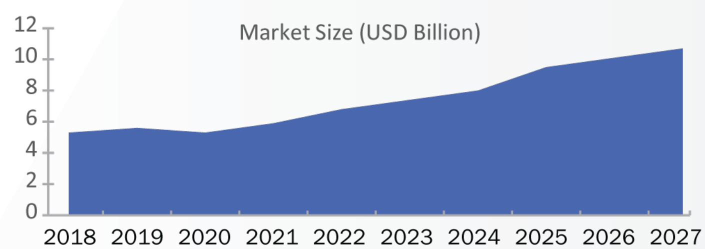
- Electric cooking sales have declined by ~19% from 2006–2017 as has their percent of total sales compared with gas-declining from 63% to 58% market share over the same period (Figure 25).
- Induction cooktop CAGR is projected to be 8.1% from 2021–2028 (Figure 26) in North America, slightly less than the global CAGR of 8.5% over the same period.
  - Growth drivers include residential development projects.
- Global induction cooktop market size was $18.7B in 2020; projected to be $35.96B by 2028.
- Built-in induction cooktops captured more of the market than free-standing cooktops with a 62% market share, and the residential sector dominated the market with a revenue share of ~72%.
- E-commerce for cooktops has become increasingly popular.
- Europe was the largest regional market with a revenue share of 35.5% in 2020, with North America as a relatively close second (Figure 27).

Figure 25: Electric and Gas Cooking Equipment Sales (Thousands of Units)

	Electric Cooking				Gas Cooking			
Year	Electric Ranges	Electric Ovens	Surface Cooking Units	Total Electric	Gas Ranges	Gas Ovens	Surface Cooking Units2	Total Gas
2017	4638		376	5014	3105		502	3607
2016	4528		356	4884	3042		458	3500
2015	4246		357	4603	2813		435	3248
2014	4078	718	335	5131	2628	30	403	3061
2013	3791	677	326	4794	2478	33	369	2880
2012	3439	589	304	4332	2275	31	304	2610
2011	3424	574	320	4318	2286	39	300	2625
2010	3509	604	335	4448	2432	44	314	2790
2009	3448	549	336	4333	2264	44	291	2598

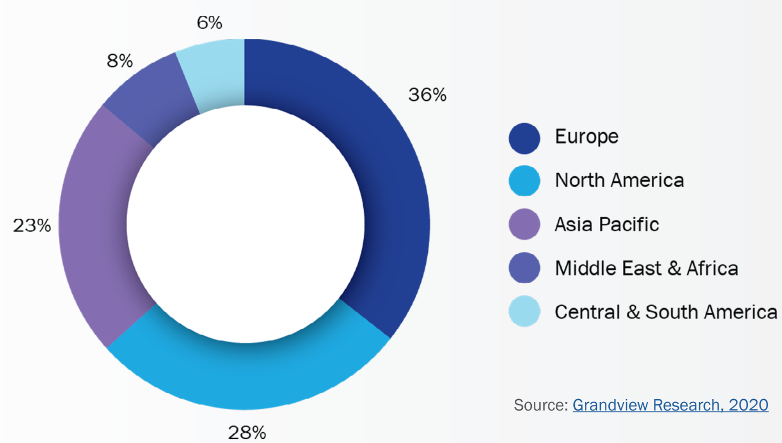
Source: DOE, 2020

Figure 26: North American Induction Cooktop Market



Source: Grandview Research, 2021

Figure 27: Global Market Segment by Region



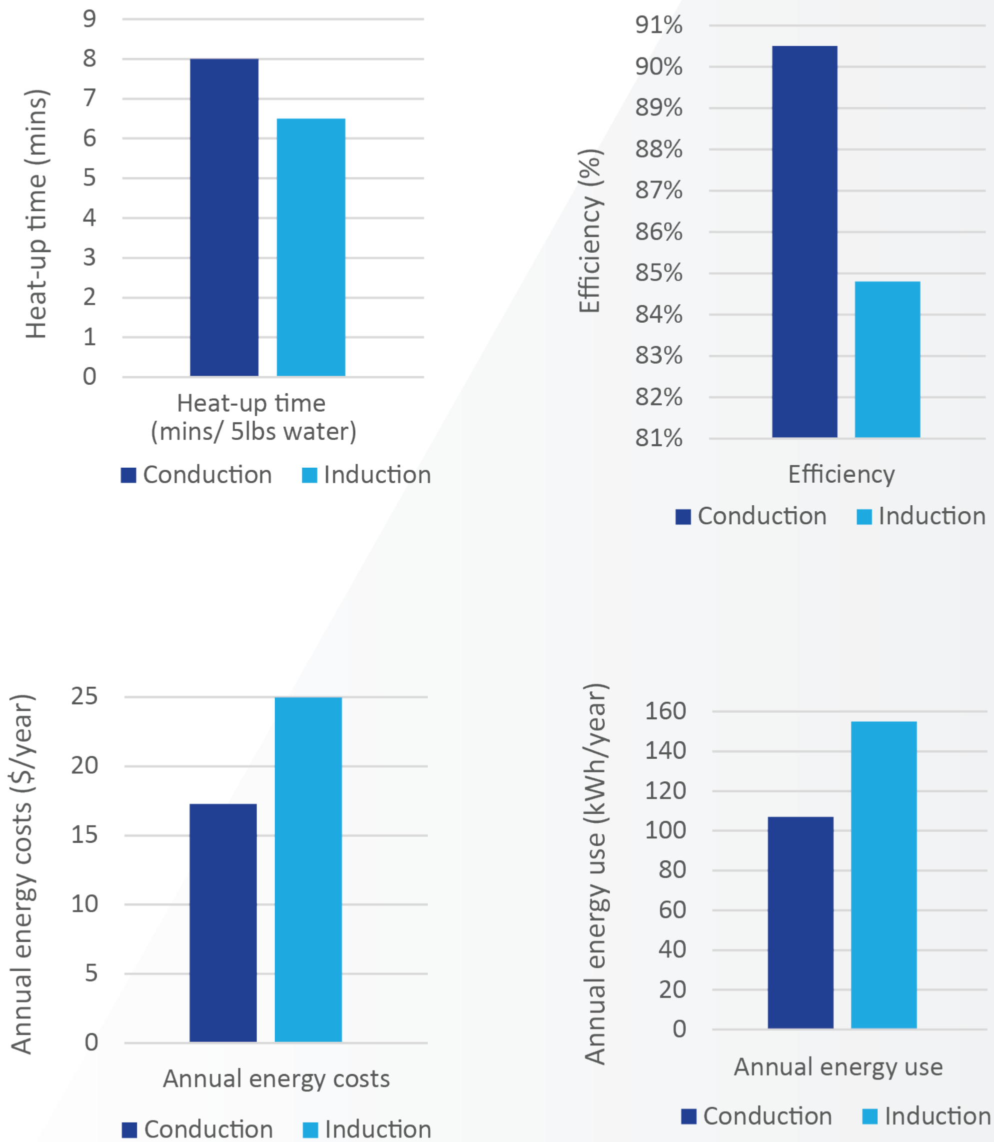
Source: Grandview Research, 2020

Conduction prototypes show promise

COOKTOP ELECTRIC INNOVATION

- Condeco's conduction prototype offers 90.5% efficiency as well as meaningful savings for higher usage households, especially those that operate in simmer mode frequently (Figure 28). When commercialized, it has significant potential.

Figure 28: Performance for Conduction Prototype vs. Induction



Source: [Frontier Energy, 2019]

Federal policy is increasingly focused on **GHG** emissions reductions.

THE CLEAN AIR ACT

The 1990 Clean Air Act is the most recent version of a law first passed in 1970 to clean up air pollution; it contains key provisions to control common pollutants which had formed dense, visible smog in many of the nation's cities and industrial centers. The Act calls for states and the EPA to solve this and other air pollution problems through programs based on the latest science and technology information. Congress designed the law to minimize pollution increases from the growing numbers of motor vehicles, and from new or expanded stationary sources, such as buildings. It calls, for example, for new stationary sources to be built with the best technology, and allows less stringent standards for existing stationary sources.

PARIS CLIMATE AGREEMENT

The Paris Agreement is a legally binding international treaty on climate change that was adopted by 196 Parties in 2015. The Agreement provided a global framework to avoid climate change by limiting global warming to below 2°C and pursuing efforts to limit it to 1.5°C. It also aimed to strengthen countries' ability to deal with the impacts of climate change and support them in their efforts.

The agreement stressed the need for global emissions to peak as soon as possible but did not set specific emission reduction goals. The U.S. plan submitted to the United Nations Framework Convention on Climate Change in advance of Paris in 2015 was to reduce emissions by 26%–28% below 2005 levels by 2025. This translates to a reduction of 13%–15% below 1990 levels by 2025. After dropping out of the agreement and rejoining in 2021, the U.S. is on track to meet this goal.

THE INITIATIVE FOR BETTER ENERGY, EMISSIONS, AND EQUITY

The Iniative for Better Energy, Emissions, and Equity, also known as the E3 Initiative, will focus on advancing the research, development, and national deployment of clean heating and cooling systems including heat pumps, advanced water heaters, low-to-no GWP refrigerants, and smarter HVAC diagnostic tools in residential and commercial buildings.

Through this Initiative, the DOE will work to develop regional solutions that support both technology innovations and accelerate deployment. The DOE is launching several efforts to make clean and efficient building technologies easier and cheaper to install including:

- The Better Buildings Low Carbon Pilot
- The Residential HVAC Smart Diagnostic Tools Campaign
- The Advanced Water Heating Initiative
- The Residential Cold Climate Heat Pump Challenge

PRESIDENT BIDEN'S BIPARTISAN INFRASTRUCTURE INVESTMENT & JOBS ACT

In November 2021, Congress passed the Bipartisan Infrastructure Deal (Infrastructure Investment and Jobs Act) to grow the economy sustainably and equitably. Although $387 billion was originally proposed for the area of Housing, Schools, and Buildings and $363 billion was proposed for the area of Clean Energy Tax Credits within the plan, neither of the two proposals made it into the bipartisan proposal that was ultimately passed.

BUILD BACK BETTER ACT

The Build Back Better Act offers opportunities to improve affordable housing, upgrade home heating, transform industry, boost affordable transportation options, and make other timely investments, some of which would reduce GHG emissions. The bill faces an uncertain future, but the version passed by the House in November 2021 included the following provisions:

- $5.89 billion in rebates for whole-home efficiency upgrades, with at least 25% going to LMI households plus $360 million for workforce training contractors;
- $6.25 billion in rebates to electrify space and water heating, with $3.8 billion dedicated to LMI and tribal communities;
- $2 billion (with up to $4 billion in lending authority) for improving energy and water efficiency;
- Updated and expanded tax incentives for efficient new and upgraded homes—including incentives for constructing new homes that are zero energy; and
- $300 million to support building codes.

DOE'S HOME PERFORMANCE WITH ENERGY STAR® PROGRAM

The U.S. DOE has upgraded one million American homes with energy efficiency improvements through the Home Performance with ENERGY STAR® program. This is a national home improvement program administered by DOE in collaboration with the U.S. EPA to improve the energy efficiency of single-family and low-rise multifamily homes. Since 2001, the program has helped American homeowners and renters save $7.7 billion on their energy bills and cut carbon emissions equivalent to a year's worth of 11 coal-fired power plants. The investments from the Bipartisan Infrastructure Deal and the Build Back Better agenda are planned to accelerate this program.

POLICY TIMELINE
CA STATE BUILDING DECARBONIZATION

California has a history of supporting building decarbonization. More recently, the State has taken direct action and set targets to help achieve higher levels of building efficiency and on-site renewable production.

2015

SB-350: Clean Energy and Pollution Reduction Act. *Established GHG reduction goal to reduce by 40 percent below 1990 levels by 2030 and 80 percent by 2050.*

SB 350 IN DETAIL: The Clean Energy and Pollution Reduction Act, or SB 350 established clean energy, clean air, and GHG reduction goals. The CEC is working with other state agencies, such as the California Public Utilities Commission, CARB, and the California Independent System Operator, to implement the bill. This act will increase the use of RPS eligible resources, including solar, wind, biomass, geothermal, and others.

2016

SB-32: California Global Warming Solutions Act of 2006. *Mandated GHG reduction by 40% below 1990 levels by 2030.*

SB 32 IN DETAIL: Direct emissions from buildings comprise 10% of the State's GHG emissions and mostly stem from natural gas appliances. In 2006, the legislature adopted the AB 32 that required California to reduce GHG emissions to 1990 levels by the year 2020; this goal was met early in 2016. SB 32 continued that effort to reach further targets and provided another intermediate target between 2020 and 2050. SB 350, for example, increased California's renewable electricity procurement goal from 33% by 2020 to 50% by 2030. This bill gave the CARB the authority to adopt further regulations to ensure the technology used in buildings is chosen to be the most cost-efficient way to reduce GHG emissions.

2018

SB-1477: Low-Emissions Buildings and Sources of Heat Energy. *Developed BUILD and TECH initiatives to advance building decarbonization.*

SB 1477 IN DETAIL: The Low-Emissions Buildings and Sources of Heat Energy, or SB 1477, authorized $50 million per year through 2023 to reduce direct GHG emissions from buildings by developing two clean building pilot initiatives, BUILD and TECH. They are funded from the GHG emission allowances directly allocated to natural gas corporations and consigned at auction through CARB's Cap and Trade program.

AB-3232: Zero-Emissions Buildings and Sources of Heat Energy. *Passed and directed the CEC to study the potential to reduce GHGs from buildings to 40% below 1990 levels by 2030.*

AB 3232 IN DETAIL: The Zero-emissions Buildings and Sources of Heat Energy, or AB 3232 required the CEC to assess the potential for the state to reduce GHG emissions from residential and commercial building stock by at least 40% below 1990 levels by 2030. The CEC was also tasked to identify policies that would enable the building sector to reduce emissions. AB 3232 was designed to put California on a path to require all new buildings be zero-emission after 2030.

SB-100: California Renewables Portfolio Standard Program. *Mandated renewable energy and zero-carbon resources supply 100 percent of electric retail sales by 2045.*

SB 100 IN DETAIL: The 100 Percent Clean Energy Act of 2018, or SB 100, set a 2045 goal of powering all retail electricity with renewable and zero-carbon resources, such as solar or wind energy. There is currently no comparable policy that exists for the natural gas system to reduce GHG emissions. The act formally requires a 60% renewable portfolio standard by 2030 and 100% of retail sales served by zero carbon electricity by 2045.

NET ZERO CARBON BUILDINGS COMMITMENT. *Required by 2030, that existing buildings reduce energy consumption and eliminate emissions and new construction follows highly efficient standards.*

NET ZERO CARBON BUILDINGS COMMITMENT IN DETAIL: In 2018, California joined the Net Zero Carbon Buildings Commitment, administered by the World Green Building Council for the Global Climate Action Summit. The commitment calls on signatories to enact regulations and planning policies to ensure that all new buildings operate at net zero carbon emissions by 2030 and all buildings by 2050.

2019

R.19-01-011. *Provided guidance to layer incentives so the cost of appliances is low enough to encourage fuel substitution.*

R.19-01-011 IN DETAIL: In 2019, the CPUC instituted a new rule on building decarbonization, R.19-01-011. The scope of the rule includes: (1) implementing SB 1477; (2) creating potential pilot programs to address new construction in areas damaged by wildfires; (3) coordinating CPUC policies with Title 24 Building Energy Efficiency Standards and Title 20 Appliance Efficiency Standards developed at the Energy Commission; and 4) establishing a building decarbonization policy framework. In this rule, the CPUC recommended incentives layering to reduce costs as much as possible. Energy efficiency incentives would establish an incentive "baseline" and further incentives could be added if market conditions allow. This approach aims to further building decarbonization adoption by allowing non-jurisdictional entities to adjust complementary incentive offerings and program rules to what local conditions demand. The CPUC further recommended an evaluation formula for program attribution.

D.19-08-009. *Modified the Fuel Substitution Test: removed barriers to installing electricity-based appliances.*

D.19-08-009 IN DETAIL: The CPUC established the Fuel Substitution Test in August 2019, Decision 19-08-009. The test clarified how to demonstrate that an existing building measure does not (1) increase total source consumption or (2) adversely impact the environment when compared with the baseline measure using the original fuel. In addition, this decision determined that a fuel substitution measure should no longer be required to pass a cost-effectiveness threshold at the measure level in favor for the overall portfolio level.

TITLE 24 BUILDING ENERGY EFFICIENCY STANDARDS AND TITLE 20 APPLIANCE EFFICIENCY STANDARDS. *Updated California building standards to focus on minimizing building GHG emissions.*

TITLE 24 IN DETAIL: The CEC's 2019 building energy efficiency standards, Title 24, became effective in 2020 and shifted from minimizing building energy use to minimizing building GHG emissions. Homes built under the 2019 standards are expected to use 53 percent less energy than those under the 2016 standards, which should reduce greenhouse gas emissions by 700,000 metric tons over three years.

SB 1477 IN DETAIL: Similarly to the Title 24 requirements, the CEC's appliance energy efficiency standards, Title 20, has been rolling out since January 2018. Title 20 sets minimum efficiency levels for energy consumption, water consumption and plumbing equipment in consumer electronics and household appliances.

In early 2019, city and county jurisdictions began to consider and pass reach codes, which are local ordinances that require more stringent building standards than the statewide Title 24 building code. While these codes can address several types of regulations (e.g., water conservation, electric vehicle charging infrastructure, etc.) Energy-related reach codes have been surpassing Title 24 regulation in recent years. Of the 58 counties and 482 cities in California, 52 jurisdictions have adopted some form of building electrification reach codes.

While some of the codes make modest modifications to Title 24, other codes are more elaborate. Cities such as Carlsbad and Berkeley, have reach codes that either require heat pump and solar water heaters to be used in residential buildings or require phasing out all gas hookups. Other cities such as Santa Barbara, Burlingame, Santa Cruz, and Daly City take it a bit further and require new construction to be all-electric.

Jurisdictions with Reach Codes within California

GLOSSARY: DESCRIPTION OF ABBREVIATIONS

AB	Assembly Bill
ASHP	Air-Source Heat Pump
ASHPWH	Air-Source Heat Pump Water Heater
BTUH	British Thermal Units per Hour
CAGR	Compound Annual Growth Rate
CARB	California Air Resources Board
ccASHP	Cold Climate Air-Source Heat Pump
CCE	Cool Climate Efficiency
COP	Coefficient of Performance
CPUC	California Public Utilities Commission
DF	Demand Flexibility
DOE	Department of Energy
DR	Demand Response
EE	Energy Efficiency
EER	Energy Efficiency Rating
ER	Electric Resistance Heating
EPA	Environmental Protection Agency
GHG	Greenhouse Gas
GSHP	Ground-Source Heat Pump
GWP	Global Warming Potential (Metric)
HSPF	Heating Seasonal Performance Factor
HVAC	Heating, Ventilation, and Air Conditioning
IEA	International Energy Agency
MMBTU	Million British Thermal Units
O&M	Operation and Maintenance
R&D	Research and Development
RPS	Renewables Portfolio Standard
SB	Senate Bill
SCOP	Seasonal Coefficient of Performance
SEER	Seasonal Energy Efficiency Rating

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