Energy+Environmental Economics

Residential Building Electrification in California

Consumer economics, greenhouse gases and grid impacts

Prepared for SCE, LADWP and SMUD

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Agenda

+ **Introduction**
+ **Methodology: Buildings and technologies**
+ **Consumer economics of building electrification**
    - Capital costs
    - Bill savings
    - Lifecycle savings
+ **Greenhouse gas savings and grid impacts from building electrification**
+ **Conclusions and Recommendations**

Study Approach, Team & Sponsors

Building Simulations
- Technology screening and efficiency assumptions
- Hourly energy demands
- Site energy consumption

Consumer Costs and Savings
- Capital cost, labor, and installation costs
- Monthly bill savings, current & projected
- Lifecycle costs and savings

GHG and Grid Impacts
- Greenhouse gas savings
- Changes in hourly electricity demand

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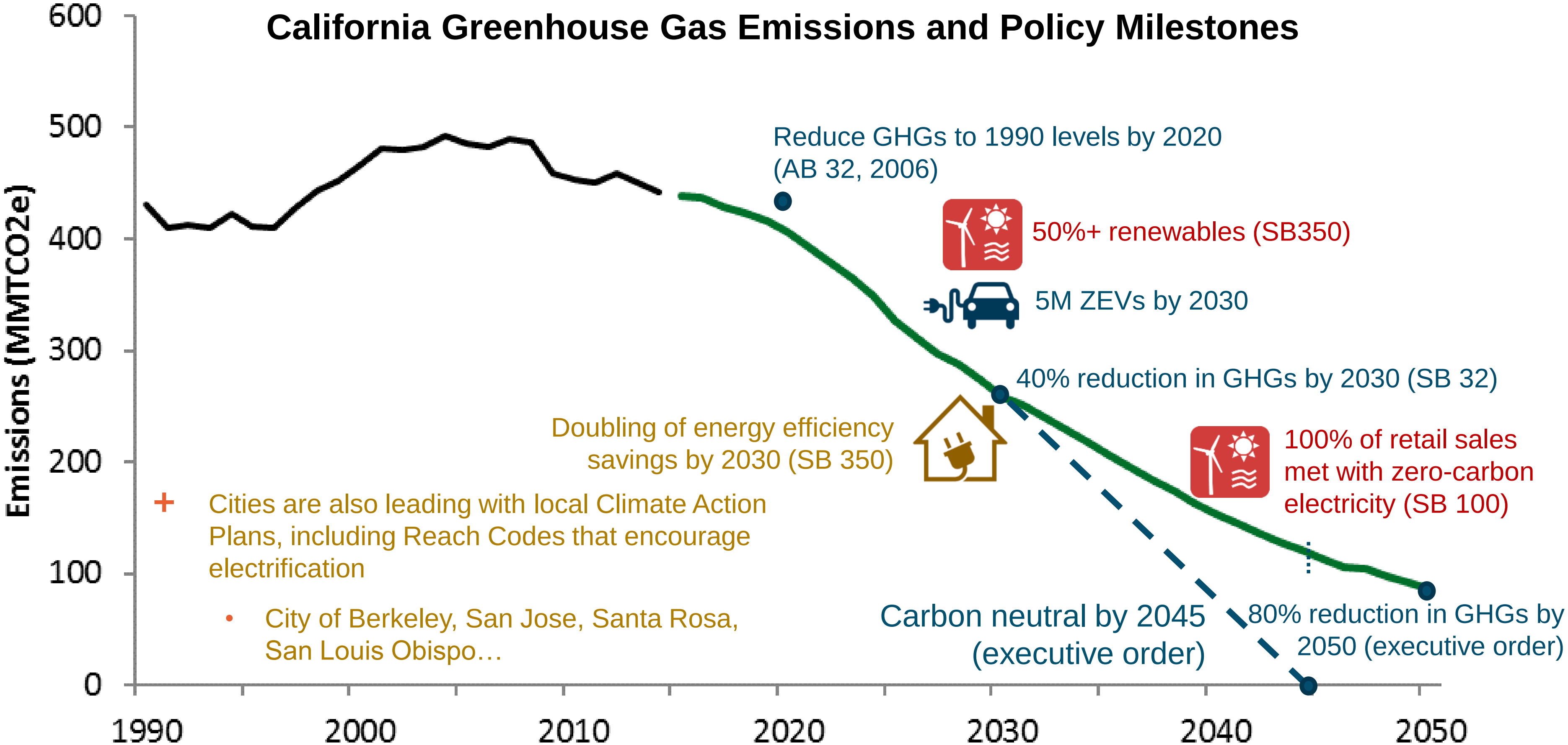
- Study was funded by: Southern California Edison (SCE), Los Angeles Department of Water and Power (LADWP) and Sacramento Municipal Utility District (SMUD)
- Study available at: https://www.ethree.com/publication/

California's commitment to climate action has deepened and broadened

+ **Achieving CA's climate goals will require _at least_ a 40% reduction in building sector GHGs by 2030, and an 80% reduction by 2050**



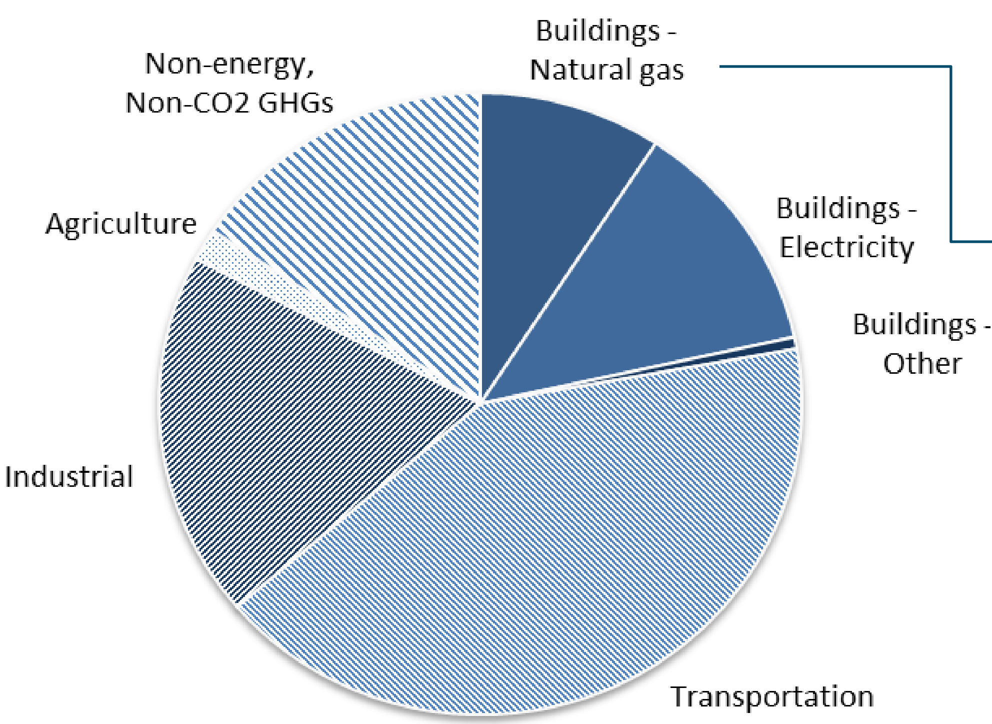
Source: E3 report on "Deep Decarbonization in a High Renewables Future" June 2018, CEC-500-2018-012

Heat pump & building electrification programs & policies in California

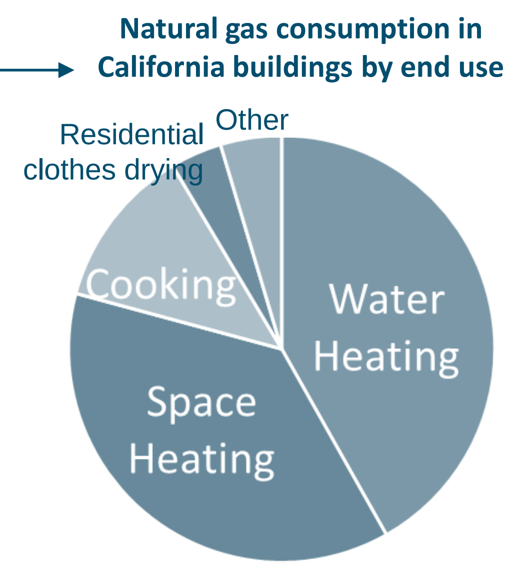
+ **SB 1477 (2018)**
  - $200 million to promote adoption of electric space and water heating in new and existing buildings, funded by gas customer cap and trade revenue
  - CPUC Building Decarbonization proceeding – implementing SB 1477 and assessing the role of utilities in building decarbonization
+ **AB 3232 (2018)**
  - Requires CEC to asses the potential to reduce GHG emissions in buildings by 40% below 1990 levels by 2040
+ **CEC Integrated Energy Policy Report**
  - Assesses role of building electrification in meeting climate goals. *"There is growing consensus that building electrification is the most viable and predictable path to zero-emission buildings" (2018 IEPR)*
+ **CEC Title 24 Building Code**
  - 2020 code update creates an all-electric baseline option for new construction
+ **40 cities statewide are considering reach codes that would favor all-electric new construction**
+ **Sacramento Municipal Utility District (SMUD)**
  - Home Performance Program with a go-electric bonus package, rebates up to $13,500
+ **PG&E pilot programs**
  - Advanced Energy Rebuild Program & Zonal Electrification Pilot, electrification incentives for areas impacted by wildfire
  - San Joaquin Valley Disadvantaged Communities Program replaces propane with electric end uses

California's greenhouse gas emissions by sector

+ **Buildings in California represent 20-25% of the state's total GHG emissions**



+ **Natural gas use in buildings represents 10% of total state GHG emissions, mostly space heating and water heating**

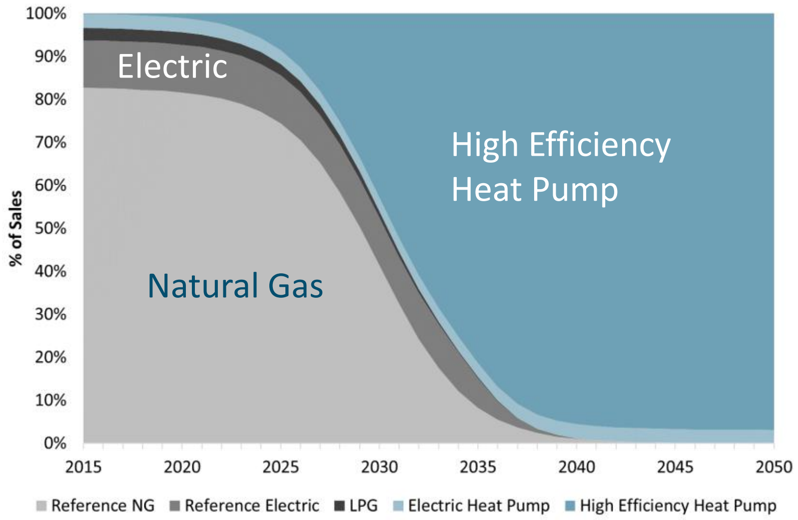


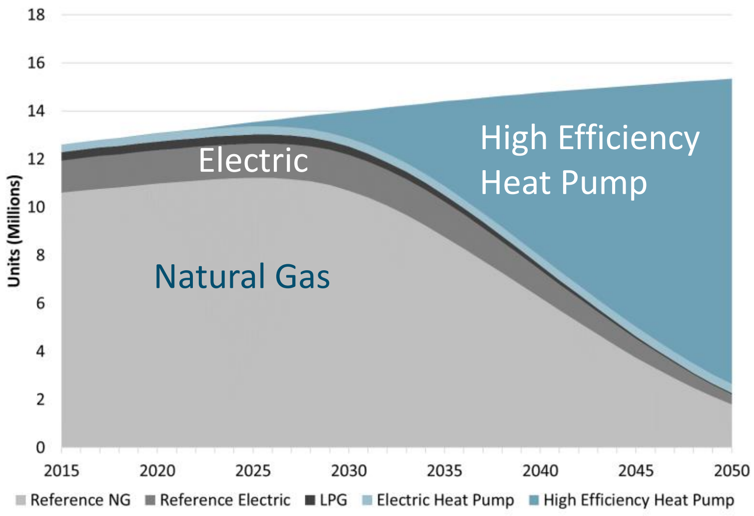
Source: Author's estimates based on E3's California PATHWAYS model v.2.3.2.

Prior analysis has assumed high levels of building electrification to meet CA's climate goals

Residential Space Heating Technology
(CEC PATHWAYS High Electrification Scenario)

Sales Share → **Equipment Stock**





- **Is this a realistic scenario from a consumer economics perspective?**
- **What policies or technology changes would be needed to achieve this future?**

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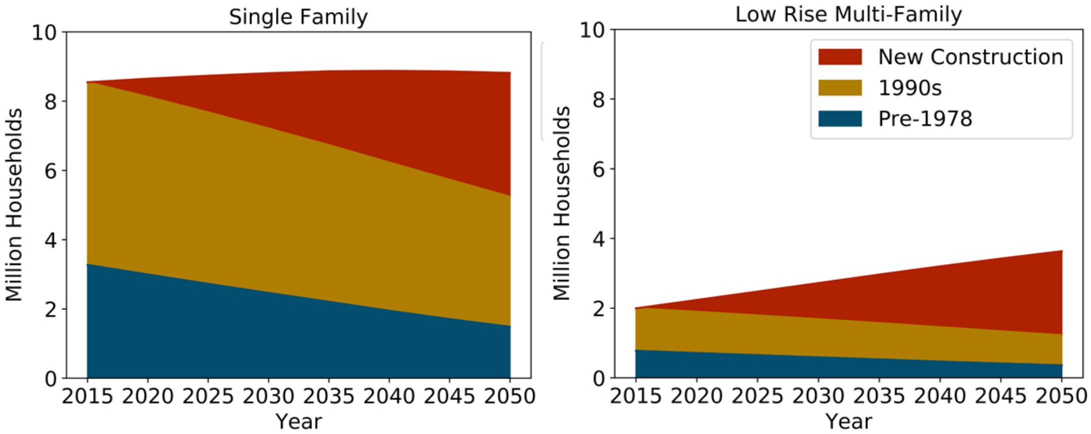
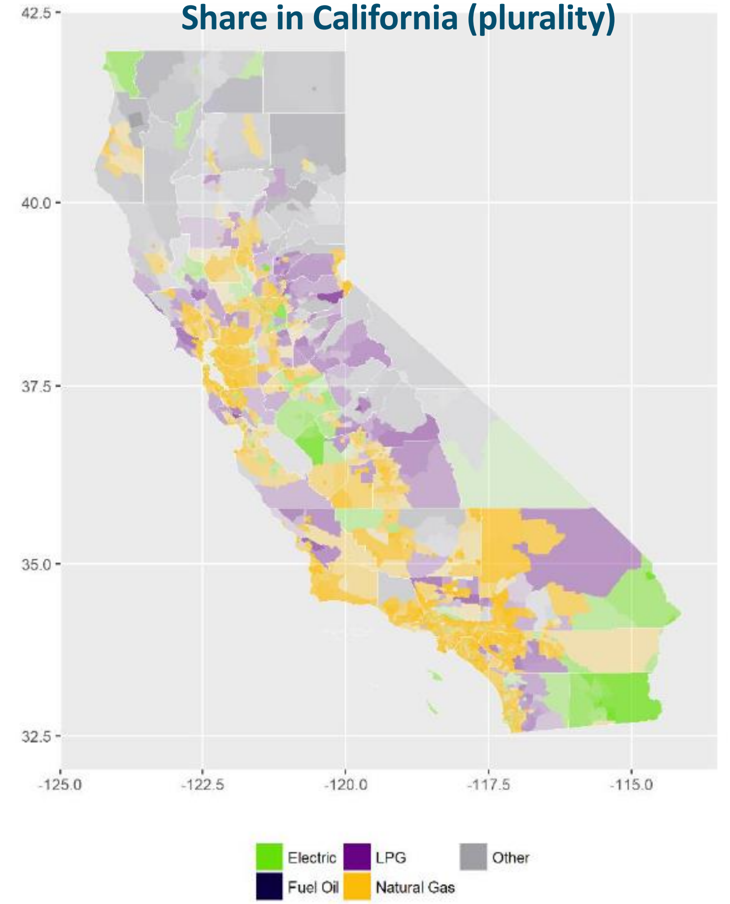
Buildings and Technologies

Building and appliance stock assumptions are based on population growth forecasts and California residential appliance saturation survey (RASS)

- 93% of homes in California's IOU service territory currently have gas space heating
- Even if California were to ramp up to 100% sales of electric heat pumps by 2040, getting to 90% heat pump adoption statewide would still require retrofitting at least half the existing residential building stock, more than 7 million homes, with electric heat pump space heating



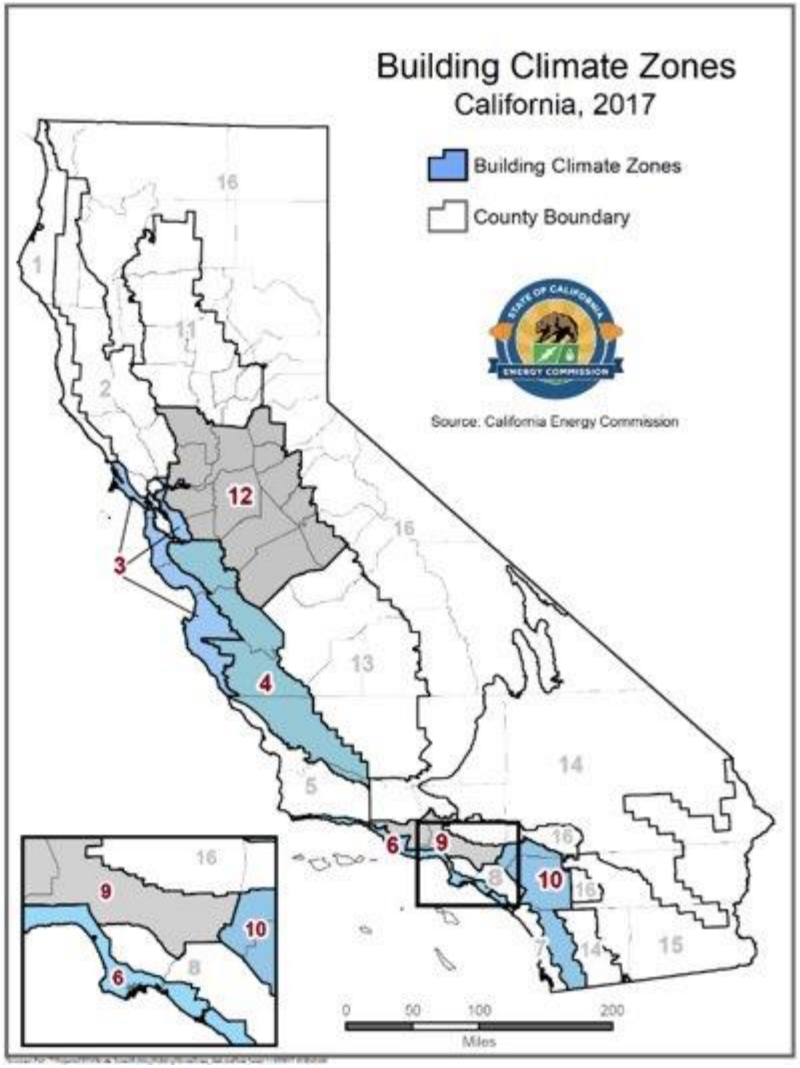
Residential Space Heating Fuel Market Share in California (plurality)



Source: Authors' visualization from E3 report on "Residential Building Electrification in California," April 2019. Data from the American Community Survey (2016). Only the plurality heating fuel is shown in each geographic region.

Six climate zones studied cover ~50% of California's population

Climate Zone	6 Major Cities
CZ03	San Francisco
CZ04	San Jose
CZ12	Sacramento
CZ06	Coastal LA
CZ09	Downtown LA
CZ10	Riverside



Six low-rise residential building types are simulated

- Using BEopt & EnergyPlus
- All retrofit single family homes are assumed to upgrade to ducted air conditioning systems for comparable comfort levels to electric heat pump homes

3 Vintages	Single family	Low-rise multi-family
Retrofit (Pre-1978) (No insulation, single pane windows)	**1,400 sf**	**8 units** (780 sf/unit and 960 sf/unit)
Retrofit (1990s) (T24 building code 1992 construction)	**2,100 sf**	**6 units** (1,500 sf/unit)
New Construction (2019 T24 building code)	**2,700 sf**	**8 units** (780 sf/unit and 960 sf/unit)

Studied residential end use technologies

- Heat pumps exceed code minimum, but represent commonly available tech.
- "Best-in-class" higher efficiency options are evaluated in sensitivity analysis

	Gas Home	Electric Home
HVAC	Gas Furnace + AC	Packaged Terminal Heat Pump OR Mini-split Heat Pump OR Ducted Split Heat Pump
Water Heating	Gas Storage WH (retrofits) OR Gas Tankless WH (new)	Heat Pump Water Heater
Cooking and Clothes Drying	Gas Stove OR Gas Dryer	ELECTRIC OR INDUCTION; ELECTRIC OR HEAT PUMP

Modeled Equipment Efficiency

Efficiency of HVAC Systems

HVAC Equipment	Modeled Efficiency
Furnace	80 AFUE ducted attic furnace
Split AC	14 SEER, 12.2 EER, 2-speed
Ducted Split Heat Pump	18 SEER, 14 EER, 10 HSPF, 2-speed
Mini-split Heat Pump	21 SEER, 13 EER, 11 HSPF
Packaged terminal heat pump	11 EER, 3.3 COP

Efficiency of Water Heating Systems

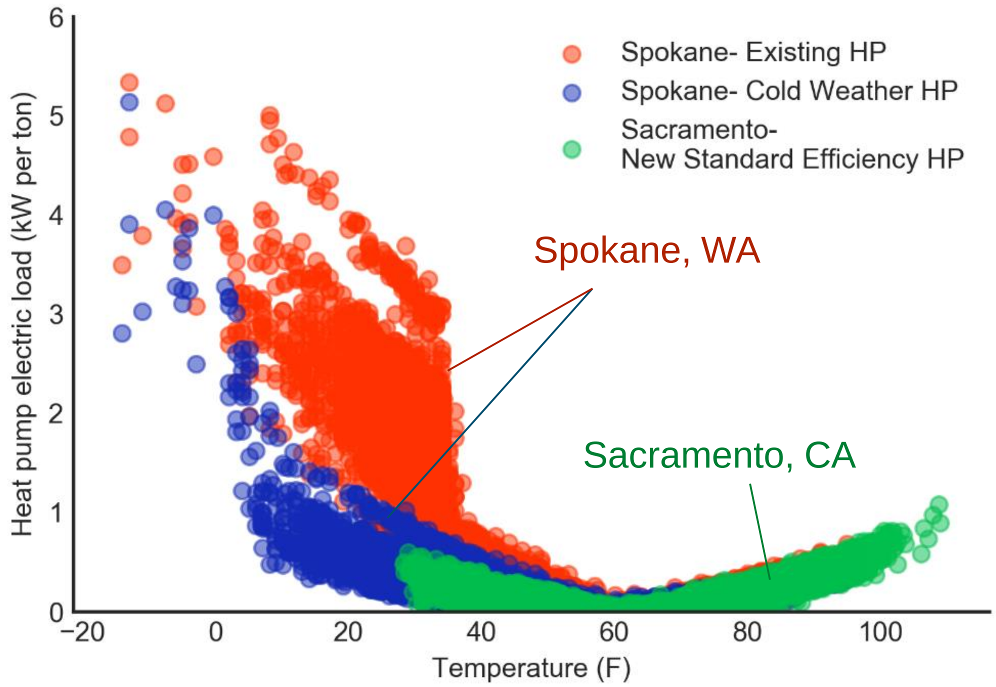
Water Heating Equipment	Modeled Efficiency
Gas Storage	0.63 UEF (0.60 EF)
Gas Tankless	0.81 UEF (0.82 EF)
Heat Pump	3.0 EF, NEEA Tier 3

Efficiency of Other Appliances

Appliances	Efficiency
Cooking	Cooktop: 0.4 Energy Factor Oven 0.058 Energy Factor
	Cooktop: 0.74 Energy Factor Oven 0.11 Energy Factor
	Cooktop: 0.84 Energy Factor Oven 0.11 Energy Factor
Clothes Dryer	2.75 Energy Factor
	3.1 Energy Factor
	4.2 Energy Factor
Clothes Washer	1.41 MEF

All simulation parameters and schedules are based on NREL's BEopt and the House Simulation Protocols

HVAC Heat Pump Performance depends on outdoor temperature & technology type



- With moderate climate in California, heat pumps maintain high efficiency (efficiency > 1) throughout the modeled weather year, supplemental electric resistance heat is not triggered in these simulations
- In low temperature conditions (30 degrees F or below), supplemental resistance heating (efficiency = 1) may be triggered; the temperature threshold depends on the heat pump technology

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Consumer Economics

Capital costs

Capital Costs

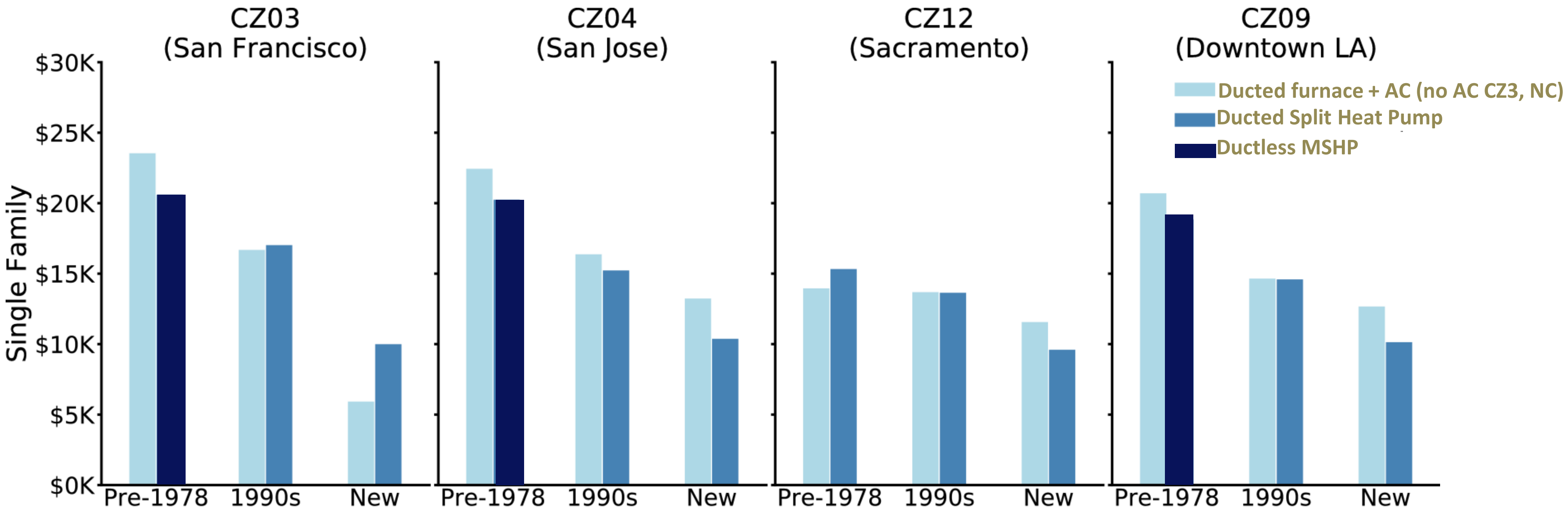
Example of installed equipment capital cost data developed for this analysis: Singe family HVAC heat pump retrofit, 1990s vintage, CZ06

- This study relied on a professional cost estimator (AECOM) to create a consistent set of data across technologies and climate zones
  - Cost assumptions for labor rates & mark-ups, installation, equipment
- Retrofits of HVAC account for the value of delayed AC replacement when gas furnace is replaced on burnout
- Panel upgrade costs applied to pre-1978 homes retrofitting to electric heat pump HVAC and DHW
- Avoided costs of natural gas infrastructure applied to all-electric new construction
- Capturing the variability in costs is a challenge, retrofit costs in particular are heterogeneous and site-specific

Demolition		
Remove existing furnace		
Labor		680
Disposal		500
		1,180
Installation		
Furnace	*Included in heat pump*	
New Furnace, equipment price		
Heating included in split system heat pump		
Miscellaneous supplies		
Labor		
Air Conditioner		
New Air Conditioner, equipment price	$	5,400
Ducted split heat pump AHU in attic,		
3-ton 18 SEER/14 EER, 10 HSPF, two-	$	-
Concrete pad, precast	$	100
Refrigerant piping and refrigerant	$	400
Miscellaneous supplies	$	400
Labor	$	1,360
Controls		
Thermostat & wiring	$	400
Gas and Electrical Supply		
New electrical circuits to equipment	$	190
Panel and main service modification	*Not required*	
Gas supply piping	*Not required*	
Labor	$	340
Ductwork modifications	$	-
Miscellaneous supplies	$	250
Labor	$	680
	$	9,520
Subtotal	$	10,700
	$	-
General Conditions and Overhead	$	1,605
Design and Engineering	$	1,231
Permit, testing and inspection	$	169
Contractor Profit/Market Factor	$	274
Recommended Budget	$	13,979

Single family HVAC capital costs

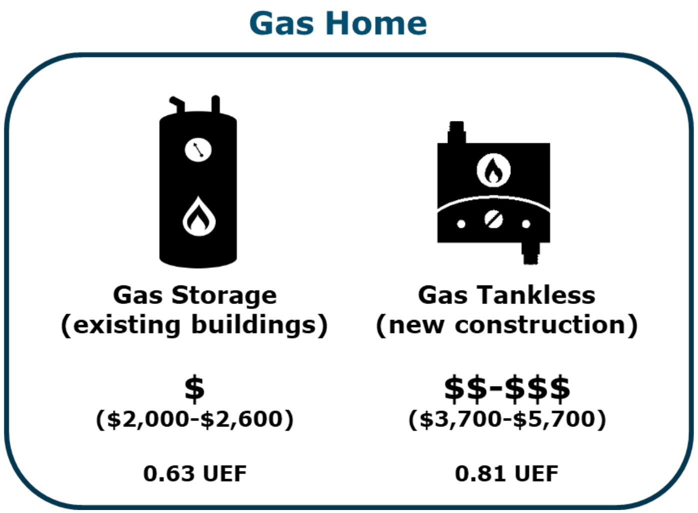
- Heat pump HVAC systems see capital cost savings in most homes with AC
- Retrofit assumptions matter a lot – are you adding ductwork for central AC?

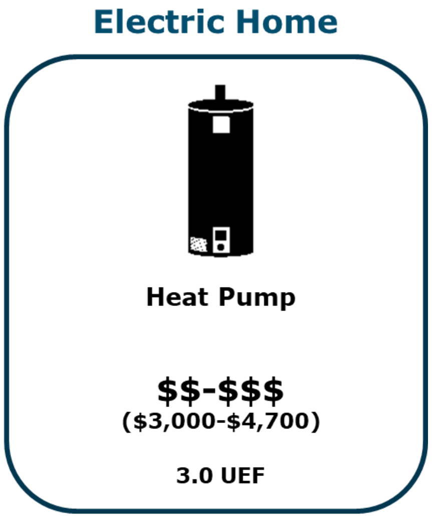


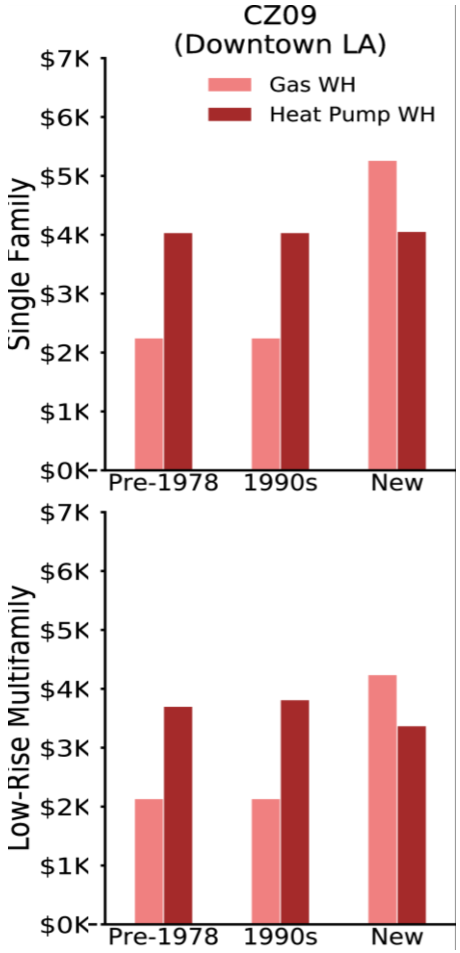
Existing system	CZ03 (San Francisco)	CZ04 (San Jose)	CZ12 (Sacramento)	CZ09 (Downtown LA)
Pre-1978	Wall furnace, no AC	Wall furnace, window AC	Ducted furnace + AC	Wall furnace, window AC
1990s	Ducted furnace, no AC	Ducted furnace + AC	Ducted furnace + AC	Ducted furnace + AC

Single Family
Hot Water Heater Capital Costs

- **Heat pump water heaters are more expensive than gas storage water heaters (retrofit)**
- **Heat pump water heaters are less expensive than tankless gas water heaters (new construction)**

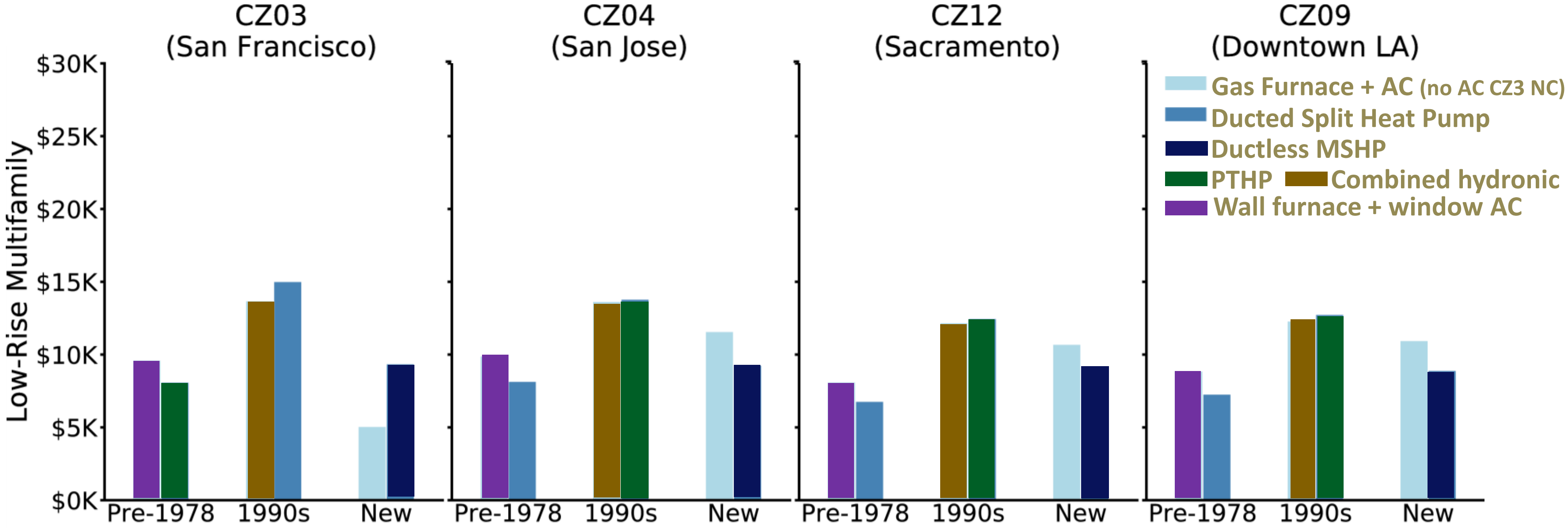






Low rise multi-family HVAC capital costs

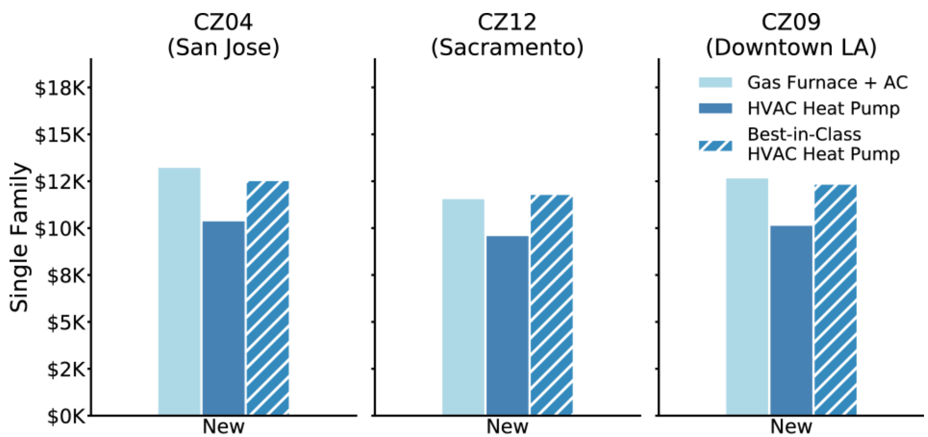
- Heat pump HVAC systems see capital cost savings in most homes with AC
- Multi-family HVAC costs are lower than single-family due to smaller sq.ftage



Existing system	CZ03 (San Francisco)	CZ04 (San Jose)	CZ12 (Sacramento)	CZ09 (Downtown LA)
Pre-1978	Wall furnace, no AC → wall furnace, window AC	Wall furnace, window AC	Wall furnace, window AC	Wall furnace, window AC
1990s	Combined hydronic, no AC	Combined hydronic, split AC	Combined hydronic, split AC	Combined hydronic, split AC

Heat pumps in new construction save upfront costs relative to mixed fuel home

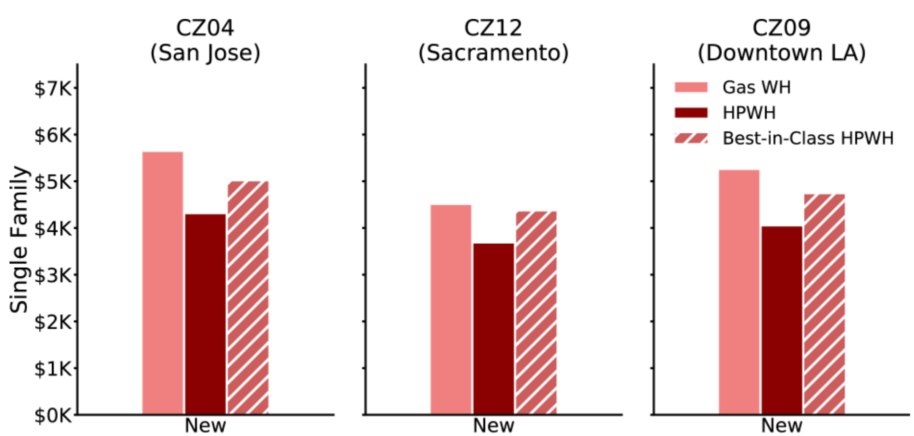
Capital Costs of HVAC Systems



Efficiency of HVAC Systems

HVAC Technology	Modeled Efficiency
Furnace	80 AFUE ducted attic furnace
Split AC	14 SEER, 12.2 EER, 2-speed
HVAC Heat Pump (Ducted Split)	18 SEER, 14 EER, 10 HSPF, 2-speed
Best-in-Class HVAC Heat Pump	21 SEER, 15 EER, 13 HSPF

Capital Costs of Water Heating Systems



Efficiency of Water Heating Systems

Water Heating Technology	Modeled Efficiency
Gas Storage	0.63 UEF (0.60 EF)
Gas Tankless	0.81 UEF (0.82 EF)
Heat Pump	3.0 EF, NEEA Tier 3, 3.5 COP
Best-in-Class Heat Pump	3.4 EF, NEEA Tier 3, 4.3 COP

Cooking and Clothes Drying Capital Costs and Performance

- Electric resistance clothes dryers are comparable in cost to gas clothes dryers
- Heat pump clothes dryers are more expensive than gas & currently may not perform as well as gas or electric resistance clothes dryers

Clothes Dryer

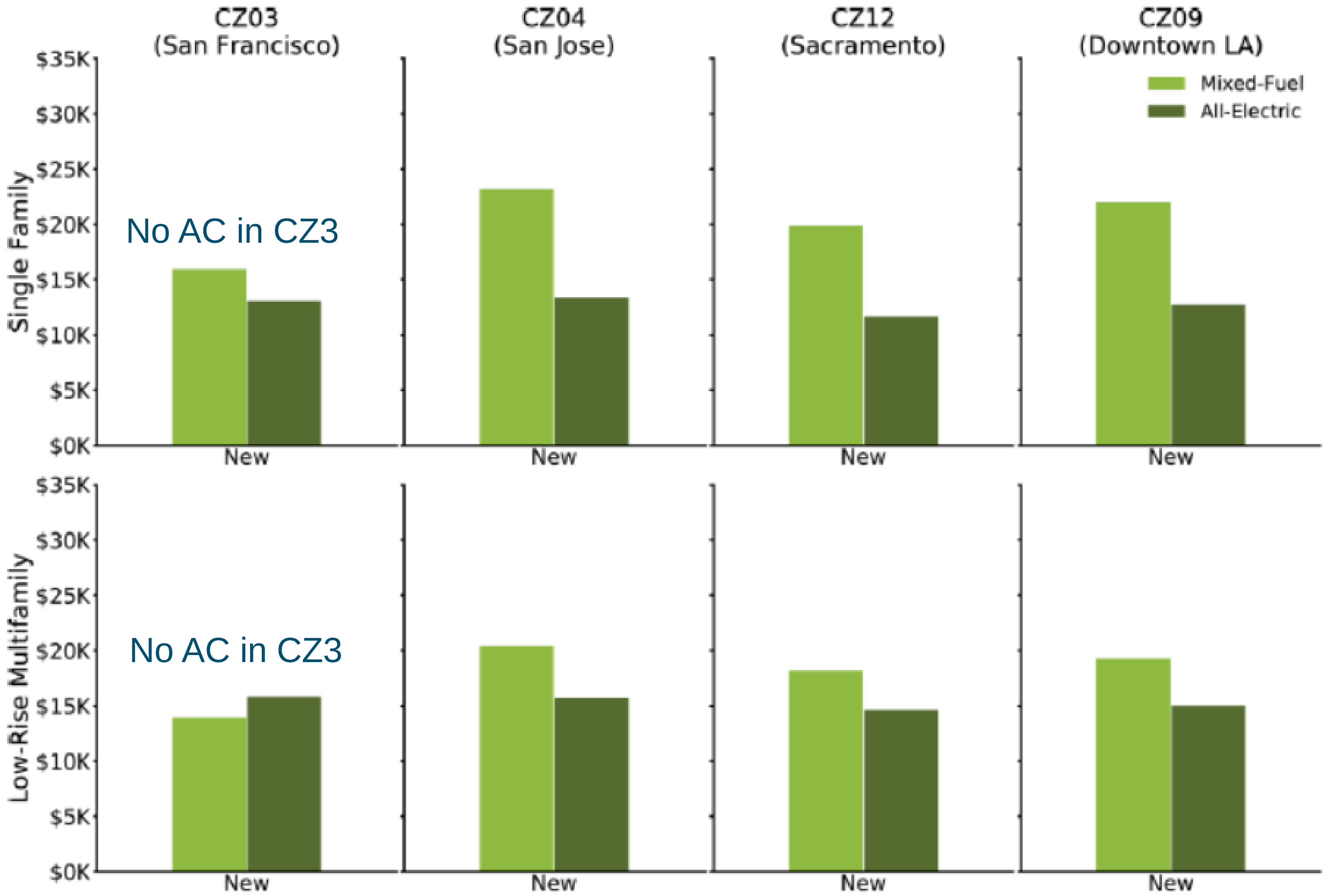
GAS	ELECTRIC	HEAT PUMP
$$	$$	$$$
$2,100	$2,100	$2,900
2.75 Energy Factor	3.1 Energy Factor	4.2 Energy Factor

- Induction (electric) cookstoves are slightly more expensive than gas stoves
  - Opinions about their performance vary, may perform better than gas
- Electric resistance cookstoves are comparable in cost to gas stoves, may not perform as well as gas

Cookstove

GAS	ELECTRIC	INDUCTION
$	$$	$$$
$1,400 – $2,200	$1,700 – $2,100	$1,900 – $2,300
0.4 EF cooktop 0.058 EF oven	0.74 EF cooktop 0.11 EF oven	0.84 EF cooktop 0.11 EF oven

All-electric new construction sees lower capital cost than mixed fuel homes



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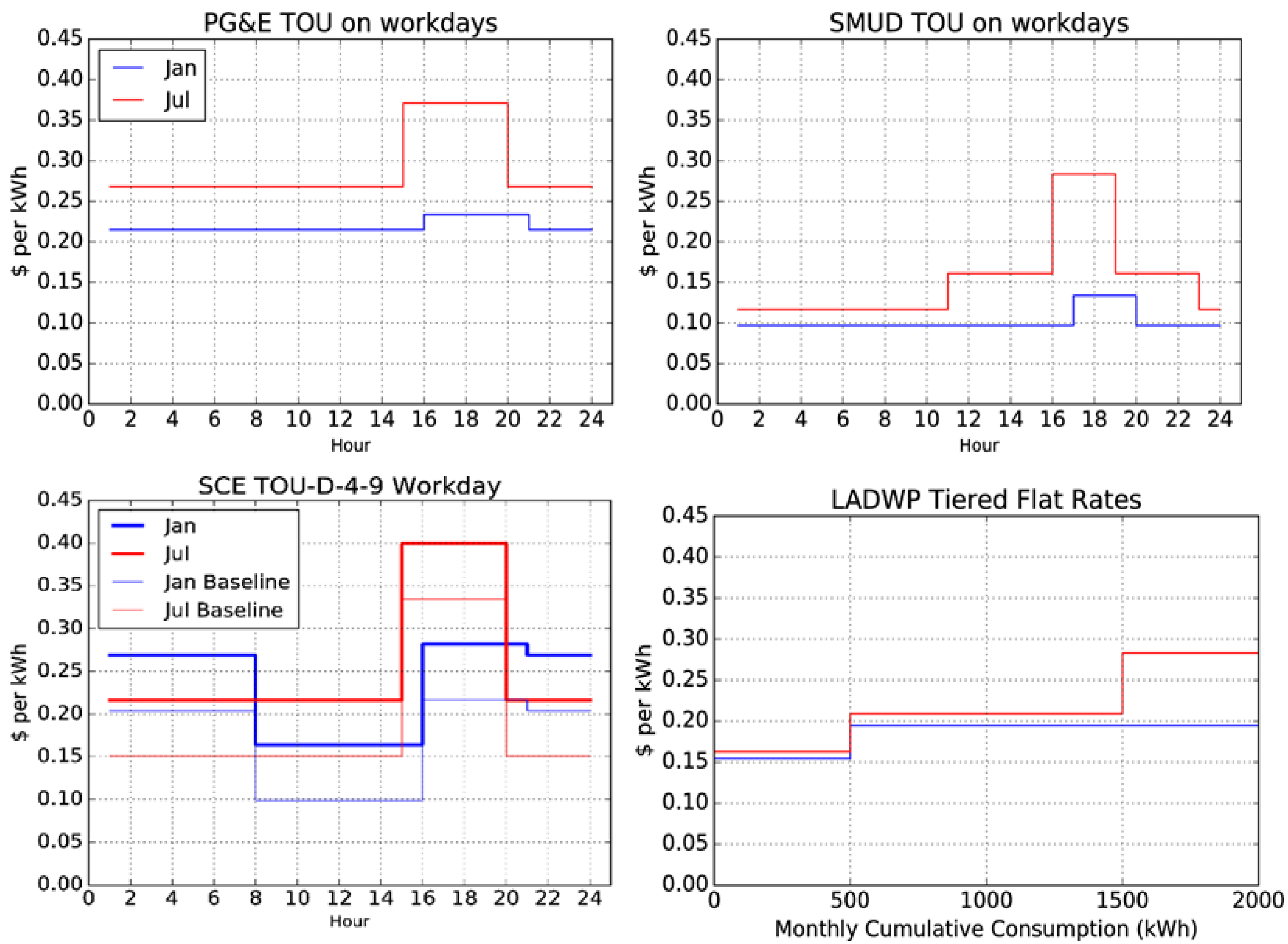
Consumer Economics

Bill Savings

Electric rate structures

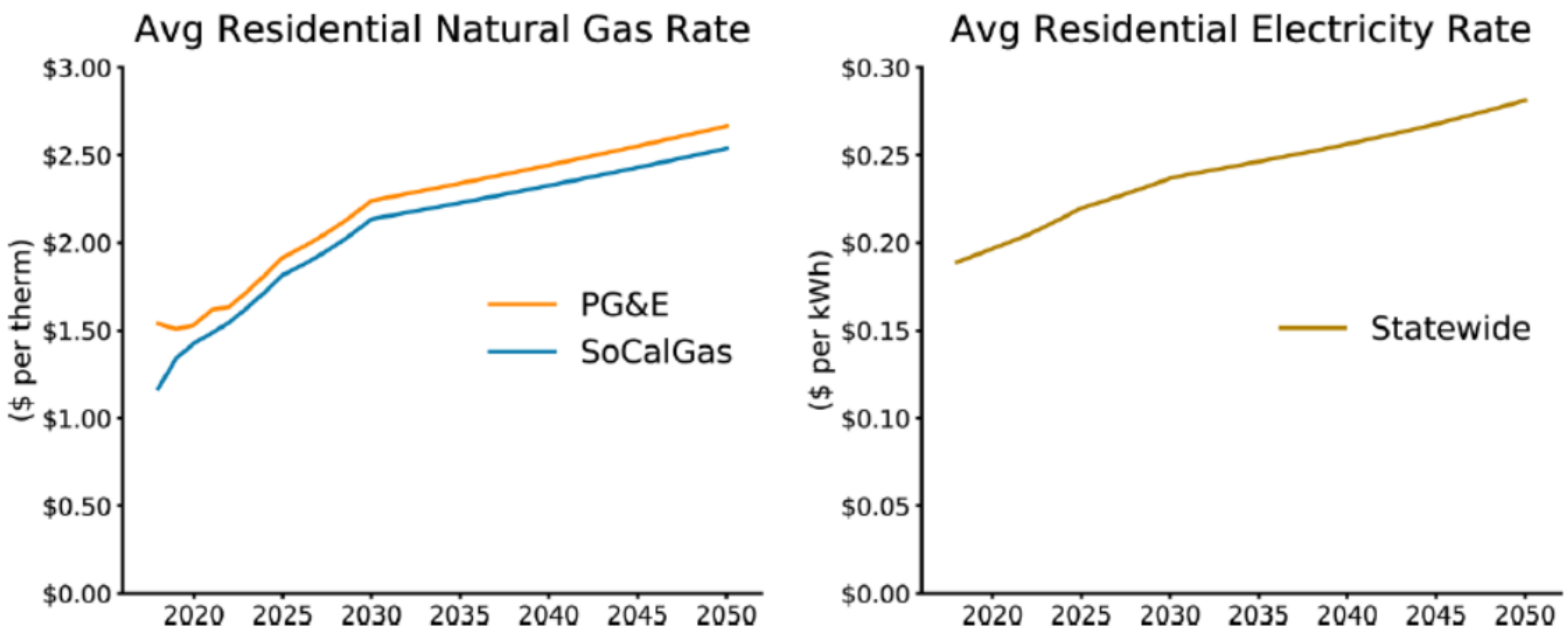
+ **Time-of-use rates are generally more favorable to electric end uses**



Utility Rate Escalation Assumptions

- Gas rate escalation assumptions are based on filed general rate case applications through 2022
- Electric rate escalation assumptions are based on recent trends
- Future gas & electric rates are uncertain, rate sensitivity was also tested

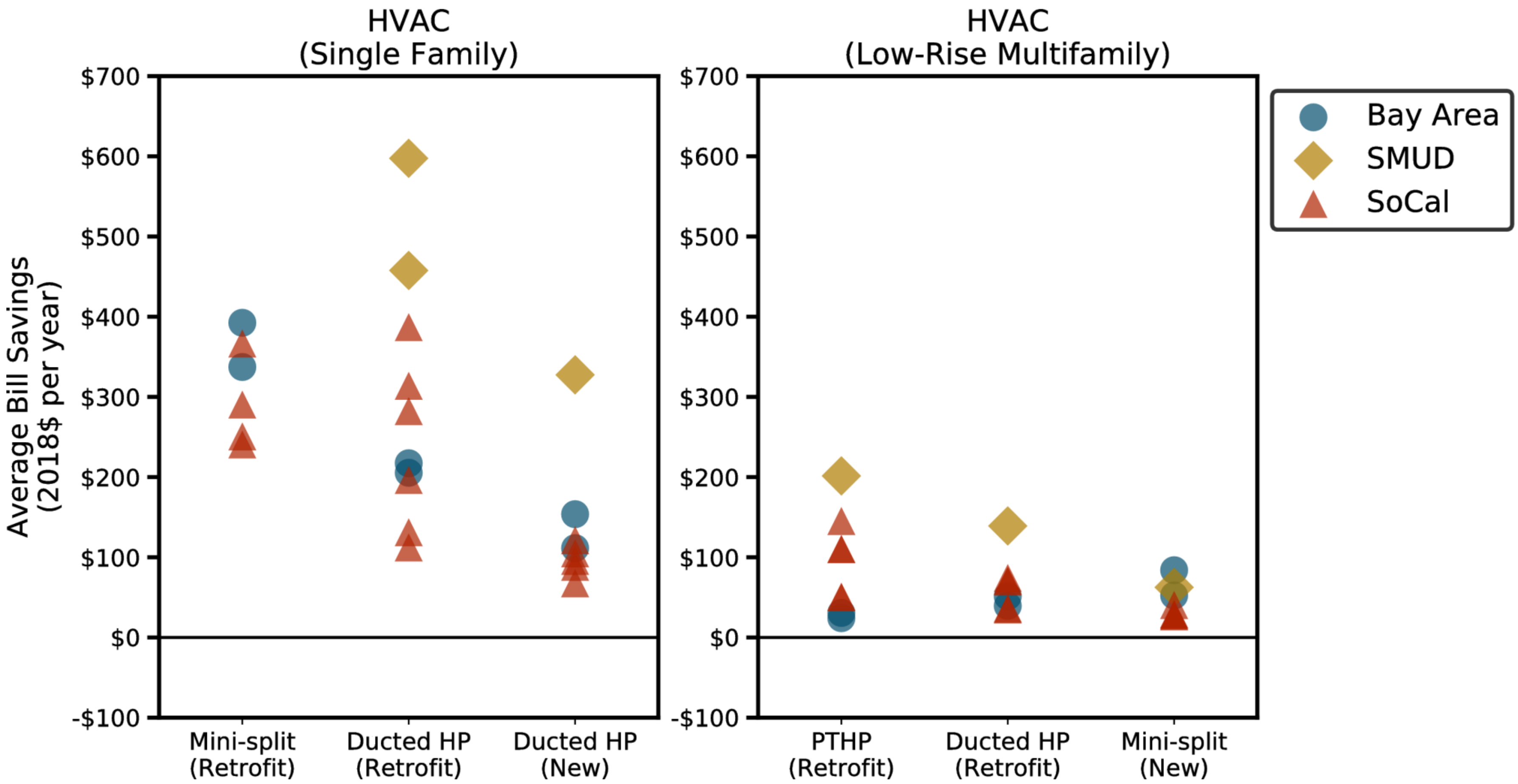
Figure 2-10: Residential natural gas and electricity rates, reference scenario (real 2018$)



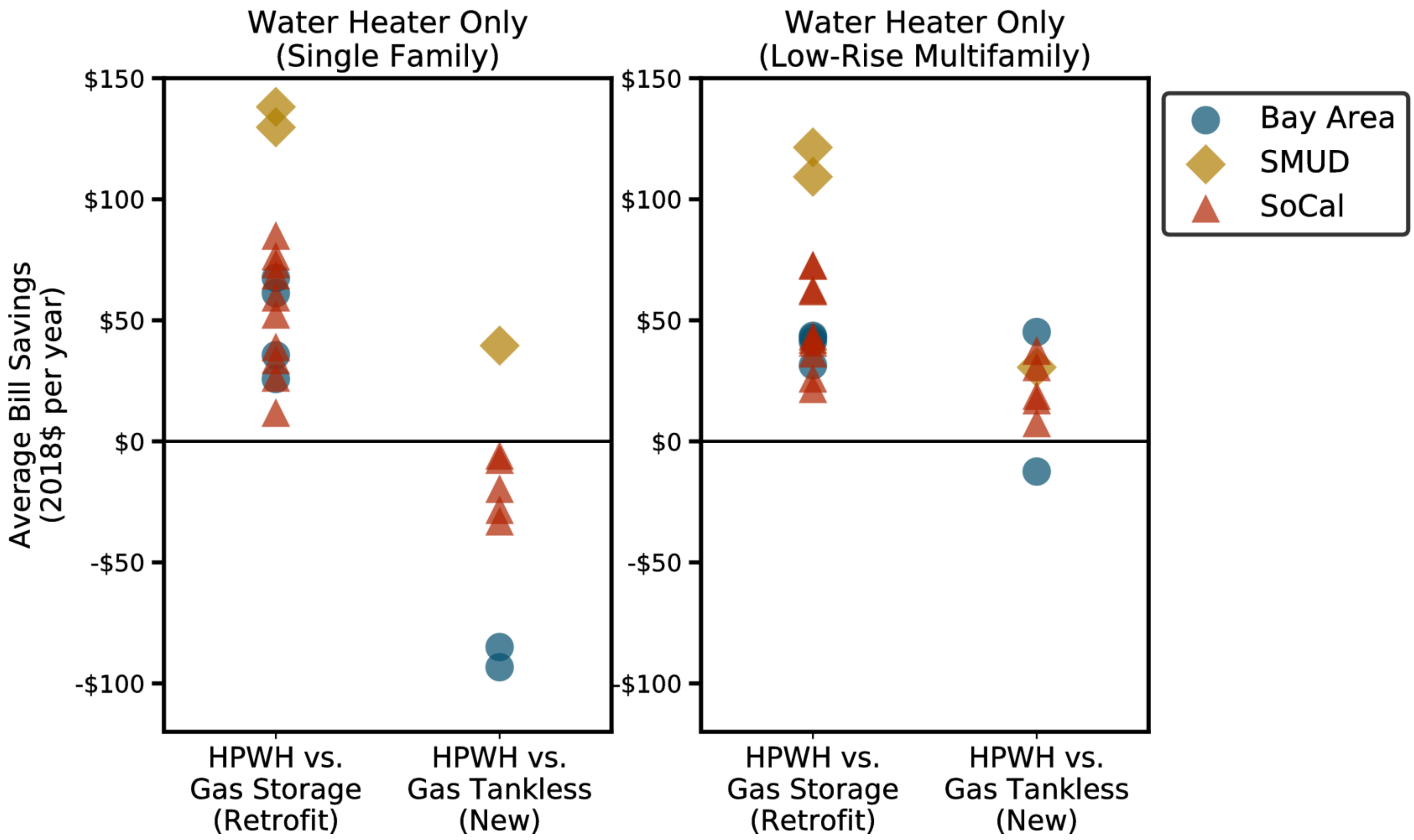
Rates are averaged over delivered natural gas for core customers and electricity for all end uses.

Heat pump HVAC results in utility bill savings, up to $600/year

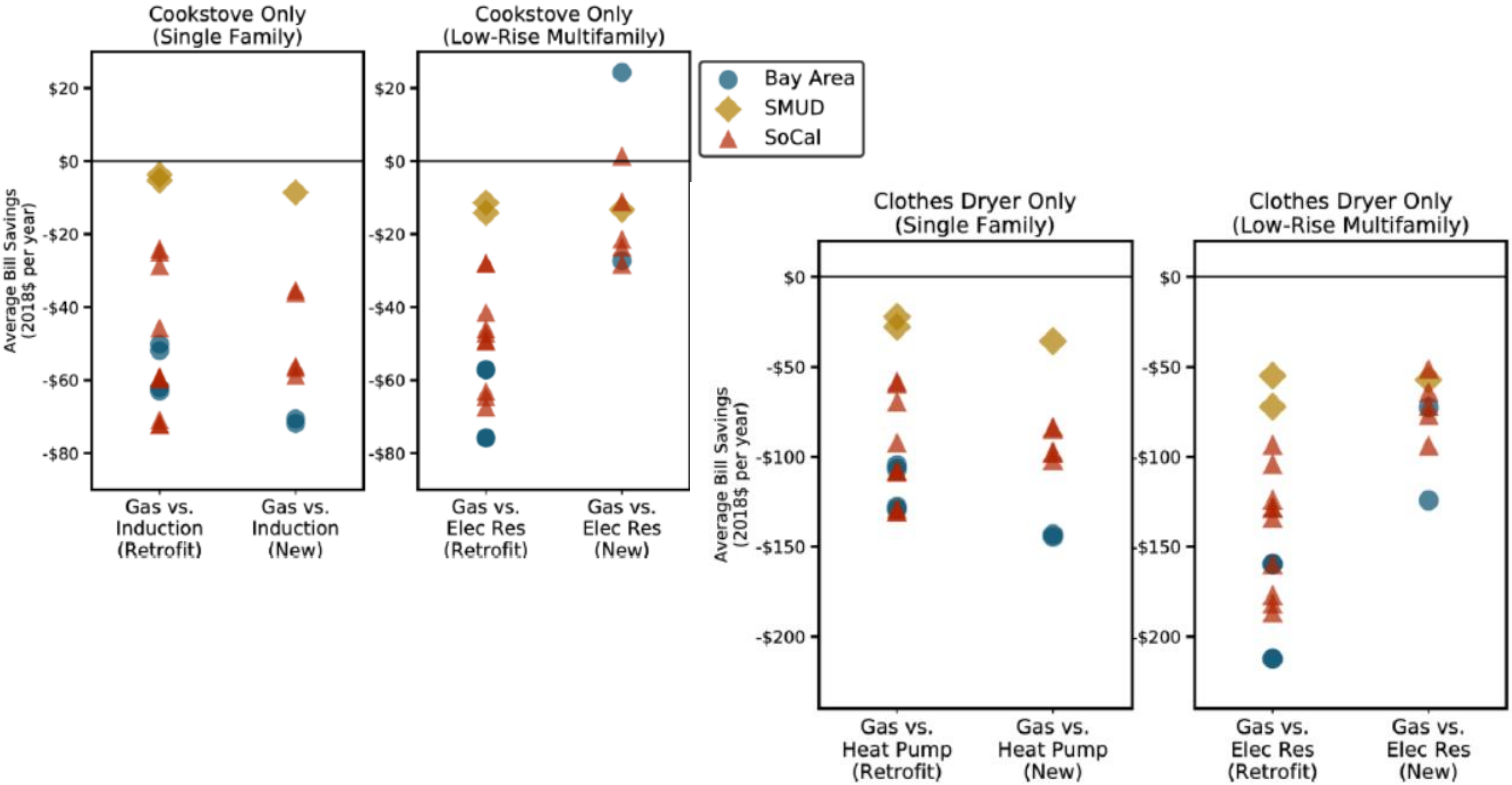
+ **Average bill savings = annual present value of the total bill savings of an appliance throughout its lifetime**



Heat pump water heater results in bill savings for retrofits, mixed story for new construction

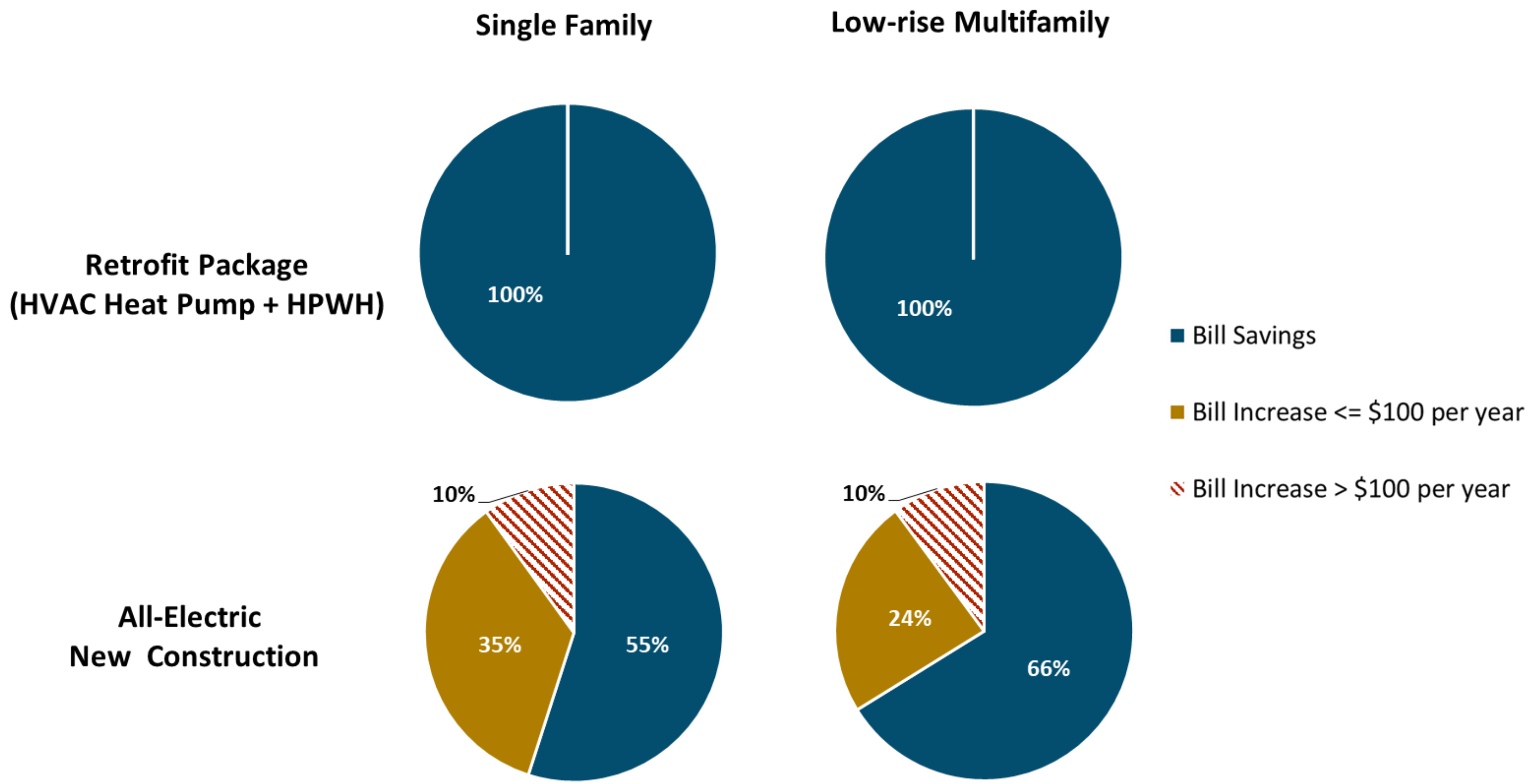


Electric cooking and clothes drying generally increase utility bills



Heat pumps save energy costs in all retrofit homes and the majority of new construction

Consumer Bill Impacts of Building Electrification



Consumer Economics

Lifecycle Savings

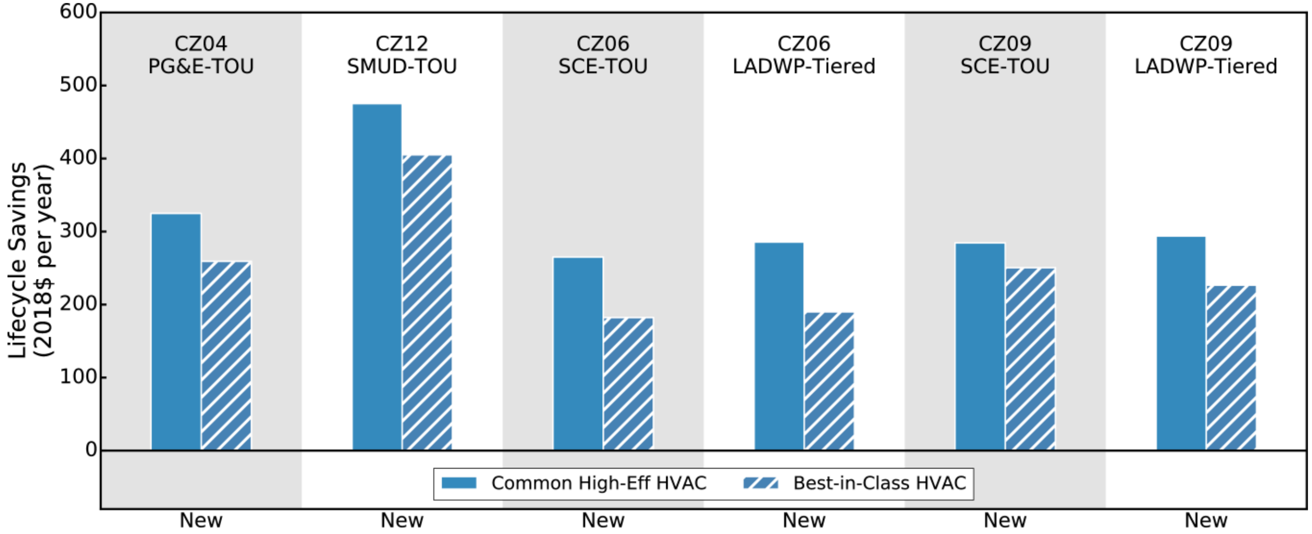
Lifecycle Cost Analysis

- Lifecycle cost = annual present value of the total capital costs and bill costs of an appliance throughout its lifetime
- 30 yr analysis period for new construction
- Equipment lifetimes used for lifecycle analysis of individual end uses
- 3.35% after-tax real discount rate

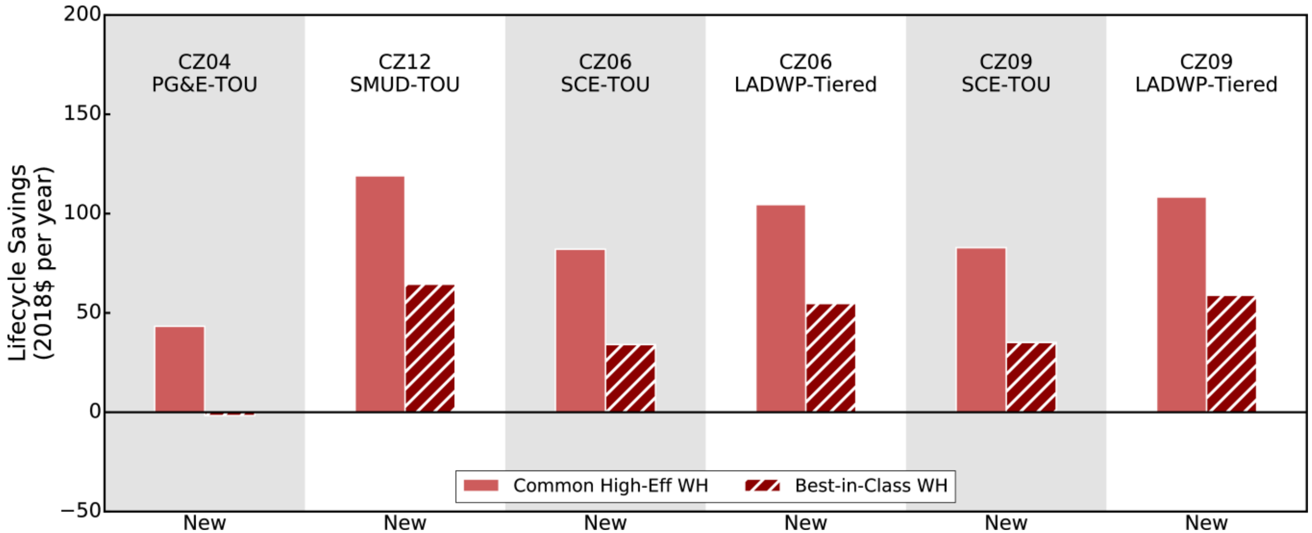
	Equipment lifetime
Heat Pump	18
Gas Fired Furnace	
Central AC	
Gas Water Heater	13
Heat Pump Water Heater	13
Cookstove	12
Clothes Dryer	13
All-Electric Home (for bill impact calculation only)	30

Best-in-class Heat Pump HVAC and Water Heaters are cheaper than gas equipment in lifecycle costs

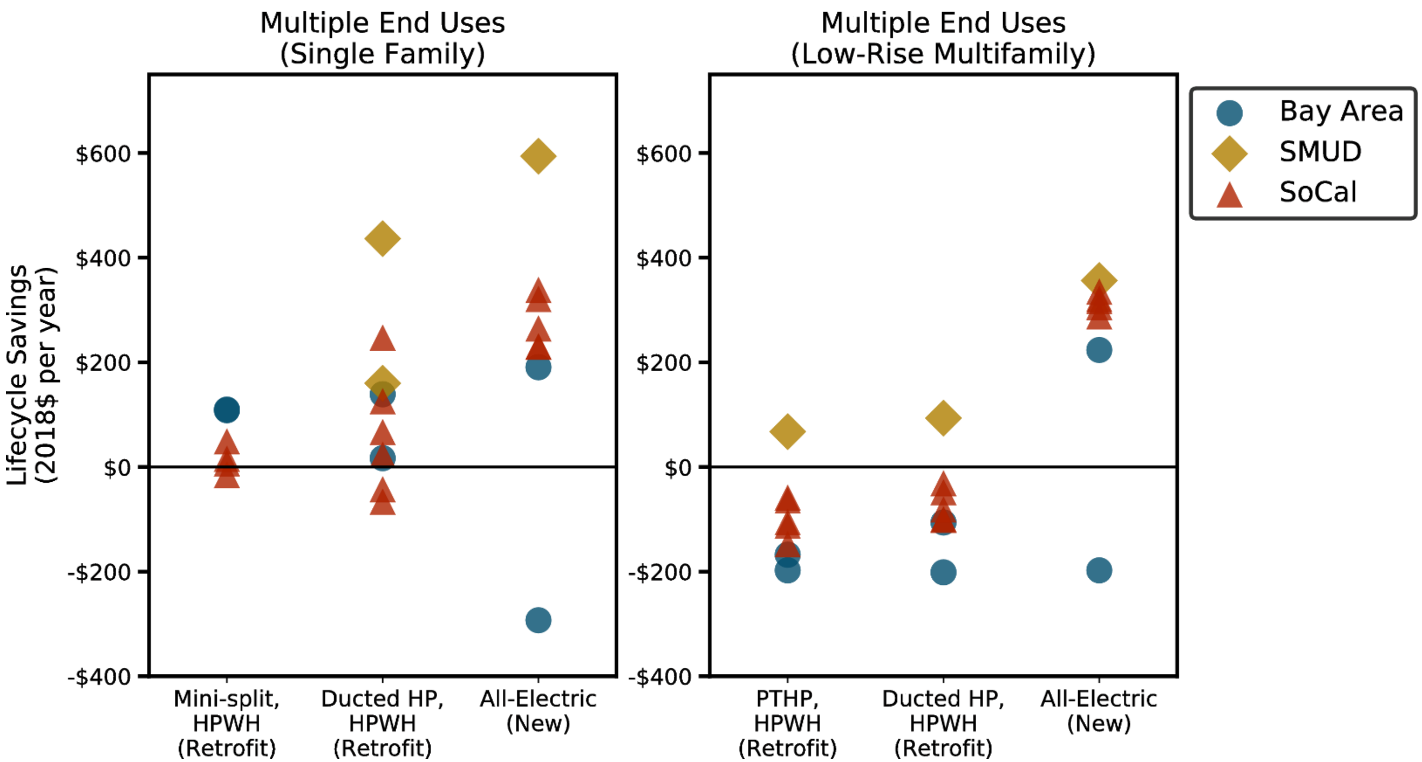
HVAC



Water Heaters



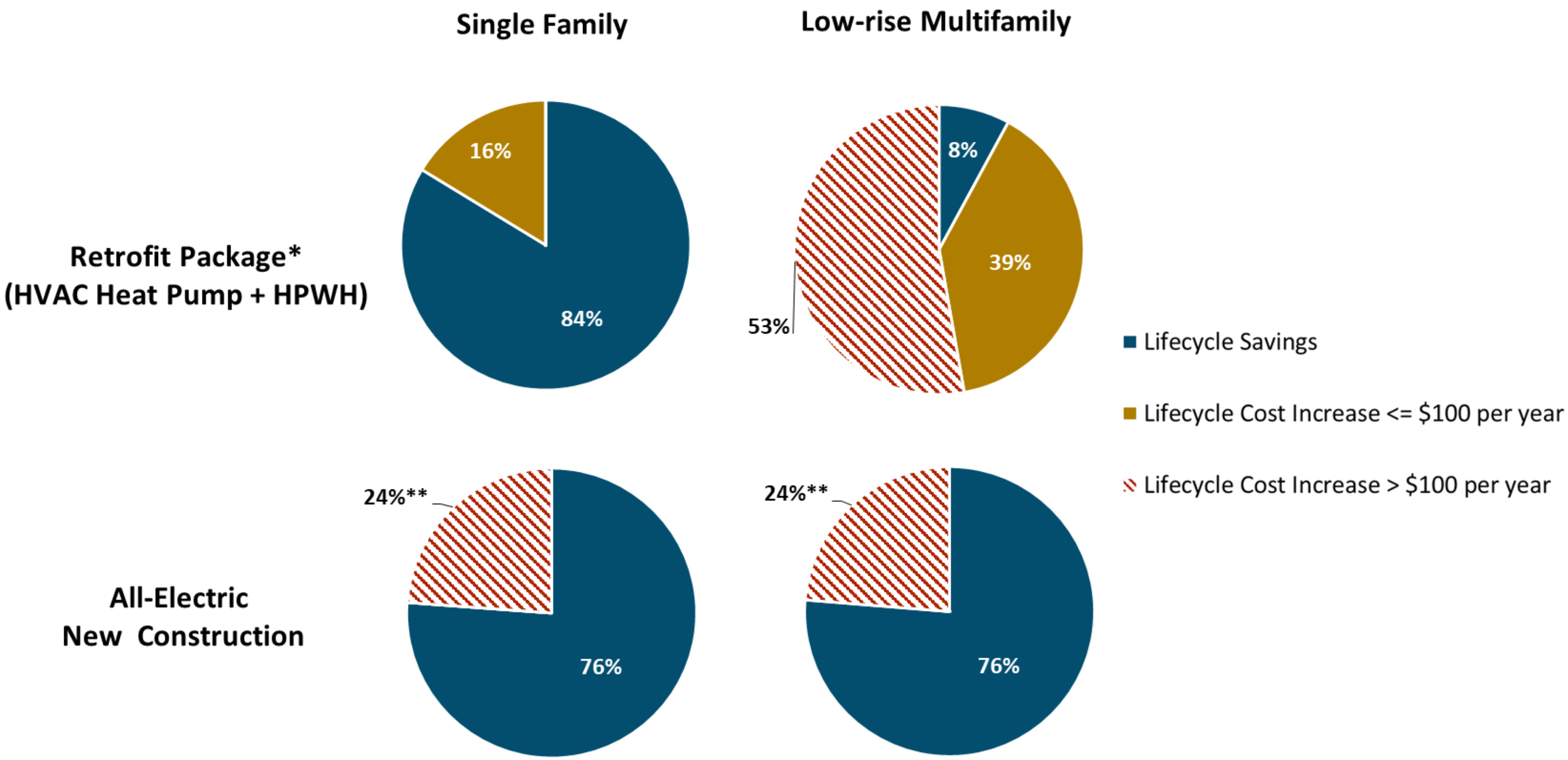
Lifecycle savings of electrifying multiple end uses



The multiple data points for each color represent the different climate zones in each area. Colors of the dots show the location of the modeled homes: the San Francisco Bay Area including CZ03 and CZ04 (Bay Area), Sacramento including CZ12 (SMUD), and Southern California including CZ06, CZ09 and CZ10 (SoCal). Positive values represent savings in both capital and operating costs throughout the lifetime of all appliances over the gas counterpart; negative values indicate lifecycle costs. Heat pump technologies here are the same as modeled for individual appliances above. The new construction blue dot (Bay Area) is an outlier here because in the gas baseline there is no air conditioning assumed.

Heat pumps generate lifecycle savings in many retrofits & new construction homes

Lifecycle Costs of Building Electrification



* We assume that all consumers in retrofit homes have or would install air conditioning in the mixed fuel baseline.
** This category corresponds to buildings modeled in San Francisco (Climate Zone 3) that we assumed would not install air conditioning in the gas baseline home. 100% of all-electric new construction single family and low-rise multifamily homes that include air conditioning show lifecycle savings.

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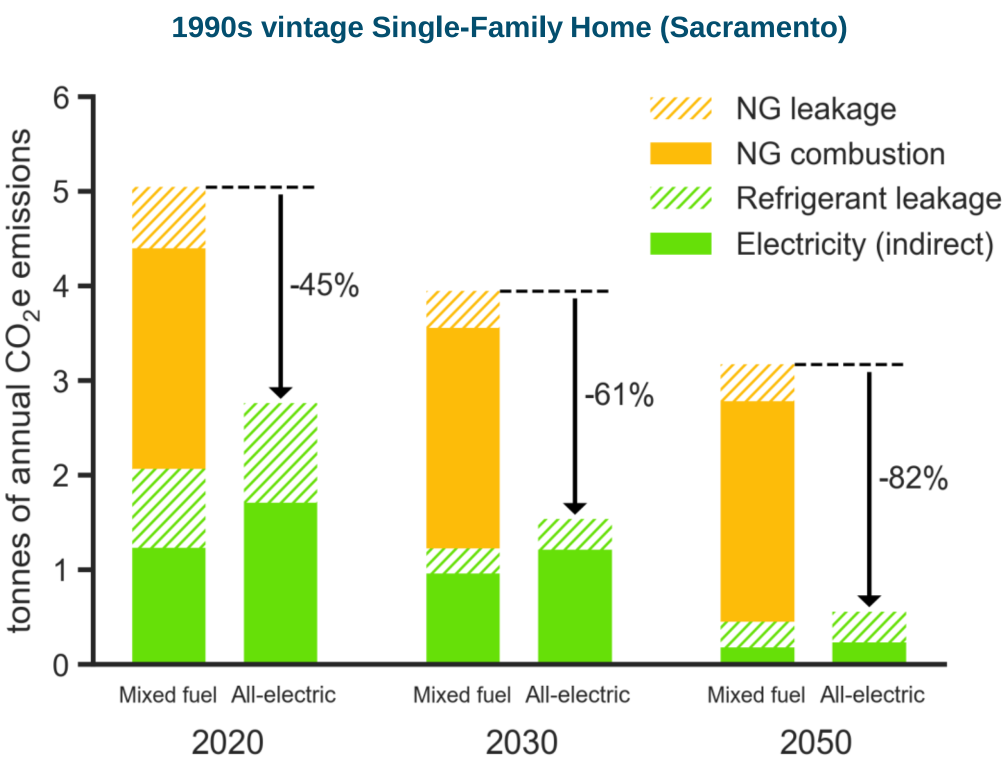
Greenhouse Gas Savings and Grid Impacts

Up to 60% GHG emission reductions can be achieved in the near term by electrifying a whole home

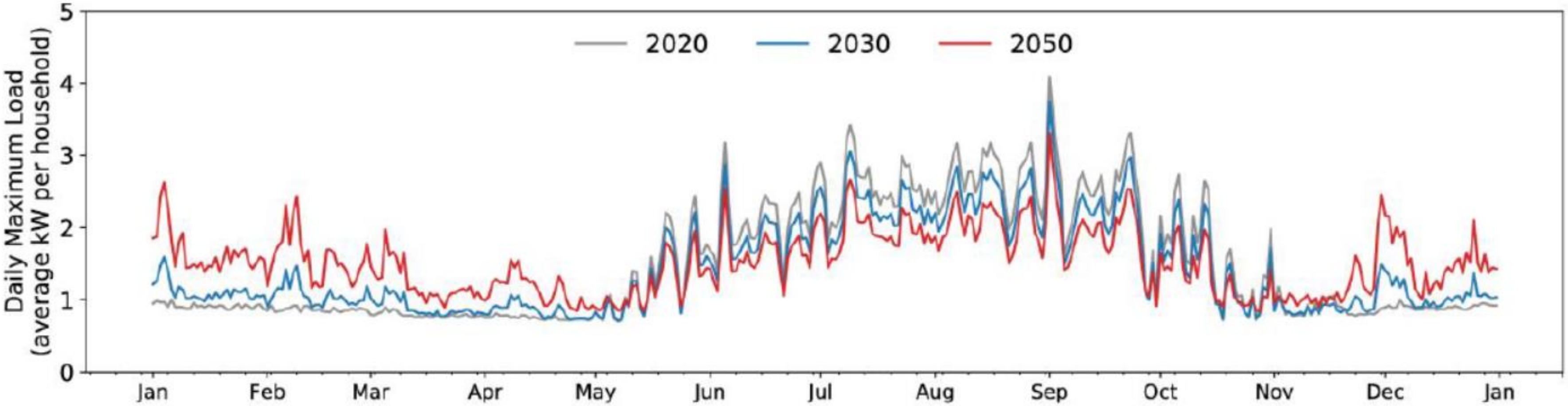
Greenhouse Gas Savings



- In the long-term, switching to an **all-electric home** reduces **GHG emissions** by **80-90% or more** if the grid and refrigerants become cleaner
- Emission reduction is mainly due to switching away from NG combustion with small increase in electricity emissions
- Phasing out **high-GWP refrigerants** and using low-GWP substitutes shows significant GHG reduction potentials

Grid Impacts of Residential Building Electrification in California study area

- Increase in winter electricity demand
- Statewide winter electricity demand likely will remain lower than summer peak demand, at least under typical weather year conditions
  - Even assuming high electrification rates by 2050
- Electrification contributes to a better utilization of the bulk power grid
- More localized impacts at regional and distribution-level grid



* The average load per household reflects a changing share of natural gas-fueled vs. all-electric homes

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Conclusions and Recommendations

Key conclusions

- **Electrifying a single-family home in California can reduce greenhouse gas emissions by 30% - 60% even with today's grid, and will get better as the grid & refrigerants get cleaner**
- **Near-term opportunities for both equipment and energy cost savings:**
  - **All-electric new construction saves $130 - $540/year** relative to gas-fueled new homes **with air conditioning** over the building's lifetime
  - **Retrofit single family homes** – 87% of modeled homes in study area see lifecycle savings when electrifying HVAC and water heater together
  - **High-efficiency heat pump HVAC makes sense when replacing a gas furnace and air conditioner** – 100% of modeled homes with A/C needs see lifecycle savings
- There are **near-term cost barriers** for electrifying **old homes** and **homes without a need for cooling**, and for electric cookstoves and clothes dryers.
- **Policy** needs to overcome **non-economic barriers** for consumers to be willing to electrify homes, and to reach the level of adoption needed for climate goals

Recommendations

- **Incentivize all-electric new construction and update the building code**
- **Incentivize high-efficiency heat pump HVAC, particularly in areas with high air conditioning loads**
- **Ensure efficient price signals are conveyed in electric and natural gas rates**
  - More efficient electricity rates
  - Higher carbon prices, or complementary policies aimed at reducing the GHG emissions from natural gas
- **Develop a building electrification market transformation initiative**
  - Consumer education and workforce training
  - Retrofit-ready electrification technology options
  - Technology transfer from other markets –higher efficiency, ultra-low global warming potential refrigerants, or low-voltage options
- **Align energy efficiency goals and savings with GHG savings opportunities**