



State of Practice in Residential Decarbonization: Recent Survey Findings

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There's No Place Like Home

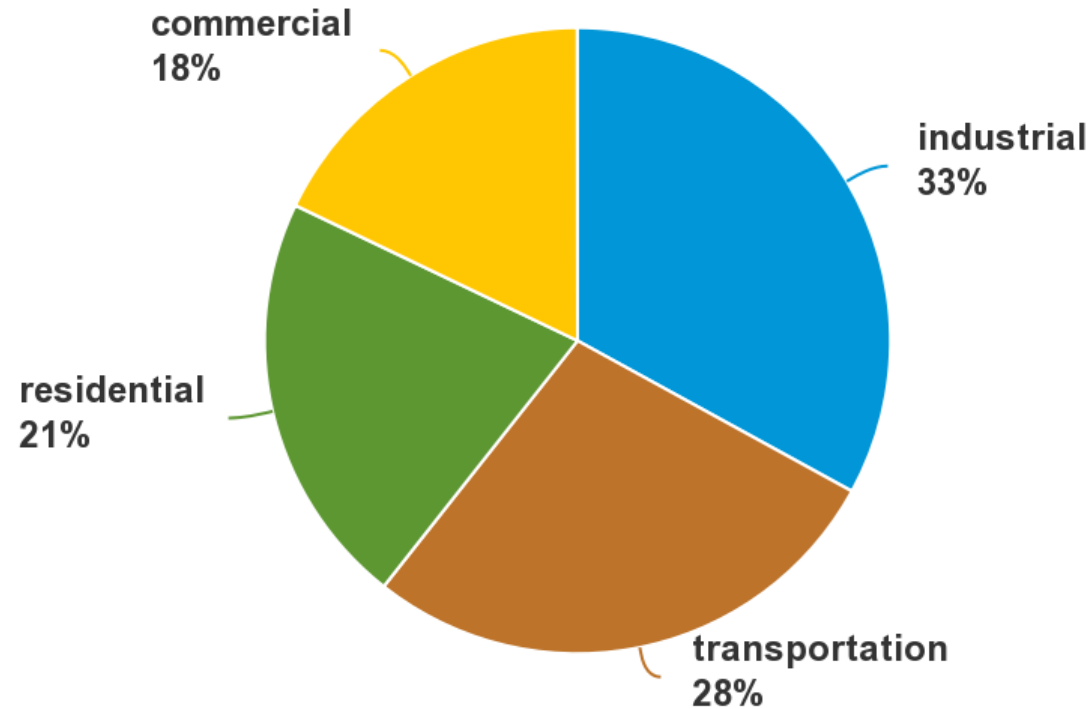
- **Human behavior** is at the center of interactions between people and the homes they live in.... and the **technology they interact with**.
- Researchers grapple with **complex sociotechnical dynamics** when researching/ diffusing technology in residential buildings.
 - *And they often are unaware they are doing this!*
- Many factors make this dynamic more complex:
 - Building stock characteristics
 - Region and community density
 - Income
 - Race, cultural background, ethnicity
 - Education, including technology background
 - Age, life-stage
 - Preference



Why is Decarbonization Important?

Share of total U.S. energy consumption by end-use sectors, 2021

Total = 97.33 quadrillion British thermal units



- Residential buildings account for **22% of primary energy consumption** in the United States.
- Fossil-fuel combustion in buildings leads to **roughly 30% of total greenhouse gas emissions**.
- 68% of existing housing stock in the United States was **built before energy codes were enacted**, resulting in underperforming (by current standards), energy intense buildings.

There's a Big Difference Between This....

- Provide **refuge** from outdoor exposures
- **Limit infiltration** of particulate matter with tight envelopes
- **Efficient HVAC** for heating/cooling
- Whole-house **mechanical ventilation**
- High-capacity active **filtration for IAQ**
- **Reduce energy consumption/CO₂ emissions**
- Integrate **renewable energy systems**

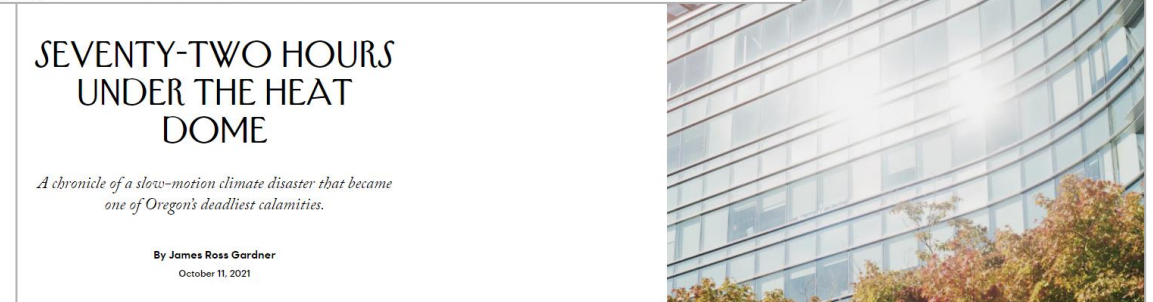
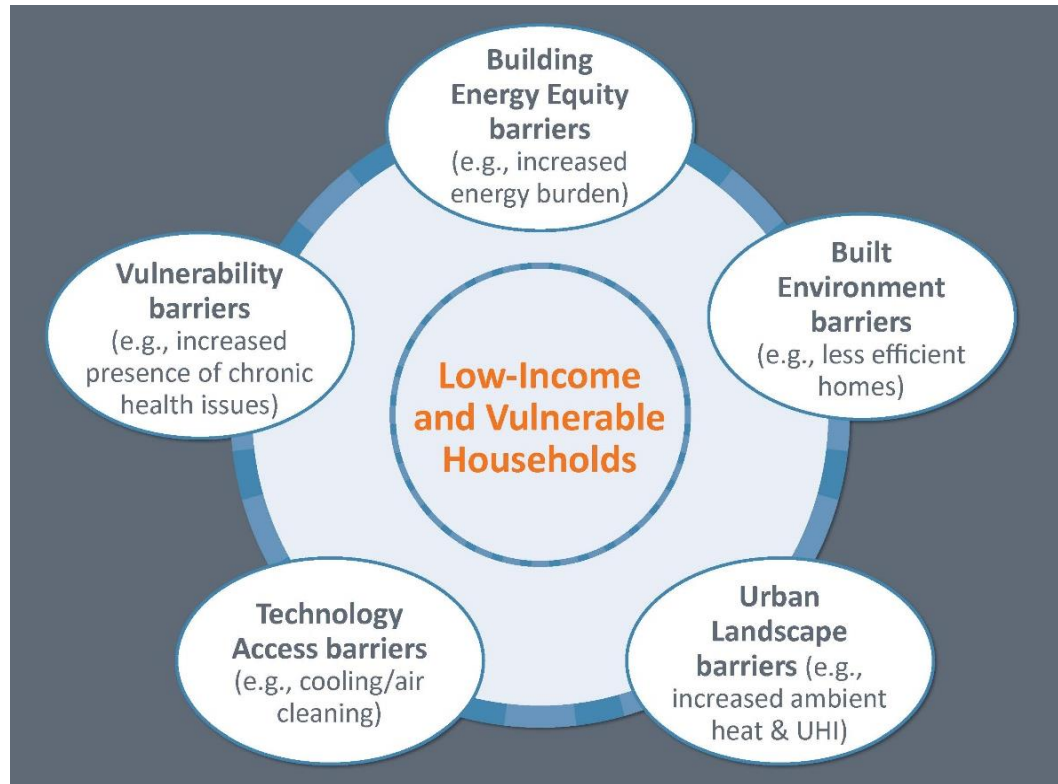


....And This

- Provide **refuge** from outdoor exposures
- Old construction, little to no insulation and air sealing, thus **high infiltration**
- Likely **no air conditioning** installed
- No **whole-house mechanical ventilation** or active filtration
- **Old, dated systems**
- Increased **likelihood of hazardous materials** (lead, asbestos, mold)
- **Energy intense**, increased CO₂ emissions



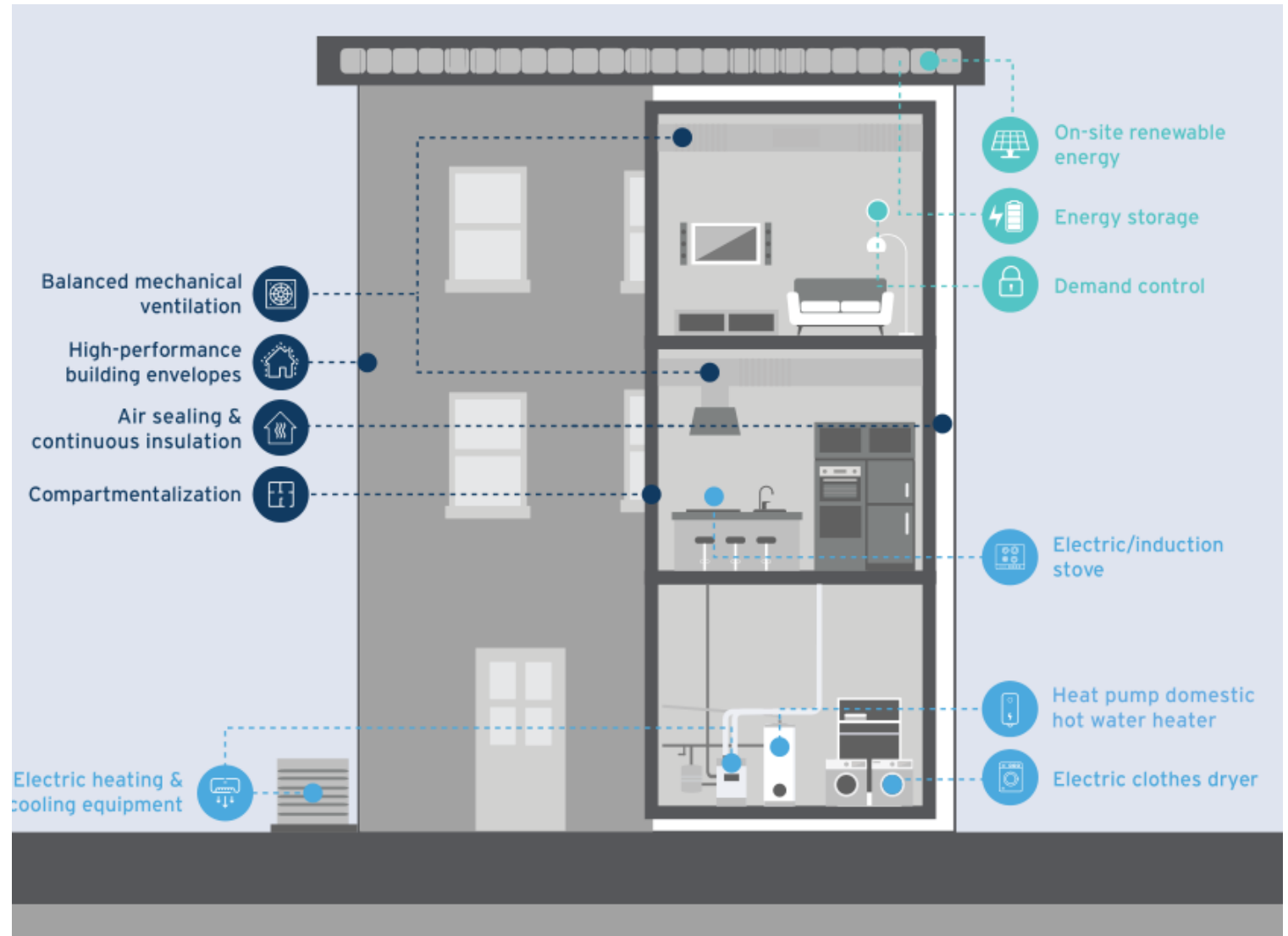
Equity is an Important Climate-Change Issue



Decarbonizing our Homes

Objectives:

- Building enclosure efficiency.
- Low-load HVAC.
- Electrification of end use appliances/equipment.
- Integration of renewables, energy storage and “smart” energy technologies for demand control.
- Low-carbon material selection.



Approaches to Behavior Change in Residences

The Challenge:

- Household behavior and technology adoption patterns are **difficult to predict**.
- Even with incentives, many energy-efficient technologies and home upgrades have had **slow uptake**.

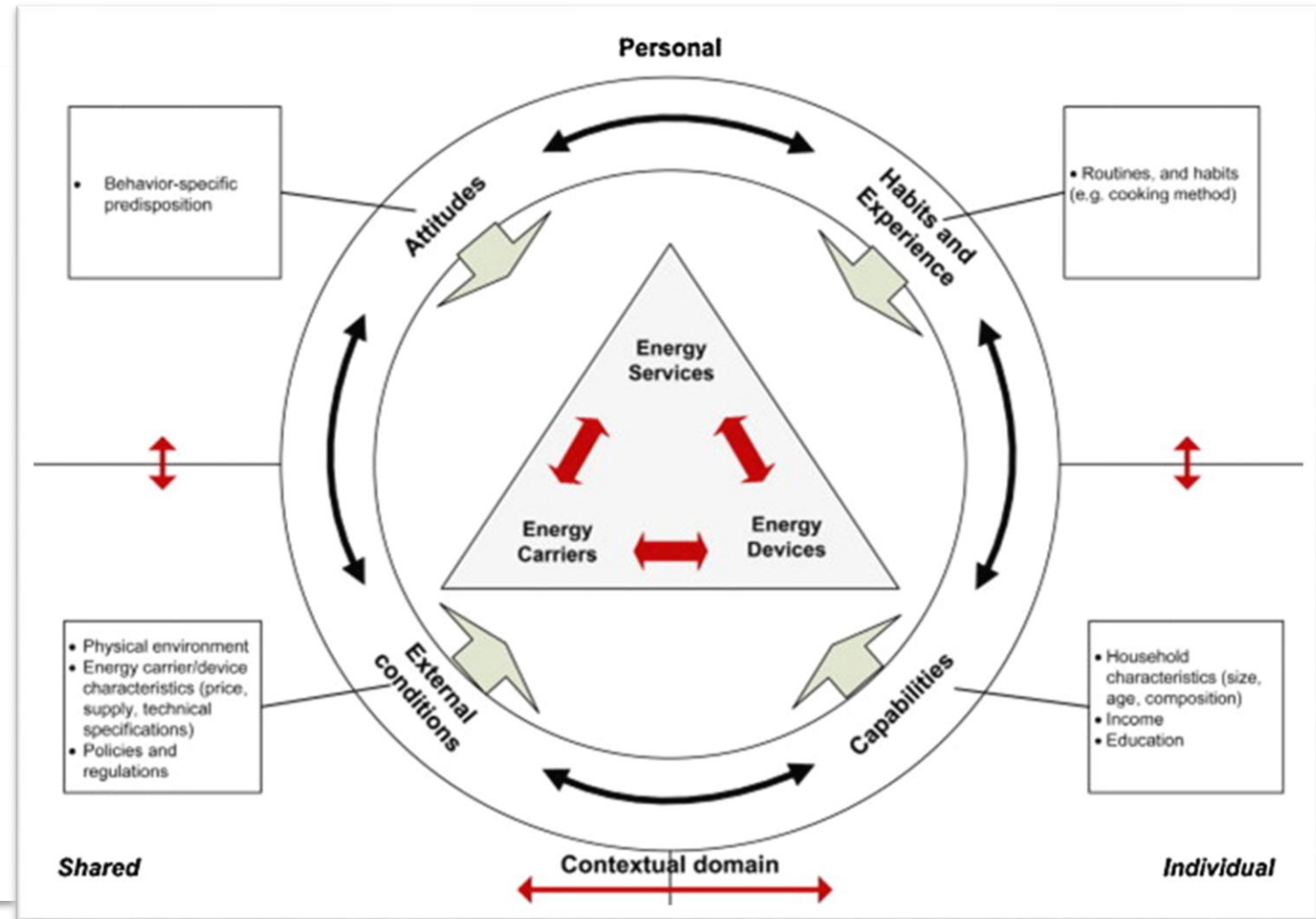
Typology	Intervention	Examples
Stick	Regulation Prohibiting Behavior	Ban on natural gas installations in new home construction
	Regulation Requiring Behavior	Building codes requiring high levels of energy efficiency
Carrot	Reward for Discouraging Behavior	Utility rate system tiered to actual energy use
	Reward for Engaging in Behavior	Subsidy for installing energy efficient appliances
Sermon	Provide Information About Energy Conservation	Utility information campaigns
	Provide Feedback About Household Energy Use	Utility inserts, smart meters

Typology from Vedung (1998); Harrison (1998) and Pacheco-Vega (2020) are examples of how typology applies to environmental regulation and governance

Human-Centered Research in Homes

Human-centered methods:

- Identify **human dimensions** to energy use
- Identify multidimensional role of **attitudes, habits and experience**
- Allow for more accurate understanding about the **influence of culture and lifestyle**
- Provide **frameworks for problem-solving** at the household level



Cited by: Sovacool, 2014 from Kowsari and Zerriffi, 2011

Surveys in Social Science Research

- Done correctly, surveys can be **powerful tools!**
- Surveys instruments allow data collection from a **broad sample** of the population.
- Promotes **qualitative, quantitative and mixed-methods** approaches.
- Often used as **primary data collection method** in social-science research.
- Allows for **deeper understanding** of human interactions with energy systems.

Project Team

- **Interdisciplinary PNNL team** led the study design, research execution, analysis and findings.
- **ILLUME Advising** conducted household interviews and collaborated on study findings.
- Study design and execution was informed by an **international advisory committee**, comprised of over 25 experts in the field.



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Overall Research Approach

Primary Research Activities:

- **HVAC manufacturer outreach** to learn about customer discovery and marketing.
- **Reviewed literature** to identify previous study findings.
- **Developed research protocols**, sampling strategy, participant criteria, analytical methods and gained *Institutional Review Board (IRB)* approval.
- **Conducted in-depth, semi-structured interviews** with 121 households to better understand purchasing decisions, use patterns and energy efficiency perceptions and behavior.
- **Executed national-scale survey** to 10,000 homeowners and renters, using questions developed from interview outcomes.
- **Assembled an international external advisory board**, comprised of experts in the field to inform methods and research protocol.
- **Synthesize results** from interviews and survey to inform decarbonization strategies.
- **Collaborate** with relevant stakeholders to enhance findings and expand decarbonization efforts.

U.S. Department of Energy (DOE) Building Technology Office (BTO) is funding research to investigate how residents make home energy decisions and to explore whether those decisions help meet decarbonization goals.

Research Questions:

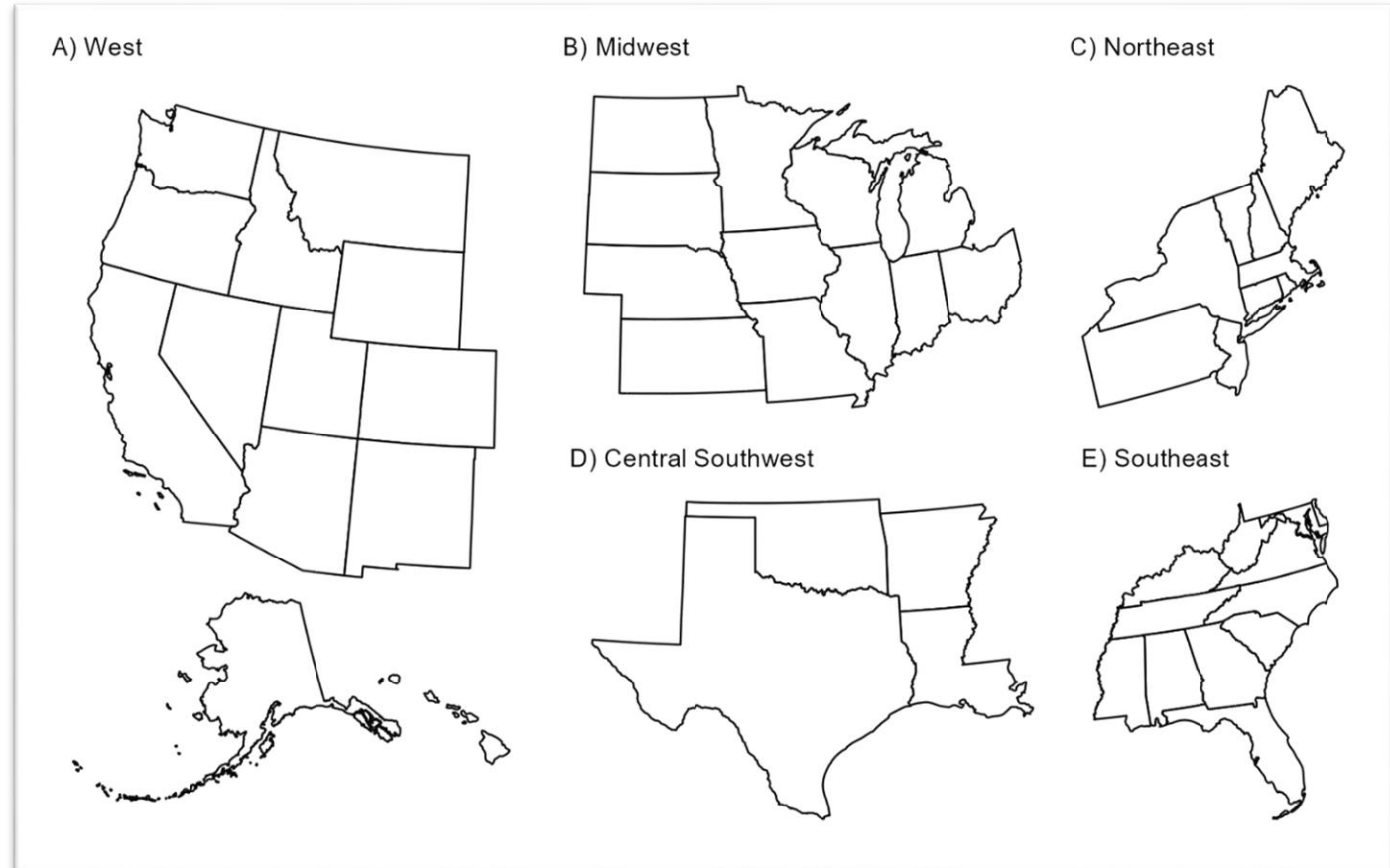
1. What are the motivations and key decision points for energy-related home renovations and upgrades?
2. How do different residential stakeholders decide to buy and use key technologies relevant for residential electrification?

Survey Release and Targets

- Survey was released on August 12th and closed on October 17th 2022.
- Available in **English and Spanish**.
- **10,000 responses** distributed evenly across the country.
- **Race/ethnicity criteria** was set to **match the US Census**.
- **70% homeowners, 30% renters, also matching US Census**.
- Partial responses not counted.
- Survey recruitment and data collection conducted by **Qualtrics**.

Methods

- Analysis of **10,000 respondents**:
 - 77 homeowner questions
 - 87 renter questions.
- Divided survey data into regions, based on **US Census and REEOs**.
- Statistically tested regional differences using **ANOVA, Games-Howell post-hoc tests and pairwise comparisons**.
- **Logistic regression model testing** for making any home changes.
- **Binomial regression models** for households that had made decarbonization changes.



Placement of 50 states and District of Columbia in regions:
A) West, B) Midwest, C) Northeast, D) Central Southwest, and E) Southeast.

Results: Demographics

- Average respondent age in all regions was **between 36-55 years old**
- **Slightly more women** took the survey than men
- Average home tenure was between **5-10 years residency** in all regions
- **71% / 29%** ratio of Homeowners / Renters
- Median reported rent/mortgage was between **\$701-\$1,500/month** in all regions
- Trend for **Race/ethnicity similar to US Census**, with more Black/African Americans taking the survey.
- Statistically significant **regional differences** in:
 - Home ownership
 - Urban/rural locations
 - Race/ethnicity
 - Education
 - Household composition
 - Median household income

Results: Building Characteristics

- Primary **heating/water heating fuel** aligns with regional energy sources: **more oil/natural gas in the Northeast, more electric in the South**
- Median home size between **1,500-2,000 ft² of living area**
- Median of between **\$151-\$200/month for utilities** in all regions
- ~50% of respondents reported they don't have trouble paying utility bills:
 - ~25% minimize energy use to keep bills lower
 - ~15% often miss paying bills
 - ~10% receive financial assistance
- Statistically significant **regional differences** in:
 - Fuel type
 - House age (year built)
 - Ability to pay monthly energy bills

Regional Technology Adoption - Electrification

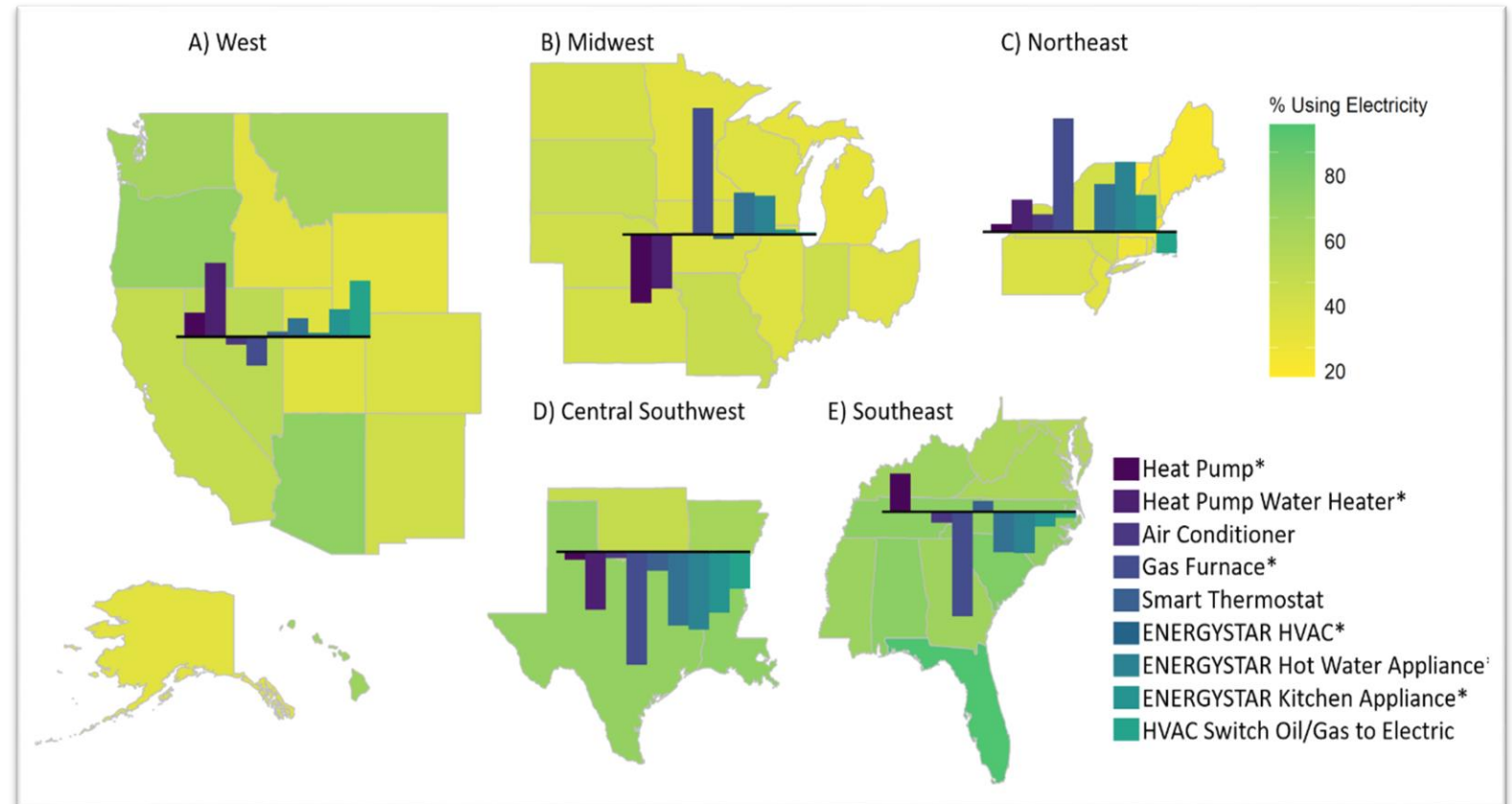
		West	Mid-west	North-east	Central South-west	South-east
Kitchen	ENERGY STAR Appliances****	+	+	+	-	+/-
	Electric Stove****	-	-	-	-	+
	Gas Stove****	+	+/-	+	+/-	-
HVAC	ENERGY STAR Certified***	+	+	+	-	-
	Heat Pump****	+	-	+		+
	Portable AC**		-	+		-
Hot Water	Gas Furnace****	+/-	+	+	-	-
	ENERGY STAR Certified***		+	+	-	-
	Heat Pump Water Heater*	+	-			
	Electric Water Heater****	-	-	-	-	+
Renewables, EV	Gas Water Heater****	+	+	+	-	-
	PV w/o Storage****	+	-	-		-
	PV with Storage****	+	-	-	-	-
	Geothermal****	+	-	-		-
Smart Tech	Bought EV****	+	-	-	-	-
	Home Energy Management**	+	-	-		

- West dominates most decarb-friendly tech adoption, especially renewables/ EVs/Smart tech.
- ENERGY STAR appliances widely accepted.
- Electric stoves adopted most in SE.
- Heat pumps adopted in W, NE and SE.
- Portable AC used for cooling in NE.
- Gas furnace installs most common in MW and NE.
- HPWHs installed in W, lags everywhere else.

For full ANOVAs, asterisks represent statistical significance (*p<0.05, **p<0.01, ***p<0.001, ****p<0.0001). For pairwise comparisons, a +, -, or +/- indicates that the region was significantly higher, lower, or both lower and higher than at least one other region. Not all modifications that had statistical significances are presented in this summary table.

Regional Technology Adoption and Receptivity to Electrification: Relative to National Averages

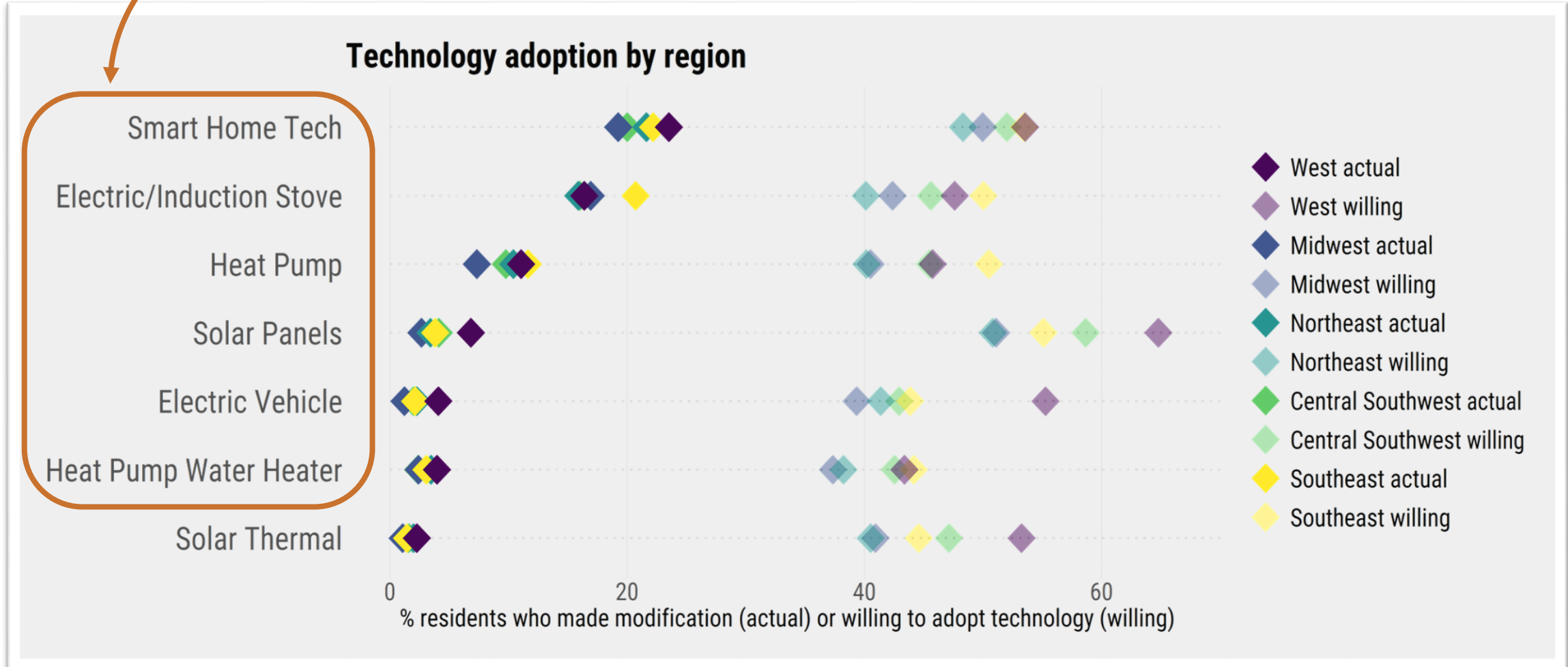
- Heat pumps adopted more in SE, W and NE.
- Heat pump adoption lagged in Central SW.
- HPWH installs highest in W and NE – lagged everywhere else.
- HPWH installs highest in W and NE – lagged everywhere else.
- Fuel switching more in W.
- Gas furnaces installed more in NE and MW.
- ENERGY STAR appliances adopted more in W, MW and NE.



Regions, relative adoption of selected technologies and percentage of respondents reported using electricity as primary fuel (yellow is less electricity, green is more). Bar graphs show more, or less regional adoption compared to the national average. The height values for each bar are ratios and do not have meaningful units, thus specific values are not labeled. Technologies with * indicate significant ANOVA results at $p < 0.05$.

Willingness to Adopt Technology vs. Actual Adoption

Six of the seven surveyed technologies prioritize electrification, and the seventh trades utility energy for solar thermal!



Variation in Motivations and Preferences by Region

Motivations for making change:

- West rated **reducing harmful health impacts and reducing environmental impacts** more than other regions.
- **Fixing something broken** ranked higher in Midwest

General household preferences:

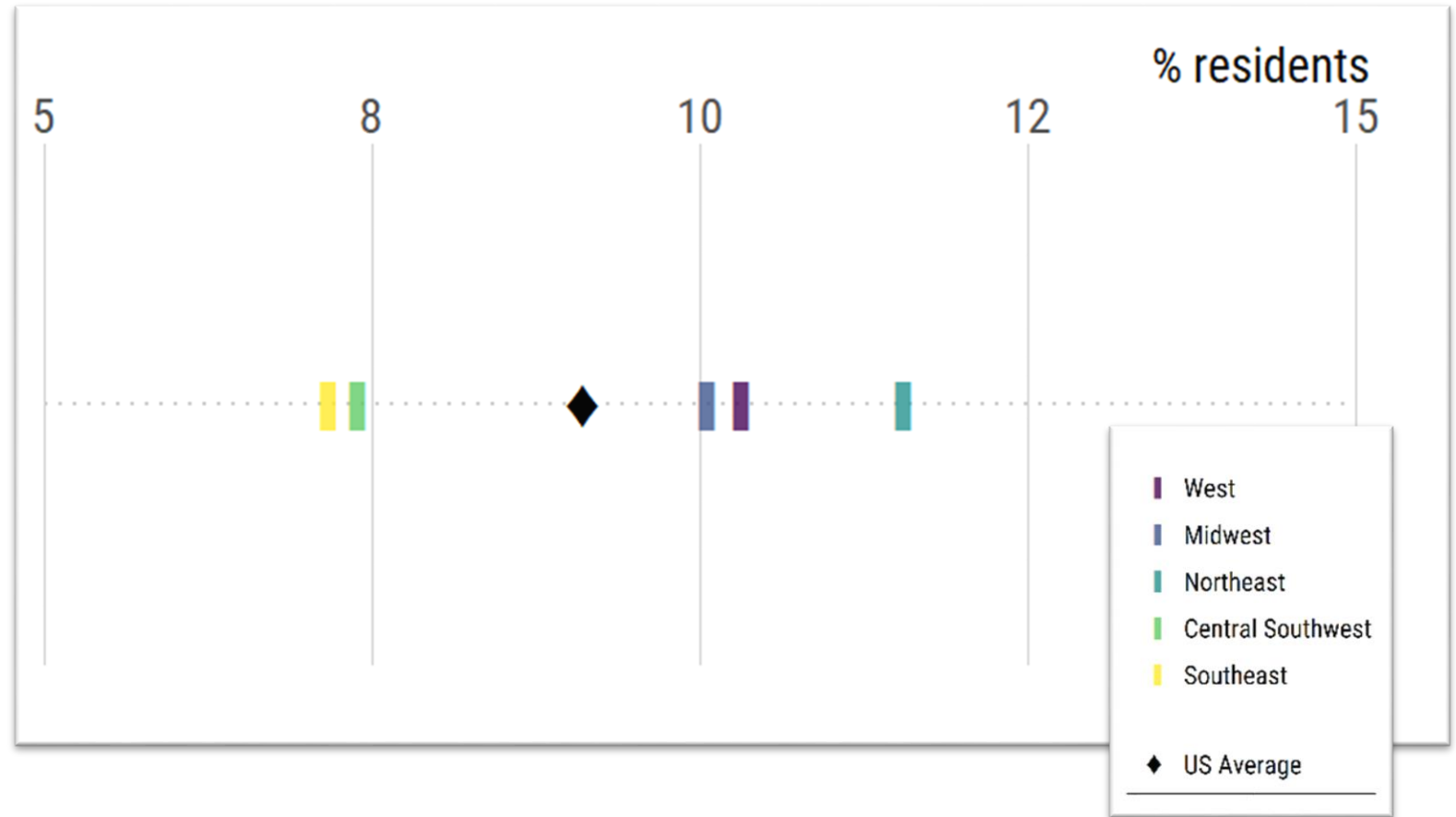
- **Southeast** only region to rank **aesthetics** highly
- West rated **home working spaces** (chef's kitchen, craft space, home office, shop space) highly.
- Midwest and Northeast had higher ratings for **safe space**.

		West	Mid-west	North-east	Central South-west	South-east
Motivations	Reduce Harmful Health Impacts*	+		-		
	Reduce Environmental Impacts**	+	-	-		-
	Fix Something Broken*	-	+			
Preferences	Aesthetics***		-			+
	Chef's Kitchen	+	-	+/-		
	Craft Space	+	-	-		
	Entertain	+	-			
	Exercise Space	+	-	+		
	Home Office	+	-	-		
	Shop Space	+	-	-		
	Safe Space	-	+	+/-		

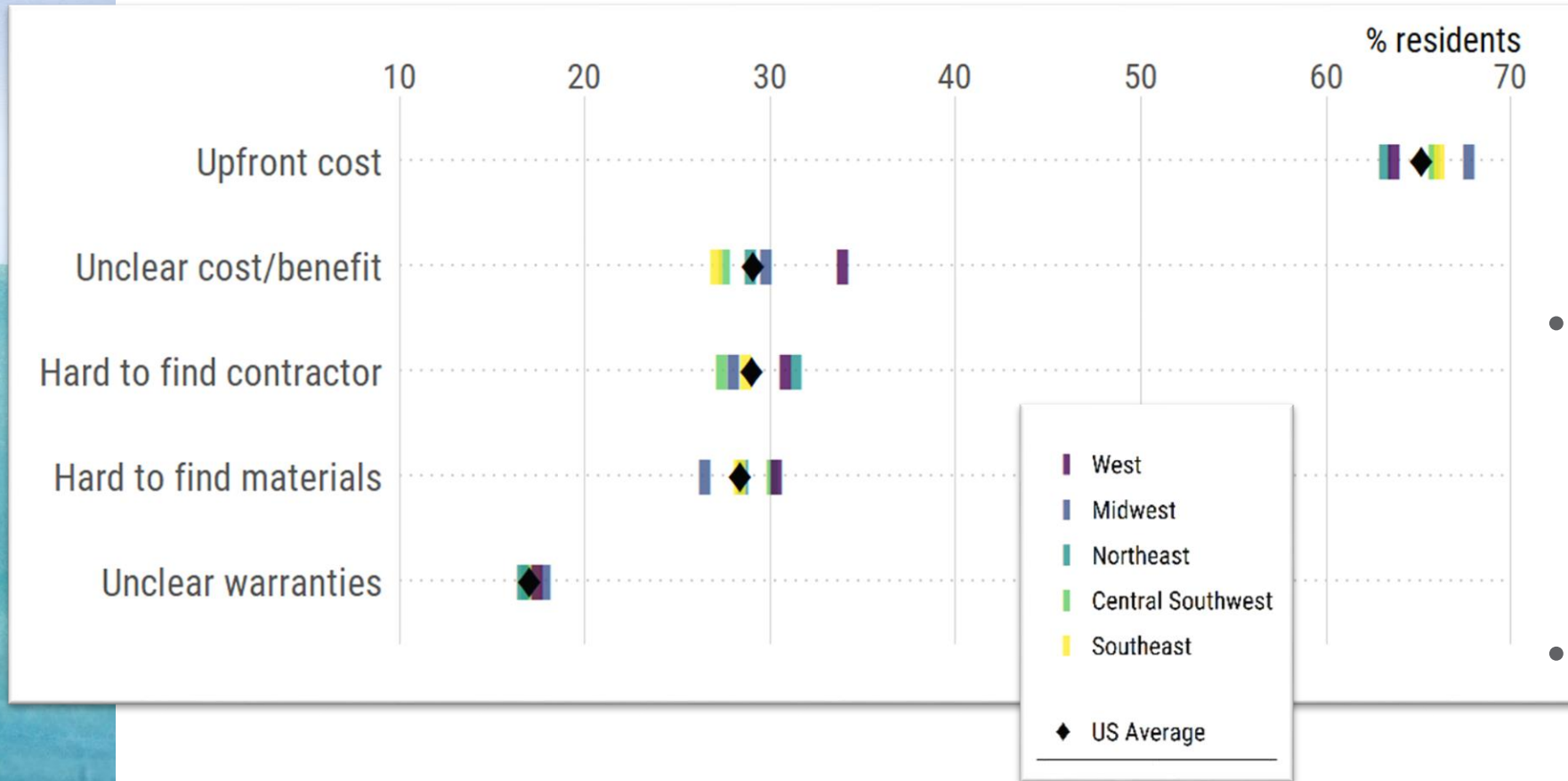
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Energy Efficiency Program Participation

- Program participation (federal, state, utility, etc.) in low in all regions (~9% national average).
- Even lower in the Central SW and SE (<8%).
- Highest in NE, W and MW (10%-11%).



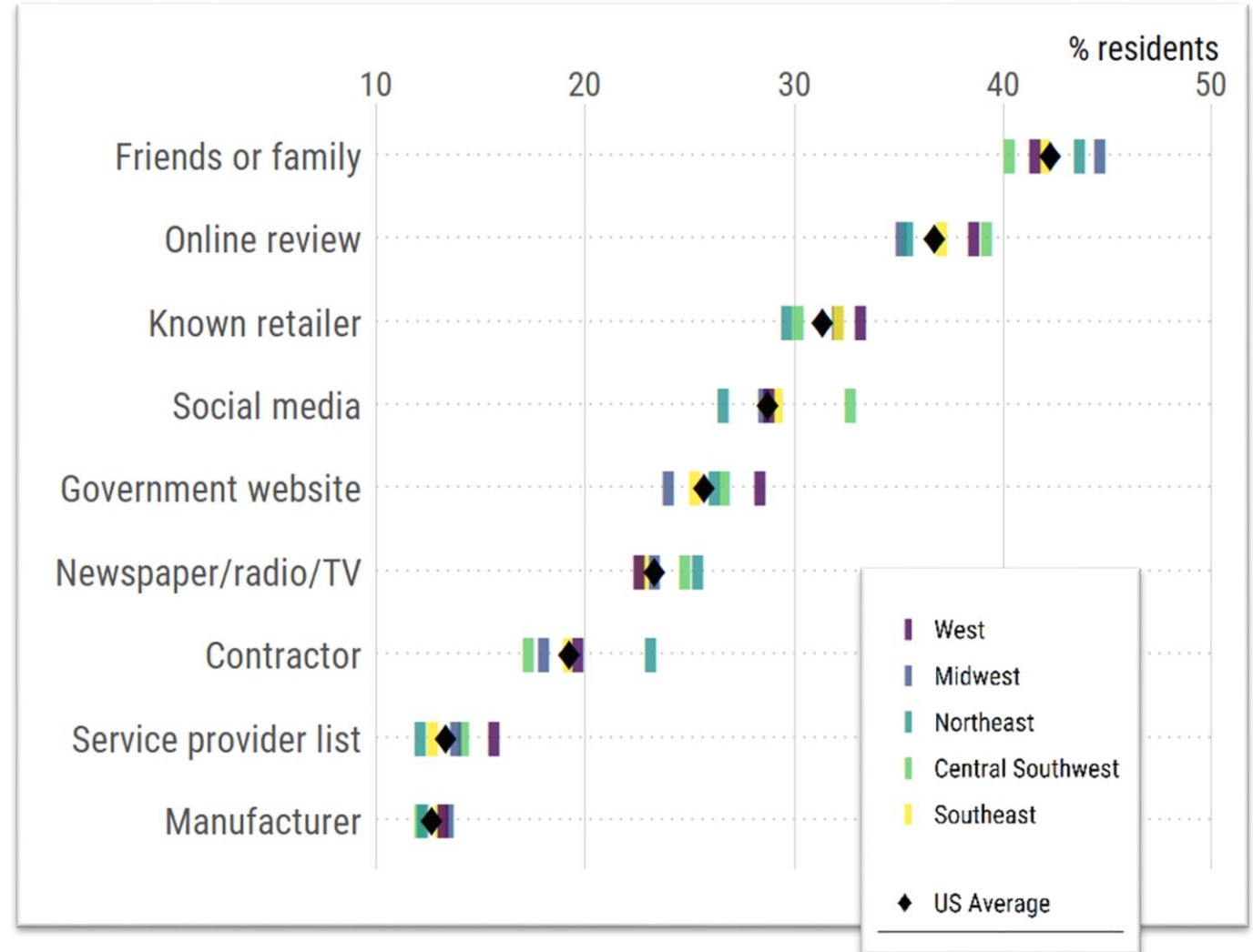
Barriers to Home Modifications



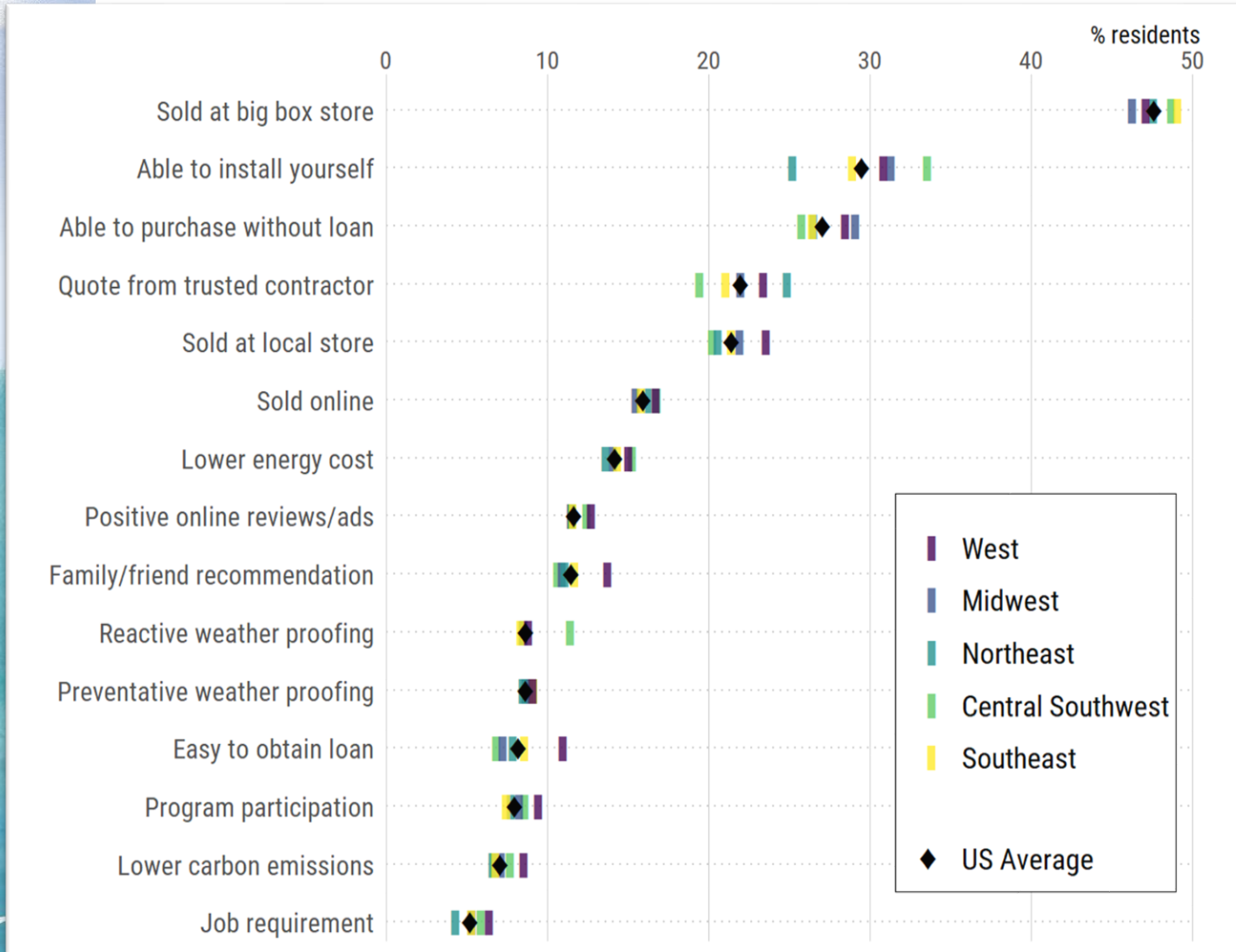
- **Upfront cost** noted in all regions as primary barriers to completing home modifications (~62%-68%).
- West identified **unclear cost/benefit** more than other regions.
- NE noted more **issues with finding contractors**.

Trusted Sources of Information

- **Friends/Family** most trusted as information sources in **all** regions.
- **Social media** more preferred in the **Central SW** compared to other regions, especially **NE**.
- **West** relies more on **government websites** over other regions
- **NE** trusts **contractors** more than other regions.



Considerations for Making Modifications



- More regional variability observed in this category than others.
- Availability at **Big Box stores** most important consideration in all regions (>45%).
- **DIY appealing** to all regions, but more important in Central SW over other regions, especially NE.
- Like trusted sources, NE also factors in **contractors** more when making decisions.

Key Recommendations from Combined Results

Region	Primary Recommendations
West	<ul style="list-style-type: none"> • Focus program messaging on reducing health and environmental impacts as it relates to technology choice. • Promote induction stove installation, highlighting occupant health. • Promote heat pump technologies to households without cooling.
Midwest	<ul style="list-style-type: none"> • Increase heat pump technology uptake as an alternative to gas furnaces. • Focus program messaging on increasing comfort and reducing energy bills. • Promote decarbonization technologies through friends and family programs. • Emphasize safety in messaging around fuel switching from gas to electric
Northeast	<ul style="list-style-type: none"> • Develop robust heat pump initiatives, pair with efforts to minimize the need for increasing electric panel capacities in homes. • Utilize contractor pipeline for sharing information on decarbonization options. • Emphasize cooling capacity of heat pumps as alternative to portable AC.
Central Southwest	<ul style="list-style-type: none"> • Promote heat pump technologies as alternatives to electric furnaces and electric resistance water heating. • Focus program messaging on reducing energy bills. • Use social networks as a source of information for decarbonization efforts.
Southeast	<ul style="list-style-type: none"> • Increase program focus on heat pump water heaters and continue momentum in heat pump efforts • Pilot more demand response through promotion of smart thermostats/energy management systems. • Tie program incentives to others focused on home aesthetics.
All Regions	<ul style="list-style-type: none"> • Enhance efforts to reach renter households. • Promote decarbonization through big box stores. • Develop programs to reduce upfront costs.

Progress and Future Work

Complete:

- Clean data, develop final dataset for **sharing and publishing**.
- Finalize **framework for collaborative analysis** of PNNL and LBNL survey instruments.
- Finalize **interview results** and submit manuscript.
- Finalize **survey results** and submit manuscript.

In Progress:

- Cross-cut analysis based on **socio-demographic groups**.
- Publish data as **open source**.
- Synthesize both sets of results and publish as a **PNNL Technical Report**.
- Publish findings for **collaborative PNNL/LBNL analysis**.

Future Work:

- Help entities **craft messaging** for decarbonization programs.





**Pacific
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Thank You!

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