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NHPC '22 NASHVILLE

TRANSITIONING FROM HOME PERFORMANCE TO DECARBONIZATION: FINDING AFFORDABLE AND SCALABLE SOLUTIONS

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LEARNING OBJECTIVES

At the completion of this session, attendees will :

Identify potential economic and technological solutions that can be implemented to quickly achieve decarbonization through electrification.

Understand how the proposed economic and technological strategies are necessary for the decarbonization process of the existing building stock in the US

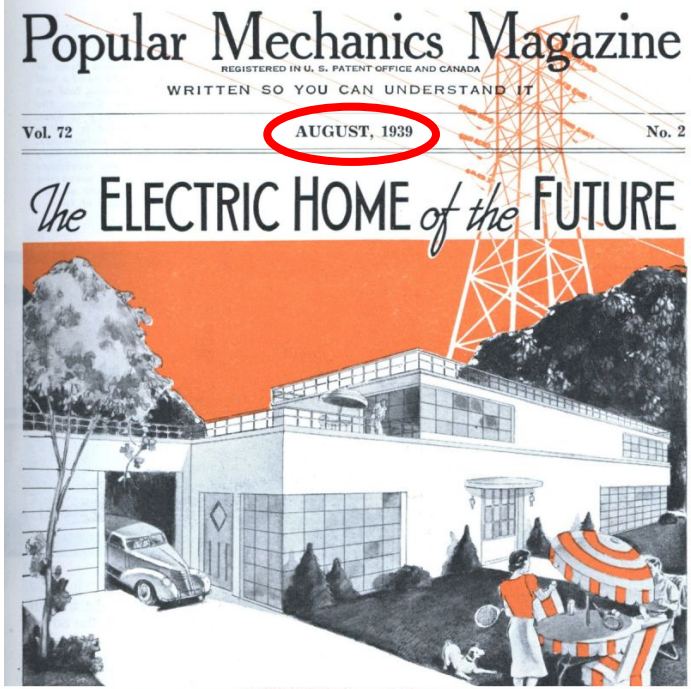
Improved understanding of the costs and performance of electrification as a pathway to decarbonization.

WHAT IS HOME DECARBONIZATION AND WHY SHOULD I CARE?

WHAT IS HOME DECARBONIZATION?

Stop emitting CO_2 related to your home

1. No more burning fossil fuels at home
2. Switch to electricity from renewable sources
3. Remove all natural gas infrastructure: Gas leaks typically about 2-3% (0.5% inside homes) but higher GWP makes this a 20-30% increase in greenhouse gas emissions
4. Think about it as the completion of the electrification program begun in the US 100 years ago



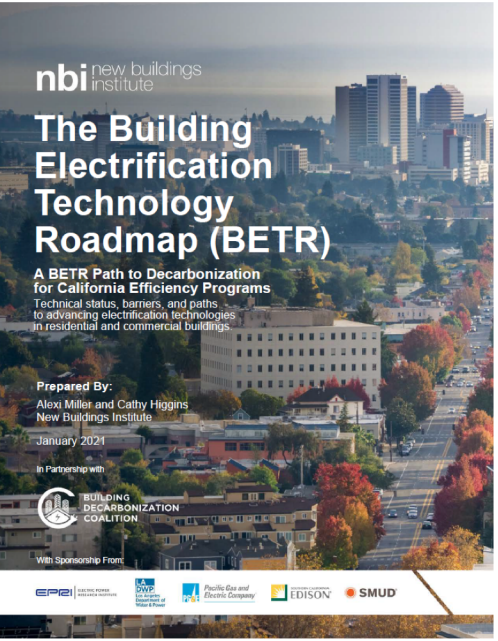
Three Principles for Home Decarbonization

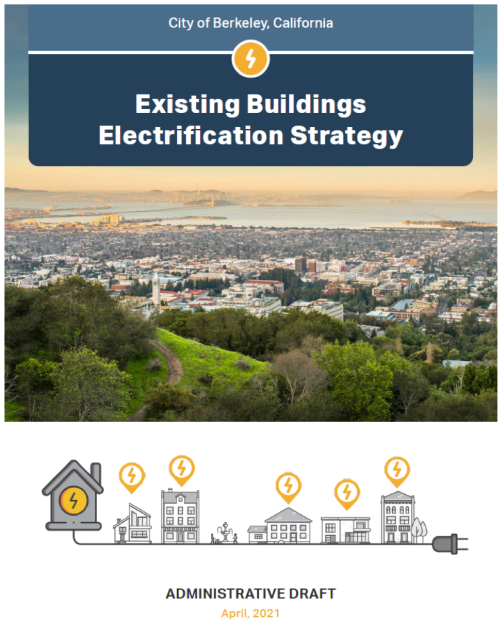
Principle #1: We can't efficiency our way to zero emissions

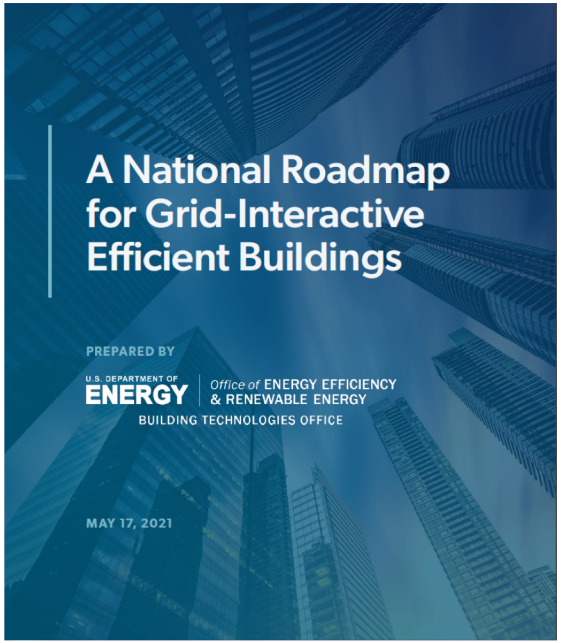
Principle #2: Homes will have to be electrified

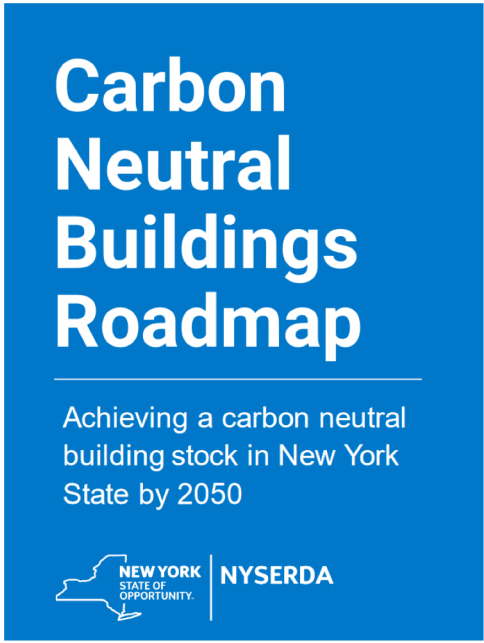
Principle #3: Solutions need to be affordable

EMERGING CHANGES IN CONSTRUCTION

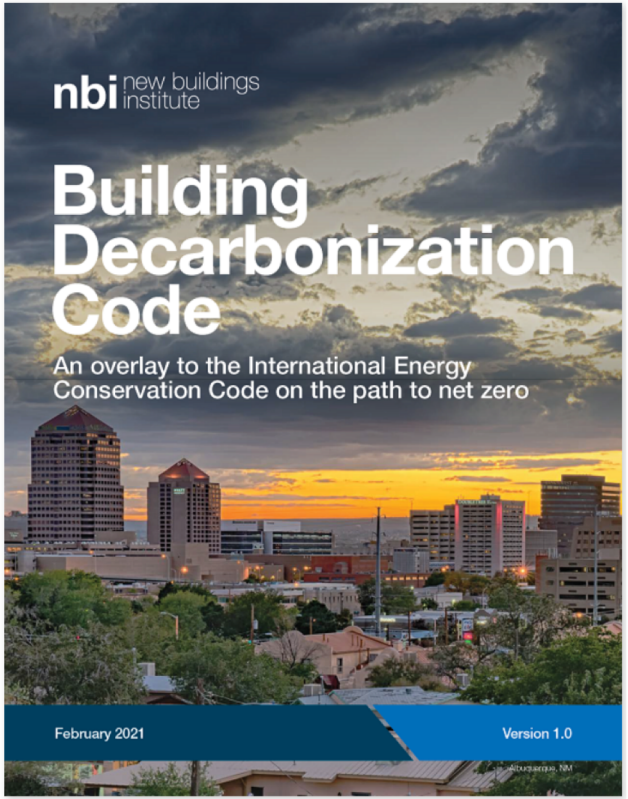








EMERGING CHANGES IN CODES



https://newbuildings.org/resource/building-decarbonization-code/

Heat Pumps as reference systems + PV on all Single Family homes in California

LOCAL ACTION TO LIMIT GAS INSTALLATIONS

https://www.sierraclub.org/articles/2021/07/californias-cities-lead-way-gas-free-future

New York Phases Out Fossil Fuels in New Construction

NY governor unveils plan to electrify homes, achieve zero-emissions construction

HIGHLIGHTS

Targets zero-emissions for all new construction by 2027

Electrifying at least 1 million homes by 2030

Ithaca, New York becomes first U.S. city to begin 100% decarbonization of buildings, an urban climate change milestone

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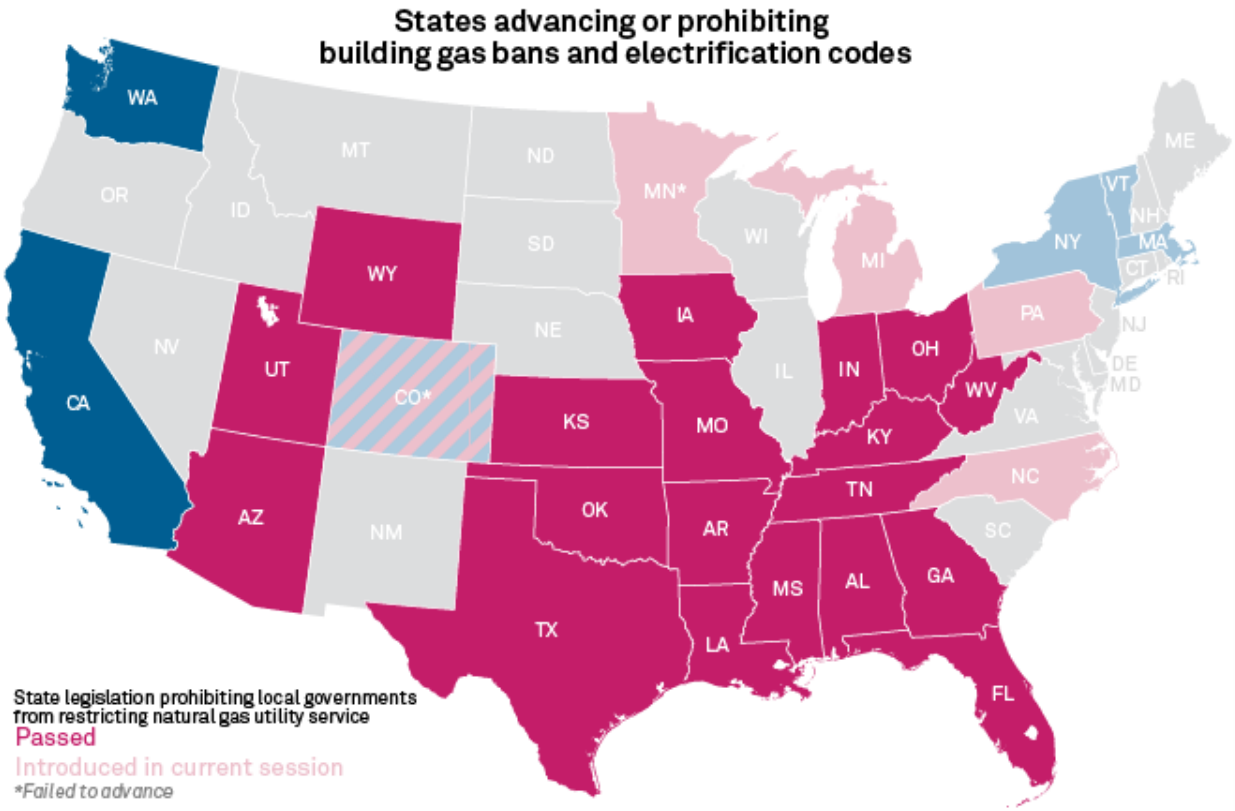
PETALUMA
SONOMA COUNTY
CALIFORNIA-USA

PROHIBITION OF ELECTRIC REQUIREMENTS



EMERGING CHANGES IN RATINGS – CARBON INDEX

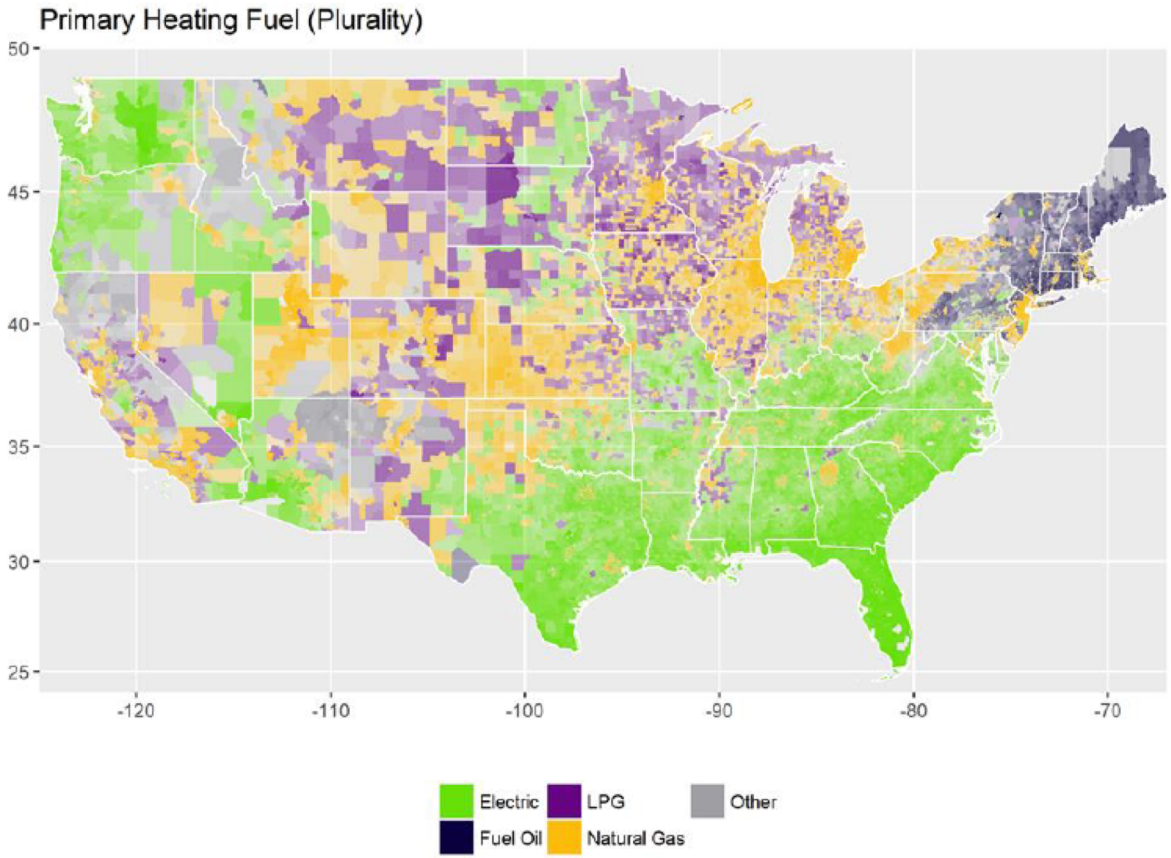
RESNET
RESIDENTIAL ENERGY SERVICES NETWORK

RESNET 301 Addendum D: CO_2 rating index (awaiting final approval)

- **For electricity:** Cambium database used to estimate **CO_2** emissions on a local scale
- **For fossil fuels:** Fixed emission rate per **MBtu**

$$CO_2\text{index} = \frac{CO_2\text{rated home}}{CO_2\text{reference home}}$$

CURRENT HEATING FUEL USE IN THE US

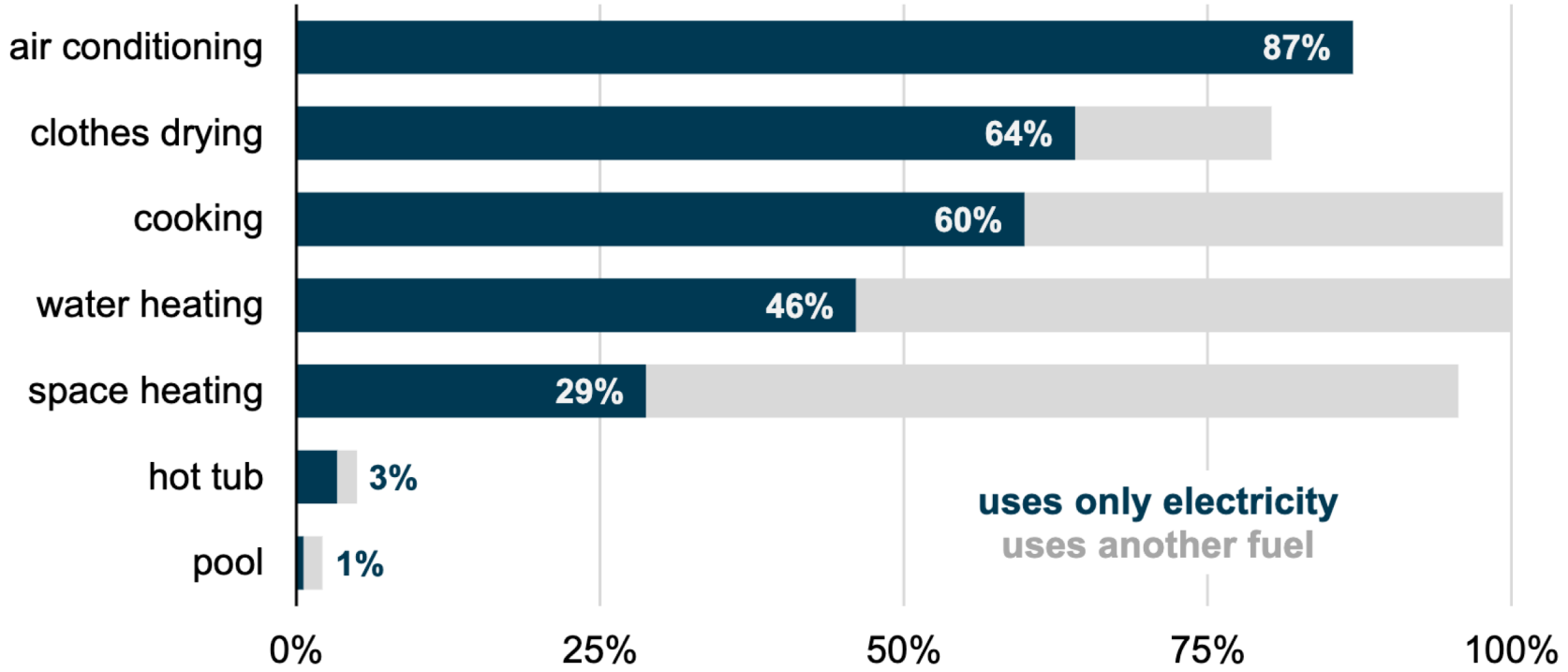


Data from the American Community Survey (2016).

- 40% of homes have electric primary heating
- >25% of homes are already all-electric
- 75% of homes have central AC and will likely not need electric panel upgrades or utility infrastructure upgrades

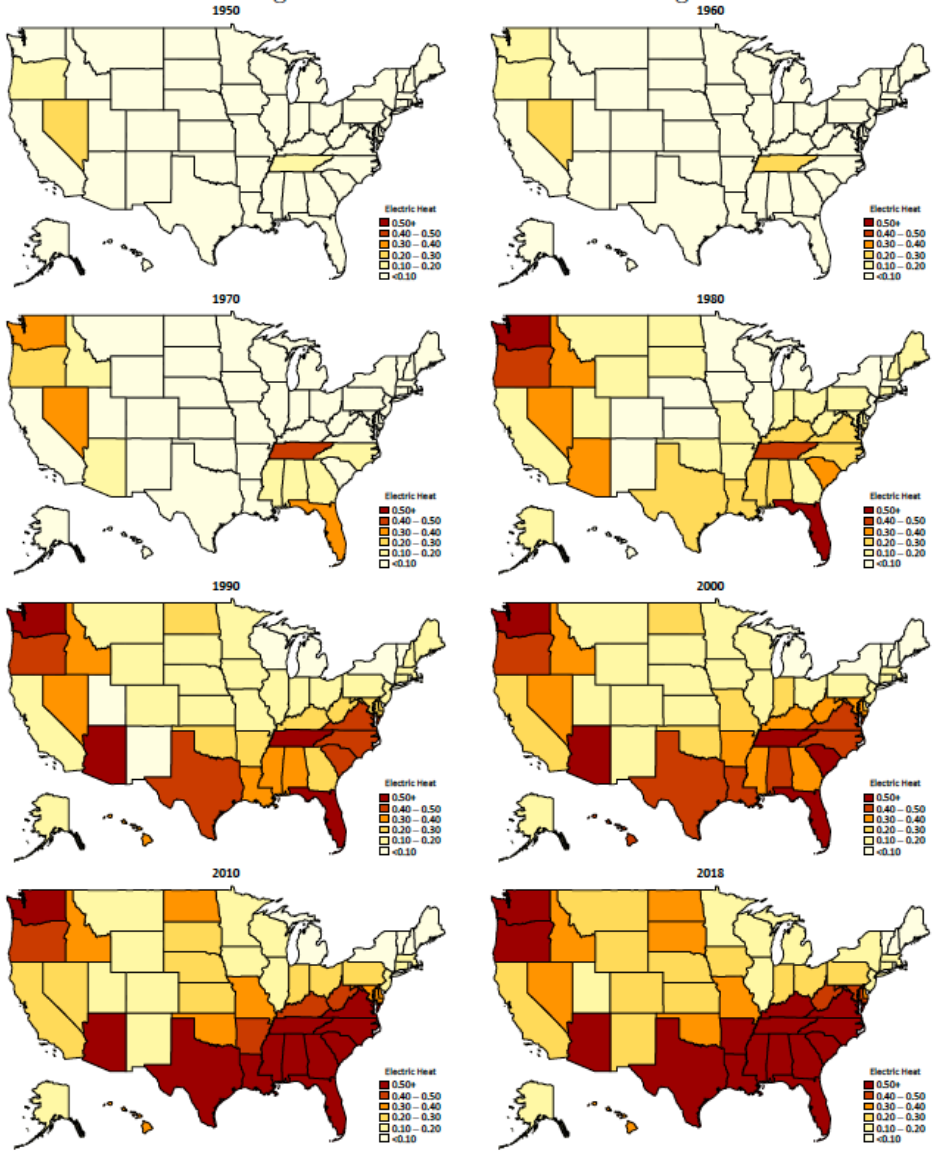
ELECTRIC APPLIANCES IN THE US

Presence of equipment and use of electricity in U.S. homes (2015)
share of all primary residences



Source: U.S. Energy Information Administration, 2015 Residential Energy Consumption Survey

https://www.eia.gov/todayinenergy/detail.php?id=39293



GROWTH OF ELECTRIC HEAT

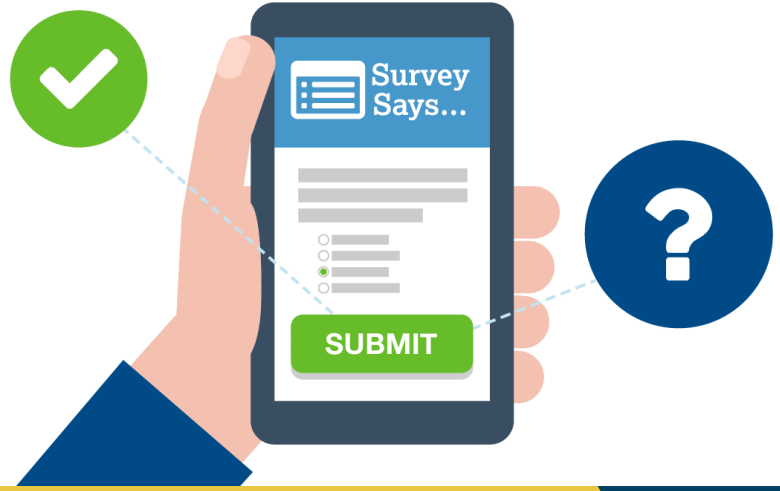
- Electrification of largest end-use has been increasing for years.
- We are just going to accelerate this trend.
- Most new-home growth in areas where homes are electrified for heating/cooling.

WHAT DO INDUSTRY PROFESSIONALS THINK?

Survey originally for Deep Energy Retrofits (DERs) – but most answers apply to decarbonization also

MARKET SURVEY

- Qualtrics survey platform
- 20-minute online survey to gather information from building energy professionals on their DER experiences and opinions
  - What motivates and deters DER projects in today's market?
  - Promising strategies and technologies
  - Non-cost aspects of retrofit measures
- 73 survey participants
  - Home performance contractor (25%)
  - Consultant (15%)
  - Program manager (14%)
  - Researcher (12%)
  - General contractor (11%)
  - Other (23%), e.g., engineer, architect, energy rater



CUSTOMER PERSPECTIVE

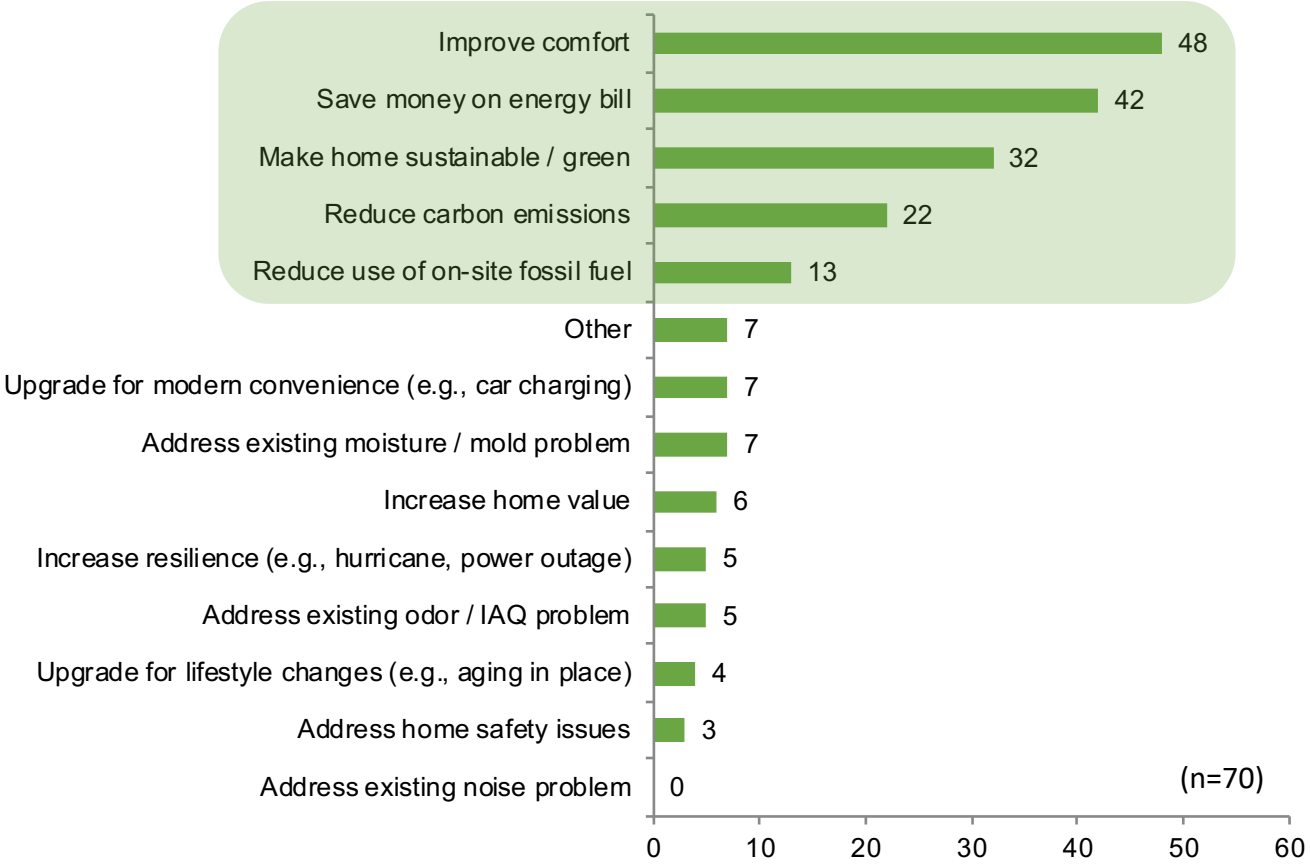
What are the main motivations of homeowners / building owners?

Residential <> Commercial

Profit is not the motive

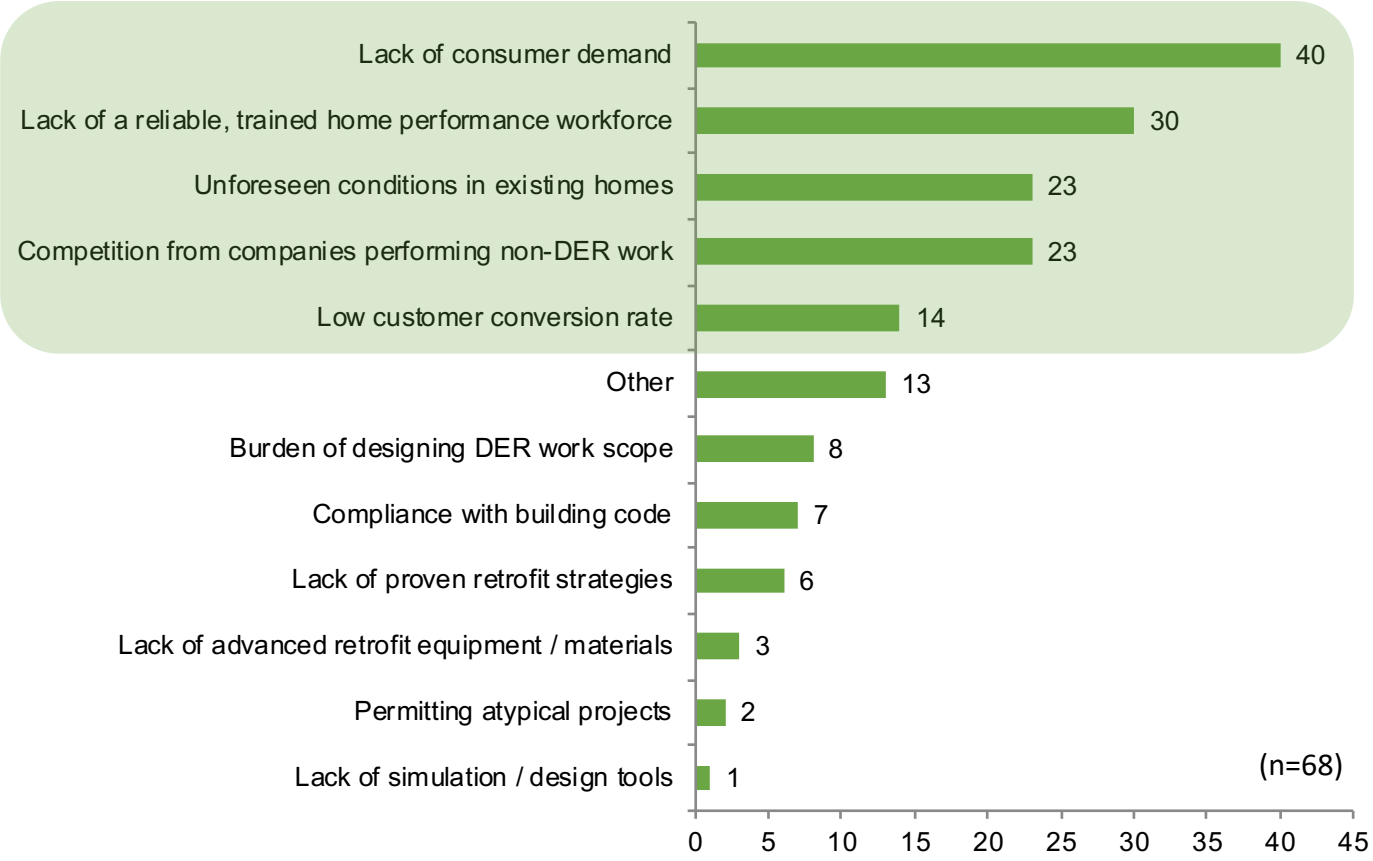
ROI, payback and other traditional investment metrics are misleading and the wrong ones to use

“Affordability” and financing are key



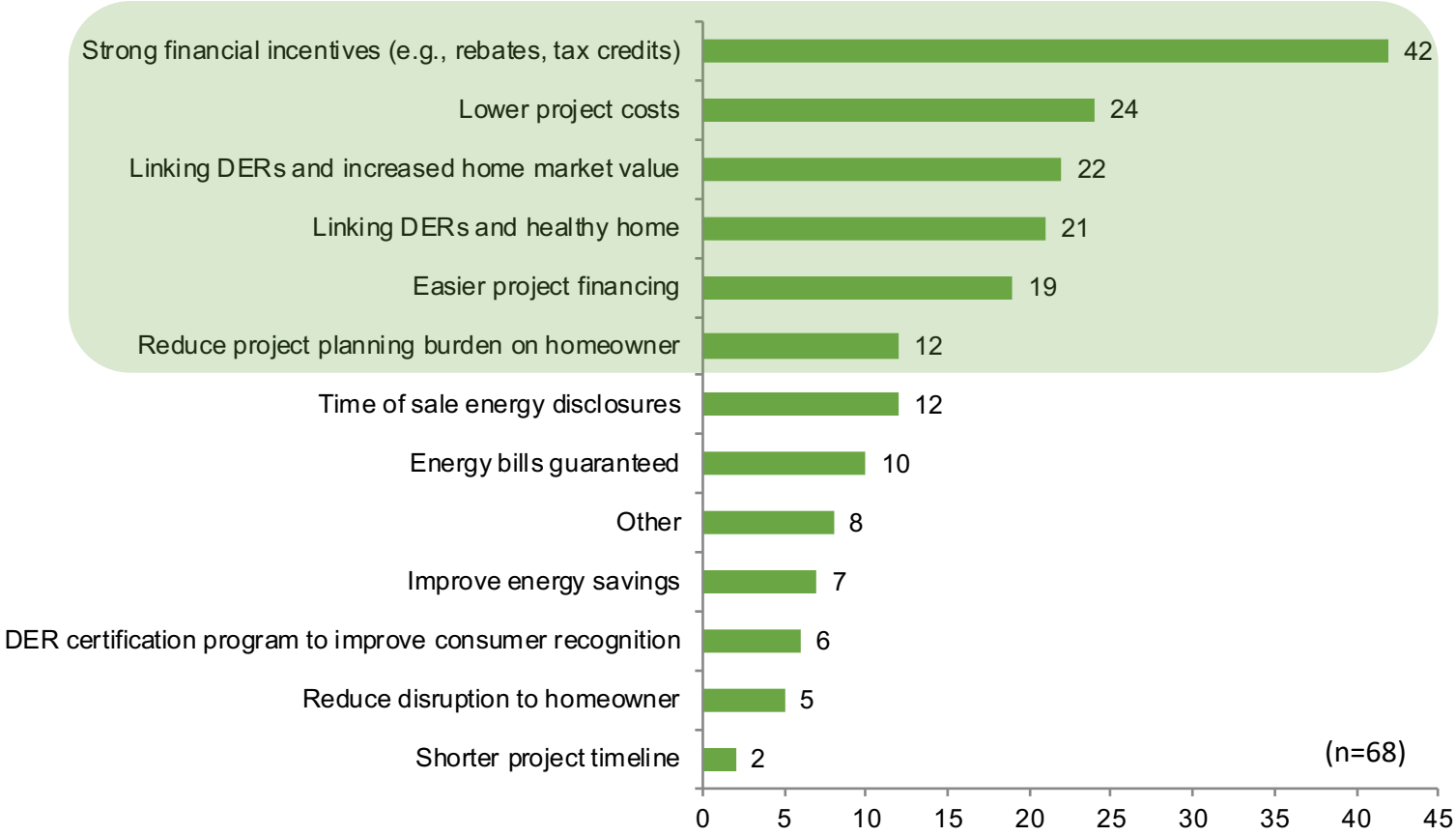
INDUSTRY PERSPECTIVE

Aside from costs, what are the biggest barriers?



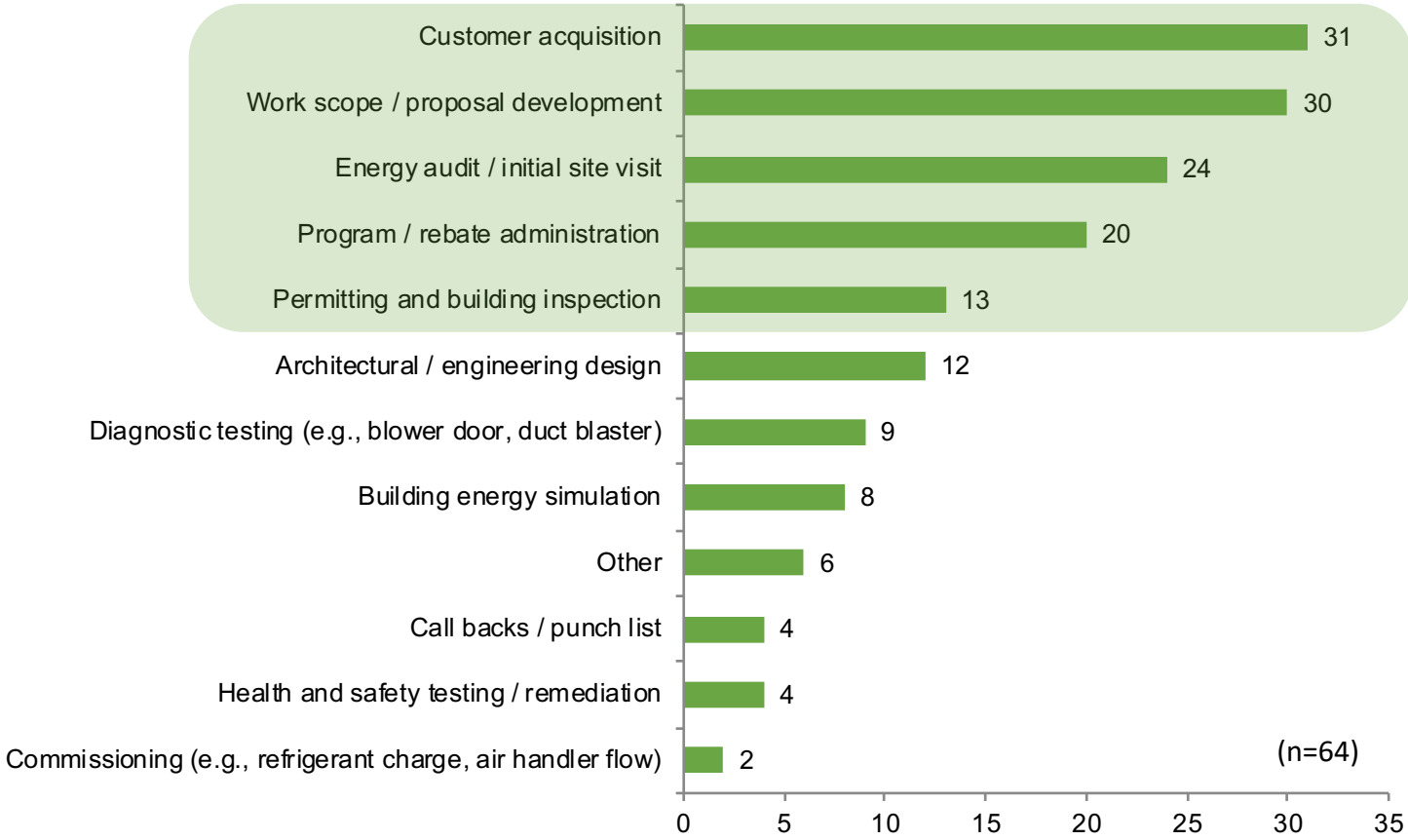
INDUSTRY PERSPECTIVE

What are the most effective ways to increase customer demand?



WORK SCOPE AND APPROACHES

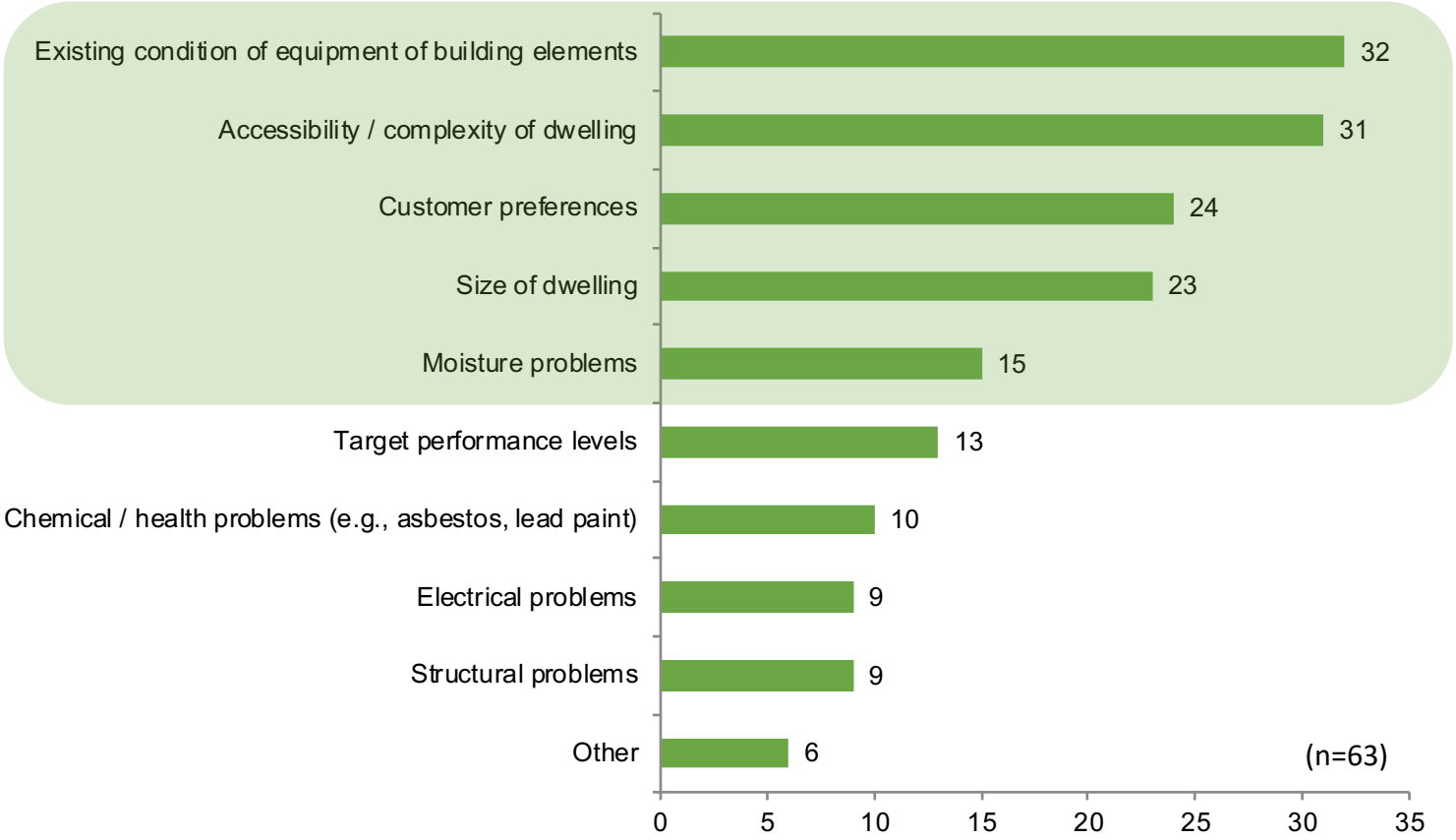
Non-construction tasks that survey respondents found to be the most time consuming



PROJECT COST ESTIMATES

What are important drivers of cost variability in DER projects?

Shows why existing homes are harder to electrify than new construction



AUDIENCE FEEDBACK

How are you selling electrification/decarbonization to homeowners?

What is working/not?

What are people's concerns with electrification technologies?

Can the home performance workforce adapt to this new focus?

WHAT'S IT ALL GOING TO COST?

New Construction Costs: $25,000 less to build all-electric homes

Graphic courtesy of Sean Armstrong, Redwood Energy

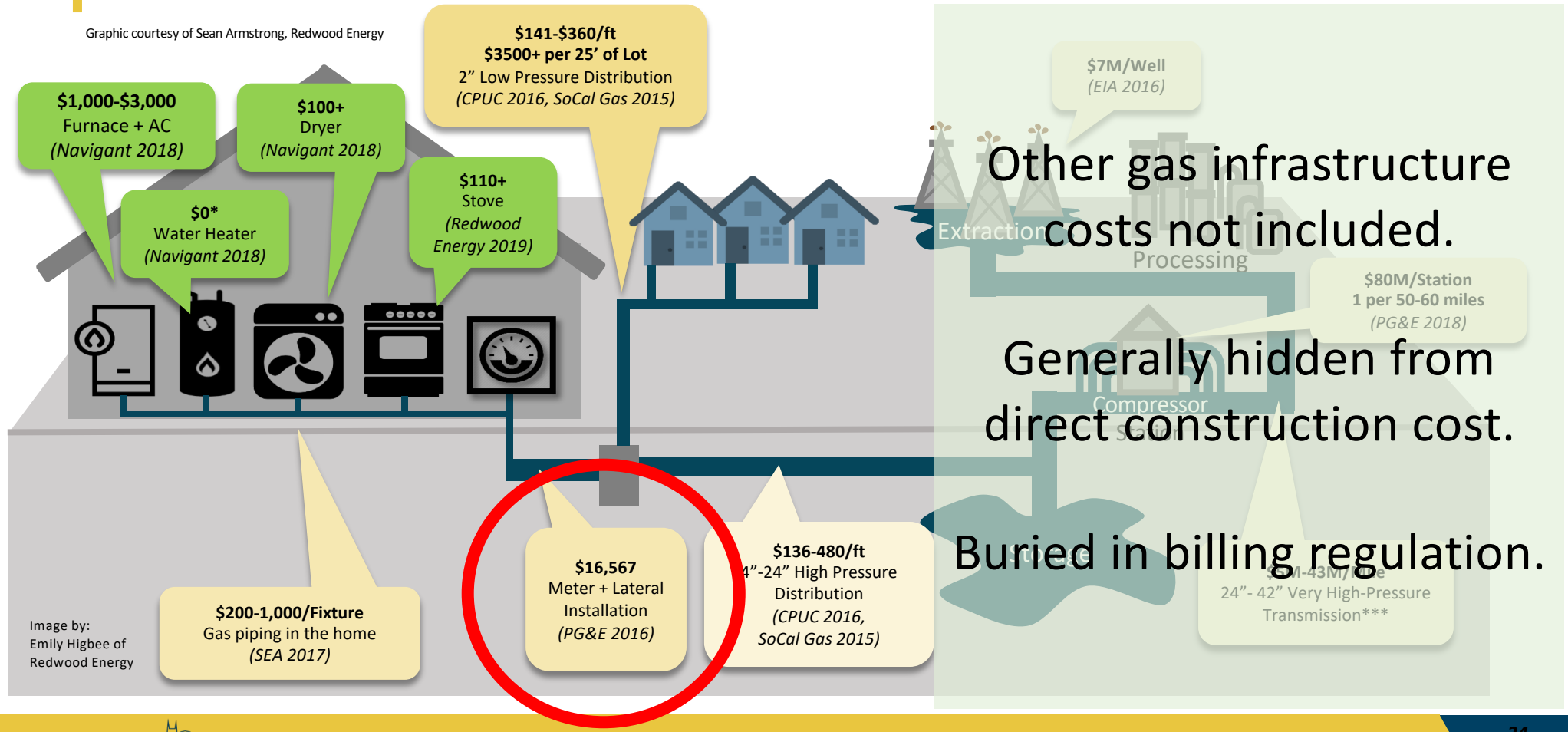


Image by:
Emily Higbee of
Redwood Energy

Other gas infrastructure costs not included.

Generally hidden from direct construction cost.

Buried in billing regulation.

HOME UPGRADE COSTS

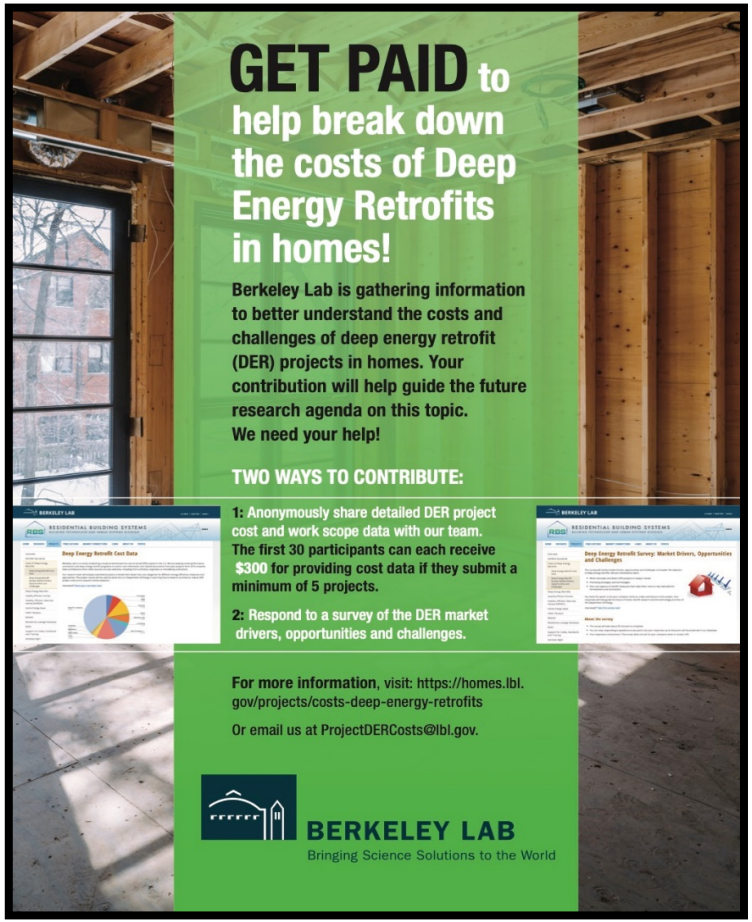
DOE/LBNL effort to create a database of:

- Costs - broken down by measure
- Energy (and calculated CO_2) savings

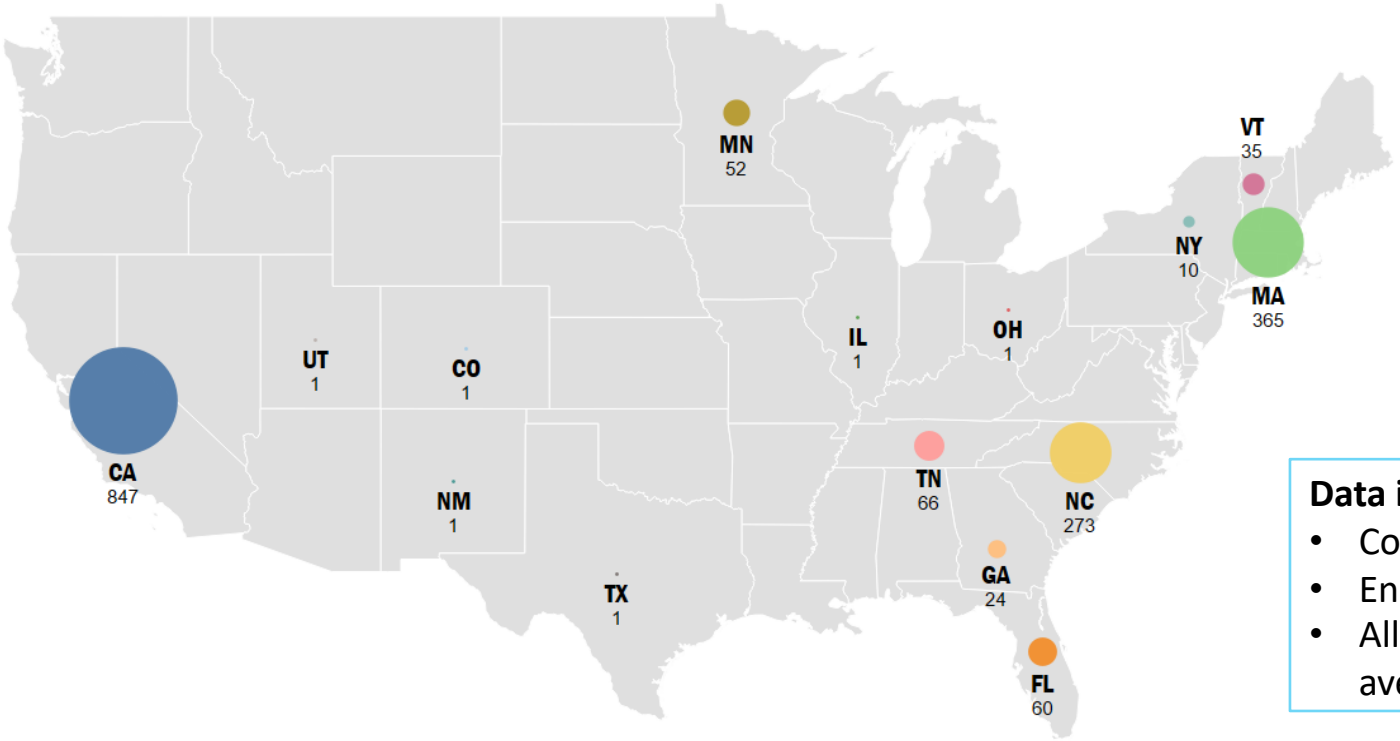
Sample of convenience:

- Most data voluntarily provided by energy programs
- Paid contributions for 475 homes
- Looking for home with significant energy reduction

Initial focus on Deep Energy Retrofit (DER) not Electrification/Decarbonization



DATABASE SUMMARY



Sample of convenience:

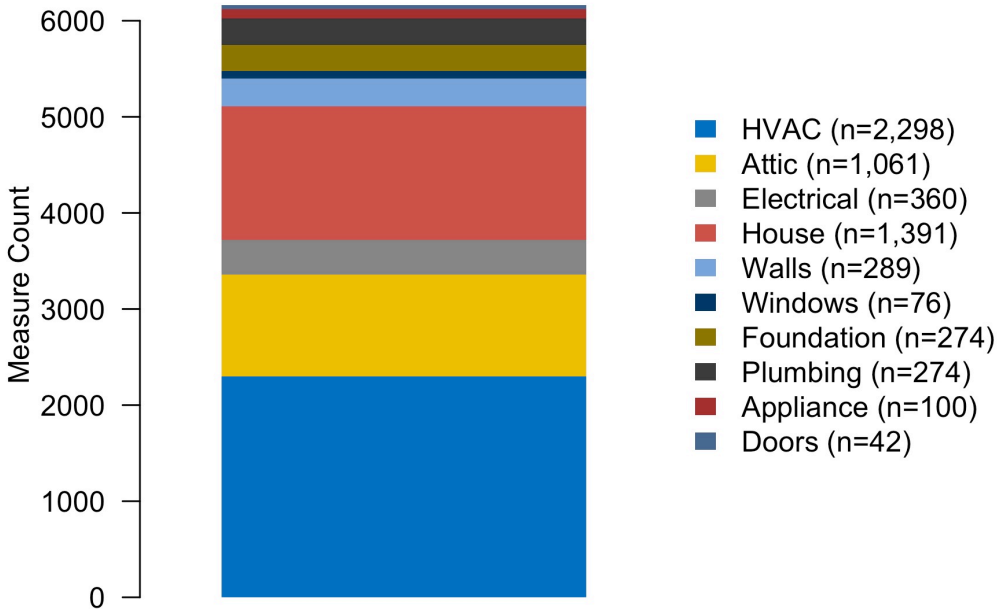
- Most data voluntarily provided by energy programs
- Paid contributions for 475 homes

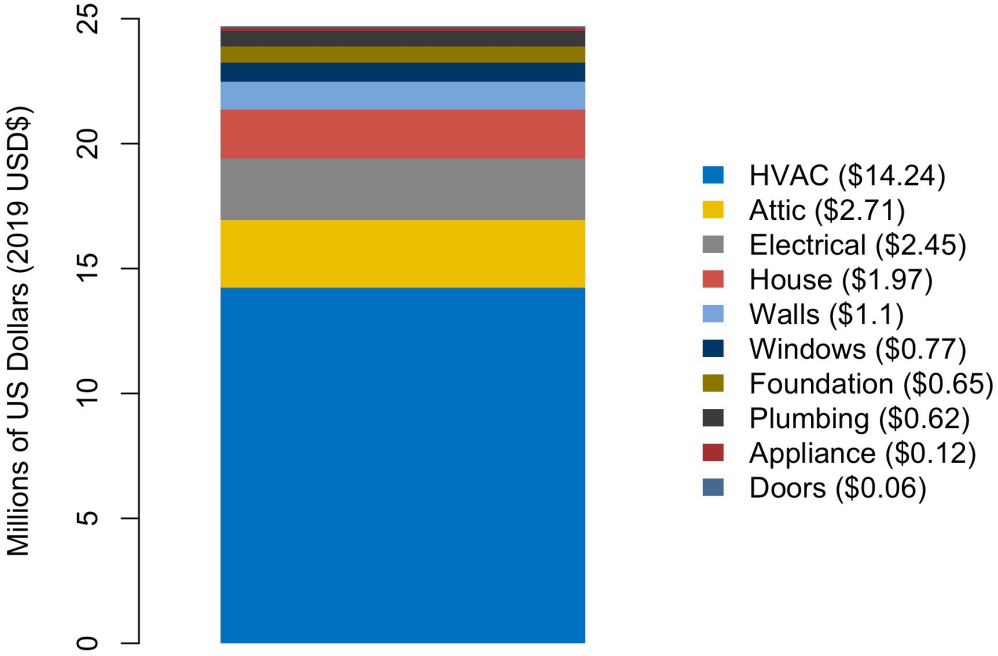
Data included:

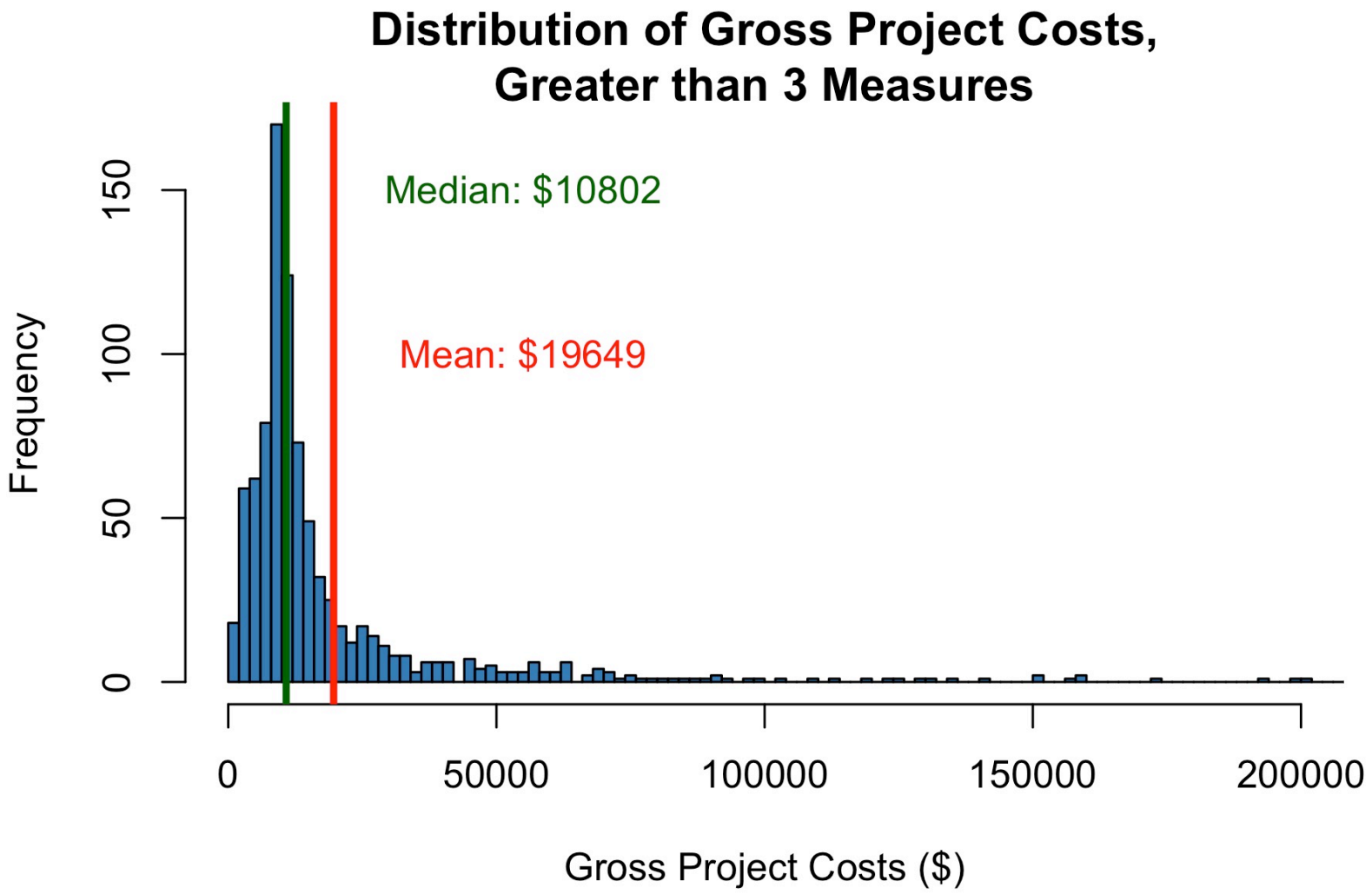
- Costs - Broken down by measure
- Energy (and calculated CO_2) savings
- All costs in $2019 and nationally averaged

12 Programs	**1,739 Projects**	**10,512 Measures**	**3,294,946 ft^2**	**$24,689,213**

MEASURE OVERVIEW



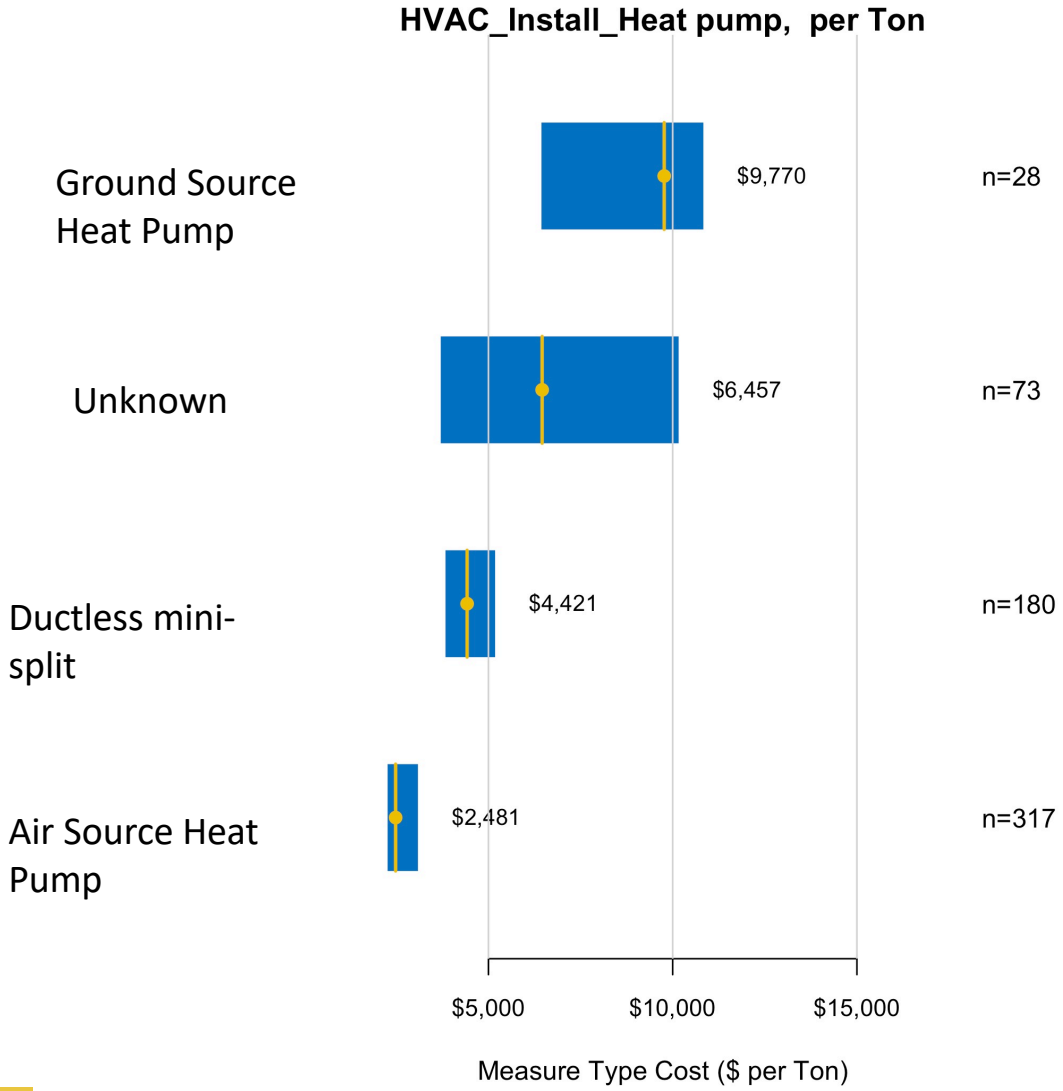



Distribution of Gross Project Costs,
Greater than 3 Measures
Median: $10802
Mean: $19649
Frequency
0
50
100
150
0
50000
100000
150000
200000
Gross Project Costs ($)

HEAT PUMP COSTS

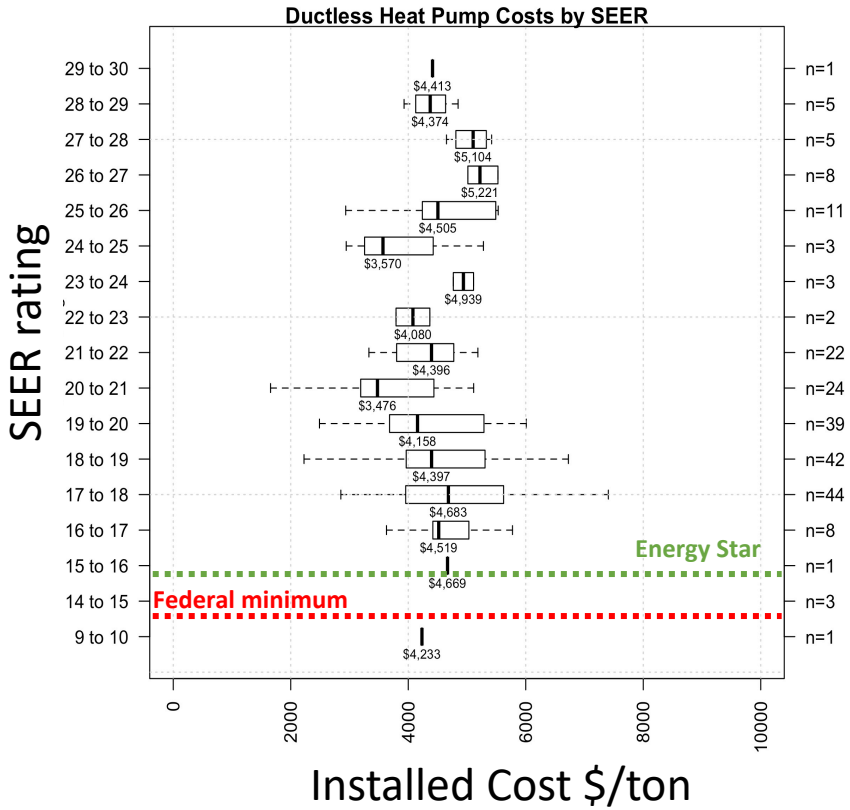
Some measures broken down by size, for example, heat pump costs per ton

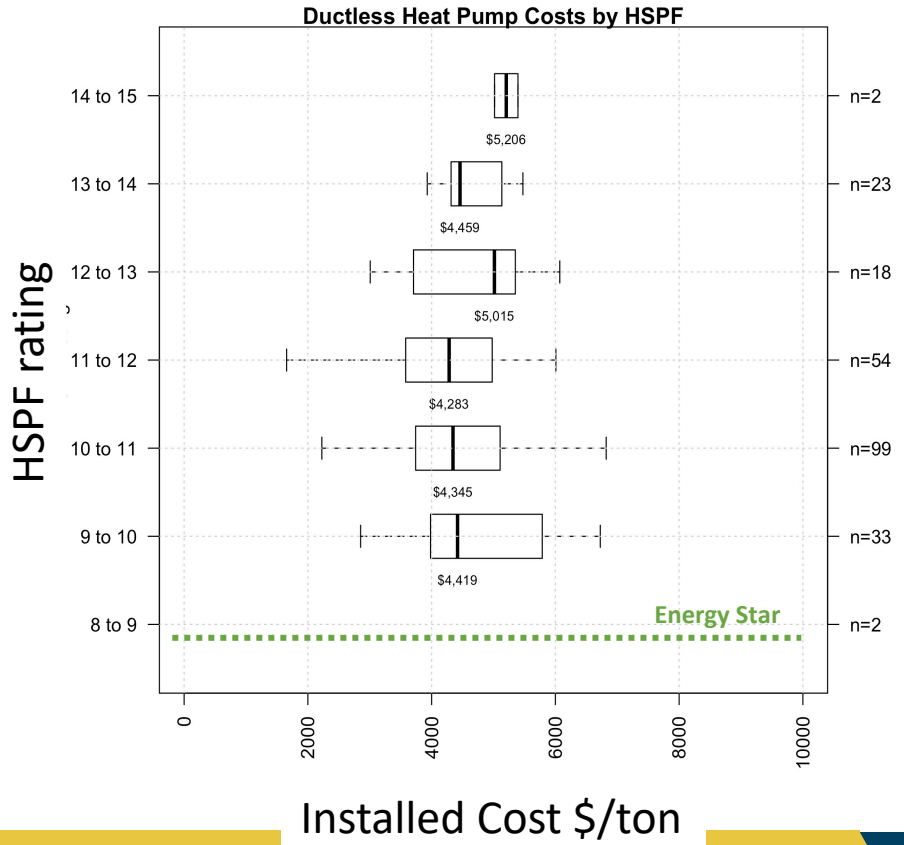
This allows tradeoffs
e.g., Balance cost of envelope load reduction with reduced heat pump cost



IS "BETTER" MORE EXPENSIVE?

Non-efficiency features dominate installed costs: brand, location, installer, site access, electrical requirements, etc.



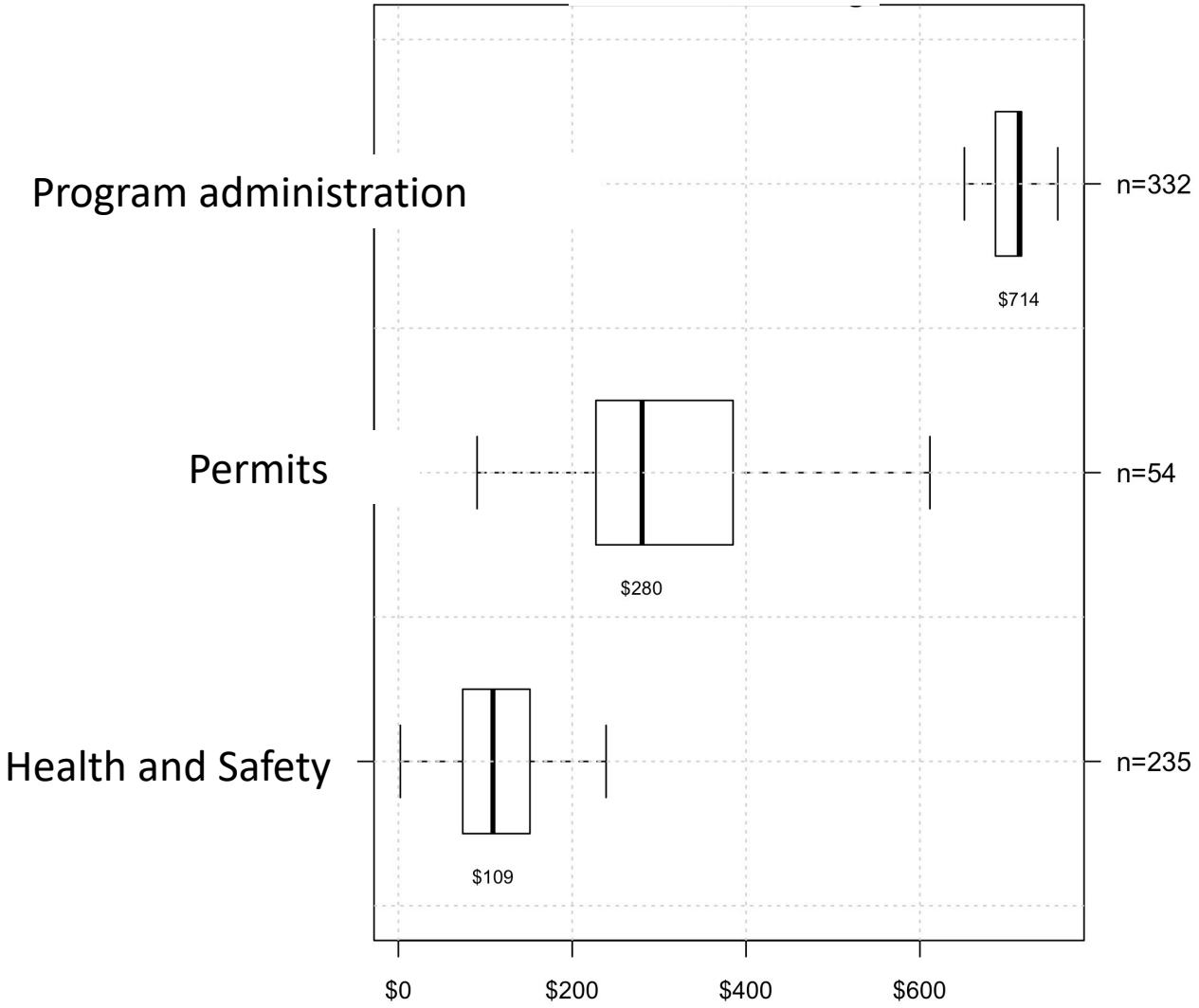


SOFT COSTS

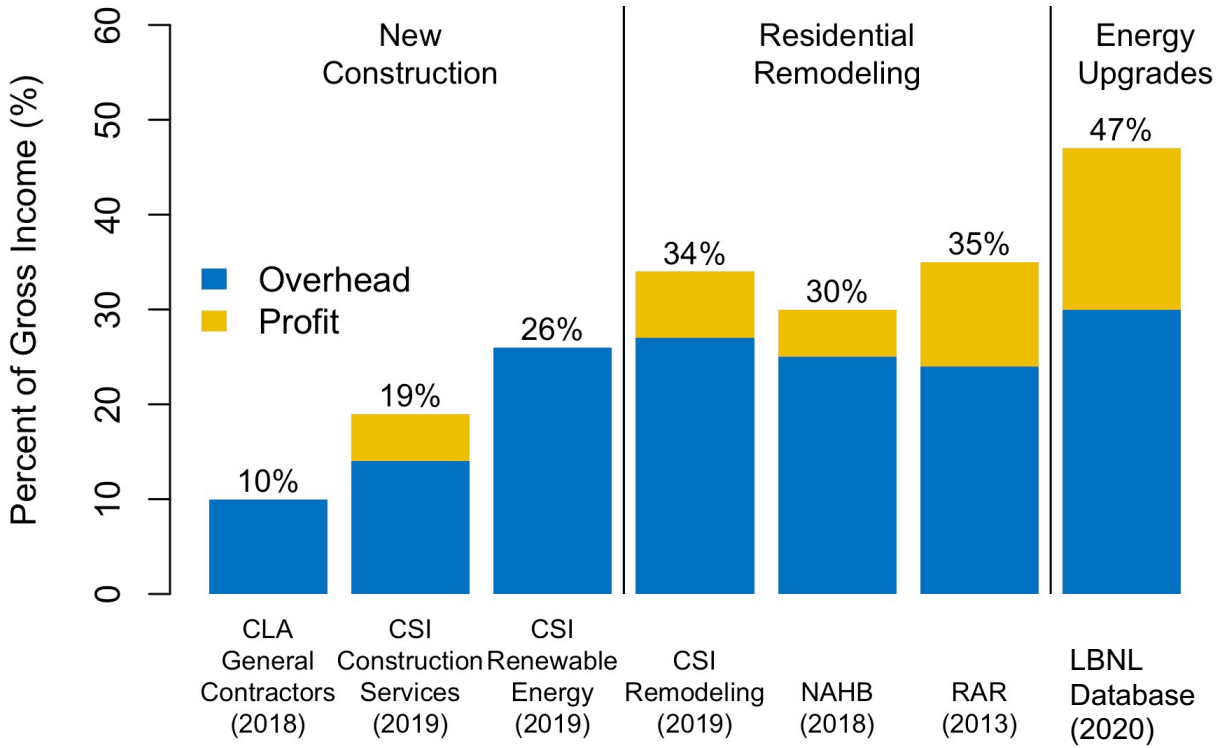
Time required to work with programs is not insignificant

Permits are typically not expensive
(but the associated labor costs might be!)

Very little H&S



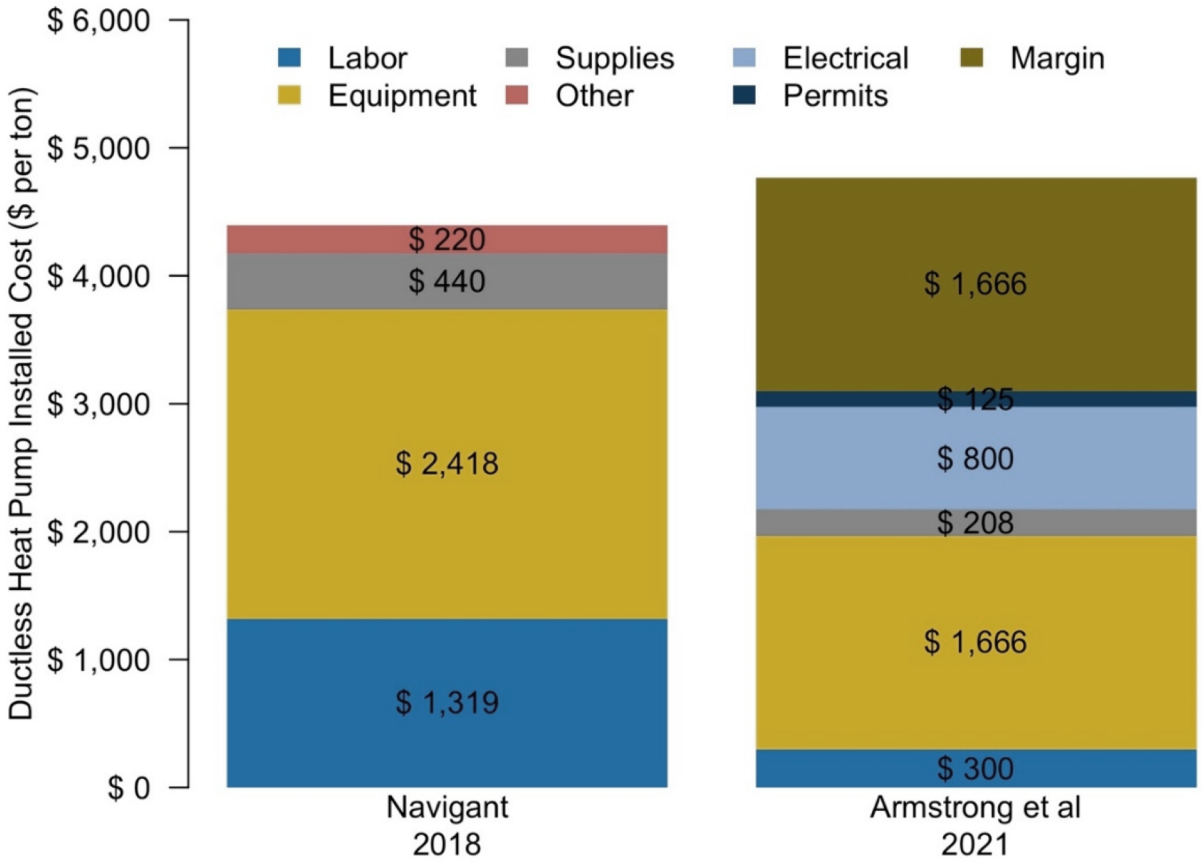
SOFT COSTS ARE HIGH FOR ENERGY/CARBON RETROFITS



Need to reduce Soft Costs:

- Customer acquisition
- Testing
- Program participation
- Project design

INDIVIDUAL MEASURE COST BREAKDOWN

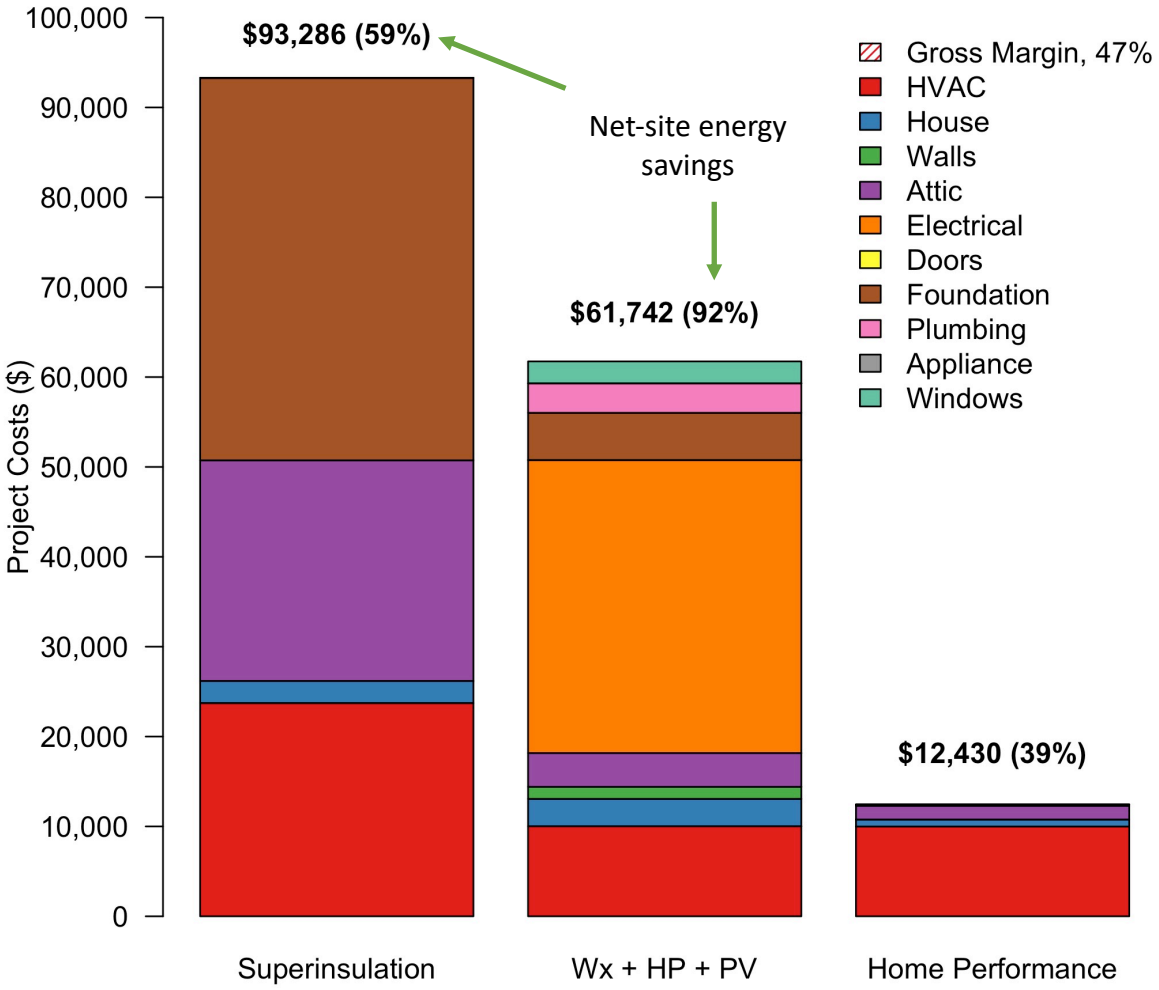


- Cost breakdowns highly variable
- Cost breakdowns not done by most contractors
- High margins
- Residential industry is small companies that do not have the size or desire to optimize their costs or even ***know or track*** them

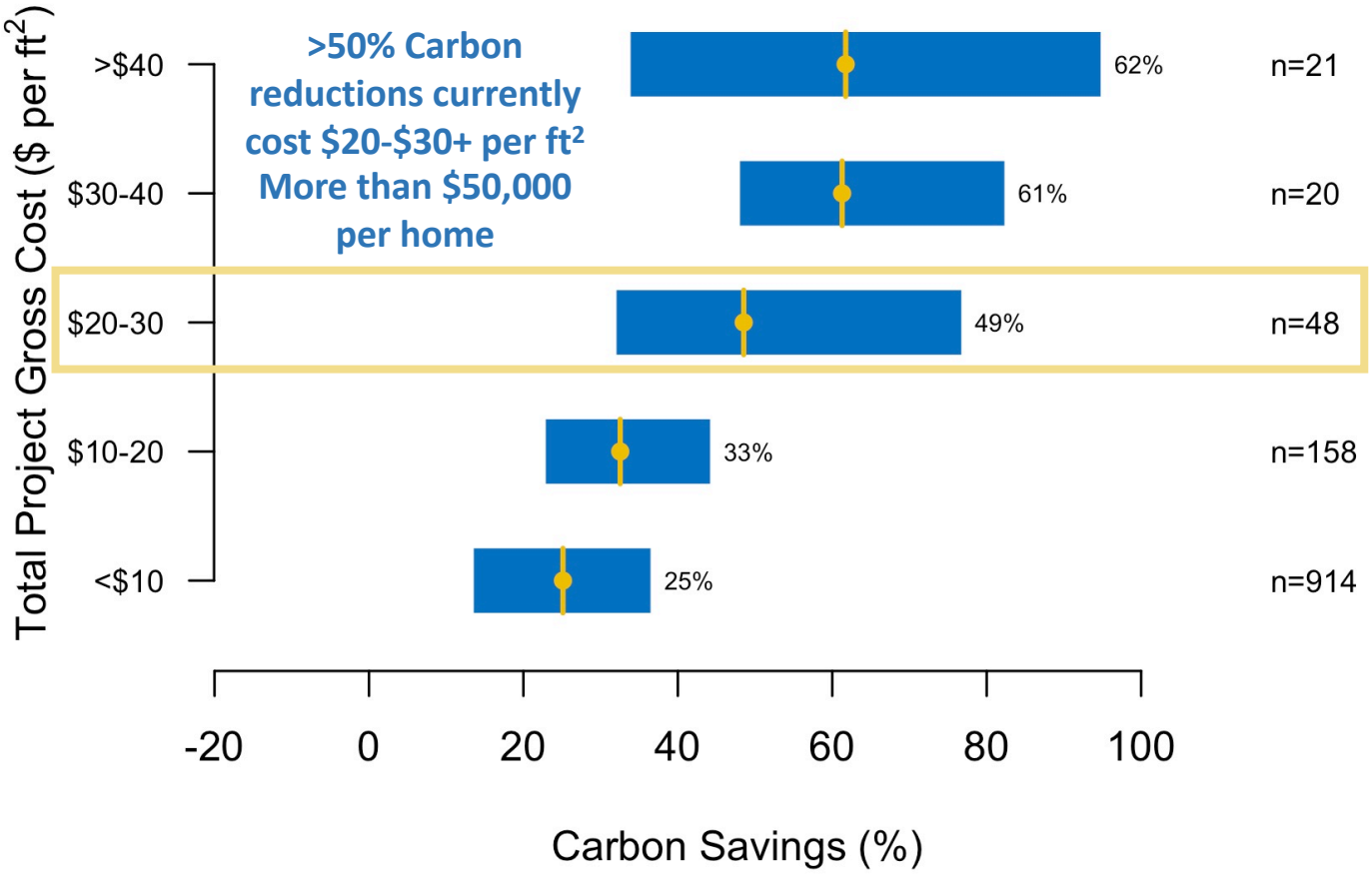
ARCHETYPAL PROJECT COST BREAKDOWN

Three archetypal retrofits – these are specific projects NOT averages

Traditional super-insulation is outperformed by emerging Weatherization + Heat Pumps + Solar PV (Wx + HP + PV)



HOW MUCH DOES IT COST TO GET TO 50% CARBON SAVINGS?



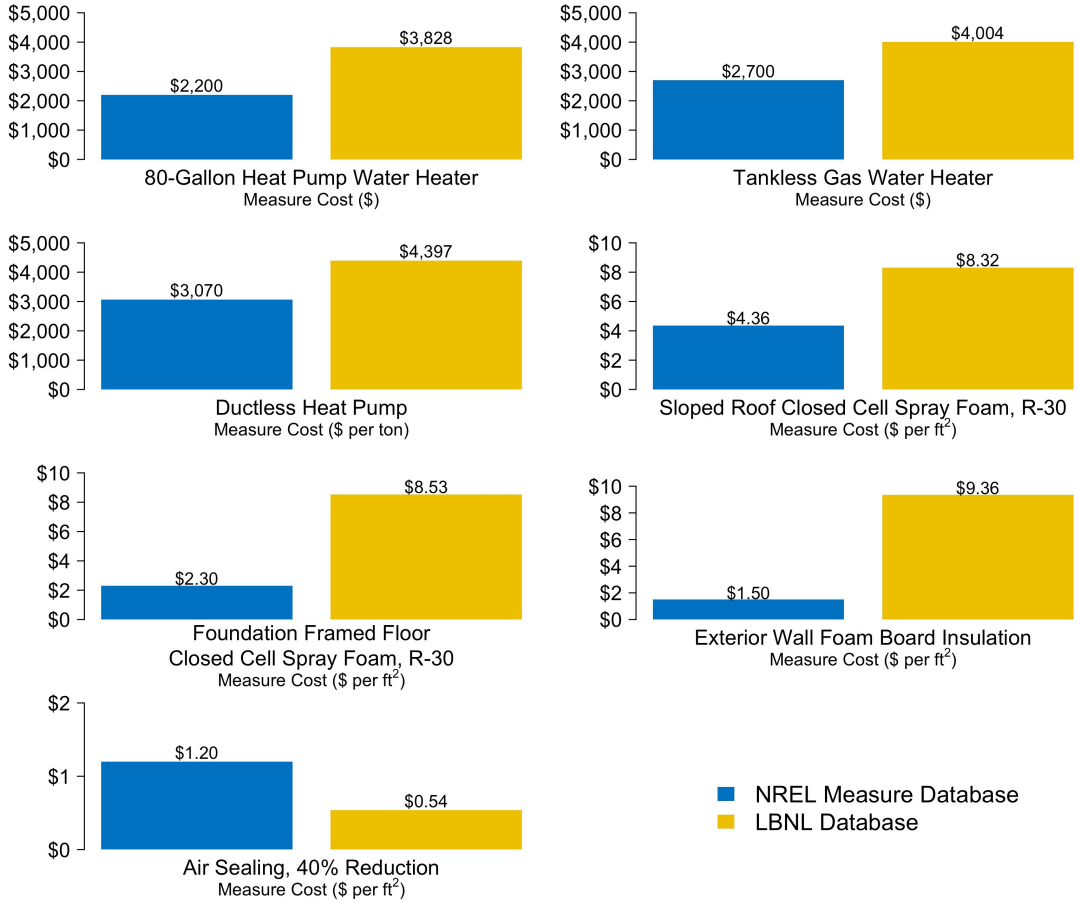
Higher cost projects have diminishing returns

COMPARISON TO EXISTING NREL DATABASE

Most reported costs higher than NREL database

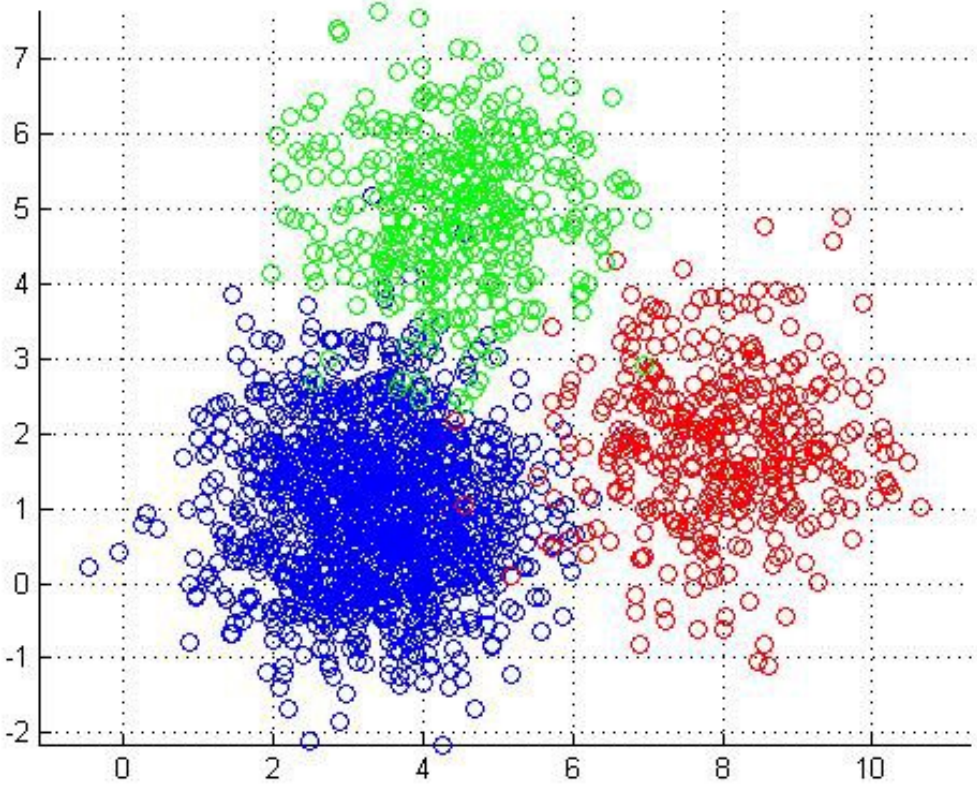
LBNL & NREL collaborating to update NREL database

Anecdotally – these costs have increased by >20% since 2019….



REDUCING COSTS

UPGRADE OPTIMIZATION



Unsupervised **Machine Learning** approach that groups similar objects such that the objects in the same group are more similar to each other than to objects in the other groups.

Upgrade projects were clustered based on total project costs.

UPGRADE OPTIMIZATION

$ - Total Cost
(% - CO_2e reduction)

Costs remain too high For decarbonization

BASIC
Low-cost, basic projects with mostly envelope and limited HVAC work

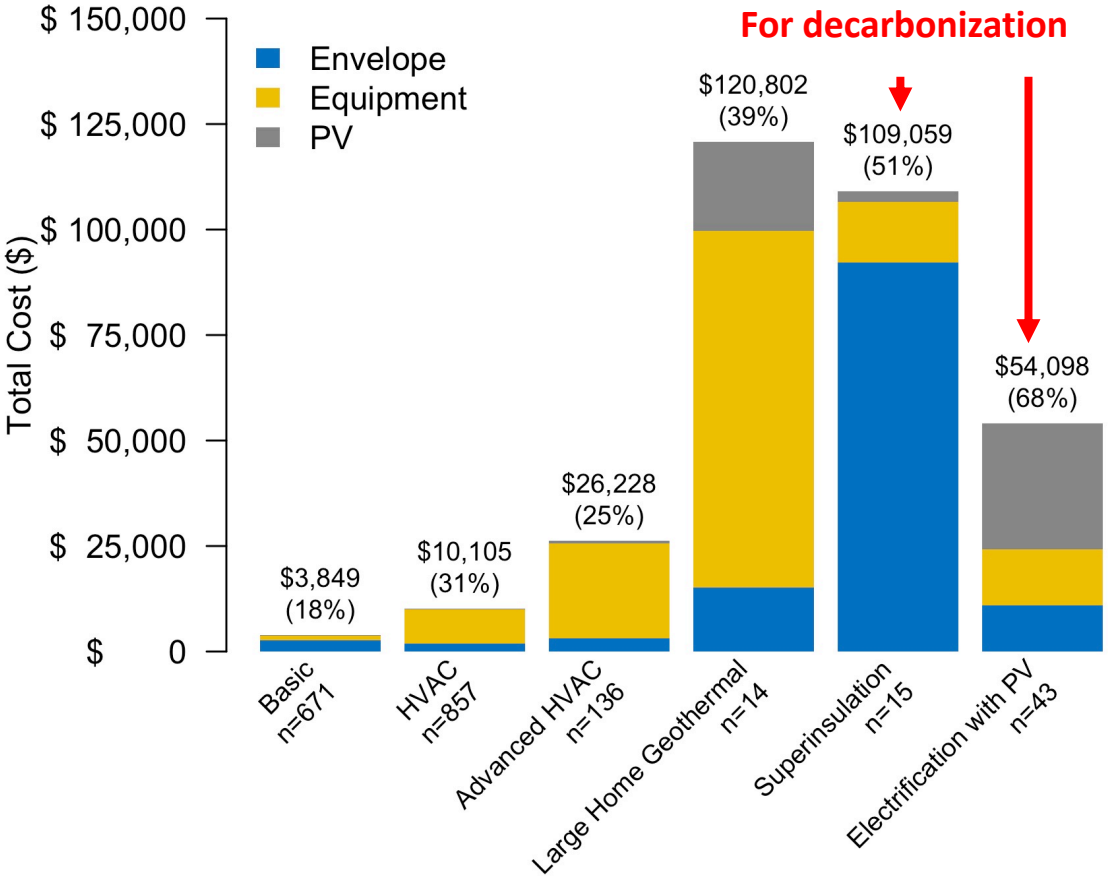
HVAC
HVAC projects with standard equipment (~1/2 heat pumps), including some envelope work

ADVANCED HVAC
Advanced, higher-cost HVAC projects (>2/3 heat pumps), including some envelope work

LARGE HOME GEOTHERMAL
HVAC-focused projects in large homes with geothermal heat pumps (90%) and some envelope and PV work

SUPERINSULATION
Comprehensive deep retrofits focused on aggressive envelope upgrades (e.g., exterior wall insulation, triple pane windows, etc.) with some gas equipment and little or no PV

ELECTRIFICATION WITH PV
Equipment electrification projects that include moderate envelope upgrades and PV

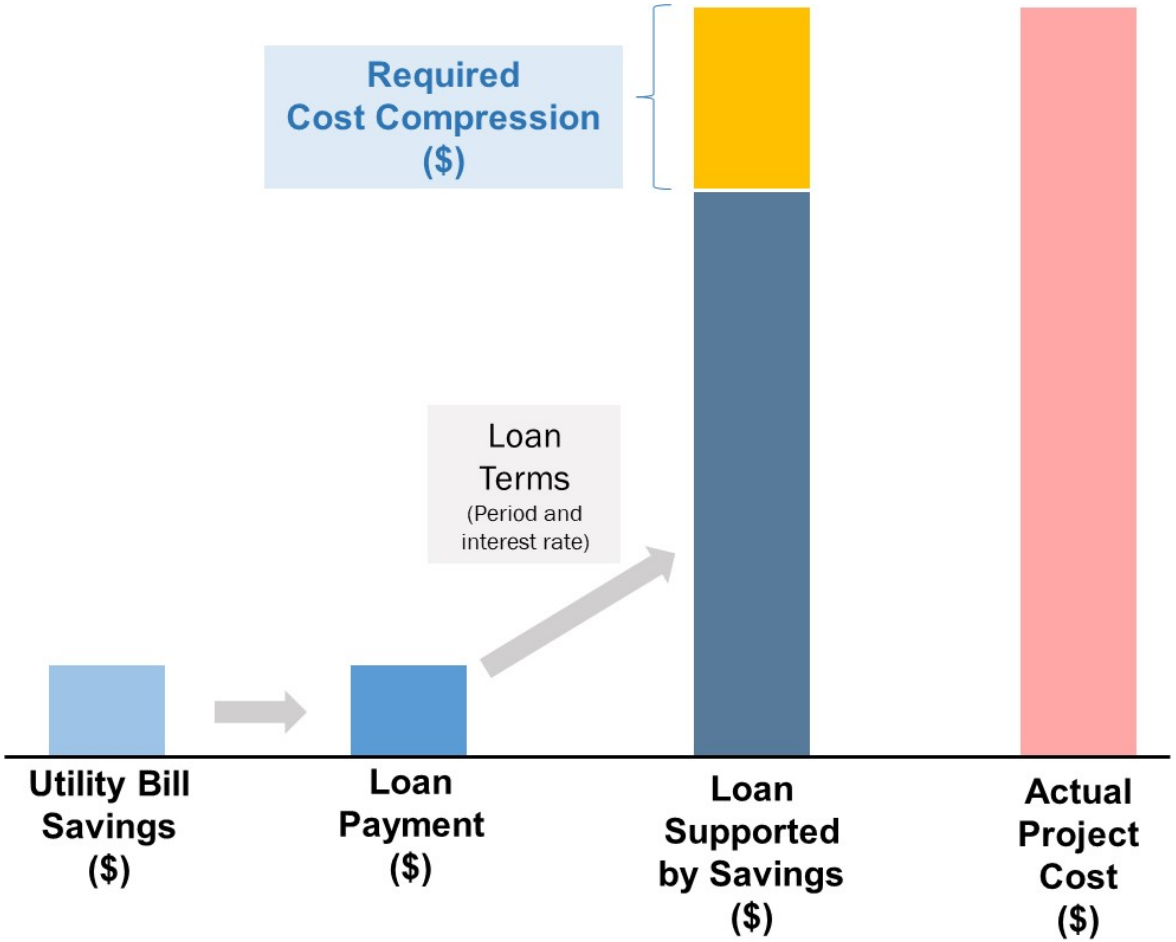


AFFORDABILITY

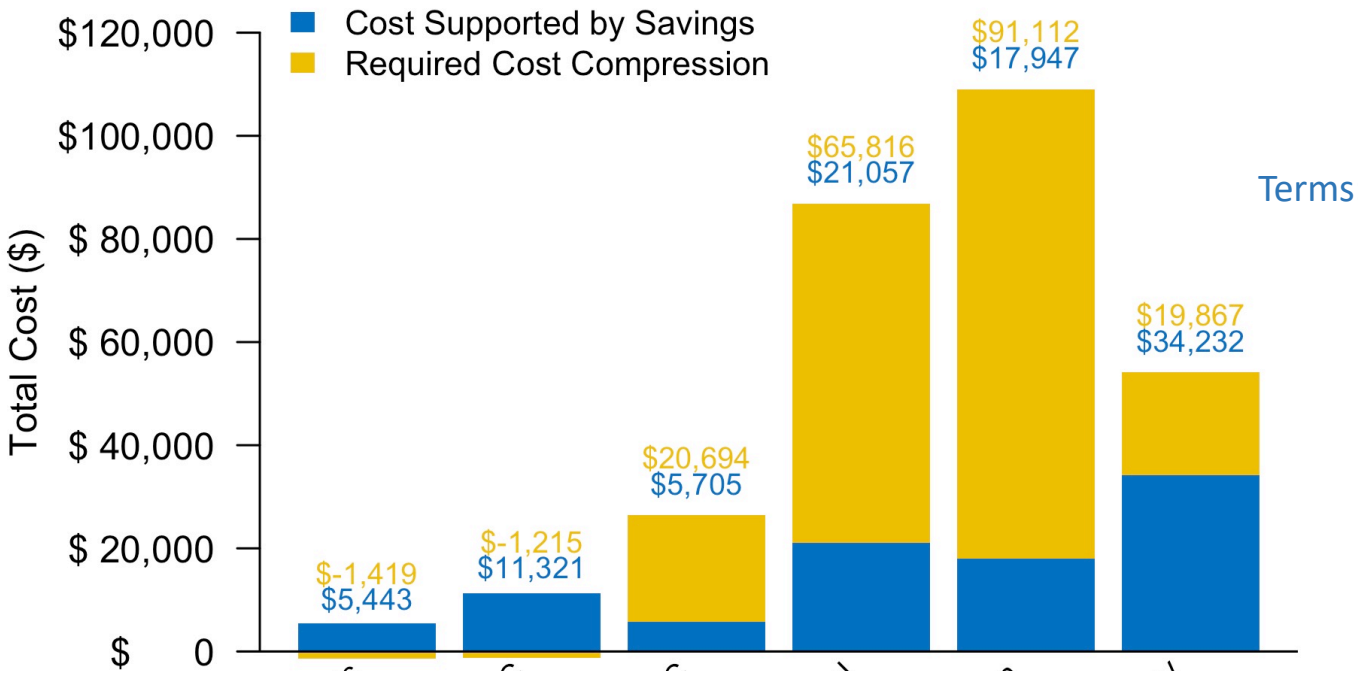
- Upfront costs are a major barrier to getting to scale with decarbonization
- Financing needed

But… Bill savings will not cover loan payment for significant decarbonization (>50%)

Current decarbonization projects are rarely financed – but this will have to change



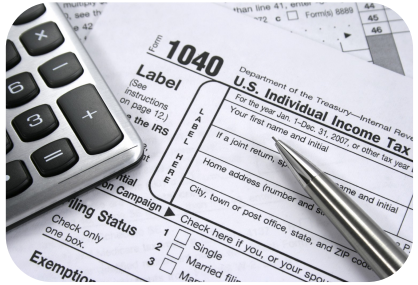
REQUIRED COST COMPRESSION



Terms: 30-year, 3% interest

CO_2 Reduction	**18%**	**31%**	**25%**	**39%**	**51%**	**68%**

REDUCING COSTS

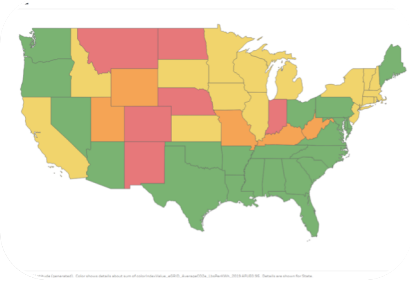


Rebates and Affordability

Upgrade Package Optimization

Technology Innovation

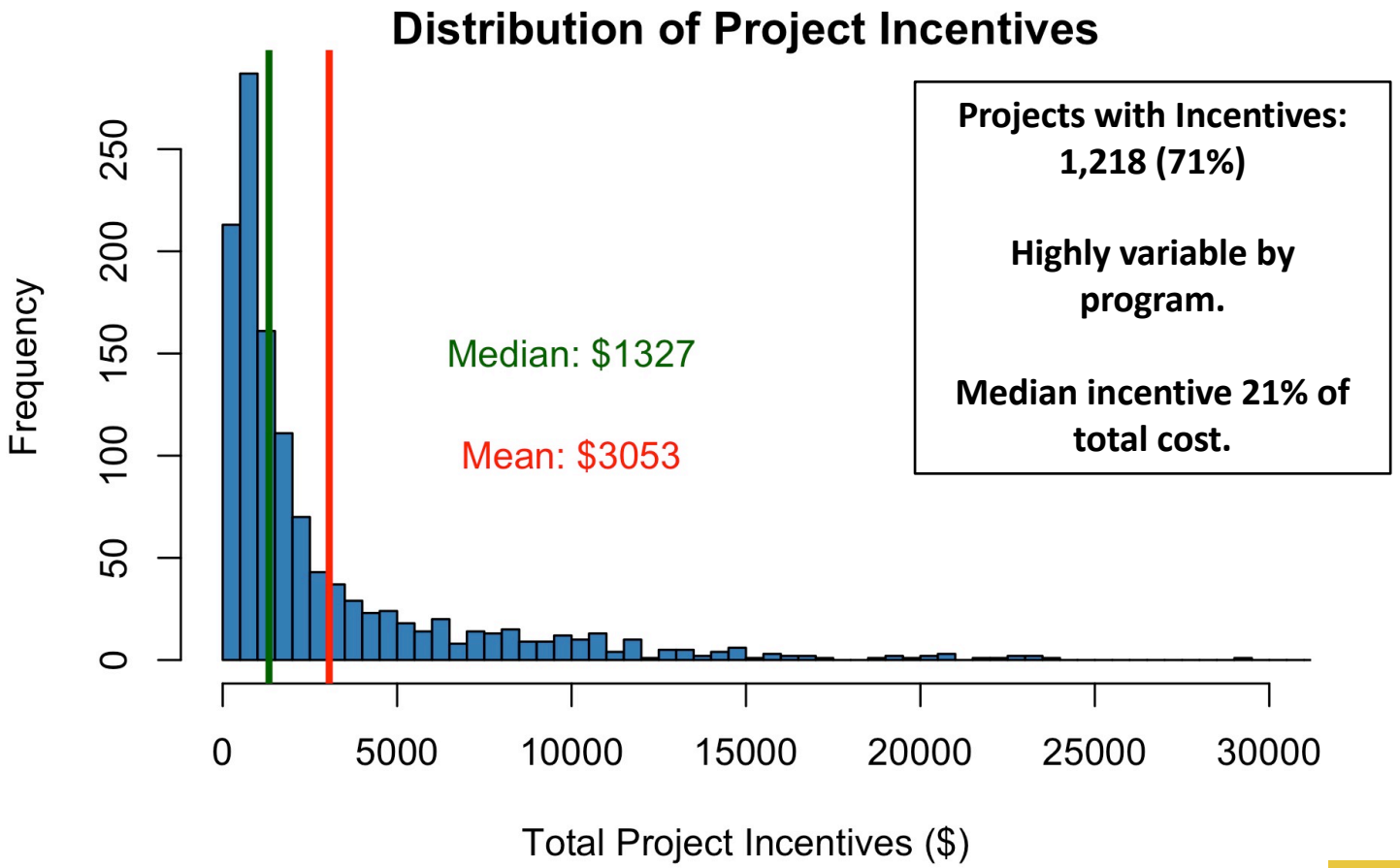
Soft Cost Reductions



New Metrics

No- and Low-Cost Methods

REBATES – LBNL DATABASE

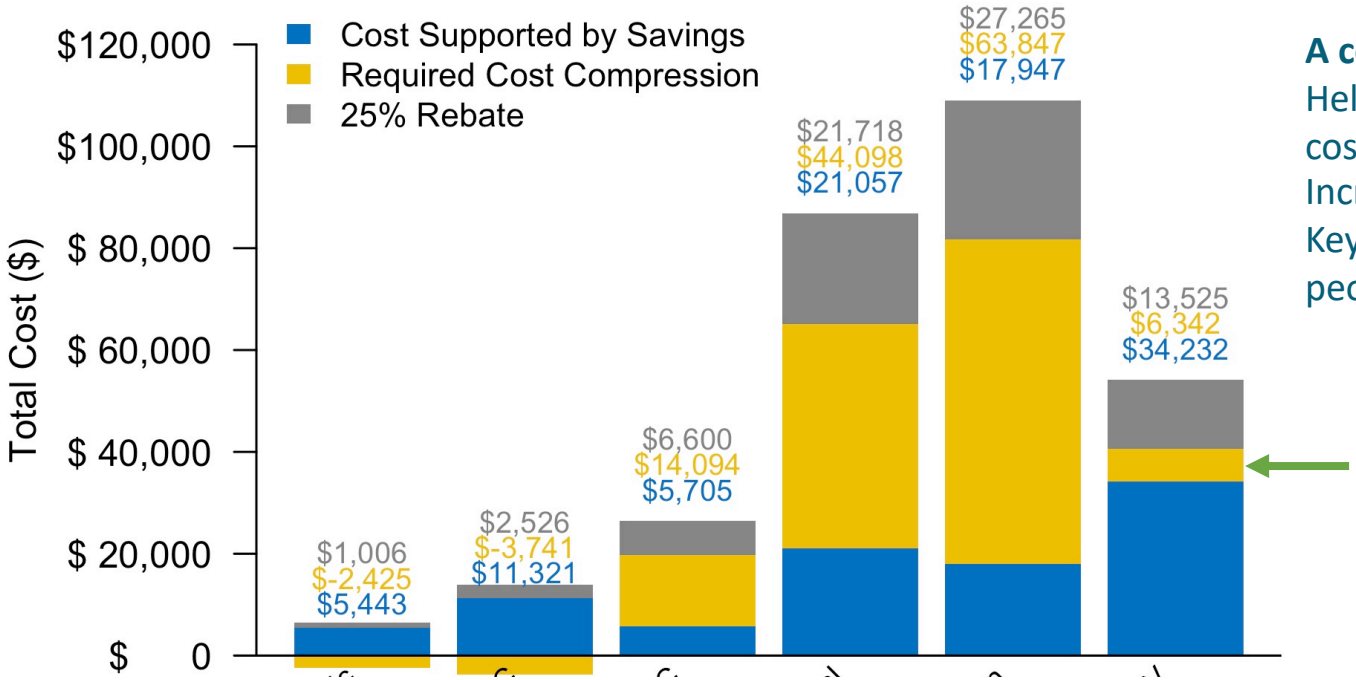


Projects with Incentives: 1,218 (71%)

Highly variable by program.

Median incentive 21% of total cost.

REQUIRED COST COMPRESSION – WITH REBATES

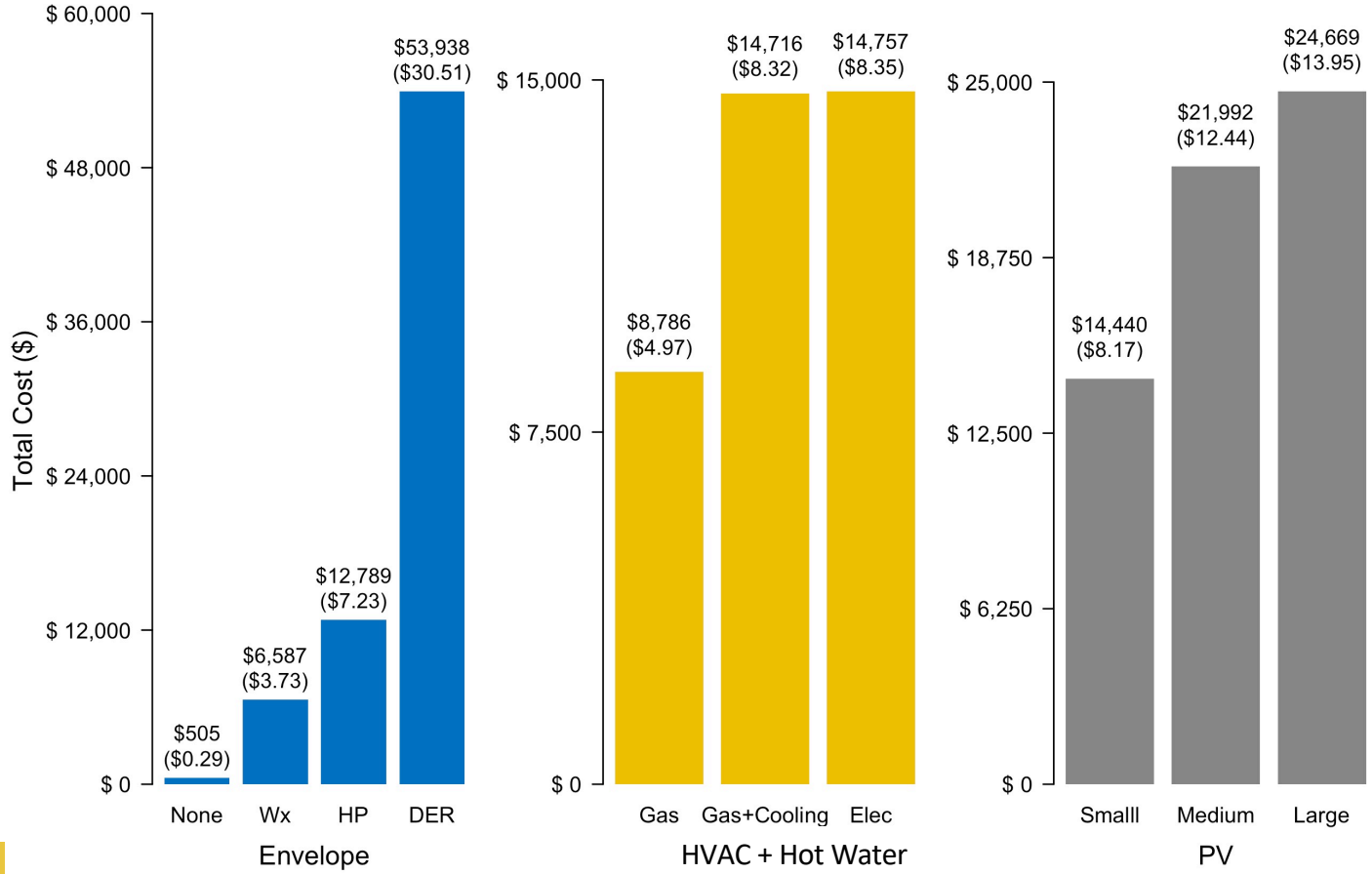


Cluster	Basic	HVAC	Advanced HVAC	Geo-thermal	Super-insulation	Electrification with PV
CO_2 Reduction	18%	31%	25%	39%	51%	68%

A contractor favorite!
Helps reduce up-front costs
Increases affordability
Key marketing strategy – people like to get a "deal"

More feasible cost compression

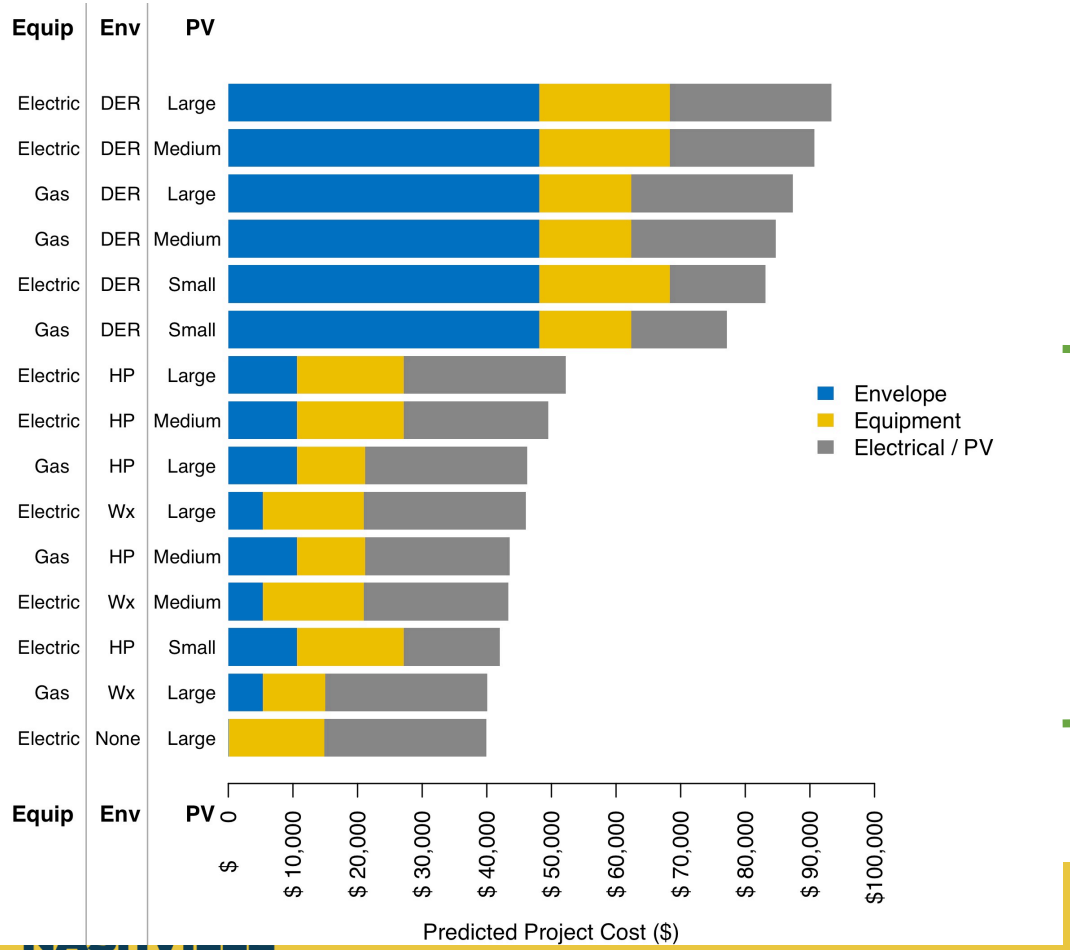
COST COMPRESSION – PACKAGE OPTIMIZATION



Architypes Created from 4 envelope, 3 HVAC & DHW and 3 PV options

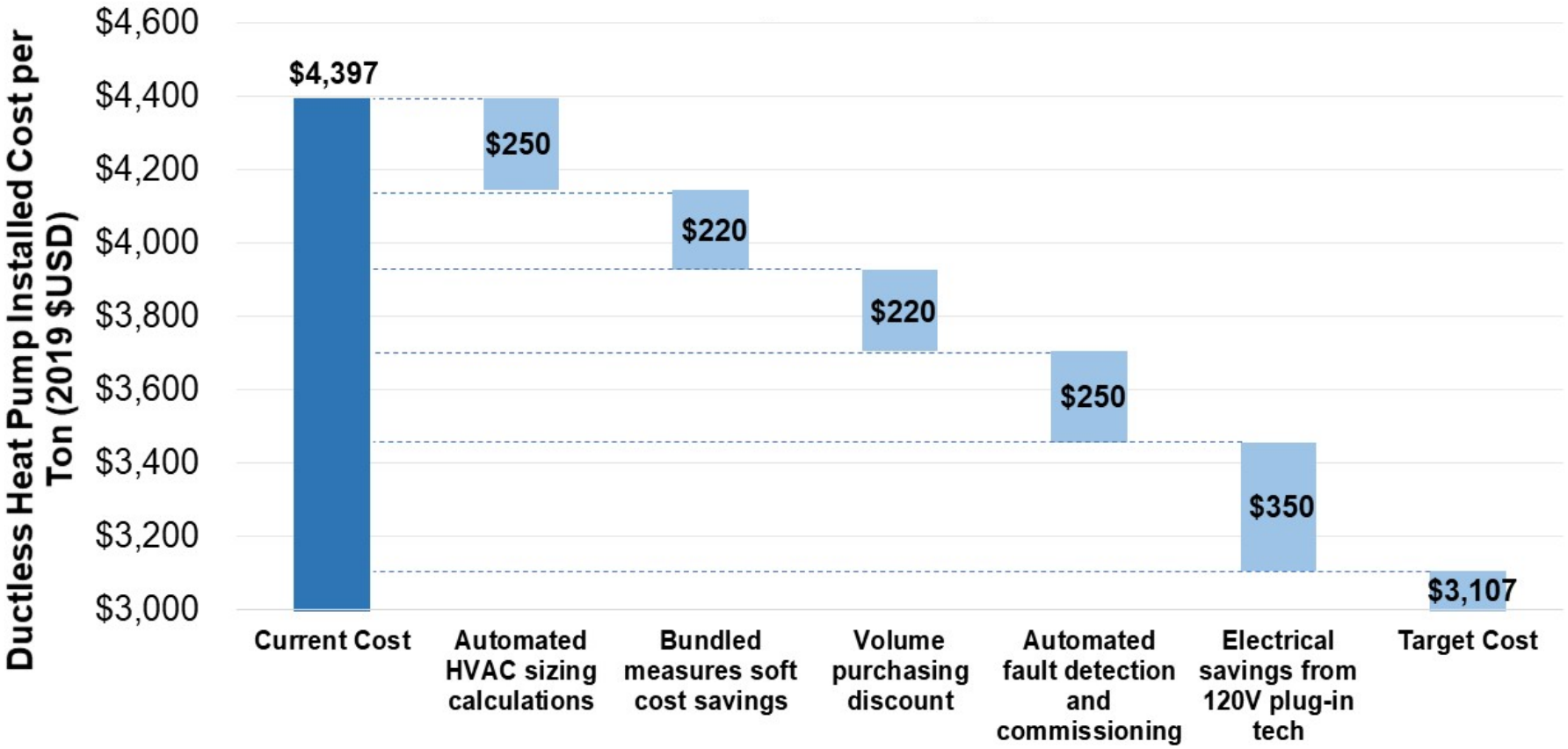
COST COMPRESSION – PACKAGE OPTIMIZATION

60-70% CO_2e Savings

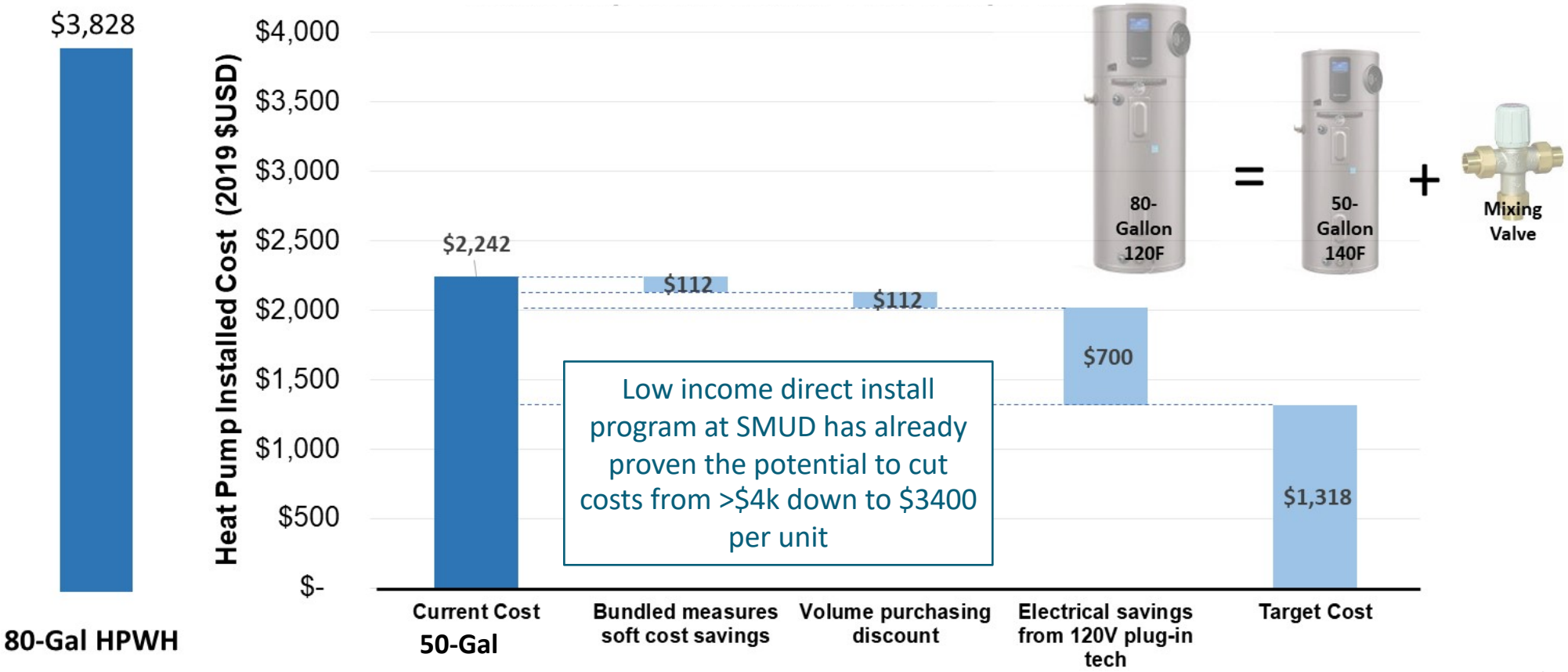


Mild Envelope upgrades + PV gives good carbon savings at least cost

COST COMPRESSION – DUCTLESS HEAT PUMPS



COST COMPRESSION – HEAT PUMP WATER HEATER



Low income direct install program at SMUD has already proven the potential to cut costs from >$4k down to $3400 per unit

COST COMPRESSION – AVOID PANEL/CIRCUIT UPGRADES?

$1,954

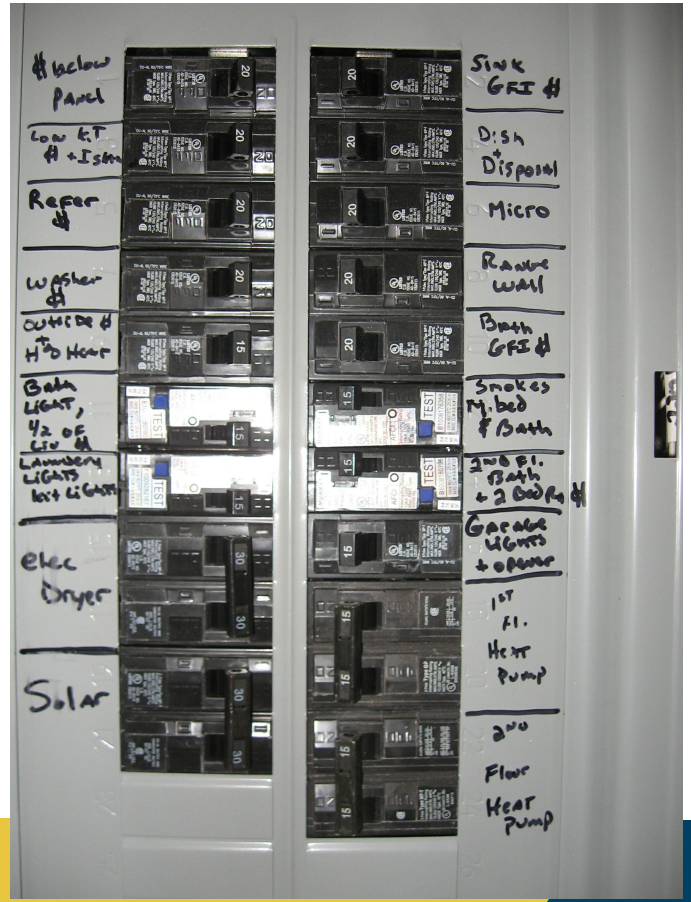
Average range: **$1,500 - $4,000**

Low	Average Cost	High
$800	$2,500	$4,500

(replace an existing panel with a new model with new housing)

https://www.fixr.com/costs/install-electrical-circuit-panel-upgrade

- Add ~$250-500 for each new high amp circuit
- Big increases in past couple of years
  - Material costs
  - Everyone is busy
  - Codes can requiring moving panel
  - Currently $5,000 in CA Bay Area
- Only needed in the 25% of homes that do not have central A/C
  - Exception is adding hot water and E V charging



AUDIENCE FEEDBACK- II

What are high-cost issues for you?

What changes do you think might reduce costs?

INNOVATIONS

COST COMPRESSION – AVOID PANEL UPGRADES?

Innovative technologies

Smart Circuit Splitters and Sharing

EV-PowerShare[xliii]
EV-PS Smart

SimpleSwitch[xliv]
240V / EV Circuit Switch

BSA Electronics[xli]
Dryer Buddy

Neo Charge[xlii]
Smart Splitter

Programmable Subpanels

Eaton[xxxix]
Energy Management Circuit Breaker (EMCB)

Power-efficient Appliances (120V)

4.5 cu ft Condensing Washer/Dryer Combo	Heat Pump Water Heater	Through-Wall Heat Pump
10A, **1200W**	8.3A, **1000W**	6.3-15A, **~1400W**
LG WM3998HBA	GE GeoSpring	Innova HPAC 2.0

Source - Sean Armstrong, Redwood Energy (2020)

Understanding the NEC: Watt Diet Calculator

All Electric 100 Amp Home (2,000 square feet)
Ducted heat pump, medium power heat pump water heater, hybrid heat pump dryer

Device Volts	Device Amps	100 Amp Panel				Device Amps	Device Volts
120	8	Lights/Plug	15	15	Lights/Plug	8	120
120	8	Lights/Plug	15	15	Lights/Plug	8	120
120	8	Lights/Plug	15	15	Lights/Plug	8	120
120	10	Garbage Disposal	20	20	Kitchen Outlets	13	120
120	7	Refrigerator	20	20	Kitchen Outlets	13	120
120	0	Spare	15	20	Dishwasher	12	120
120	0	Furnace (removed)	15	20	Clothes Washer	13	120
240	20	Heat Pump Centrally Ducted	30	20	Hybrid Heat Pump Dryer	14	240
240	20	EV Charger	25	50	Range (cooktop +oven)	40	240
240	16	Solar Input	20	20	Heat Pump Water Heater	12	240

House square footage = 2000 Total Counted Panel Amps = 96.7

Source - Sean Armstrong, Redwood Energy (2020)

TECHNOLOGY INNOVATION: COLD CLIMATE HEAT PUMPS

NEEP'S COLD CLIMATE AIR SOURCE
Heat Pump List

Performance Requirements

- *For Non-Ducted systems:* HSPF ≥10
- *For Ducted systems:* HSPF ≥9
- COP @5°F ≥1.75 (at maximum capacity operation)
- SEER ≥ 15

>4,000 products listed

U.S. DEPARTMENT OF ENERGY
Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

Residential Cold-Climate Heat Pump Technology Challenge

Performance Requirements

Seasonal Heating

- 8.5 HSPF2 (ASHRAE Region V)
- Heating at 5°F [-15°C]
- Minimum COP of 2.1-2.4 at 5°F
- Capacity ratio of 100% for 5°F capacity to 47°F capacity
- Minimum turndown ratio at 47°F
- Compressor cut-in and cut-out temperatures

Heating at -15°F [-26°C] (optional)

- HP operation at -15°F as measured by compressor cut-in and cut-out temperatures

Auxiliary heat

- Staged auxiliary heating

Low GWP Requirement

- Employ refrigerant with a global warming potential (GWP) value of no more than 750 (AR4,100 year)

Connected Product Criteria

- Offer the connected product capabilities within the latest ENERGY STAR specification (v6.0).

Further details on the challenge specifications can be found here.

GRID INTEGRATION TECHNOLOGIES

Active Electric Panels

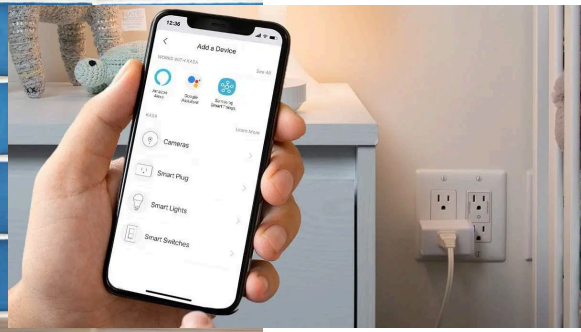
(some still in development, some with full energy management between loads)

Thermolec[xxxv] DCC-9	Span[xxxvi]	Eaton[xxxvii] Pow-R-Command	Koben[xxxviii] GENIUS Smart Panel
$1025 – 1125	$2,500 including installation costs	-	-
• Connects EV charger to panel to manage energy loads • real-time reading of total power consumption of electrical panel; if panel exceeds 80% rated load, then temporarily de-energizes the vehicle charger. Reconnects automatically when other loads allow	• Replaces traditional electrical panel in the home • Can monitor and control electrical usage at the circuit level • Puts control into the hands of the homeowner with intuitive smartphone app • Plug in play solution for rooftop solar, battery storage and EV charging	• Control lighting and plug loads with time and space occupancy schedules to maximize energy savings • 15 A, 20 A and 30 A configurations in single- and two-pole models suitable for voltage systems up to 480V • Can add expansion panels up to 168 controllable circuit breakers	• Replaces old electrical panel and allows home to become "Smart Grid" ready • integrates EV Charging, Solar, Battery Storage, Generator and your utility whether you are planning for the new energy era or have already installed your new energy technology.

Source - Sean Armstrong, Redwood Energy (2020)

NEW TECH

- Nicer, better-performing equipment
- Switchable outlets or power strips so you can really turn stuff off
  - A lot of things use power even when “off”
- Smart plugs/strips can operate on timers or smart phone apps using Bluetooth/wi-fi



GRID INTEGRATION TECHNOLOGIES- STORAGE

Can be charged from onsite solar or low-cost mid-day grid power

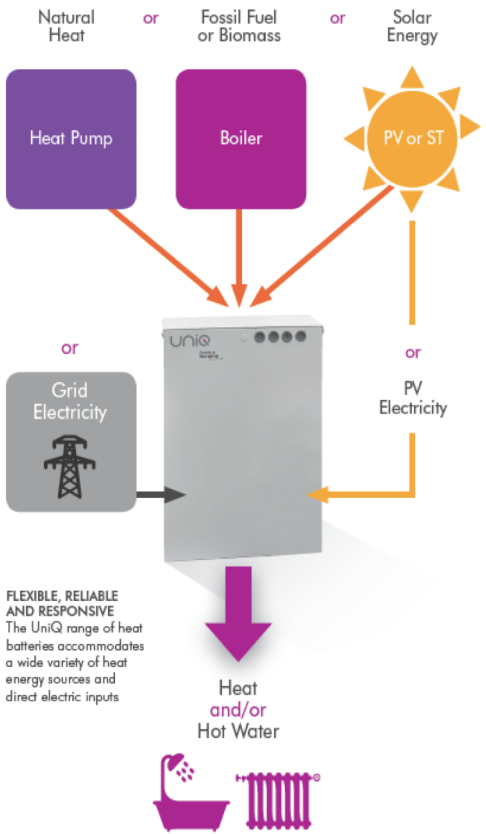
Good for disadvantaged / low-income communities: avoid peak pricing and demand charges

Electric Battery – available now

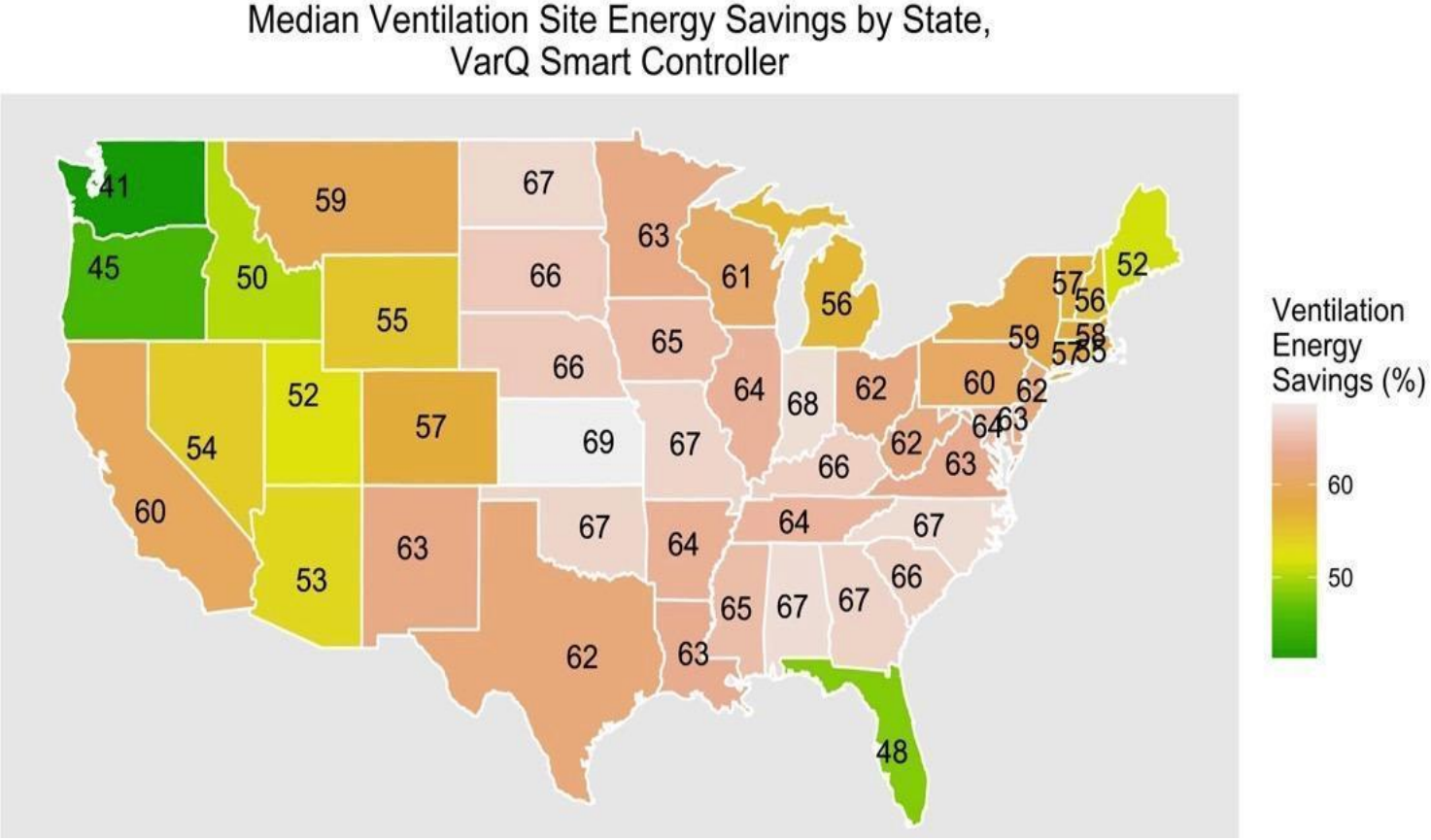
- 3 to 5 KWh in every home @ $1000/kWh?

Thermal Storage – coming soon

- Safe, common, cheap phase change materials
- 10.5 KWh in same space as 50 gallon tank



EMERGING TECHNOLOGIES: SMART VENTILATION



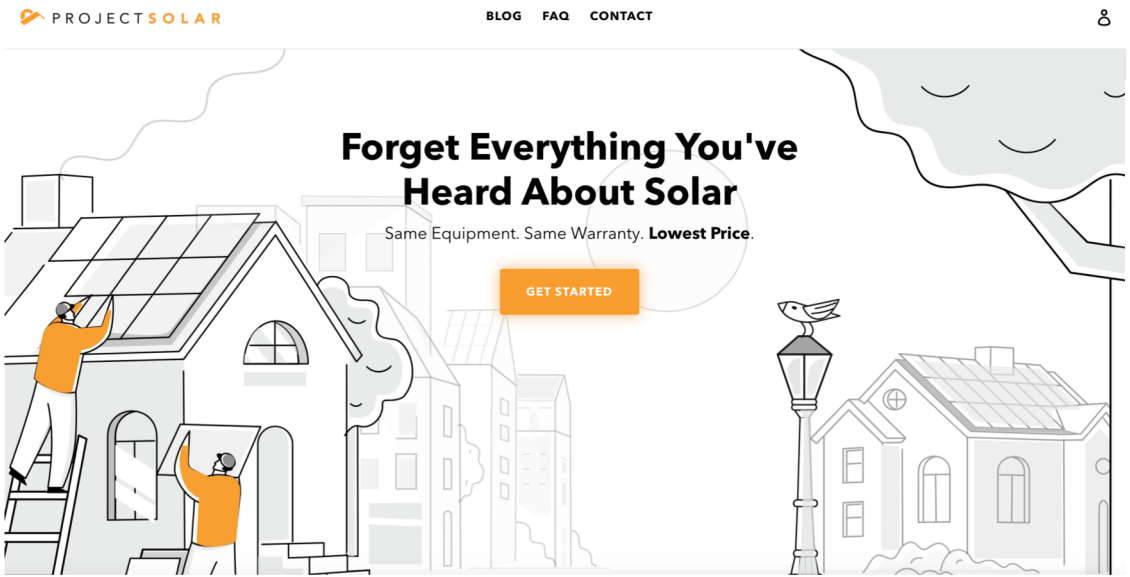
Annual ventilation energy savings for a smart ventilation controller.

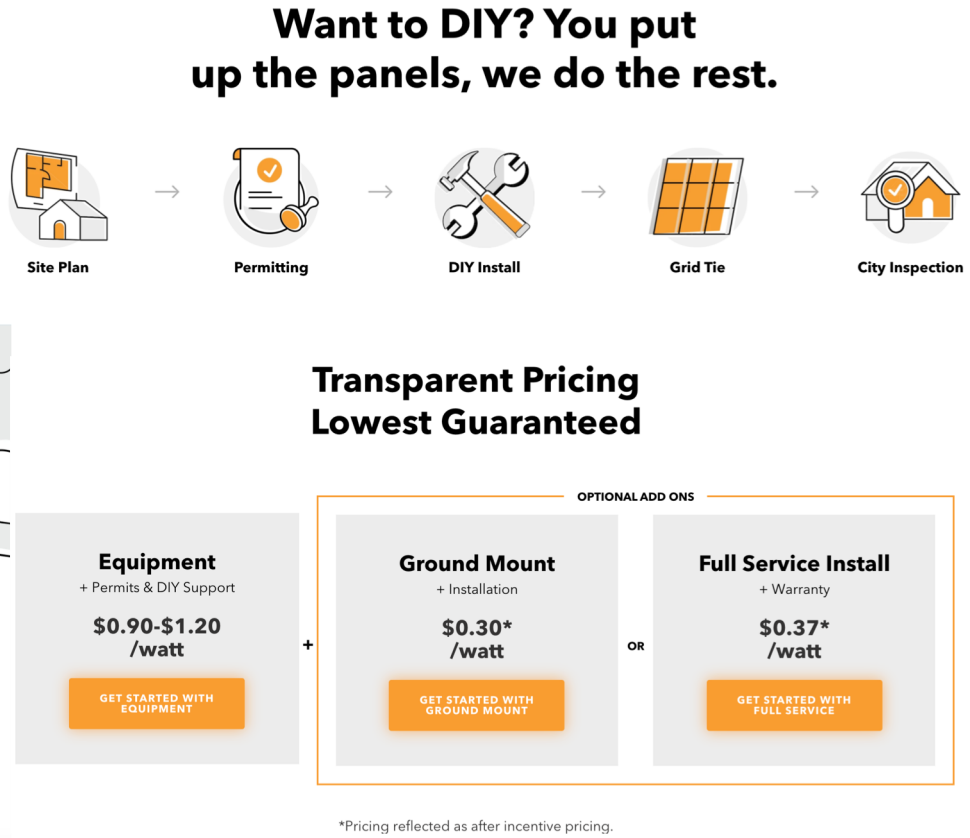
COST COMPRESSION – SOFT COSTS

	Outsource customer acquisition to programs with marketing and sales expertise	Reduce diagnostic testing and commissioning	Remote approaches to customer acquisition, management and sales	Automated, rapid HVAC equipment sizing
CURRENT	$1,000-2,500 per project	Combustion: $387	Remote audits: 40% cost savings for individual projects	$564
COMPRESSED	$700	$0	60% savings for executed projects	$100

SOFT COST COMPRESSION – SOLAR PV EXAMPLE

- Eliminate overhead with online experience
- Flat pricing across the US
- DIY or full-service options





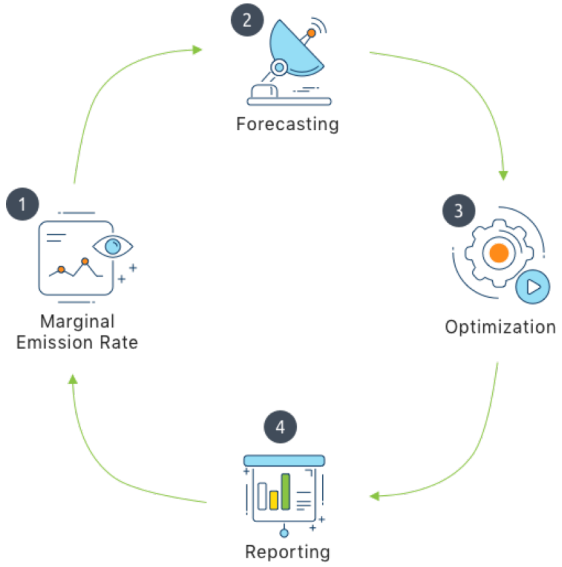
SOFT COST COMPRESSION – DUCTLESS HEAT PUMP EXAMPLE

- Custom design
- Pre-insulated line sets
- Simplified fittings
- Strong marketing

NO/LOW-COST OPTIONS - BEHAVIOR

WattTime™

Easy and low cost
Should be part of every project?



HOME intel

"We cut our bill in half and are on track to save over $2,000 after the changes we made with HomeIntel's help."

HomeIntel customer

Their story: This couple has lived in their 3,000sqft home in Stanford, CA for 30 years.

Despite completing HVAC upgrades, they still had high energy use.

Their results: Saving $220 per month and over $2,500 annually.

The customer above found **4 Energy Hogs** using HomeIntel.

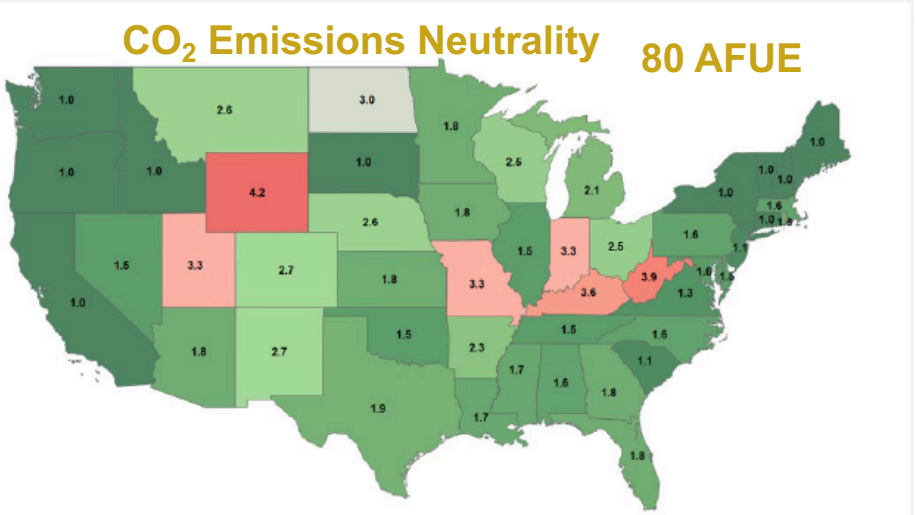
(1) Old **baseboard heaters** costing $100 per month

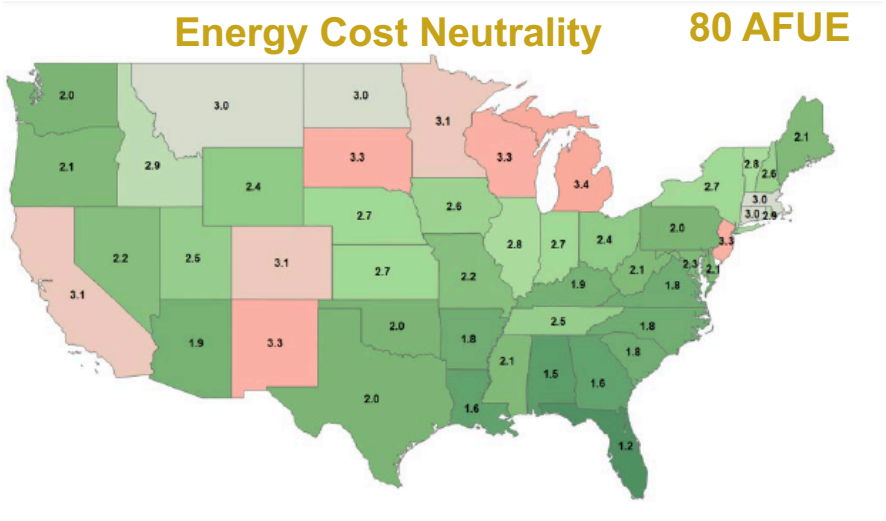
(2) Continuous hot water **recirculation pump** costing $50 per month

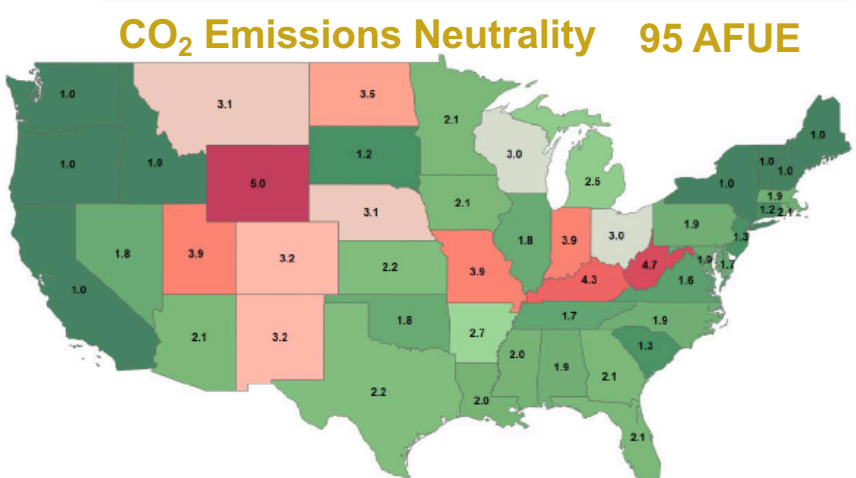
(3) 20 year old **wine cellar** (cooler pictured) costing $120 per month

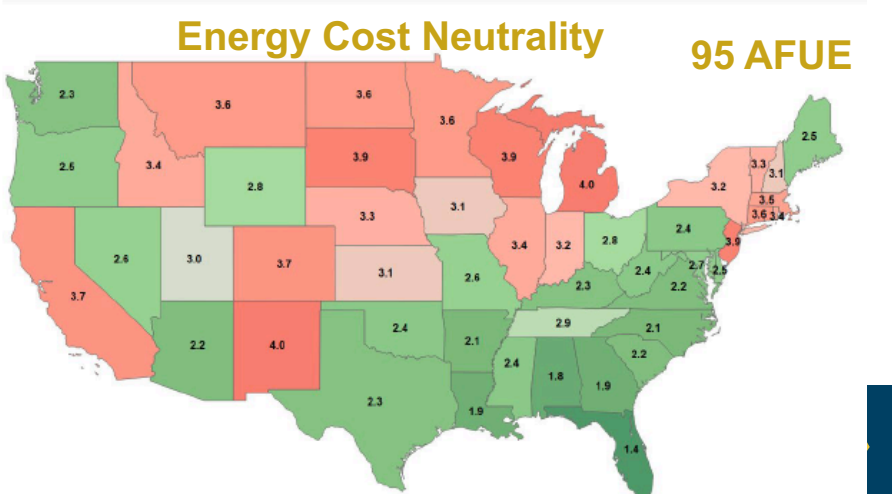
(4) Instant **hot water dispenser** under the sink costing $30 per month

NEW METRICS: BREAK EVEN COP VS. GAS FURNACE

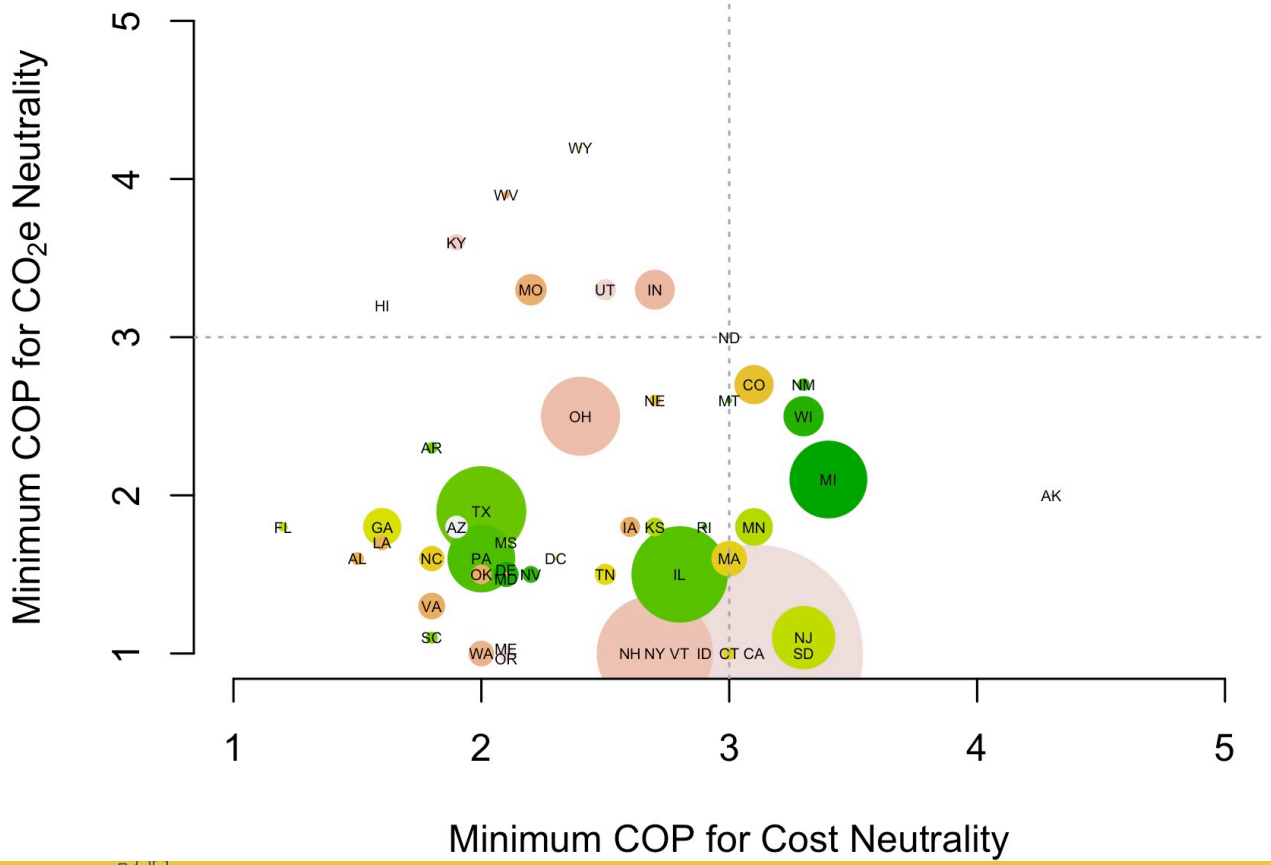








NEW METRICS: HEAT PUMP PERFORMANCE FOR COST AND CARBON NEUTRALITY



Gas Furnace: 80 AFUE

bubbles scaled according to count of natural gas heating appliances in each state

AUDIENCE FEEDBACK- III

Are there other technical innovations that you think would help?

Do we need disruptors to fundamentally change the home performance industry like Tesla did for EVs or UBER for taxis?

Should we try to make everything simpler and more DIY?

BEYOND CARBON EMISSIONS

Health

Other GHG concerns – methane + refrigerants (not today)

Embodied Energy – not today

Health Reasons to Eliminate Fossil Fuels

- **Burning fossil fuels:** emit several contaminants of concern:
  - $PM_{2.5}$, NO_2, CO, aldehydes and leaking unburned CH_4

- **In the home:**
  - Main sources are cooking and poor appliance venting
  - This would serve Low-Income/Disadvantaged households the most
    - More likely to have poorly vented appliances
    - Smaller dwellings have higher contaminant concentrations
    - Low income dwellings less likely to have ventilation systems

- **Outside air:** PM2.5 & NO_2
  - Environmental Justice Issue – often worse in disadvantaged communities

SAFER HOMES

Key safety issues are:

- **Carbon monoxide** – No concerns if home is all-electric
- **Fire safety** – No flames
- **Kitchen safety** - No flames
  Induction cooking inherently safer – cooler surfaces for induction cooktops, no flames
- **No gas explosions**
  A key risk factor for utilities
- **Earthquake safety**
  Post-earthquake fires usually a bigger hazard than the earthquake itself

COOKING EMISSIONS

Gas

More Particles,

CO_2 & H_2O

NO_2 (and NO), CO

Electric

Fine and ultrafine particles

Less so from ***induction***

Food

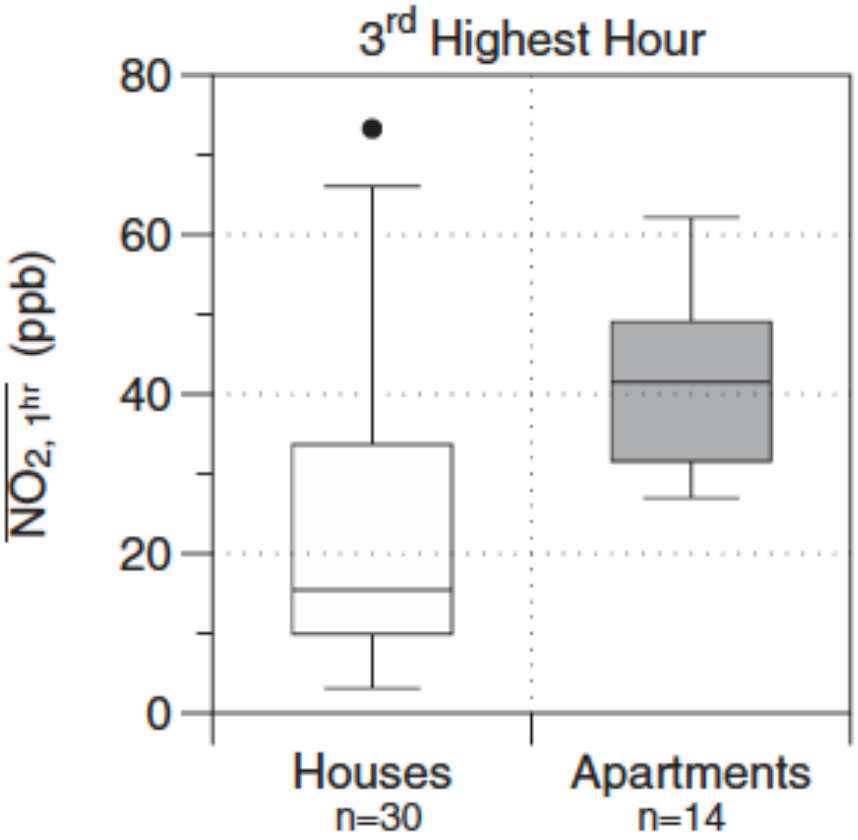
Particles, Formaldehyde, Acetaldehyde, Acrolein,

H_2O, Odors

COOKING EMISSIONS: APARTMENTS & SMALLER HOMES MORE CRITICAL – ENERGY JUSTICE ISSUE

Low Income Apartments (LIA) :

- About twice as much cooking
- Higher rates of asthma and COPD
- Smaller home volume to dilute pollutants
- Higher pollutant concentrations
- Switching to induction cooking would have a big impact (*new studies under way in CA*)



REMOVING POOR APPLIANCES

Removing poor appliances: e.g. Wall Furnaces

- Wall furnaces are chronically poor at venting
- Causes moisture problems and high levels of combustion contaminants
- Even worse if kitchen of bath exhausts are used

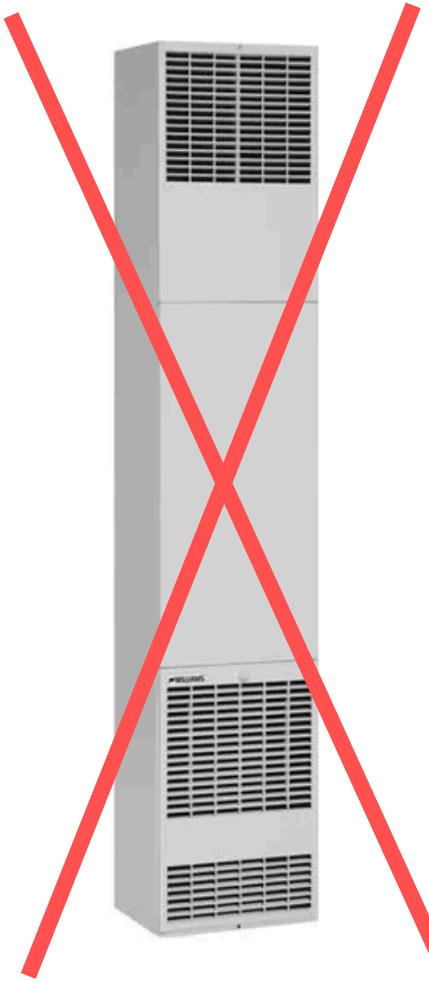
Their low capacity serving small spaces makes them ideal candidates for low-cost replacement with a Heat Pump – possibly even a 120V Heat Pump

This would serve Low-Income households the most

- More likely to have wall furnaces
- Smaller dwellings have higher contaminant concentrations
- Low income dwellings less likely to have ventilation systems

Eliminate use of GAS cooking appliances as supplemental heat

- Need to provide good low operating cost options for low income households



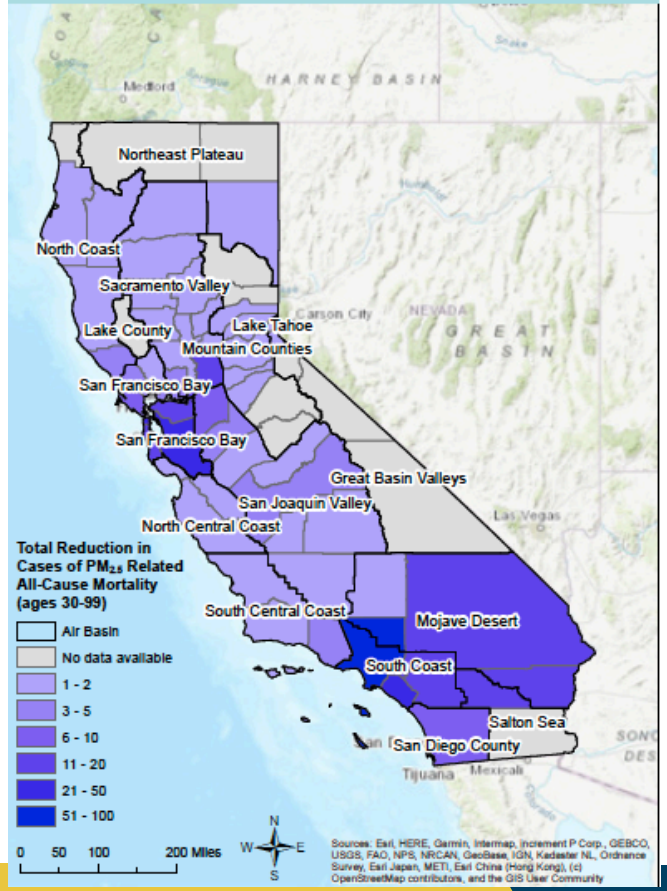
OUTDOOR AIR QUALITY: AVOIDED DEATHS

Table 3-1: Annual health impacts and monetized benefits from outdoor air quality improvements in a residential electrification scenario.

Health Impact	Avoided Mortality and Morbidity Cases (Annual)	Monetized Benefits (Annual)
All-Cause Mortality (ages 30 - 99)	354	$3.3 billion
Acute Bronchitis (children ages 8-12)	596	$0.3 million
Chronic Bronchitis (ages 27-99)	304	$150 million
Totals	—	**$3.5 billion**

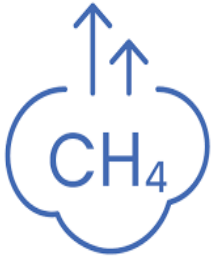
Zhu et al. 2020. Effects of Residential gas Appliances on Indoor and Outdoor Air Quality and Public Health in California. UCLA Fielding School of Public Health

Figure 3-4: Total reduction in annual cases of $PM_{2.5}$ related all-cause mortality by county in 2018.



NATURAL GAS (METHANE) A BIGGER PROBLEM THAN WE THINK

- Not considered in most analyses.
- Methane is 80 times more potent Green House Gas (GHG) than CO_2 over a 20 year period and 25 times over a 100 year period.
- Even small leaks have a big impact on GHG emissions.
- The methane leaked inside homes adds about 15% additional GHG effect.
  - Much more if distribution is included (~4% leakage)
- This is why removing all gas infrastructure is important
  - A problem for “mixed fuel” approaches where existing gas heat is retained.



OTHER ISSUES

Peak power

Resilience

Lack of infrastructure

NEW CHALLENGE: TRANSPORTATION

- Current poor public charging infrastructure:
  - Need to be able to charge at home
- Need a spare circuit or new panel/rewiring
- EV could easily be the biggest home load: up to 50 kW
  - Need to restrict power requirement to 7.2kW (or less?)
  - Use timers/smart circuit sharing

NEW CHALLENGE: PEAK POWER

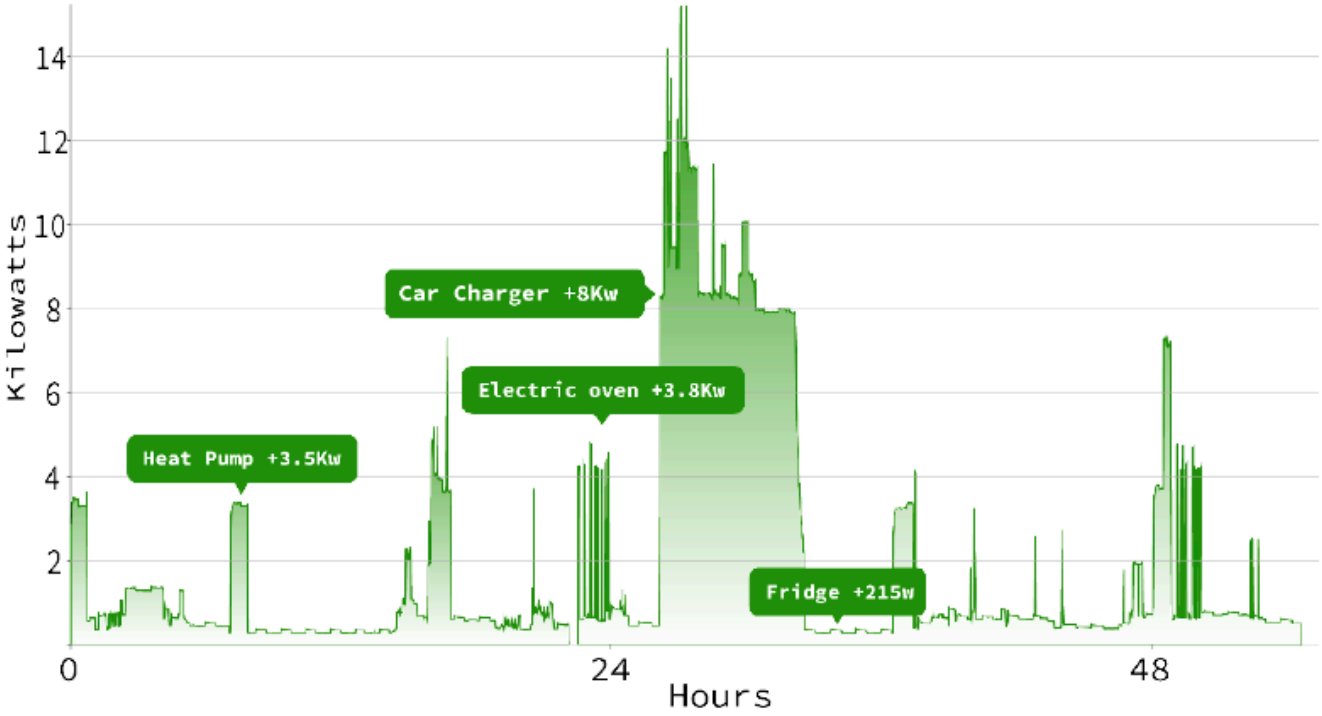


Figure from Rewiring America by Saul Griffith, Sam Calisch and Laura Fraser

- Utilities may institute peak charges for homes - just like for commercial/industrial customers
- Utilities will have time of use charges – whether homes can respond, or not
- Utilities are proposing large fines for on-site generation – even with storage
- New "peak" is 4-9 pm
- Another "peak" in the future will be 6-10 am.
- We need ways for homes to respond to this and minimize cost impacts - On-site storage – batteries or thermal

RESILIENCE

Electrical outages are much more frequent than natural gas outages

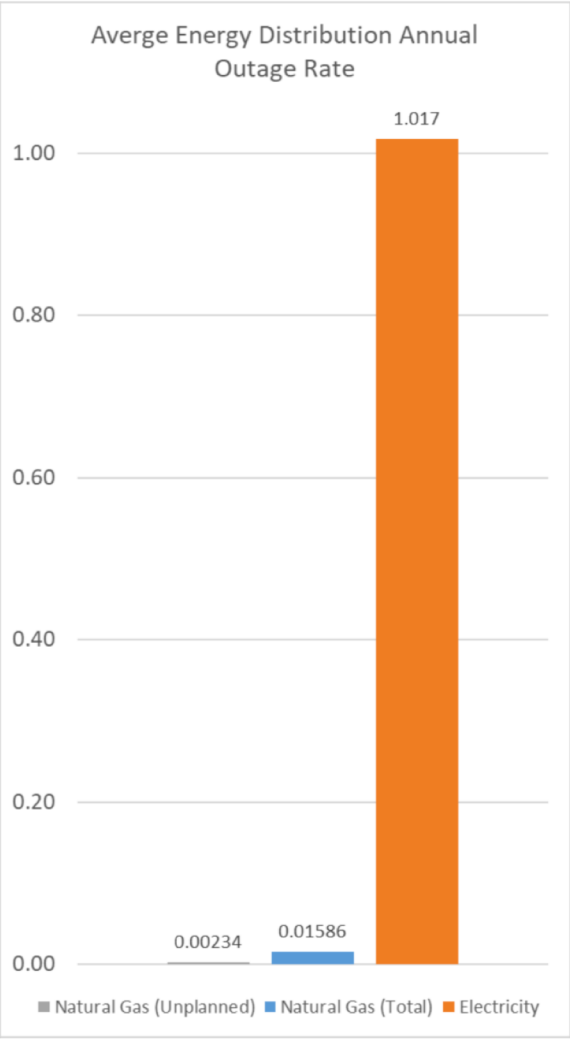
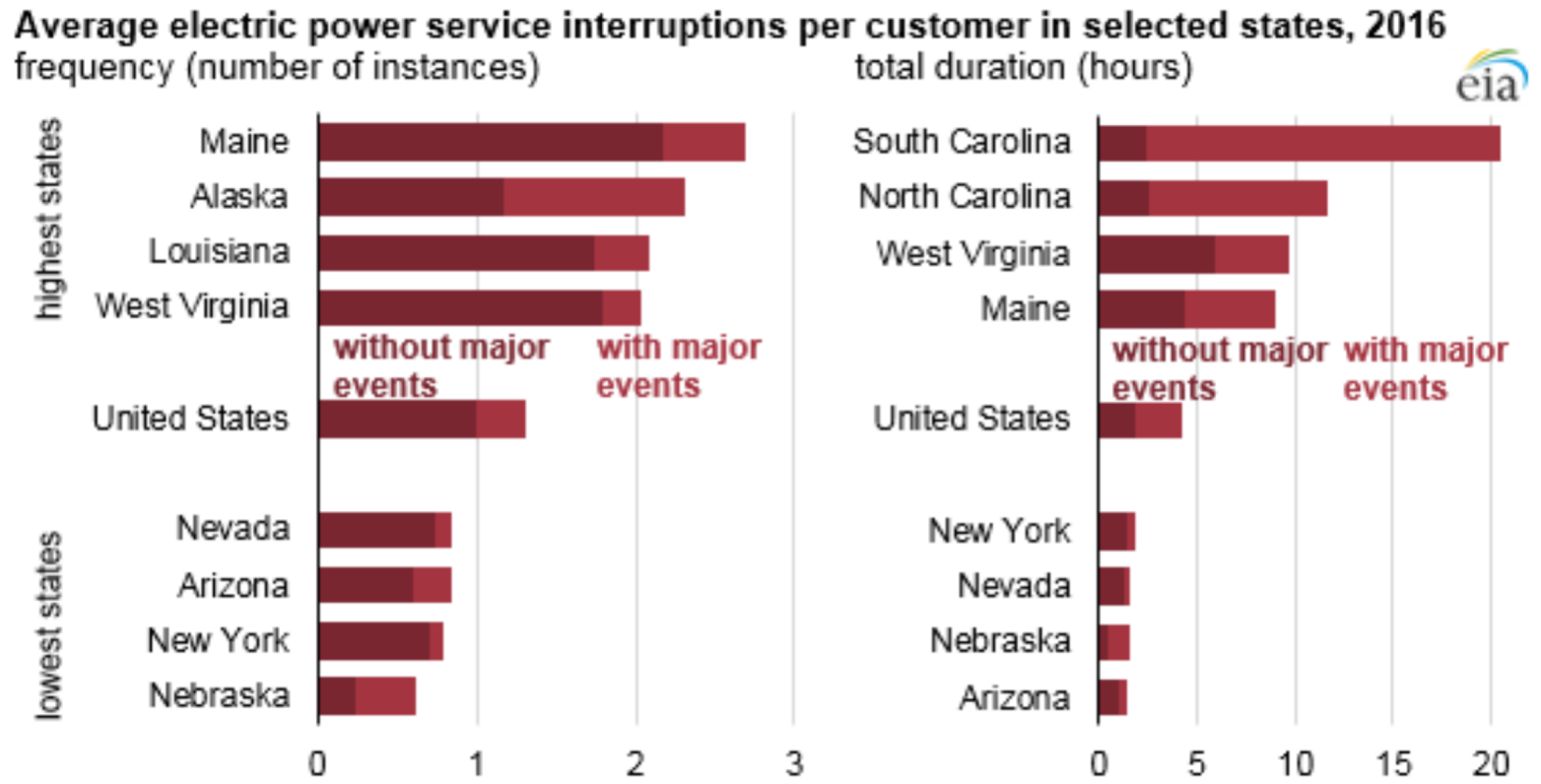


Figure 14: Comparison of Natural Gas and Electric Annual Outage Rates

RESILIENCE

But most outages are short

Typically < 24-hours

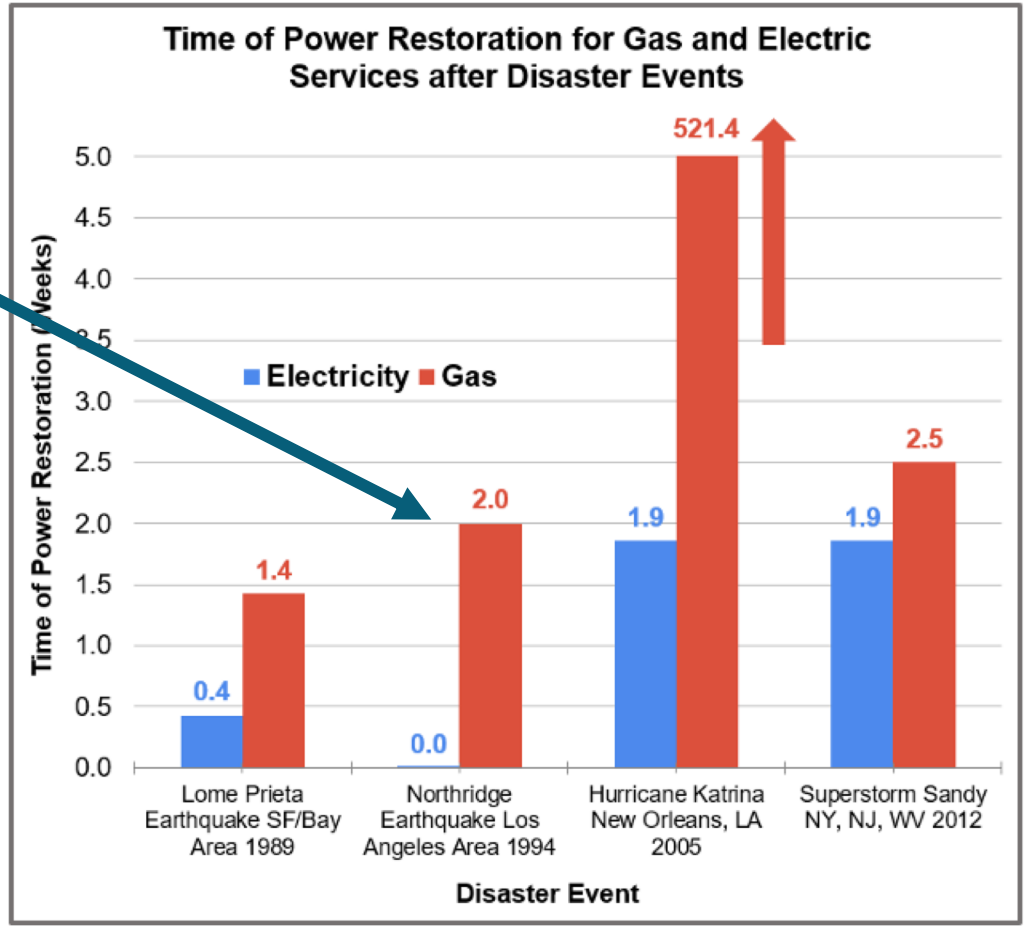


Source: U.S. Energy Information Administration, *Annual Electric Power Industry Report* (EIA-861 data file)

RESILIENCE

After disasters, gas infrastructure remains offline for much longer than electrical

- On-site **storage and generation** allows basic home operation during emergencies.



INFRASTRUCTURE PROBLEMS

Today's biggest barriers for decarbonizing homes

- Lack of workforce
  - All contractors are busy
  - Anecdotally: 6-12 months lead time
- Lack of equipment
  - Supply chain issues (COVID ?)
  - Poor US Manufacturing base
- Lack of easily available financing

NATIONAL PATHWAY TO DECARBONIZE HOMES AT SCALE

- One basic package: Air seal and insulate, add heat pumps for heat/DHW and add Solar PV
- Cost Control
  - Reduce need for panel/service upgrades
  - Avoid costly measures
  - Compress costs for individual measures
  - Provide financing & rebates
  - New business models, streamlined permitting
  - Revised electric codes for panels and PV
- More trained workers & business innovations
- More heat pumps and low power appliances to be manufactured
- Emergency equipment loans – allow staging
- Include health, safety, & comfort in value proposition

AUDIENCE FEEDBACK- IV

What are other key barriers?

Is this all a waste of time and effort?

Will you be changing what you do to address decarbonization?

RESOURCES

For electrification big picture: Rewiring America and Rewiring Communities

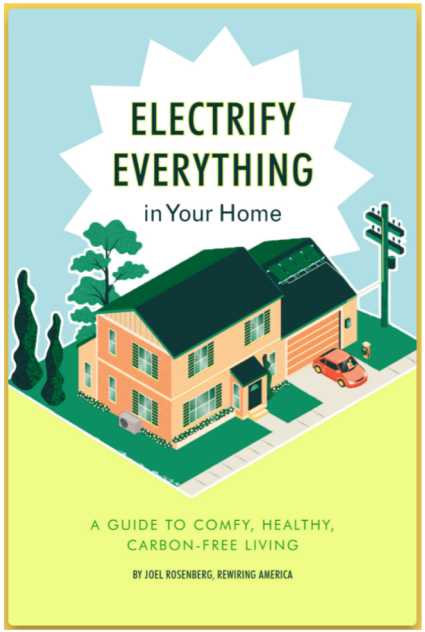
For power-restricted homes: Redwood Energy Pocket Guide

RESOURCES

https://www.natethehousewhisperer.com/electrify-everything-course.html

THE SWITCH IS ON

https://www.switchison.org/



https://www.rewiringamerica.org/electrify-home-guide

Most Efficient 2022
ENERGY STAR
www.energystar.gov

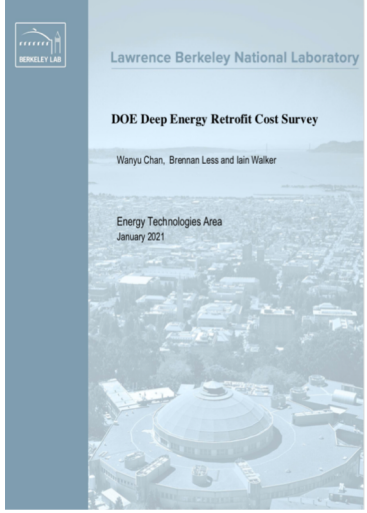
BUILDING DECARBONIZATION COALITION

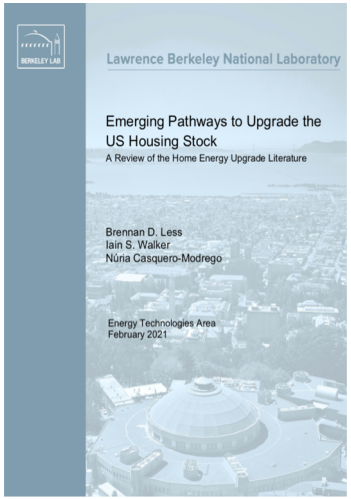
LBNL RESOURCES

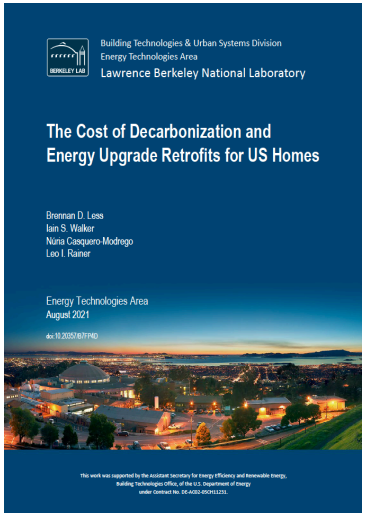
Chan, W. R., Less, B. D., & Walker, I. S. (2021). ***DOE Deep Energy Retrofit Cost Survey***. Lawrence Berkeley National Laboratory. https://doi.org/10.20357/B7MC70

Less, B. D., Walker, I. S., & Casquero-Modrego, N. (2021). ***Emerging Pathways to Upgrade the US Housing Stock: A Review of the Home Energy Upgrade Literature***. Lawrence Berkeley National Lab. https://doi.org/10.20357/B7GP53

Less, B. D., Walker, I. S., Casquero-Modrego, N., & Rainer, L. (2021). ***The Cost of Decarbonization and Energy Upgrade Retrofits for US Homes***. Lawrence Berkeley National Laboratory. https://doi.org/10.20357/B7FP4D







THANK YOU

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