BERKELEY LAB
Bringing Science Solutions to the World

U.S. DEPARTMENT OF ENERGY
Office of Science

Pathways to Home Decarbonization

Iain Walker and **Núria Casquero-Modrego**
RESIDENTIAL BUILDING SYSTEMS GROUP

ACEEE 2022 Summer Study on Energy Efficiency in Buildings | 22nd August 2022

How to Find The Best Decarbonization and Energy Savings Approaches?

1. Literature review (>160 scientific papers and technical reports)
   - summarize the academic, professional, and energy program studies attempting significant energy reductions in homes

2. Industry Survey (>70 leading building industry professionals)
   - industry perspective on home energy upgrades, identifying current barriers to decarbonization and potential ways to change the home energy upgrade market

3. Cost database (more details on Friday….)
   - cost and energy data from over 1,700 home energy upgrade projects
   - targeted significant energy/carbon reductions
   - national average costs ($2019)

State of Energy Upgrades of US Homes

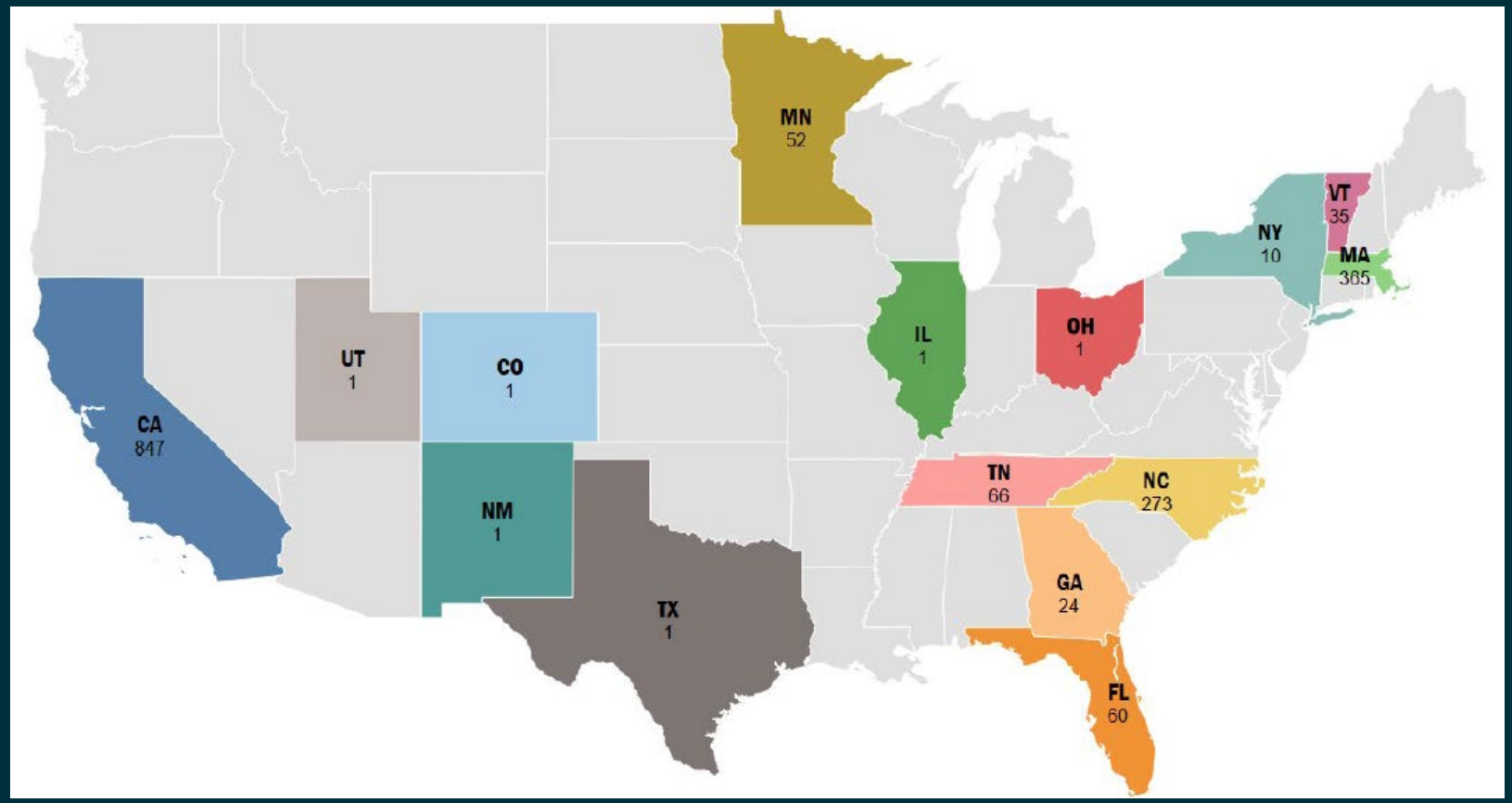
CHALLENGES

- Current energy upgrades do not save enough energy or carbon – typically in the 30%-40% range.
- Projects focused solely on energy and carbon savings are not appealing to most households.
- Costs are too high and improved financing mechanisms are needed.
- Low energy prices make financial payback arguments challenging.
- There is a lack of trained workforce with the necessary skills.
- There is a lack of real estate market valuation.

EMERGING TRENDS

- Upgrade programs are beginning to use emerging carbon-related metrics.
- Consumer demand and program support is increasing for solar PV and electrification approaches, while costly and time-intensive aggressive envelope upgrades are becoming less common.
- Health, comfort and resiliency (and rebates!!!) are key motivators
- New products for home electrification

Database Summary



Sample of Convenience:

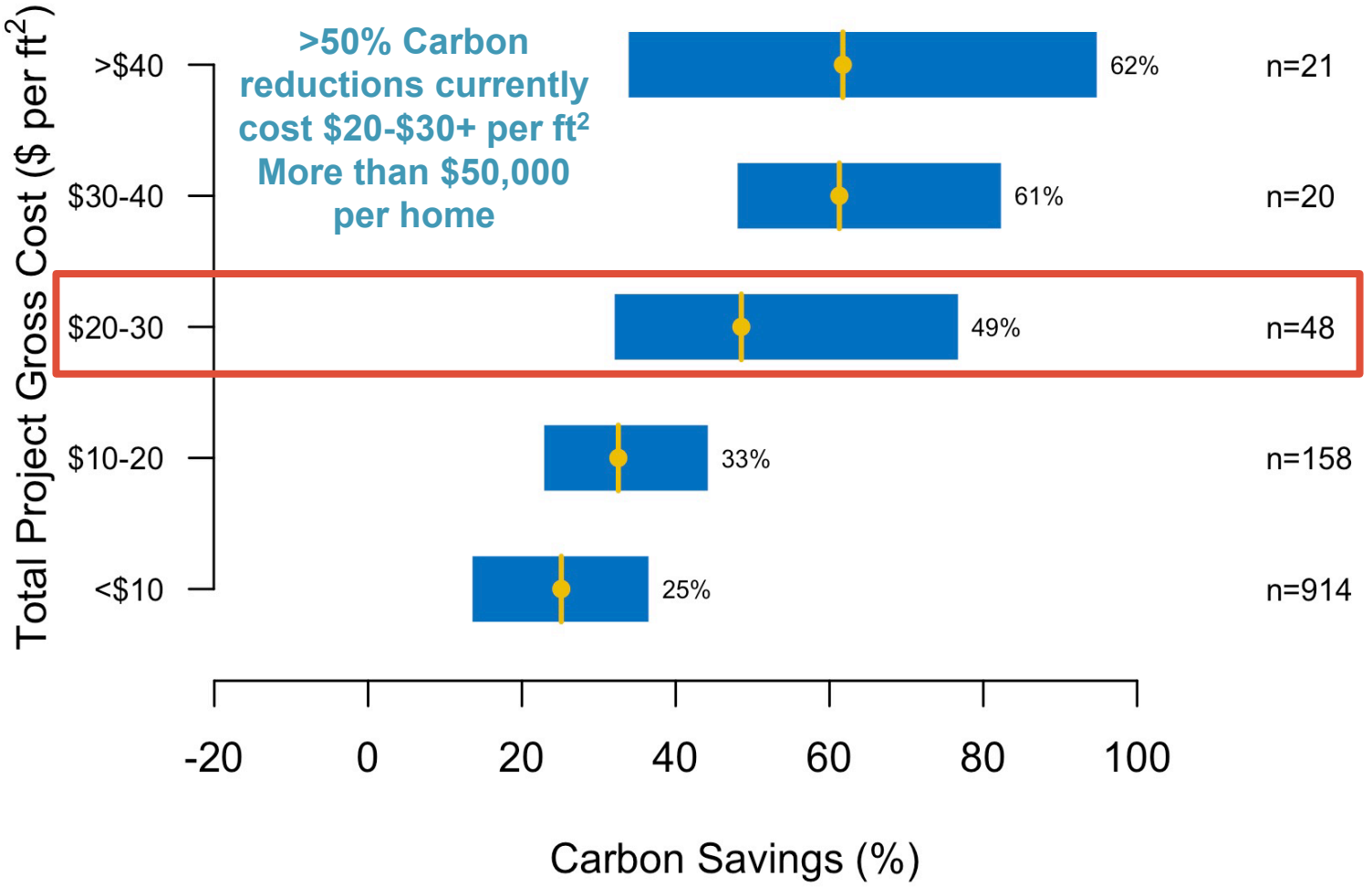
- Most data voluntarily provided by energy programs
- Paid contributions for 475 homes

Data Included:

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

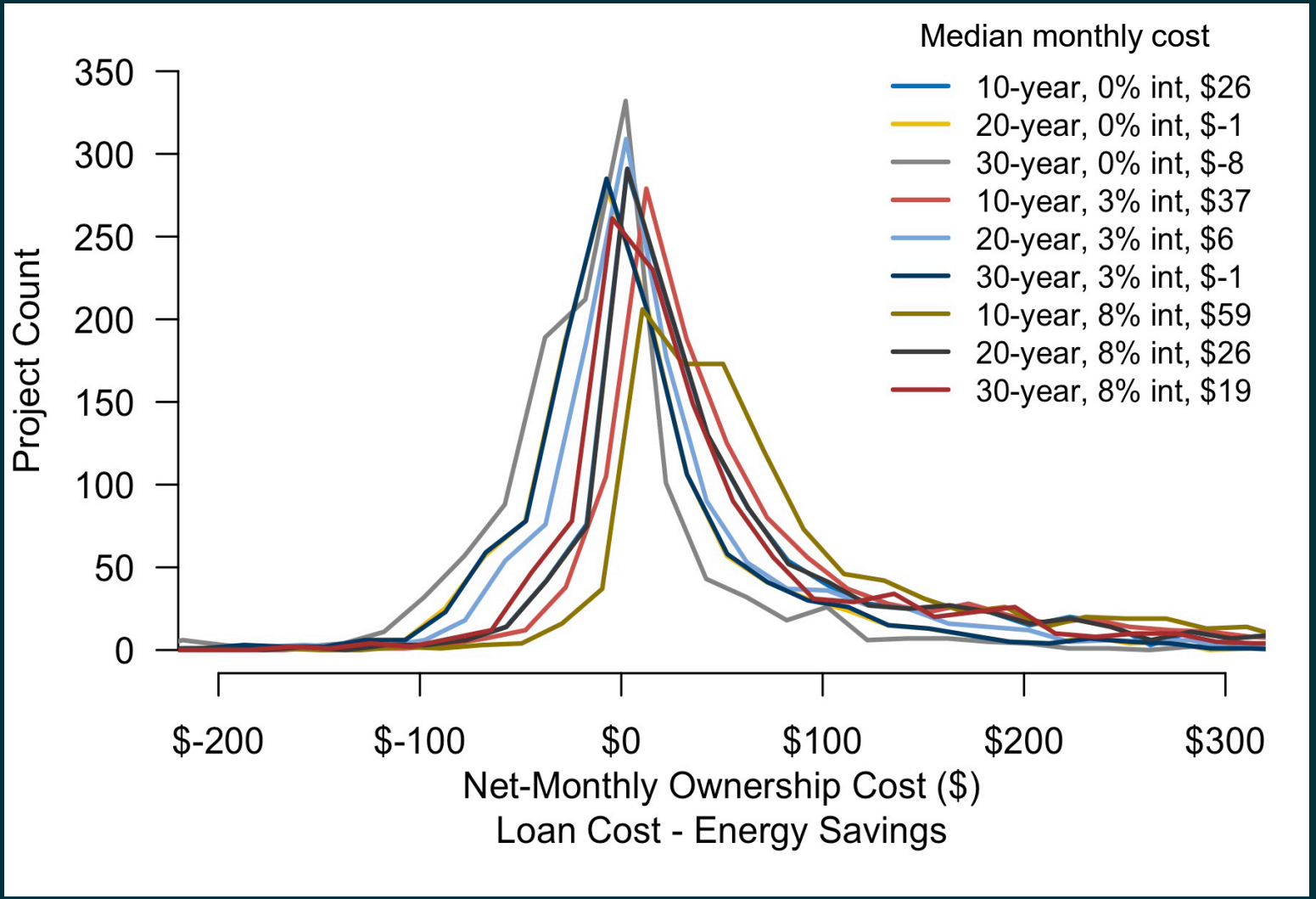
12 Programs **1,739 Projects** **10,512 Measures** **3,294,946 ft^2** **$24,689,213**

Affordability



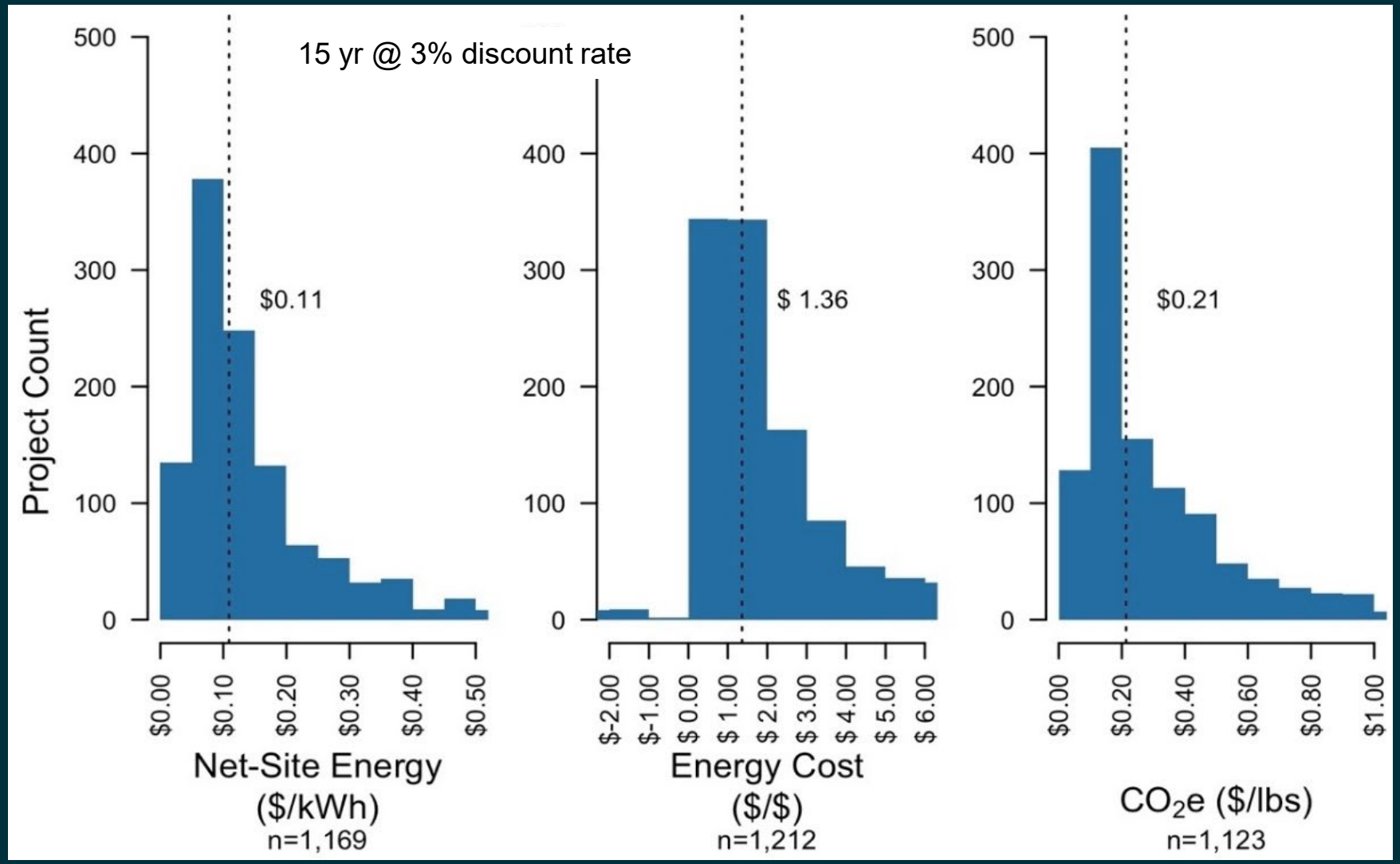
- These costs do not include rebates
- Not enough carbon emission reduction
- Costs too much for adoption at scale
- About 25% of projects used financing

Affordability: Net Monthly Costs with Financing



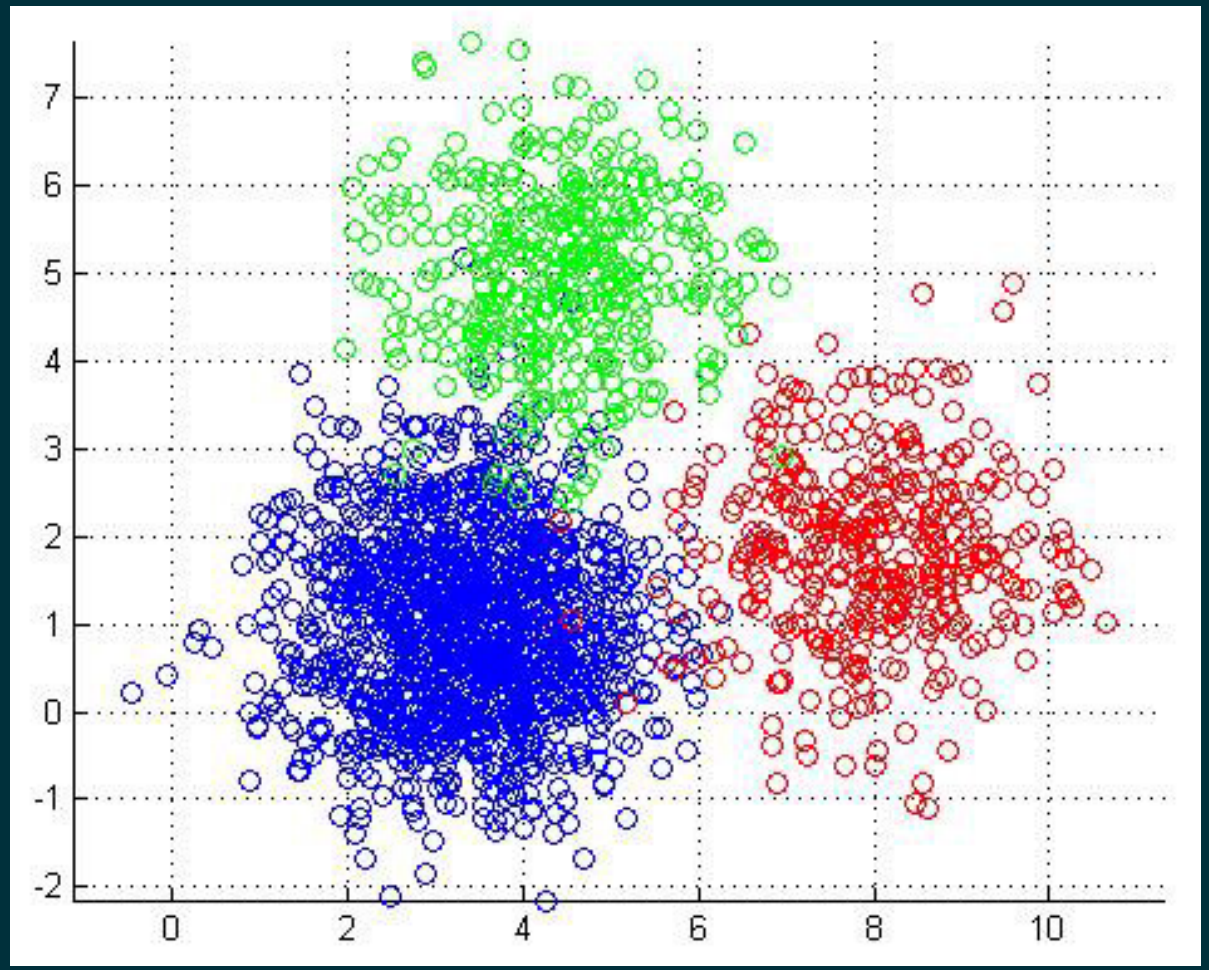
- National average costs for projects and energy – will vary by location
- OK for a portfolio, risky for individual home owners?

Affordability: Levelized Cost of Energy



- Energy compared to $0.11/kWh for electricity and $0.04/kWh for gas
- For >50% carbon savings: $0.18 to $0.39/kWh

Decarbonization 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.

Six Clusters

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

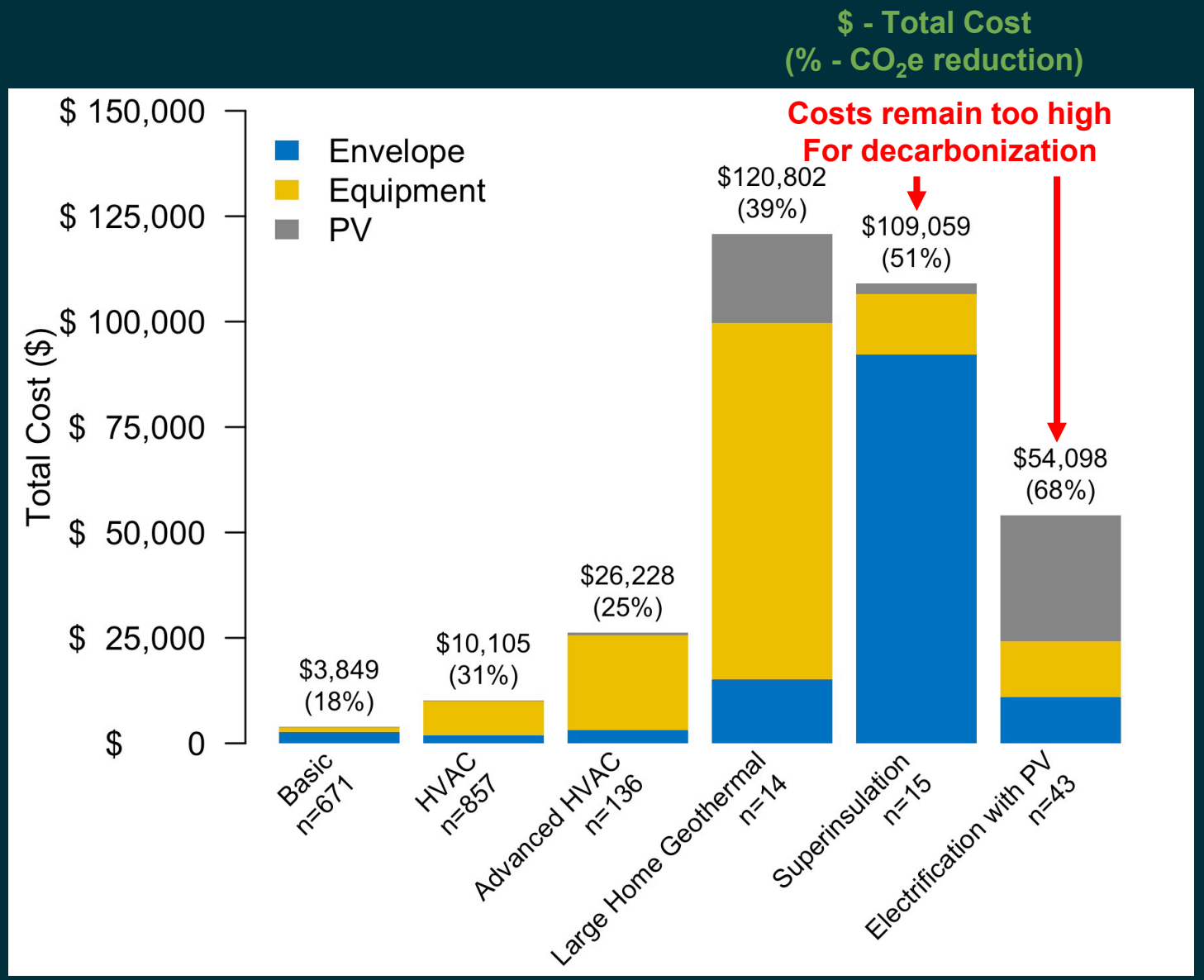
HVAC
HVAC projects with standard equipment (~1/2 heat pumps), including some envelope work

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

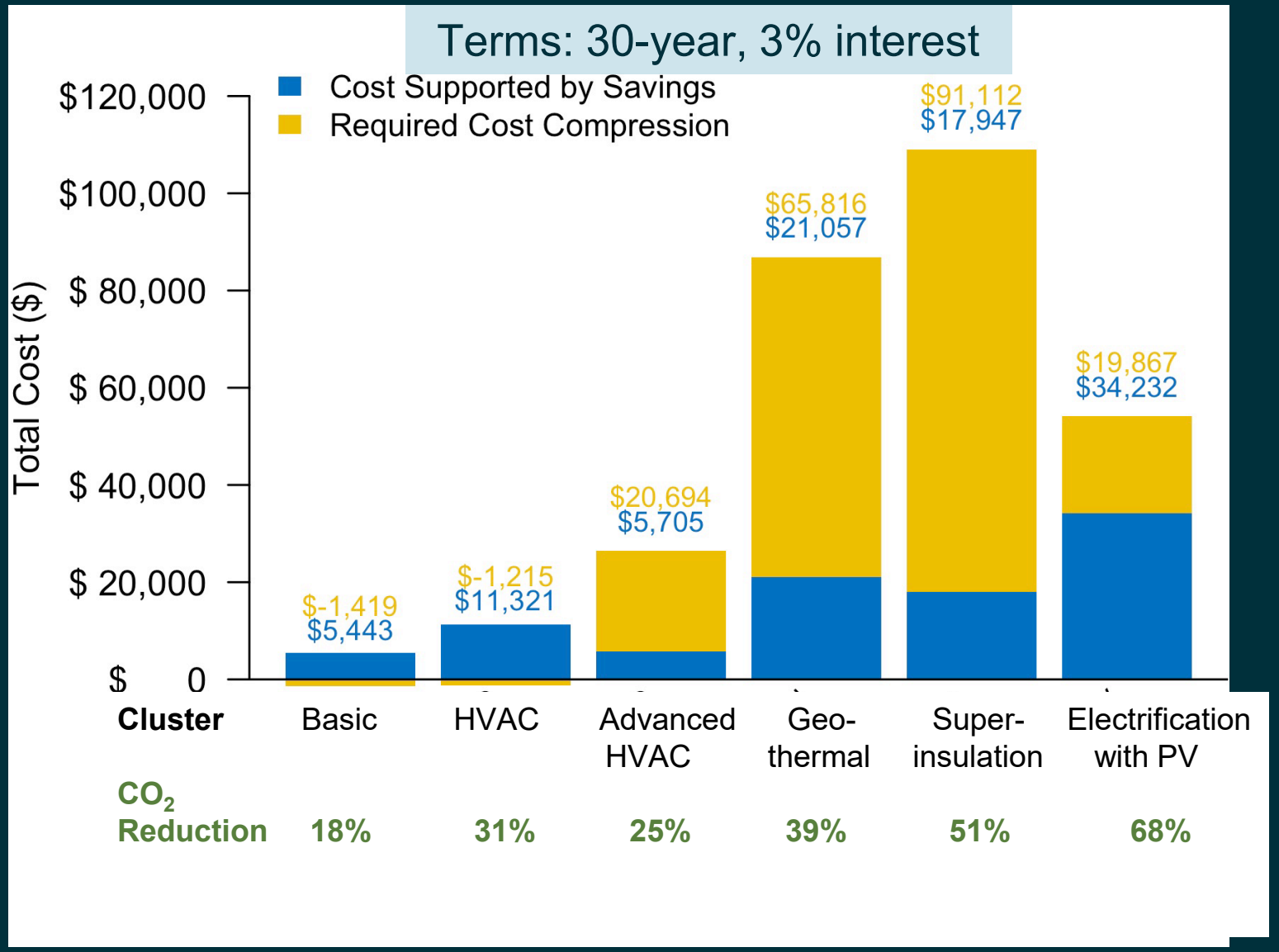
LARGE HOME GEOTHERMAL
HVAC-focused projects in large homes with geothermal heat pumps (90%) and some envelope and PV work

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 in all cases

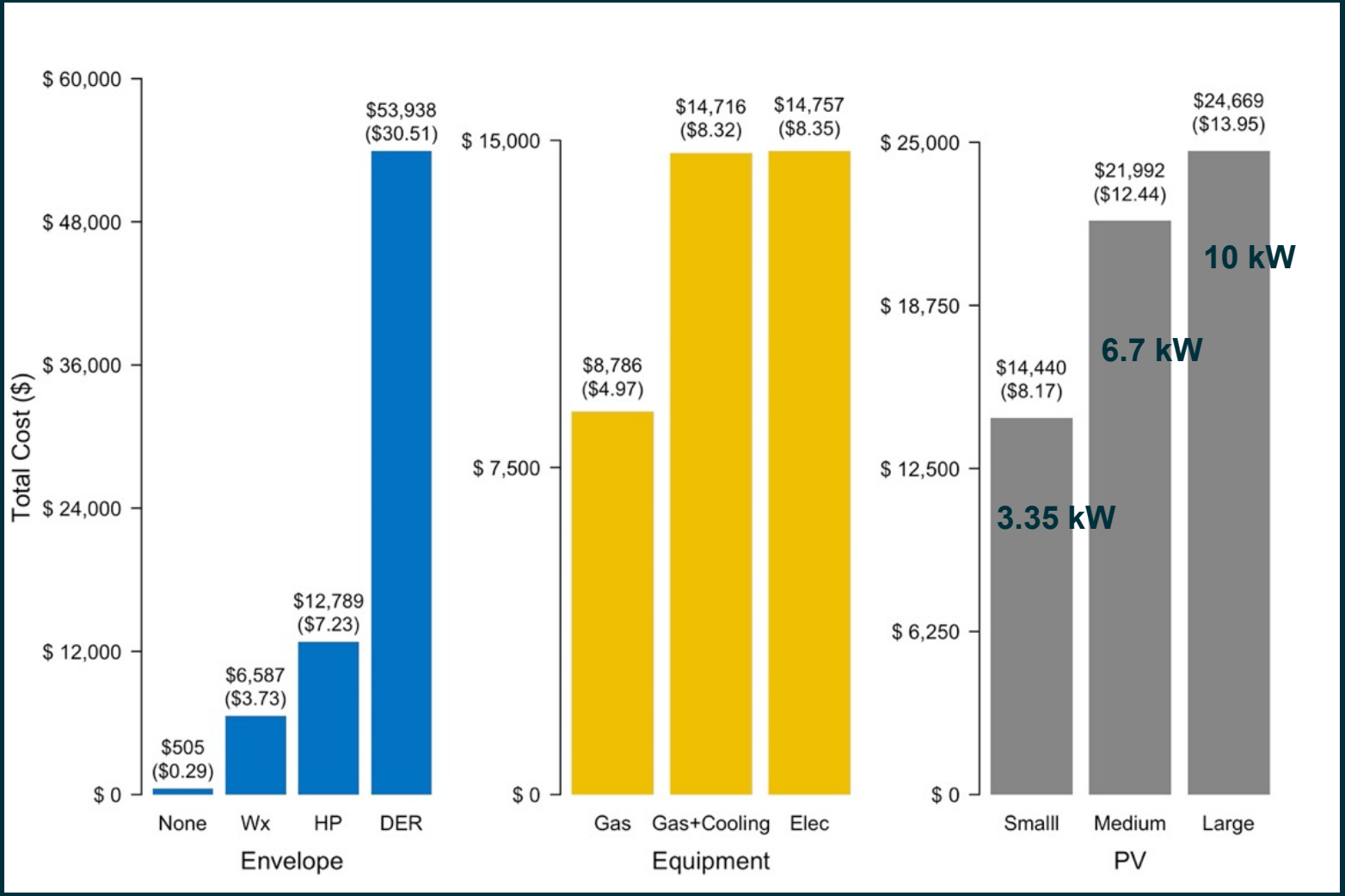


Required Cost Compression



- "Basic" and "HVAC" clusters have negative cost compression… but low CO_2 reductions
- Electrification with PV: biggest CO_2 reductions, $20k (37%) cost compression required….best option to pursue – includes $12k of envelope upgrades
- 25% rebate makes this only $6k

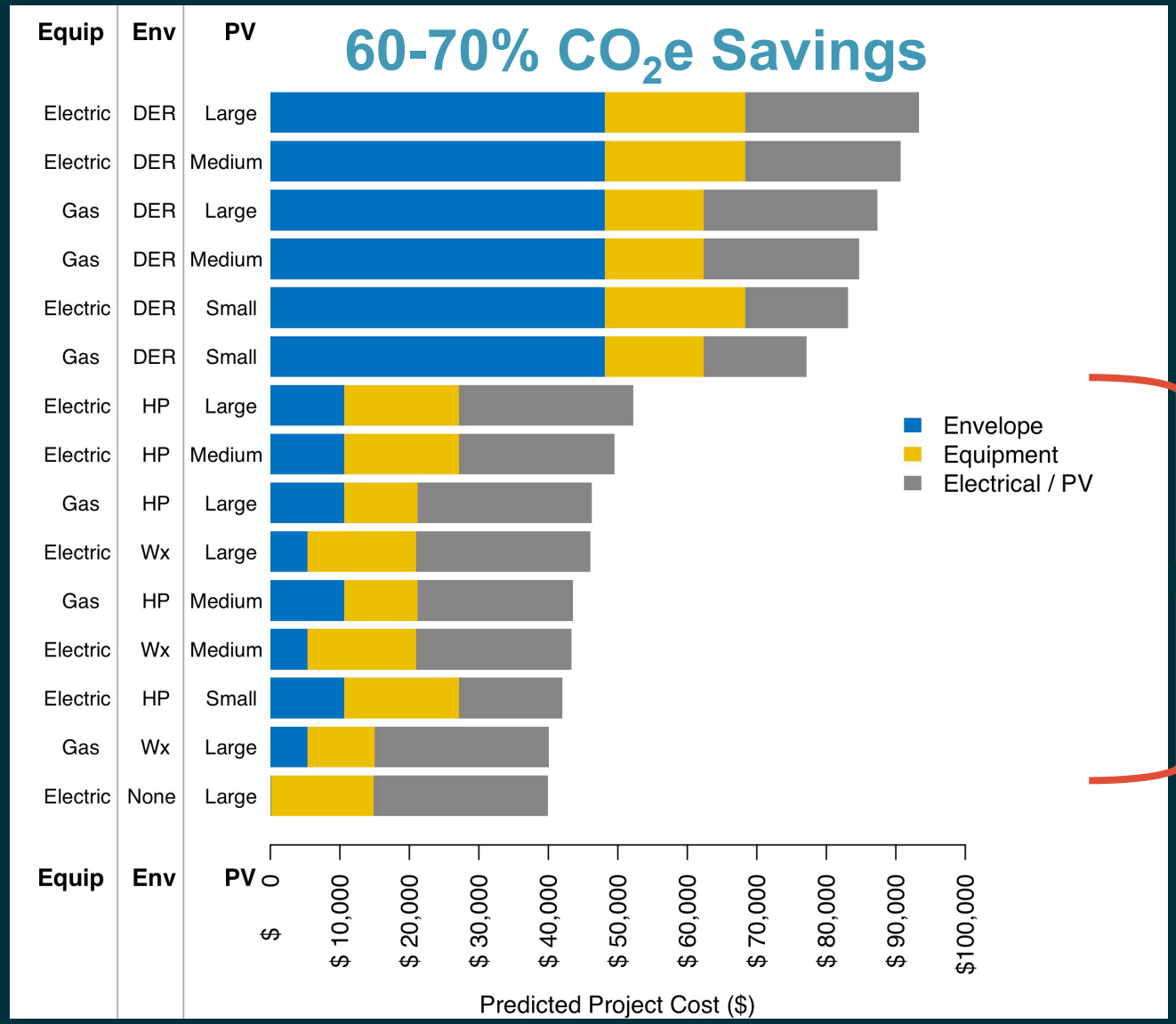
Cost Compression – Optimization for Archetypal Projects



Architypes Created from combinations of these options

Note different cost scales

Cost Compression – Package Optimization

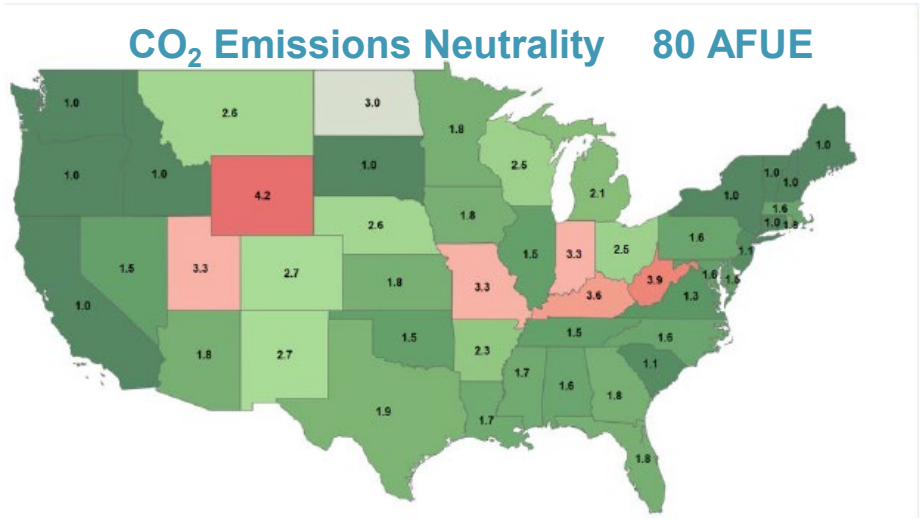


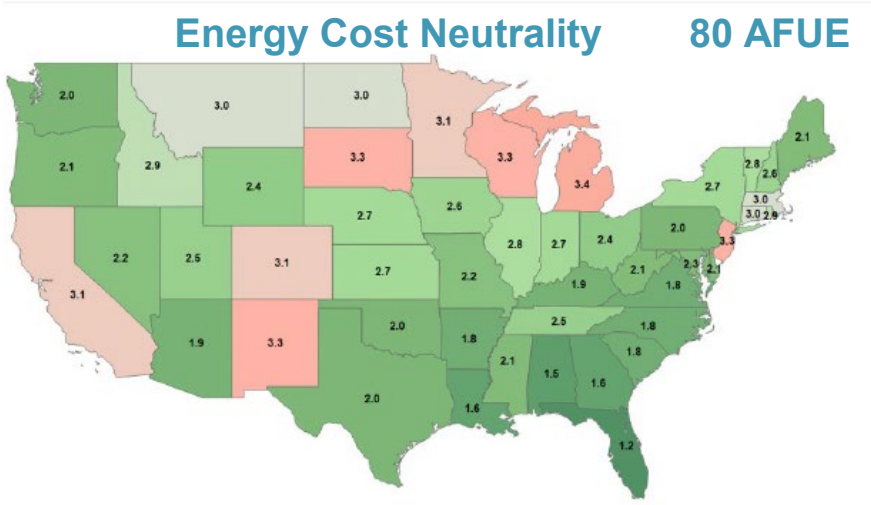
Lowest cost options are still $40,000/home - $23/ft^2

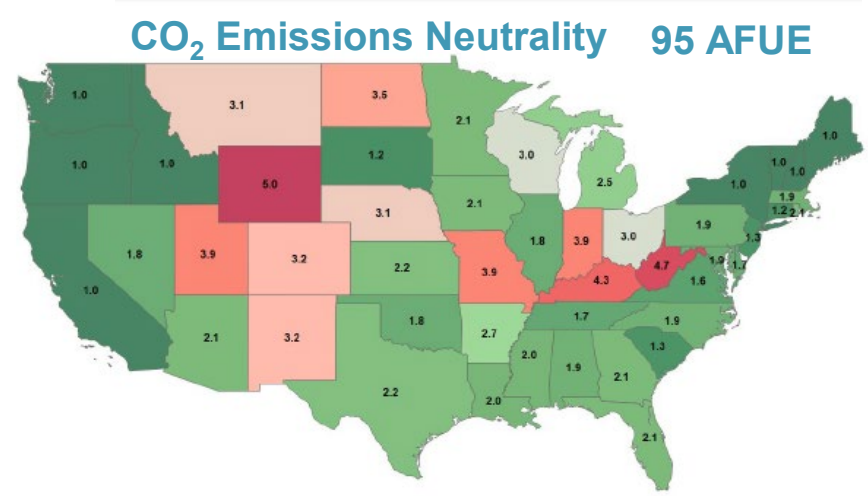
Beyond 60-70% savings requires all-electric homes

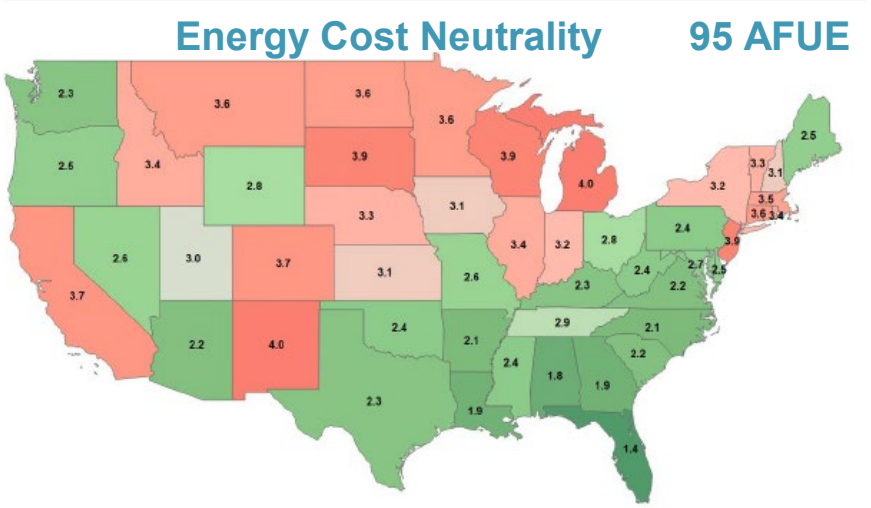
Moderate Envelope upgrades + PV gives good carbon savings at least cost

Regional Variability: Break Even Heat Pump COP

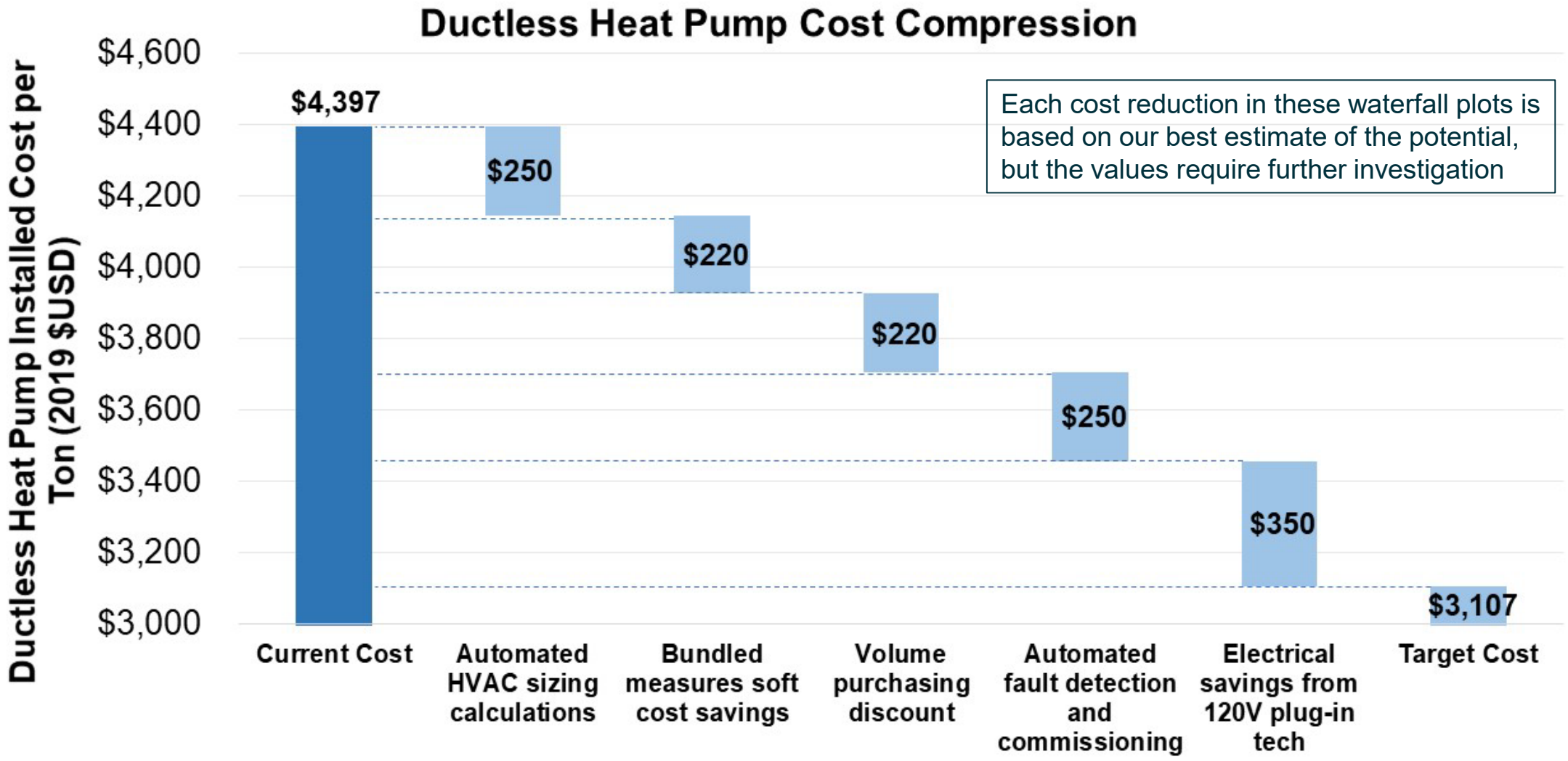




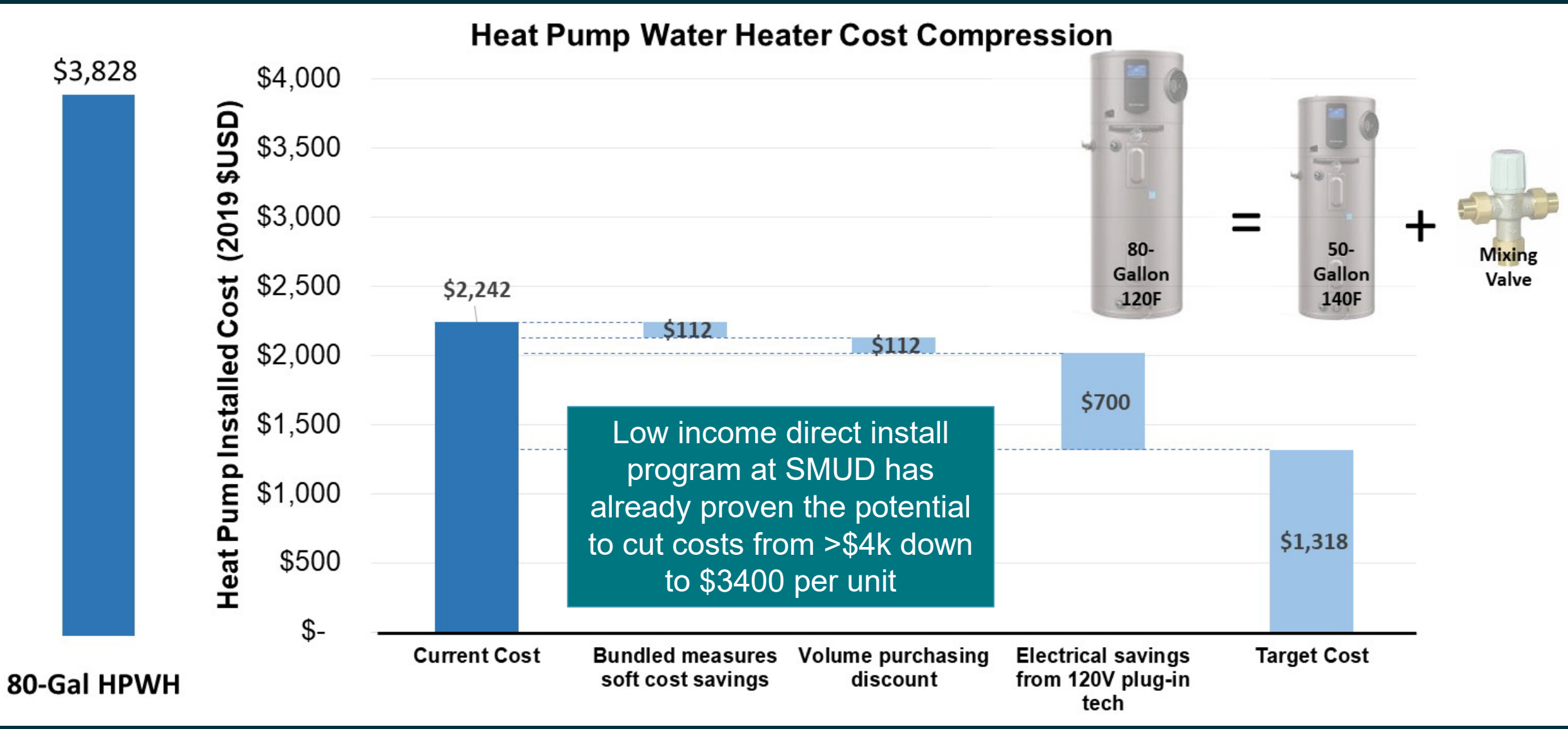




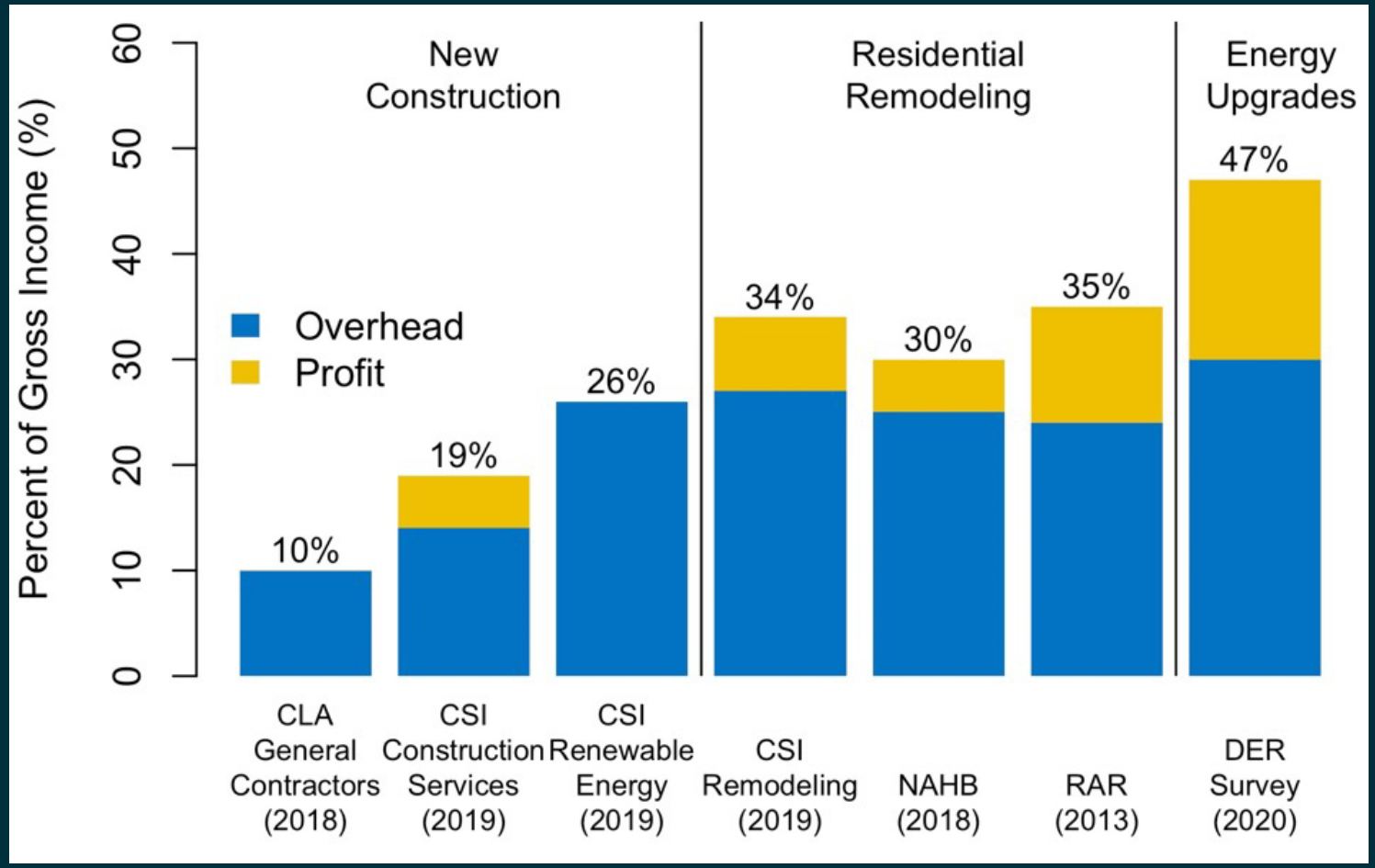
Cost Compression – Ductless Heat Pumps



Cost Compression – Heat Pump Water Heater, 50-Gal



Soft Costs Are High For Energy / Carbon Retrofits

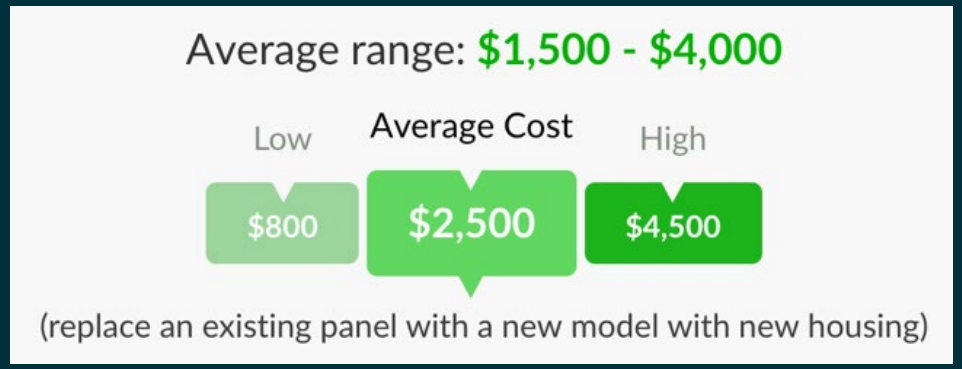


Need to Reduce Soft Costs:

- Outsource customer acquisition from contractors to programs or private companies with marketing and sales expertise. Customer acquisition typically costs $1,000 to $1,600 per project, and up to $2,500.
- Reduce or automate diagnostic testing and commissioning, e.g., combustion safety testing that is typically $387 per project.
- Automated, rapid HVAC equipment sizing, typically about $500.
- Direct install program structures.
- Direct-to-consumer or retail sales structures.
- Bulk purchasing strategies.
- Do-it-yourself (DIY) upgrades. DIY solutions are often designed with ease of installation in-mind, which also benefits trade professionals

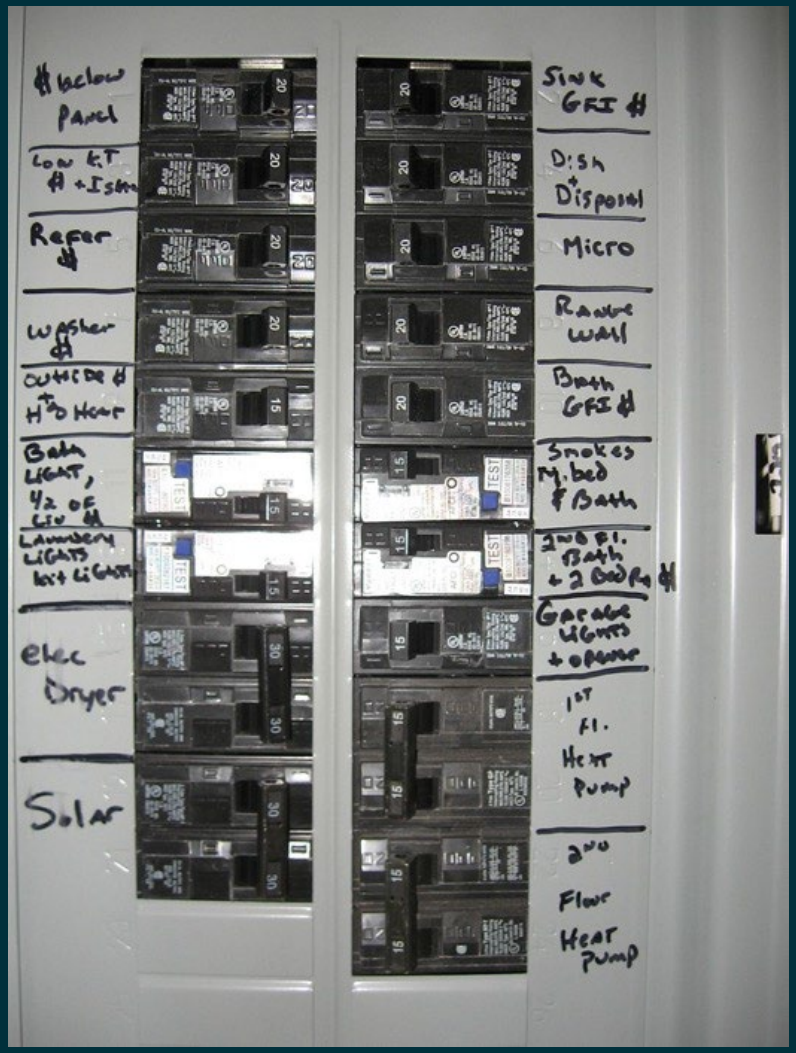
New Pathways: Avoiding Service/Panel/Circuit Upgrades

→ $1,954



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

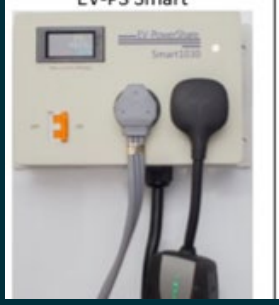
- Add ~$250-500 for each new circuit
- Add $300-$30,000 for service upgrades
- Big increases in past couple of years
  - Material costs
  - Everyone is busy
  - New codes can require moving panel
  - Currently panel replacement + service upgrade is $5,000 in CA Bay Area



New Pathways: Products & Practices

Smart Circuit Splitters and Sharing

EV-PowerShare[xlii]
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)

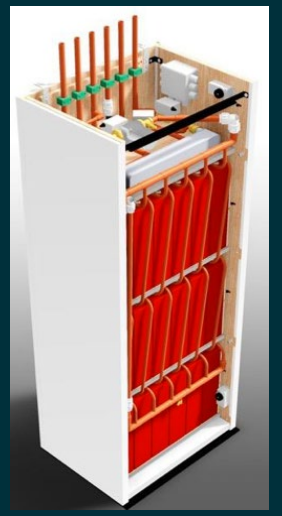
Power-efficient Appliances (120V)

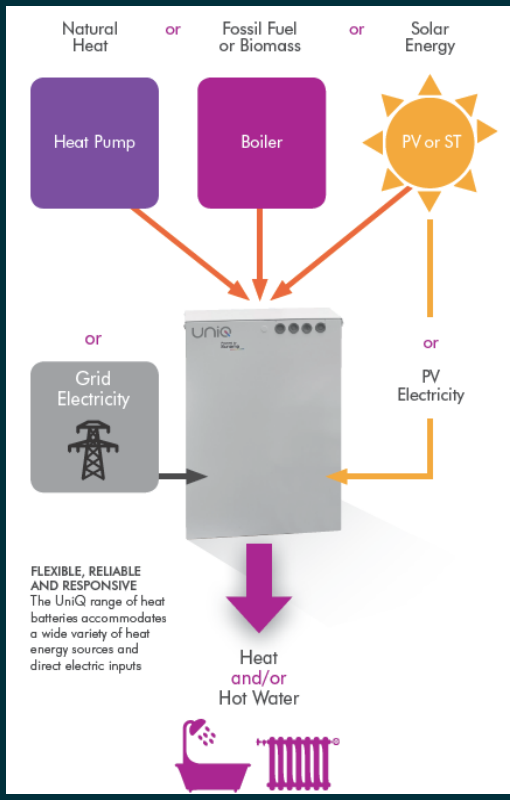
4.5 cu ft Condensing Washer/Dryer Combo	Heat Pump Water Heater	Through-Wall Heat Pump
10A, **1200W**	8.3A, **1000W**	6.3-15A, **~1400W**
LG WM3998HBA	GE GeoSpring	Innova HPAC 2.0
		

Understanding the National Electrical Code (NEC): Watt Diet Calculator

New Pathways: Products & Practices

- Technology development
  - Integrated thermal and battery storage
  - DIY options
  - Better packaging and lower noise
  - Grid integration
- Indirect benefits: health
  - Burning fossil fuels: emit several contaminants of concern: $PM_{2.5}$, NO_2, CO, aldehydes and leaking unburned CH_4
  - In buildings: Main sources are cooking and poor appliance venting
    - This would serve Low-Income/Disadvantaged households the most
    - Service industry: bars/restaurants/etc.
  - Outside air: $PM_{2.5}$ & NO_2
    - Environmental Justice Issue – often worse in disadvantaged communities





National Pathway to Decarbonize Homes at Scale

MARKET LEVEL

- Alternative business models to reduce soft costs/overheads
- Low-cost long-term financing
- Larger scale programs to even out the risks and extra costs for homes that are hard to decarbonize
- Streamline supply chain to reduce mark ups and time delays – increase domestic manufacturing
- Rebates to offset both the real and perceived impact of project costs

PROJECT LEVEL

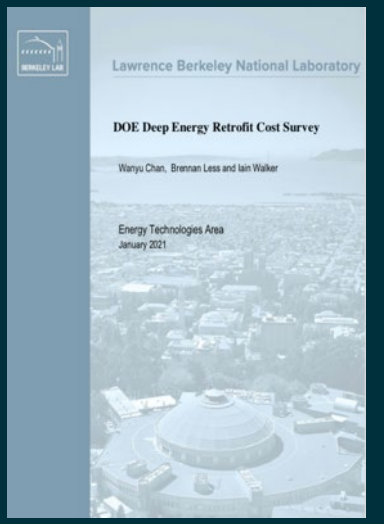
- Most promising approach: moderate envelope upgrades, electrification of end-uses, add solar PV
- Streamlining and improving the productivity of contractor efforts: customer acquisition, program compliance/documentation, HVAC sizing and specification, diagnostic testing, and code compliance

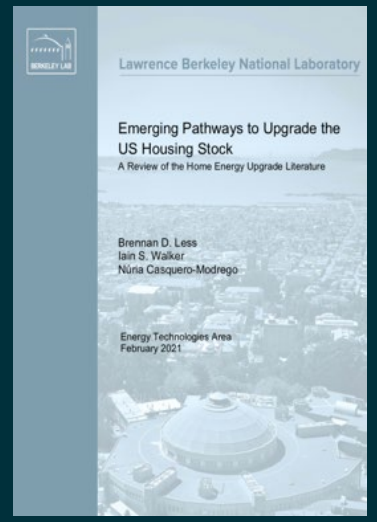
MEASURE LEVEL

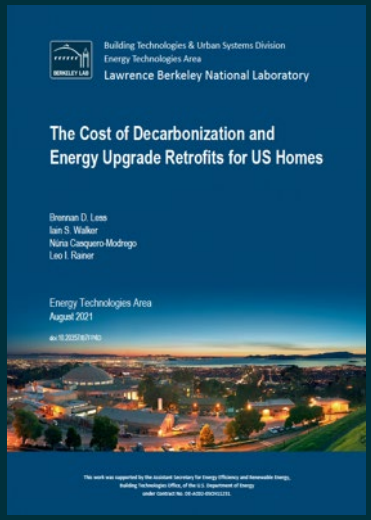
- Improved cold climate performance for heat pump technologies
- Development of advanced methods for low-power electrification without panel or service upgrades
- Advancements in sound, form factor, ease of installation (including DIY) for key products
- Grid integration
- Include other benefits: health, safety, comfort, resilience, home value.

LBNL Resources @ homes.lbl.gov

- Less, B. D., Casquero-Modrego, N., & Walker, I. S. (2022). Home Energy Upgrades as a Pathway to Home Decarbonization in the US: A Literature Review. Energies, 15(15), 5590. https://doi.org/10.3390/en15155590
- Walker, I. S., Less, B. D., & Casquero-Modrego, N. (2022). Carbon and energy cost impacts of electrification of space heating with heat pumps in the US. Energy and Buildings, 259, 111910. https://doi.org/10.1016/j.enbuild.2022.111910
- 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
- 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
- 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







BERKELEY LAB
Bringing Science Solutions to the World

U.S. DEPARTMENT OF ENERGY
Office of Science

Thank You...!
Questions?

Iain S. Walker
Staff Scientist
ISWalker@lbl.gov

Núria Casquero-Modrego
Postdoc
NuriaCM@lbl.gov