Emerging Pathways to Decarbonize the US Housing Stock

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BERKELEY LAB
BUILDING TECHNOLOGY & URBAN SYSTEMS DIVISION
Energy Technologies Area

Building AMERICA
U.S. Department of Energy

What's The Issue?

HOMES USE A LOT OF ENERGY

- **New residential homes** are pretty good and are only about 1% of homes in any given year
- **Existing residential homes** use (almost) all the energy

WE NEED TO FIX EXISTING HOMES

- Why aren't all homes upgraded?
- What are the barriers to scaling upgrades?
- Can we make upgrade costs more manageable?

Switching from **Energy Efficiency** to **Low Carbon:** We can't efficiency our way to zero carbon homes

How to Address Those Questions

STATE-OF-THE-ART REVIEW

- Recent documented developments for Energy Efficient / Low Carbon homes
- Past experiences and programs in the US and Europe
- What has been successful
- What has not been successful

MARKET SURVEY

- Understand what motivates and deters DER projects in today's market
- Identify promising approaches and technologies from the industry perspective
- Learn from people doing this work about barriers, what works, possible future strategies to get to scale

PROJECT COST SOLICITATION

- Learn from people currently doing this work about costs
- Breakdown costs by category (e.g. "sunshot" program for solar PV) to get "cost stacks"

State-of-the-art Review

REPORT

Emerging Pathways to Upgrade the US Housing Stock: A Review of the Home Energy Upgrade Literature (2021)

Brennan D Less, Iain S Walker, Núria Casquero-Modrego

Integrated Approaches at Large Scale

The Netherlands

Climate Mission The Netherlands

- "One Stop Shop" packaged approaches including: financing, planning, design, installation
- Makes it simple and easy for home owners.

www.climatemission.eu

EnergieSprong

- More than 5,000 homes.
- Simplified panelized retrofits pre-fab in factory.
- Best for simple homes.

https://energiesprong.org

Summary of 12 Deep Energy Upgrade Programs

IS THIS ENOUGH?

INDUSTRY NEEDS BIG CHANGES

Program Name	Number of Homes	Average Cost ($)	Average Site Energy Savings	Notes
Energy Upgrade California - CA	20,000	$6,300	274 kWh, 16 Therms	Actual bill savings. Predicted savings were typically much higher.
Zero Energy Now - VT	24	$54,500	39% delivered site energy savings; 64% fossil fuel and grid energy savings; 60% energy cost savings	Weather normalized savings from utility bills and fuel delivery invoices. Most projects electrified, including insulation, heat pumps and PV.
Home MVP – MA: Deep	66	$49,126	48%	Predicted energy savings
Home MVP – MA: All	341	$21,675	33%	Half were electrified
Extreme Energy Makeovers - TN	3,420	$9,000	35% (4,900 kWh)	Deemed energy savings; affordable housing
National Grid Deep Energy Retrofit Pilot Community - MA and RI	60	$34.59 /ft^2	55%; 43% source energy savings	For 29 comprehensive projects
FSEC DERs - FL	10	$14,323	38%	DER increment was $7,074; affordable housing
FSEC DERs - FL	70	$16,424	30%	DER increment was $3,854; affordable housing
EnergyFIT Philly - PA	67	$14,257	36% gas, 22% electric	Affordable housing
EnergySmart Ohio - OH	11	$30,173		Cost data from Redwood Energy Guide
HomeLink by Home Energy Analytics - CA	17,100	Effectively zero	10%	CA's first pay-for-performance utility program; Includes automated energy end-use feedback and customized coaching
HomeLink by Home Energy Analytics - CA	16	Effectively zero	42% electric, 17% gas	Higher performing subset
Sealed - NY	338	$10,000	20% heating, 5% electricity	

Emerging Changes in DER

- **Shift away from high-cost super-insulation strategies**, with increasing recognition that traditional weatherization/home performance strategies are adequate for most dwellings.
- **Importance of when homes use energy**, and what type of energy they use and from what source.
- **Electrification as a core strategy**, with rapidly improving heat pump systems and lower-cost electrification strategies.
- **PV is becoming cheap and desirable**, necessitating a reassessment of energy upgrade priorities.
- **Financial payback arguments are challenging** due to low electricity and natural gas prices.
- **Sell comfort, convenience, aesthetics and health**. Big opportunity for PAYS program types with low upfront costs and pay for performance outcomes.
- **Emerging smart home technologies** are facilitating the ability to manage, reduce and communicate about energy use and carbon.

Getting to Scale

KEY BARRIERS TO SCALING UP DEEP ENERGY RETROFITS

- Projects focused solely on energy savings are not appealing to enough people.
- Market interest and acceptance is low amongst homeowners.
- Costs are too high.
- Economic justifications are challenging and possibly inadequate. **Low electricity** and **natural gas prices** make financial payback arguments challenging.
- Lack of trained workforce with the necessary skills.
- Lack of real estate market valuation of DERs/home upgrades.
- Energy programs need to add financing (PAYS / PACE).

Emerging Program Changes

Make DERs Appeal to Home Owners

Energy Programs – NEED TO

- Provide information.
- Use the right language
- Efficiency plus health
- Guaranteed energy savings
- One stop shop - approach
- Include rebates, attractive financing and other incentives (e.g. PAYS and PACE)
- Make it easy, make it fast.
- Invest in a well-qualified workforce that homeowners trust and use contractors as program ambassadors.

Emerging Program Changes

NEW METRICS

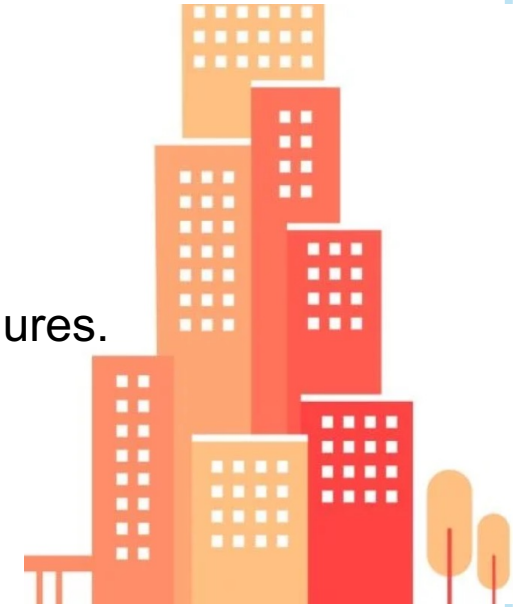
- CO_2 (and other Green House Gas) emissions.
- Grid interactivity and grid services.
- Peak demand and time of use.
- Electrical and thermal storage.
- Resilience
- Assessments of health, safety and IAQ associated with home energy upgrades including fire risk, CO, particles, wildfire and pandemic resistance

Emerging Technologies

Develop a standardized set of strategies that apply to the many building typologies that have broad consumer appeal

The strategies should focus on:

- Decarbonization and electrification.
- Demand-responsive and resilience-focused technologies including electric batteries and thermal storage.
- Heat pump technologies.
- Grid connectivity.
- Smart technology and web-connectivity.
- Resilience to natural and manmade disasters: wildfires, infrastructure failures.
- Health and safety.



Emerging Technologies

INCREASED INTEREST IN ELECTRIFICATION

- Electrification is a core strategy to achieving deep carbon reductions in buildings (and vehicles).
- Existing consumer demand for PV.
- Solar generation and storage is becoming more affordable.
- Improvements in Heat Pump Systems, particularly for cold climates and water heating.
- Reduced health and safety concerns.
- Elderly people safety concerns.

Market Survey

REPORT

DOE Deep Energy Retrofit Cost Survey (2020)

Wanyu R Chan, Brennan D Less, Iain S Walker

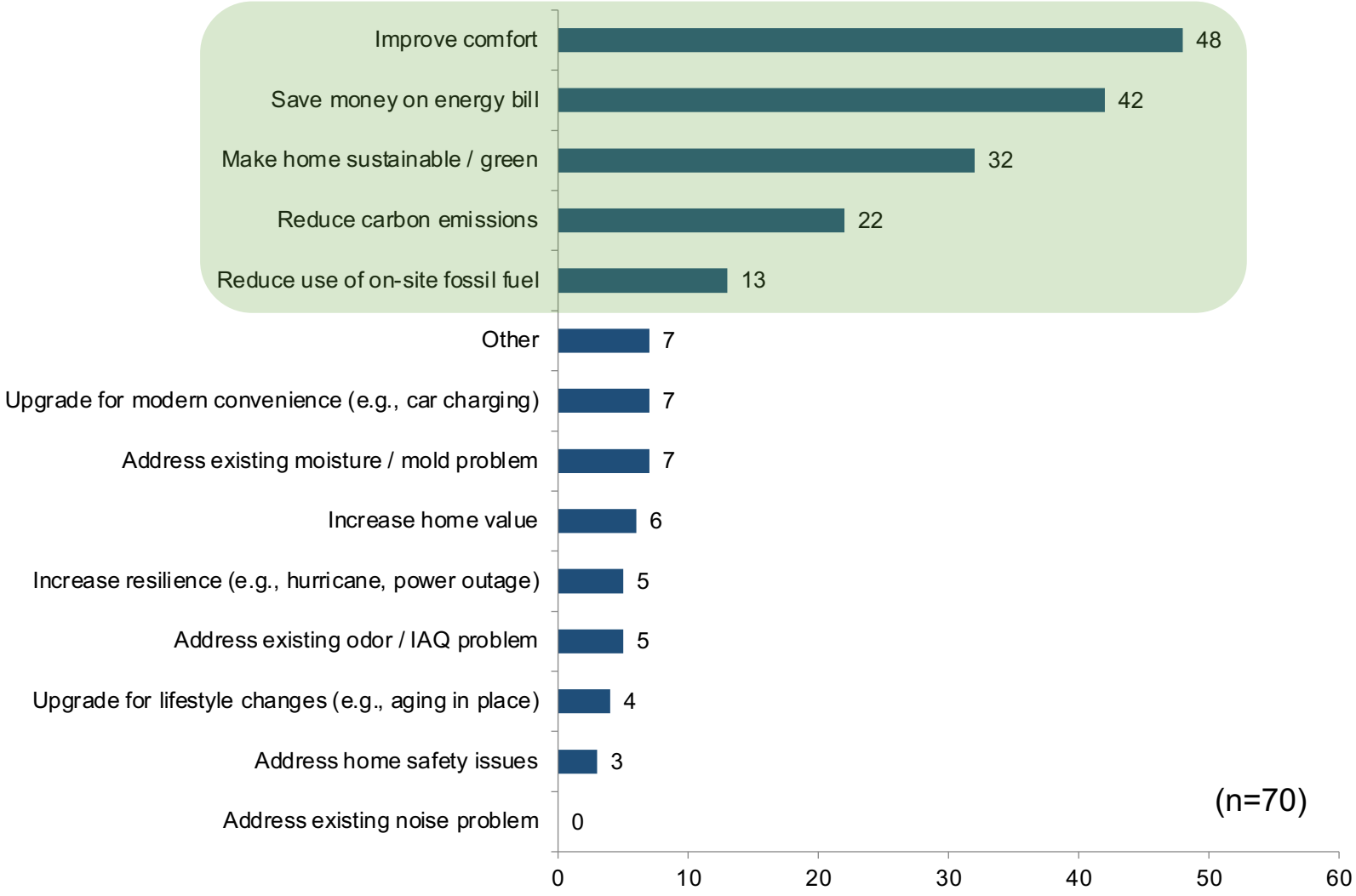
Market Survey

Survey questions organized by main sections of topic:

- Background information about past DER experiences of the respondent
- Consumer perspective on DER projects
- Home performance contractor perspective on DER challenges
- Promising technologies and approaches to advance DER
- Work scope and approaches to DER from past experiences
- Project costs for performing DER

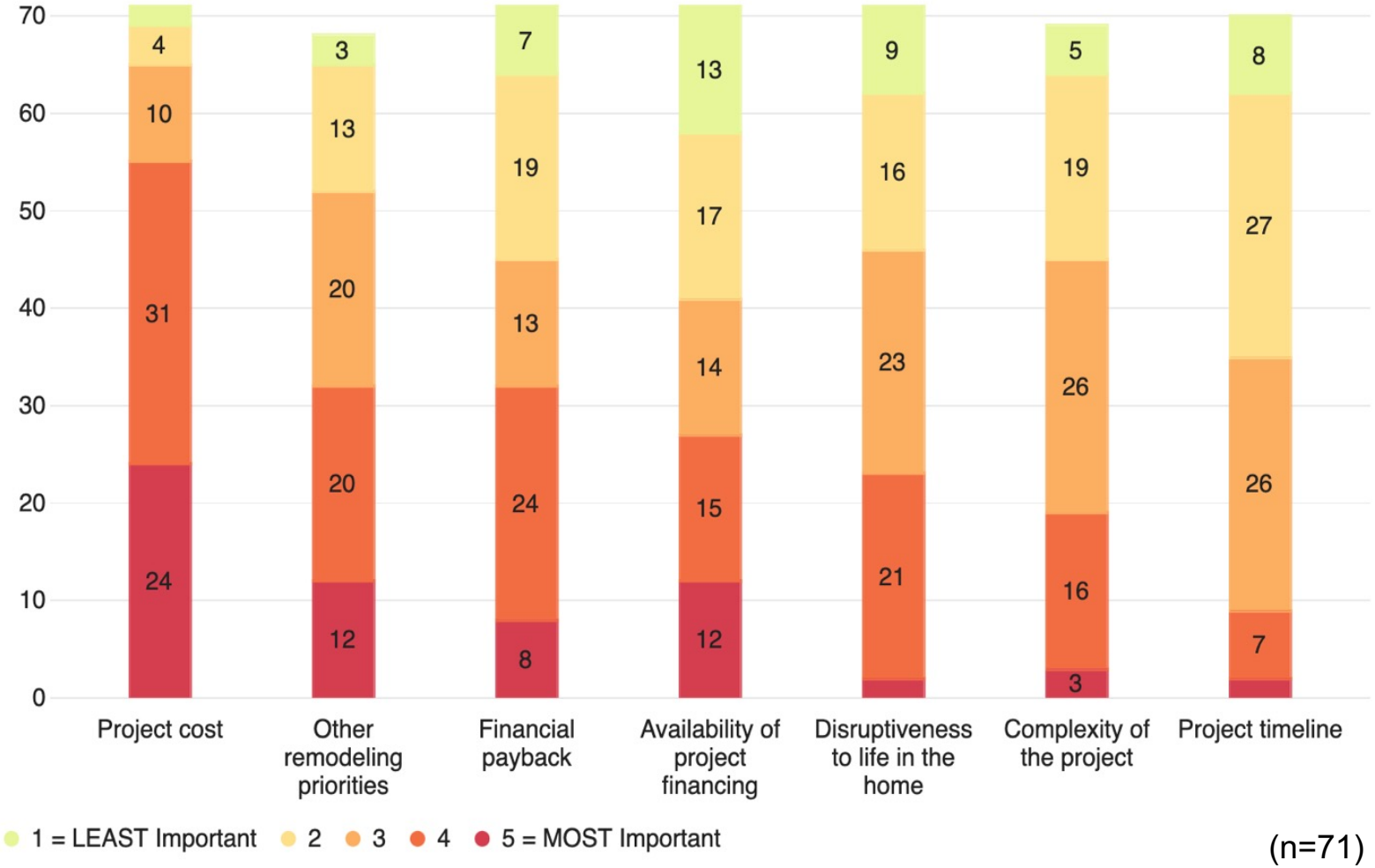
Customer Perspective

What are the main motivations of homeowners / building owners when seeking to perform a DER project?



Customer Perspective

Importance of factors when homeowners decide whether or not to proceed with a DER project



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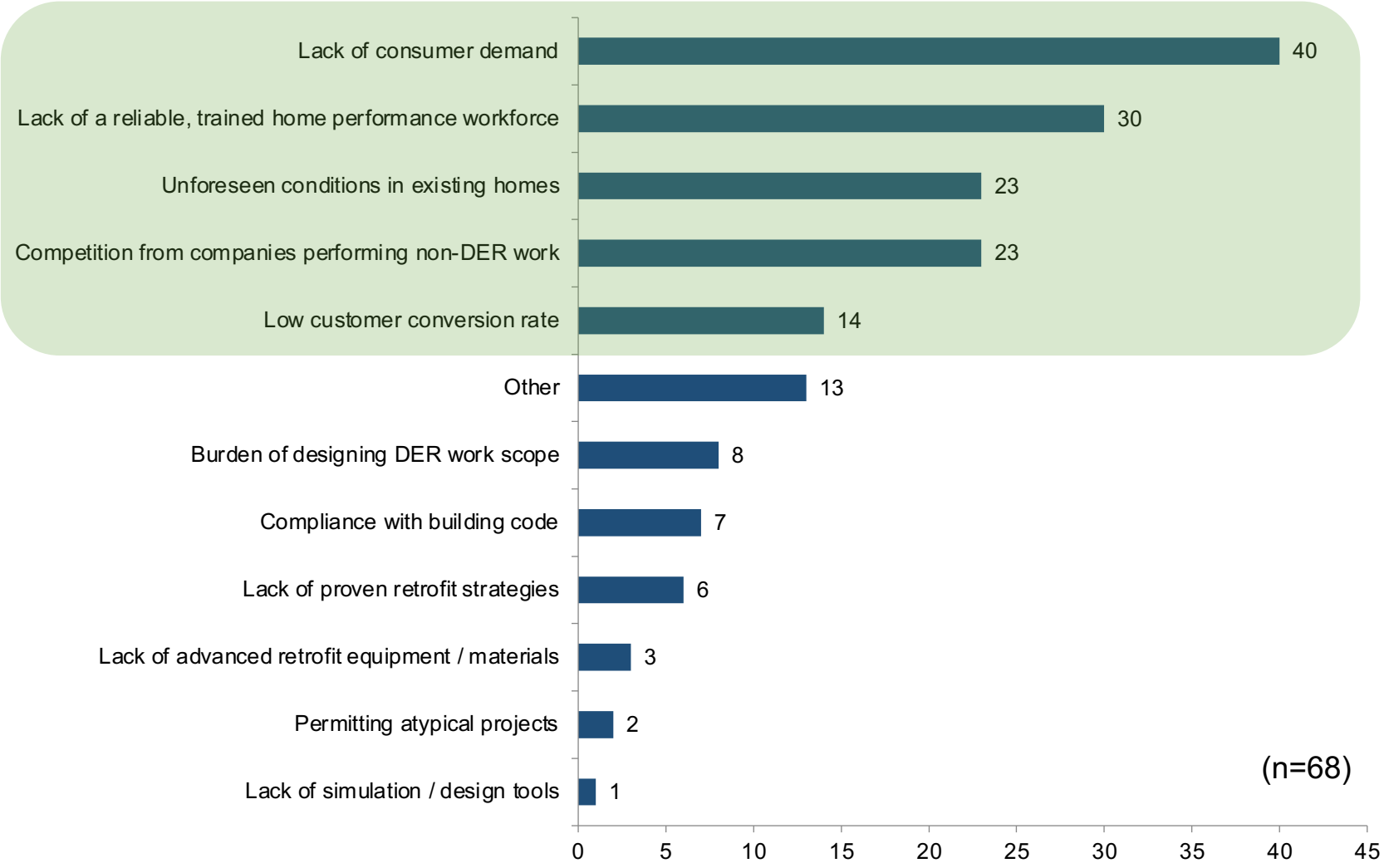
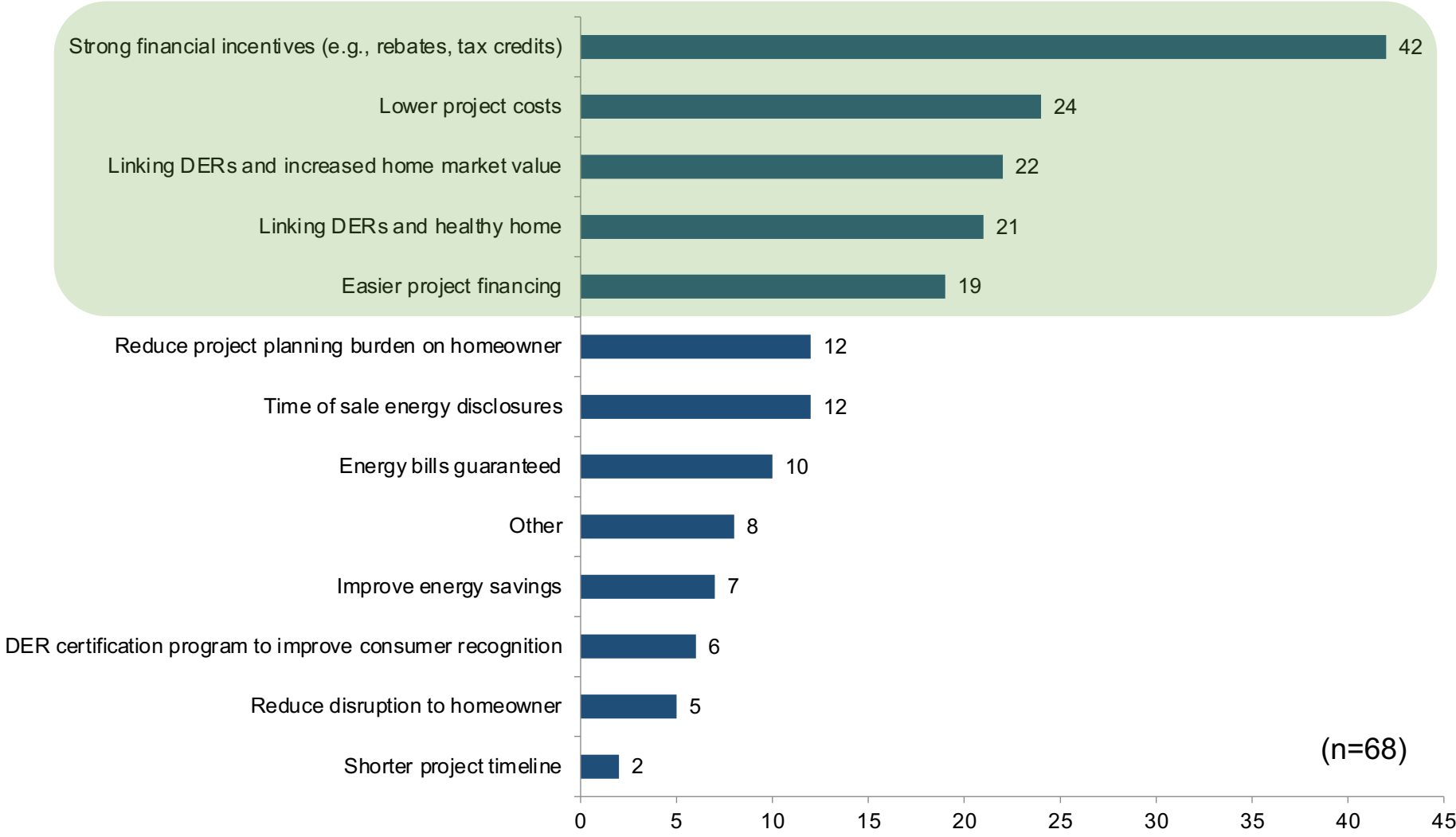
Industry Perspective

Aside from costs, what are the biggest barriers when performing DER projects?



Industry Perspective

What are the most effective ways to increase customer demand for DER projects?



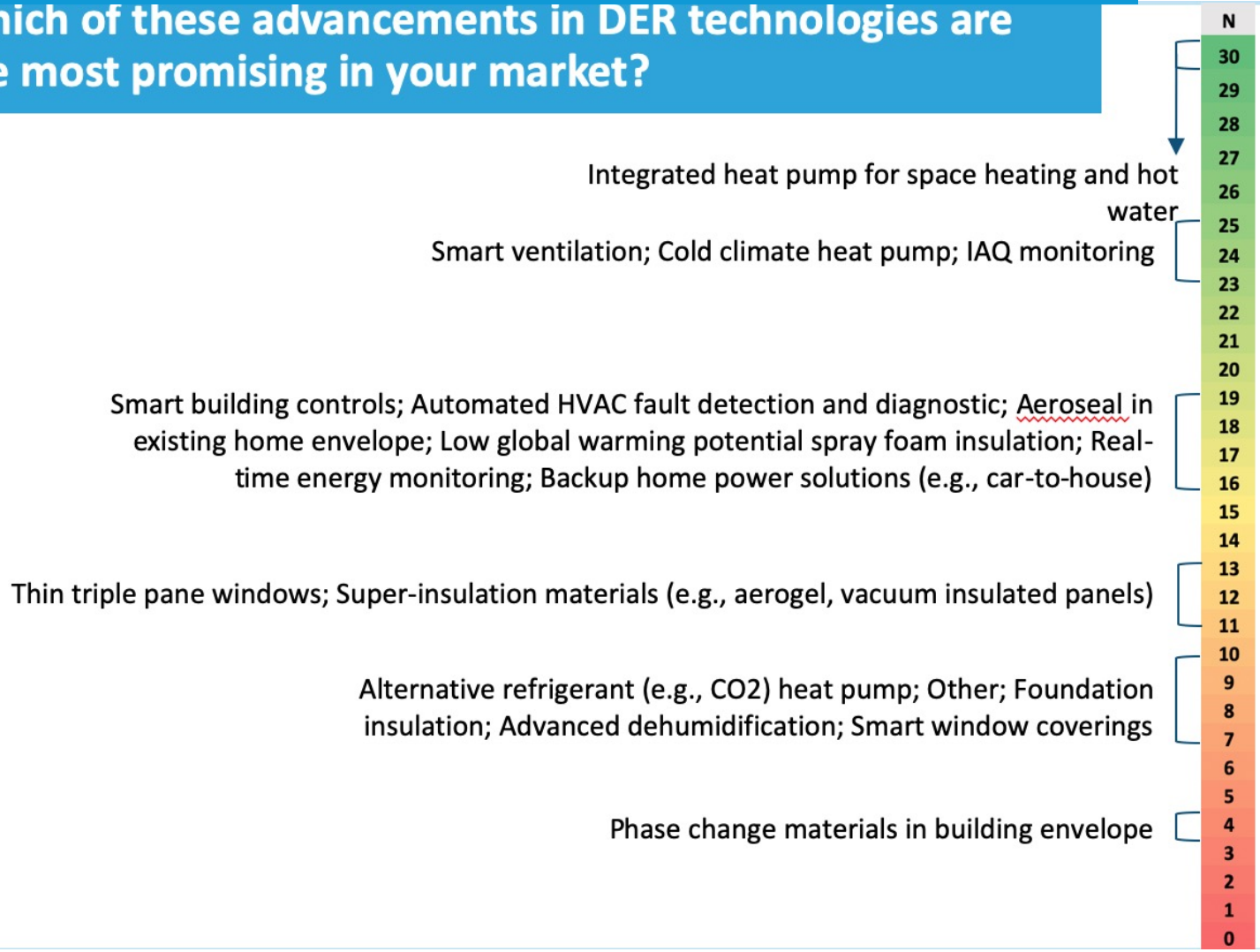
Advanced Technologies and Approaches

Rating of approaches for performing DER in your market.

Ratings =	1	2	3	4	5	Total Responses
"One-stop shop" with energy audit, work scope, financing, permits, construction, testing	2	2	10	21	28	63
Energy plus healthy home retrofit	1	5	23	22	13	64
Standard weatherization combined with heat pump and PV	4	13	18	19	12	66
Over-time DER aligned with equipment replacement / upgrade	6	7	20	16	15	64
Home electrification retrofit	10	8	18	18	10	64
Exterior retrofit with minimal disturbance inside home	9	20	14	14	5	62
Pre-fabricated panelized envelope retrofits (e.g., EnergieSprong)	16	23	11	9	4	63

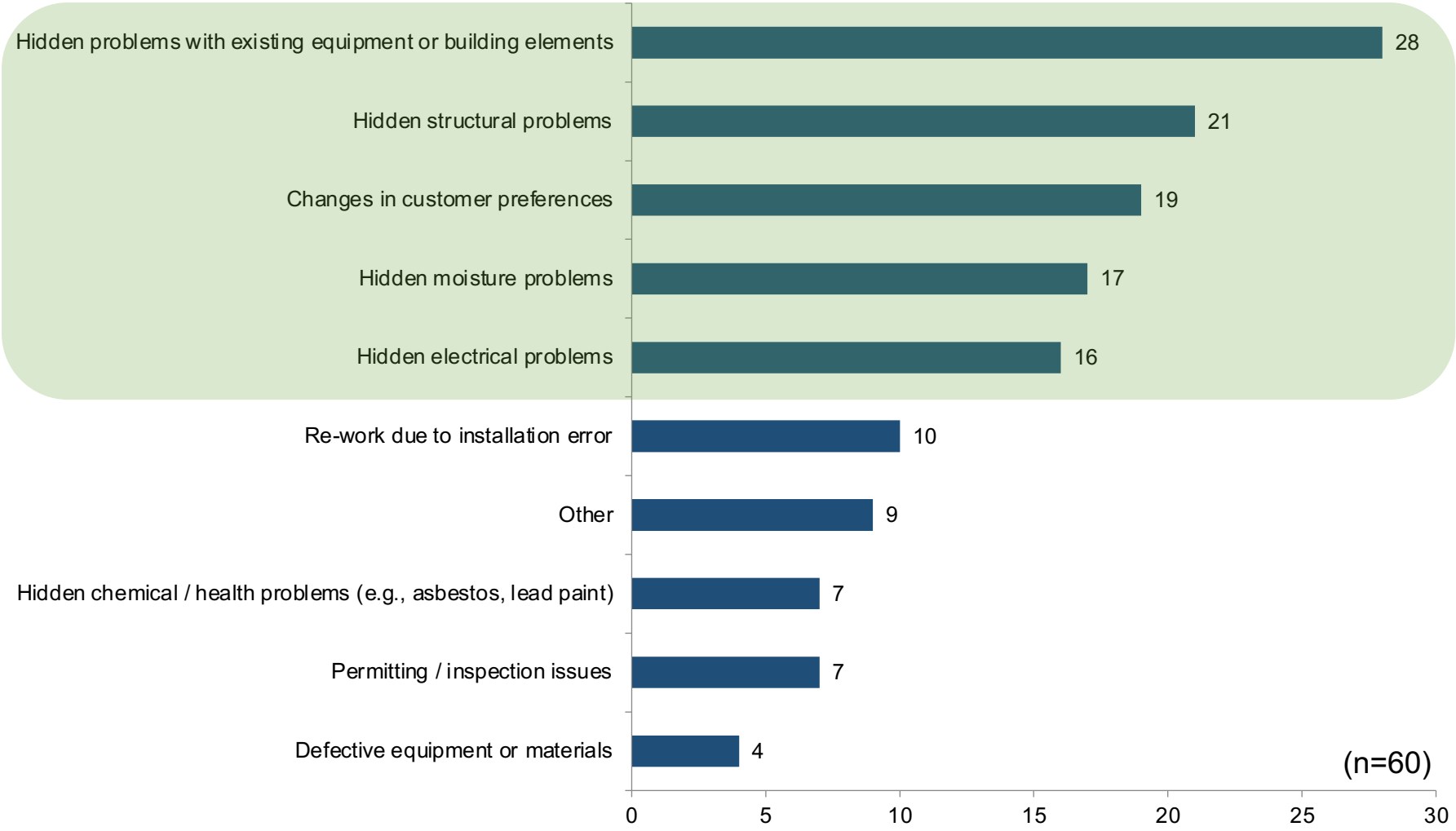
Advanced Technologies and Approaches

Which of these advancements in DER technologies are the most promising in your market?



Project Cost Estimates

Common causes of DER project cost increase.



Market Survey: Additional Suggestions from Contributors

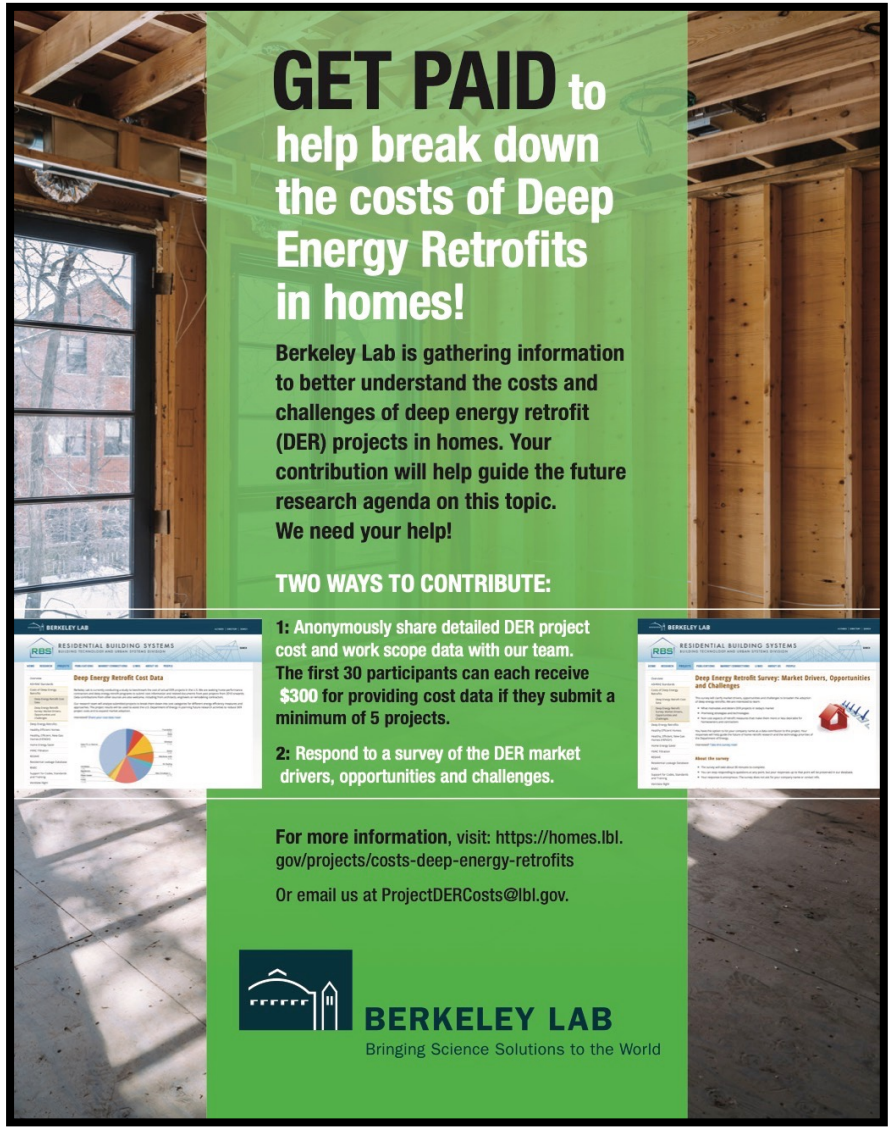
DEEP ENERGY RETROFITS NEED TO

- Define its role in the **Energy Efficiency** market.
- Focus on **carbon reduction** over the life cycle of the home.
- Continue **technology innovations**.
- **Enable** contractors to make money and build partnership.
- **Include** disadvantaged communities.
- Rethink how to **drive** customer demands.
- **Broaden work scope** to include plug loads, inefficient plumbing.

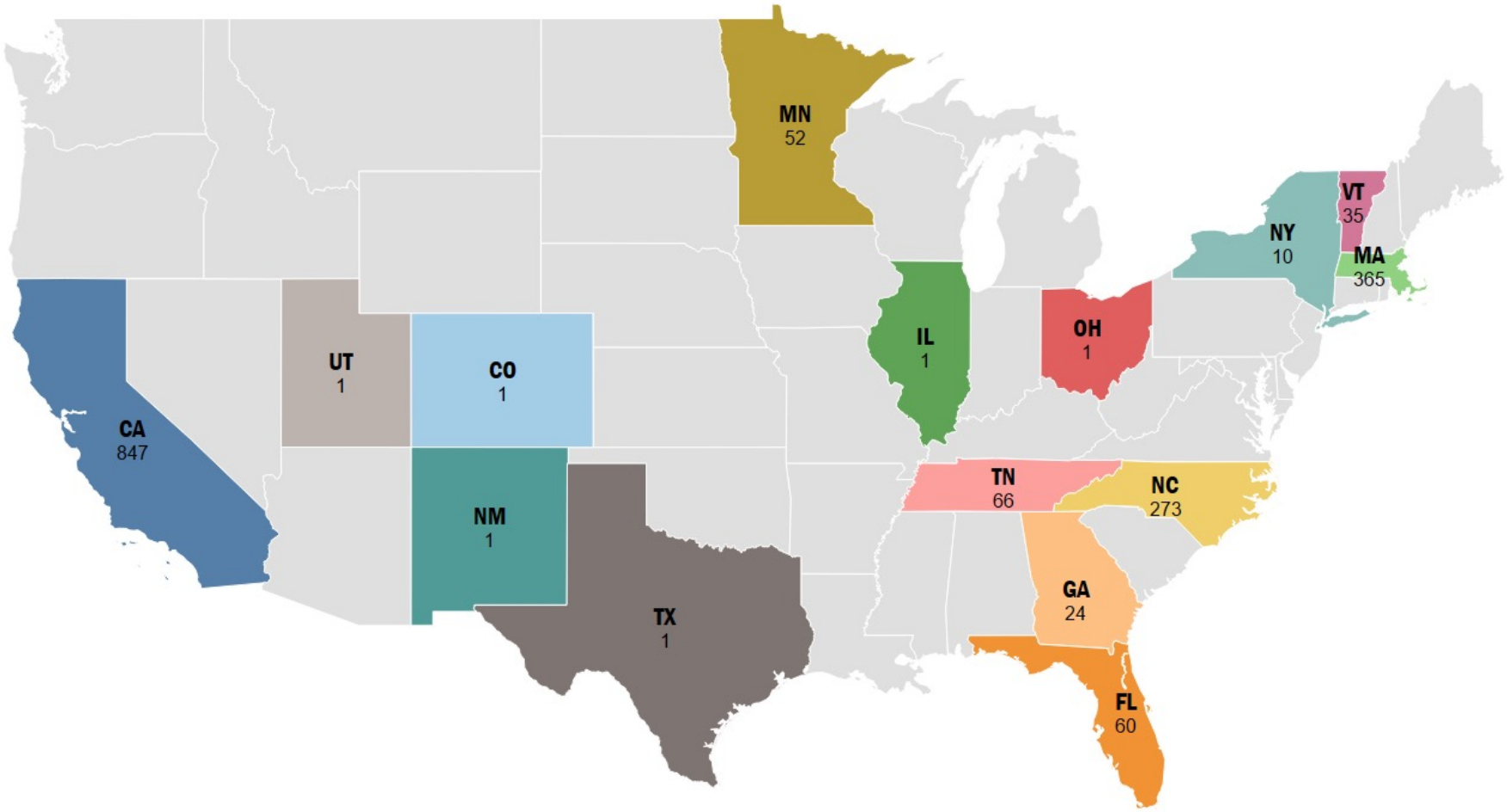
Market Survey

- Homeowners motivations
  - Improve comfort and save money on energy bill.
  - Reduction of projects costs.
- Industry
  - Lack of consumer demand.
  - Lack of trained home performance workforce.
  - Strong financial incentives.
- Advanced Technologies
  - “One-Stop Shop”
  - Integrated Heat Pump for space heating and hot water.
- Existing Buildings
  - Hidden problems.

Project Cost Solicitation

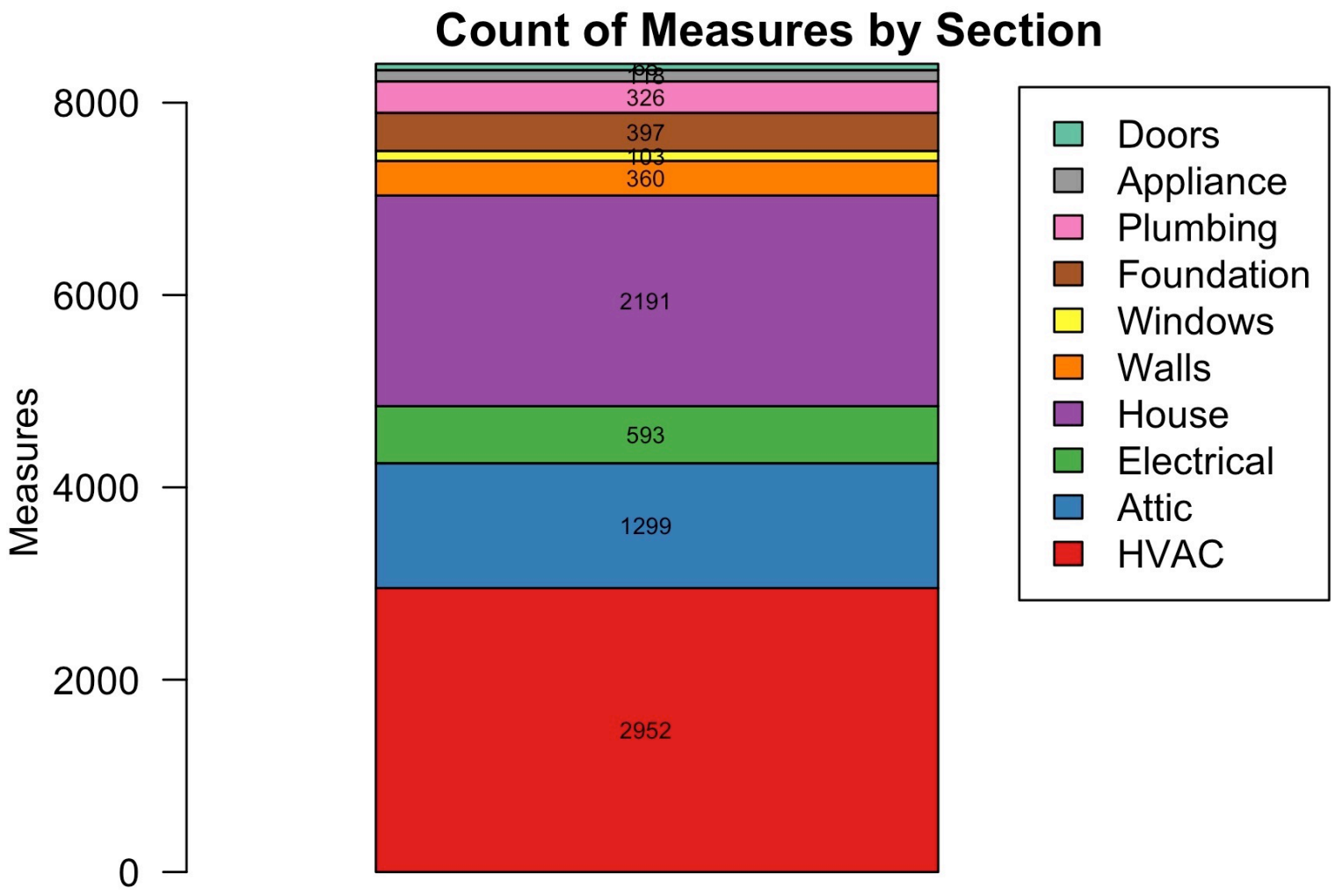

GET PAID to help break down the costs of Deep Energy Retrofits in homes!
Berkeley Lab is gathering information to better understand the costs and challenges of deep energy retrofit (DER) projects in homes. Your contribution will help guide the future research agenda on this topic.
We need your help!
TWO WAYS TO CONTRIBUTE:
1: Anonymously share detailed DER project cost and work scope data with our team. The first 30 participants can each receive $300 for providing cost data if they submit a minimum of 5 projects.
2: Respond to a survey of the DER market drivers, opportunities and challenges.
For more information, visit: https://homes.lbl.gov/projects/costs-deep-energy-retrofits
Or email us at ProjectDERCosts@lbl.gov.
BERKELEY LAB
Bringing Science Solutions to the World

Sample of convenience, not representative of all retrofit projects or program activity

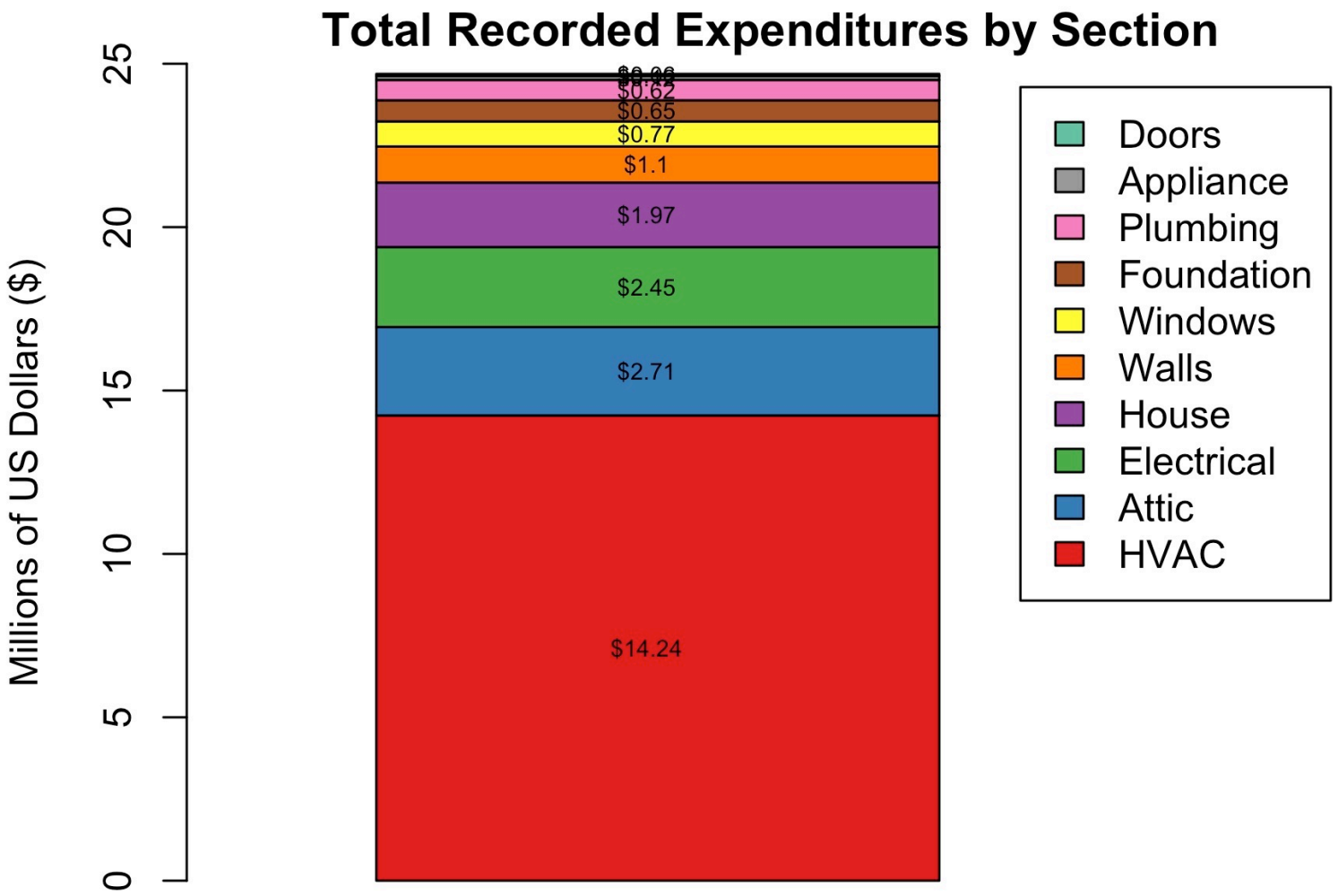


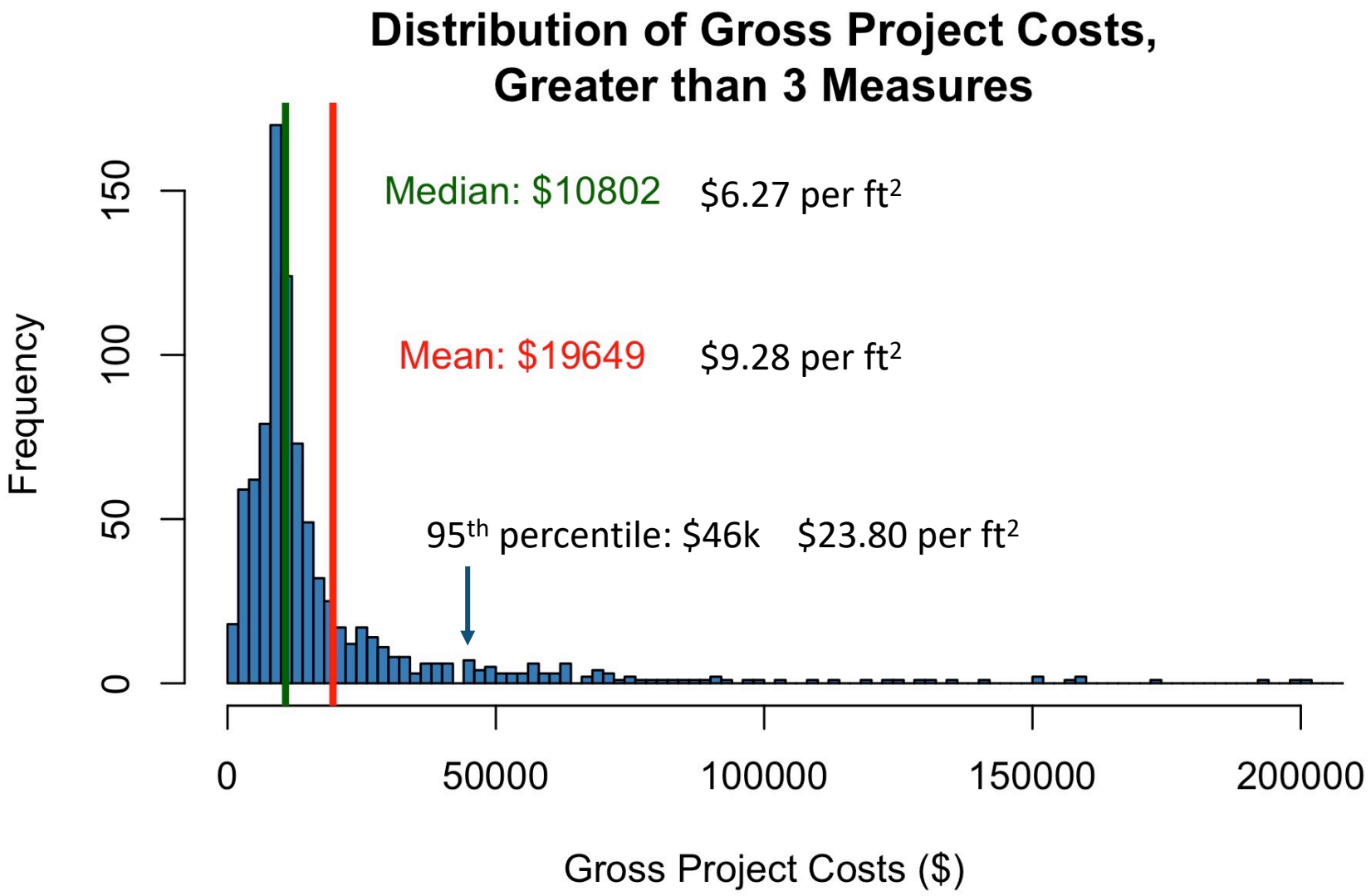
12 Programs 1,739 Projects 10,512 Measures 3,294,946 ft^2 $24,689,213

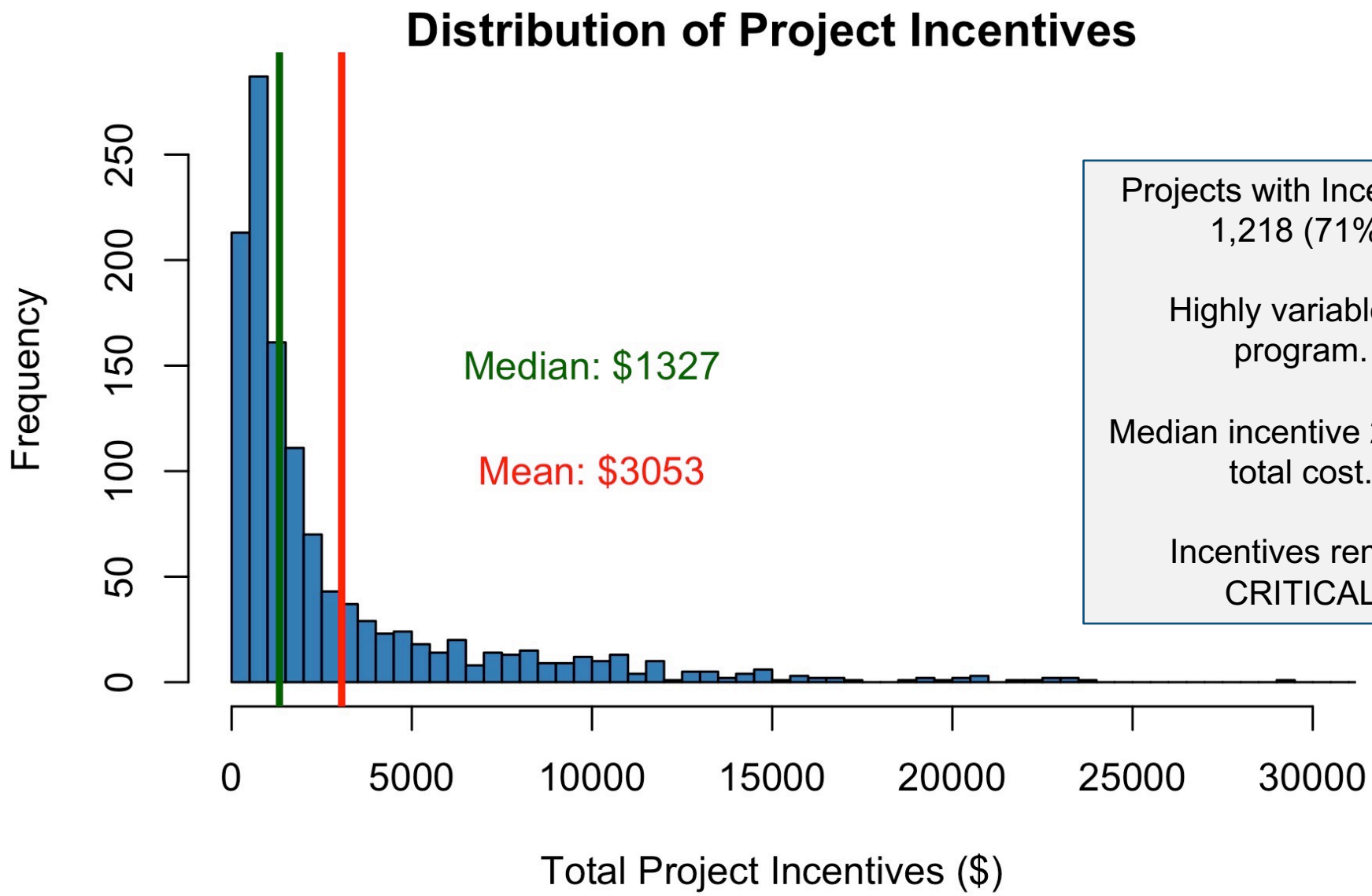
Count of Measures by Section



Costs by Section




Distribution of Gross Project Costs,
Greater than 3 Measures
Median: $10802
$6.27 per ft2
Mean: $19649
$9.28 per ft2
95th percentile: $46k
$23.80 per ft2
Frequency
0
50
100
150
0
50000
100000
150000
200000
Gross Project Costs ($)



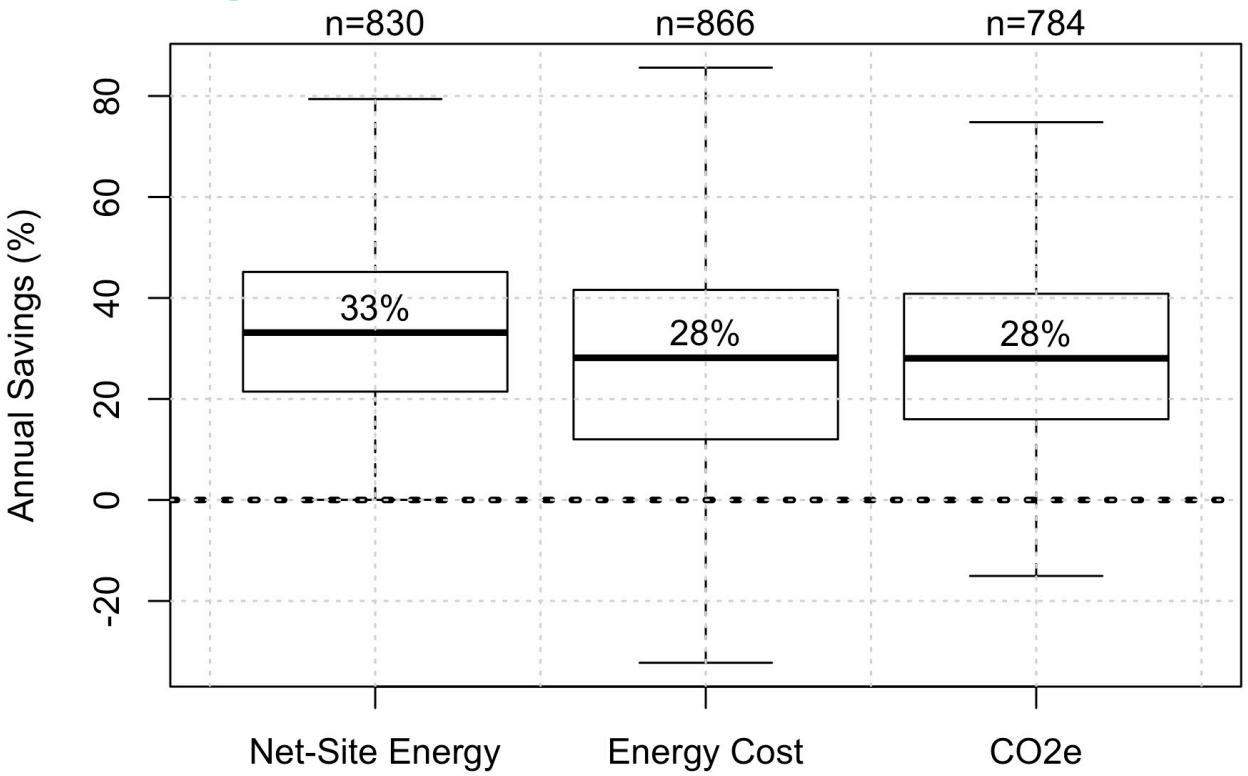
Projects with Incentives: 1,218 (71%)

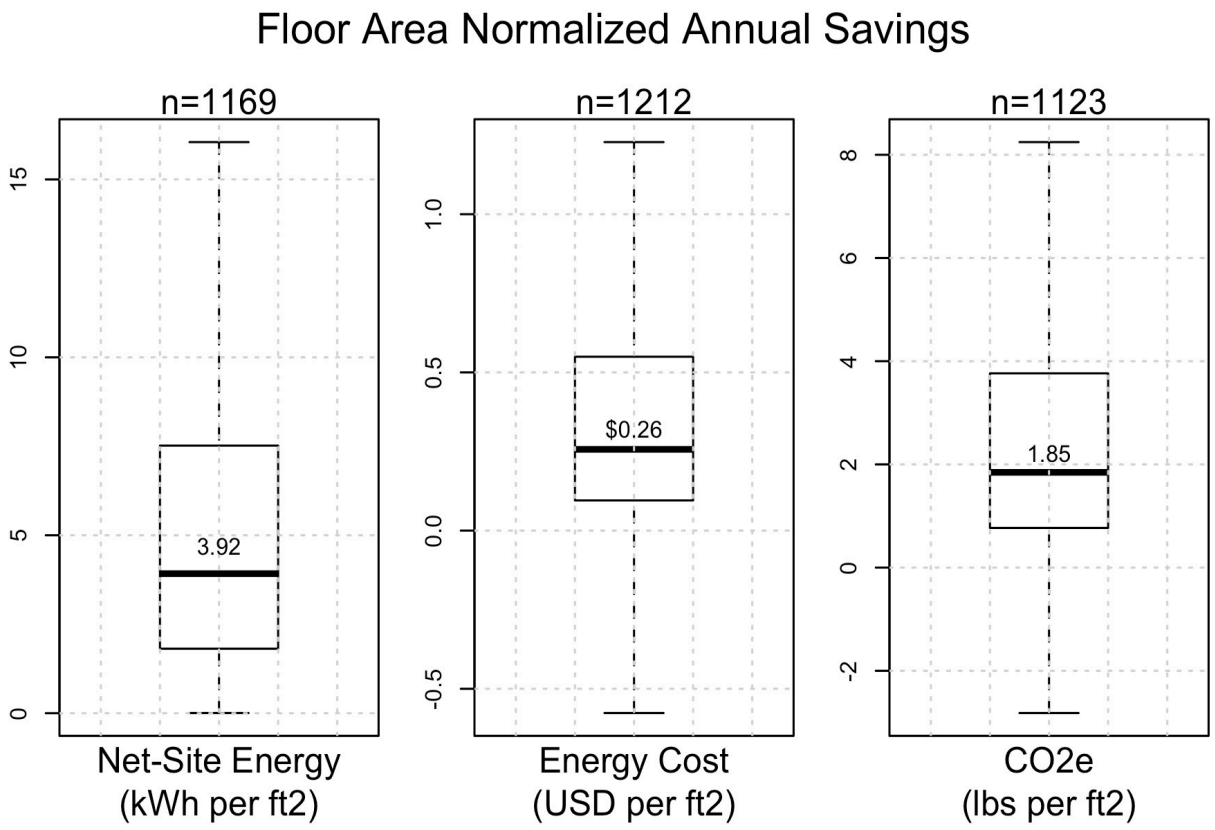
Highly variable by program.

Median incentive 21% of total cost.

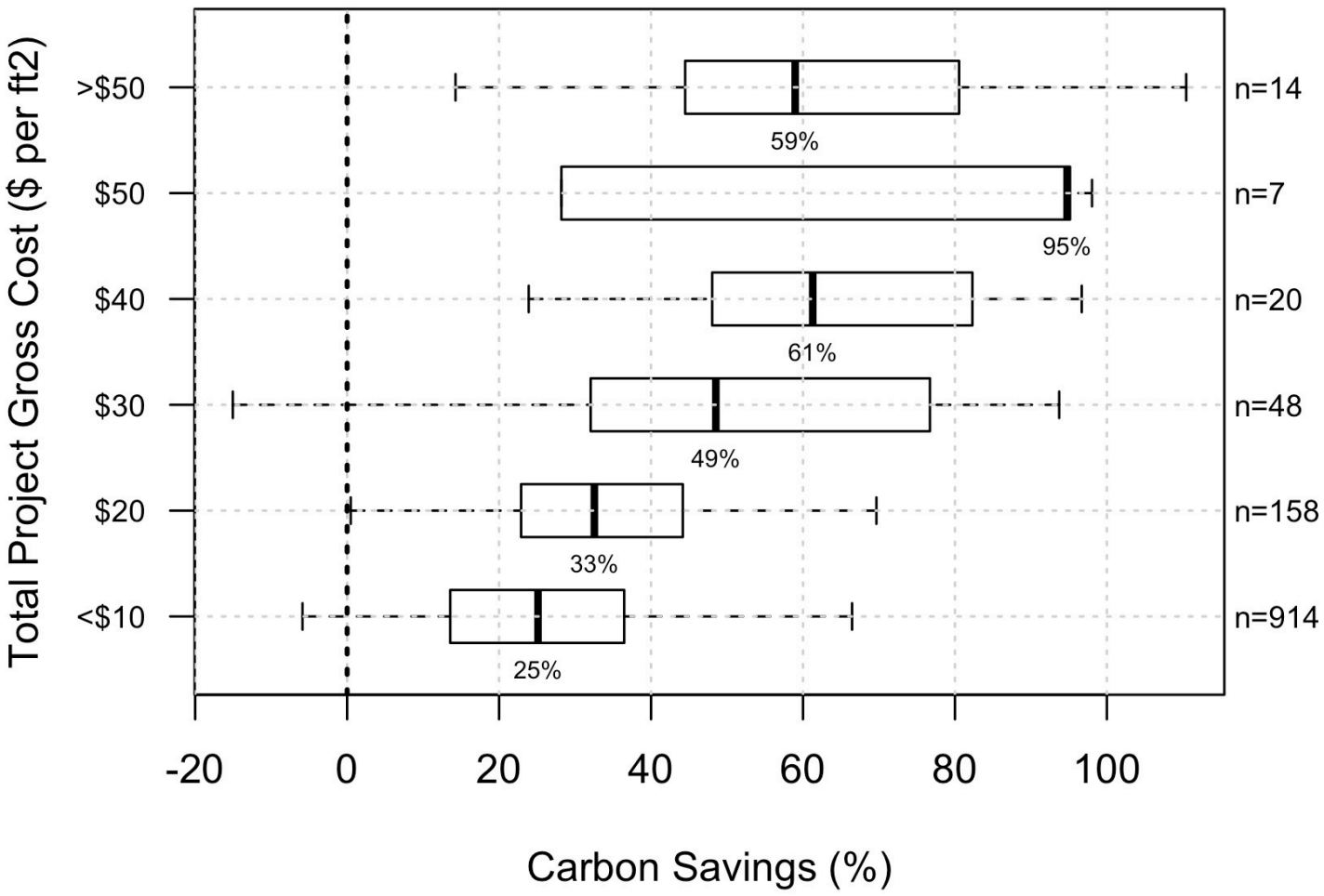
Incentives remain CRITICAL

Energy Use and Savings Distributions





Project Costs and Carbon Savings

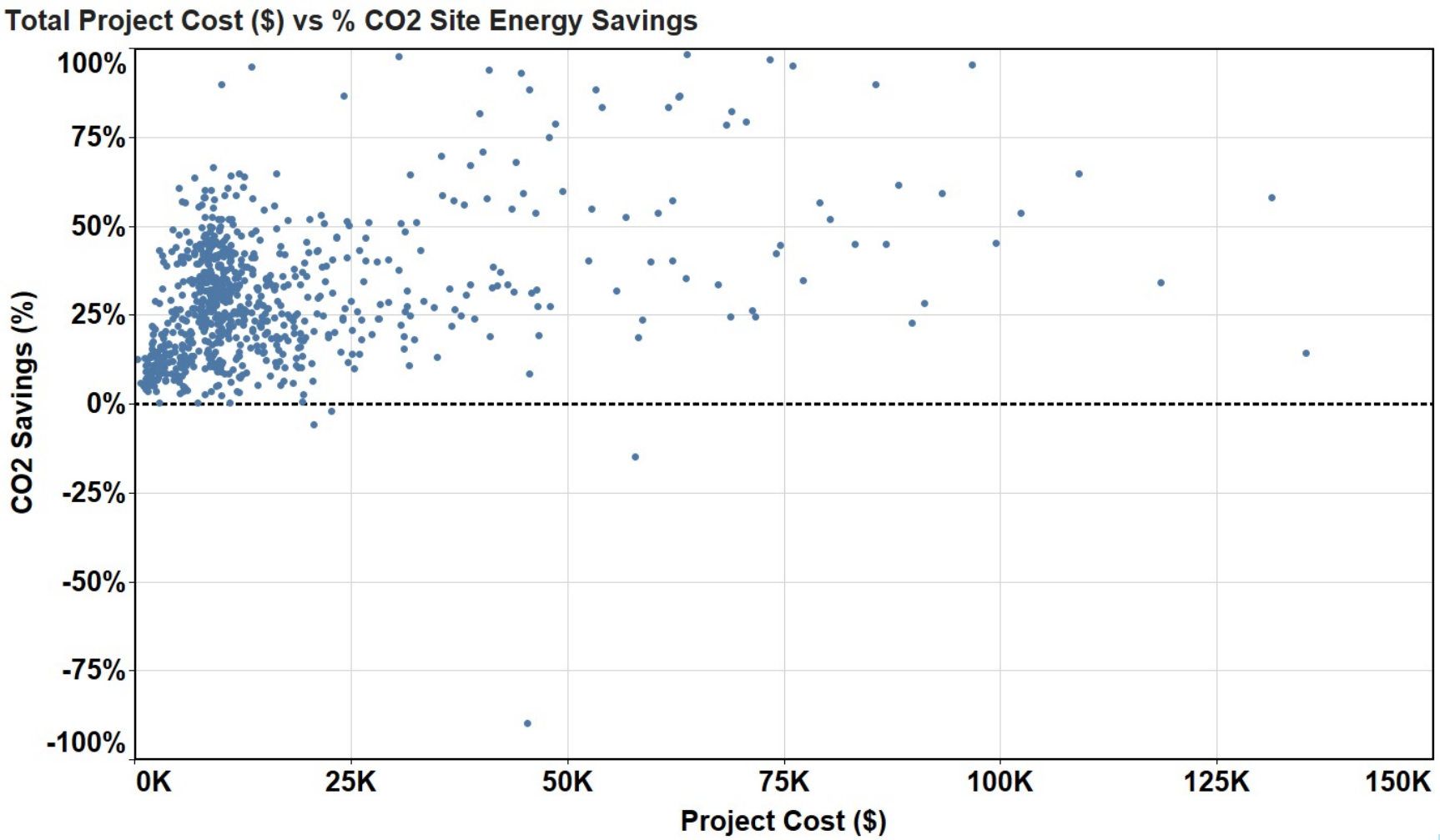


We probably need to be here

Project Costs and Carbon Savings

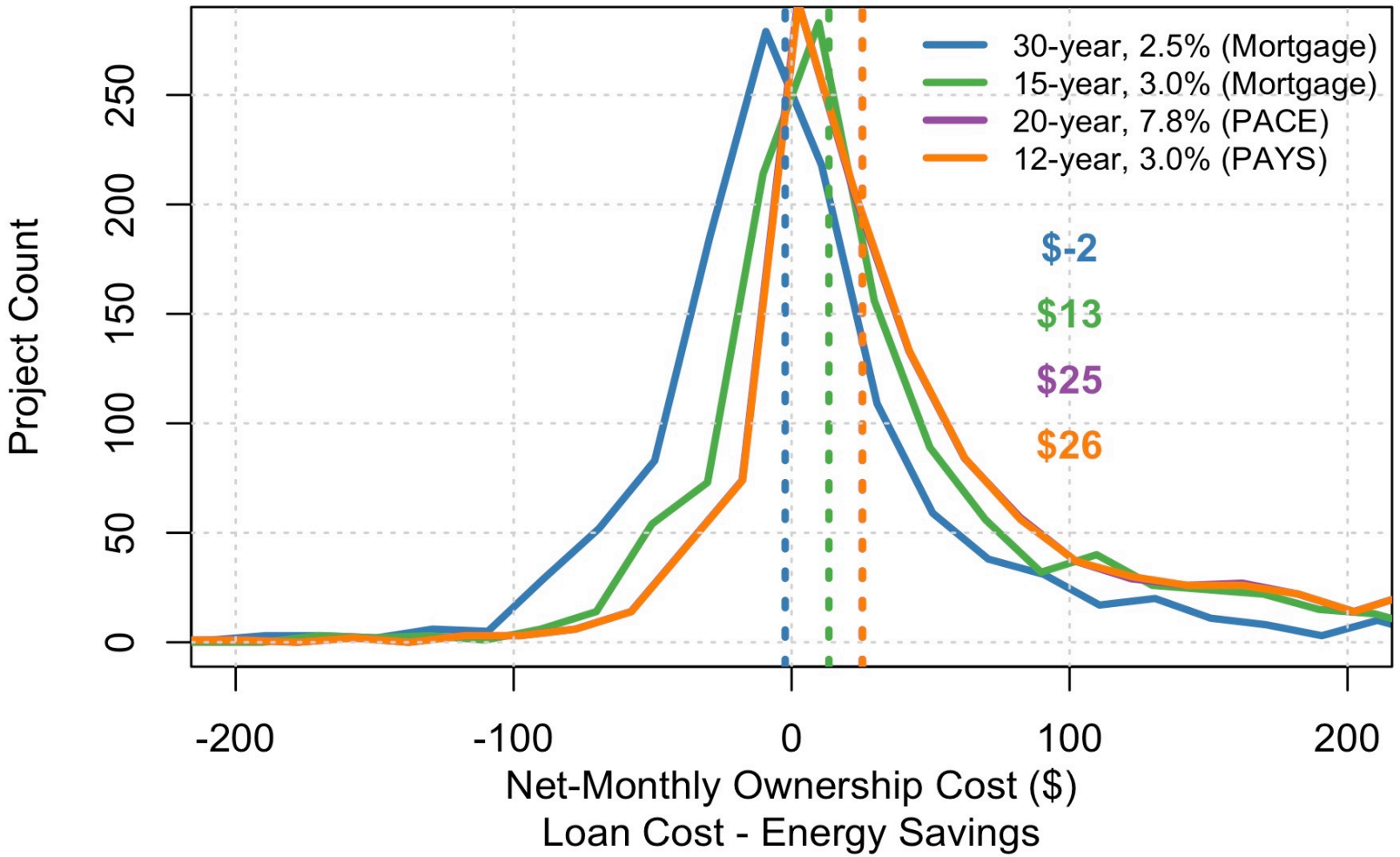
Some projects saved 50% at ~$10,000.

How do we make more projects like that?



Sum of Cost Gross Scatter vs. sum of Savings All lbsCo2% All. Details are shown for Project Id. The view is filtered on sum of Savings All lbsCo2% All and sum of Cost Gross Scatter. The sum of Savings All lbsCo2% All filter keeps non-Null values only. The sum of Cost Gross Scatter filter keeps non-Null values only.

Financing and Affordability



Net-monthly cost of homeownership under 4 financing scenarios

Almost always +/- $100 per month

Does not include fees or mortgage interest deductions, etc.

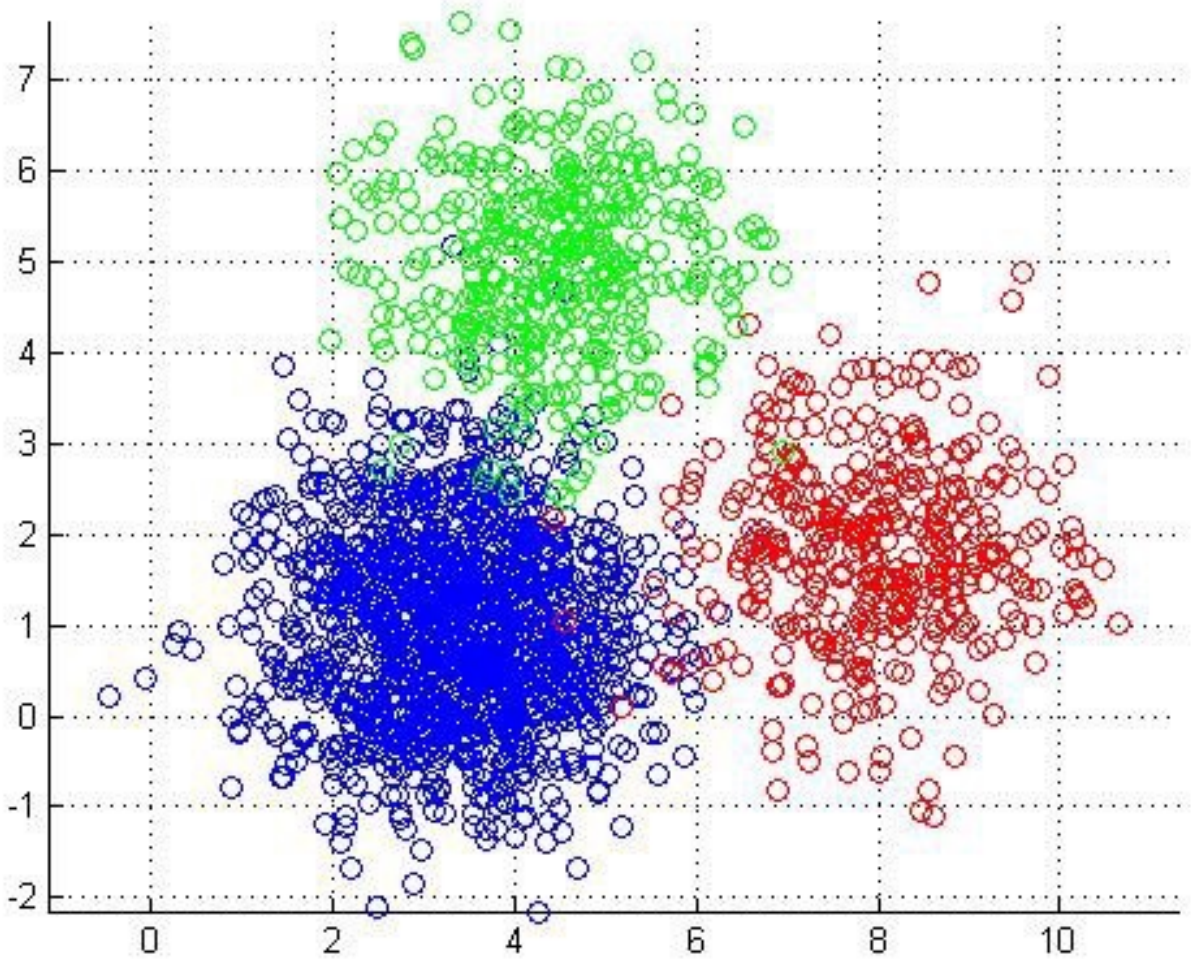
Financing and Affordability

Very little trend by Net-Site Savings.

Greater chances of increasing net-monthly costs when targeting >45%

Clustering Project Types

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.



Clustering Project Types - Descriptions

Label	Description	Total Project Cost ($)	Number of Projects	Number of Measures	Project Length (months)
Low Cost Weatherization	Low-cost, basic retrofit (insulation with some HVAC)	$3,849	671	2	1
Medium Cost Weatherization	Medium cost, basic retrofit (HVAC with some insulation)	$10,105	857	3	1
Medium Cost HVAC Focused	Medium cost, HVAC-focused retrofit (HVAC with some insulation)	$26,228	136	2.5	1
High Cost Large HVAC Focused	High cost, HVAC-focused retrofit of large homes (HVAC, insulation, DHW, some lighting and PV)	$120,802	14	9	3
High Cost Envelope Focused	High cost, classic comprehensive deep retrofit (HVAC, Insulation, some DHW, and Windows)	$109,059	15	16	15
Medium Cost HP/PV Focused	Medium cost, heat pump and PV-focused retrofit (PV, HVAC, insulation, and some DHW)	$54,098	43	10	4

Median Cluster Annual Energy Metrics

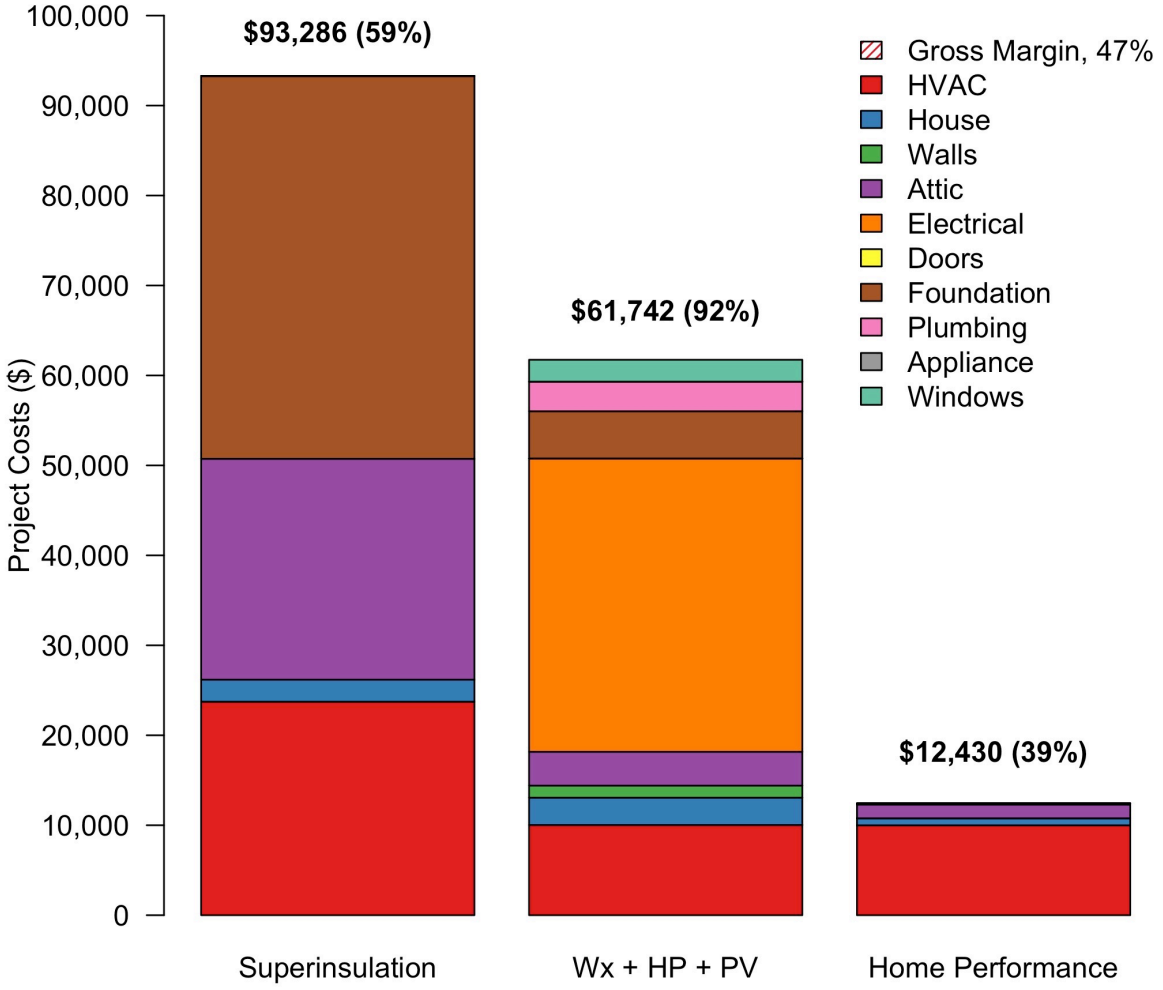
Cluster	Net-Site Energy Savings (%)	CO_2 Savings (%)	Net-Site Energy Savings (kWh/ft^2)	Energy Cost Savings ($/ft^2)	CO_2e Savings (lbs. CO_2e/ft^2)	Levelized Cost of Saved Net-Site Energy ($/kWh), 15-year, 3% discount	Net-Monthly Cashflow ($), 12-year, 3% interest	Simple Payback (years)
Low Cost Weatherization	20%	19%	2.3	$0.15	1.1	$0.077	$7	15
Medium Cost Weatherization	33%	31%	4.2	$0.38	2.4	$0.118	$35	16
Medium Cost HVAC Focused	40%	25%	6.8	$0.14	2.1	$0.155	$192	60
High Cost Large HVAC Focused	56%	39%	9.0	$0.25	3.1	$0.238	$562	82
High Cost Envelope Focused	64%	51%	14.0	$0.61	5.8	$0.385	$798	120
Medium Cost HP/PV Focused	72%	68%	14.5	$0.89	5.0	$0.178	$317	31

Typical CO_2e savings were roughly 70 vs. 50% for the highlighted clusters.

Examples of Clustered Projects

Three archetypal retrofits – these are real, specific projects, NOT averages

Traditional super-insulation is outperformed by emerging Heat pumps + Wx + PV

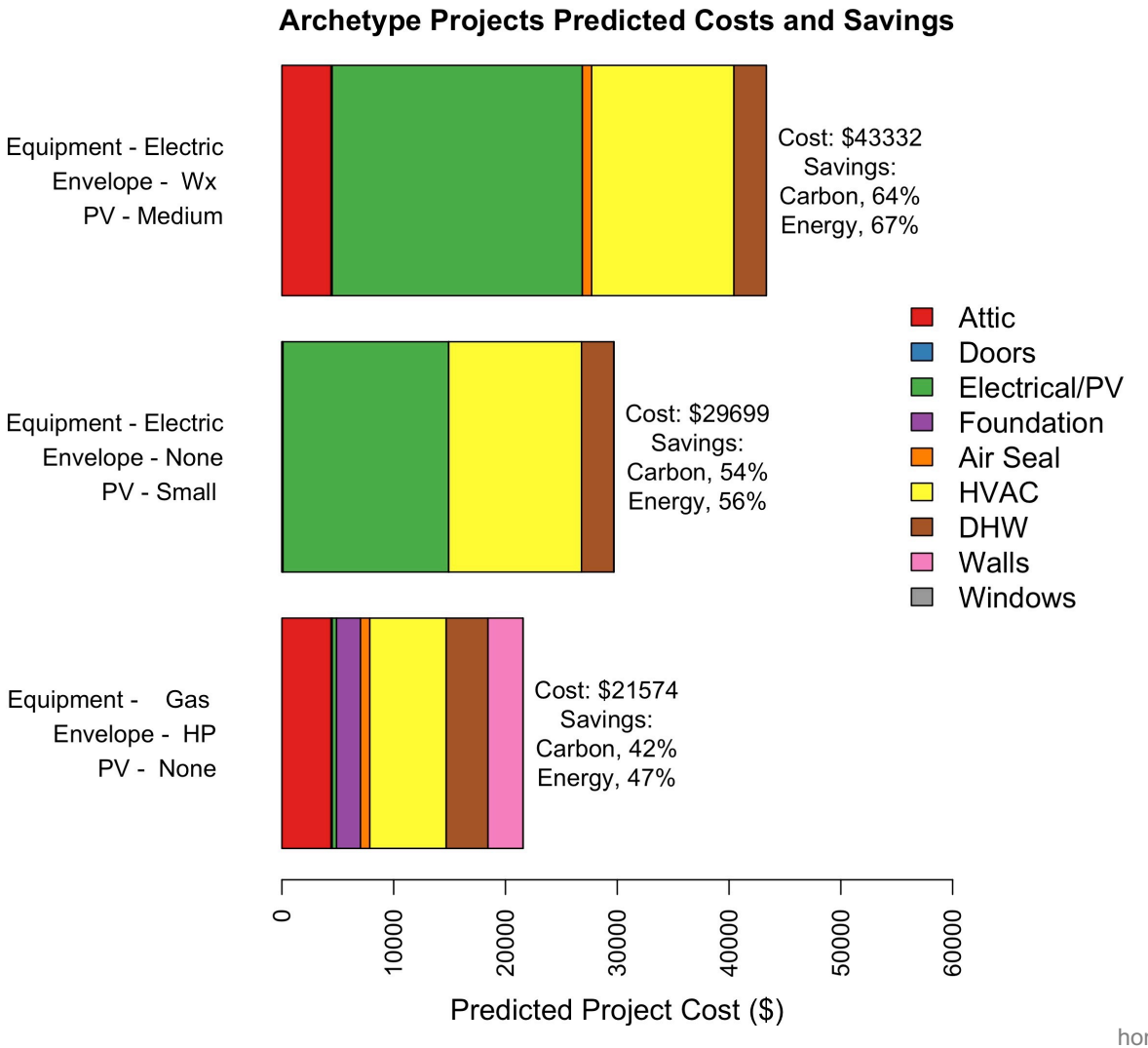


Regression Modeled Archetypes for Generic US Home

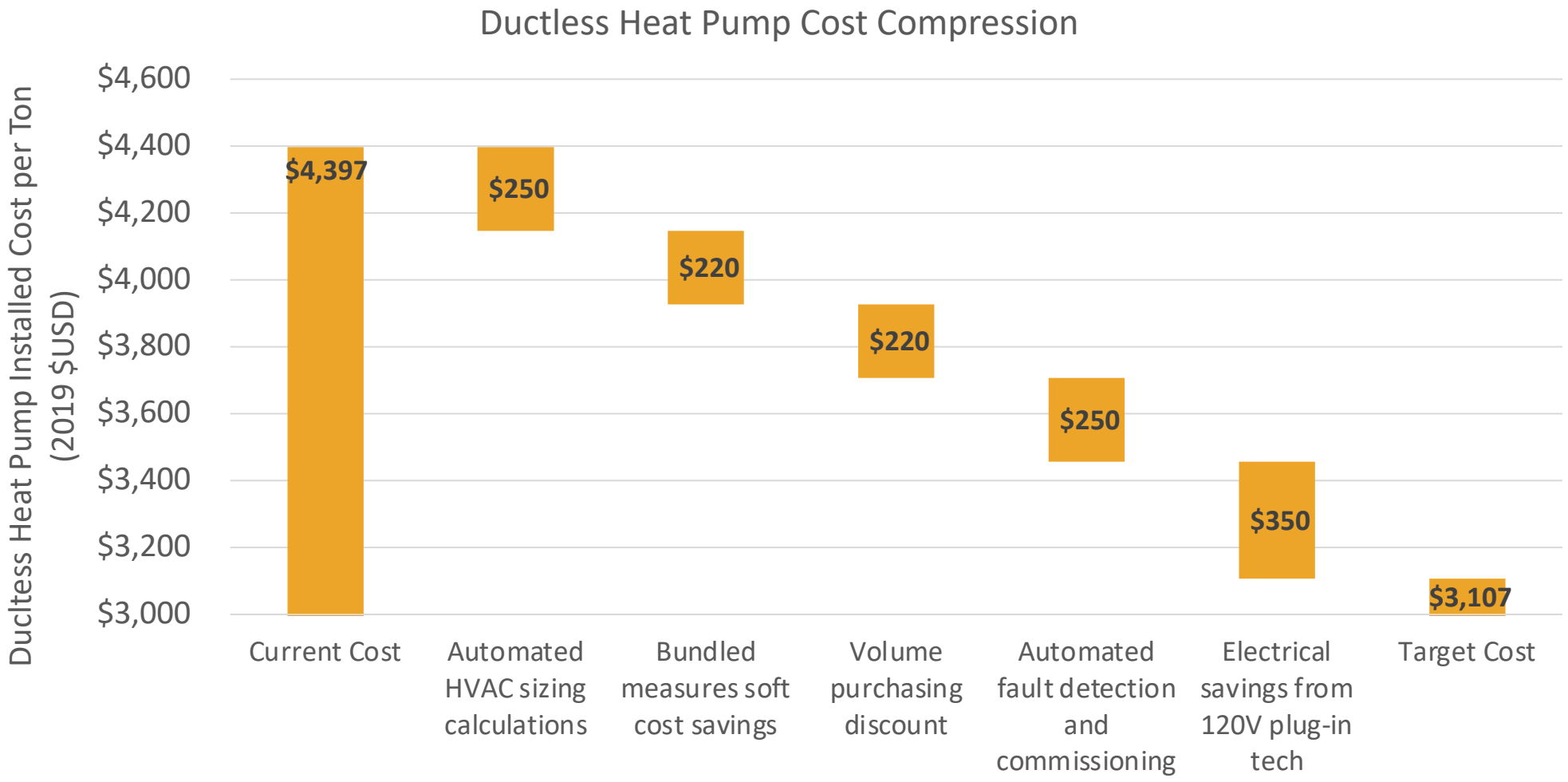
Upgrade equipment with electrical heat pumps, focused insulation/sealing and medium PV system.

Equipment-only upgrade with electrical heat pumps and small PV system.

Traditional, aggressive home performance upgrade without fuel switching and no PV.



Cost Compression - Technology



Cost Compression - Technology

INNOVATION FOR EASIER HOME ELECTRIFICATION

Avoiding panel upgrade/new service/home rewiring costs

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)

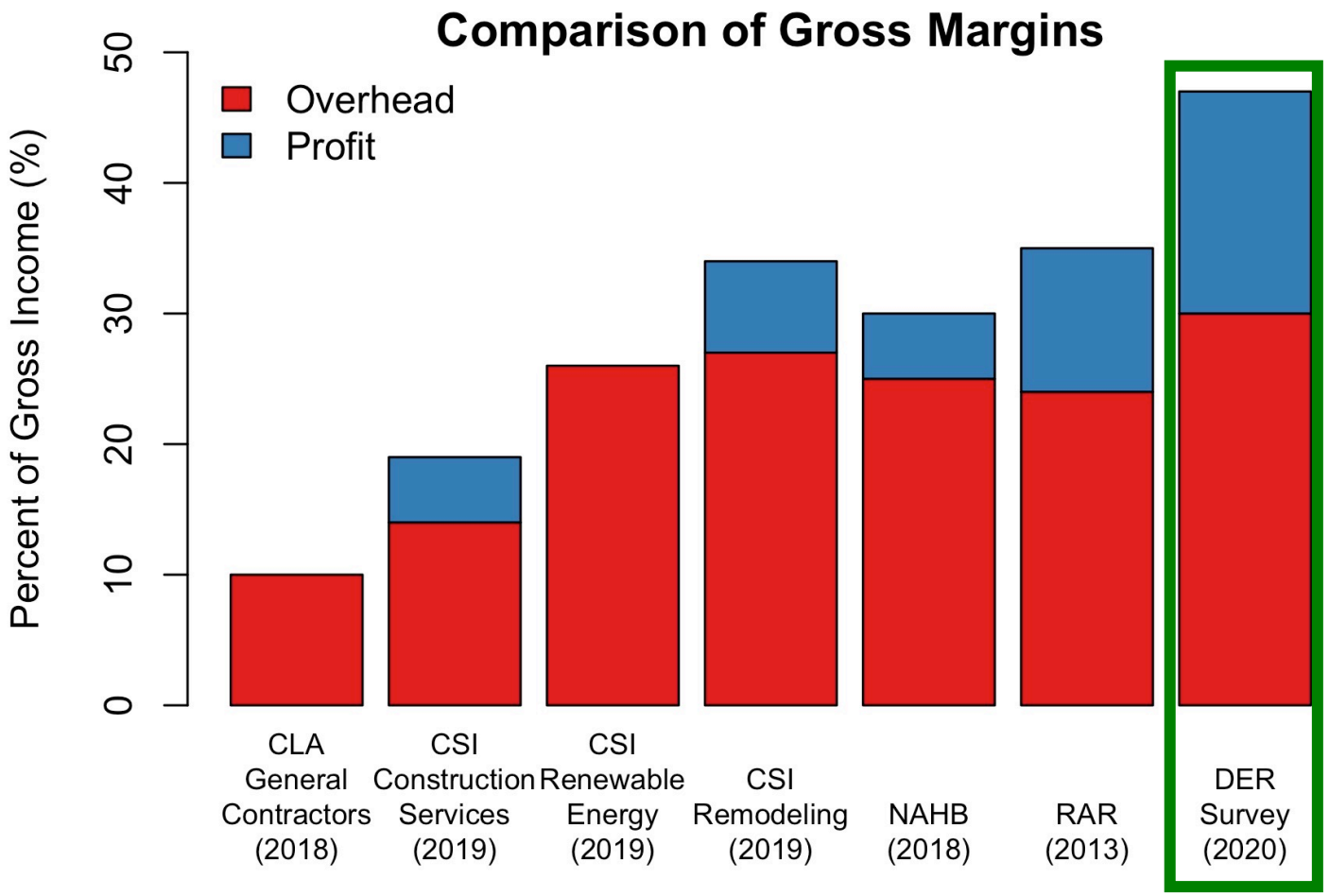
Lumin[xl]
Smart Panel

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)

Cost Compression – Soft Costs



Need to reduce soft costs:

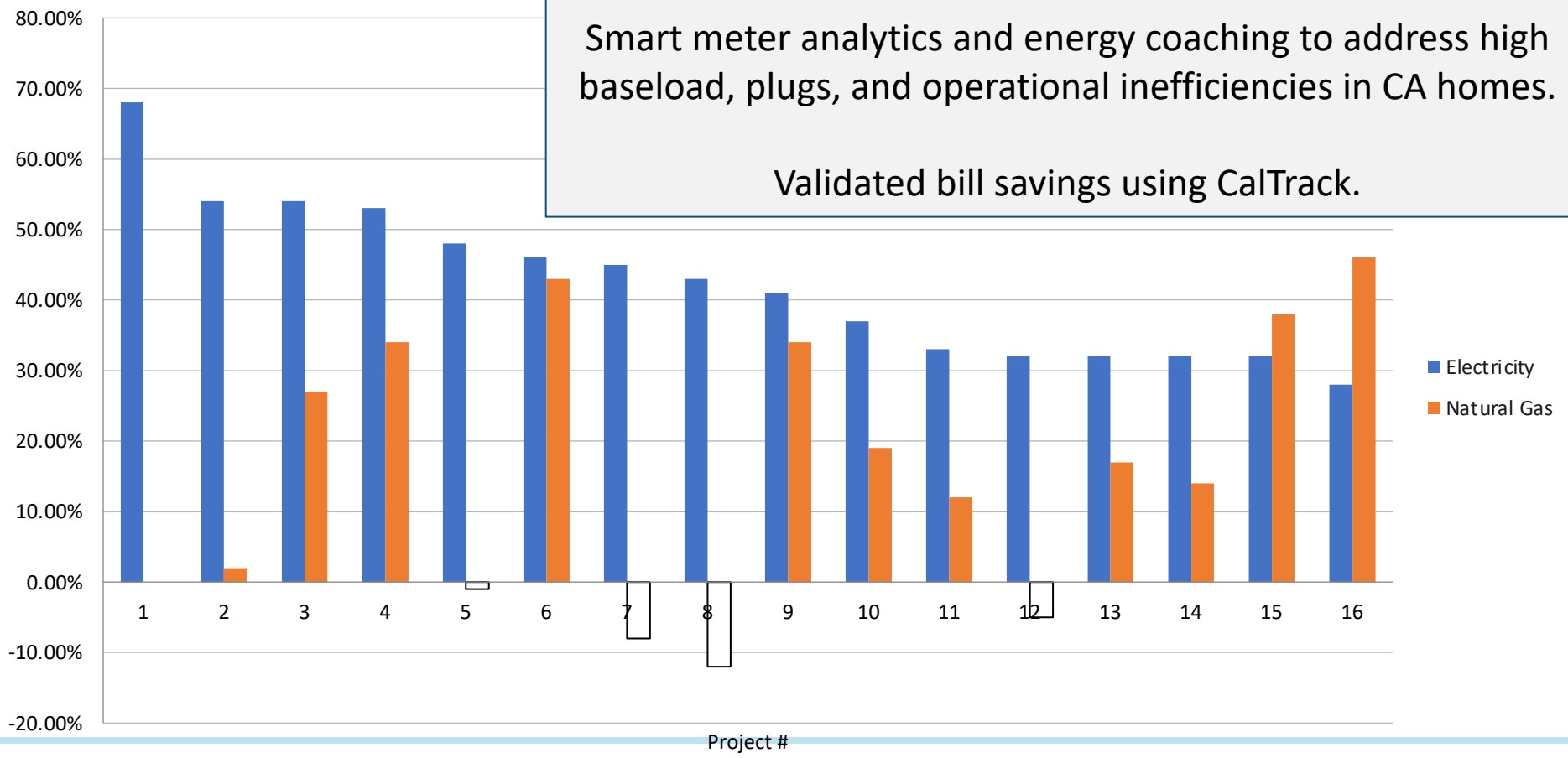
- Customer acquisition
- Testing
- Program participation
- Load calculations

Cost Compression – Analytics and Behavior

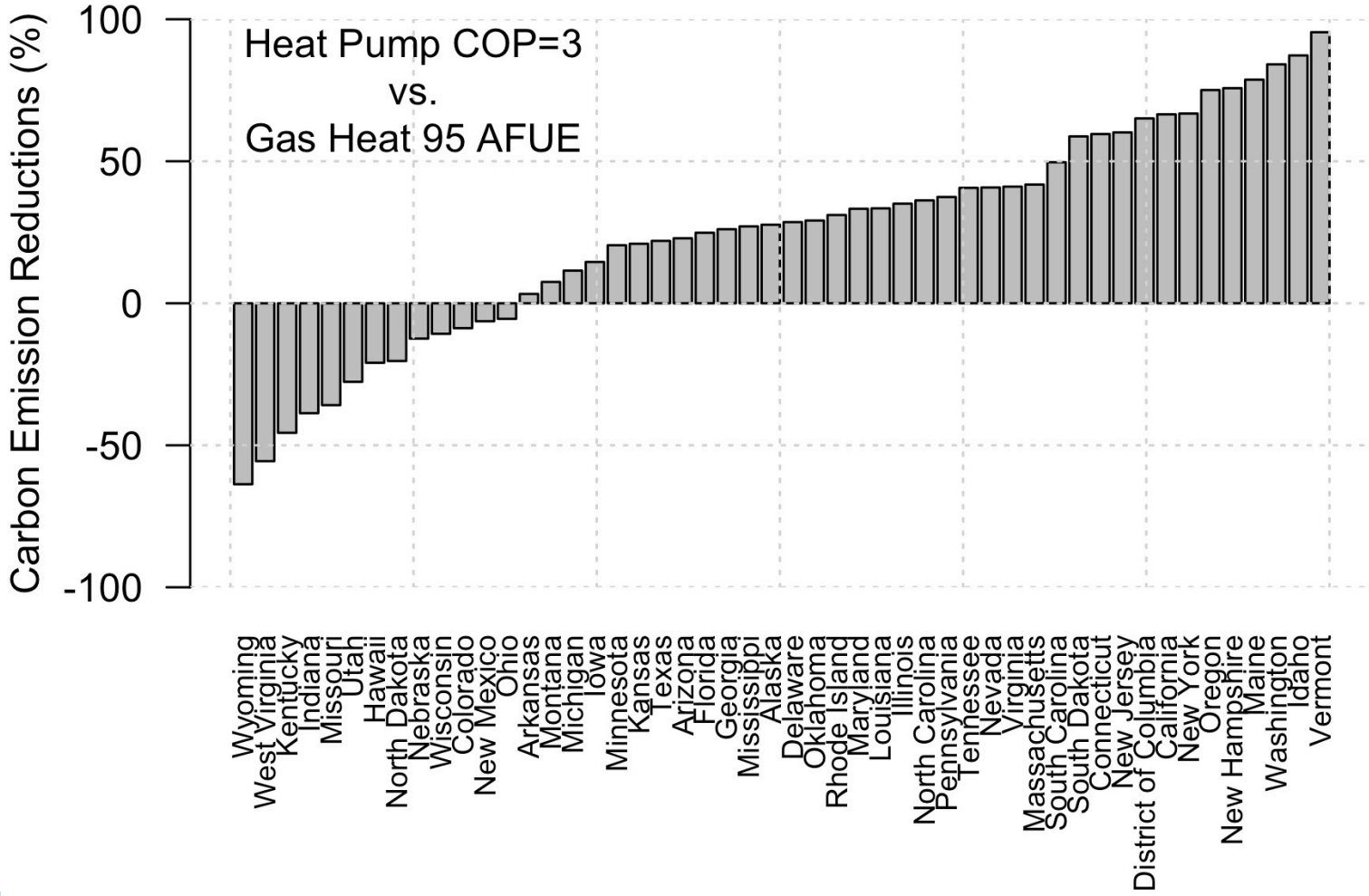
<u>Don't ignore the "small" stuff</u>

Smart meter analytics and energy coaching to address high baseload, plugs, and operational inefficiencies in CA homes.

Validated bill savings using CalTrack.



COST COMPRESSION – NEW METRICS



Future Work

- Cost Compression
  - Technology, Soft Costs, Behavior, New Metrics
- Cost-optimized pathways to deep carbon reductions
- Develop useable and appropriate metrics for home upgrades
- Standardized packages of upgrades meeting new metrics
- Electrification for low-income households
- Over-come market fears about heat pump performance and higher energy costs
- Document health and IAQ outcomes of electrification

Thank You…!

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