NHPC'23 SEATTLE

CONFERENCE PARTNERS:

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THE COSTS OF DECARBONIZING EXISTING MULTIFAMILY BUILDINGS

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LEARNING OBJECTIVES

At the conclusion of this session, participants:

- Identify scalable and affordable solutions that we can implement to achieve decarbonization in existing multifamily buildings.
- Outline what approaches we can use to reduce the costs of energy retrofits of multifamily buildings.
- Understand how the actual economic and technological strategies are necessary for the decarbonization process of the existing building stock in the US.

Introduction

Today's Presentation → Need better Information on Decarbonization Costs

- **Inform Policy**
  - Where to focus programs
  - Support decision-making
- **Inform R&D**
  - New database on MF
  - Identify key cost barriers
- **Inform Industry**
  - New products
  - New business opportunities and models
  - Challenges with the adoption of decarbonization technologies

Introduction

To Be Considered Next → Need Better Information on Decarbonization Issues Specific to MF Buildings

- **Solar PV**
  - Community Solar?
  - Billing policy?
- **EV Charging**
  - How to give equal access
  - How to bill
- **Benefit Occupants or Owners?**
  - Transportable solutions?
  - Bill switching from common gas to unit-based electricity
  - Who saves?
  - Identifying opportunities for collaboration and education.
- **Common Equipment**
  - How to replace central boilers
  - How to replace central HVAC
- **Energy Equity**
  - Do rents go up?
  - Do bills go up?
  - Decarbonization while occupied?
- **Building Codes**
  - More work is needed address decarbonization and electrification goals

NON-ENERGY BENEFITS

Healthier Homes

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
  - 1000's of lives and Billions of dollars

- **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:** $PM_{2.5}$ & NO_2
  - Environmental Justice Issue – often worse in disadvantaged communities

Safer Homes

Key safety issues are:

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

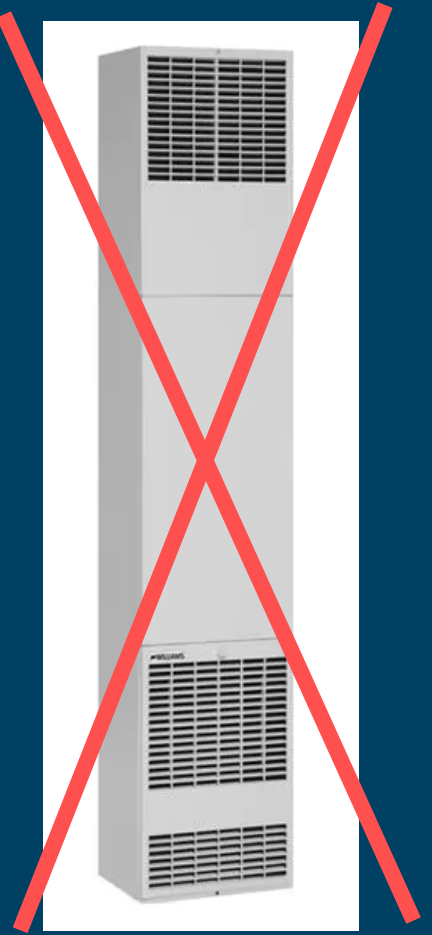
Removing Poor Appliances

- **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



CHALLENGES OF DECARBONIZING EXISTING MULTIFAMILY BUILDINGS

Common Barriers with Single Family Homes

Today's biggest barriers for decarbonizing homes

- **Cost and affordability**
- **Lack of workforce**
  - All contractors are busy
  - Anecdotally: 6-12 months lead time
- **Lack of equipment**
  - Supply chain issues (COVID, Economic crisis, etc.)
  - Poor US Manufacturing base
- **Lack of easily available financing**
- **Minimize grid impacts**
- **Current practice**
  - Like-for like equipment replacement
- **Existing buildings**
  - Emit all the carbon and are hardest to fix.
- **Lack of real estate market valuation**

Equity and Decision Making

TOTAL US Homes = 123.5 millions*

Housing Units

- **68% Single Family**
  26% Multifamily
  6% Mobile homes

Ownership

- **SF = 88% units owned**
  SF = 28% units rented

  MF = 5% units owned
- **MF = 69% units rented**

Low-Income

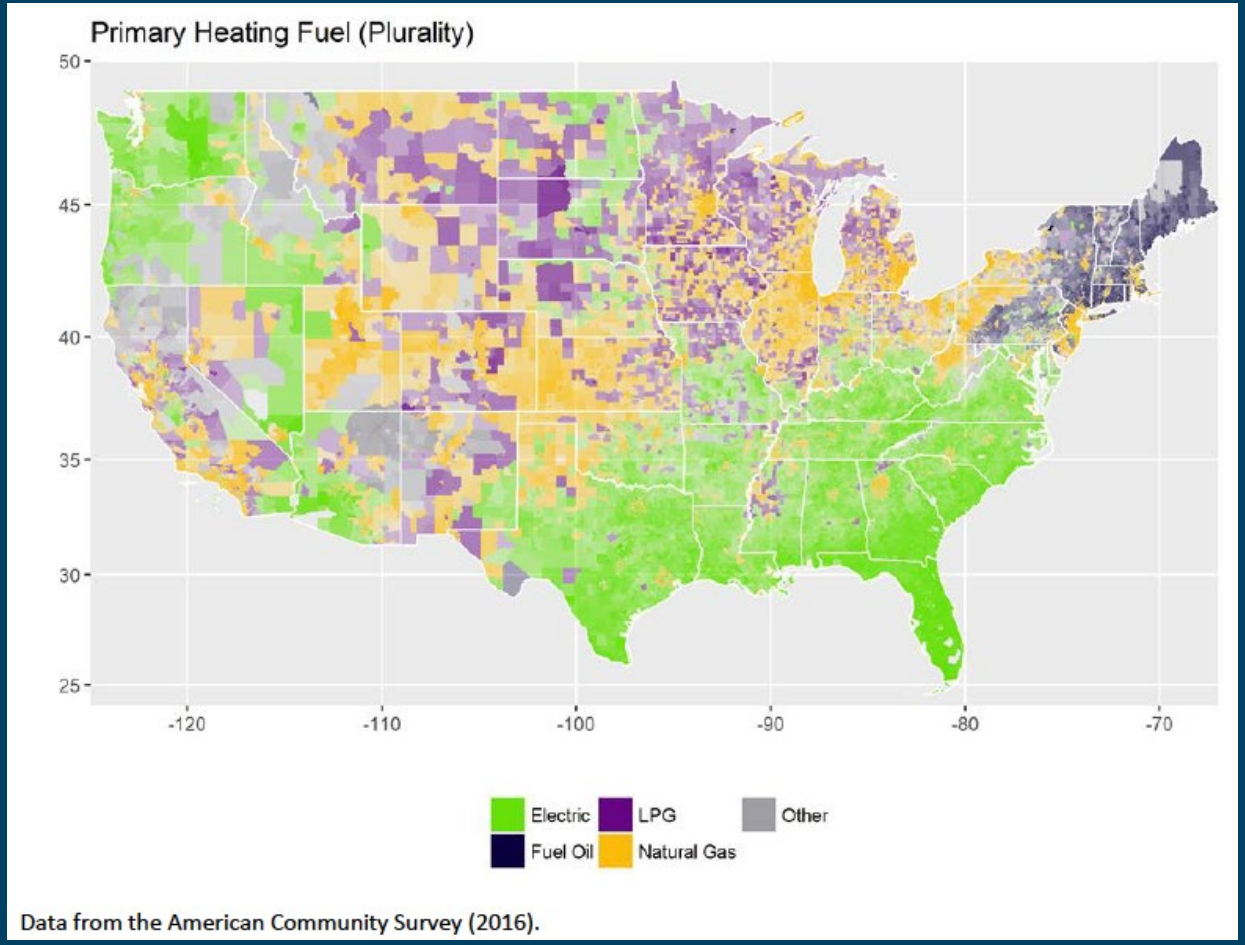
- 9% Single Family
- 27% Multifamily

Who pays ?
Who benefits ?
(Transportable solutions)

- **Market rate vs Affordable Housing**
- **Access to capital**
  - **Large high-rise buildings vs duplex**

*eia data from 2020/2021

Decarbonization = Electrification = Regional Issue



Data from the American Community Survey (2016).

- >25% of homes are already all-electric
- 75% of homes have central AC

Electric Heating
- 51% of MF units
- 27% of SF units

Electric DHW
- 55% of MF units
- 41% of SF units

Electric Cookers
- 67% of MF units
- 56% of SF units

*Residential Energy Consumption Survey (EIA) 2020

DEVELOPING A COST DATABASE FOR DECARBONIZING EXISTING MULTIFAMILY BUILDINGS

Preliminary data from ongoing study

► Data to share ??? – Let us know !!!

Decarbonization Costs

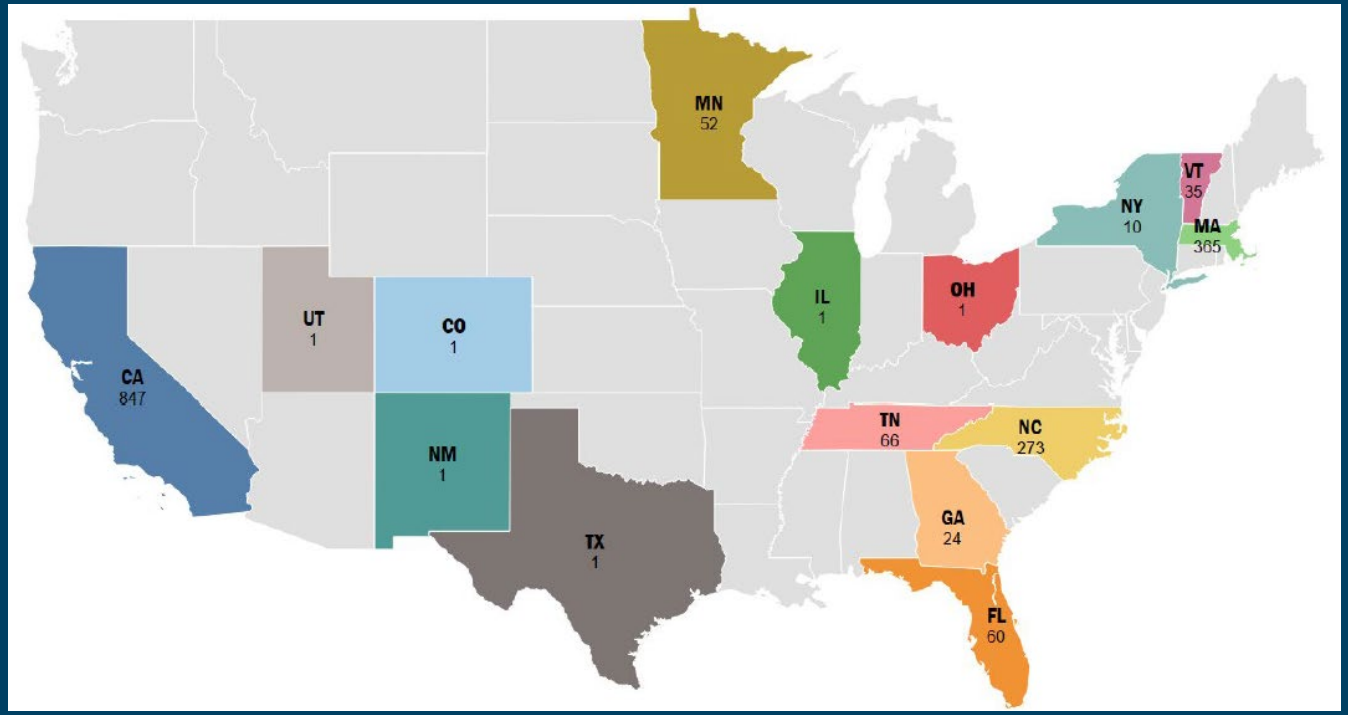
DOE/LBNL Effort to Create a Database of

- Costs - broken down by measure
- Energy (and calculated CO_2) savings, both real and modeled/predicted
- All costs in $2019 and adjusted for location and inflations

Sample of Convenience

- Data not systematically recorded (e.g., separating labor materials and soft costs)
- No standard format
- Looking for buildings with significant energy reduction

Single Family Cost Database



Sample of Convenience:

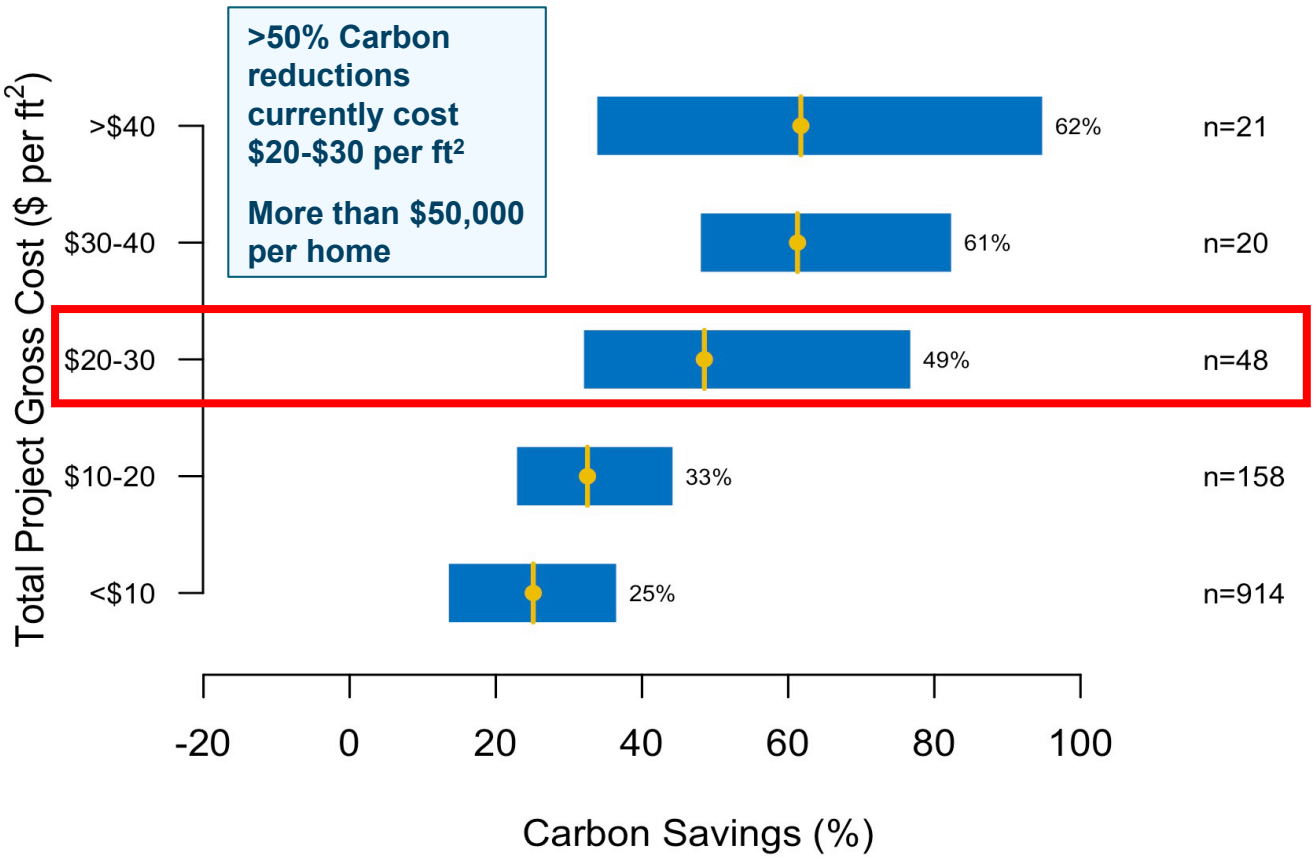
- Most data voluntarily provided by energy programs
- Paid contributions for 475 homes

Data Included:

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

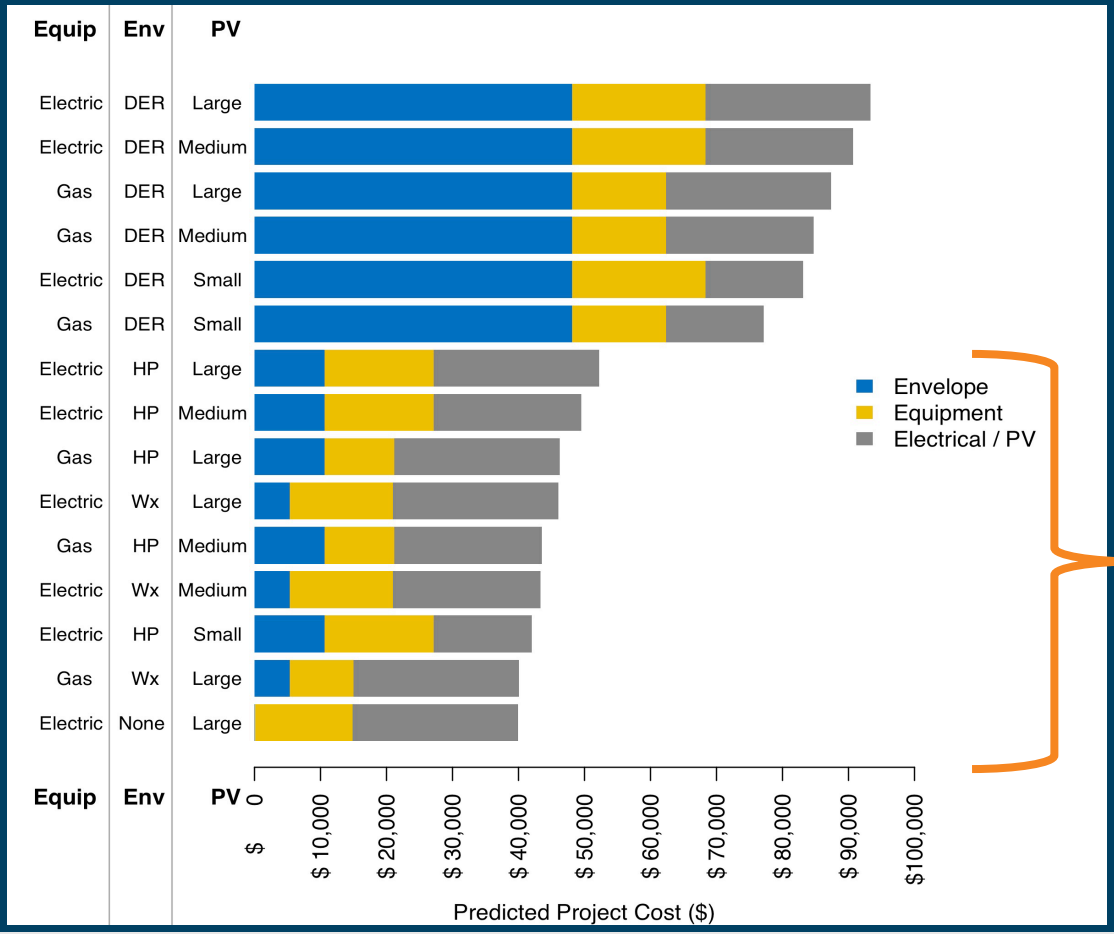
12 Programs **1,739 Projects** **10,512 Measures** **3,294,946 ft²** **$24,689,213**

Single Family Cost Database - 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.

Single Family Cost Compression Package Optimization



Lowest cost options are still **$40,000/home - $23/ft²**

Beyond 60-70% savings requires all-electric homes

- Electrification
- Moderate Envelope upgrades
- PV

Gives good carbon savings at least cost

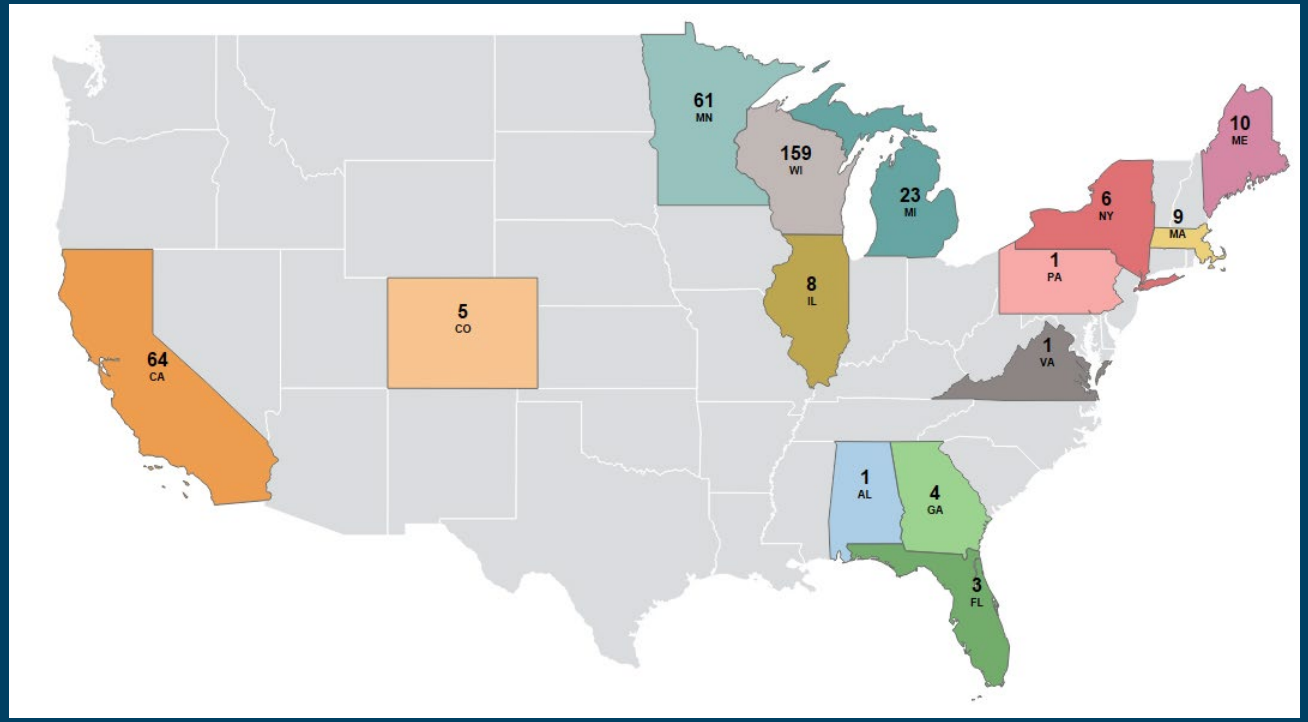
Added Complexity for Multifamily

Single-family vs Multifamily

- **Housing type:** Affordable; Market rate
- **Building typology:** Attached; semi-attached; isolated
- **Rise:** Low-; Mid-; High-Rise
- **Unit ownership:** Renter; owner
- **Historical building:** Yes; No
- **Elevator:** Yes; No
- **Original use of the building**
- **Unit type:** SRO; 1B; 2B; 3B; etc.
- **Heating, cooling and DHW configuration:** Units; Central
- **Occupied during retrofit:** Yes; No
- **Retrofit type:** Retrofit; Gut Rehabilitation
- **Non-residential space:** Lobby; Laundry; Corridors

Metric ► $/unit

Database Summary – Multifamily Buildings



355 Projects (326 Detailed / 12 Non-Detailed / 17 Audits)
2475 Measures 5,200,150 ft² $364,612,566

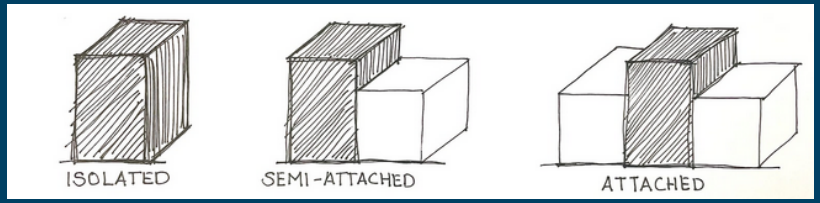
Home Vintage	Pre 1900	4
	1900-1960	27
	1960-1980	18
	1980-2000	23
	2000-2020	27
Project Year	2017	30
	2018	45
	2019	50
	2020	47
	2021	54
	2022	8
	2023	6
Project Duration	< 5 month	5
	<10 months	8
	<15 months	11
	<20 months	5
	<30 months	2
	<35 months	2
Retrofit Type	HVAC Focused	93
	DHW	60
	Lighting	40
	Attic Insulation	37
	Wall Insulation	32

All projects - Electrification Focused

Data Base - Basic Information

Community	**Urban**	**94%**
	Suburban	6%

Building Typology	Attached	25%
	Semi attached	7%
	Isolated	**67%**



Original Use	**Residential**	**85%**
	Mix Use	6%
	Industrial	2%
	Other	6%

Stories Above Grade	**Low Rise**	**66%**
	Mid Rise	25%
	High Rise	8%

- **low-rise: 1-4 Floors**
- **mid-rise: 5-8 Floors**
- **high-rise: >8 Floors**

Historical Building	**Historical**	**9%**
	Non Historical	91%

Data Base - Basic Information

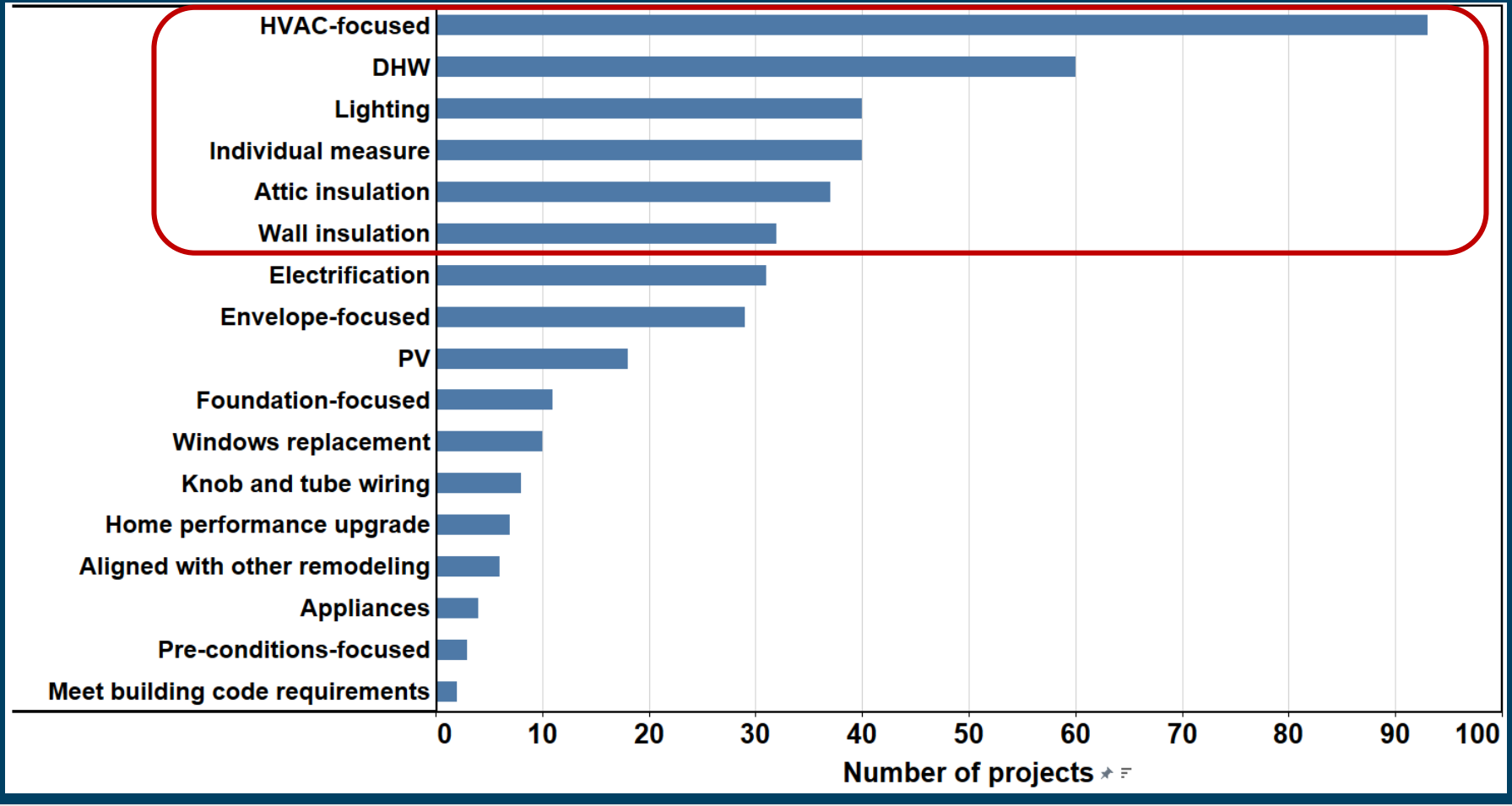
Unit Ownership	Community property	4%
	Housing Authority	2%
	Non-profit	7%
	Property Management	1%
	Rental	**86%**

Housing Type	**Affordable Housing**	**92%**
	Luxury	**1%**
	Market Rate	7%
	Other	1%

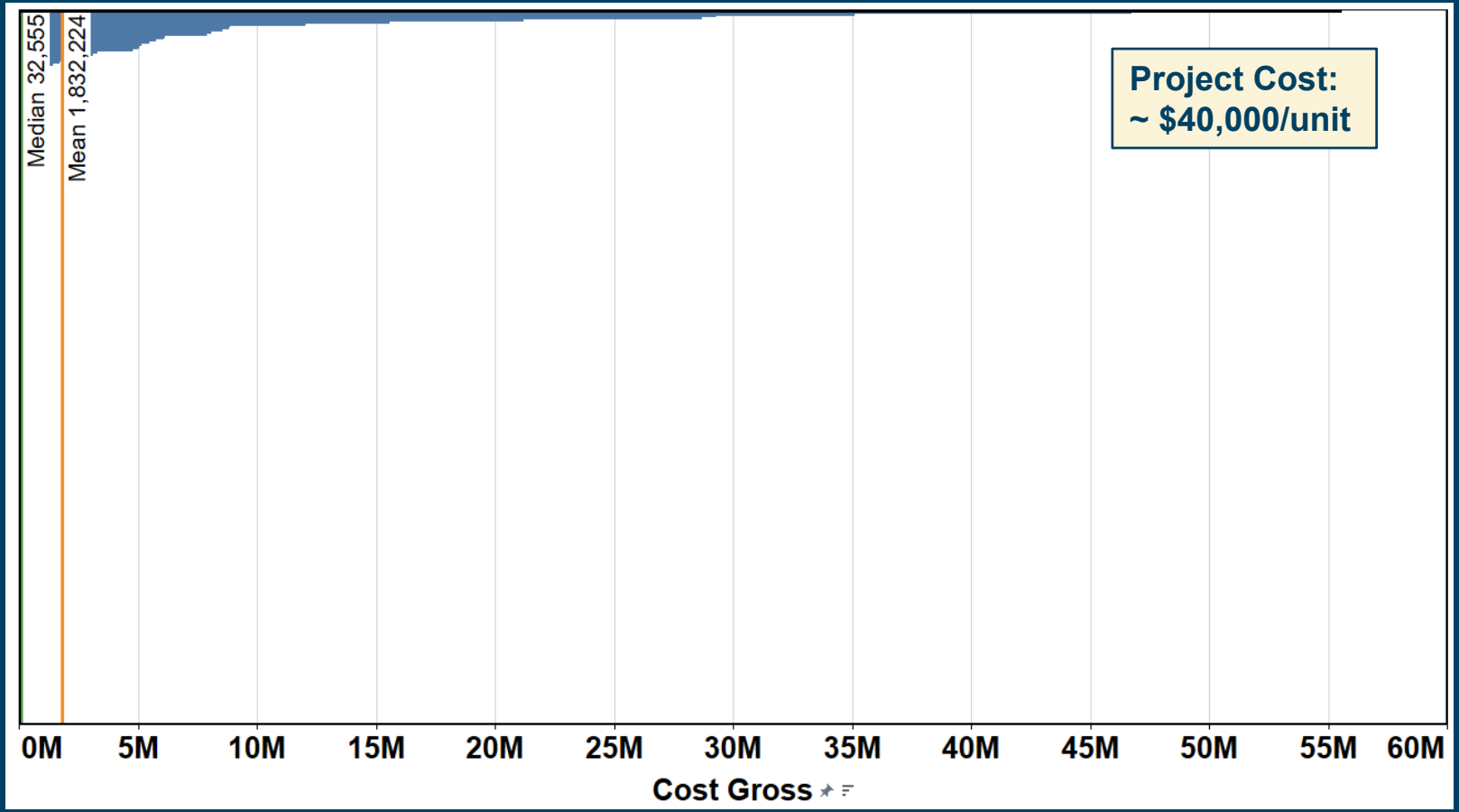
Project Status	Audit	6%
	Complete	**75%**
	Construction	**12%**
	Design	7%

Retrofit Type	Gut rehabilitation	6%
	Renovation	2%
	Retrofit	**92%**

Data Base - Retrofit Focus



Distribution of Gross Project Costs

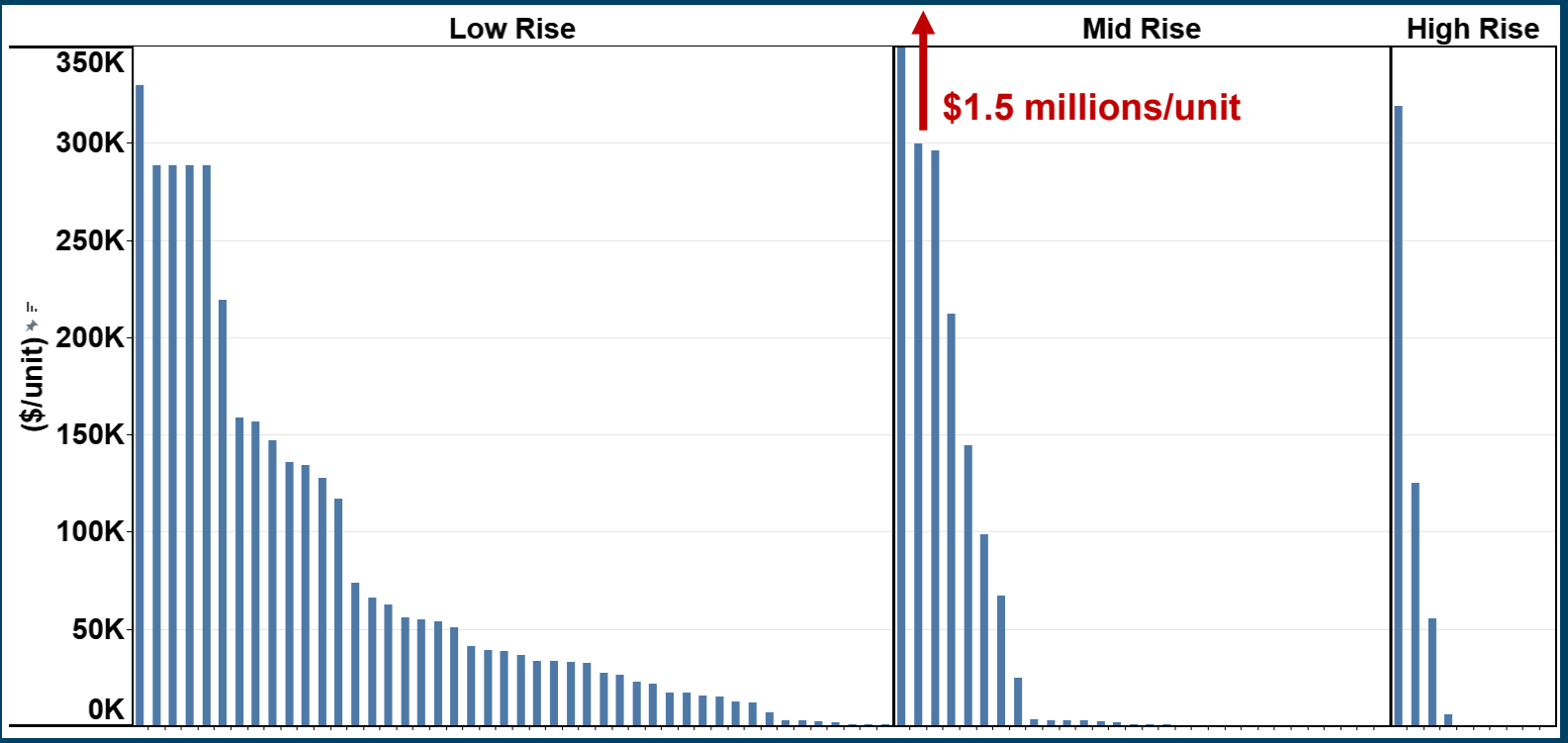


► 2,476 retrofit measures
► Cost doesn't include incentives

NYSERDA Report:
Construction cost is $40,000/unit.

Construction period, which includes interior upgrades, was expected to be **14 months** for **21 units**.

Project Costs by Unit and Building Type



Low Rise
- **Mean $ 47,456 /unit**
- Median $ 9,834/unit

Mid Rise
- **Mean $ 40,288 /unit**
- Median $ 862/unit

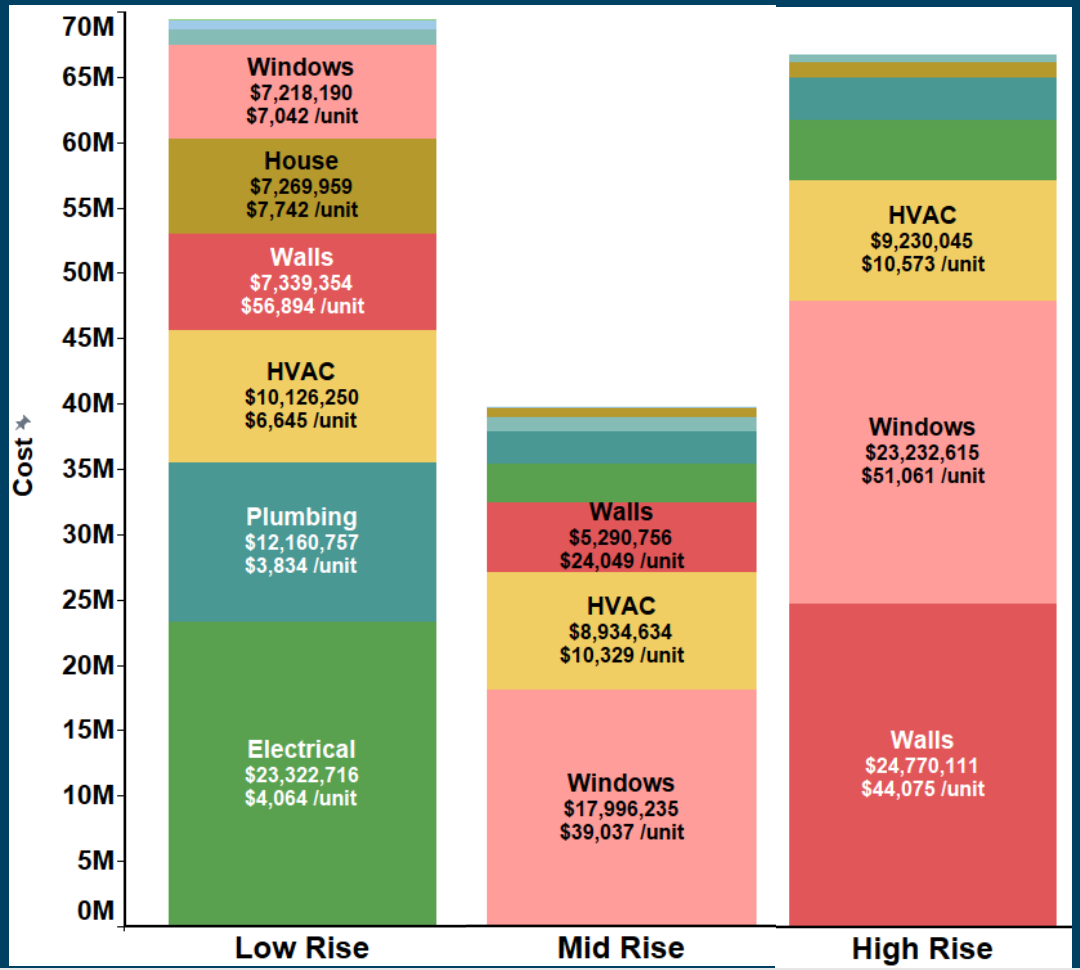
High Rise
- **Mean $ 50,730 /unit**
- Median $ 503/unit

Low Rise
Total units: 6,512

Mid Rise
Total units: 2,678

High Rise
Total units: 1,831

Measure Overview Multifamily



- **Windows work** → Replacement all the windows of the building
- **Walls** → Insulation of the exterior walls
- **Electrical work** → Lighting; Panel upgrades; Wiring; PV; Alarms
- **HVAC work** → Heat Pump; Furnace; Boiler; Heating
- **Plumbing work** → DWH

- High Rise
  - More surface area for the building envelope vs Mid- or Low-Rise.
  - More WWR compared to Mid- or Low-Rise.
- Low Rise
  - More central systems

DO YOU HAVE DATA TO SHARE ?

► LET US KNOW !!!

CASE STUDIES AND EXAMPLES

Successful decarbonization projects

EDEN HOUSING

Switching from natural gas appliances to electric

- **Eden Housing** and the **East Palo Alto Community Alliance and Neighborhood Development Organization** (EPACANDO)
- Demolished 37 apartments, renovated 57 and is building 128 new apartments.
- Affordable housing
- Third remodeled and two-thirds brand new, nine of which will offer supportive services for people who experience homelessness.

*https://www.kneedeeptimes.org/flipping-the-switch-on-all-electric-housing/

Successful decarbonization projects

Switching from natural gas appliances to electric ones

- New induction stove
- Heat pump that offers air conditioning
- 2 Electric water heaters per apartment (resilience)

- Battle with electric equipment, increases in tenant utility costs and energy use, and complex funding structure.

- Manufacturers and contractors are still getting up to speed on the new technology and how to install it.

- *"We used to know how big a gas water heater should be to heat enough hot water for a 50-unit apartment building. How many kilowatt hours do we have to come up with to heat the same amount of water for the same amount of people? We've never done that before… We're kind of on the bleeding edge,"*
  - **Tom White**, Eden Housing's associate director

*https://www.kneedeeptimes.org/flipping-the-switch-on-all-electric-housing/

Case Studies and examples

*A Transition from Gas to All-Electric

- Air sealing and insulation
- Windows
- Heating and cooling
- Other appliances and water heating
- Electric (wiring, PV)

*https://www.builditgreen.org/blog/a-transition-from-gas-to-all-electric/

ELECTRIFICATION MEASURES

Description	Total Costs	Rebates	Estimated Reduction in Utilities
Electrification Wiring and Rough Patching	$15,290	–	–
Heat Pump Water Heater (3)	$9,084	–	$400
Stoves (3), Dryers (2)	$7,900	$1,200	$30
Service Upgrade	$12,289	–	–
Subtotal / Subtotal Per Unit	$44,562 / $14,854	$1,200 / $400	$430 / $143

BUILDING ENVELOPE

Description	Total Costs	Rebates	Estimated Reduction in Utilities	Estimated Added Rental Value	Avoided Costs
Knob and Tube Wiring	$24,058	–	–	$960	–
Insulation	$10,230	$3,000	$660	–	($5,000)
Windows	$59,757	–	$1,120	$2,000	($59,000)
Subtotal / Subtotal Per Unit	$94,045 / $31,348	$3,000 / $1,000	$1,780 / $593	$2,960 / $987	$64,000 / $21,333

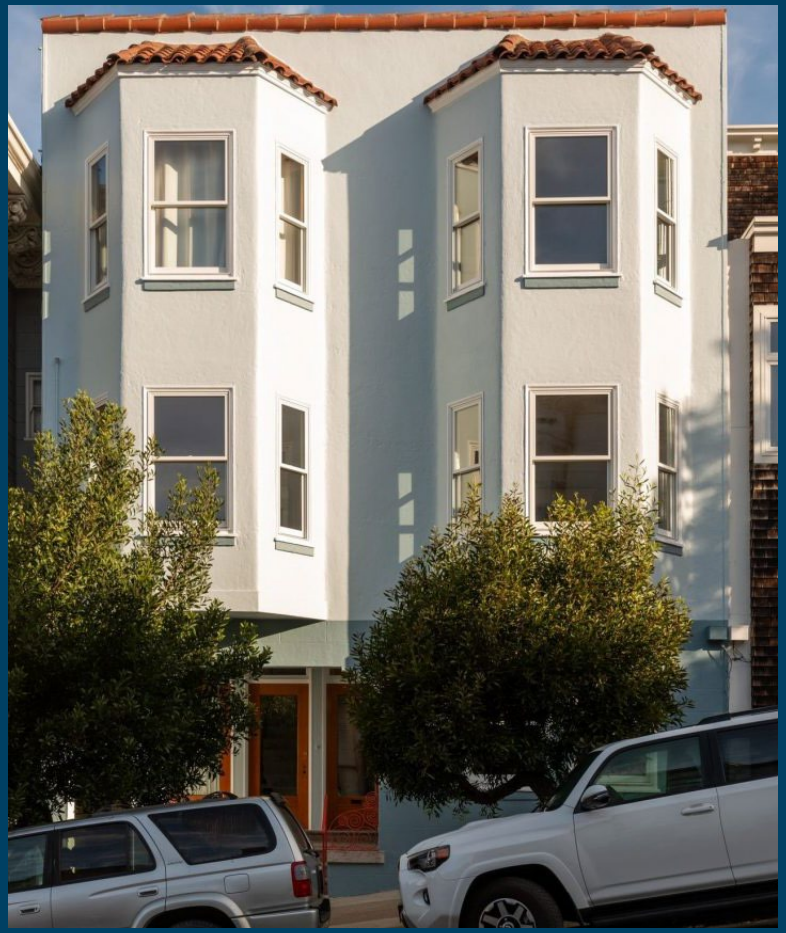
TOTALS*

Description	Total Costs	Rebates	Estimated Reduction in Utilities	Estimated Added Rental Value	Avoided Costs	Payback Period
Total	$138,607	$4,200	$2,210	$2,960	($64,000)	14 years
Total Per Unit	$46,202	$1,400	$737	$987	($21,333)	–

Case Studies and examples

*Lessons learned and best practices

- Transitioning the building from gas to all-electric has also yielded cost, safety, and health benefits, e.g., improved air quality and removed the risk of indoor fires and explosions
- Unit utility bills $40-$90 per month— $150-$200 per month in previous winters .
- **EUI = 9.75 kBtu per square foot**, passes the **Architecture 2030 Challenge** target for new construction even without using solar panels.
- That means lower energy costs in all seasons.



*https://www.builditgreen.org/blog/a-transition-from-gas-to-all-electric/

New Challenges

Transportation

► Current poor public charging infrastructure:
- Need to be able to charge at home
- Who pays for infrastructure? Only EV owners?
- How to share charging spaces and charging bills?

Resilience

► Electrical outages are much more frequent than natural gas outages
- Most outages are short (Typically <24h)
- After disasters, gas infrastructure remains offline for much longer than electrical.
- On-site storage and generation allows basic home operation during emergencies.

Peak Power

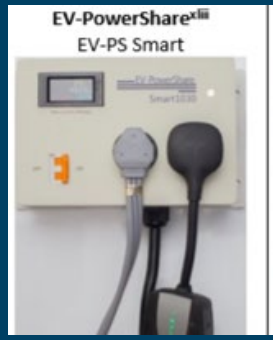
► We need ways for homes to respond to this and minimize cost impacts - On-site storage – batteries or thermal

INNOVATIONS

Cost Compression – Avoid Panel/Circuit Upgrades?

Innovative Technologies

EV-PowerShare[xliii]
EV-PS Smart



SimpleSwitch[xliv]
240V / EV Circuit Switch

Eaton[xxxix]
Energy Management
Circuit Breaker (EMCB)

BSA Electronics[xli]
Dryer Buddy

Neo Charge[xlii]
Smart Splitter

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 NEC: Watt Diet Calculator

New Products – Low Power, plug in, some transportable

Smart Circuit Pauser

Programmable Subpanels

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
		

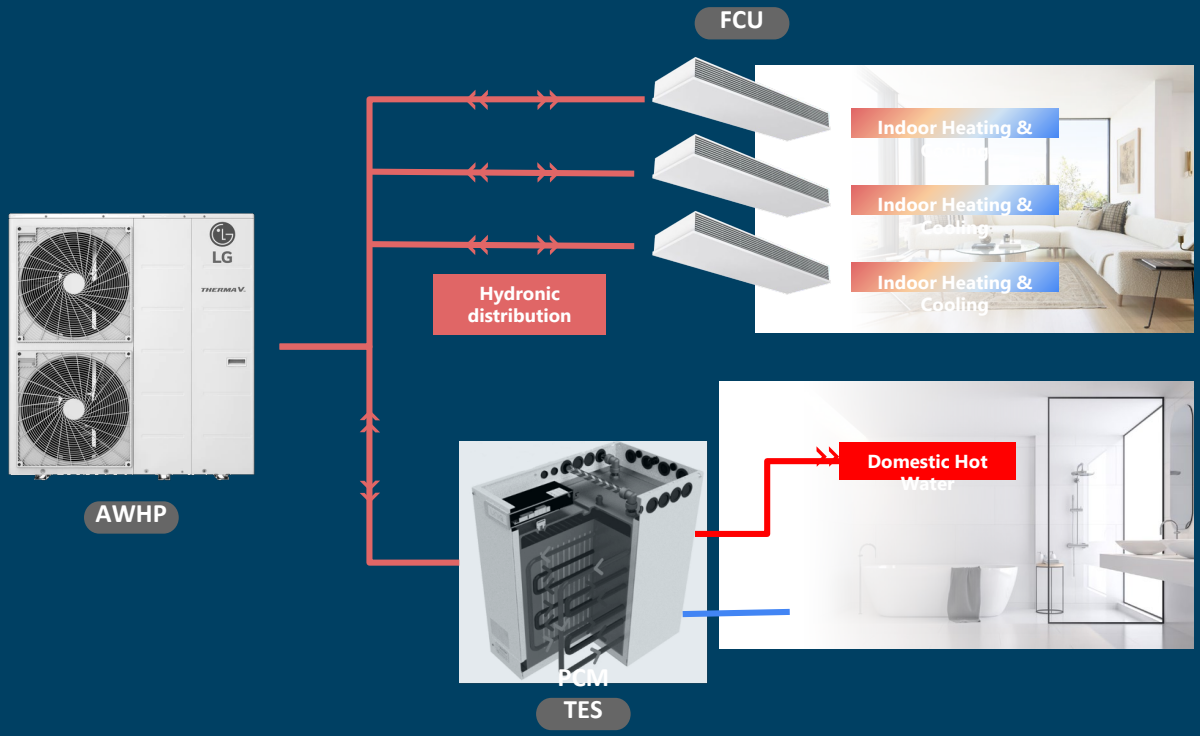
Smart Circuit Breakers

Battery Integrated Stoves

Meter Collars

Potential New Technologies: Combi HPWH

- Low power heat pump: no new electric circuits/panels/utility service drops – saves $1,000s.
- Heat pump using CO_2 that has very low GWP (= 1)
- Full capacity performance and high COP with heating design temperature of -15 to -5° F
- Provides ~190 deg F supply water for retrofit/compatibility with hydronic heat + DHW
- Thermal Energy Storage: increases capacity and shifts load



SUMMARY AND NEXT STEPS

Summary

- Mostly low-rise → Affordable housing occupied by renters
- Building envelope vs building systems

- Typical Measures (Low-Rise)
  - Lighting upgrade (LEDs indoors and outdoors)
  - HVAC (Install Heat Pumps)
  - Plumbing (Low-Flow fixtures)
  - Install windows

- Typical Measures (Mid-Rise)
  - Lighting upgrade (LEDs indoors and outdoors)
  - Plumbing (Low-Flow fixtures)
  - Plumbing (DHW)
  - HVAC (Ventilation)

- Typical Measures (High-Rise)
  - Lighting upgrade (LEDs indoors and outdoors)
  - Plumbing (Low-Flow fixtures)
  - Install windows
  - Roof insulation

Current Costs
(will change as we get more data)

Low Rise
~$47,456 /unit

Mid Rise
~$40,288 /unit

High Rise
~$50,730 /unit

Next Steps

- Finish the database data collection – target another 500+ projects
- Identify areas prime for cost reduction
- Identify lowest cost approach to large (>70%) CO2e reductions
  - Building envelope vs building systems
- Identify policy recommendations for IRA, local, state and utility programs (support decision-making)
- Affordable housing and market valuation

Next Steps - DOE EAS-E Prize will look for specific MF solutions for hard to electrify MF buildings

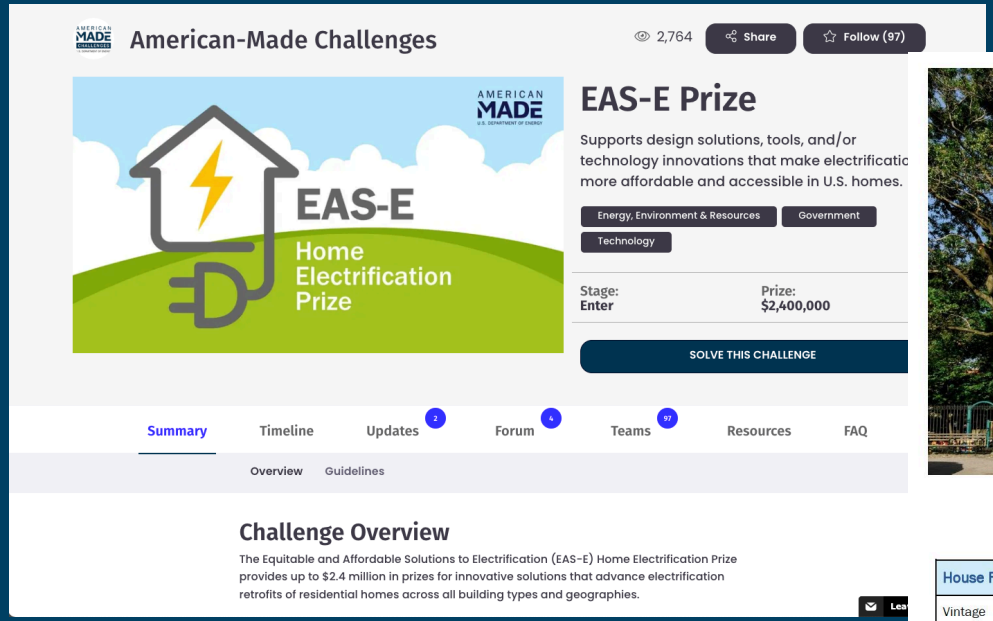


Figure 3. Exterior image of a low-rise multi-family building.

Table 3. Summary Features of a Low-Rise Multi-family Building

House Feature	Feature Description
Vintage	1950s
Floor area	750 ft² per unit, six units (two per floor) plus common areas
Stories	Three
IECC Climate Zone	5A
Garage	None
Water heating	Shared natural gas boiler in unconditioned basement, 199 kBtu/hr
Space heating	Two shared natural gas boilers in unconditioned basement, 80 AFUE, 199 kBtu/hr
Space cooling	Window AC in each unit

► Gas central boiler for space heating
Gas cooking ranges in each unit
► Gas central boiler serving hot water to all units
Shared gas vented clothes driers (3).

Air leakage	15 air changes per hour at a 50-pascal pressure difference (ACH_{50})
Cooking	Four-burner propane range
Clothes dryer	120V propane vented clothes dryer
Electric panel	30A panel and service, no free circuit spaces, no arc- or ground-fault circuit interrupter (AFCI or GFCI) protection; indoor panel is wired as a subpanel, with main service feed, meter, and disconnect located on a power pole 20 ft from dwelling
House wiring	Romex three-conductor copper wiring
Foundation	Pier and beam foundation with vinyl skirting, underbelly floor insulation at R-19, detached, ripped, and hanging down in various locations
Above grade walls	R-13 fiberglass batts
Windows	Single-pane, aluminum framed
Attic	Low-clearance, maximum height of 24 in, R-19 fiberglass batts
Roof	Low-slope roof, 20 years old

THANK YOU

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QUESTIONS ?

U.S. DEPARTMENT OF ENERGY

BERKELEY LAB
Bringing Science Solutions to the World

LBNL Resources

► Casquero-Modrego, N., Chan, W. R., Less, B. D., & Walker, I. S. (2022, September). Getting to Scale for Decarbonizing Homes in the US: An Industry Survey. In IOP Conference Series: Earth and Environmental Science (Vol. 1085, No. 1, p. 012036). IOP Publishing.

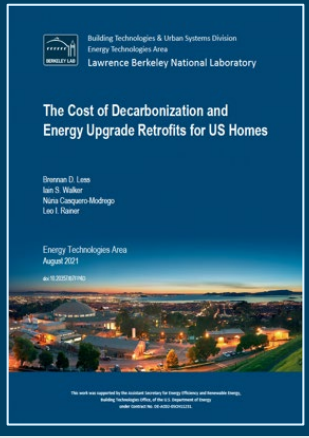
► Less, B. D., Casquero-Modrego, N., & Walker, I. S. (2022). Home Energy Upgrades as a Pathway to Home Decarbonization in the US: A Literature Review. Energies, 15(15), 5590. https://doi.org/10.3390/en15155590

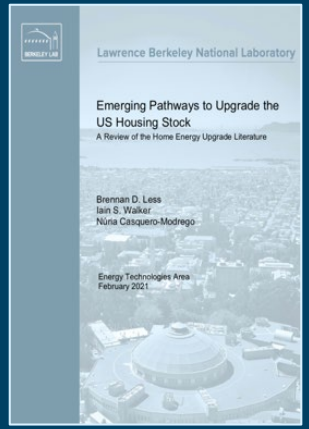
► Walker, I. S., Less, B. D., & Casquero-Modrego, N. (2022). Carbon and energy cost impacts of electrification of space heating with heat pumps in the US. Energy and Buildings, 259, 111910. https://doi.org/10.1016/j.enbuild.2022.111910

► 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





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