RESNET
RESIDENTIAL ENERGY SERVICES NETWORK
INTO THE FUTURE
Austin, TX 2.21-2.23
2022
VIRTUAL 3.10-3.11

Home Decarbonization

Iain Walker and Brennan Less | Lawrence Berkeley National Laboratory

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 and desirable

Emerging Changes in Construction

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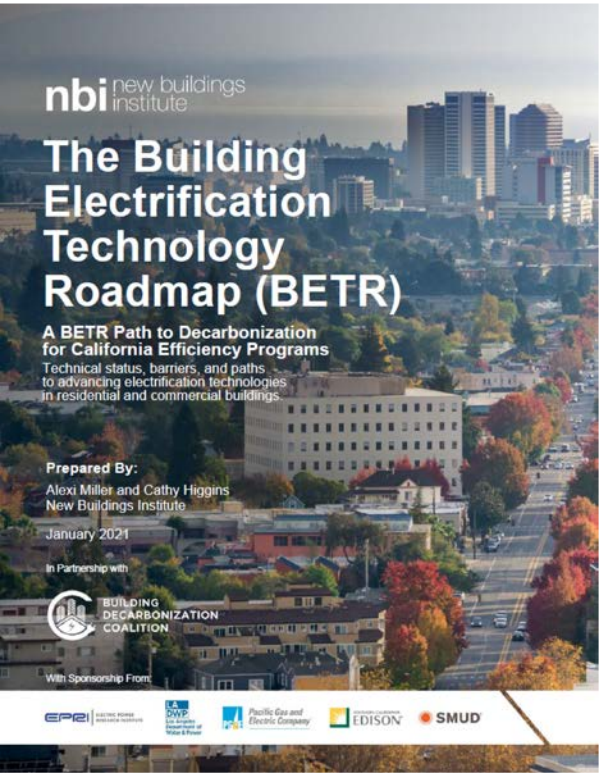

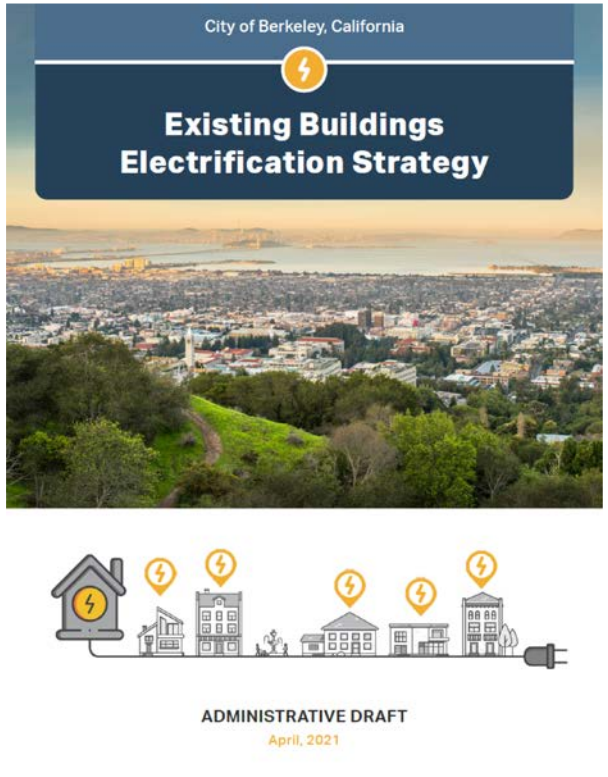

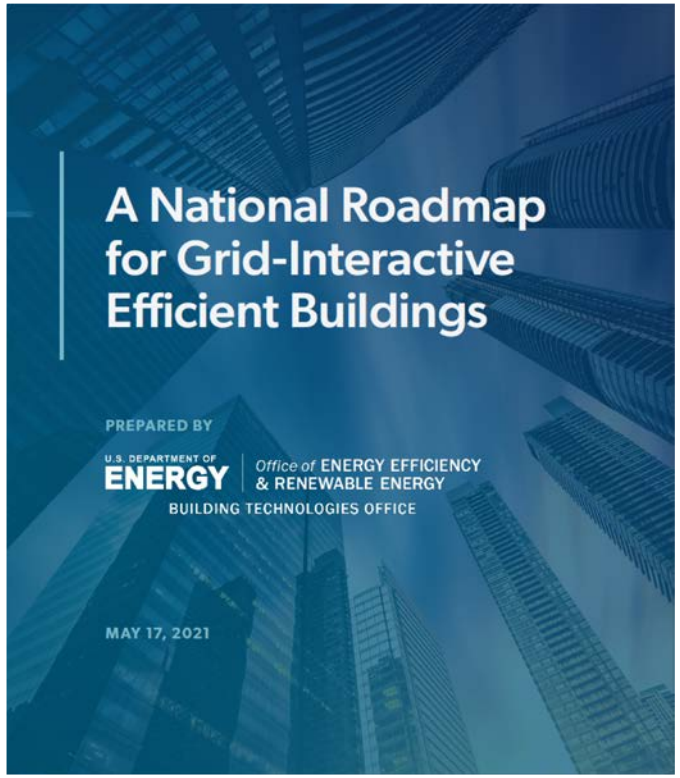

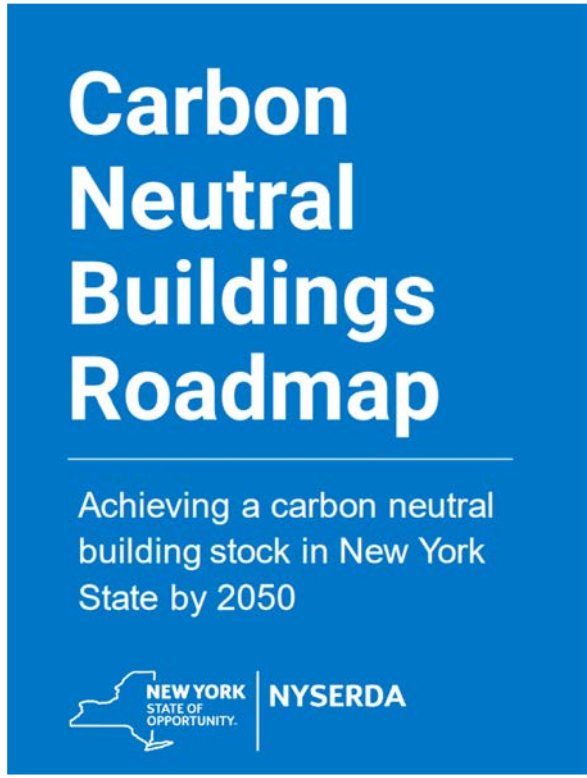

Think about it as the completion of the electrification program begun in the US 100 years ago

Emerging Changes in Construction

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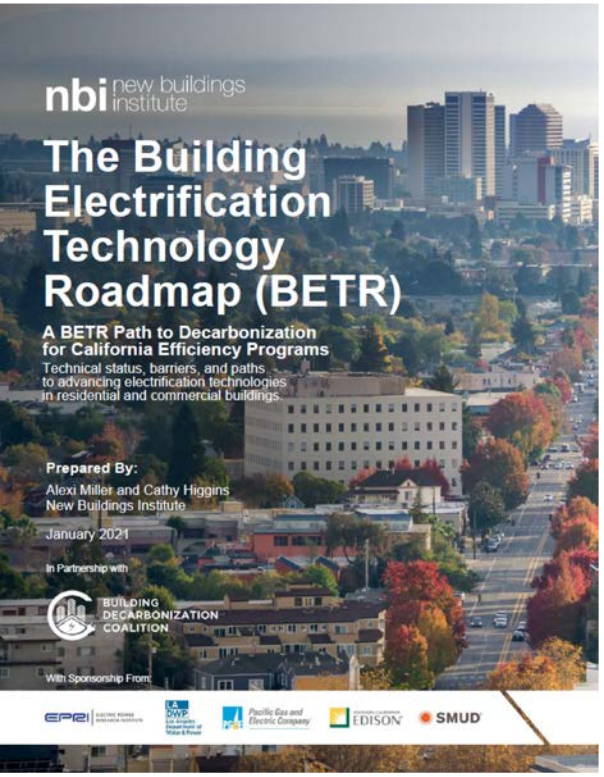
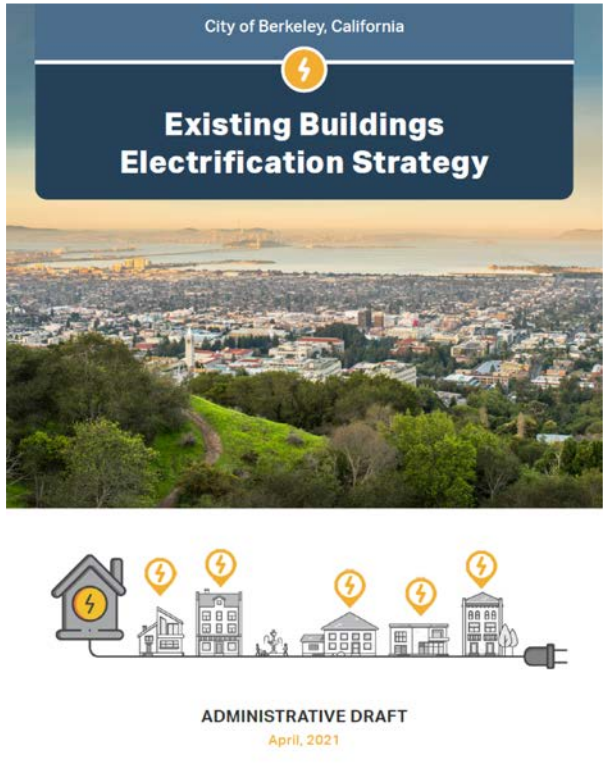
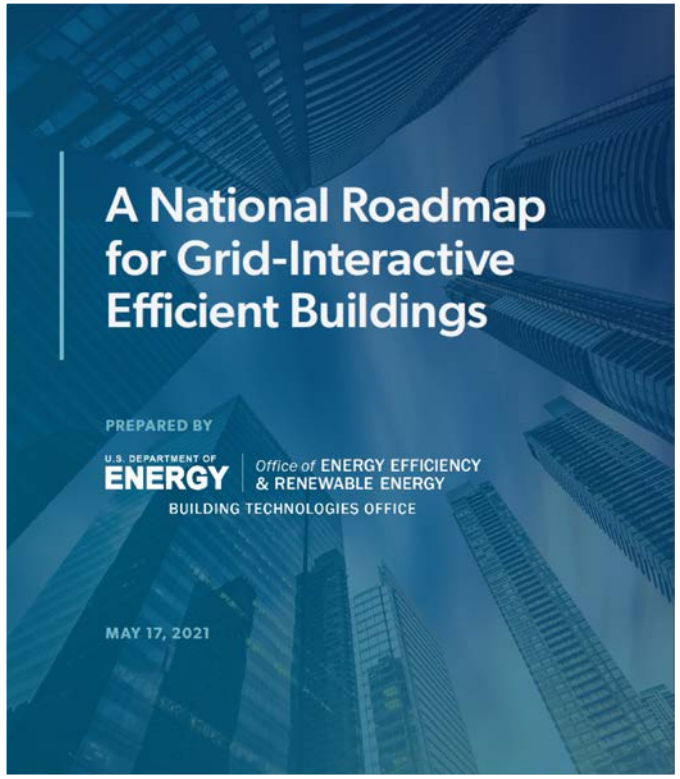
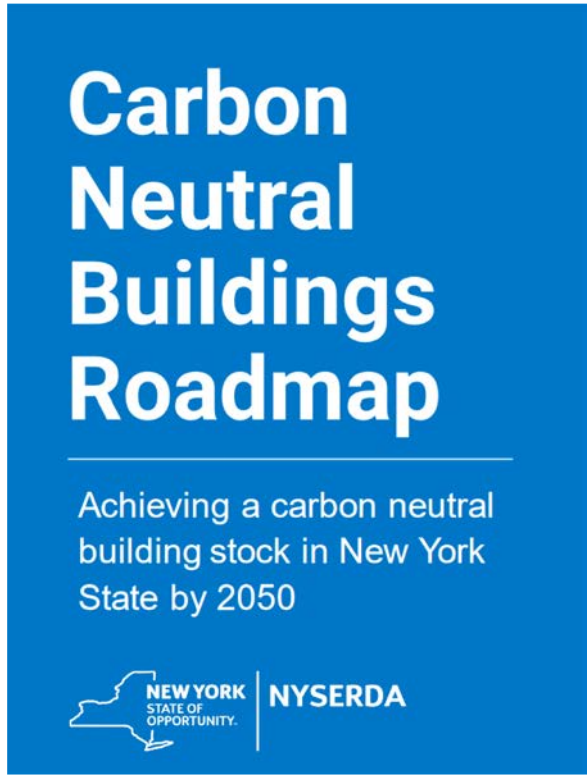








Needs to be easier and more affordable

Other RESNET Sessions

From the in-person meeting:

- Proposal for a New RESNET Standard for Embodied Carbon
- DOE Zero Energy Ready Homes – from a Raters perspective
- DOE Zero Energy Ready Home, Version 2 – a Cut Above and yet Within Reach
- Working Towards a Decarbonized Future with the CEE Integrated Home
- Affordable Housing with Low Carbon Emissions and Sequestration
- How the US Housing Market will achieve Net Zero Carbon Emissions
- Decarbonization Economy: What is it and How do We get There?

National Perspective

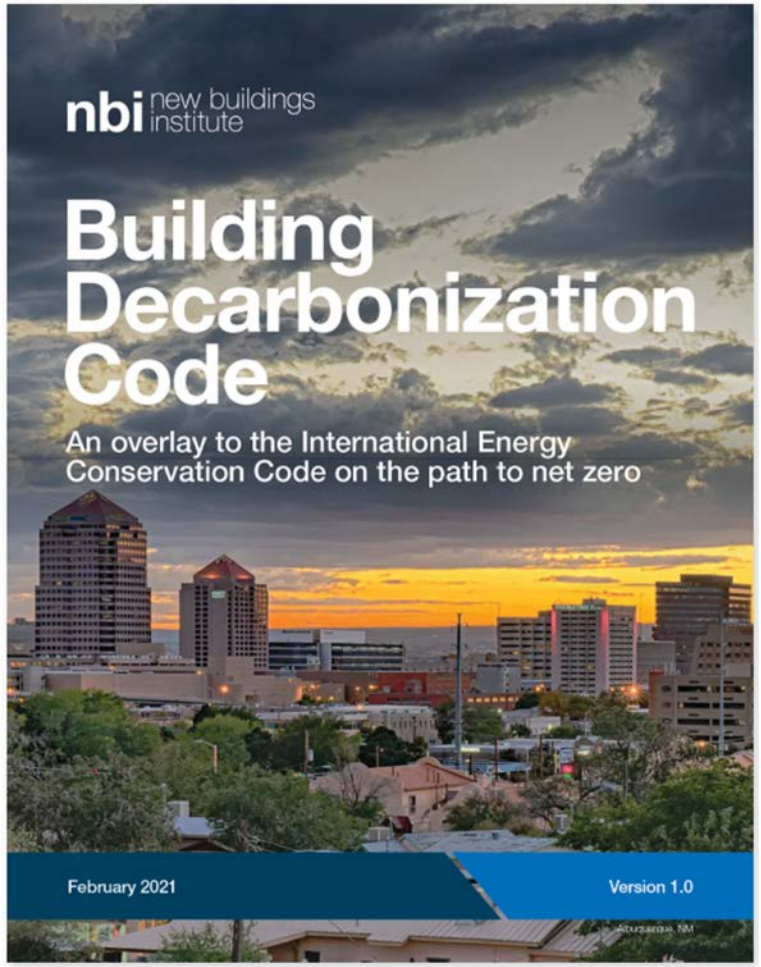
Decarbonization will be achieved by **electrification and grid decarbonization**

- All electric new homes
- Electrification of existing homes
- Use of renewables and nuclear power
- Use of energy storage

- ► How many homes are already all-electric and where are they?
- ► What are trends in new construction?
- ► Are building codes and standards changing?

Codes and Ratings

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



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

Codes and Ratings

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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**

$$\mathrm{CO_2\,index} = \frac{\mathrm{CO_2\,rated\ \ home}}{\mathrm{CO_2\,reference\ \ home}}$$

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

Current Electric Appliances in the US

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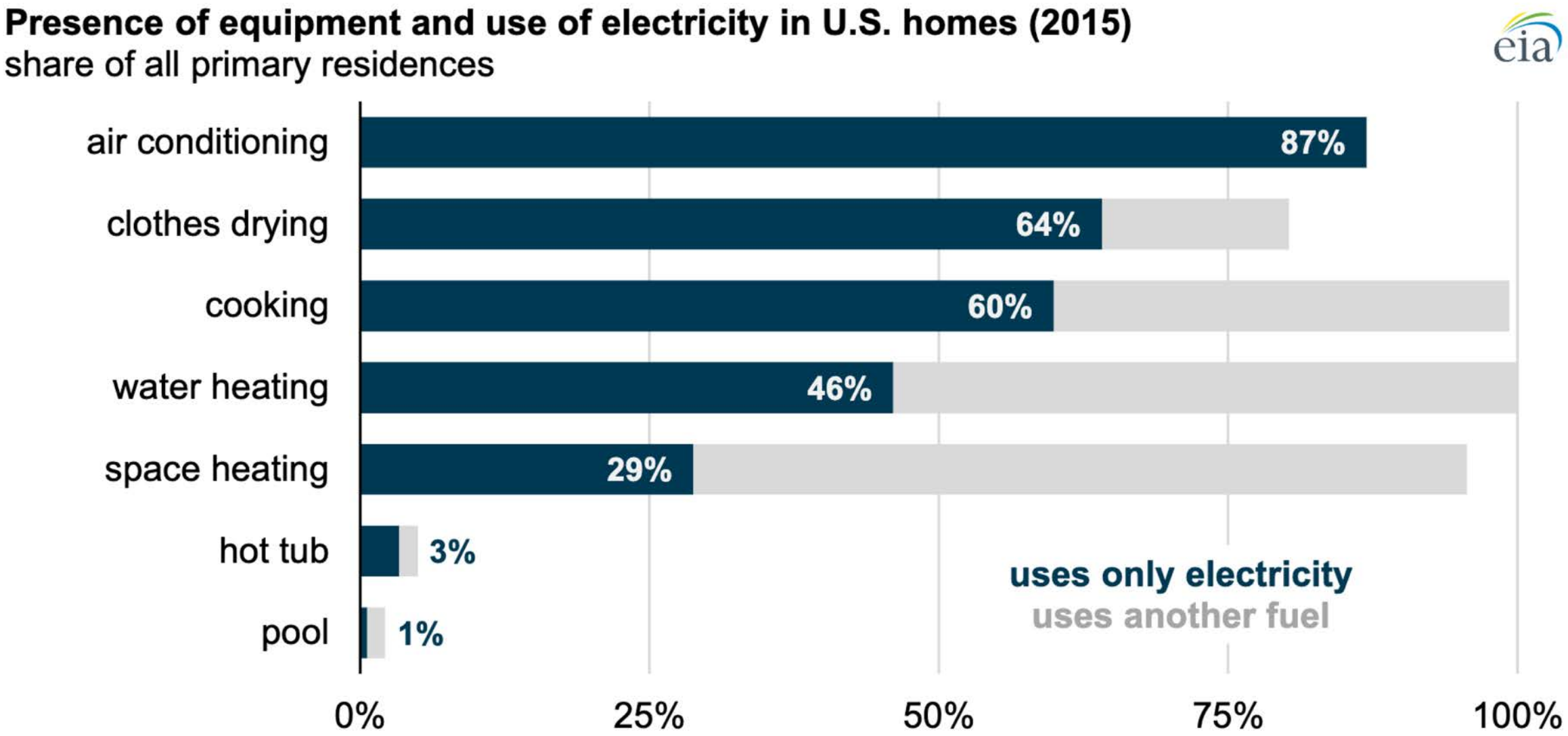
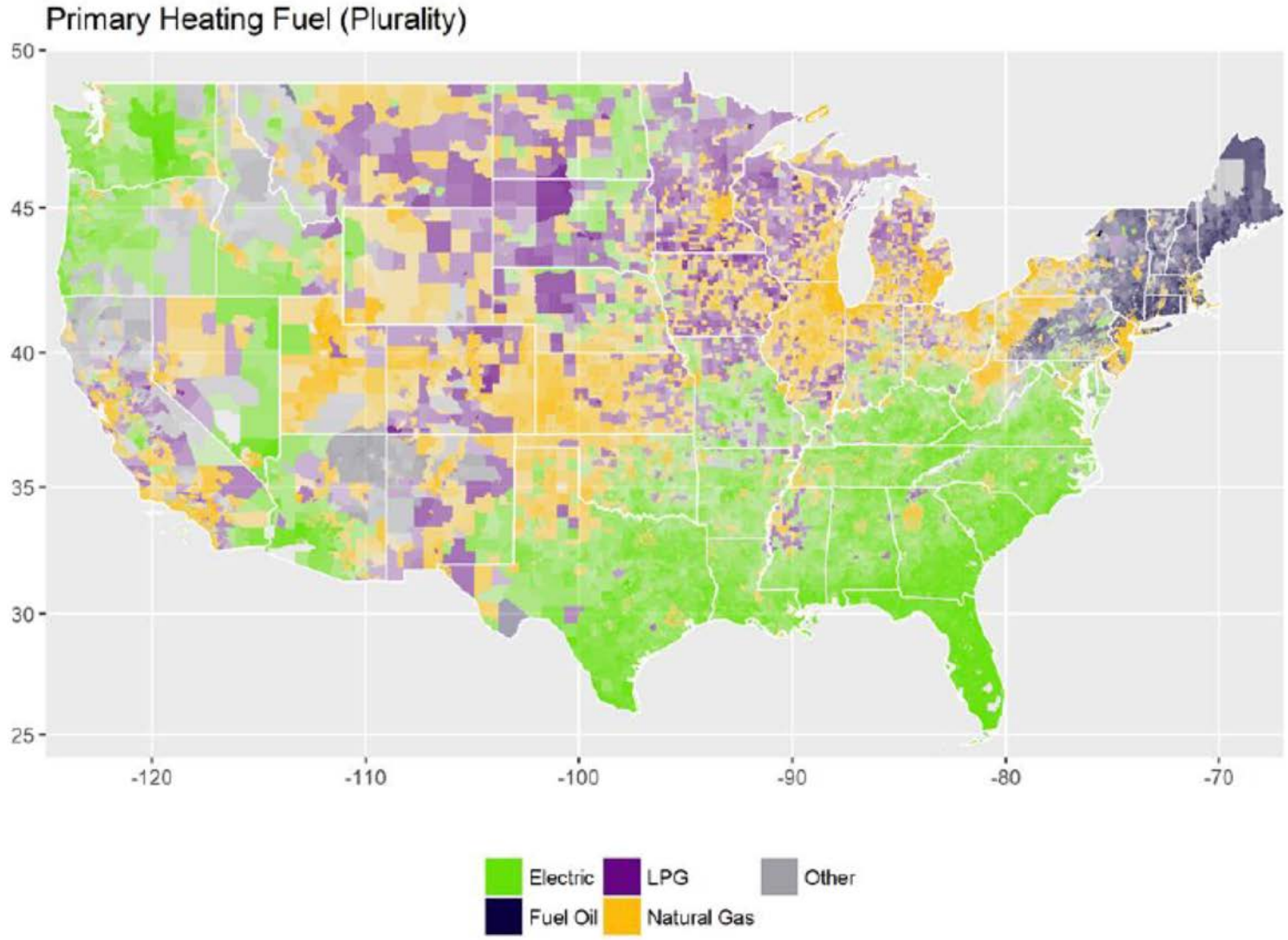


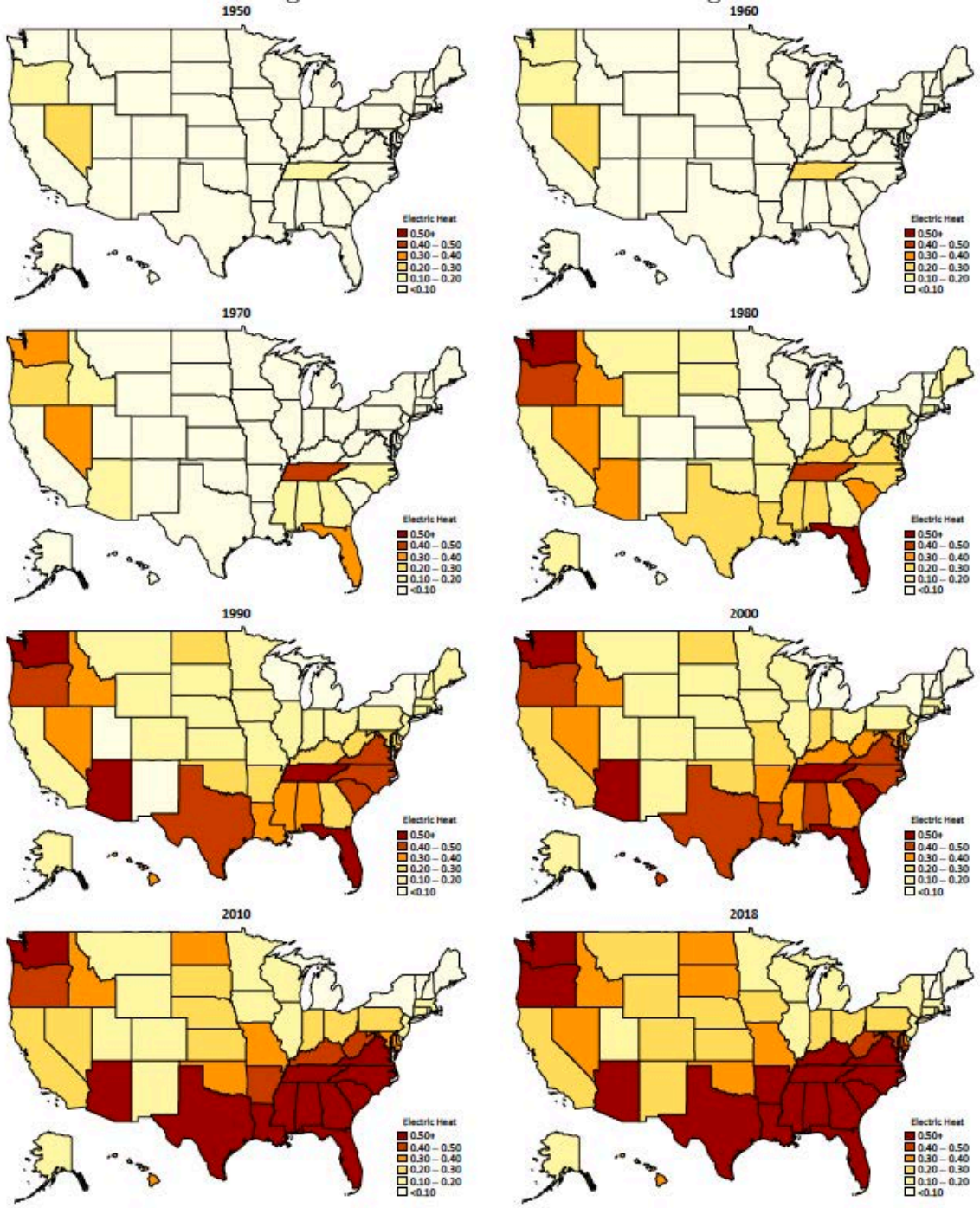
Source: U.S. Energy Information Administration, 2015 Residential Energy Consumption Survey

Current Heating Fuel Use in the US



- 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

Data from the American Community Survey (2016).



Growth in Electric Heating

- 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.

Figure from Davis, L. 2020. What Matters for Electrification? Evidence from 70 years of US Home Heating Choices. Energy Institute at Haas, WP 309.

Local Action to Ban Gas Appliances

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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

ALL-ELECTRIC CODE

Evolving Electricity Landscape – Utility Emission Reduction Targets

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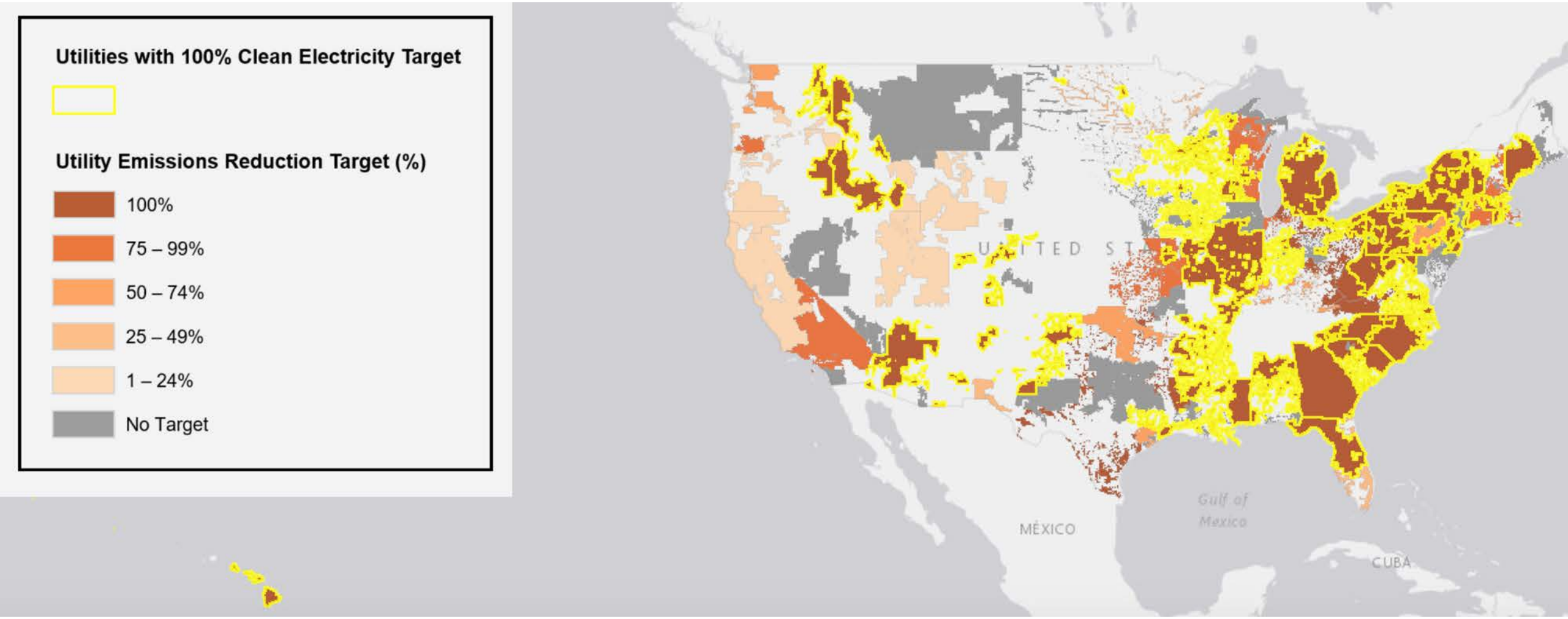
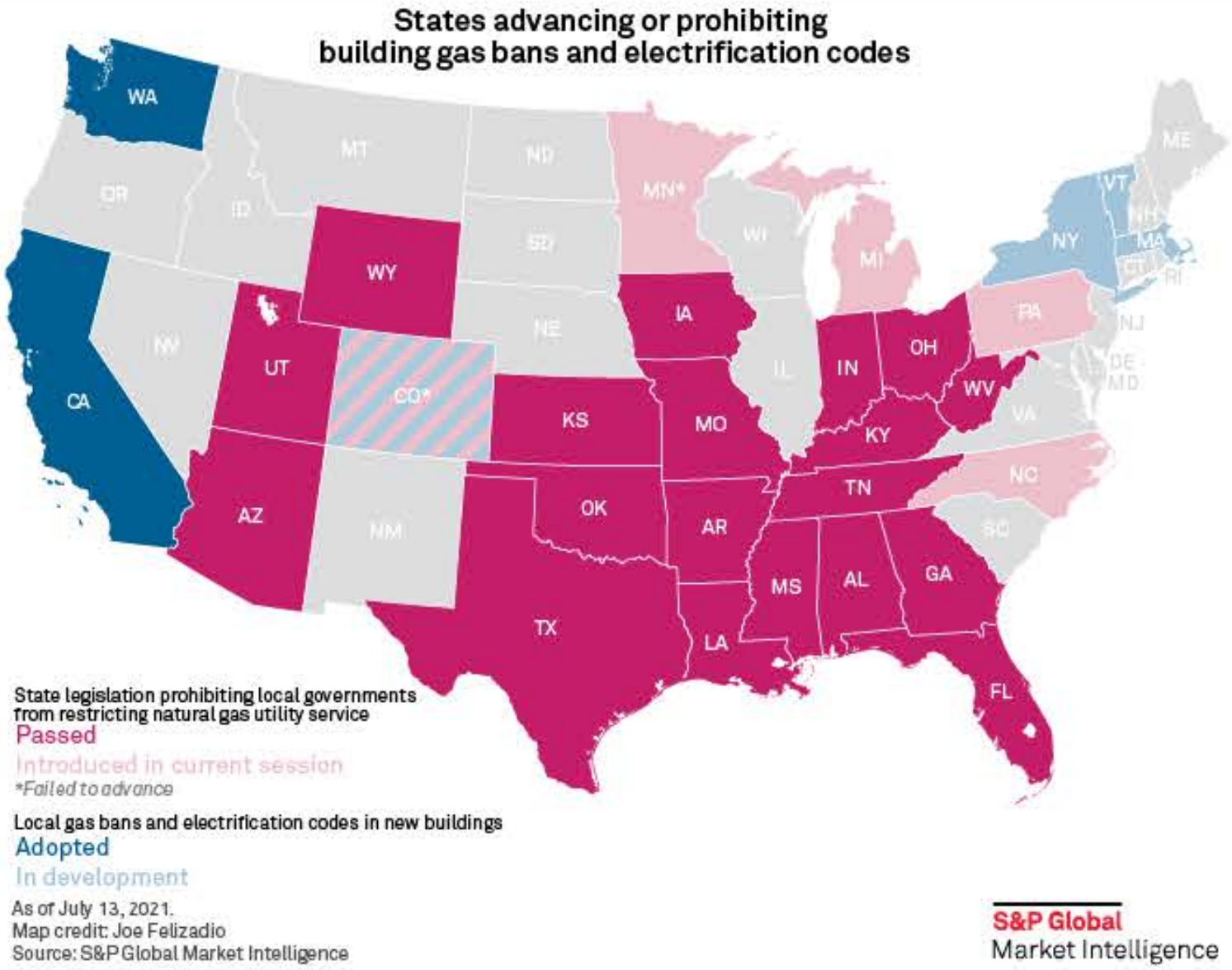


https://www.nrdc.org/resources/race-100-clean

Gas Bans and Electrification Codes



Technical Issues and Barriers

- What does it cost to electrify a home?
  - New construction
  - Retrofit

- What does it cost to operate an electrified home?
- What if the CO_2 content of electricity is high?
- Is the electric grid ready?
- Renewable generation does not always coincide with load – what should we do?

Assessing Costs

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

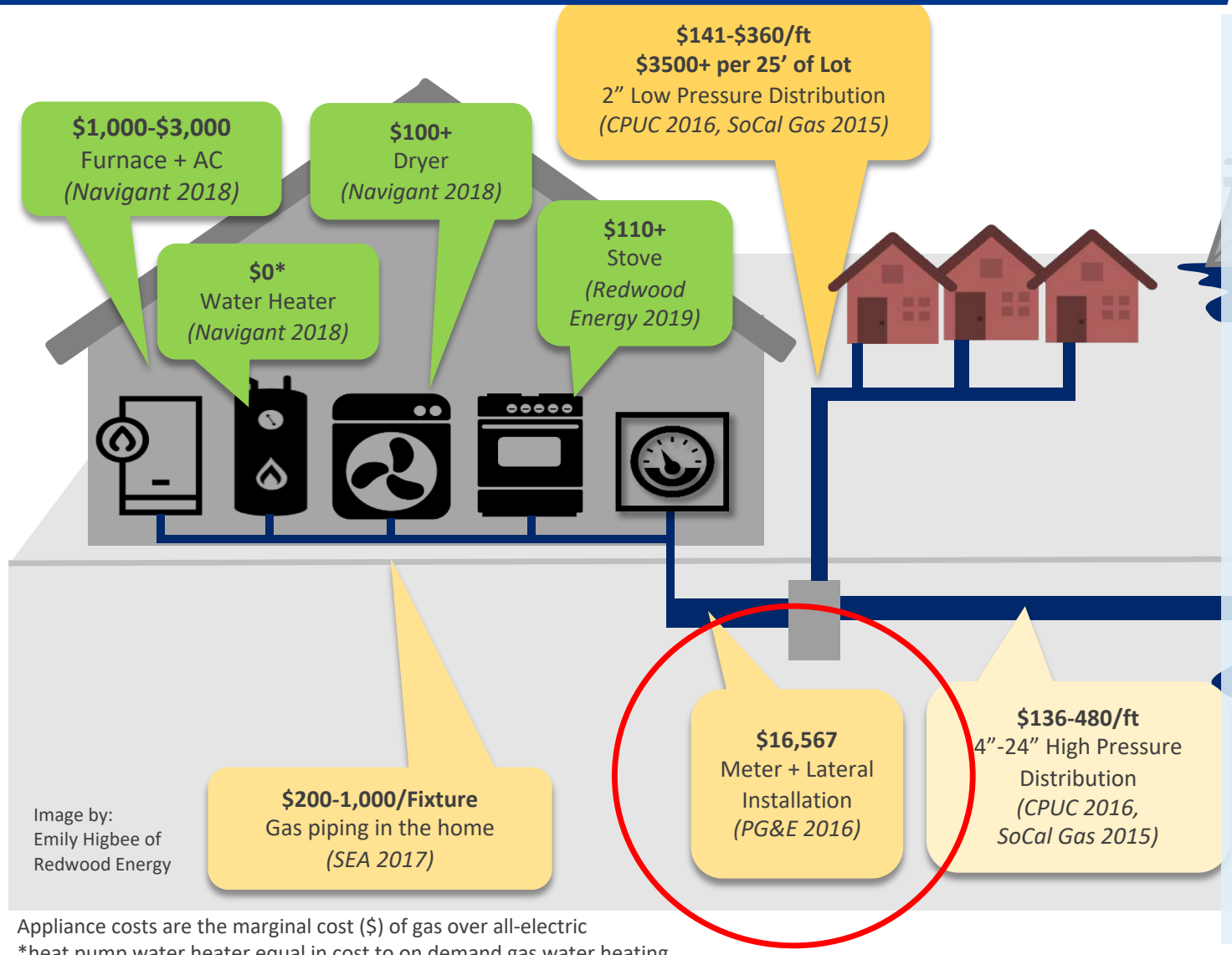


Image by:
Emily Higbee of
Redwood Energy

Other gas infrastructure costs not included.

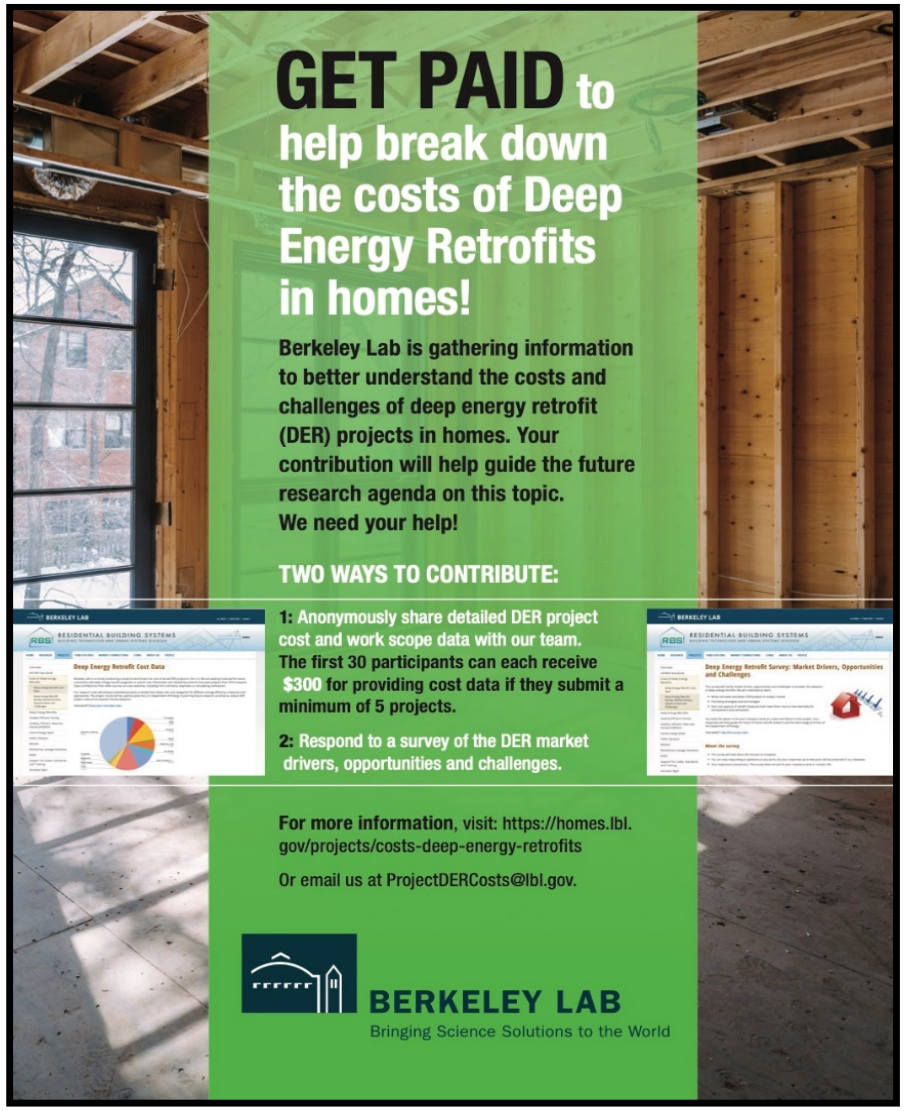
Generally hidden from direct construction cost.

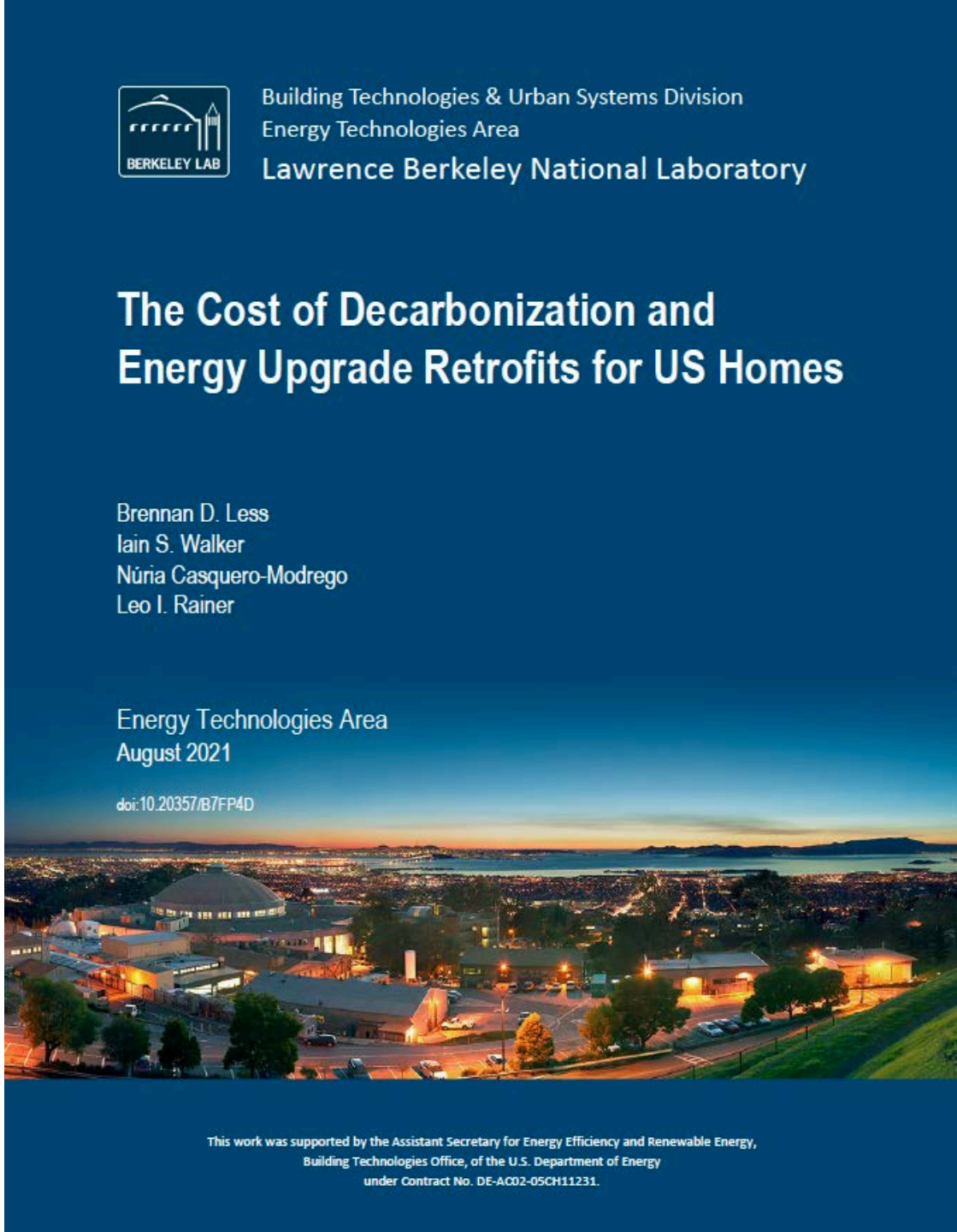
Buried in billing regulation.

Appliance costs are the marginal cost ($) of gas over all-electric
*heat pump water heater equal in cost to on demand gas water heating
**Aliso Canyon leaked 4.62 Billion cubic feet and alone cost $1.014 billion shared by 5.6 million meters - $181/meter cost (Reuters, Aug 6, 2018)
*** Average of various sources *(Cochran 2018, Lennon 2019, SoCalGas 2014, Nemec 2015, Nogueras 2011)*

Graphic courtesy of Sean Armstrong, Redwood Energy

Existing Home Costs





Building Technologies & Urban Systems Division
Energy Technologies Area
Lawrence Berkeley National Laboratory

The Cost of Decarbonization and Energy Upgrade Retrofits for US Homes

Brennan D. Less
Iain S. Walker
Núria Casquero-Modrego
Leo I. Rainer

Energy Technologies Area
August 2021

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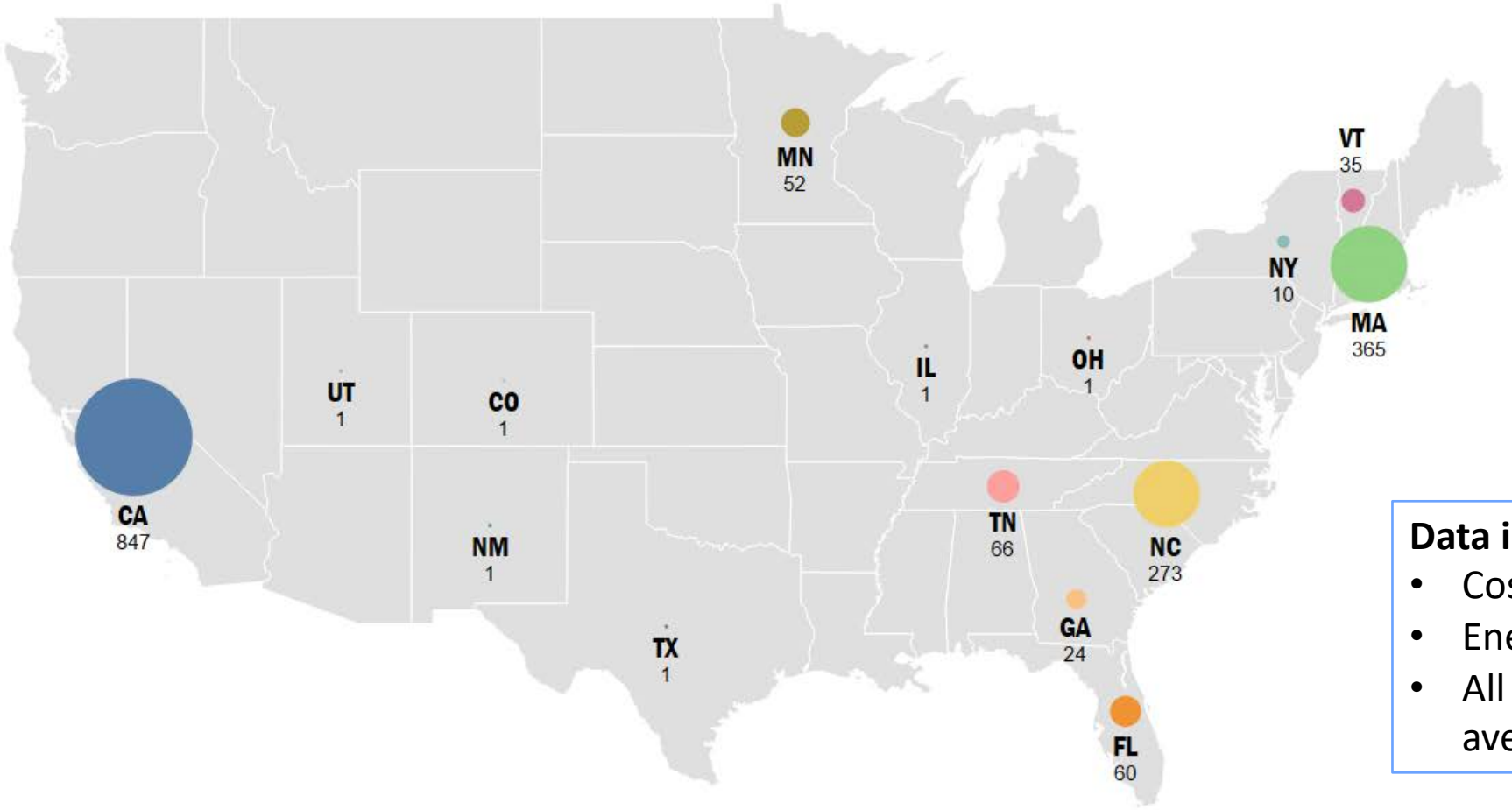
Energy Upgrade Database Summary



Sample of convenience:

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

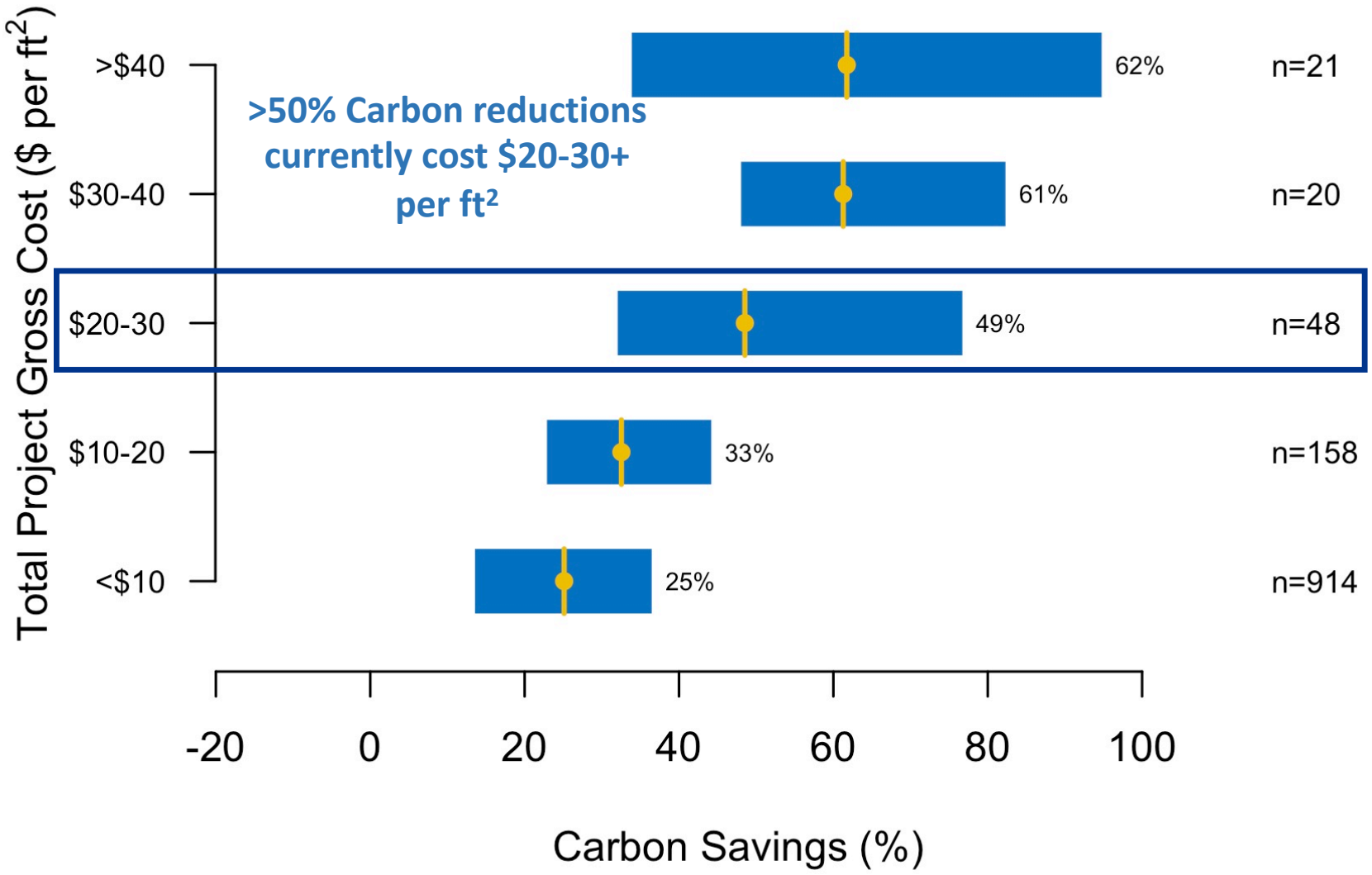
Data included:

- 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

Project Cost vs. Carbon Savings

How much does it cost to get to 50% savings?



Higher cost projects have diminishing returns

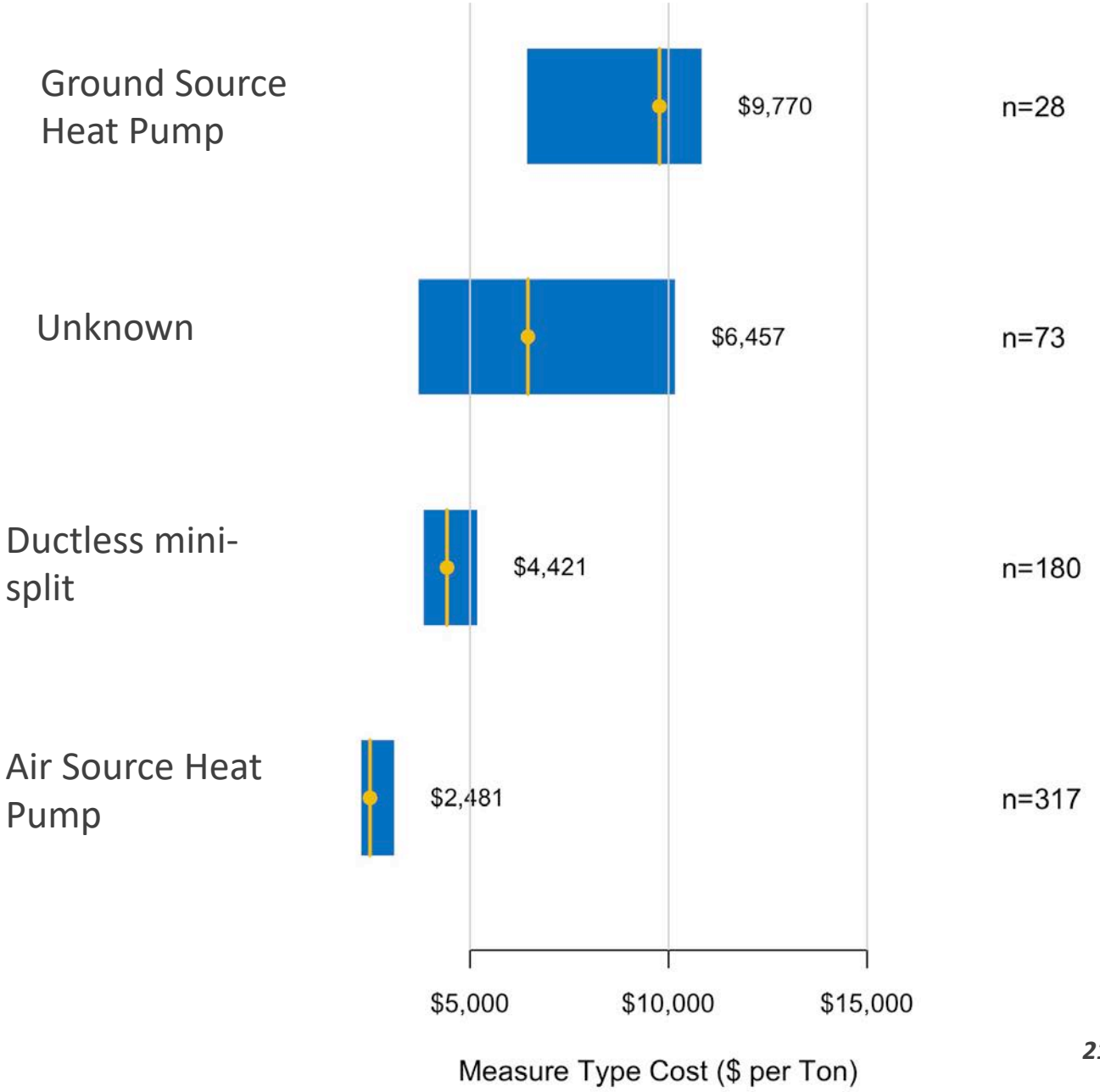
Heat Pump Costs

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

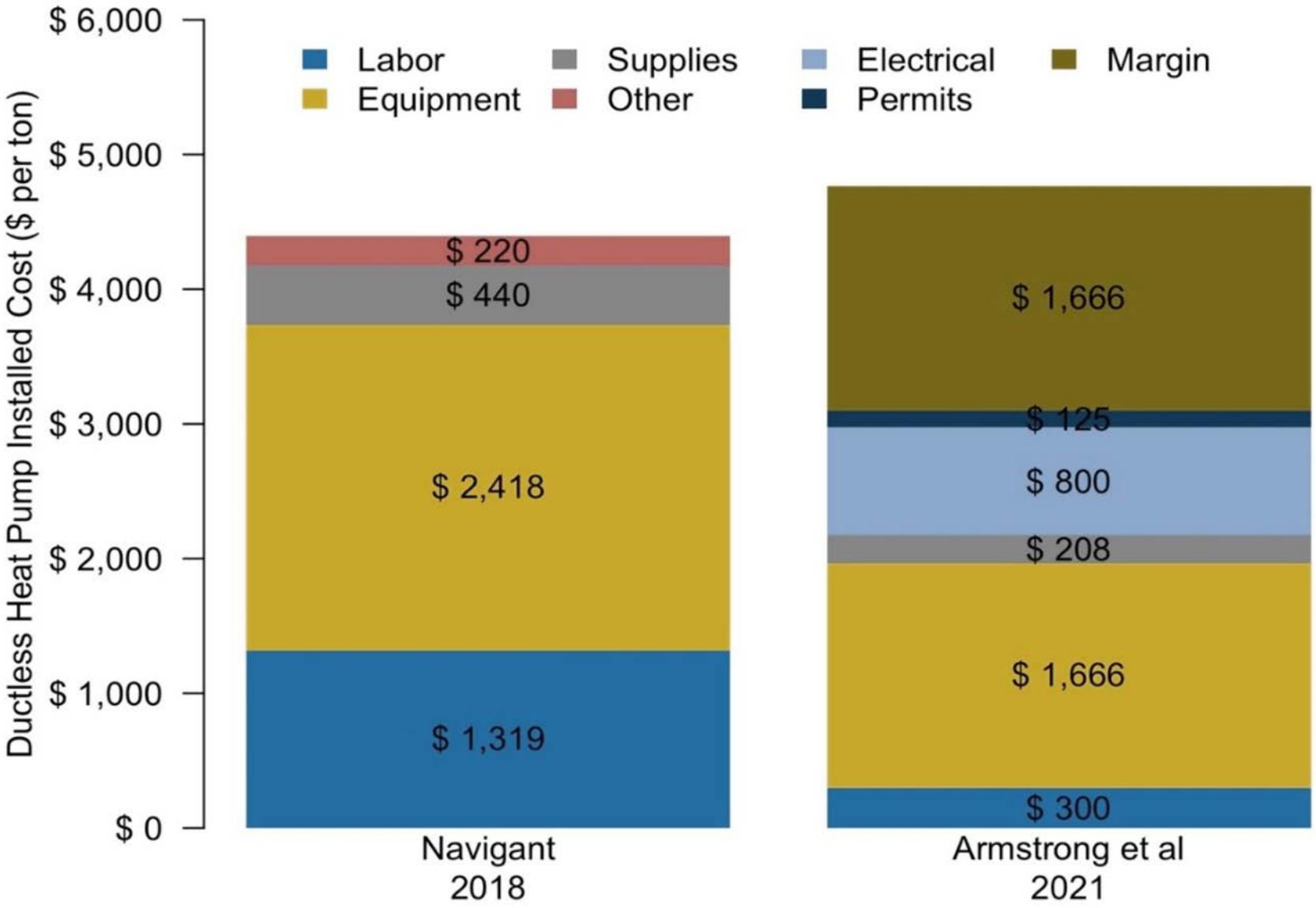
This allows tradeoffs:

Balance cost of envelope load reduction with reduced heat pump cost.

Heat Pump Installation Costs per Ton



Cost Breakdowns: where to focus cost reduction efforts



- Cost breakdowns highly variable
- Cost breakdowns not done by most contractors
- High margins

Typical Project Cost Stacks

$ - Total Cost
(% - CO_2e reduction)

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

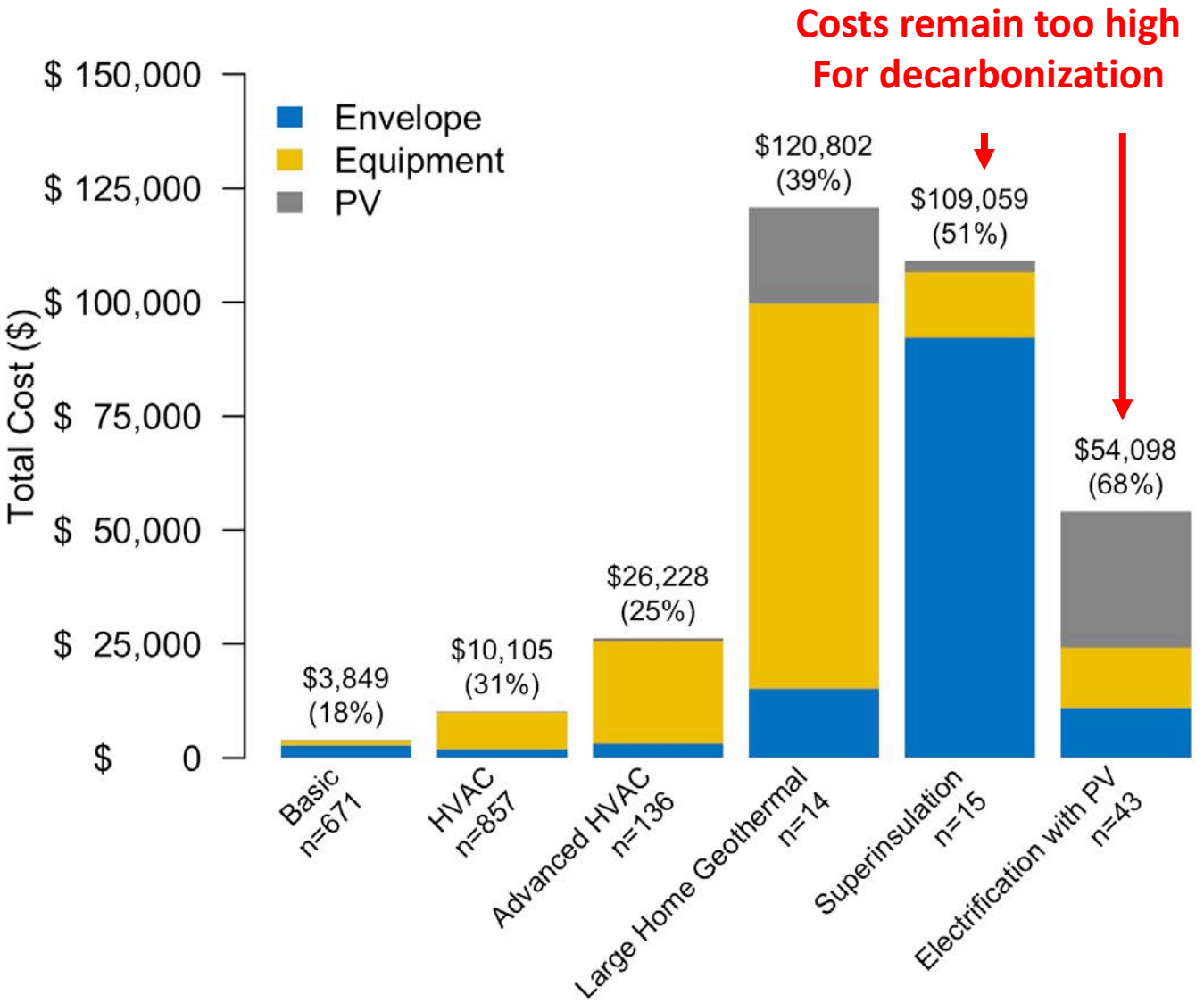
HVAC
HVAC projects with standard equipment (~1/2 heat pumps), including some envelope work

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



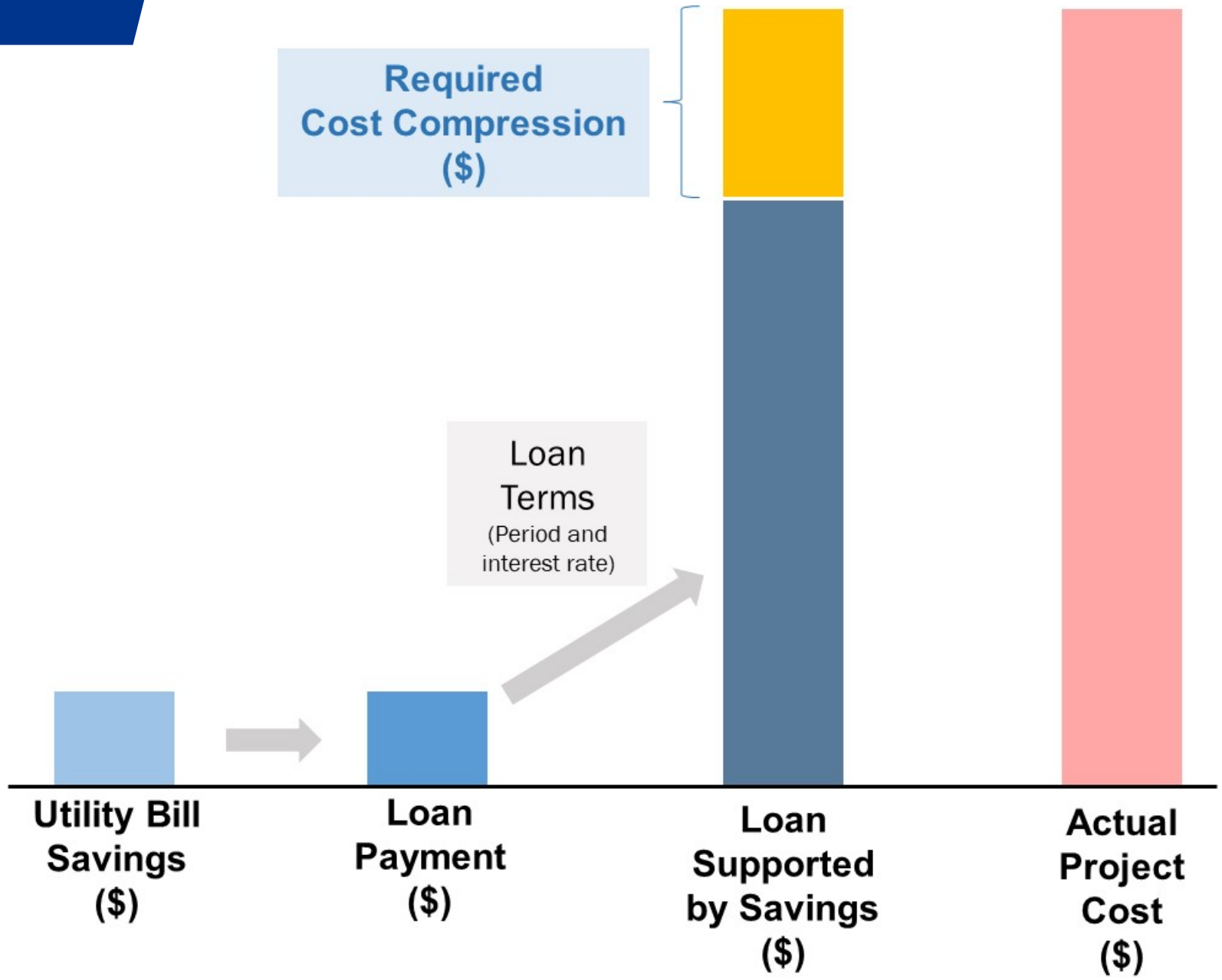
Reducing the Cost

Affordability

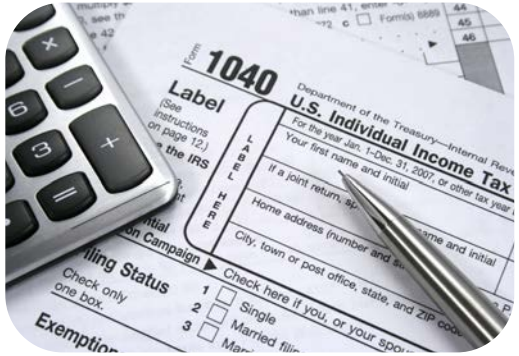
- Upfront costs are a major barrier to getting to scale with decarbonization

- Financing needed

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



Cost Compression

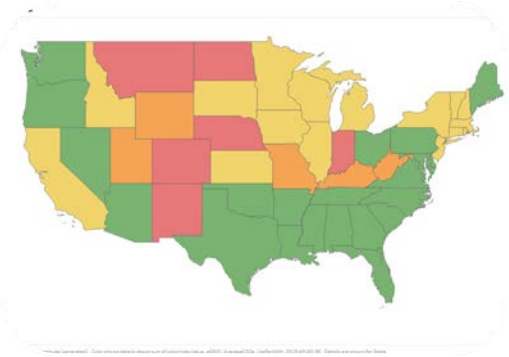


Rebates and Incentives

Upgrade Package Optimization

Technology Innovation

Soft Cost Reductions



New Metrics

No- and Low-Cost Methods

Cost Compression - Rebates

Terms: 30-year, 3% interest

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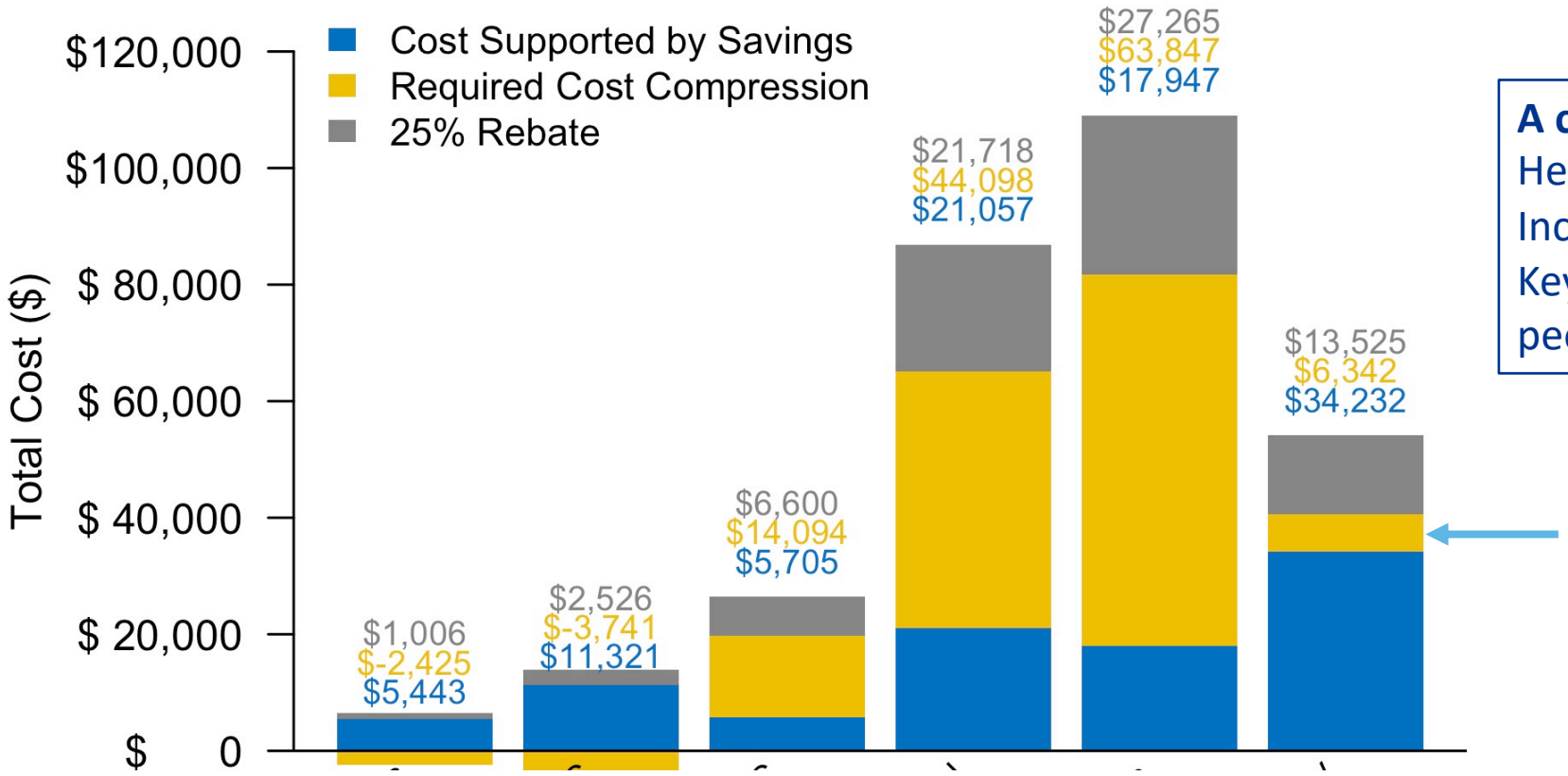


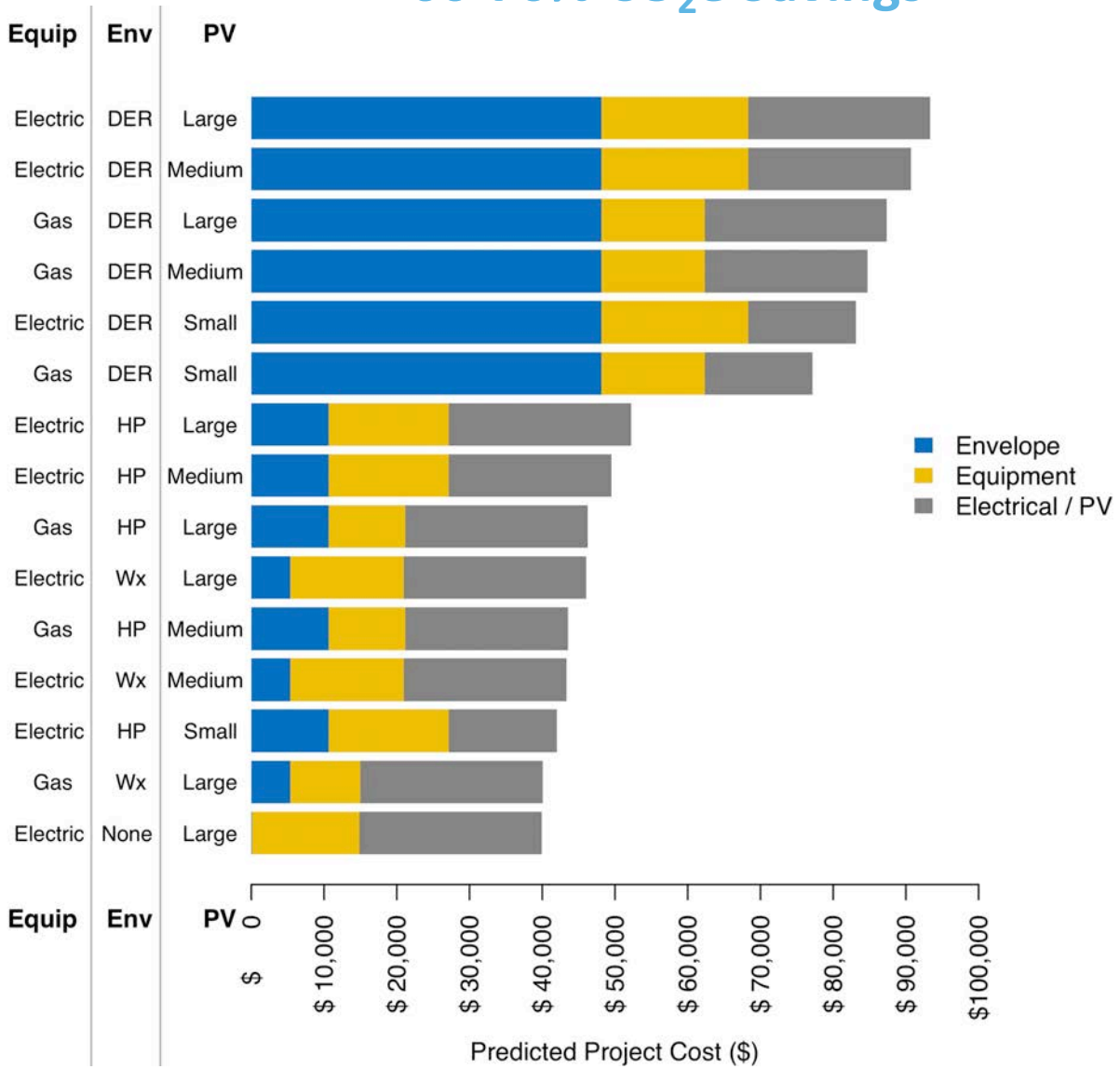
Cluster	Basic	HVAC	Advanced HVAC	Geo-thermal	Super-insulation	Electrification with PV
CO_2 Reduction	18%	31%	25%	39%	51%	68%

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

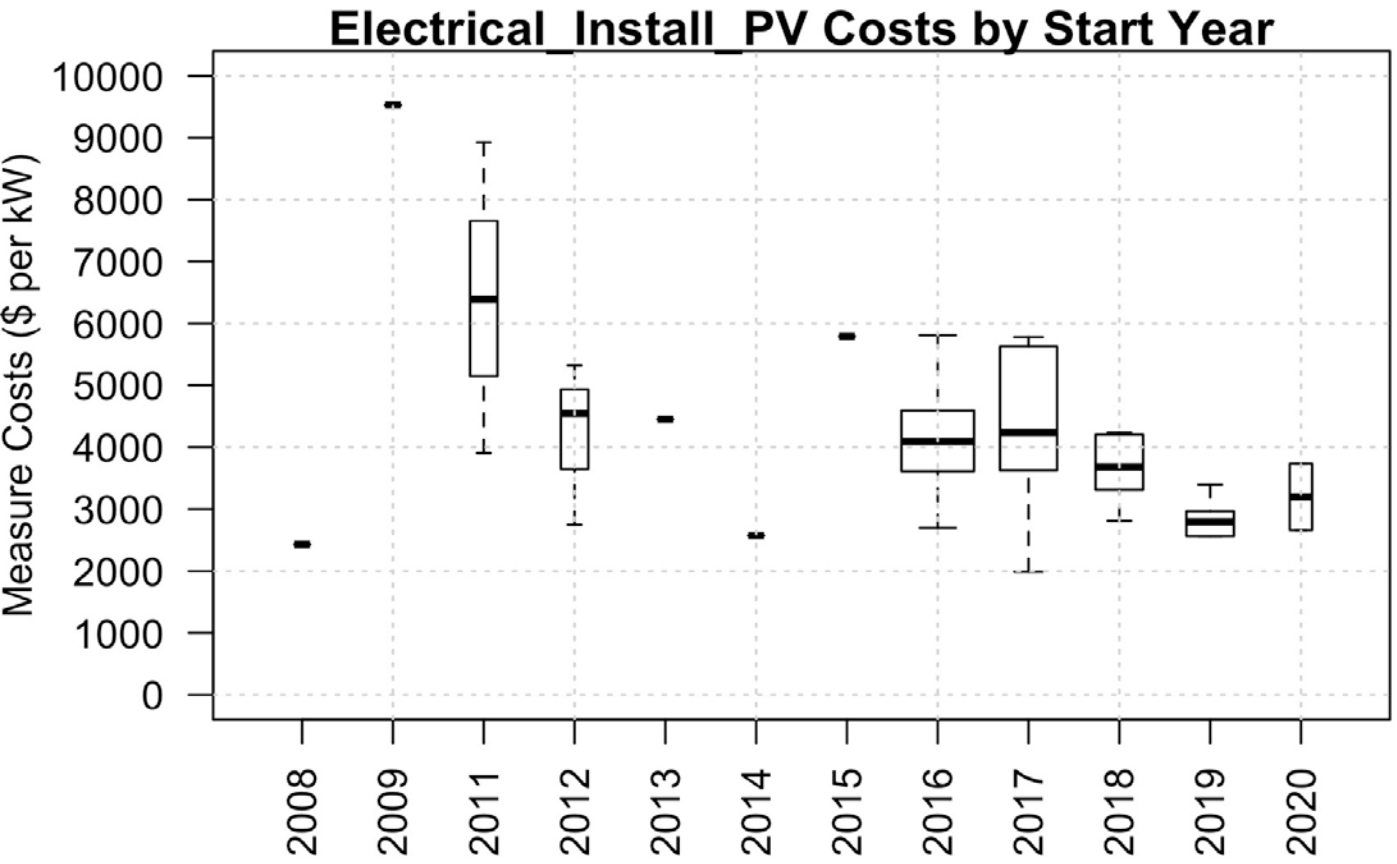
60-70% CO_2e Savings

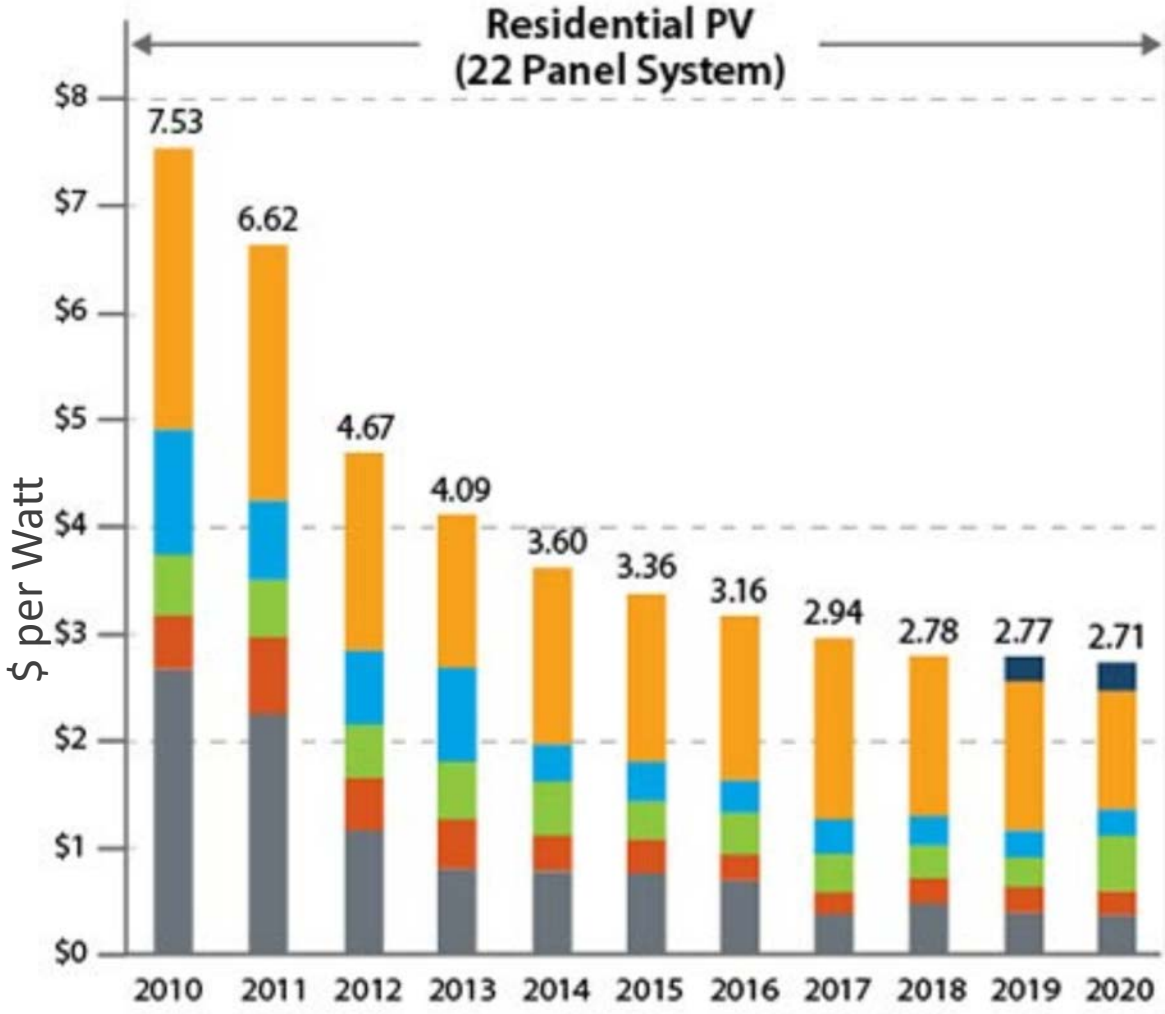


Moderate Envelope upgrades + PV gives good carbon savings at least cost

Market Maturity

Still much higher than the rest of the world
By factors of two!





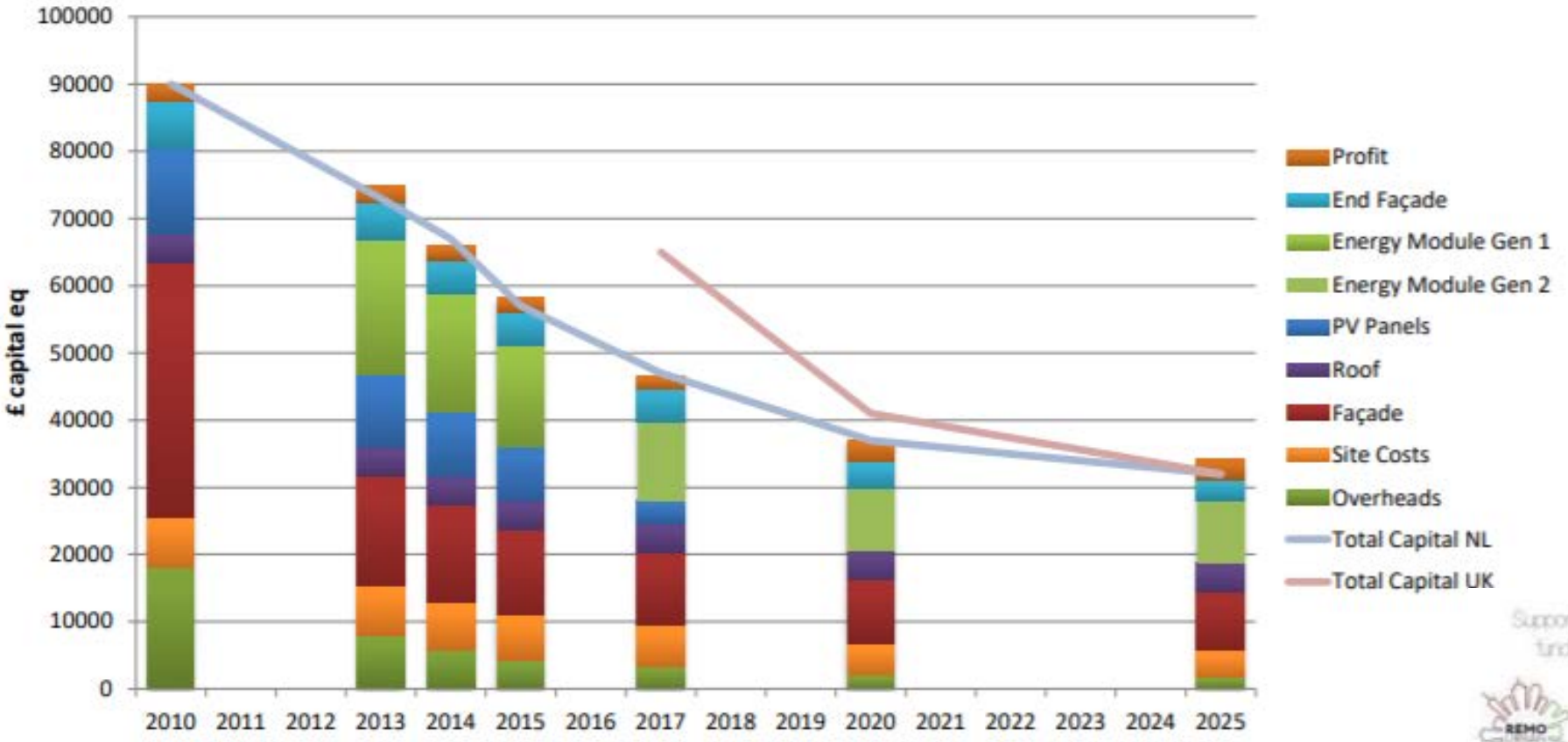
LBNL DER Database

NREL PV Database

The Energiesprong Approach: Deployment-Led Innovation

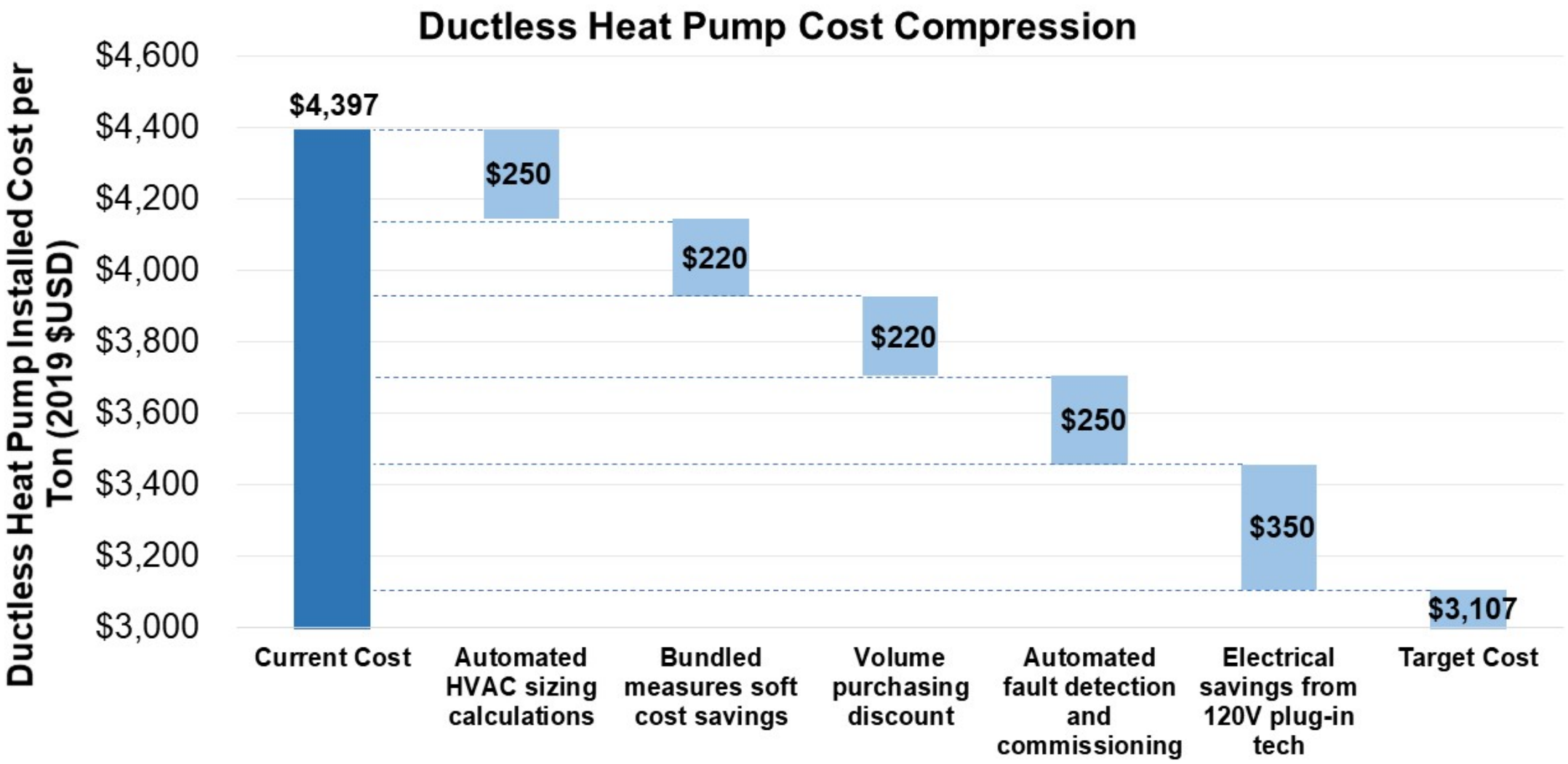
EnergieSprong has already demonstrated cost compression for retrofits

> Component Costs - volume up:cost down

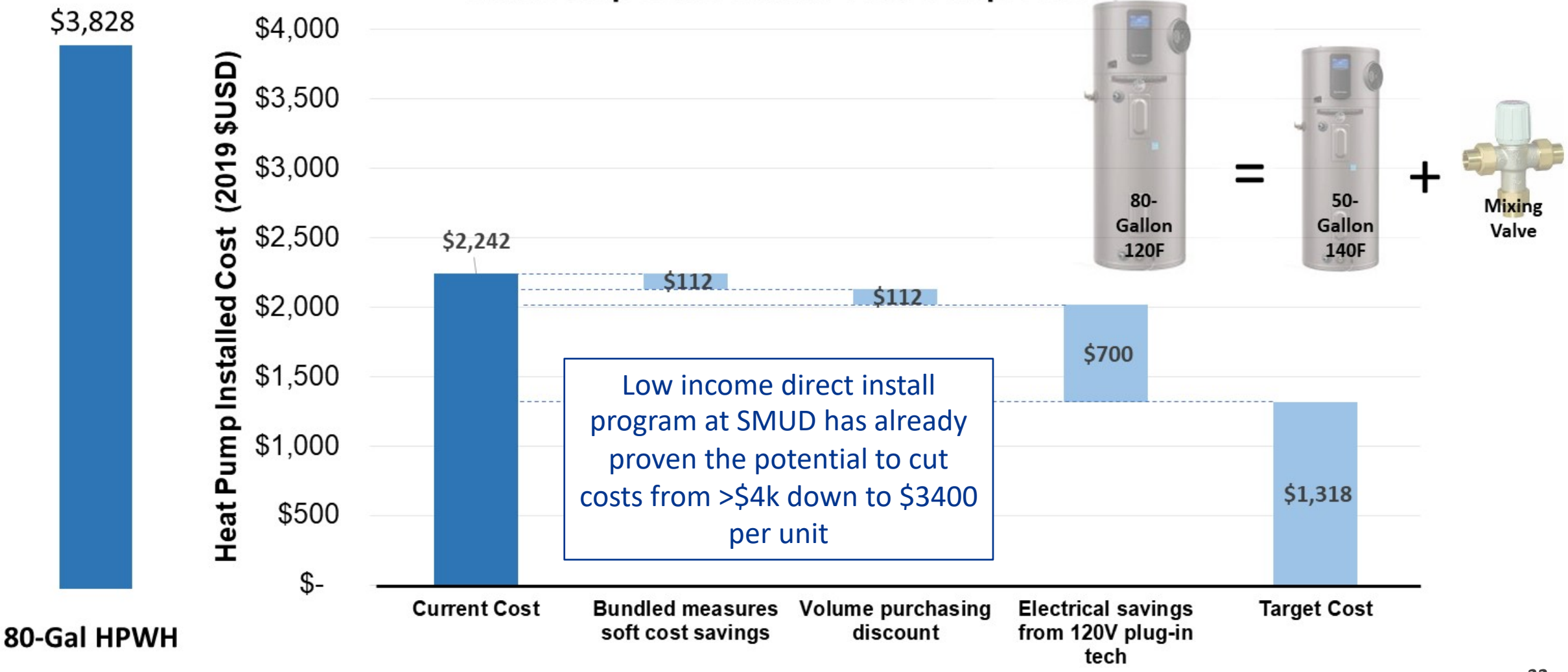


Supported by Horizon 2020 projects funded by the European Union

Cost Compression – Ductless Heat Pumps



Cost Compression - Heat Pump Water Heater, 50-Gal



Cost Compression – Low Power Electrification

Avoiding Panel Upgrade Costs

$1,954

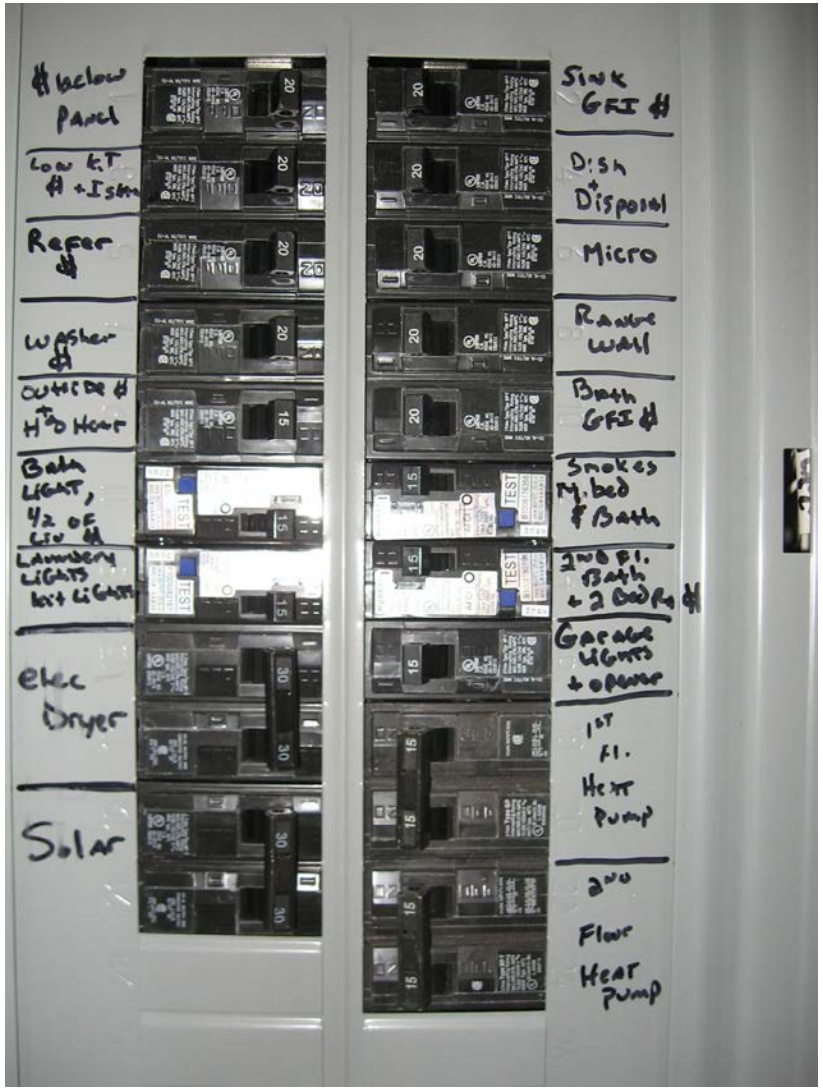
Average range: **$1,500 - $4,000**

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

- Only needed in the 25% of homes that do not have central A/C
- Exception is adding hot water and EV charging
- Big increases in past couple of years
  - Material costs
  - Everyone is busy
  - Currently $6,000 in CA Bay Area



Cost Compression – Low Power Electrification

Avoiding Panel Upgrade/Rewiring Costs & Lowering Grid Impacts

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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

Watt Diet Calculator

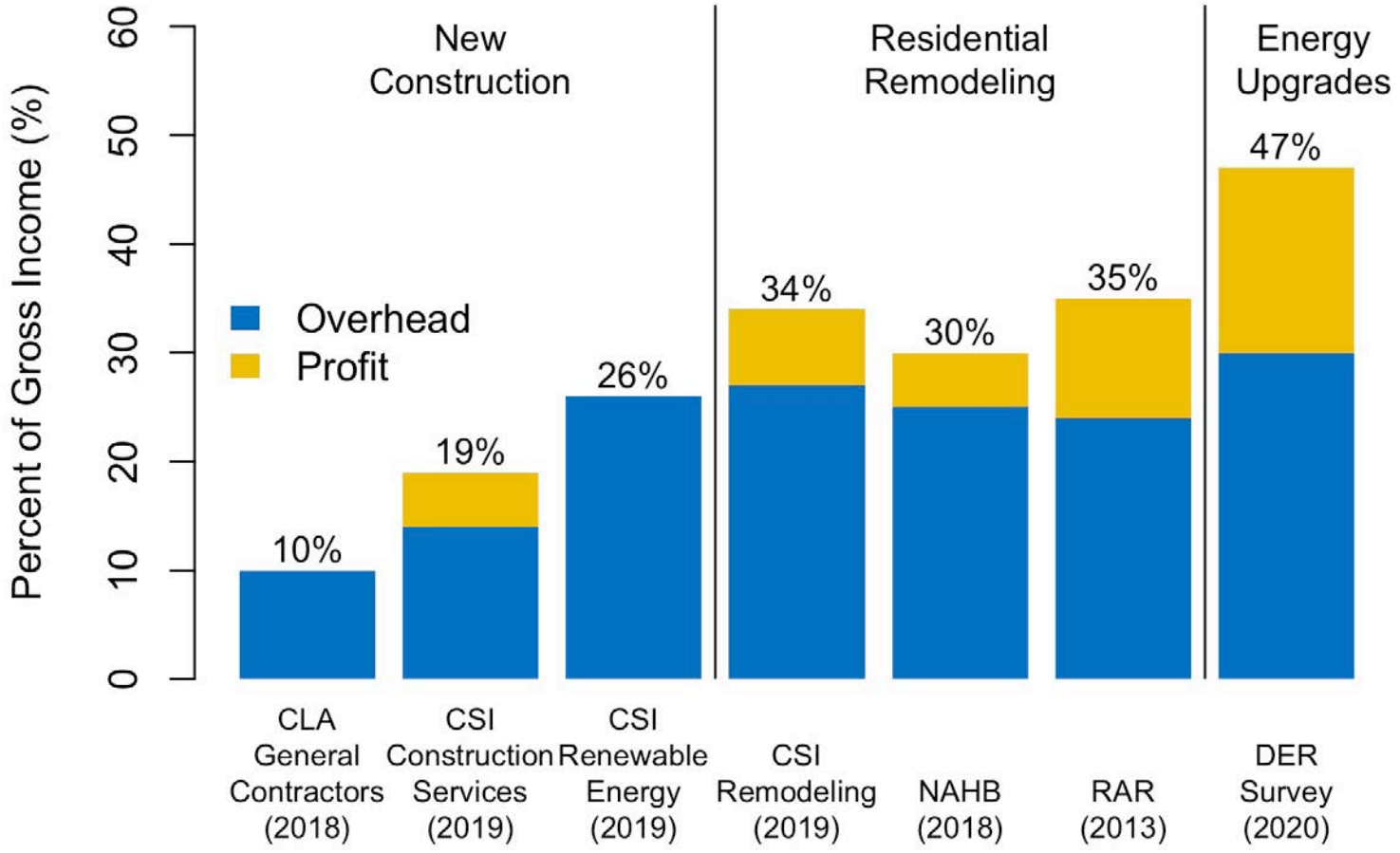
All Electric 100 Amp Home (2,000 square feet)
Ducted heat pump, medium power heat pump water heater, hybrid heat pump dryer

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)

Cost Compression – Soft Costs

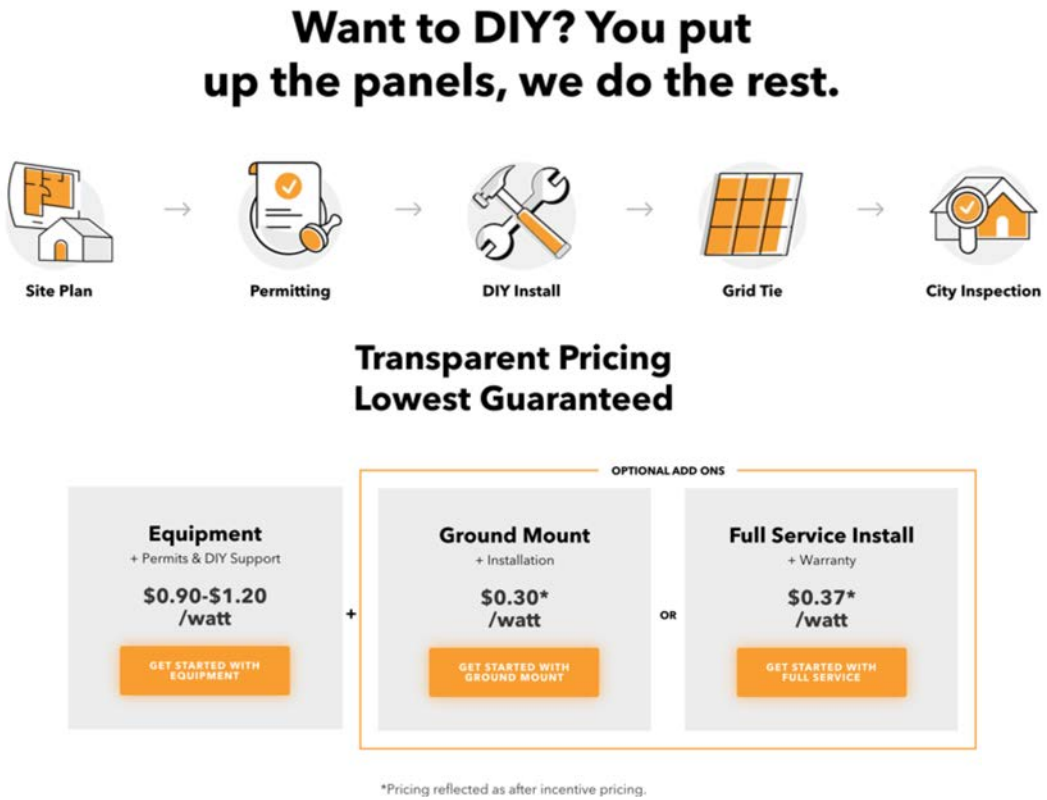


Need to reduce Soft Costs:

- Customer acquisition
- Testing
- Program participation
- Project design

Cost Compression – Soft Costs – Real Life Examples

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



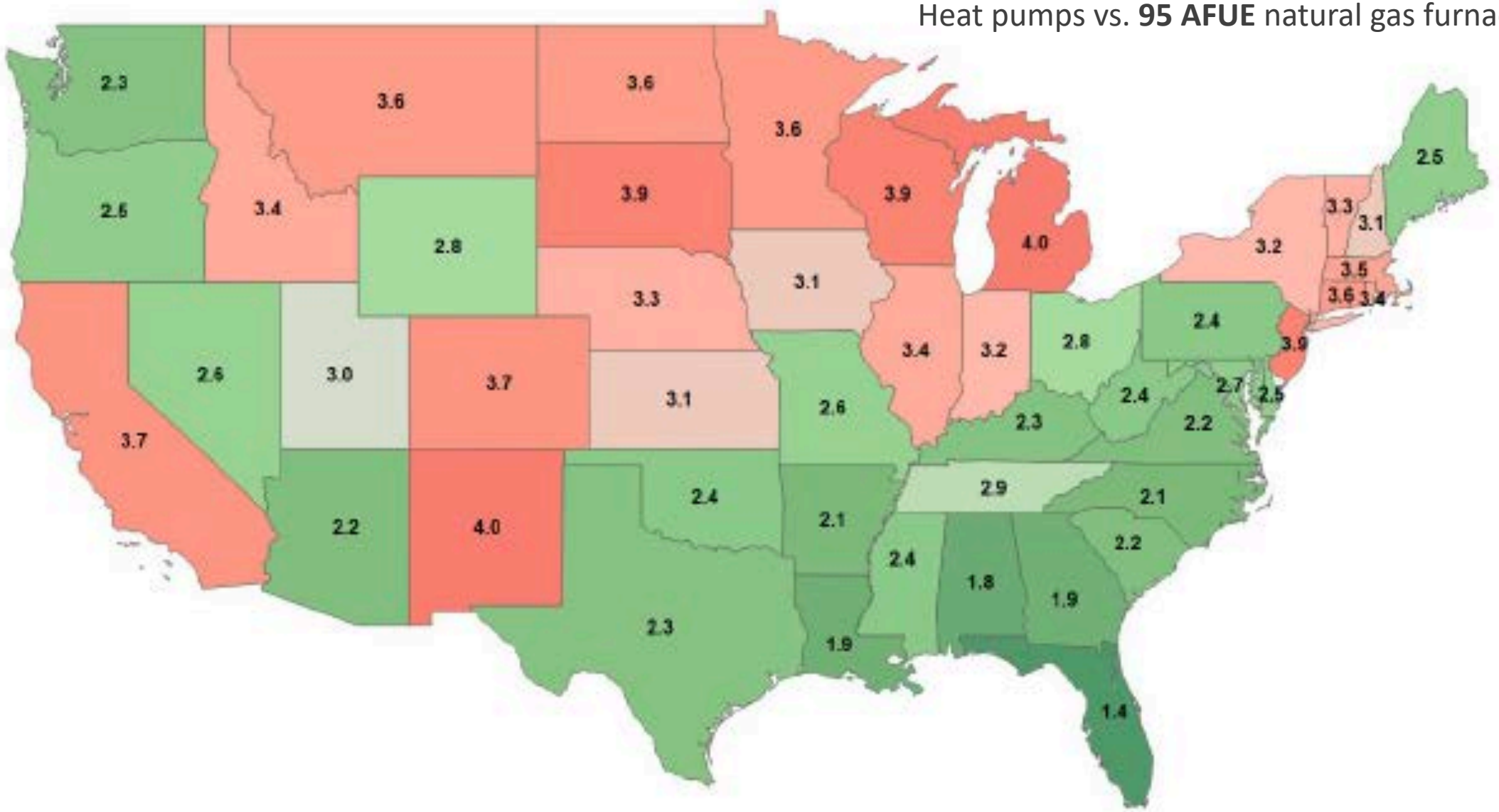
- Custom design
- Pre-insulated line sets
- Simplified fittings
- Strong advertising

Operating Costs

Operating Costs

Minimum COP required for break-even utility costs (2019)

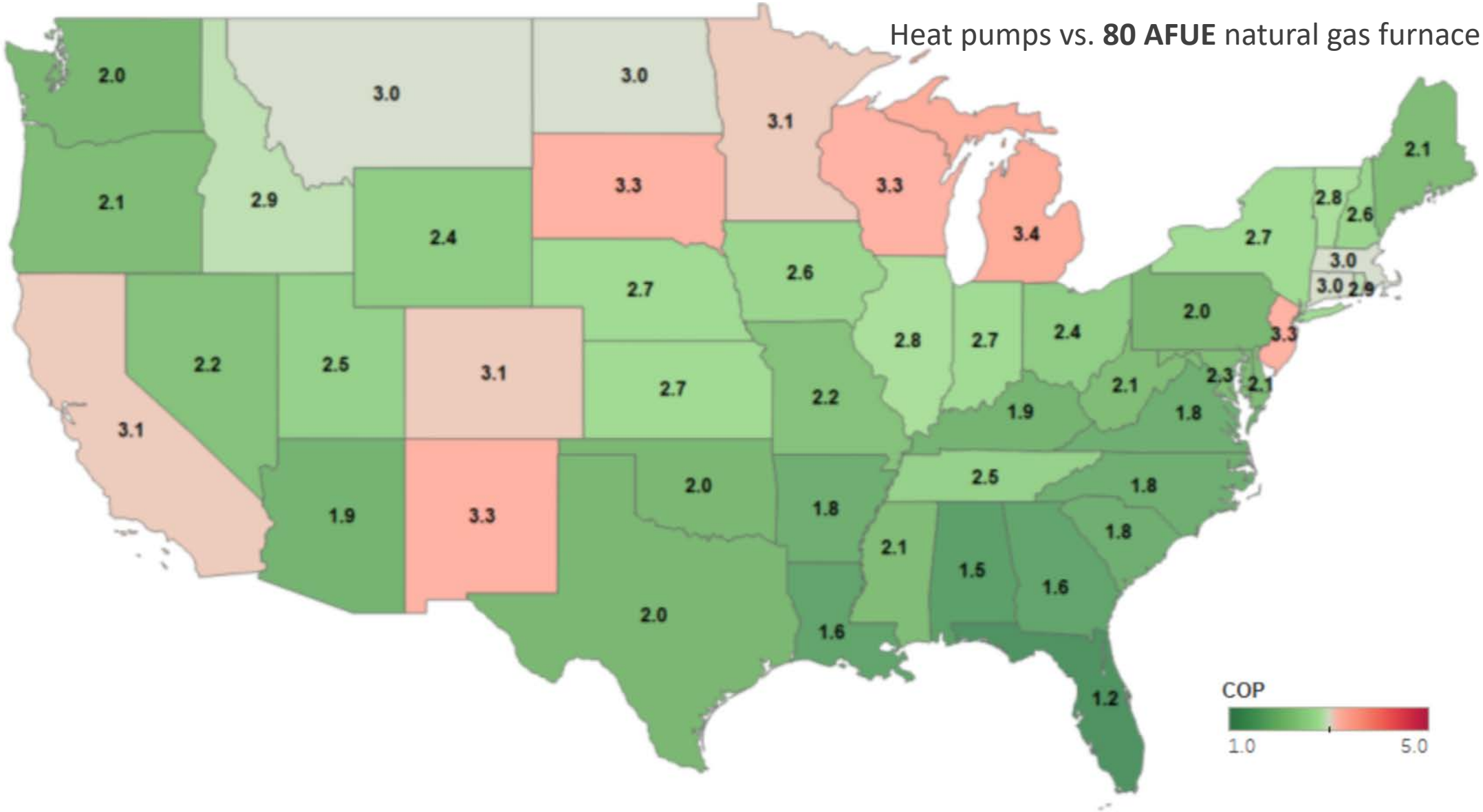
Heat pumps vs. **95 AFUE** natural gas furnace



Operating Costs

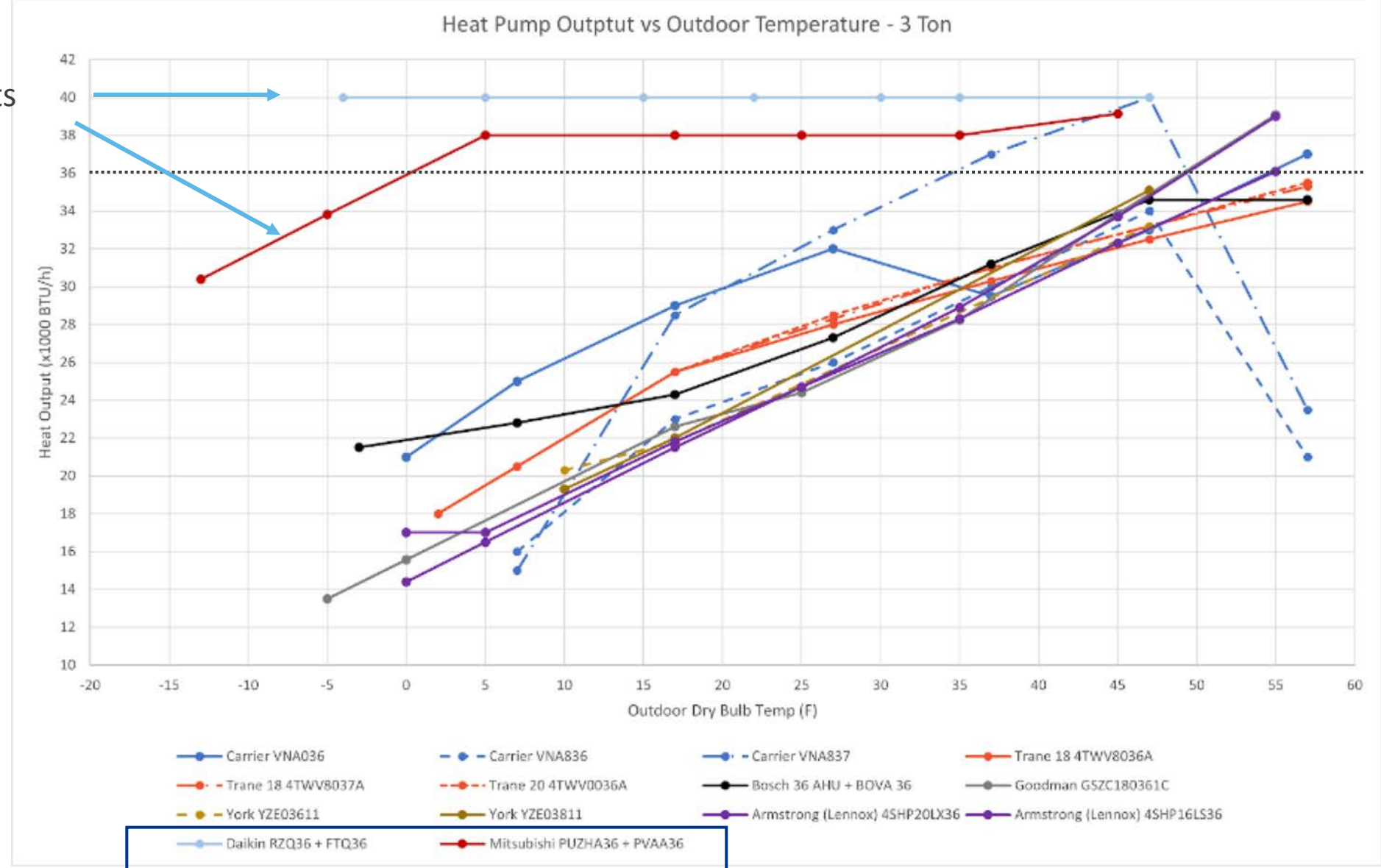
Minimum COP required for break-even utility costs (2019)

Heat pumps vs. **80 AFUE** natural gas furnace



Better low temperature performance for Heat Pumps

Cold climate units



Do heat pumps work when its cold outside?

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

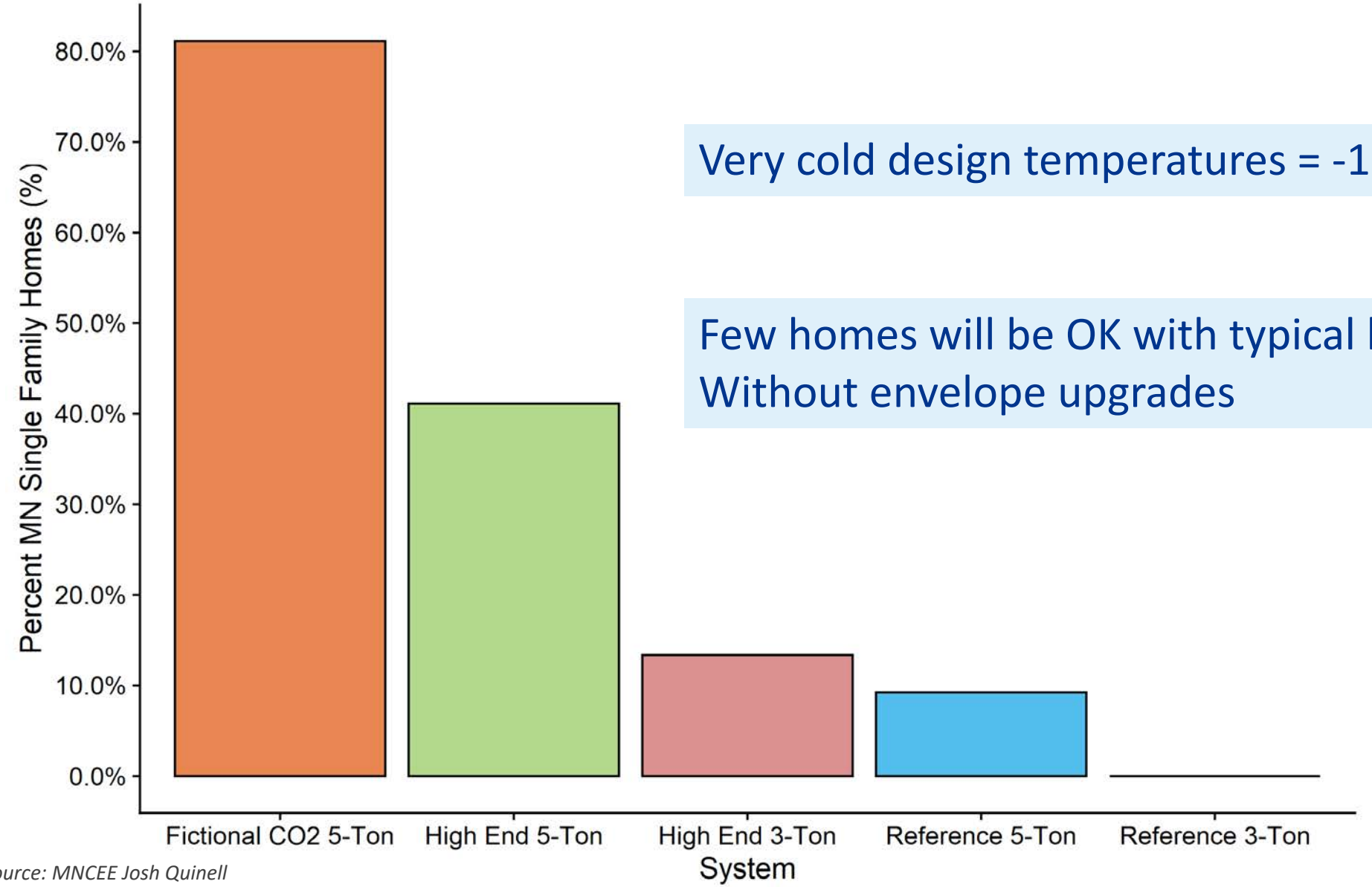
>4,000 products listed

Department of Energy

DOE to Partner with Heating Industry to Improve Performance and Energy-Efficiency of Cold Climate Heat Pumps

NOVEMBER 1, 2021

Very Cold Climates – Capacity Limited



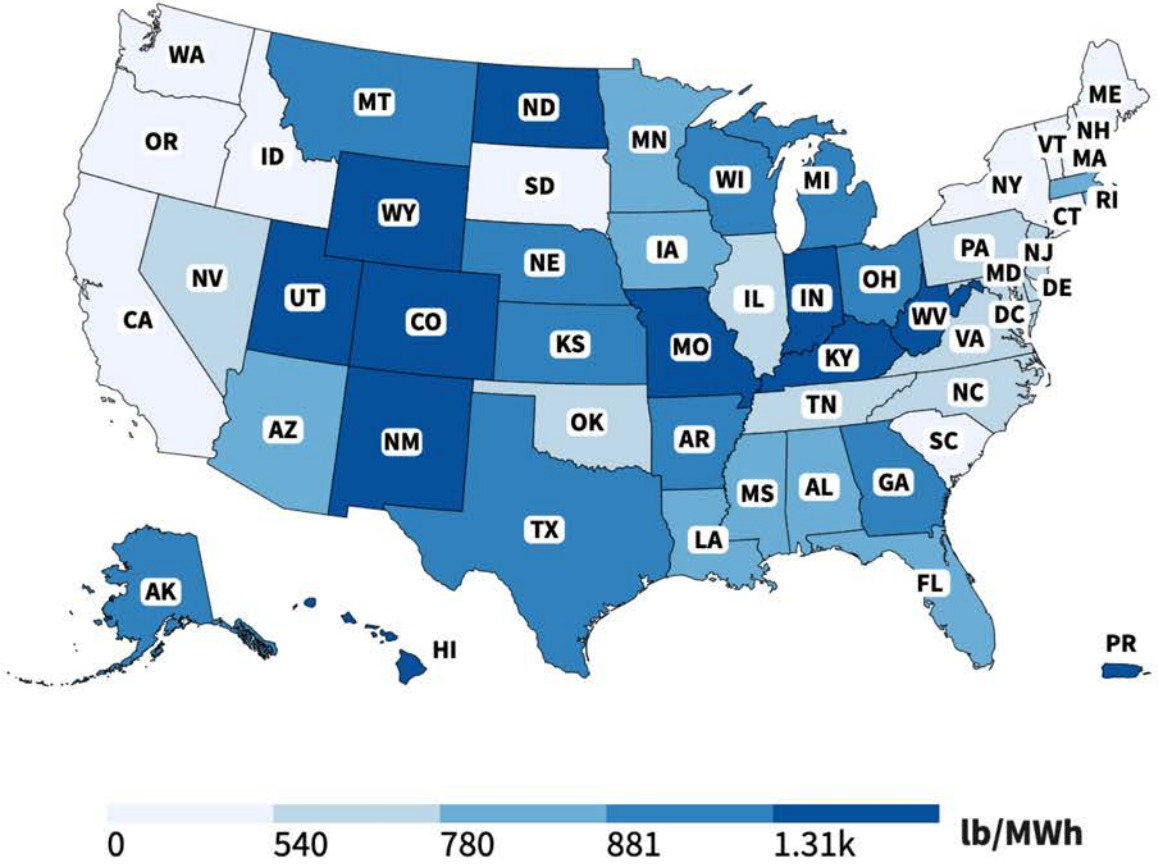
Very cold design temperatures = -11F to -20F

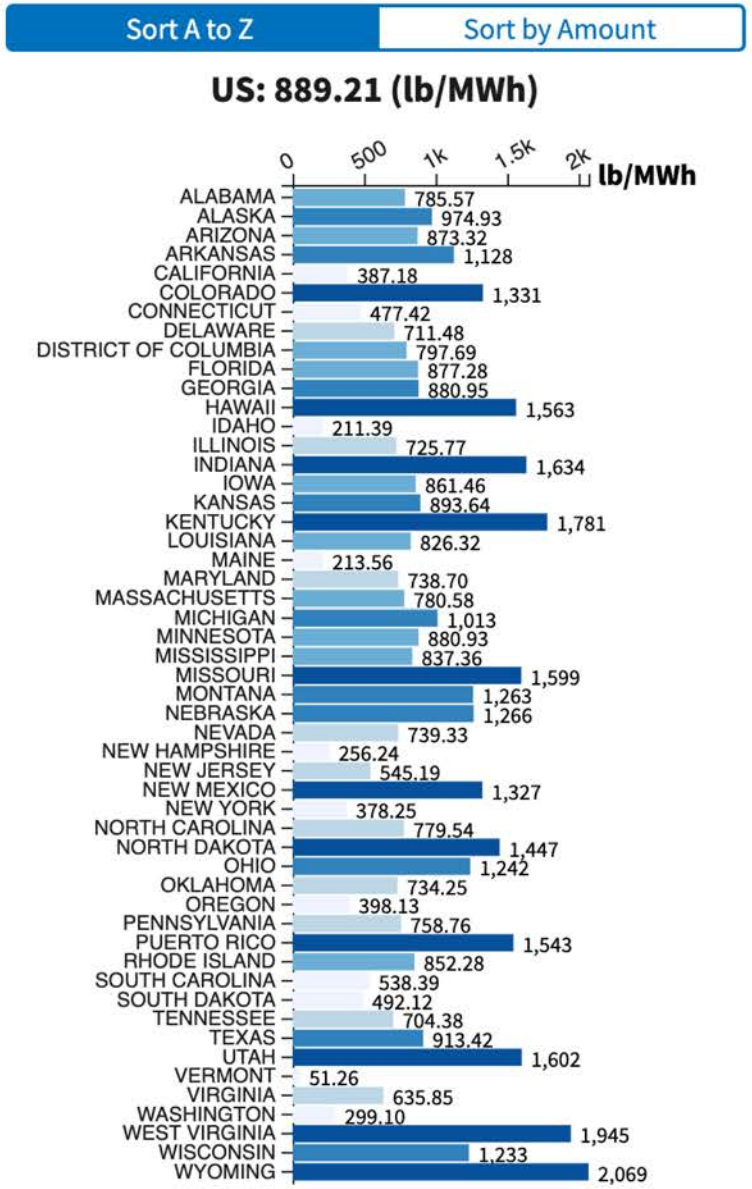
Few homes will be OK with typical heat pumps
Without envelope upgrades

Source: MNCEE Josh Quinell

CO_2 in Electricity

CO_2 equivalent total output emission rate (lb/MWh) by state, 2019

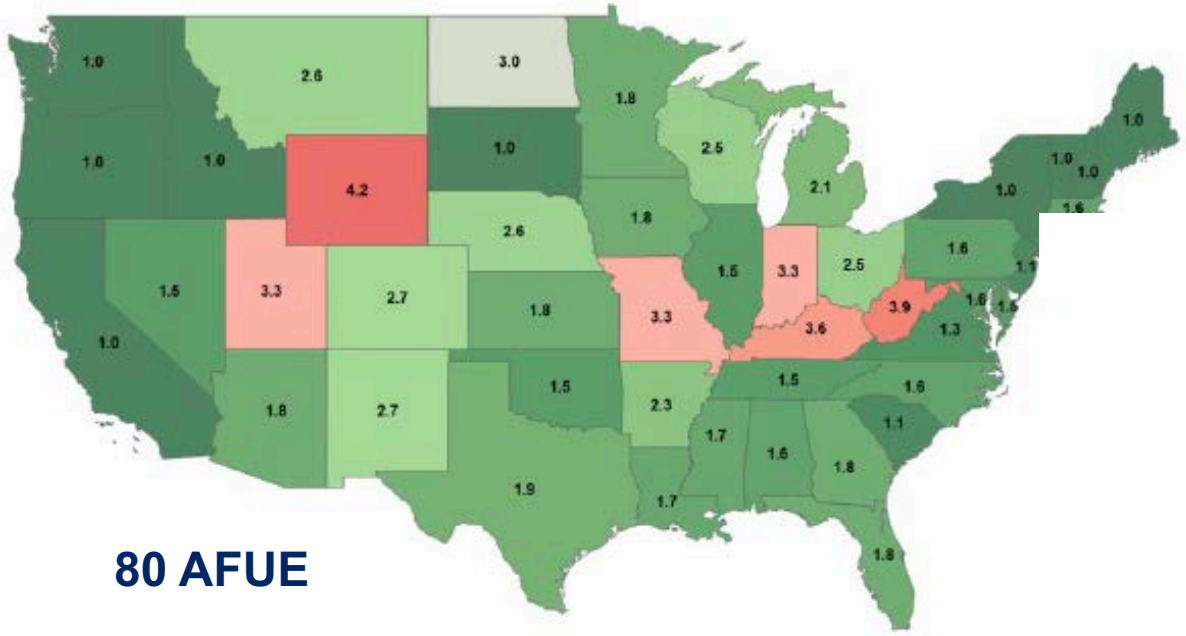




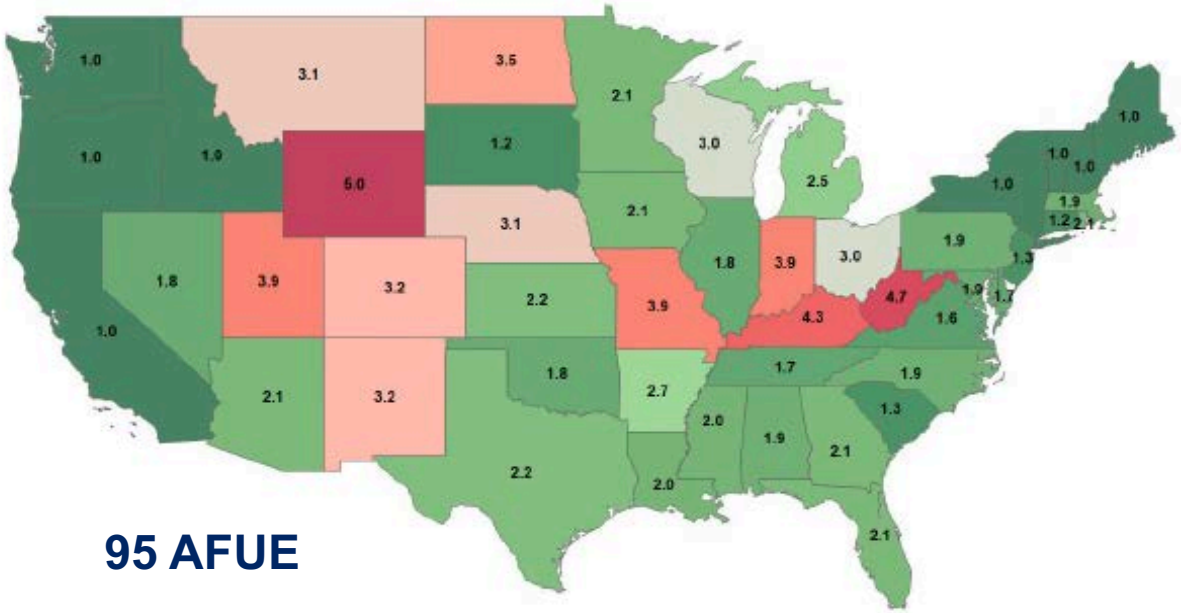
https://www.epa.gov/egrid/data-explorer

Heat Pump COP required to break even with a gas furnace

CO_2e Emissions Neutrality



80 AFUE



95 AFUE

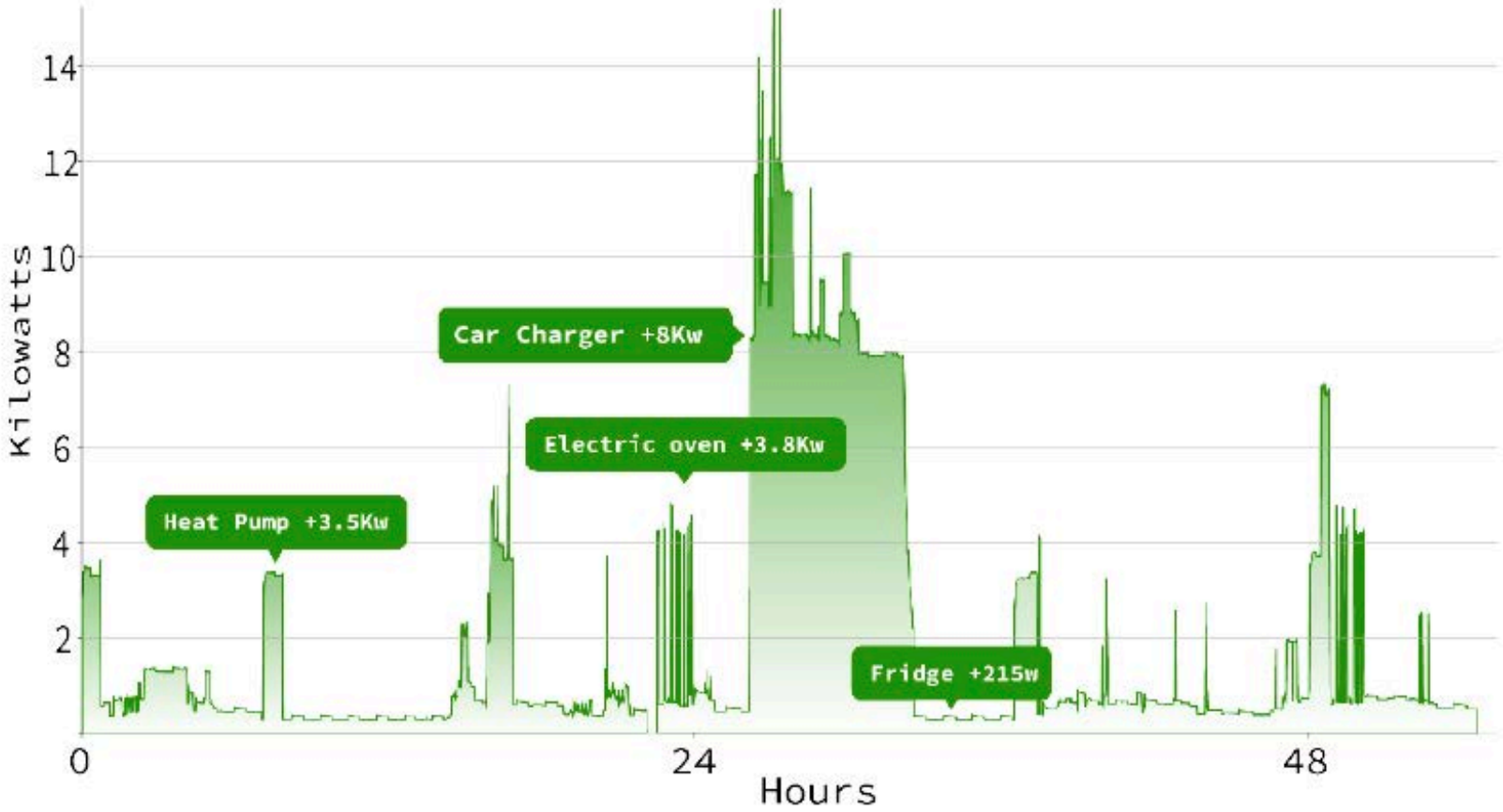
Not just CO_2 : Methane Leaks

- 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.

Peak Power

Need to Manage Peak Power



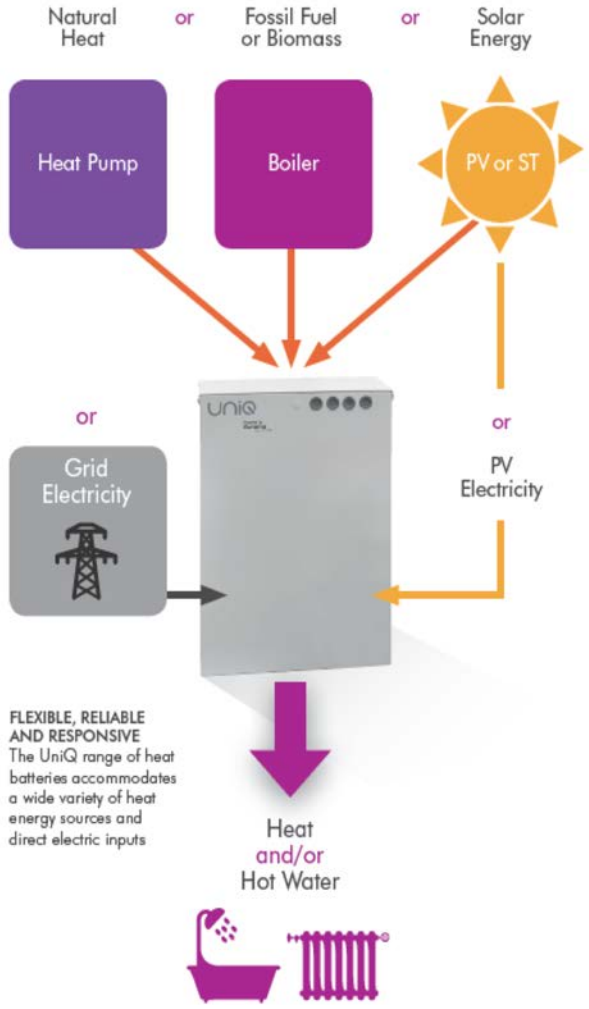
- Utilities may institute peak charges for homes - just like for commercial/industrial customers
- Utilities will have time of use charges – whether homes can respond, or not
- Utilities are proposing large fines for on-site generation – even with storage
- New "peak" is 4-9 pm
- Another "peak" in the 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

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

Grid Integration: Time Shifting Using 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

- 3 to 5 KWh in every home – much less than 13.5 kWh ($13k) Tesla Powerwall

Thermal Storage

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

Innovative 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)

Programmable Panels

Whole House 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.

Innovative Technology

- 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

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

Resilience and Outages

Resilience and Outages?

Electrical outages are much more frequent (~60x) than natural gas outages

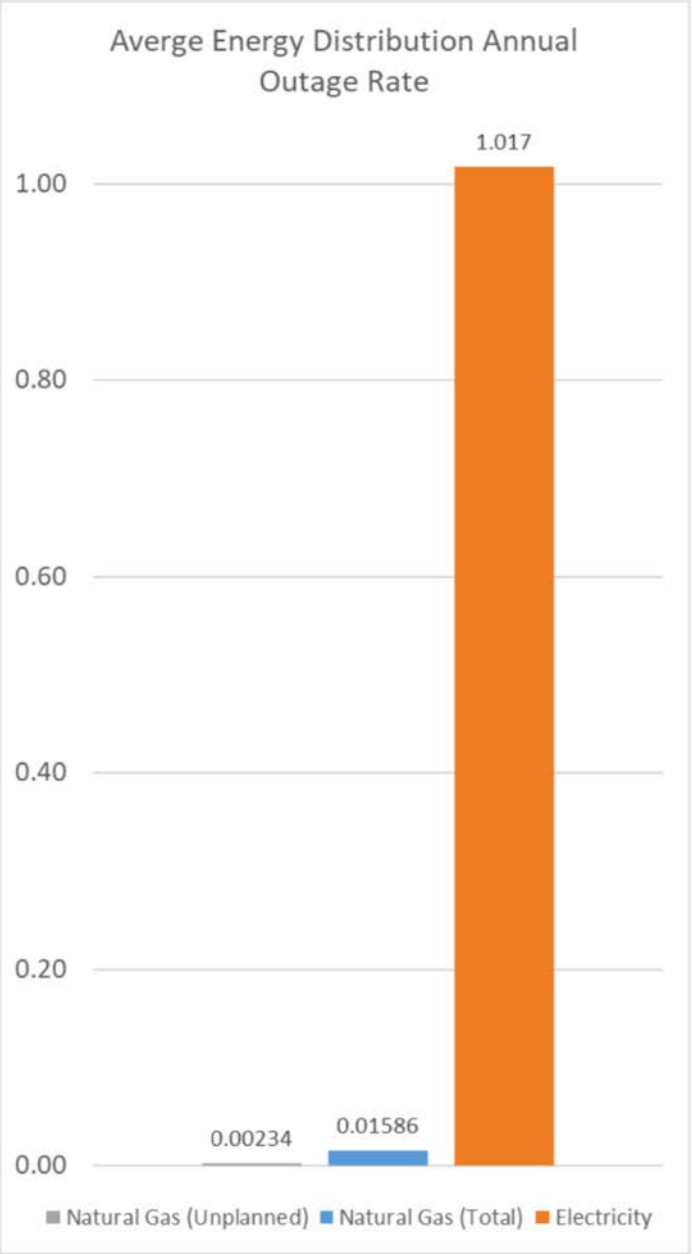
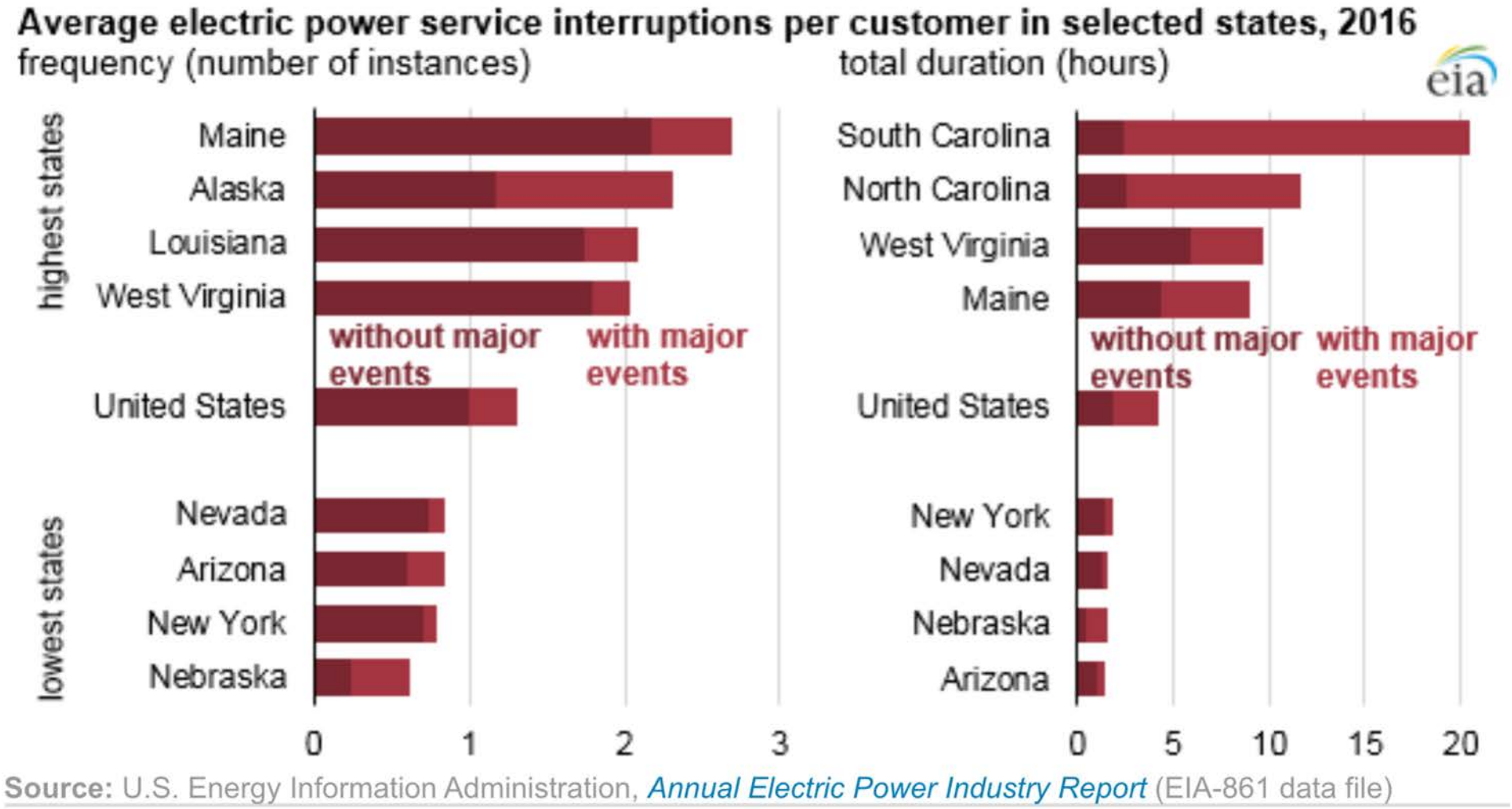


Figure 14: Comparison of Natural Gas and Electric Annual Outage Rates

https://www.gti.energy/wp-content/uploads/2018/11/Assessment-of-Natural-Gas-Electric-Distribution-Service-Reliability-TopicalReport-Jul2018.pdf

Resilience and Outages?

#RESNET2022



But most outages are short

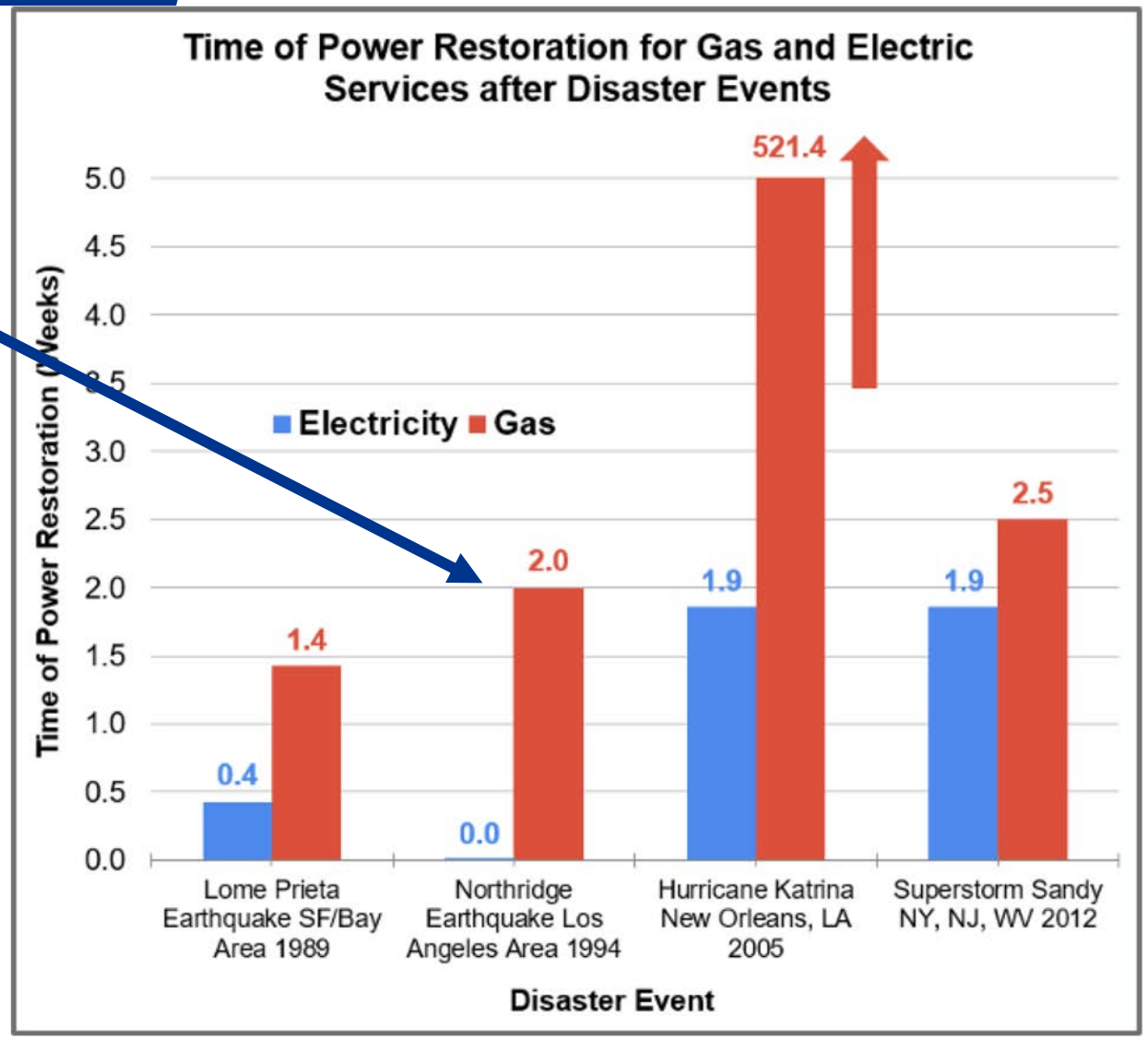
Typically < 24-hours

https://www.eia.gov/todayinenergy/detail.php?id=35652

Resilience and Outages?

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

- On-site **storage and generation** allows basic home operation during emergencies.
- About half of **natural gas** processing is along the gulf coast and highly vulnerable to *hurricanes and storm* surges.



Health Benefits of Decarbonization

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

Both Food and Heat Sources Generate Pollutants

Gas

Particles,

CO_2 & H_2O

NO_2 (and NO), CO

Electric

Fine and ultrafine particles
Less so from induction

Food

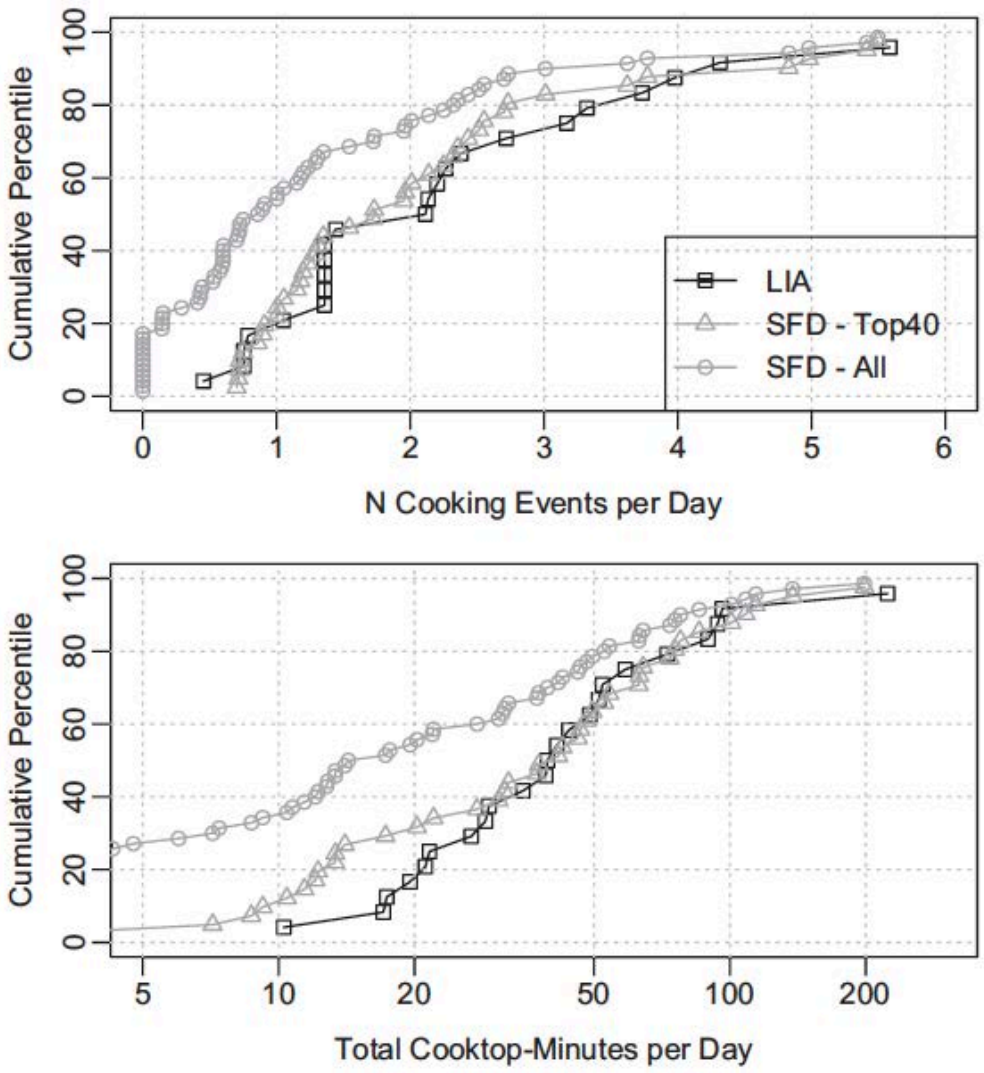
Particles, Formaldehyde, Acetaldehyde, Acrolein,

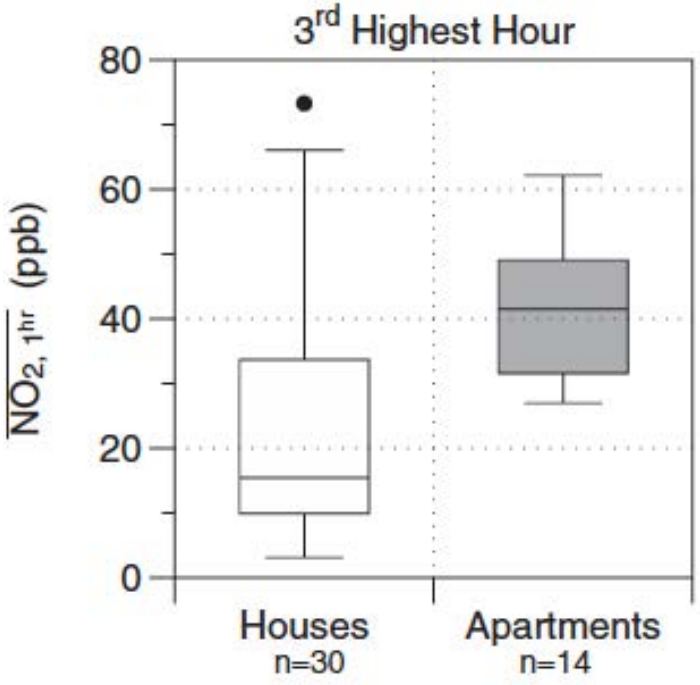
H_2O, Odors

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





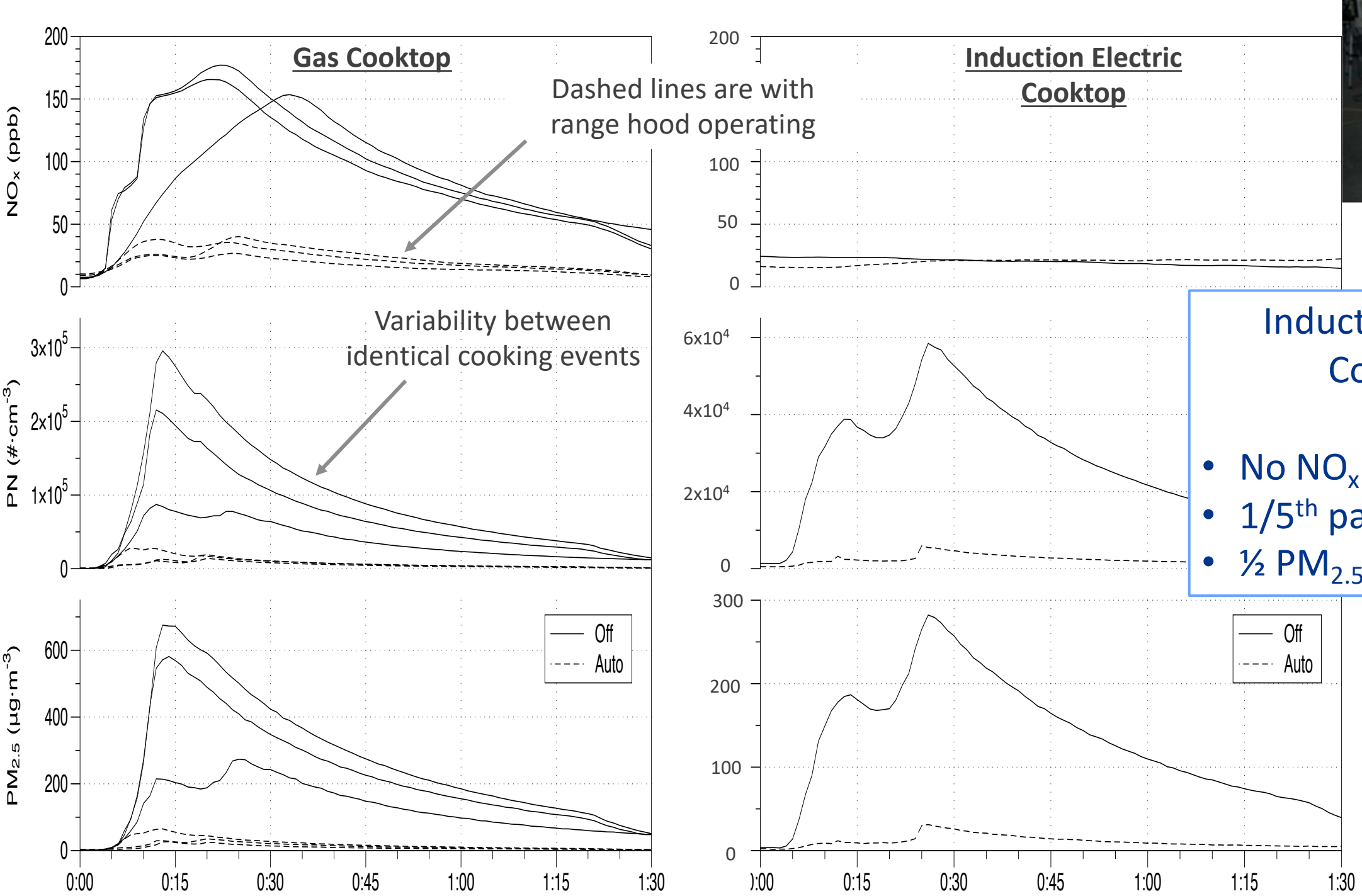
Lab testing at LBNL

Scripted Breakfast Meal

#RESNET2022

Breakfast Cooking Details - PARALLEL

Time (min)	Activity	Gas (lpm)
0	**Start front left burner on medium (2 lpm)** for hash browns	->
0:15	**Start front right burner on medium** (+2 lpm; **Total 4 lpm**) - bacon in pan (cook 12 min); remain to watch oil	->4.04
1.5	Add 2 hash browns to small skillet (cook 9 min); remain	
2	flip bacon and adjust in pan; remain	
3.5	Press hash browns 5s each; remain	
4	Flip bacon and adjust in pan; remain	
5.5	Flip hash browns; press 5s each; remain	3.99
6	Flip bacon and adjust in pan; remain	
7	Flip bacon and adjust in pan; remain	3.97
8	Press hash browns 5s each; remain	3.96
8-12	Flip bacon every 30s	
10	Return; flip hash browns; press	3.94
10:30	**Stop front left burner**; remove hash browns to plate with paper towel; place skillet on back left burner.	->2.02
12	**Stop front right burner**; remove bacon to plate; move pan to rear burner; leave uncovered	0
12.5	Place non-stick pan with butter on **front left burner, start and adjust to medium (2 lpm)**	->2.04
14	Add eggs to non-stick pan (cook 4 min); remain	2.05
17	Flip eggs	2.05
18	**Stop front left burner;** remove eggs to plate; place pan on front right burner	->0
48	Remove skillets and fry pan from cooktop	



Induction vs. Gas Cooktop:

- No NO_x
- 1/5th particle count
- ½ $PM_{2.5}$ mass

Range Hood Effectiveness

Capture efficiency (CE):

The fraction of pollutants emitted at the cooktop or in the oven that are removed before mixing into the air of the home

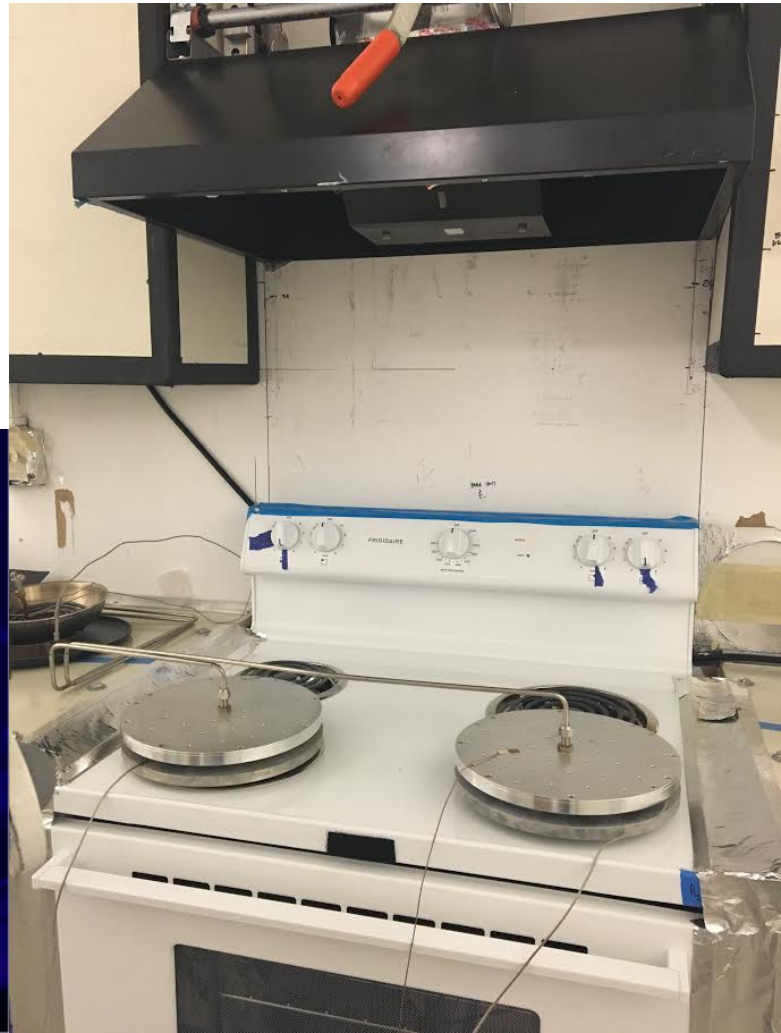
Standardized test method for rating about to become international = ratings coming soon

Designation: E3087 – 17

Standard Test Method for
Measuring Capture Efficiency of Domestic Range Hoods[1]

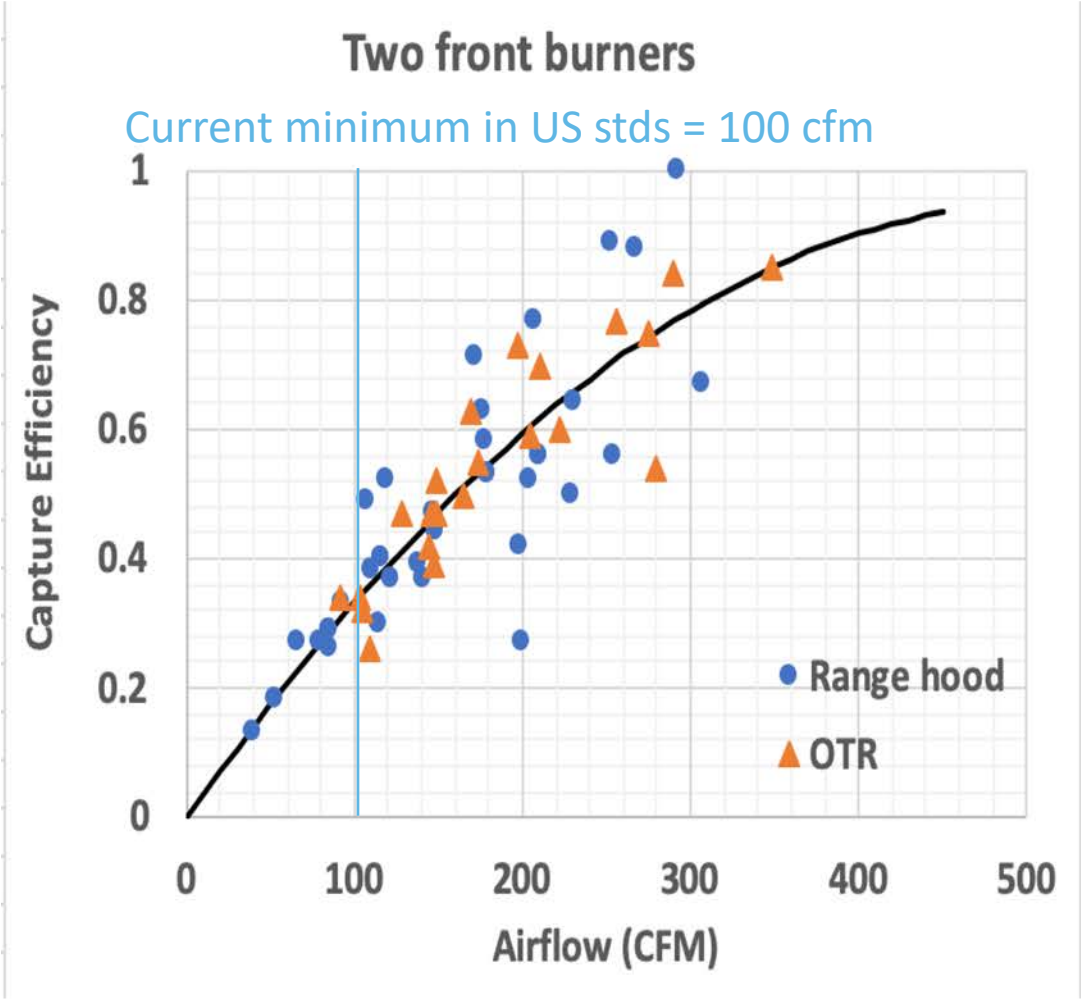
Lab Testing

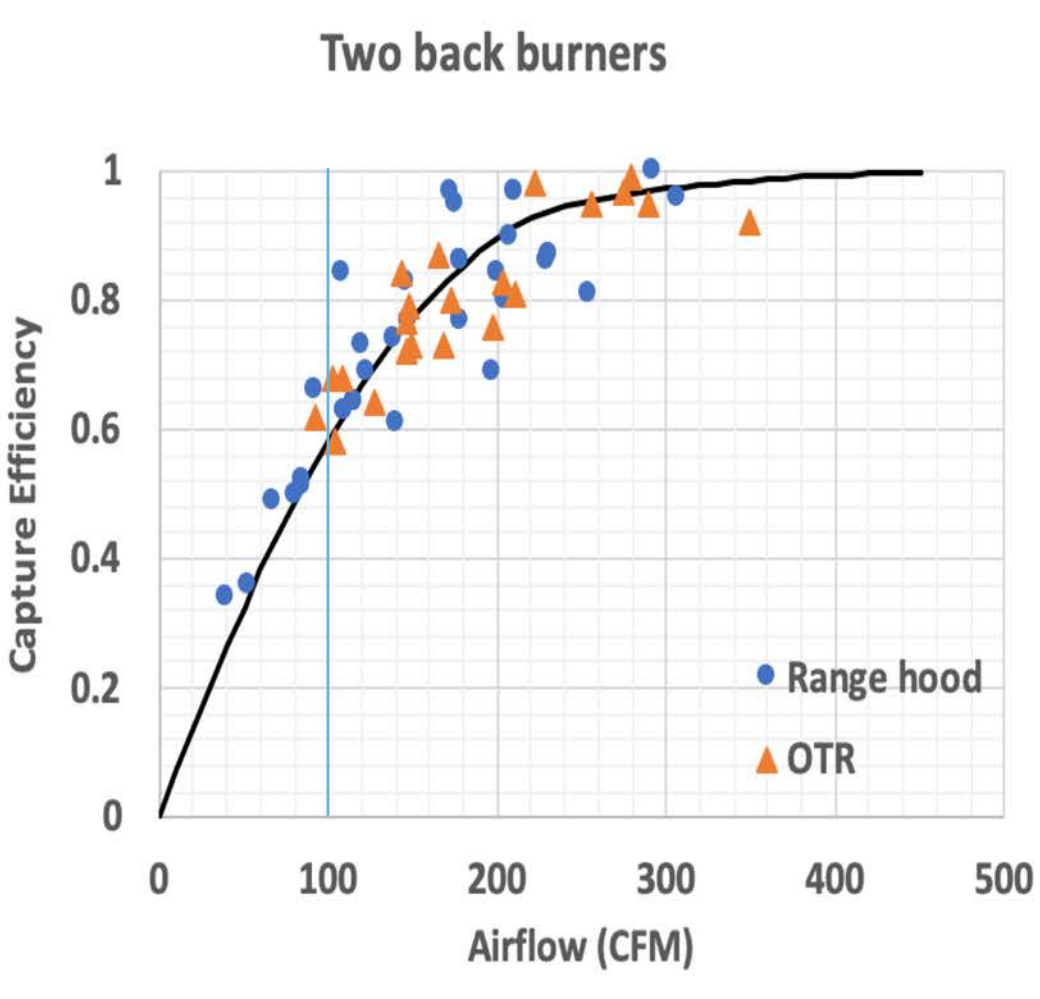
+45.8
+46.9
+54.1
+52.9
+62.6
+62.5
L0
Max = 134.9
Avg = 84.4
Min = 58.3
@eps=0.2
>170.0
+157.2
+73.4



Field Testing

Capture Efficiency





OTR = Microwave with Exhaust

New CA code requirements

- Key health contaminants are $PM_{2.5}$ (gas and electric cooking) and NO_2 (only from gas)
- To meet health guidelines better kitchen ventilation is required for NO_2, i.e., gas cooking

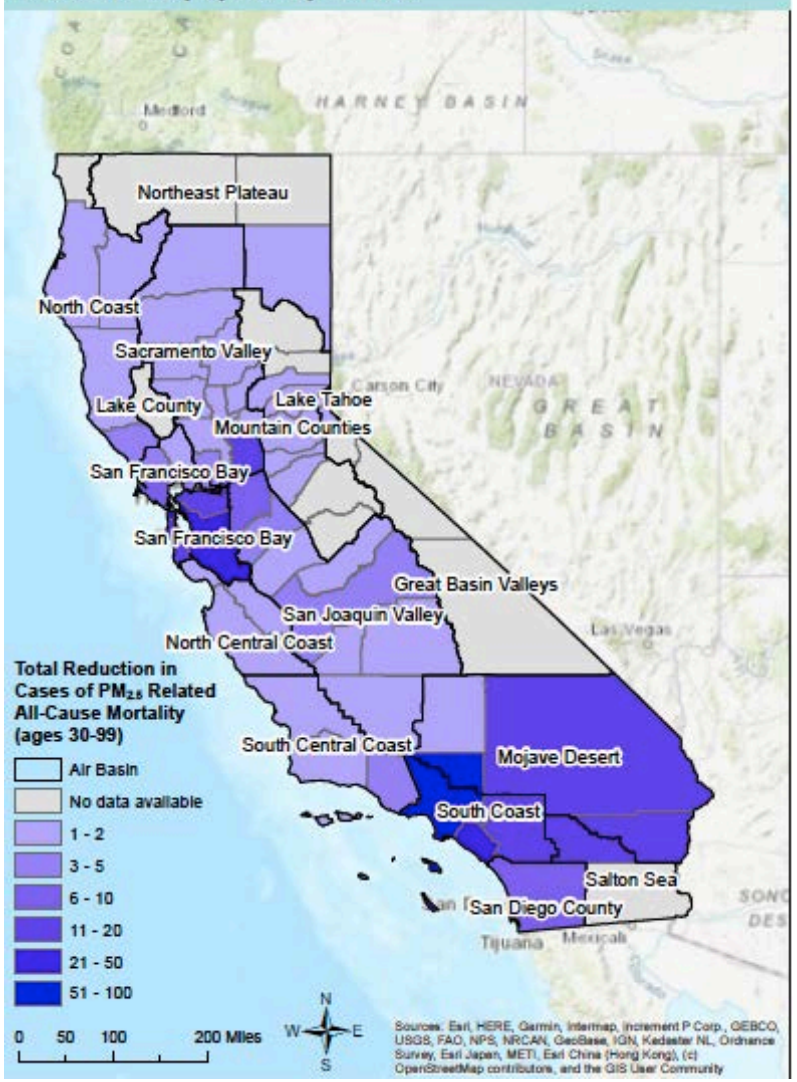
Floor Area (ft^2)	**Capture Efficiency**		**Airflow as installed (cfm)**	
	Gas	Electric	Gas	Electric
>1500 ft^2	0.70	0.50	180	110
1000 - 1500 ft^2	0.80	0.50	250	110
750 - 1000 ft^2	0.85	0.55	280	130
<750 ft^2	0.85	0.65	280	160

Outdoor Air quality: Avoided Mortality

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**

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

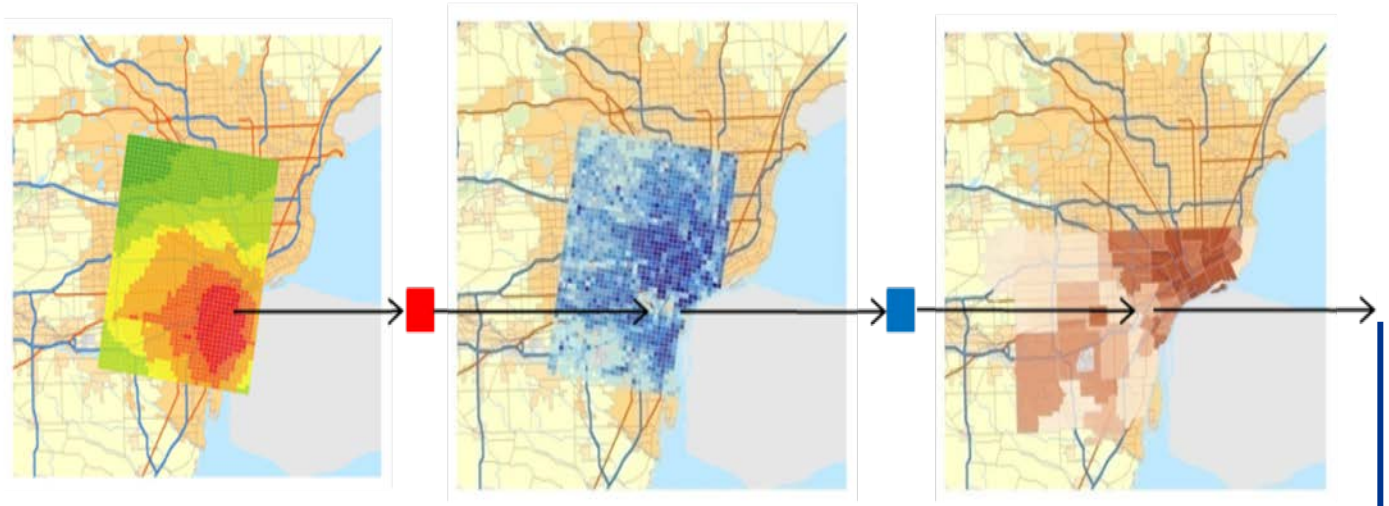


Zhu et al. 2020. Effects of Residential gas Appliances on Indoor and Outdoor Air Quality and Public Health in California. UCLA Fielding School of Public Health

Outdoor Air Quality Health Impacts Homes+Transport+some Industries (EPRI)

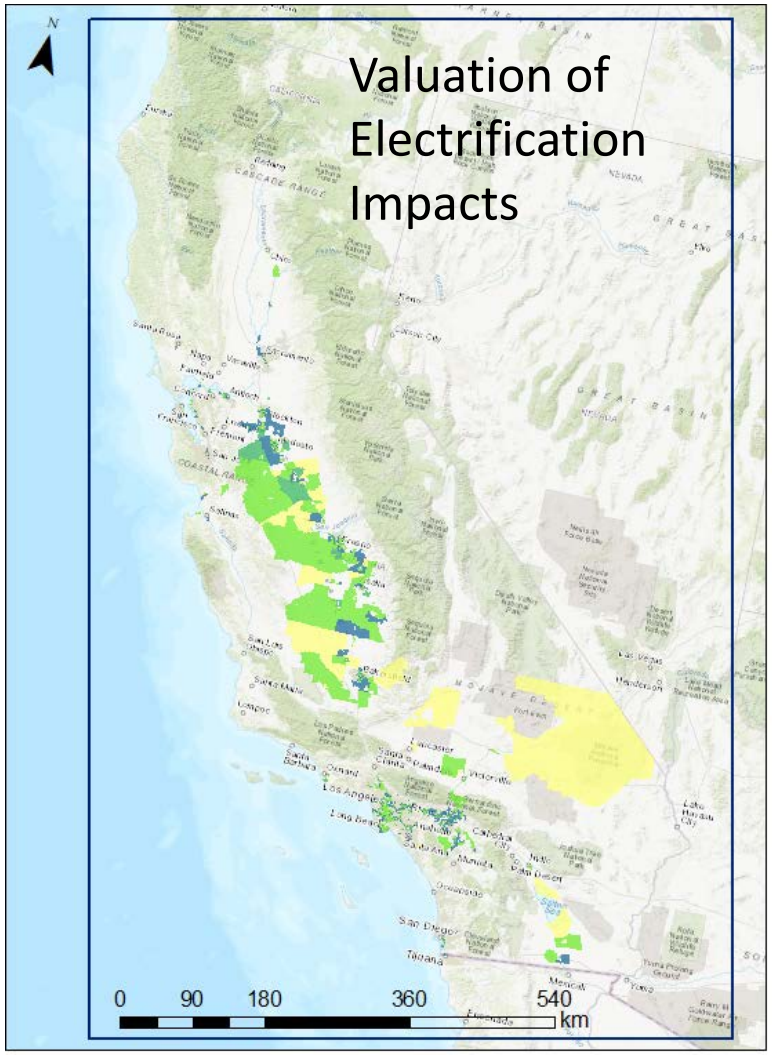
EPA's Environmental Benefits Mapping and Analysis Program (BenMAP)

Pollutant change | Population | Baseline incidence



Avoided mortality per year

EPA's Value of Statistical Life $8.7 million (2015$)



Outdoor Air Quality Health Impacts Homes+Transport+some Industries (EPRI)

EPA's Environmental Benefits Mapping and Analysis Program (BenMAP)

Pollutant change

Population

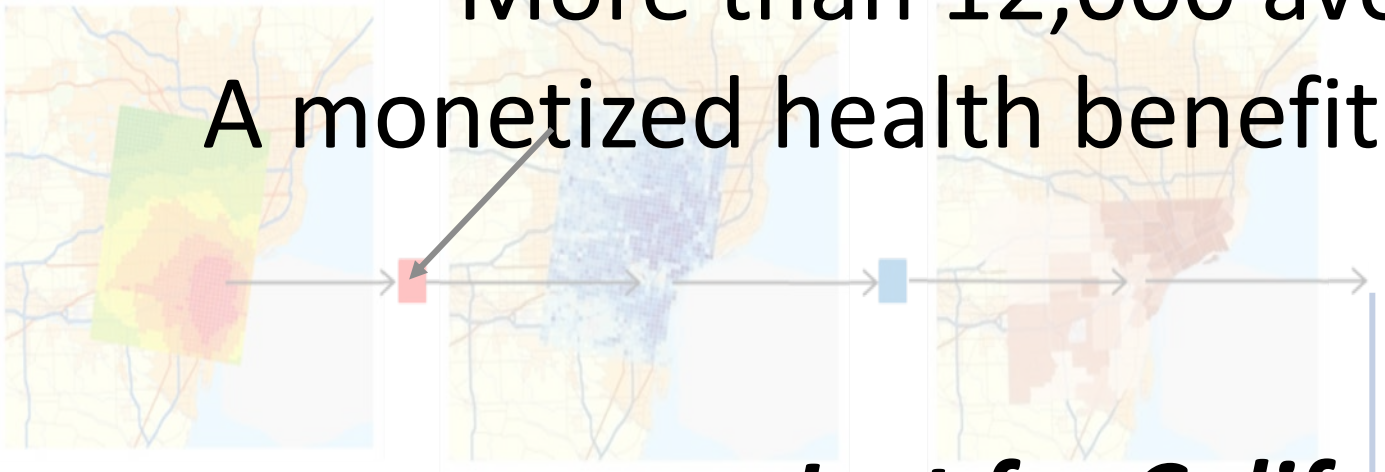
Baseline incidence

Valuation of Electrification Impacts

Electrification results in

More than 12,000 avoided deaths

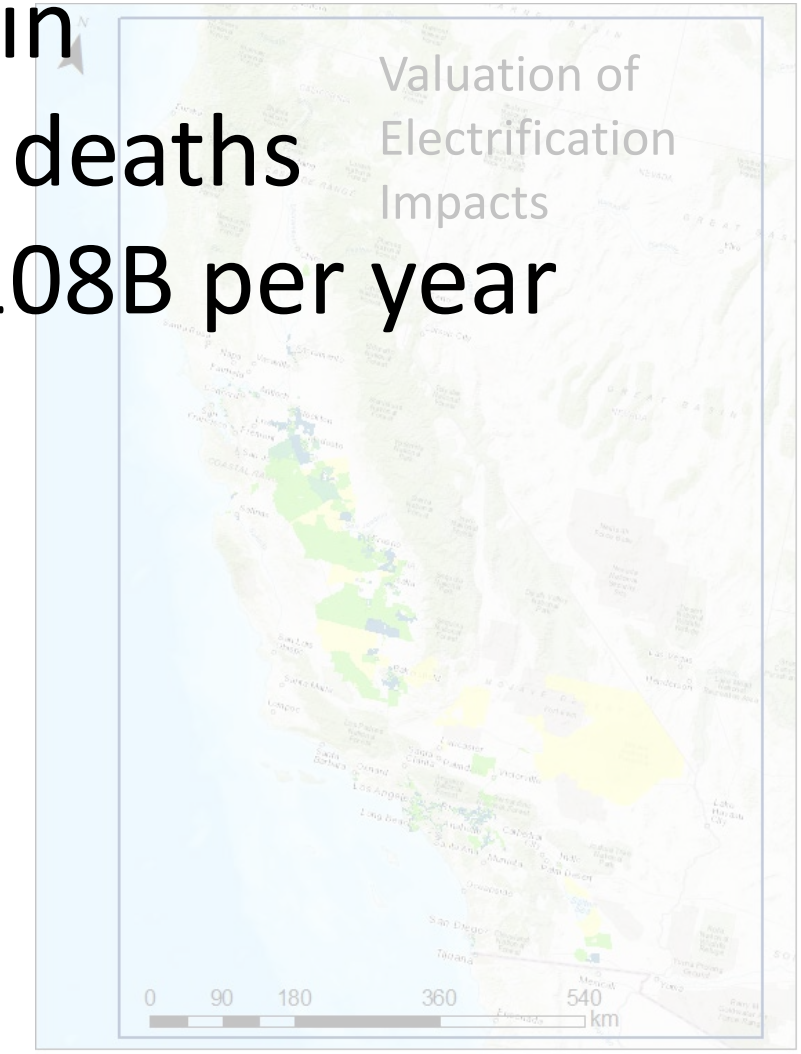
A monetized health benefit of $108B per year



Just for California!

Avoided mortality per year

EPA's Value of Statistical Life $8.7 million (2015$)



Other Barriers

Current biggest barriers for decarbonizing homes

- Lack of workforce for existing homes
  - All contractors are busy
  - Anecdotally: 6-12 months lead time
- Lack of equipment
  - COVID Supply chain issues?
  - Poor US Manufacturing base

Summary of Issues for Raters

- RESNET CO_2 index
- New building codes for all-electric homes
- New equipment: batteries, thermal storage, smart panels, EV charging
- New equipment sizing paradigms
  - A small capacity unit with storage = same performance as a large capacity unit
- No combustion safety testing
- No appliances to relight after blower door air leakage test
- Kitchen venting

Resources

- For electrification big picture: **Rewiring America** and **Rewiring Communities**
- For power-restricted homes: **Redwood Energy Pocket Guide**
- Check with your contractor or utility for rebates

Rewiring Communities:

A Plan to Accelerate Climate Action and Environmental Justice By Investing in Household Electrification at the Local Level

[1] Adam Zurofsky,[2] Jeffrey Schub,[3] John Rhodes,[4] Tony Curnes,[5] and Sam Calisch[6]

REWIRING AMERICA

Coalition for Green Capital

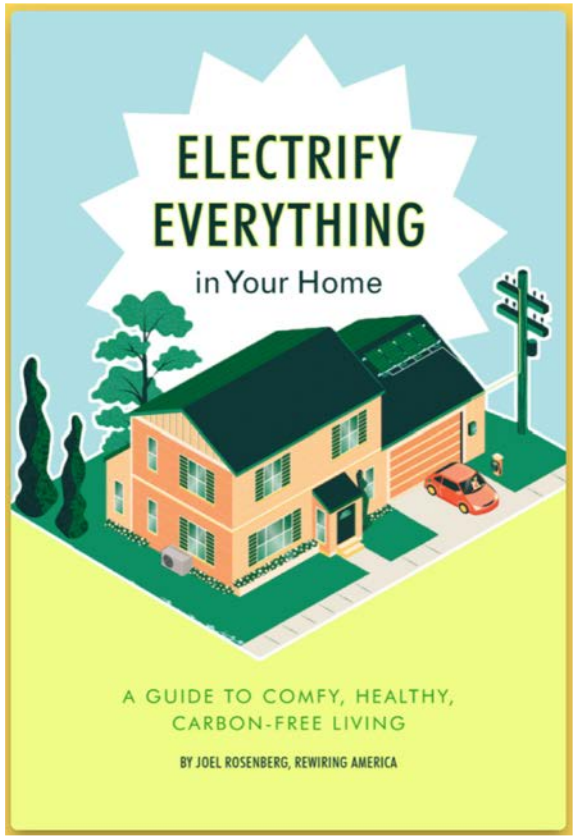
Consumer resources

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

THE SWITCH IS ON

https://www.switchison.org/

Most Efficient 2022
ENERGY STAR
www.energystar.gov



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

BUILDING DECARBONIZATION COALITION

Lawrence Berkeley National Laboratory

iswalker@lbl.gov

(510) 486-4692

MS90-3074, 1 Cyclotron Road
Berkeley, CA, 94720
USA

THANK YOU

REFERENCES

- Walker, I. S., Less, B. D., & Modrego, N. C. (2022). *Carbon and Energy Cost Impacts of Electrification of Space Heating with Heat Pumps in the US*. Energy and Buildings, 111910. *https://www.sciencedirect.com/science/article/pii/S0378778822000810?dgcid=author*

- 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 (LBNL). *https://homes.lbl.gov/publications/cost-decarbonization-and-energy*

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