Challenges and Opportunities for Home Decarbonization

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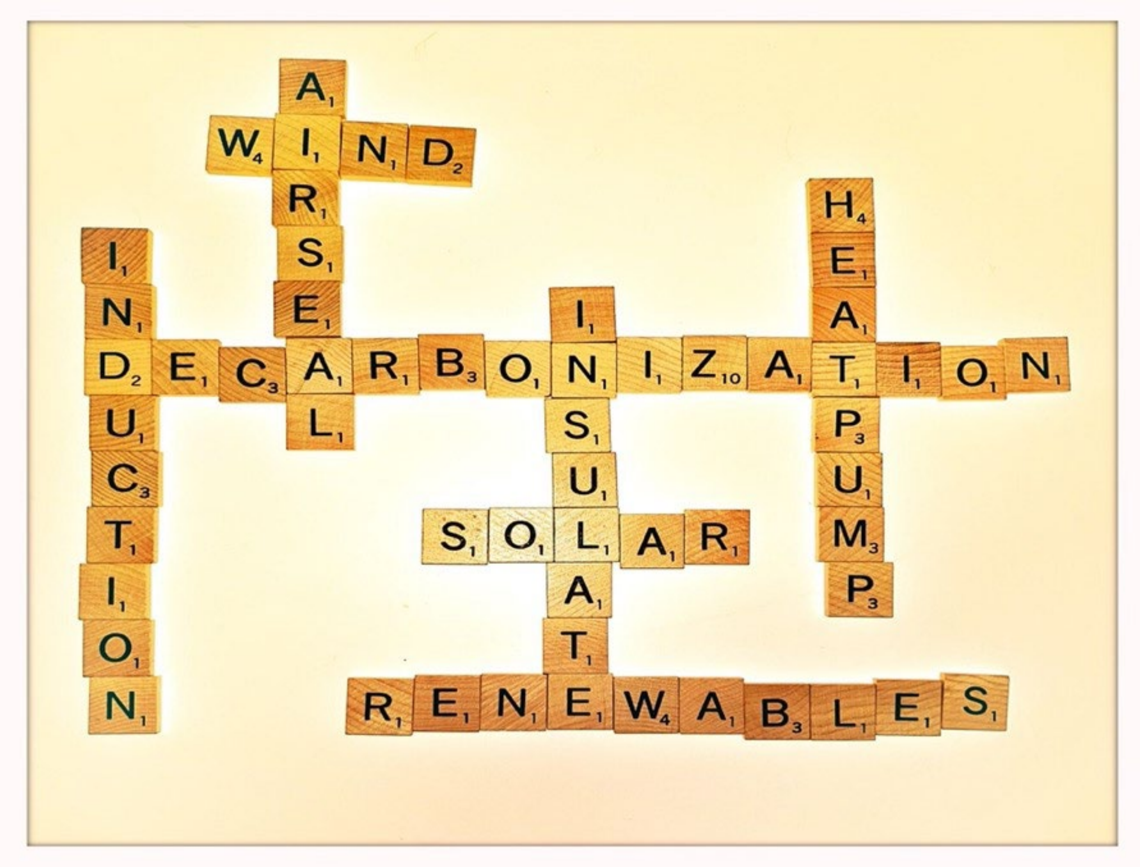


Background – recent LBNL studies

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 (> 1,700 single family energy upgrade projects)
   - cost and energy data (mix of measured and modeled)
   - targeted significant energy/carbon reductions
   - national average costs ($2019)

Challenges and Opportunities

Outline near term challenges and opportunities for scaling up residential decarbonization

- Not as simple as saying just put heat pumps every where
- Identify R&D opportunities for BTO (and others)
- Identify barriers current not sufficiently addressed in current DOE initiatives and hard to reach residential market segments
- Today – high level takeaways
- Many more recommendations in final report – coming soon

What is not included:

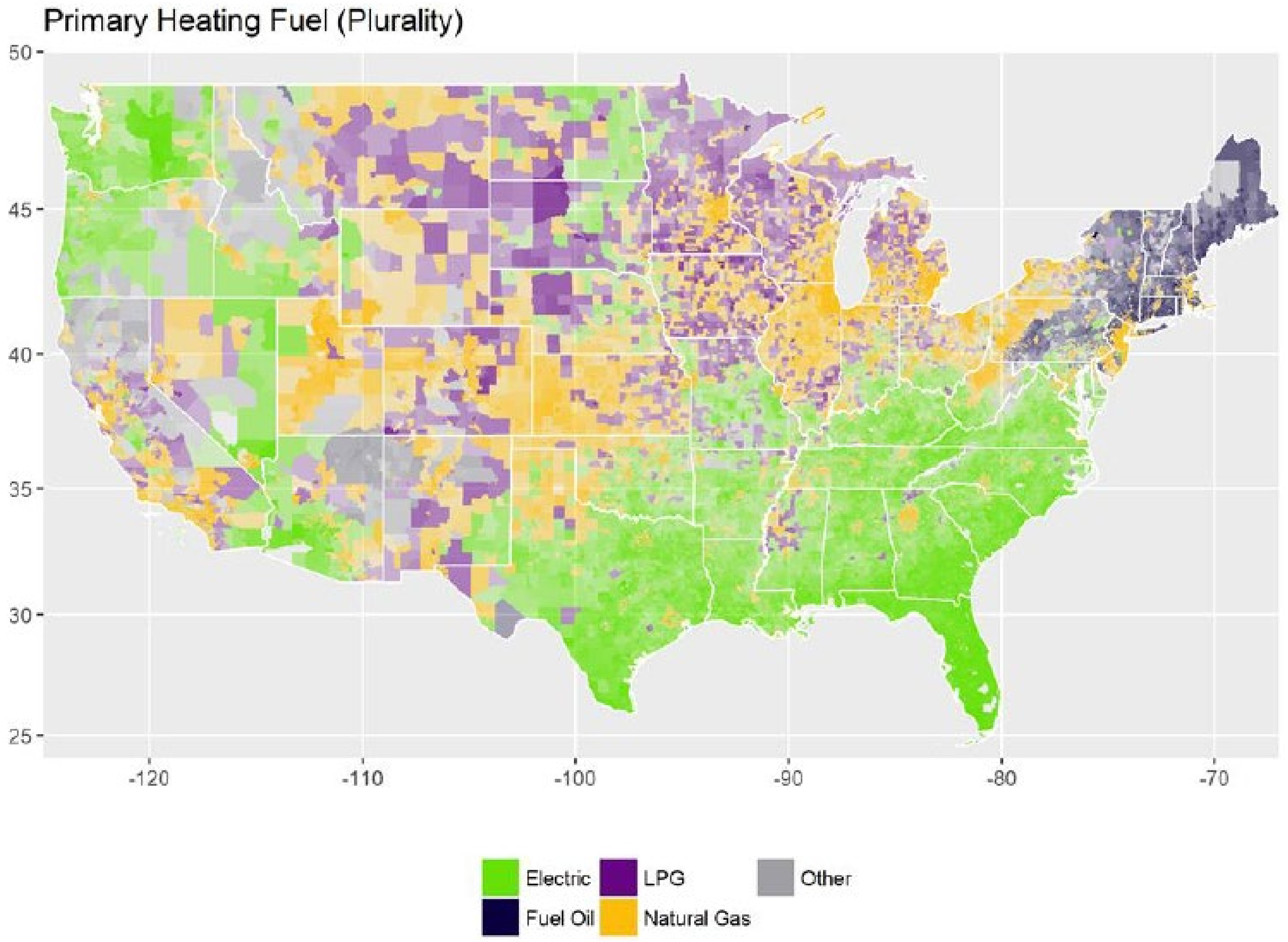
- Not a review of all existing DOE initiatives or a comprehensive guide to home decarbonization

Three Priorities for Home Decarbonization

Focus on existing homes

1. **Develop solutions for all households**
    - Beyond single-family owner-occupied:
        - 44 million rental households
        - 7 million manufactured homes
        - 12 million homes needing health and safety mitigations
2. **Make decarbonization affordable**
    - Current cost about $55,000 – ten times median household savings
    - Reduce costs – standardize and outsource customer acquisition to lower soft costs, limit service/panel upgrades & develop power efficient products
    - Look for ways to control bills, provide access to financing, use affordability not investment language and metrics
3. **Support the US clean energy economy**
    - Creates jobs + product manufacturing opportunities

Problem Scope: How Many Homes?



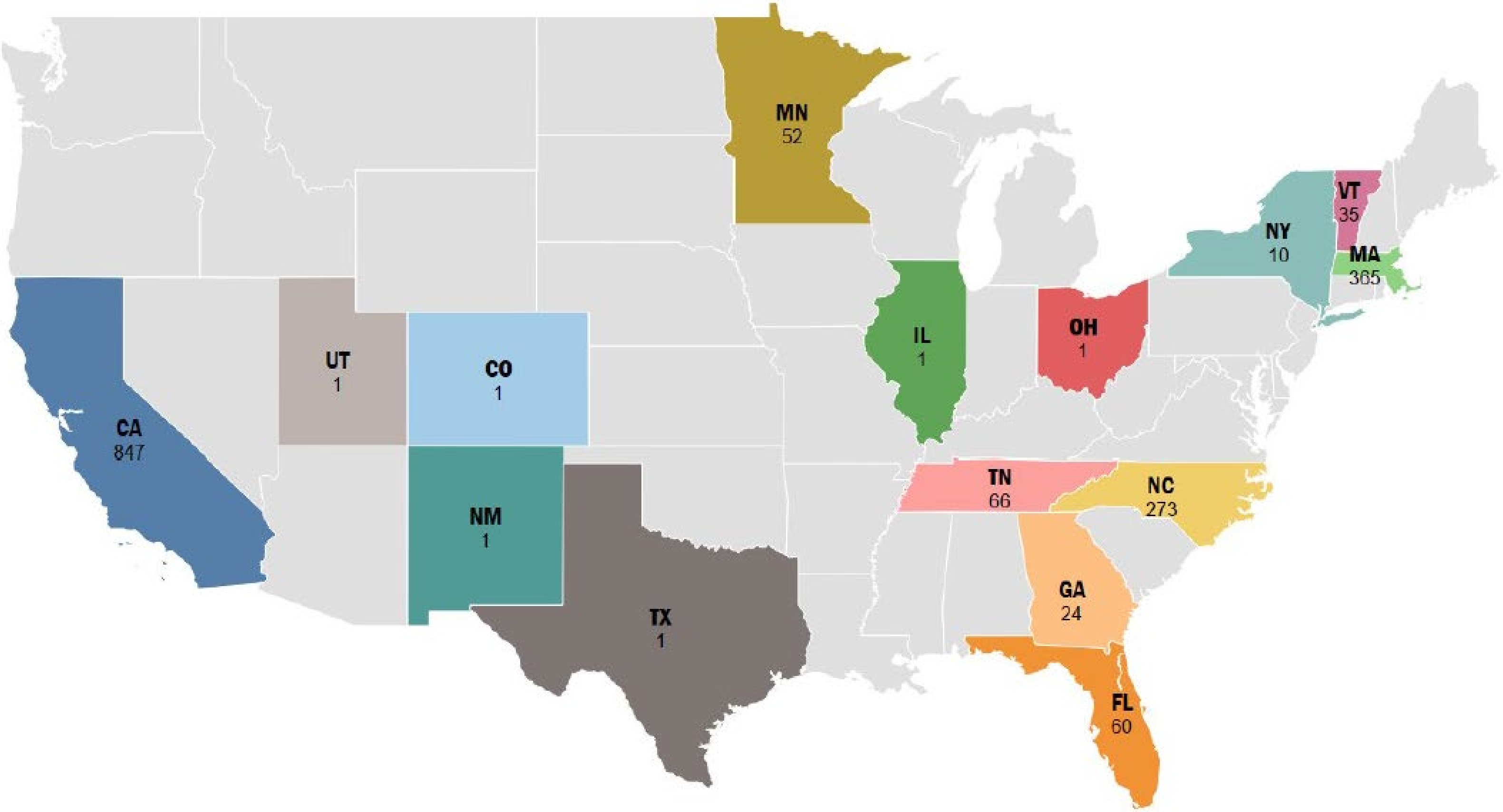
Data from the American Community Survey (2016).

>25% of homes are already all-electric: they need low carbon electricity from renewables + efficient appliances

~75% homes need to electrify end-uses - much more effort required

- DOE's EAS-E prize is focused on hard to electrify homes

The cost of Saving Carbon

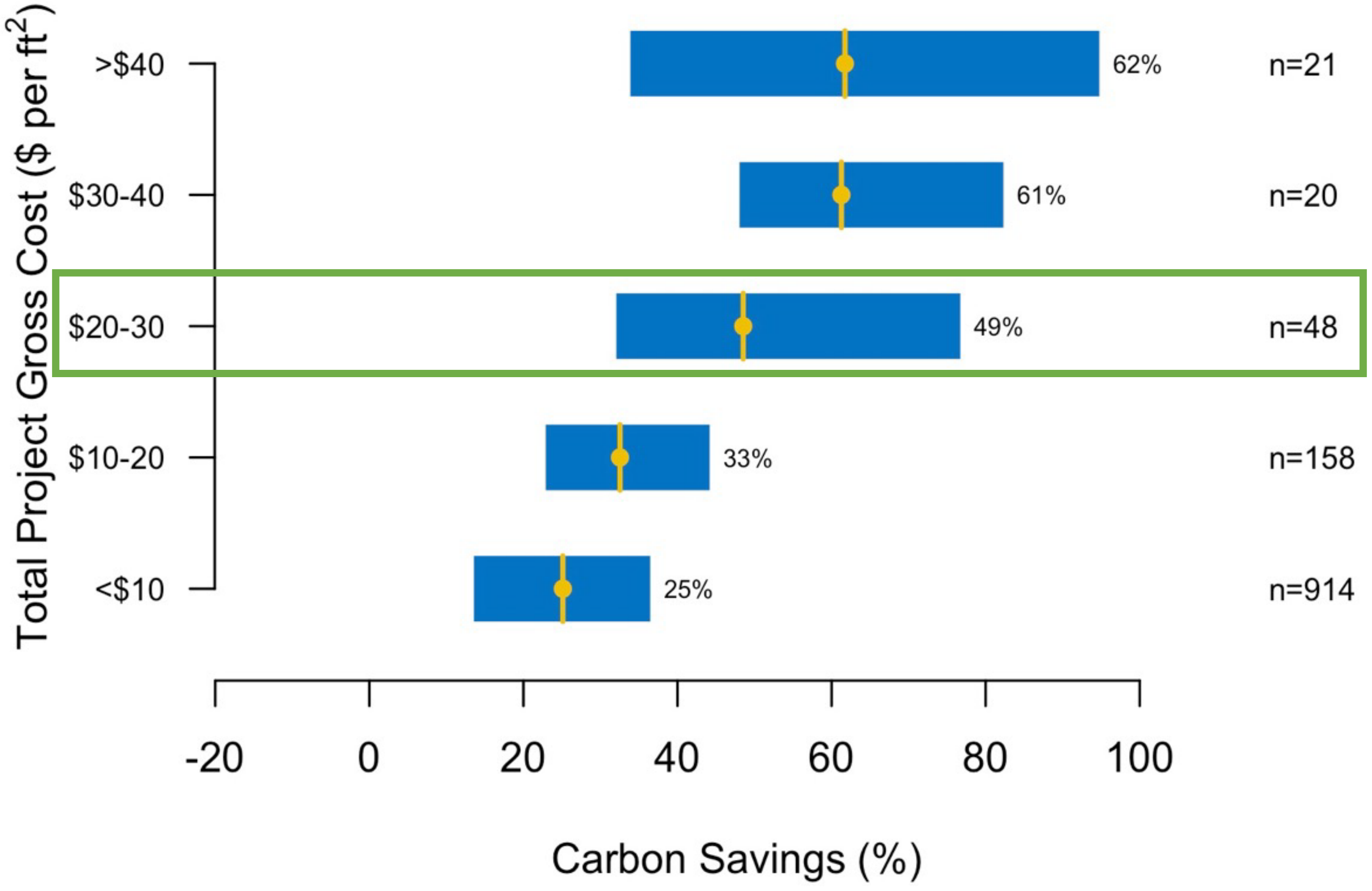


Sample of Convenience:
- Most data voluntarily provided by energy programs
- Paid contributions for 475 homes

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

The cost of current practice



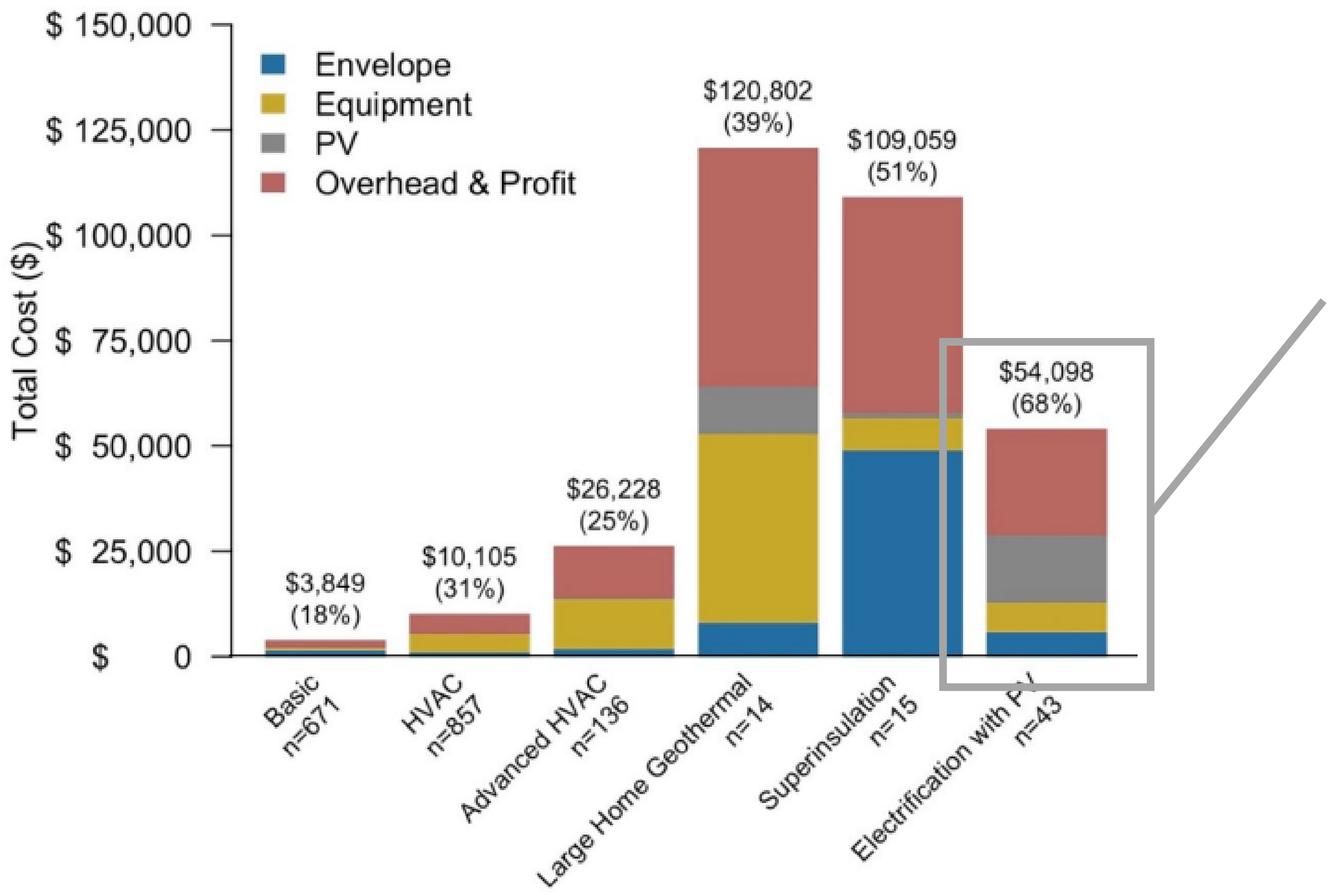
Current least-cost way to reduce CO_2e by significant amount (>50%) is about $55,000

CO_2e reduction focus could reduce this to $40,000

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

Lowest-cost Strategies to reduce carbon emissions by >50%

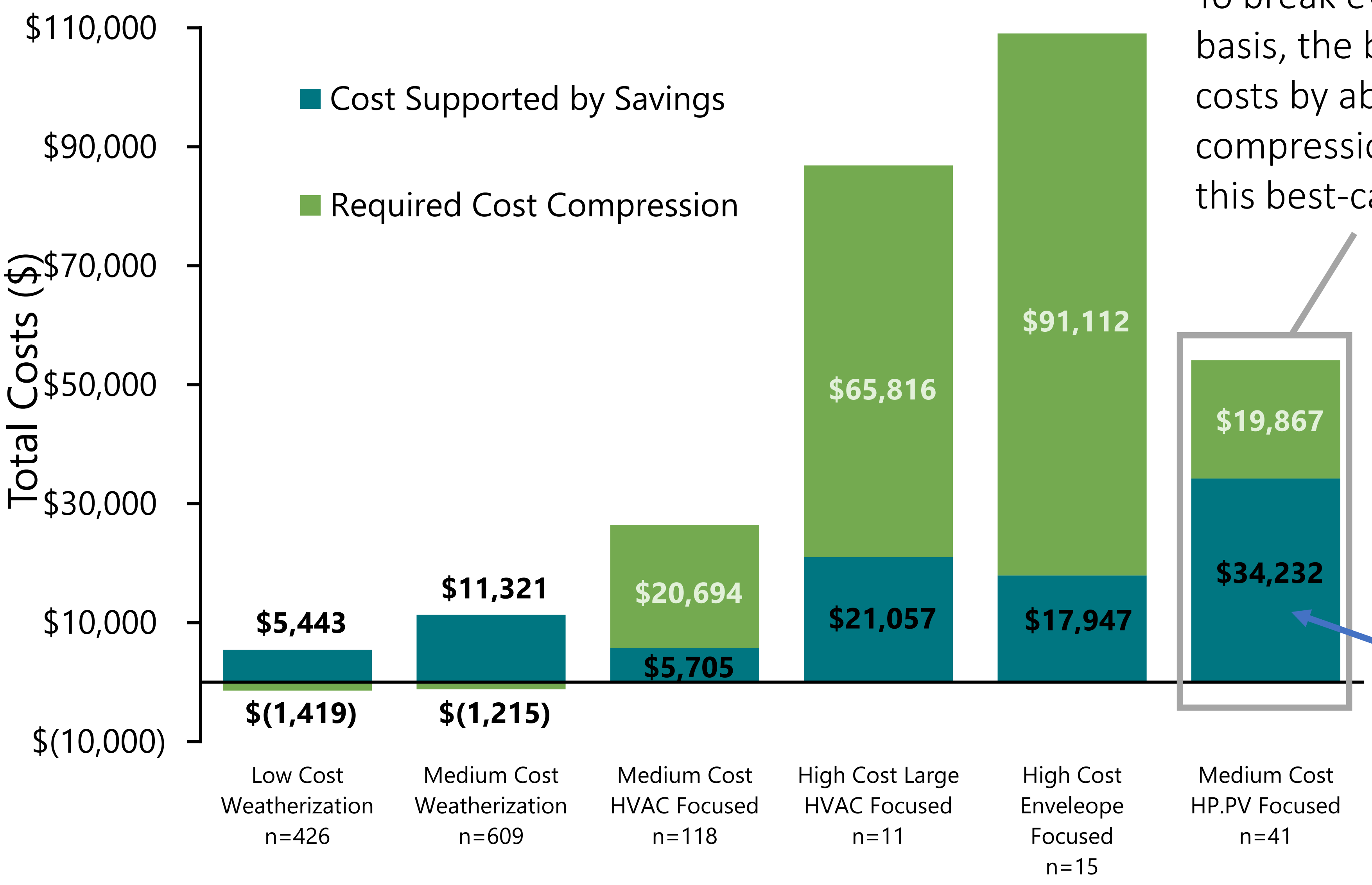
Clustered retrofit project cost data by type, including average overhead/profit (47%) for median gross project cost. Percent shows carbon savings.



The lowest cost approaches for more than 50% energy and CO_2 savings:

- **Include typical EE weatherization measures (home and duct air sealing and insulation)**
- Electrification of heating, DHW, cooking, clothes drying
- Add solar PV
- These projects cost about $54,000 ($28/ft^2) and had median CO_2 reductions of 68%
- High O&P indicates business models need to be addressed
- Homes that are not all-gas will cost less
- Snapshot in time – based on current state of the industry, e.g., may need less PV in the future with a fully decarbonized grid

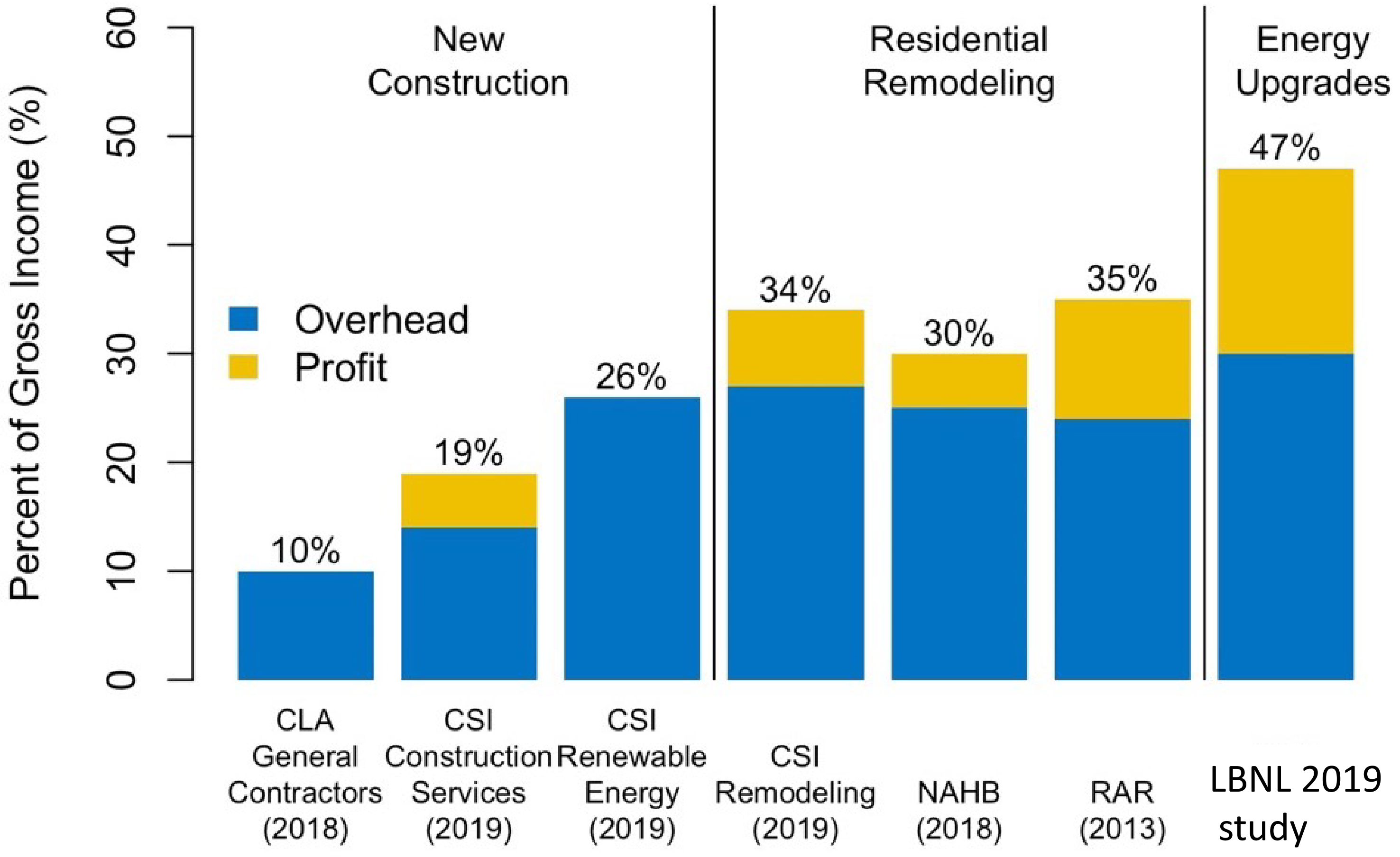
Today's Costs of Decarbonization



To break even financially on a monthly basis, the best-case projects need to reduce costs by about $20,000. Rebates and cost compression efforts are needed, even for this best-case approach.

Changes to NEM for rooftop solar PV may reduce cost savings and increase required cost compression

Opportunities for soft cost reduction



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 $1,500 per project, and up to $2,500.
- Reduce or automate diagnostic testing and commissioning, e.g., combustion safety testing that is typically $400 per project.
- Automated, rapid HVAC equipment sizing, could save $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

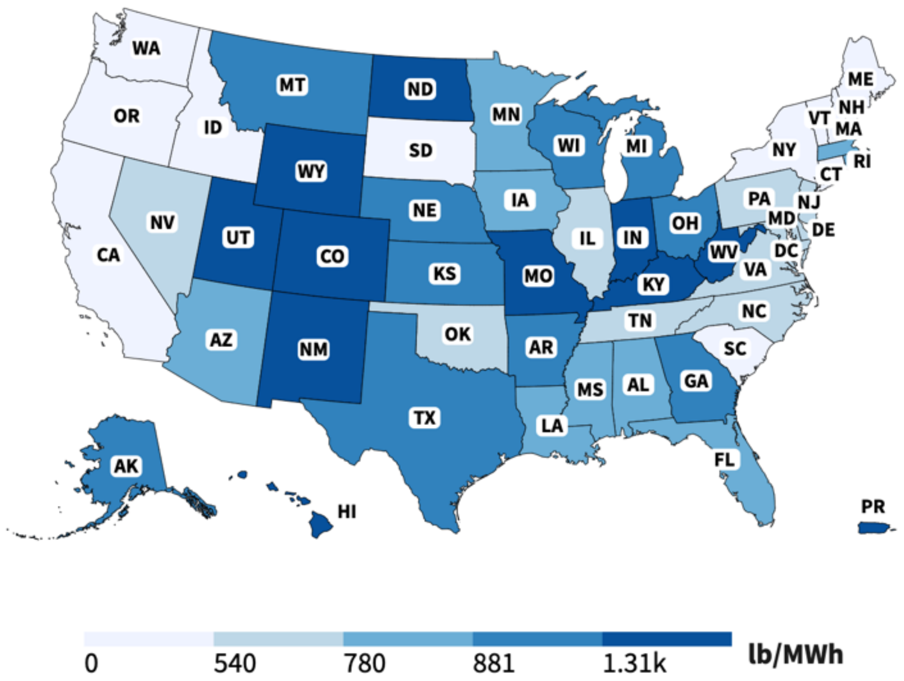
New & Emerging Metrics

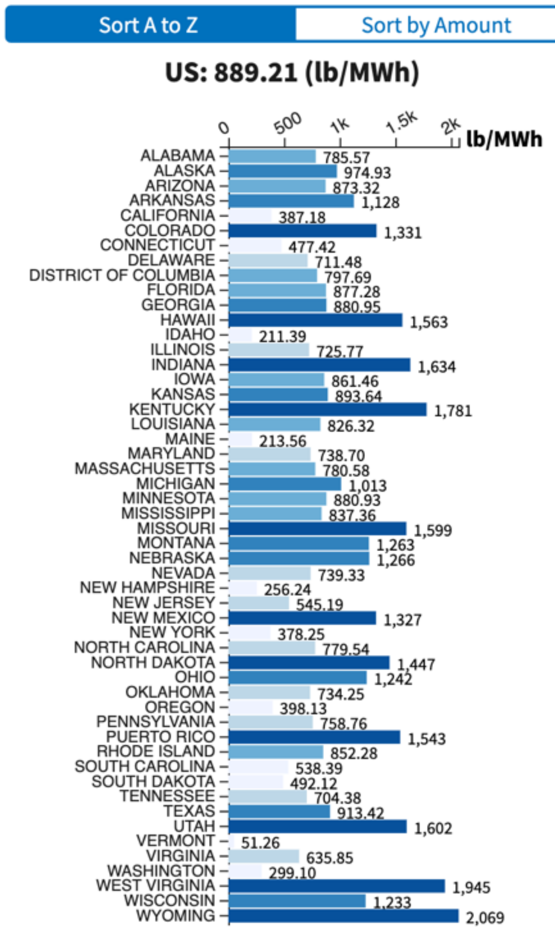
- **Household peak power**
  - Integral with panel/service upgrades and utility distribution needs
- **Appliance *power efficiency***
  - Provide the same service at lower power
  - Give consumers and contractors ability to select lower power appliances (120V, 15A)
  - Reduces grid/utility capacity costs
- **Annual carbon emissions**
  - RESNET already has a CO_2 index – pathway to replace energy codes with carbon codes
- **On-site power and storage**
  - Integrated into resiliency and grid interaction capabilities/future ratings
- **Time of energy use – linked to variation in CO_2 content of energy**
  - Give the right carbon use signals – current time of use rates can lead to more emissions: e.g., low nighttime rate for EV charging when little/no renewables in the power mix
- **Affordability (replacing ROI, LCC, TRC, etc.)**
  - Use metrics used in household decision making, e.g., Net monthly (financed) cost

CO_2e and bill savings vary greatly

- **2019** Gas and annual average electricity prices by state from EIA
- **2019** Annual average CO_2e intensity by state using US EPA eGRID

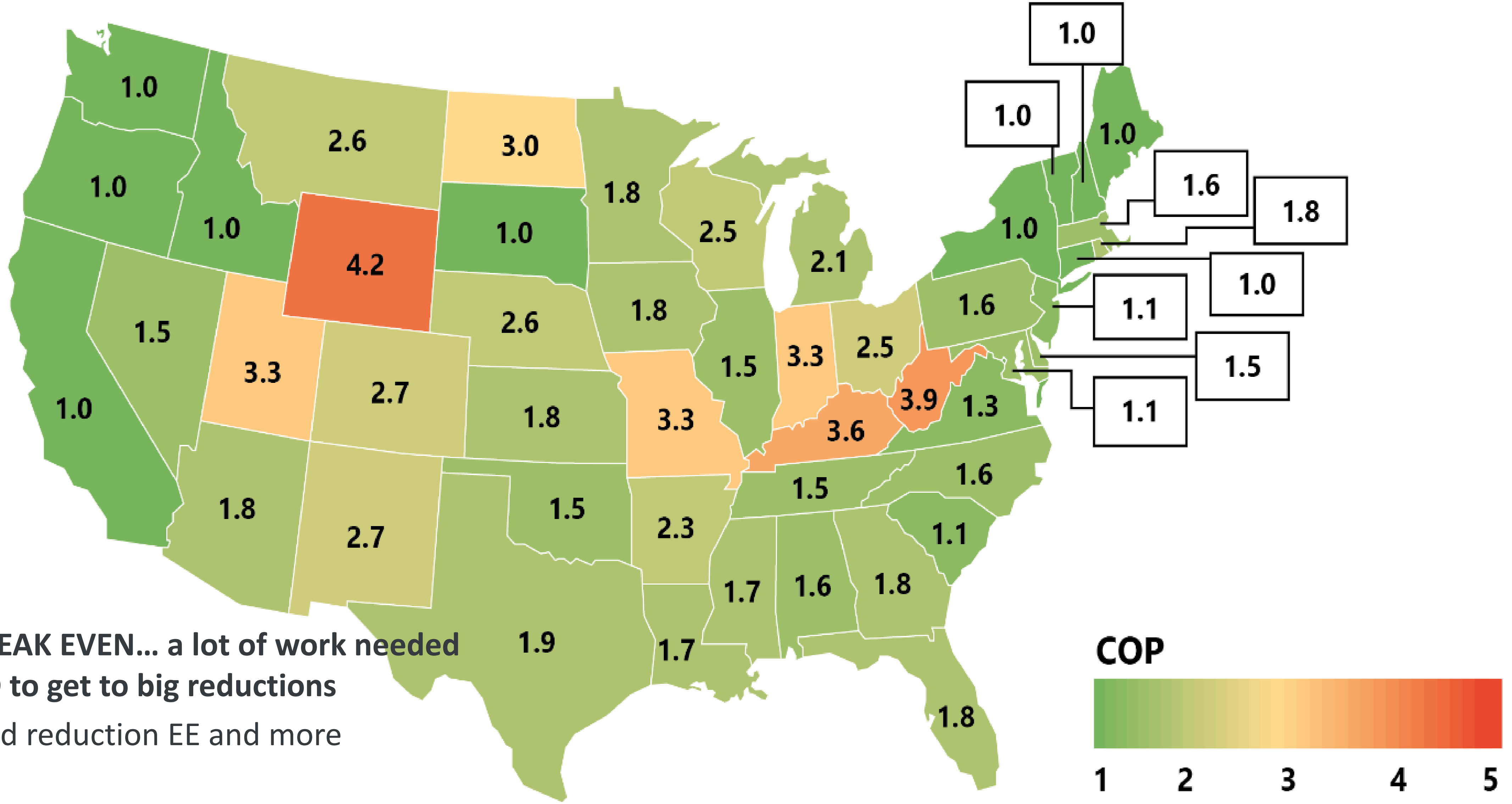
CO_2 equivalent total output emission rate (lb/MWh) by state, 2019





Regionality of Heat Pump Benefits – CO_2e

Map of minimum heat pump COP required for carbon dioxide equivalent emissions neutrality in each US state, compared with an 80% AFUE natural gas furnace

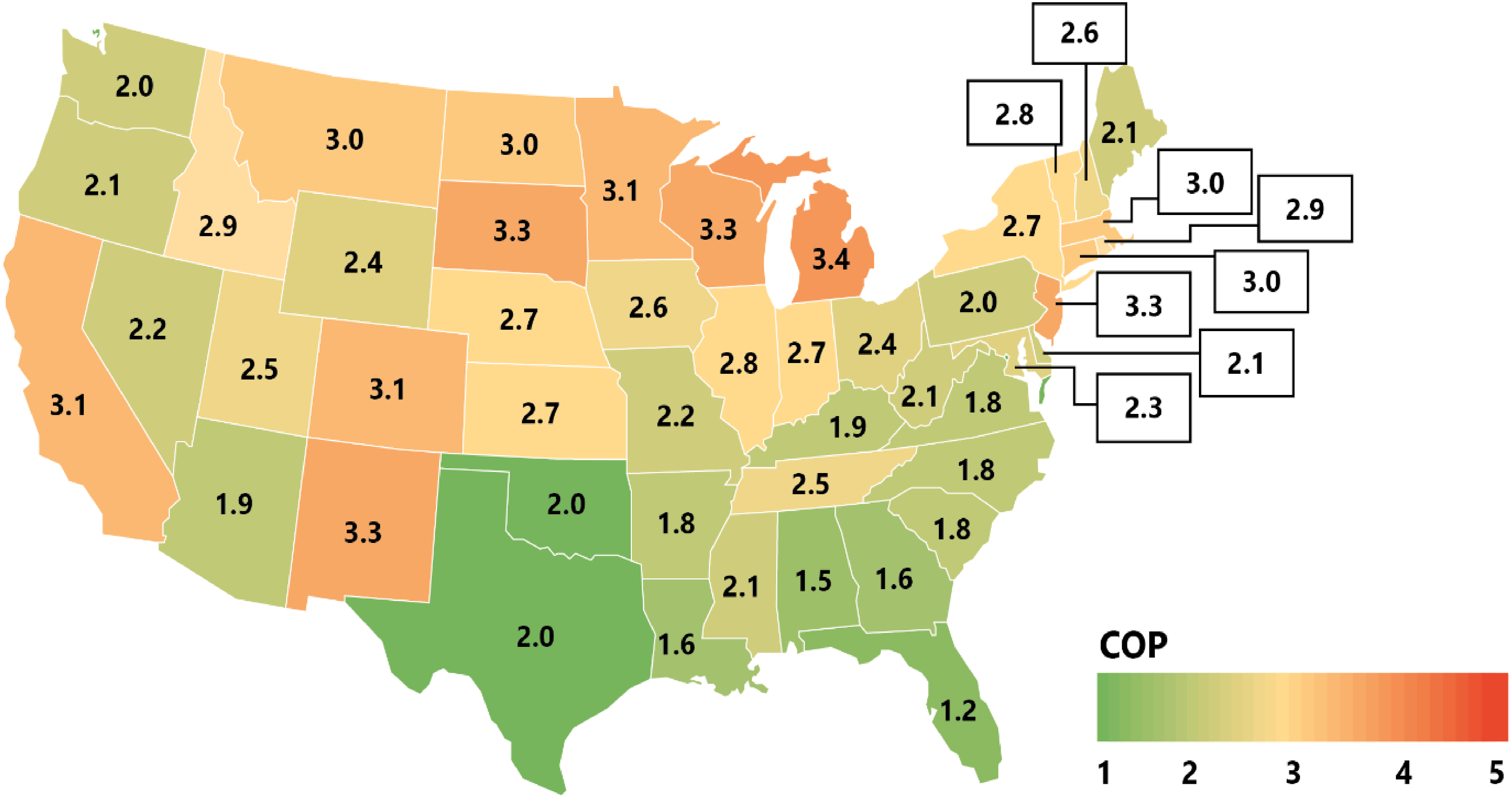


This is to BREAK EVEN… a lot of work needed by DOE R&D to get to big reductions

We need load reduction EE and more renewables

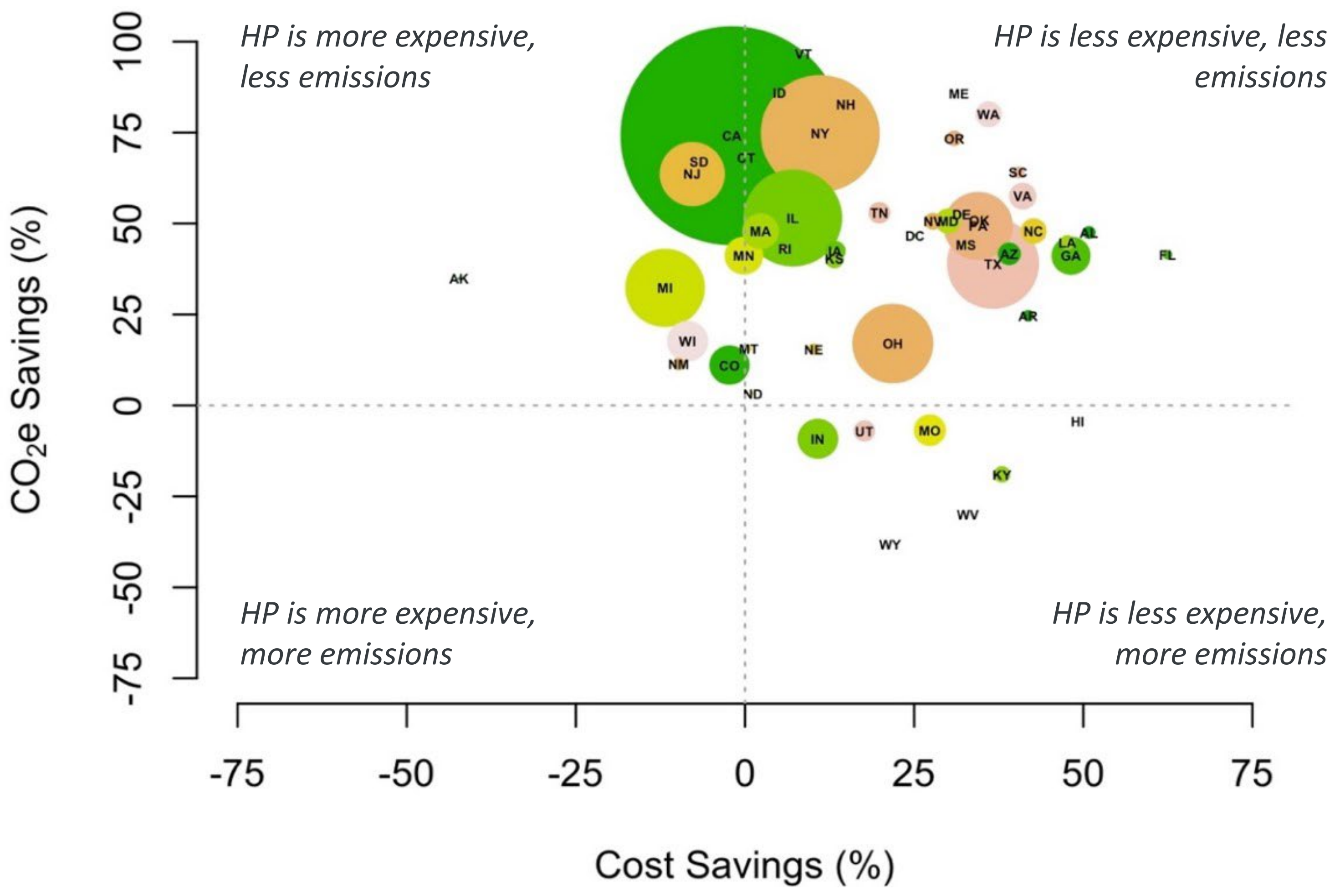
Regionality of Heat Pump Benefits – Bills

Map of minimum heat pump COP required for energy cost neutrality in each US state, compared with an 80% AFUE natural gas furnace



Regionality of Heat Pump Benefits

Percent savings for CO_{2e} and energy costs in each US state when replacing an **80 AFUE** furnace with a COP 3 heat pump *in 2019*



Points scaled according to number of natural gas heating appliances in each state

- High gas use states have big potential savings but face operating cost challenges
- Some states definitely need load reduction/EE measures to avoid bill increases
- 3 COP hard to achieve in northern tier states
- Carbon emission factors getting lower – already 10% below these 2019 values
- Costs are variable – cost savings about 20% bigger since 2019
- Future work: marginal CO_2e, compare to other fuels: propane and oil, use utility rate schedules.

Costs and benefits change over time: 2019

National Average
Weighted by number of gas furnace heating appliances in each state.

2019	COP 3 heat pump: CO_2e Savings	COP 3 heat pump: Energy Cost Savings	Break even COP: CO_2e COP	Break even COP: Energy Cost COP
65 AFUE	56%	31%	1.5	2.1
80 AFUE	45%	15%	1.7	2.6
95 AFUE	35%	-1%	2.0	3.1

Costs and benefits change over time: 2022

1. National average 2022 gas (+70% since 2019) and electric prices (+25% since 2019) – ***Financials can change a lot!***
2. 10% reduction in CO_2e/kWh - ***Gradual reduction over time***

	COP 3 heat pump		Break even COP	
2022	**CO_2e Savings**	**Energy Cost Savings (%)**	**CO_2e COP**	**Energy Cost COP**
65 AFUE	60%	50%	1.3	1.6
80 AFUE	50%	38%	1.5	2.0
95 AFUE	41%	26%	1.8	2.3

Need new products to lower installation costs and increase grid-responsiveness

Need to reduce electrification costs: panels, service and circuits

- Reducing and controlling home power draw also creates grid-responsive solutions

Challenge is greatest in “gassy” homes – they need the most changes

New products are needed

- Power-efficient appliances (create a “Power Star” label with EPA??) lower equipment and installation costs
- Form factor: HPs and HPWH that can fit in many locations: small closets, in floors
- Low noise HPWHs
- DIY products (some solar and HP already available)
- Emergency replacement – easily swapped in/out for temporary heat and DHW
- Integrated batteries and thermal storage
- Solar PV at RoW cost (less than half current cost)

Avoiding panel/service/wiring changes

- $2000-$5000 typical costs
- Add ~$250-500 for each new circuit
- Add $300-$30,000 for service upgrades
- Big increases in past couple of years (>20%)

DOE effort under way to address this issue

- Analyzing thousands of homes 1/15/60 minute data
- Collaborating with National Electric Code

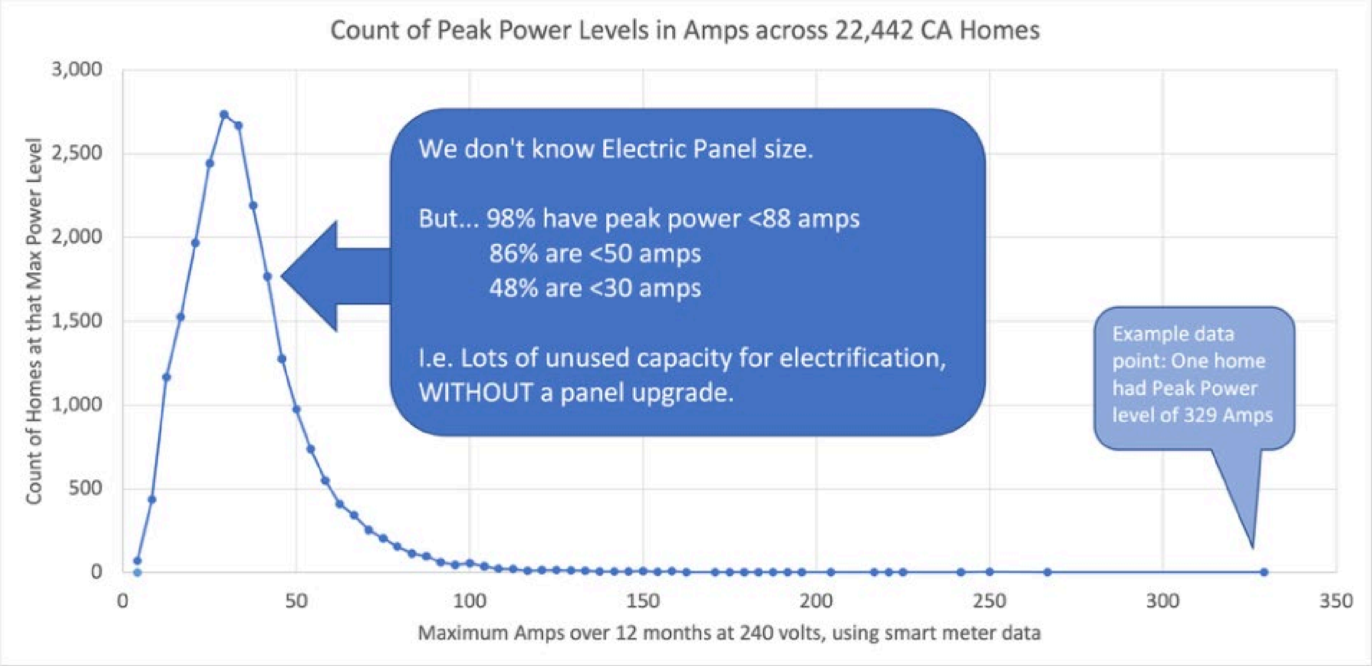


Figure from https://corp.hea.com/home-electrification

New products coming to the industry

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) that add grid-responsive capability

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
		

Battery Integrated Stoves – with a 120V outlet

Meter Collars

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

Create Added Value

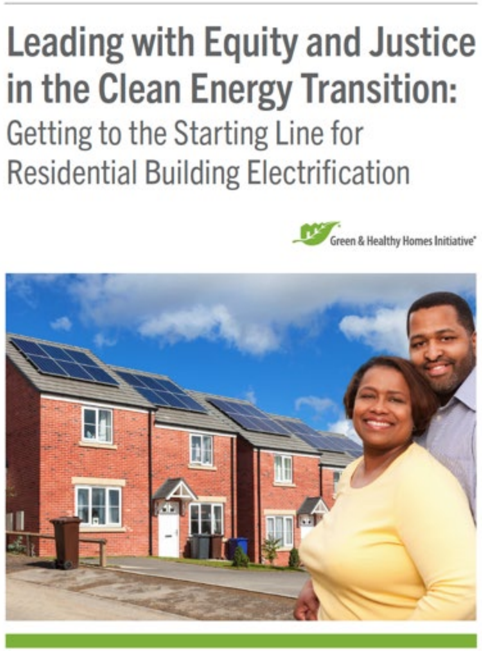
- Health and safety
  - Health – mostly cooking but also outdoor environment – *home electrification is better even for those that don't electrify*
  - Safety – no gas appliances to backdraft (reduces concerns about air tightening), no flames, no explosions, no Carbon Monoxide

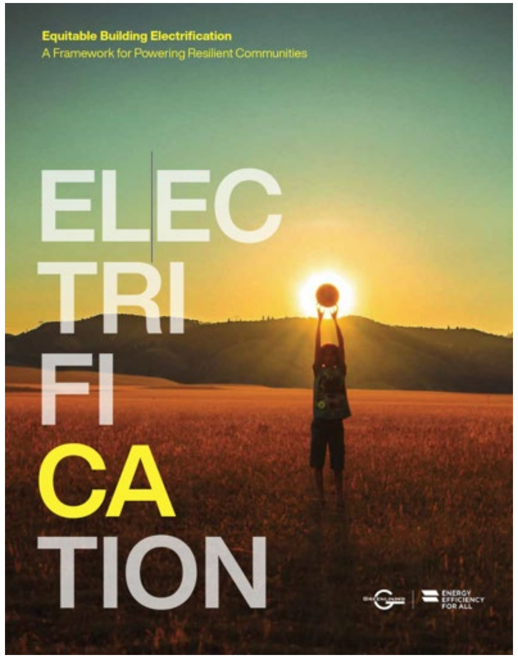
- Reliability and resilience
  - Electric outage more common – but also very short (hours) in duration c/w gas (days or weeks)
  - A well insulated and air sealed home takes longer to heat/cool and has less extreme temperatures
  - On-site PV/batteries/energy storage allows homes to function in emergencies
  - A heat pump adds the ability to cool a home

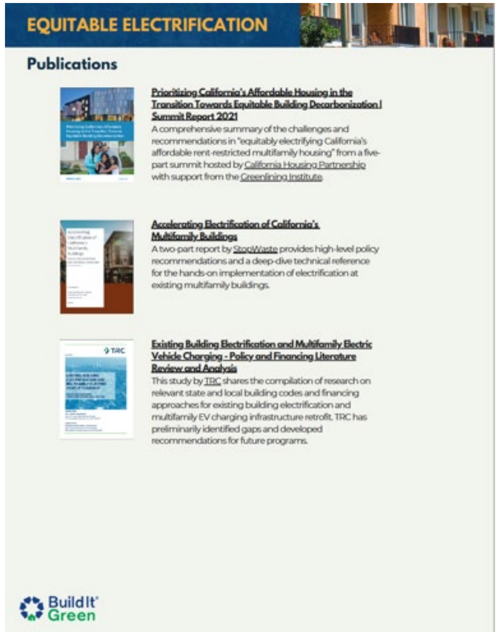
- Increase in home value?

Need solutions for renters, multi-family and low income households

- Develop solutions the do not require MF buildings to be empty
- Develop plug-in/transportable solutions
- Develop solutions for large MF where central heat and hot water maybe difficult to replace
- Need low-power solutions – Create "Power Efficient" labels with EPA, or CEE?
- More rebates less tax credits?
  - 40% of households pay no federal income tax
  - Allows ALL income levels to participate



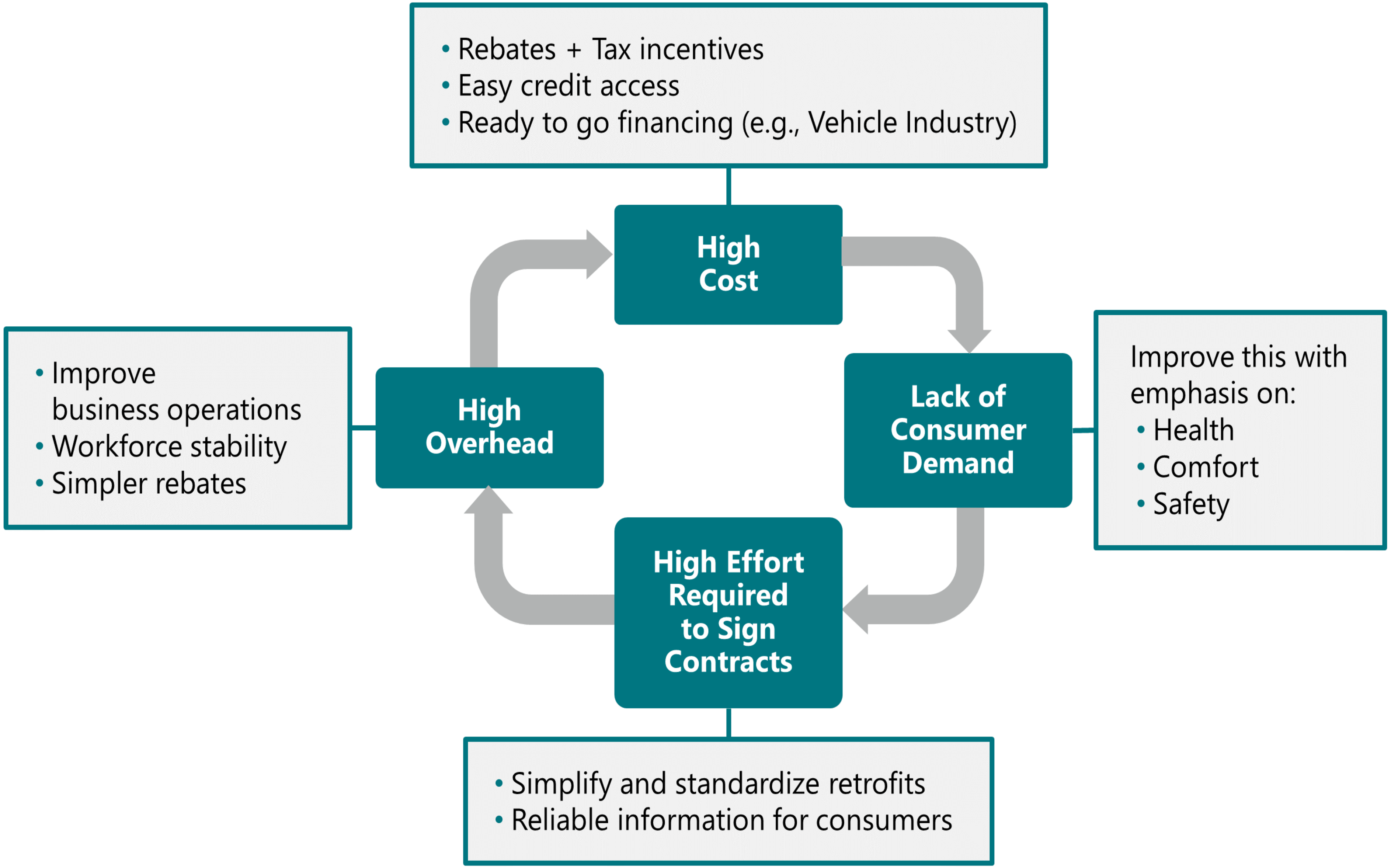




Need to create a workforce and business environment to get to scale

- Need a lot more contractors, electricians, etc.
  - Work with community colleges, non-profits, etc.
  - Businesses need to be long-term sustainable – not dependent on individual programs
- Use existing and/or well understood solutions – must be low risk and answer customer/contractor concerns
    - Will bills go up or down?
    - Is it noisy?
    - Will I be comfortable?
    - Who will fix it when it breaks?
    - Does it cost more to maintain?
- Focus on reducing overheads – how can we help the industry to grow?
  - Simpler rebate programs
  - Outsourcing customer acquisition and financing

Help businesses succeed

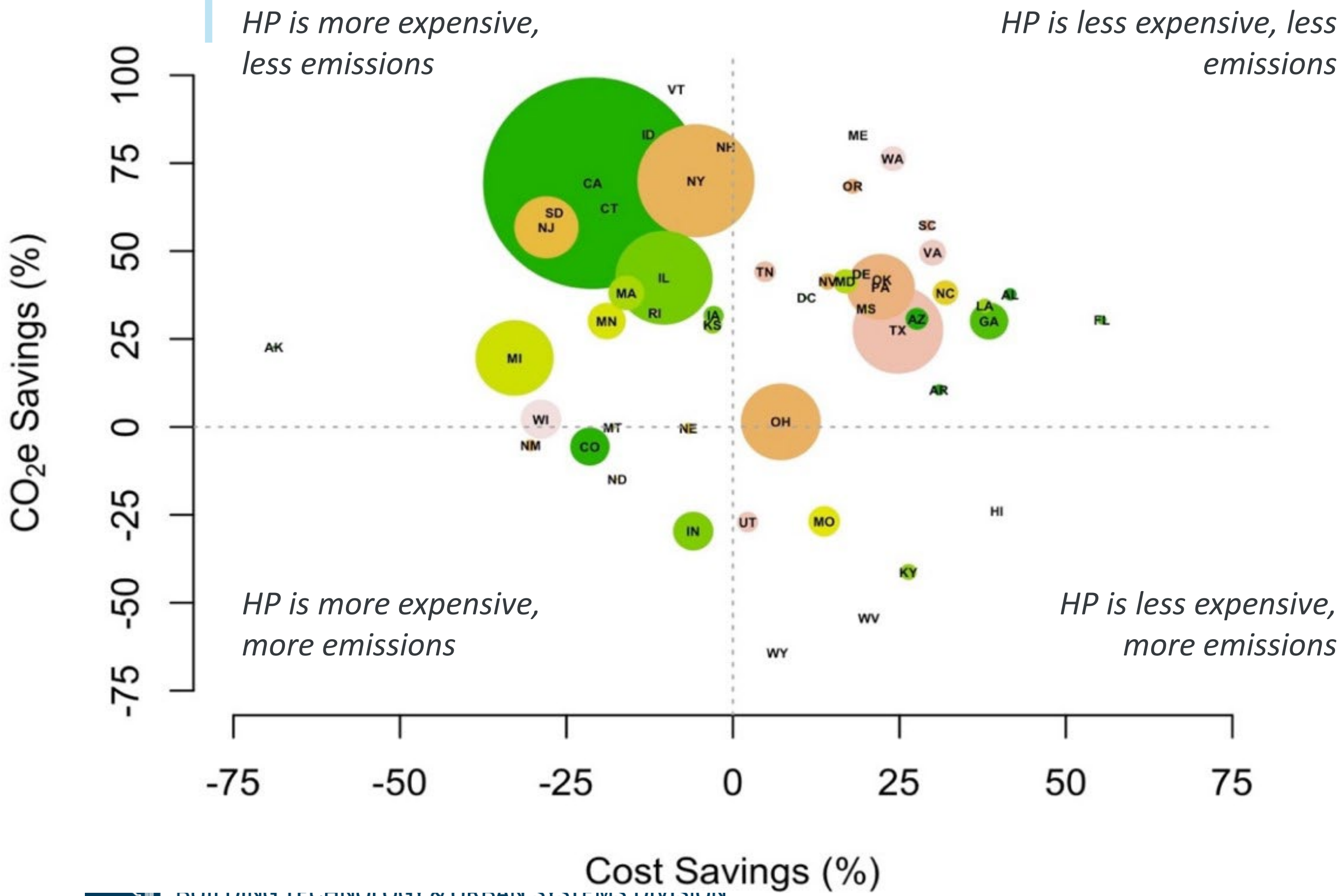


Questions and Comments

Extra Slides

Regionality of Heat Pump Benefits

Percent savings for CO_{2e} and energy costs in each US state when replacing a **95 AFUE** furnace with a COP 3 heat pump *in 2019*

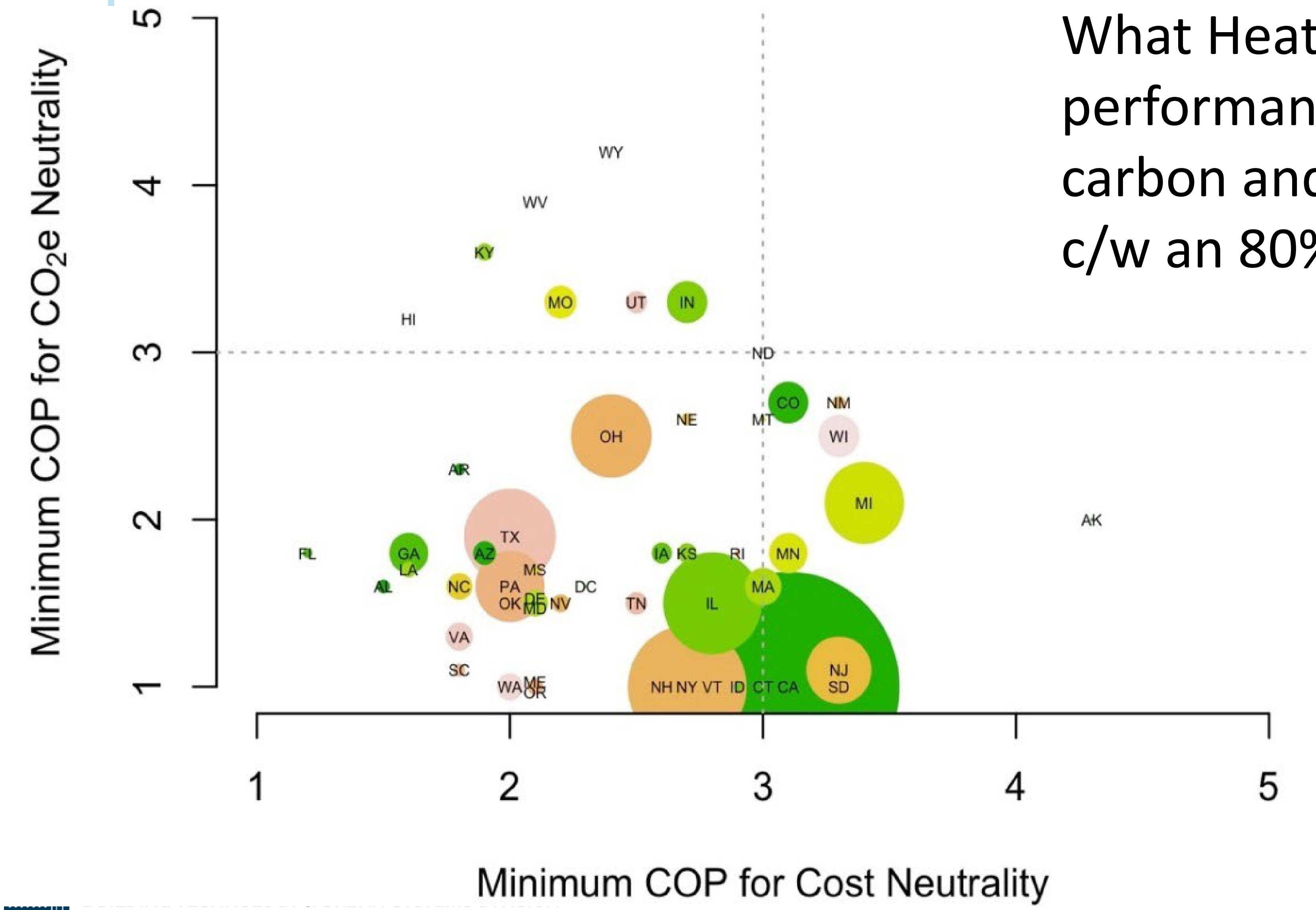


For new construction or replacing a high efficiency furnace benefits are reduced

New homes need really good envelopes and other EE measures, e.g., DOE's Zero Energy Ready Home program

Points scaled according to number of natural gas heating appliances in each state

Regionality of Heat Pump Benefits

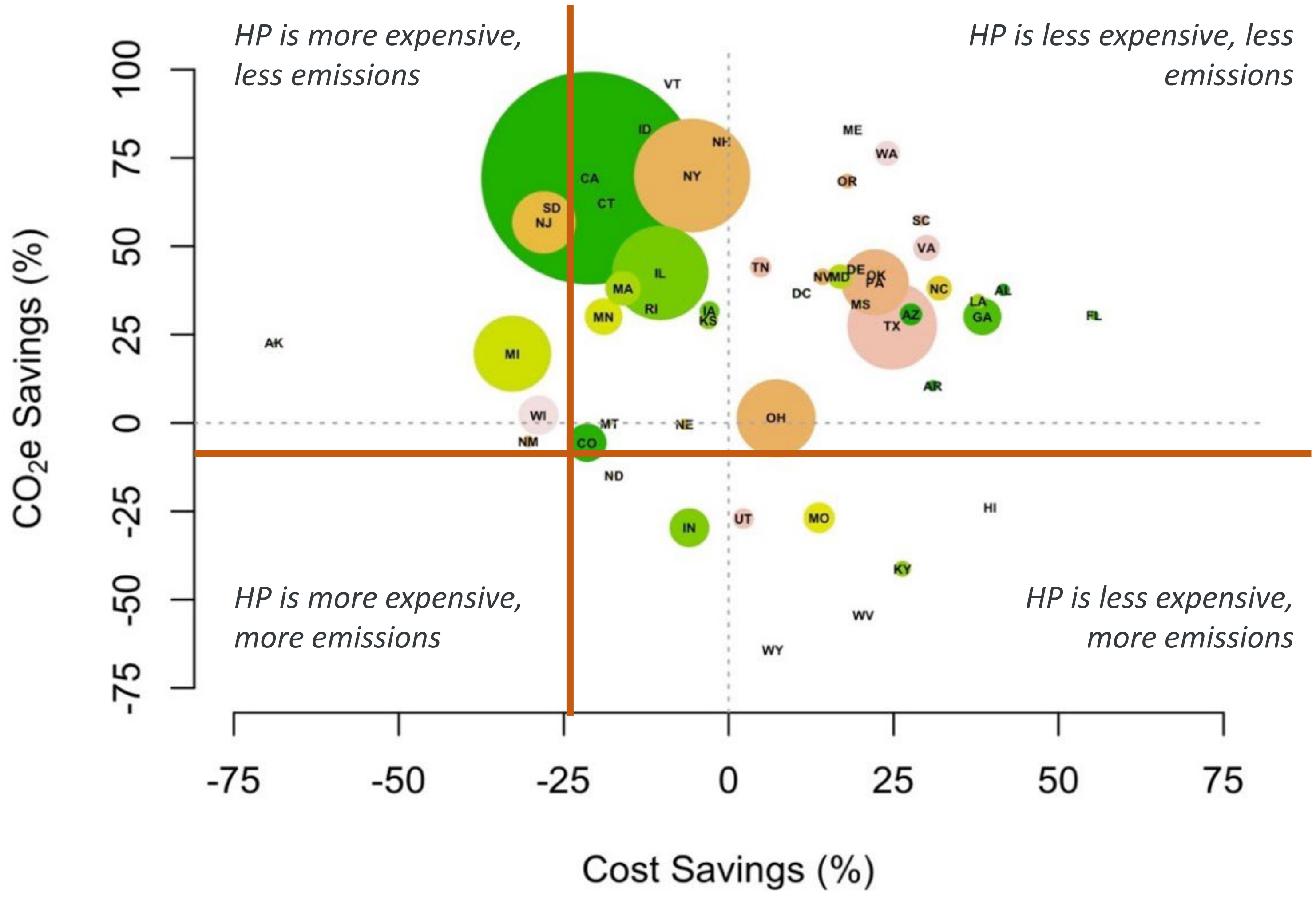


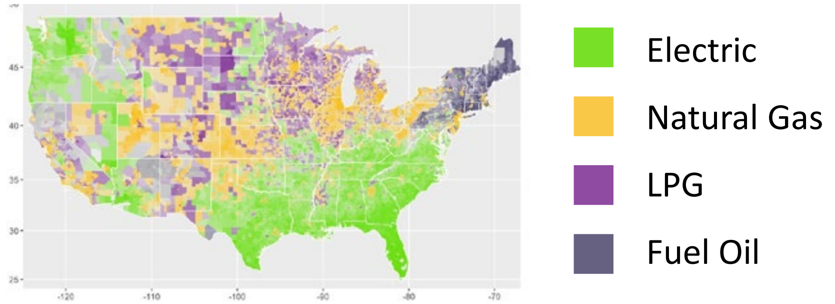
What Heat Pump performance is required to be carbon and/or cost neutral c/w an 80% AFUE furnace

Points scaled according to number of natural gas heating appliances in each state

Regionality of Heat Pump Benefits: 2022

Percent savings for CO_{2e} and energy costs in each US state when replacing a 95 AFUE furnace with a COP 3 heat pump



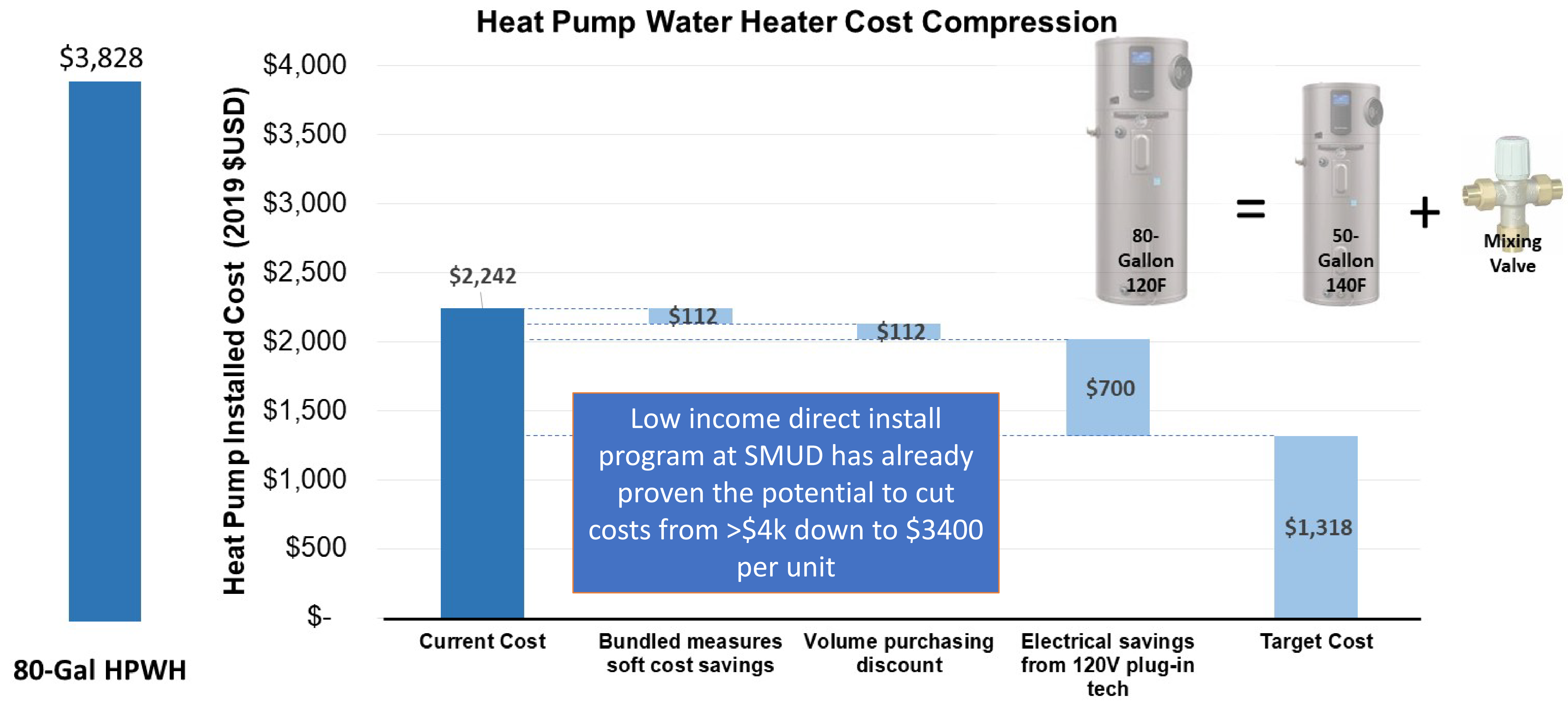


In 2022….

- Almost all states **benefited in both carbon** emissions and energy cost from a 3 COP HP compared to an **80 AFUE** furnace.
- **To get to consistently high CO_{2e} savings will require a lot more effort.**

Using 2022 changes in CO_2e energy content and gas and electric prices

Cost Compression Example - HPWH



SMUD = Sacramento Municipal Utility District

Recent Publications

- 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

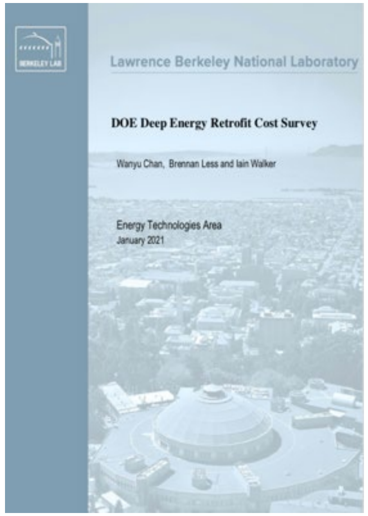
- Walker, I. S., Less, B. D., & Casquero-Modrego, N. (2022). Carbon and energy cost impacts of electrification of space heating with heat pumps in the US. Energy and Buildings, 259, 111910. https://doi.org/10.1016/j.enbuild.2022.111910

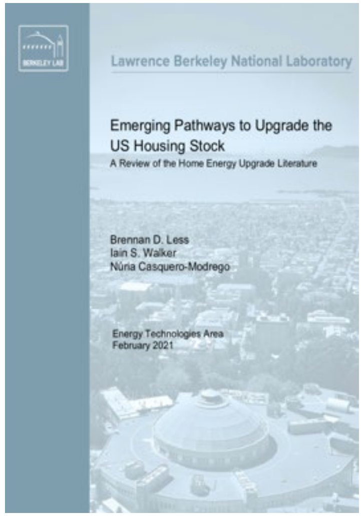
- Less, B. D., Walker, I. S., Casquero-Modrego, N., & Rainer, L. (2021). The Cost of Decarbonization and Energy Upgrade Retrofits for US Homes. Lawrence Berkeley National Laboratory. https://doi.org/10.20357/B7FP4D

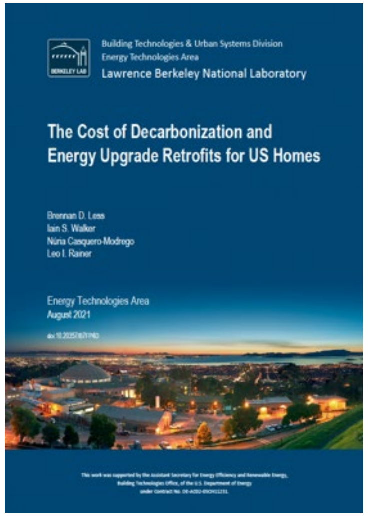
- Less, B. D., Walker, I. S., & Casquero-Modrego, N. (2021). Emerging Pathways to Upgrade the US Housing Stock: A Review of the Home Energy Upgrade Literature. Lawrence Berkeley National Lab. https://doi.org/10.20357/B7GP53

- 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
- Walker, I. , Less, B., and Casquero Modrego, N. (2022). Pathways to Home Decarbonization. Proc. ACEEE 2022 Summer Study. ACEEE Washington, DC. doi.org/10.20357/B7JG7

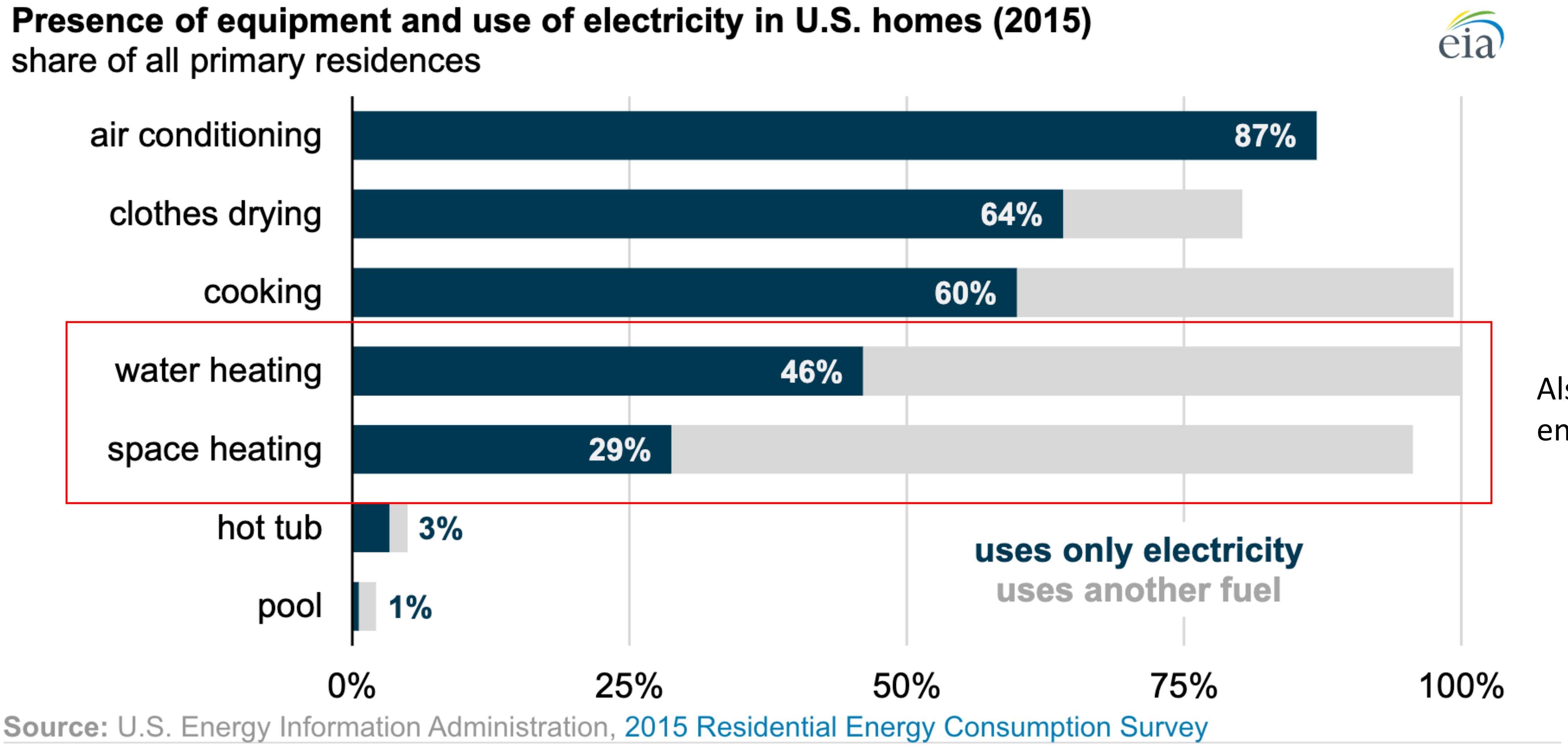
- Walker, I. , Less, B., Casquero Modrego, N. and Rainer, L. 2022. The Costs of Home Decarbonization in the US. Proc. ACEEE 2022 Summer Study. ACEEE Washington, DC. doi.org/10.20357/B7DP43







Problem Scope: Electric End-uses



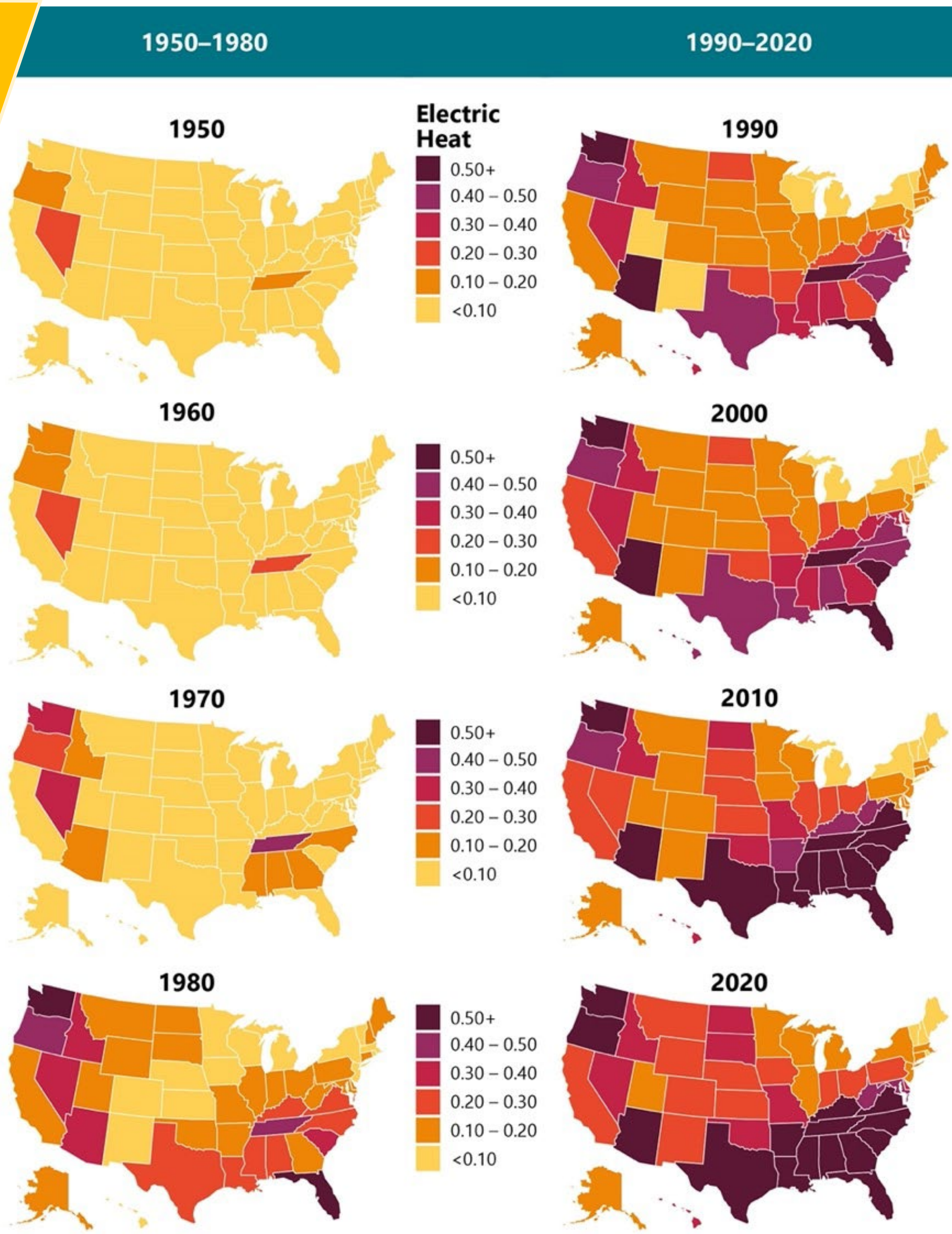
Also biggest energy users

Problem Scope: 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



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

Valuation of health benefits

Burning fossil fuels emit several contaminants of concern

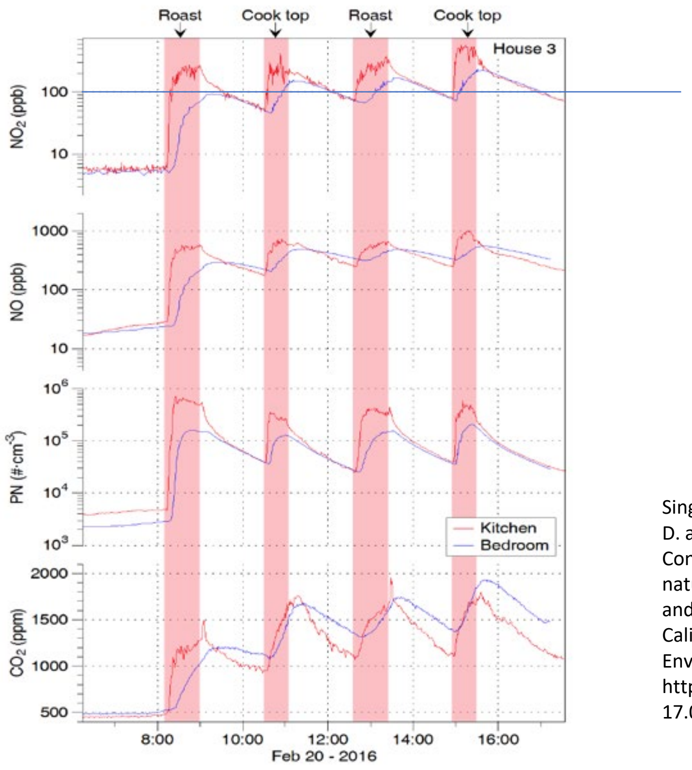
- $PM_{2.5}$, NO_2, CO, aldehydes and leaking unburned CH_4

In buildings:

- Main sources are cooking and poor appliance venting
- This would serve Low-Income/Disadvantaged households the most

Outside air:

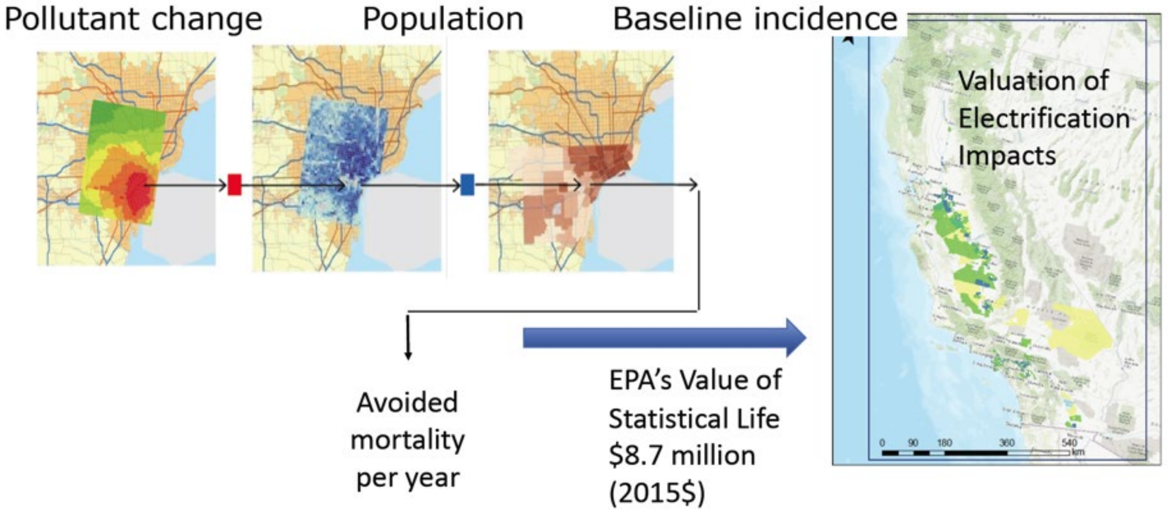
- $PM_{2.5}$ & NO_2
- Environmental Justice Issue – often worse in disadvantaged communities
- Full electrification: 12,000 fewer deaths, monetized health benefit of $108B/year just for California



100 ppb 1-hour Threshold (National Ambient Air Quality Standard

Singer, B., Pass, R., Delp, W., Lorenzetti, D. and Maddalena, R. 2017. Pollutant Concentrations and emission rates from natural gas cooking burners without and with range hood exhaust in nine California homes. Building and Environment, 122, 215-229. http://dx.doi.org/10.1016/j.buildenv.2017.06.021

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



Utility Integration

- Need to develop rate structures, regulations and programs that support or allow for decarbonization
- Need solutions that reduce need to upgrade transmission lines, transformers etc.
- Not enough transformers available or staff to install them
- No capacity to make every home >200A.

Looking to the future

- State and regional variation will remain but CO_2e and bills increasingly favor electrification
- Need to minimize the risk of increasing bills or CO_2 emissions
  - Traditional EE measures, such as envelope and HVAC improvements
  - Solar PV and other renewables
  - Very important for lower-income households we need to minimize the impact of increasing energy bills – this is **critical**
- More DOE R&D to focus solutions and programs:
  - Analyze many house prototypes in different climates with variable heat pump performance depending on weather
  - Include variability of CO_2 content of electricity with time
  - Different utility rate structures?
    - We need utilities to think about rates that lead to lower carbon emissions
  - Include installation costs, embodied carbon, impact of refrigerant and methane leakage
  - Implications of time shifting using energy storage