Making Housing Sustainable: Finding a Path to Home Decarbonization

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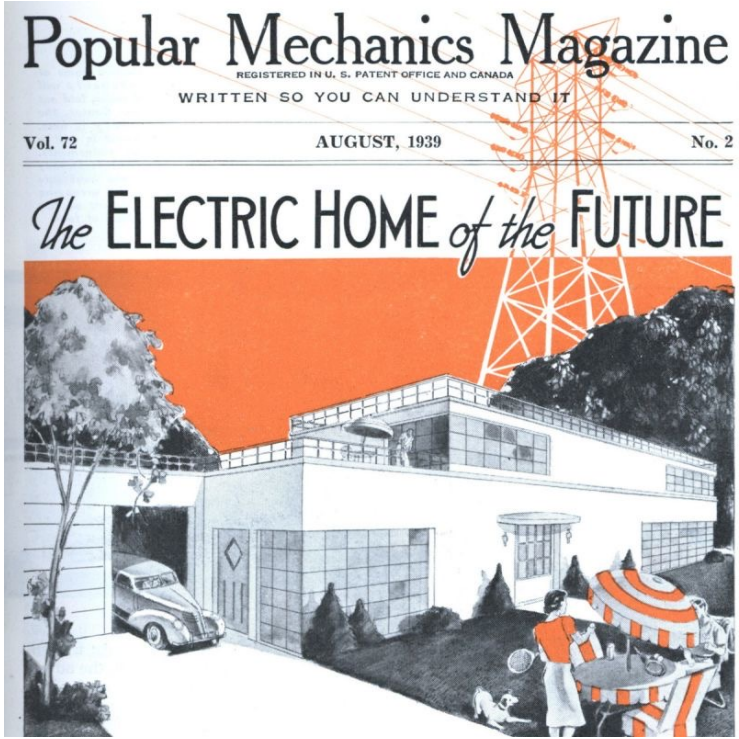
May 1st 2024

ENERGY TECHNOLOGIES AREA
BERKELEY LAB

WHAT IS A DECARBONIZED HOME?

ALL ELECTRIC HEAT/COOL/HOT WATER/COOKING/CLOTHES DRYING – in California pretty hard: We have very gassy homes in CA

USE LOW CO_2 CONTENT ELECTRICITY – in California pretty easy: We have a good level of renewables on our grid



New Concepts

- Old – Energy Efficiency
- New – Power efficiency, maximum power, low power electrification

- Old – Energy Use
- New – CO_2 (GHG) emissions

- Old – Monthly total energy
- New – Which hours, exactly

New and Emerging Metrics

- Annual carbon emissions
  - RESNET already has a CO_2 index – pathway to replace energy codes with carbon codes
- Household peak power
  - Integral with panel/service upgrades and utility distribution needs
- Embodied Carbon?
- Appliance power efficiency
  - Give consumers and contractors ability to select lower power appliances

New and Emerging Metrics

- 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 TOU leads to more emissions: low nighttime rate when little/no renewables in the power mix
- Affordability (replace ROI, LCC, TRC, etc.)
  - Use metrics more aligned with household decision making
  - Net monthly (financed) cost

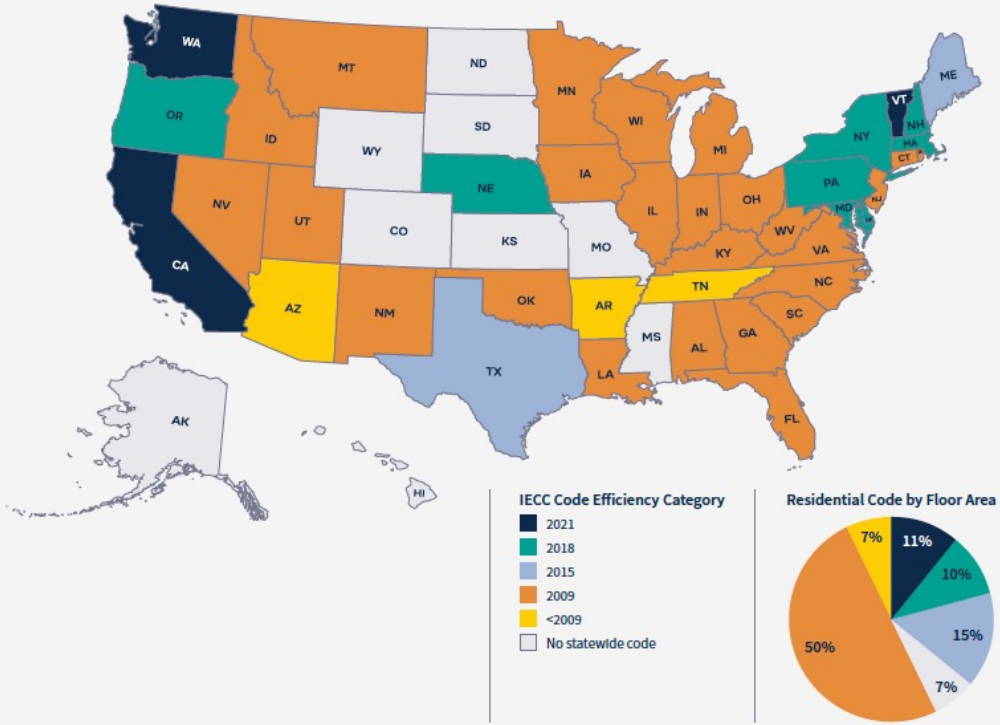
	Power	
Energy	**High**	**Low**
High	EV, PV	HP/HPWH
Low	Cooking Dryer	Lights, plugs, etc.

New homes are pretty good…

All-electric new construction cheaper than dual fuel

Barrier is mostly cooking

Exhibit 11. Status of Residential Energy Code Adoption Relative to Model Energy Codes



Source: US Department of Energy BECP, "Status of State Energy Code Adoption: Residential," https://public.tableau.com/app/profile/doebecp/viz/BECPStatusofStateEnergyCodeAdoption/ResidentialDashboard

Advanced Building Construction Collaborative, 2024, Accelerating Residential Building Decarbonization. USDOE.

Existing homes are a challenge… but we know what to do to minimize CO_2 emissions

Replace gas furnaces and boilers with heat pumps

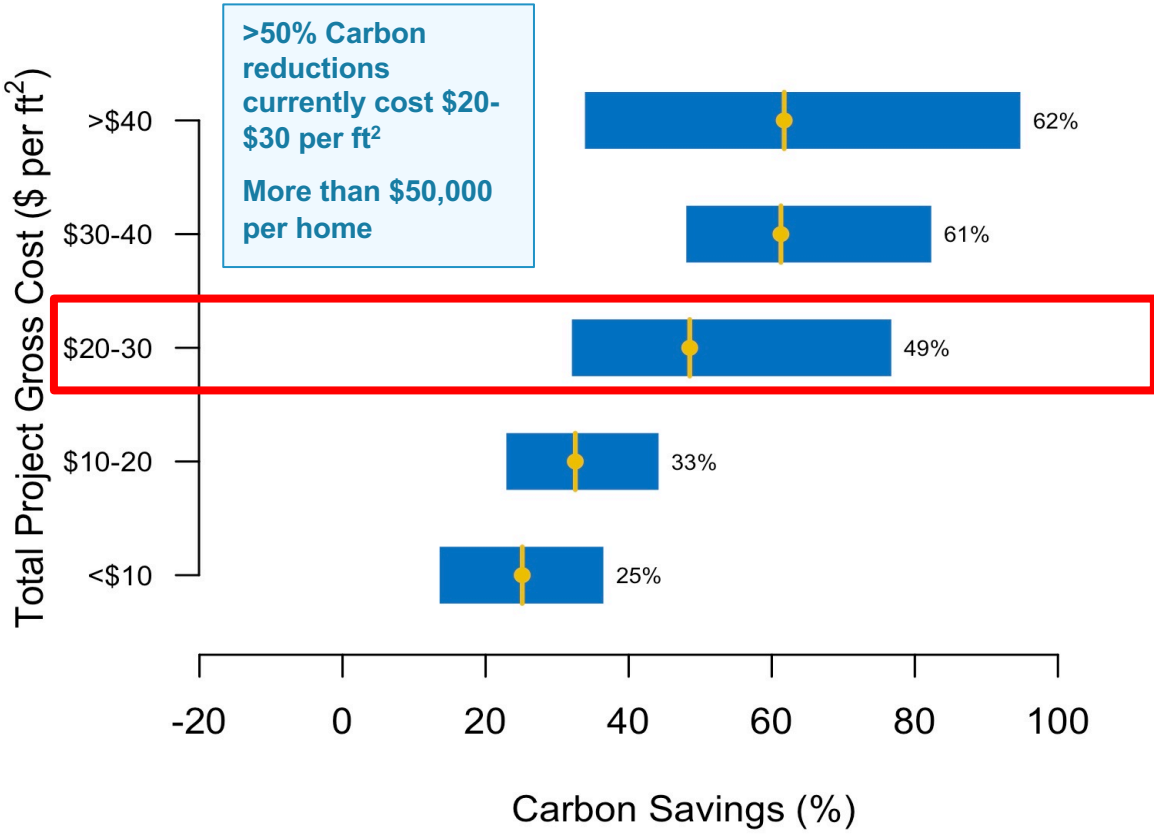
Replace gas water heaters with heat pump water heaters

Replace gas cookers with induction cookers

Replace gas clothes dryers with condensing or heat pump clothes dryers

BUT… now we want to charge cars at home….

Critical Issue #1: UPFRONT COST



Data from 2019..
Add at least 25%

Typical project combined basic air sealing/insulation with heat pumps and solar PV

Critical Issue #1: UPFRONT COST

Highly variable:

- Home with A/C trivial to add heat pump
- Home with no A/C – needs new 240V circuit(s), ductwork fabrication, drains, etc.

- Newer home needs no envelope upgrades
- Older home needs air sealing, attic/wall insulation

- Adding EV Charger or Solar PV?
- Asbestos abatement?
- Ducted or ductless heat pump?
- Electrification has high overheads

Key CA Issue: Electric Panel/Service Replacement

Why not just replace all the panels?

What does it cost?

Circuits: **$500-$1,500 each**
Panel: **$1,000-$5,000**
Service: **$1,000-$25,000** to homeowner + similar amount for utility
Rewiring trigger: **$10,000 - $20,000**

Time delays

3-6 months project delays
>1-year lead time on transformers
Utility might reject your interconnection

Image courtesy of Eric Morrill

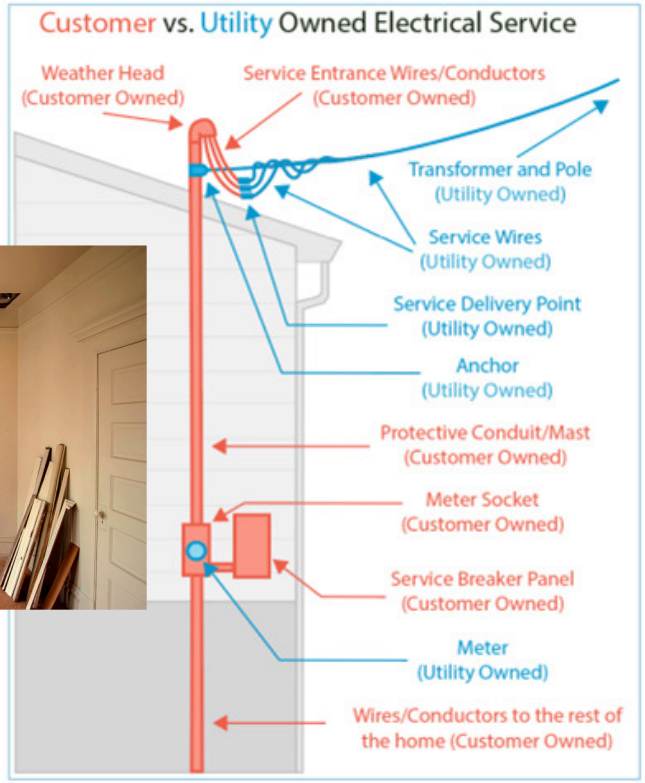


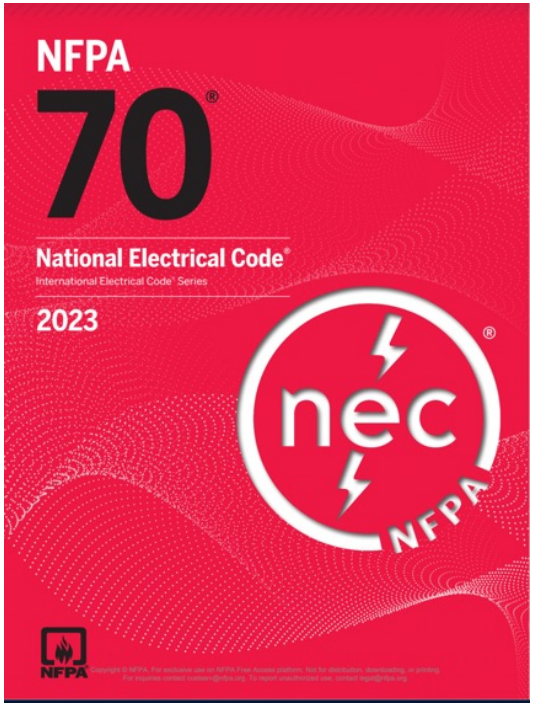
Image courtesy of Redwood Energy

Additional ratepayer costs for:

- Utility distribution system capacity increases + new generation/storage

What is driving panel replacement and service changes?

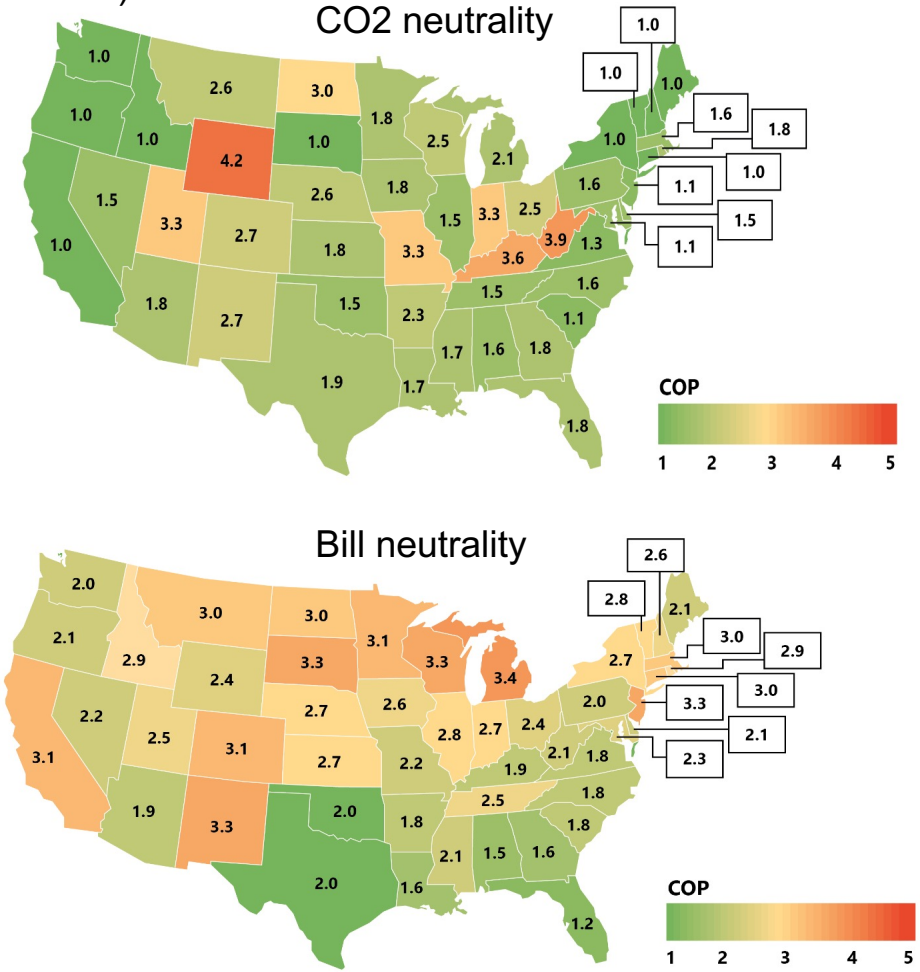
1. Reports from utilities: Current main drivers are adding Solar PV and EV Charging
2. Simplified approaches by electricians
   - Not using existing paths in the National Electric Code, e.g., using metered data
   - Profitable upsell?
   - Habit/comfort
3. NEC unclear and not developed with home electrification in mind
4. Local code authorities unprepared
   - Some will not allow circuit sharing or smart panel controls



Critical Issue #2: OPERATING COST

1. In CA electricity is expensive. Operating costs are complex – mostly *savings* using pro-Electric rates (E-ELEC) from IOUs and lower rates for munis. Need protections for low income – like existing CARE programs.
2. Any additional grid infrastructure costs passed on in future rate increases. Important to minimize added load.

Heat Pump compared with an 80% AFUE gas furnace (in 2019)

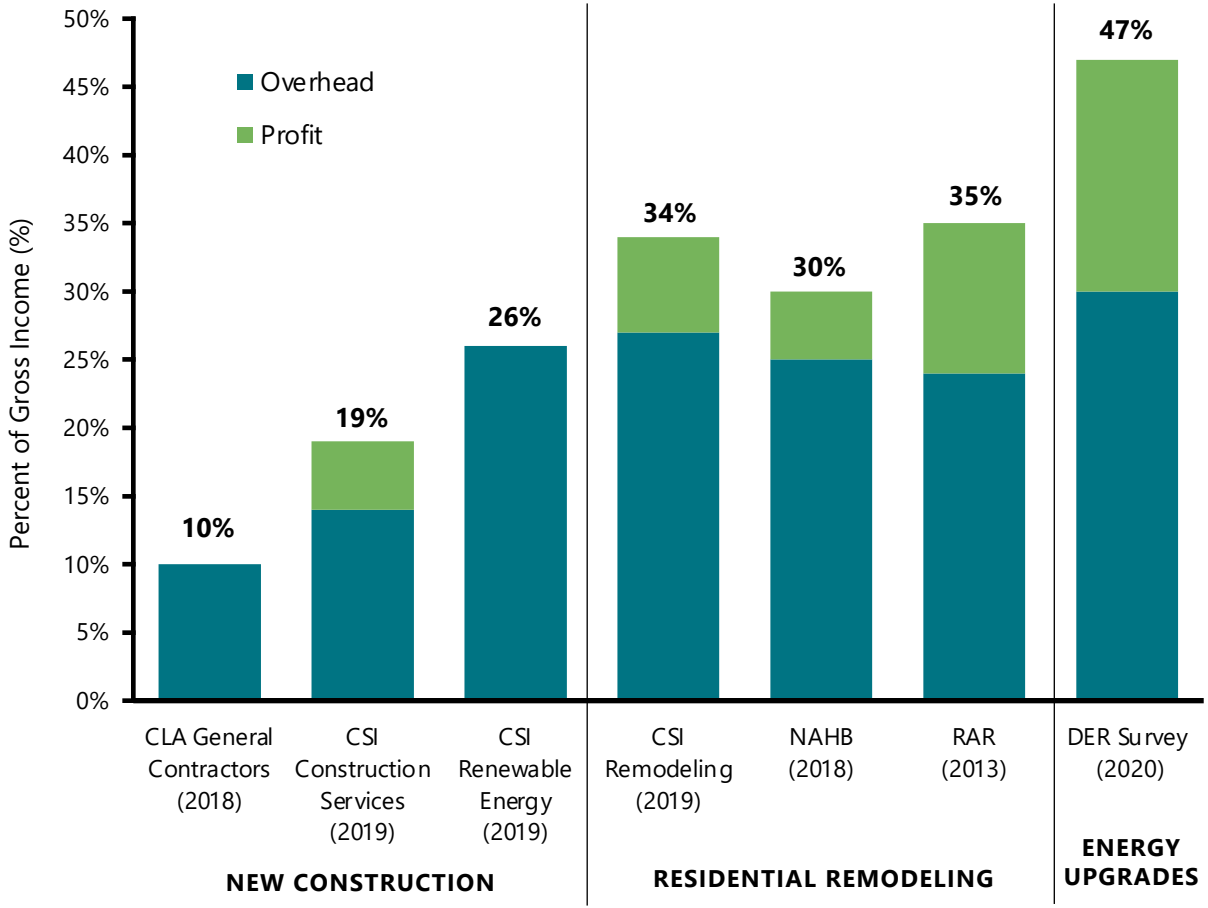


Critical Issue #3: SO MANY QUESTIONS…

- 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?
- Who do you call?
- If you find someone, can they do it?
- If they can, how long do you need to wait? Many months for a contractor + many more months if a utility is involved
- What is the value?

Critical Issue #4: WHO WILL DO ALL THE WORK?

- Not enough installers/contractors – fewer electricians and plumbers every year…..
- Work is not attractive for contractors
- Energy/Decarbonization upgrades have very high overhead – we need to address business models



Pathways and Solutions

The Pathway

1. Start now, if not sooner
2. Low power electrification of heating, hot water, cooking and laundry (using heat pumps)
3. Air seal and insulate older homes & HVAC systems
4. Optionally, add Solar PV
5. Use the best performing heat pumps you can
6. Use integrated appliances for cooking/laundry
7. Easy access to rebates/financing
8. Help contractors with new business models
9. Develop homeowner and trades guidance/reassurance/risk assessment
10. Emphasize health/safety benefits
11. Train more trades
12. New rate structures + rebates + financing
13. Make every AC replacement a heat pump

HOME DECARBONIZATION IS:

Costly
Time Consuming
Hard

HOME DECARBONIZATION NEEDS TO BE:

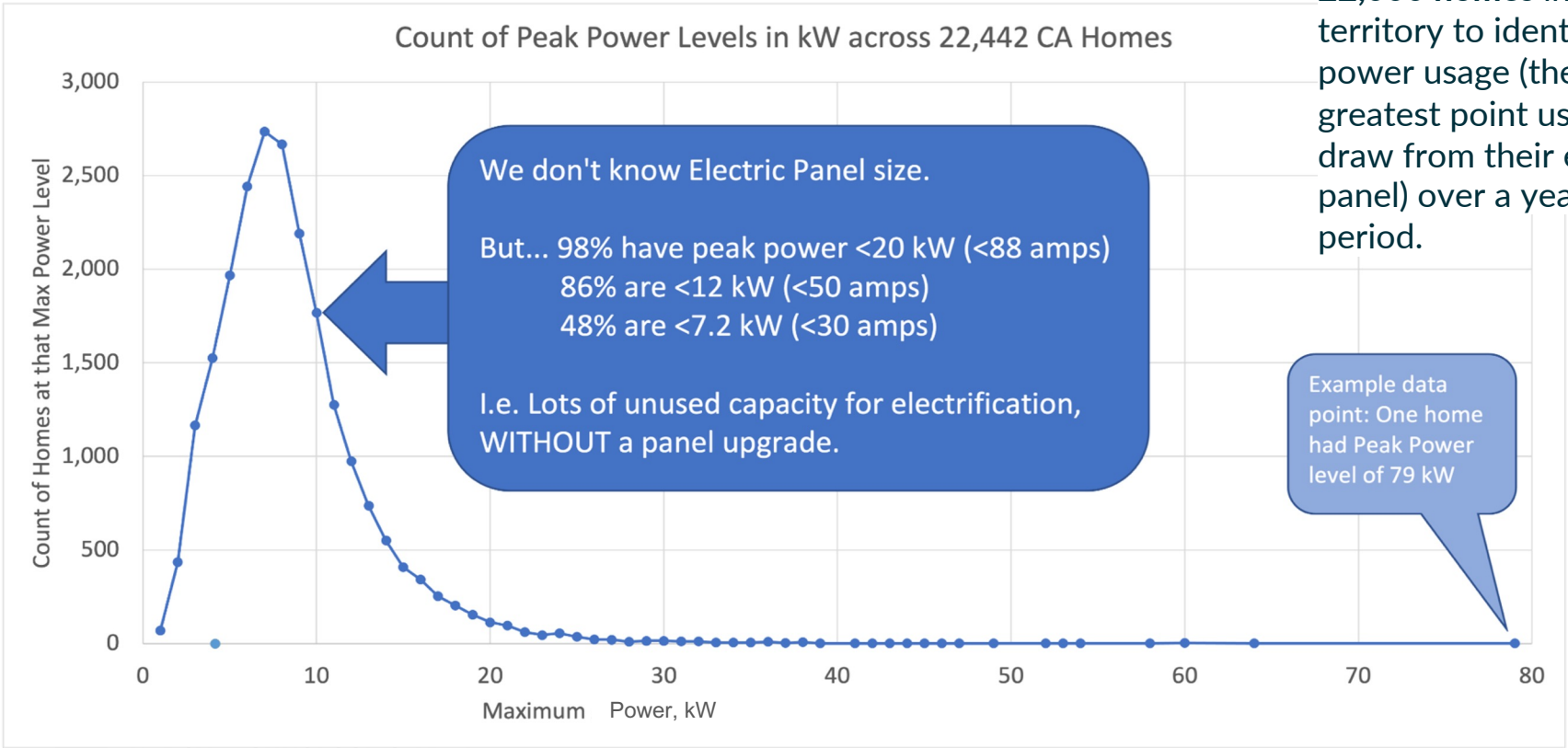
Affordable
Simple
Easy

Low Power Electrification

- Reduces costs by about $3k to >$20k
- Limits maximum power draw of the home
  - Reduces future operating costs
- Reduces utility and electrician delays
- Allows for emergency replacement using 120V appliances
- Allows for portable appliances for renters
- Load reduction and selecting more efficient devices all reduce power requirements
- HOWEVER: No incentive for contractors other than avoiding utility delays

Lets not replace all the panels…

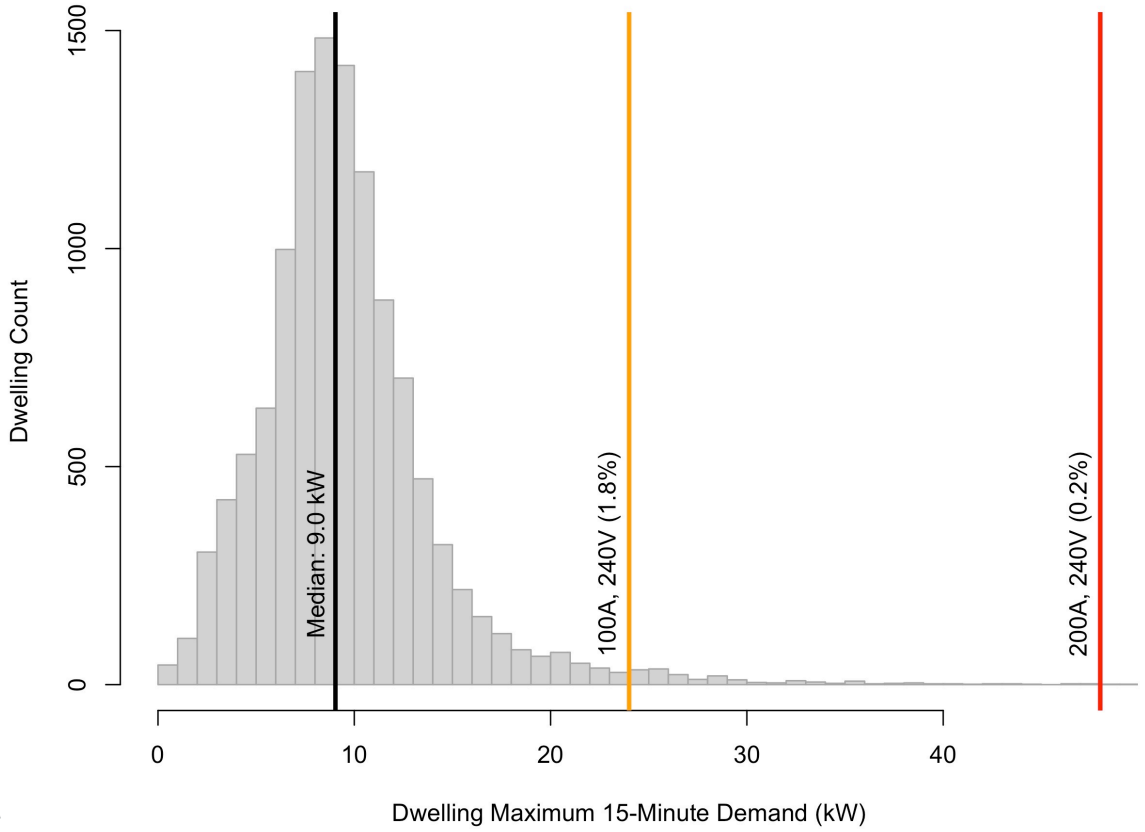
An analysis from HEA of smart meter data across **22,000 homes** in PG&E territory to identify peak power usage (the single greatest point use power draw from their electrical panel) over a year-long period.



Source: HEA, HomeIntel

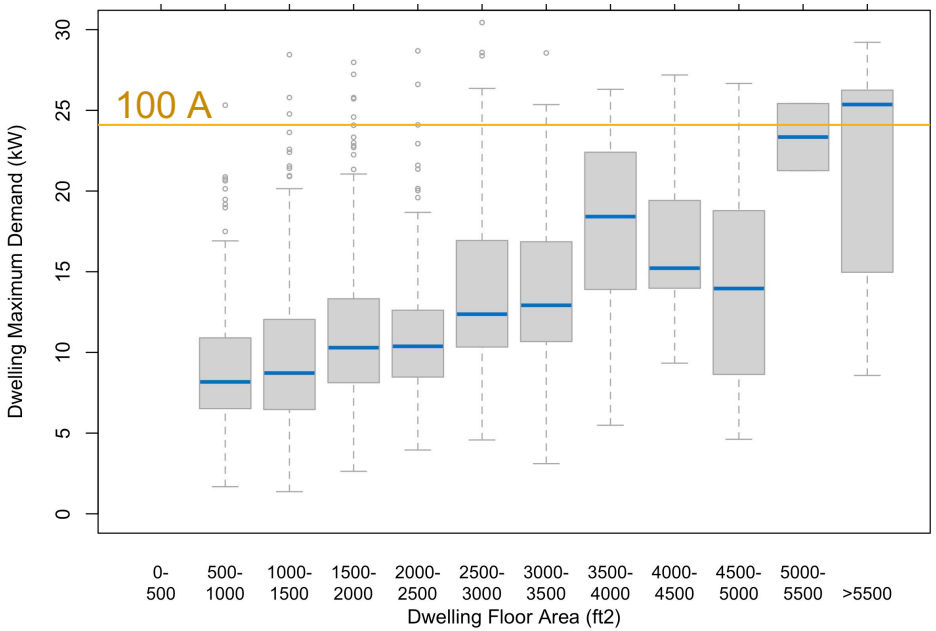
National Data

Vast majority never exceed 100A

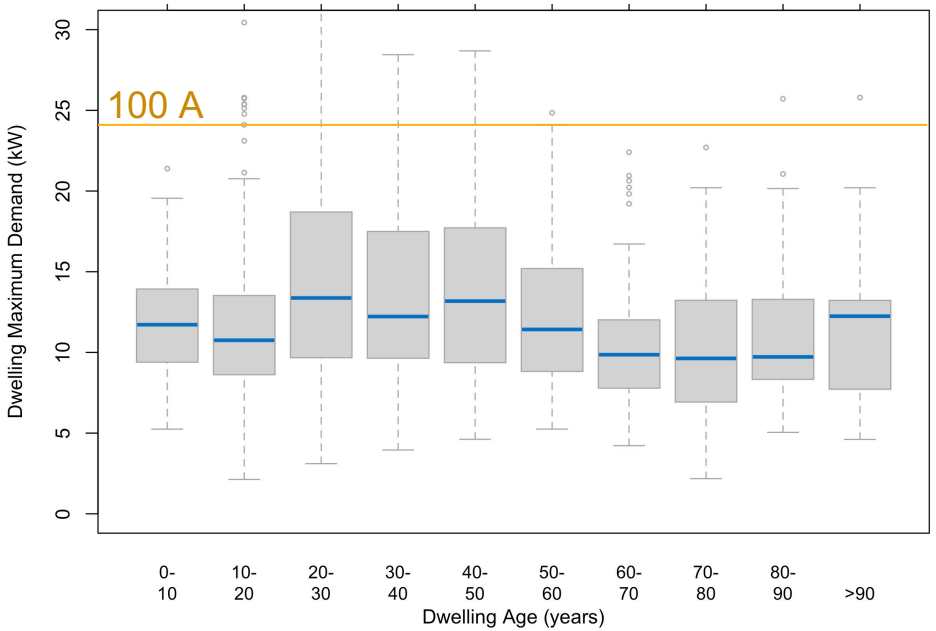


National Data – what homes more likely to get a new panel/service?

Bigger homes have bigger peak



Age doesn't matter



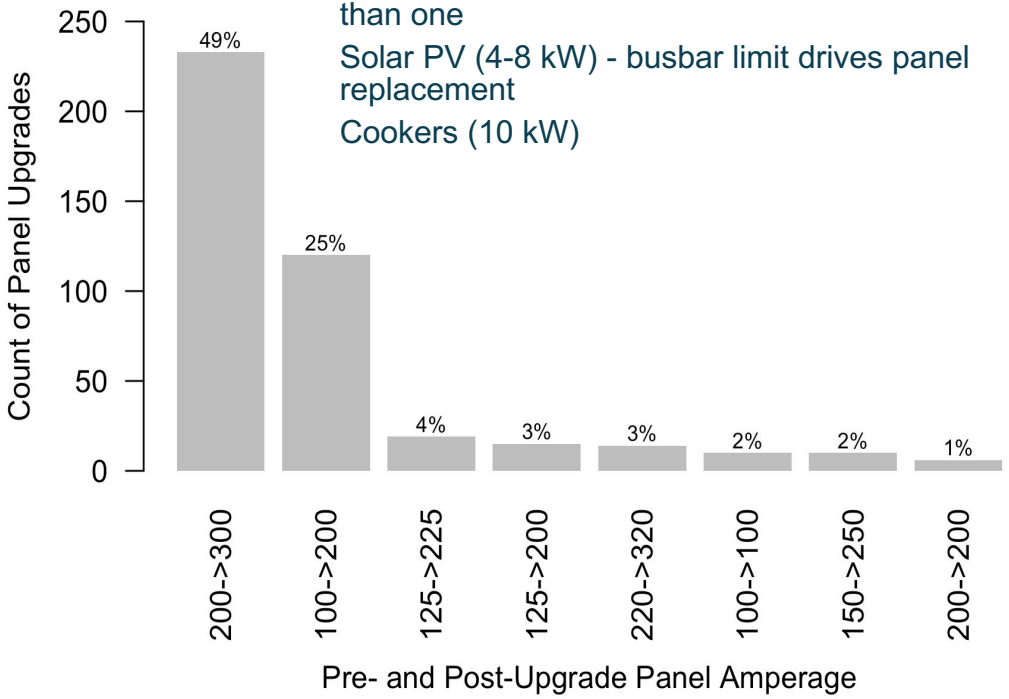
TECH Clean California Data

- 6% of 21,146 heat pump projects replaced panels
- Most panel upgrades were from 200A to 300A
- Smaller set of upgrades were from 100A to 200A
- More replacements with heat pump water heaters, in part due to incentive structure
- Cadmus ccASHP study found
  - 8% service panel replacement
  - 10% subpanel installs
  - 1% utility transformer replacement

Panel/service replacement NOT driven by heat pumps or HPWH

Driven by big POWER applications:

- EV Chargers (7 kW or more) – some time more than one
- Solar PV (4-8 kW) - busbar limit drives panel replacement
- Cookers (10 kW)



Solutions for Avoiding Panel and Service Upgrades

Smart Electrical Panels

$3-5k + install

Most complicated and flexible

Circuit Sharing

$300-600 + install when hard-wired

Least complicated, sometimes DIY

Others

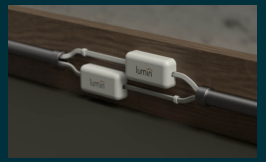
NEC Load Calculations

Low Power Appliances

Meter collar solutions

Smart circuit breakers

Circuit Pausing



$400-900 + install

Medium complicated, requires CTs

Low power products

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)

Battery Integrated Stoves

Power-efficient Appliances (120V)
Can be portable for renters and DIY
AVOID – Resistance Emergency Heat

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
		

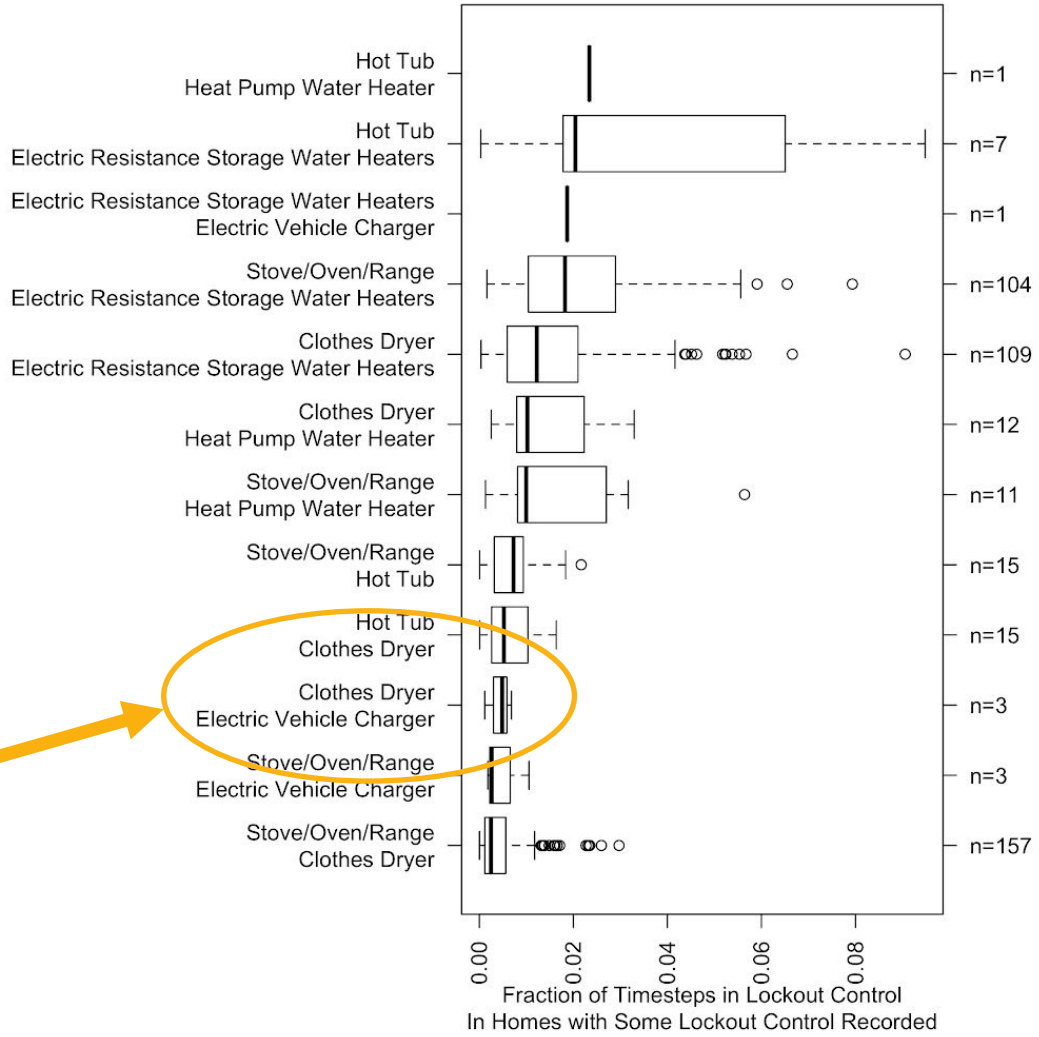
Meter Collars – for Solar PV or EV Chargers

Circuit Sharing Inconvenience?

15 minute data from 1300 homes from NEEA study

If high power devices share a circuit how often would one have to be switched off?

40 minutes/week



Utilizing and Updating the NEC

Watt Diet Strategies

Basic strategies for avoiding an electrical panel upsize can include:

01 - Select appliances that combine two functions into one machine

For example, the kitchen range (combining an oven and cooktop in one slide-in appliance), which lets us avoid a separate high power circuit for wall ovens. Another example is a combined washer/condensing dryer machine that lets us avoid needing a circuit for the clothes dryer.

02 - Select power efficient versions of the appliances

Choose the 15-amp version of a heat pump water heater instead of the 30-amp nearly identical version. Selecting high performance, power sipping versions of heat pumps instead of lower performance versions. Select power efficient and energy efficient heat pump dryers if you want a separate clothes dryer.

03 - Reduce heat loss and cooling loss by insulating and air sealing

04 - Use prioritized circuit sharing devices

These handy devices can automatically pause car charging while other appliances, like the dryer, finish.

05 - Use EV charger pausing circuits

These briefly pause EV charging if many devices are on at once and the main breaker is at risk of popping.

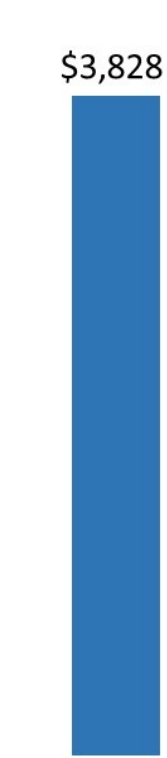
06 - Avoid overkill in your EV charger settings.

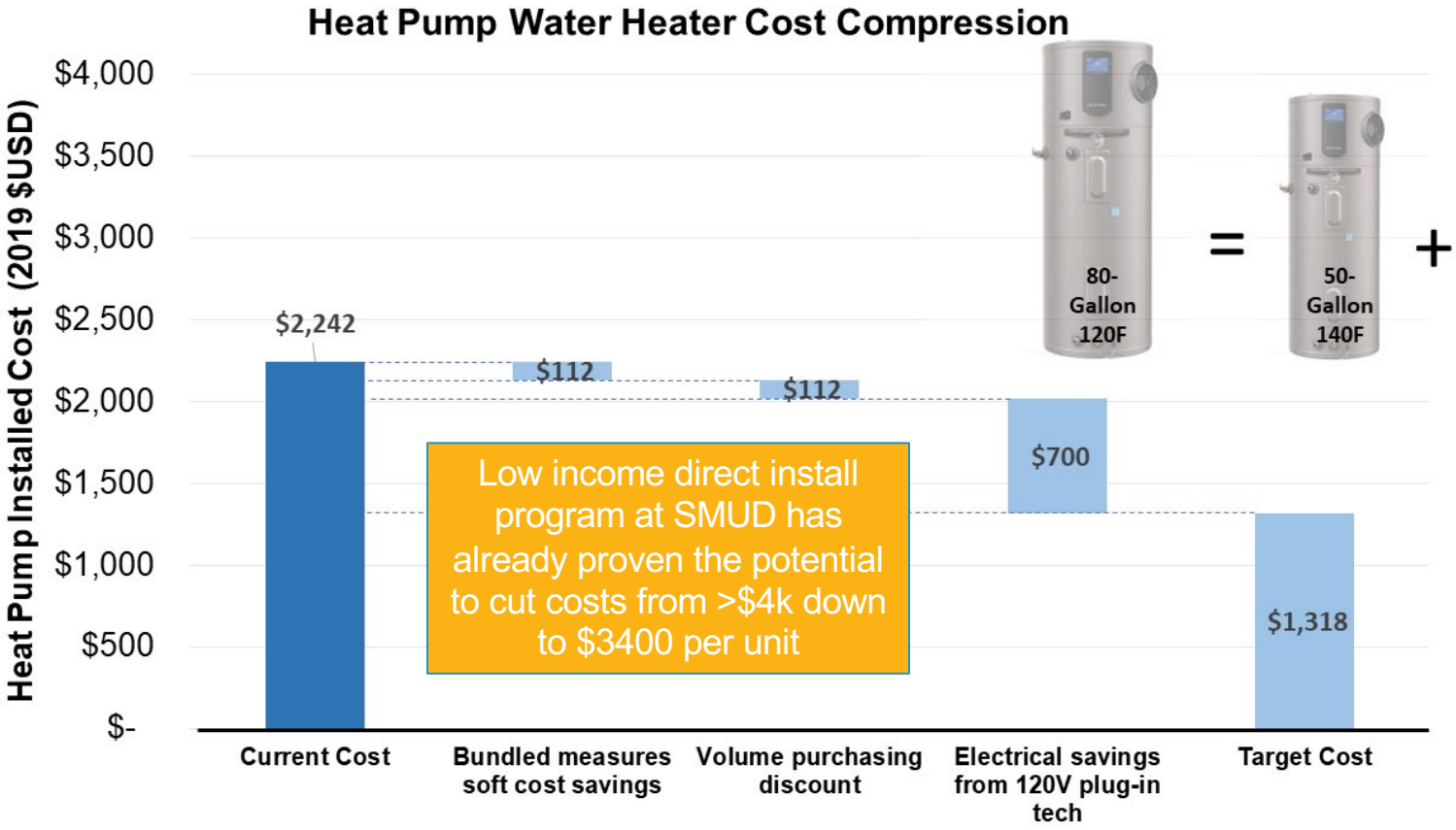
For example, pick a 20-amp or 30-amp outlet for your EV charging and avoid 50-amp chargers at home. A 20-amp outlet can deliver 100 miles of charge overnight and more than 50,000 miles of charge in a year. Bigger car batteries don't require bigger circuits; they give you flexibility about when you charge.

Potential NEC updates to better account for HP loads, and 60 to 15 minute conversion to allow use of smart meter data

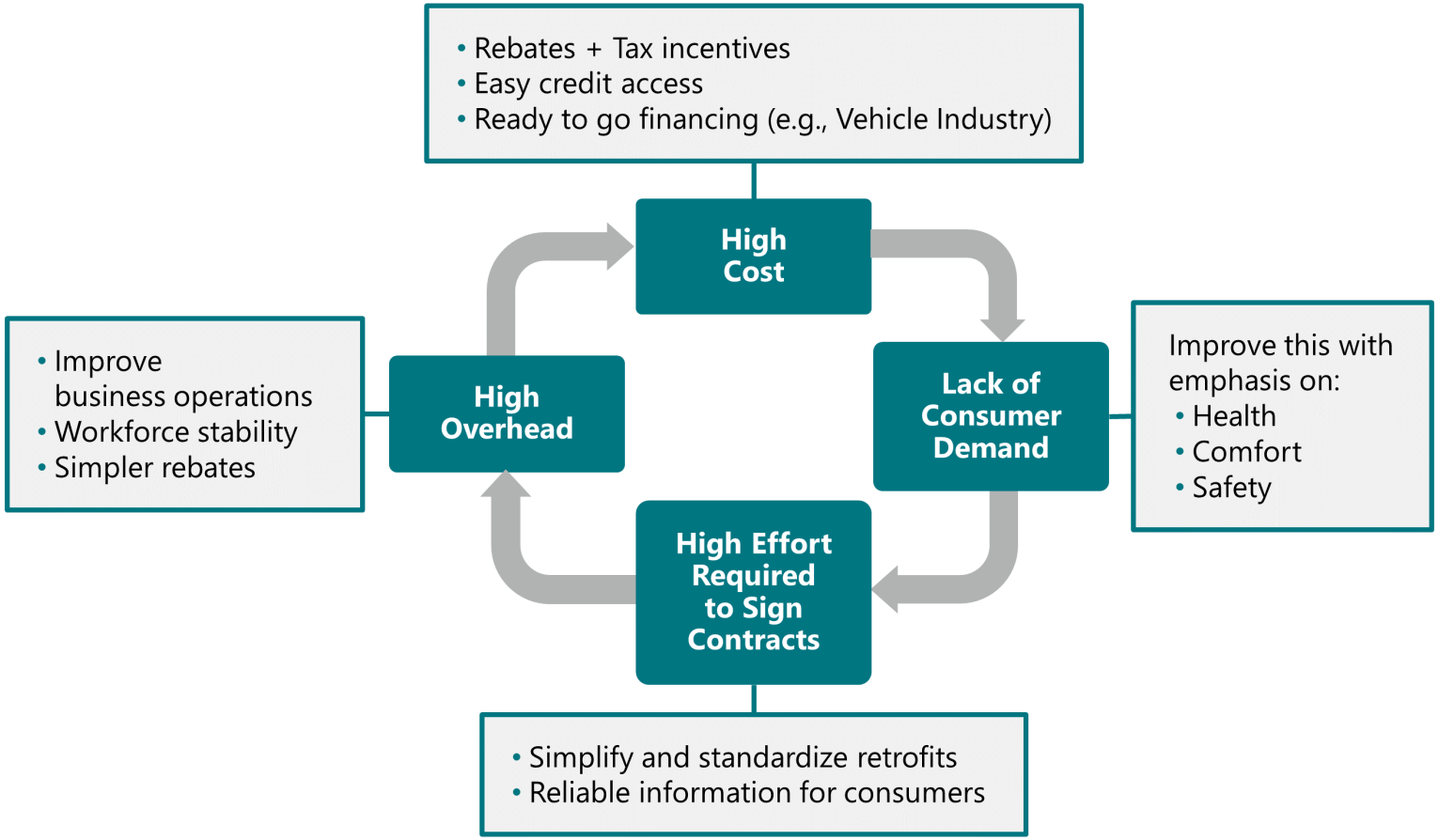
https://www.redwoodenergy.net/watt-diet-calculator

Appliance Cost Compression





Building up Businesses



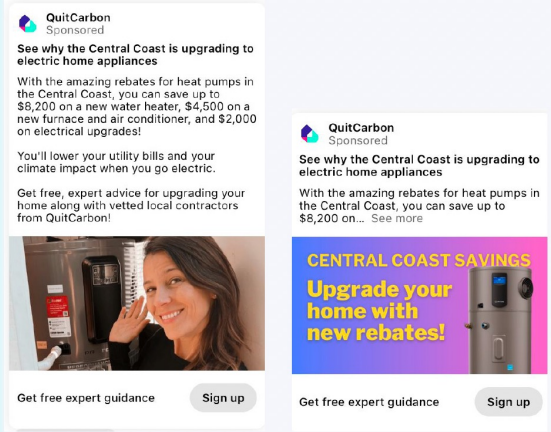
Building up Businesses

Better marketing and business models:

- How to get people to choose to go electric? Companies connecting contractors to customers
- Keeping it simple & address first cost concerns – up front rebates very effective
- CEC developing online tools to help homeowners/occupants
- Need training for contractors for good installs – HP and HPWH controls not always obvious

Marketing and Outreach Research - 3C-REN Nextdoor

- Images with real photos had 50% higher CTR than images with graphics
  - Also converted to signups at a much higher rate
- Ad on left = 11 signups at $15 per signup
- Ad on right = 0 signups at a similar spend



From Quit Carbon PG&E Training

Non-energy benefits – considering added value

Functionality:

Comfort – steady temperatures with heat pumps + air sealing + insulation

Health & safety:

No combustion in the house: Burning fossil fuels emit several contaminants of concern: $PM_{2.5}$, NO_2, CO, aldehydes and leaking unburned CH_4

Indoor Air: 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: Environmental Justice Issue – often worse in disadvantaged communities

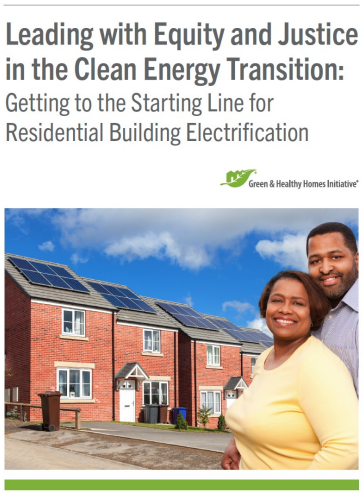
Mental health: electric bill smore stable/predictable

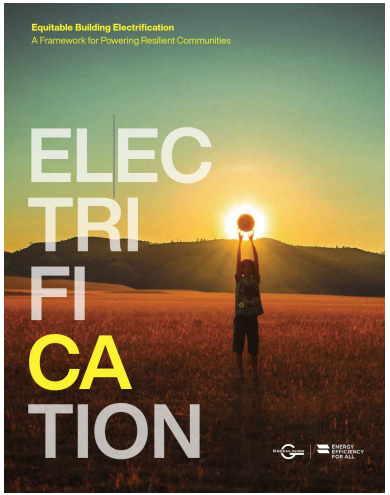
Cooler surfaces with induction cooking

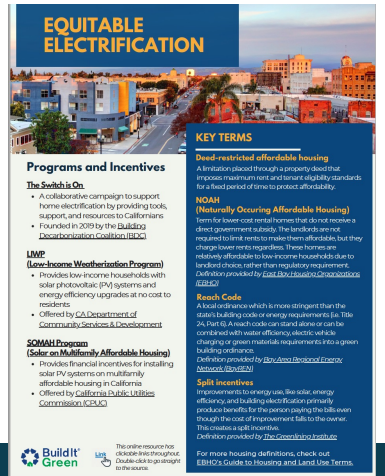
Heat stress: Provision of cooling + more affordable heating/cooling

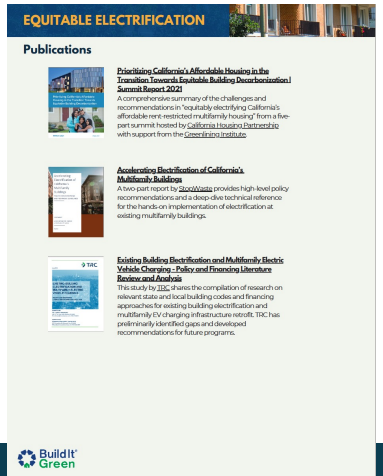
Solutions for renters, multi-family and low income households

- Renters need protection form increased rents and eviction
  - Look for solutions the do not require MF buildings to be empty
  - In MF occupants often pay electric bill, but not gas bill if heat and hot water are central systems. How to compensate if someone starts to use a portable heat pump?
  - Current focus of many non-profits
- Develop plug-in/transportable solutions
- Develop solutions for large MF where central heat and hot water maybe difficult to replace









Leaking Gas

- 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.
- This is why removing all gas infrastructure is important
  - A problem for “mixed fuel” approaches where existing gas heat is retained.
  - Needs to be planned/staged – otherwise last people connected pay full infrastructure costs
  - Accounted for in CPUC Avoided Cost Calculator*

Remaining Challenges

Solutions for hard to electrify homes

- Cold climates
- All-gas homes
- Multifamily homes
- Manufactured homes
- Old/historic homes

Technical Challenges

Noise:
- Quieter HPWH

Maintenance:
- HPWH have filters that need to be inspected and changed

Form Factors:
- HPWH (and some HP) don't fit in same space as current Water Heaters

Refrigerants:
- High GWP (except for CO_2). We need to not have leaks. No more flare fittings? More sealed systems?

HPWH and HP controls:
- Currently opaque to installer and user. Need manufacturers to step up and allow user/installer control and/or remove controls that are energy and power inefficient
- Communication-ready appliances and equipment.

Devices that can be paused mid-cycle and then resumed seamlessly

Behaviour:
- Occupants: Don't set back your high efficiency variable speed HP
- Installers: How to properly install a heat pump: fix the ducts for capacity and efficiency, ensure controls are set up properly (not trivial in many cases – manufacturer support needs to improve), etc.

Some Policy Implications

Rethinking Electric System Rebates

Currently $2500 for a panel upsize (IRA up to $4000 + $2500 for additional wiring)

- Allows high power devices and higher peak load from home to utility
- New distribution and transformer upsizing - these costs passed on to ratepayers
- Allowing oversized panels locks out future electrification – City of Palo Alto

Future panel/service replacement rebates should only be allowed if shown to be necessary using NEC 220.87 or 220.83

EV Chargers also rebated, consider NOT rebating anything higher than Level 2.

Rethinking Electric System Rebates

- Minimizes new infrastructure delays and future bills
- Low power electrification strategies to avoid need for new service (not enough grid capacity or workforce capacity to put high power into all homes)

What to incentivize? ⟹ Low Power and Time-Shifting

- Sizing (include current weatherization programs and insulating rebates for older uninsulated homes)
- Better understanding of how much a heat pump load adds to existing load – NEC updates coming
- Circuit sharing and modulation
- Meter collars?
- Battery integrated cooking (120V 20A replaces 240 V 50A)
- Batteries and controls & enable V2G
- Low power laundry (120V HP or condensing dryer)
- Low power heat/cool (120 V 1200W (x2 or 3)
- Low power hot water (120 V 400W)
- Integrated appliances: combo washer/dryer, range not separate cooktop and oven
- Not installing electric resistance supplementary heaters in Heat Pumps and HPWH

Equity

Split Incentive Problem may become more complex:

- OLD: If MF building owner does not pay bills – no financial incentive for savings
- NEW: If MF building owner does not pay bills – no potential exposure to higher bills
- Switching from central heat or DHW to in-unit… how are savings passed on to tenants – needs regulation. Also a problem for condominiums.

- Rebates not tax credits
- Don’t leave communities behind – who pays for legacy infrastructure?
- Minimize bill impacts: include load reductions in programs, and consider higher performance equipment

Other Regulation Challenges

Update codes and standards to allow for easier electrification:

- Outdoor Heat Pump unit location – difficult for many (older) existing homes and + Multi-Family
- Electric codes – improving NEC but need collaboration with AHJs & utilities (e.g., make AMI data available to allow previous use path in NEC)
- Green bock – leads to expensive work – moving panels, rewiring, new service drop, potential service denial

CO_2-based TOU rates?

We should charge EVs, operate water heaters, maybe run dishwashers…

Here

NOT here

Emissions intensity, in mTCO2/MWh

Hour	Jan	Feb	Mar	Apr	May	Jun	Jul
0	0.332	0.314	0.292	0.297	0.280	0.299	0.301
1	0.334	0.317	0.296	0.303	0.283	0.302	0.306
2	0.333	0.315	0.298	0.303	0.281	0.302	0.306
3	0.340	0.322	0.295	0.305	0.284	0.307	0.315
4	0.334	0.319	0.297	0.304	0.280	0.312	0.319
5	0.330	0.315	0.298	0.303	0.277	0.307	0.314
6	0.334	0.321	0.313	0.306	0.277	0.293	0.296
7	0.332	0.303	0.288	0.265	0.215	0.257	0.247
8	0.277	0.217	0.196	0.173	0.165	0.222	0.207
9	0.215	0.149	0.132	0.133	0.150	0.211	0.195
10	0.202	0.133	0.123	0.124	0.142	0.208	0.183
11	0.196	0.131	0.119	0.119	0.130	0.200	0.173
12	0.198	0.137	0.105	0.112	0.124	0.186	0.167
13	0.185	0.132	0.102	0.102	0.123	0.181	0.161
14	0.196	0.123	0.104	0.095	0.122	0.187	0.167
15	0.218	0.146	0.097	0.099	0.131	0.189	0.178
16	0.300	0.205	0.131	0.115	0.143	0.201	0.193
17	0.340	0.297	0.183	0.146	0.149	0.209	0.200
18	0.347	0.315	0.248	0.214	0.195	0.234	0.225
19	0.346	0.319	0.294	0.304	0.279	0.272	0.267
20	0.341	0.319	0.298	0.313	0.295	0.298	0.291
21	0.342	0.327	0.290	0.306	0.288	0.297	0.289
22	0.343	0.334	0.293	0.310	0.281	0.299	0.294
23	0.342	0.335	0.289	0.311	0.287	0.302	0.297

https://www.paloaltoonline.com/blogs/2022/07/24/the-emissions-intensity-of-californias-electricity-grid/

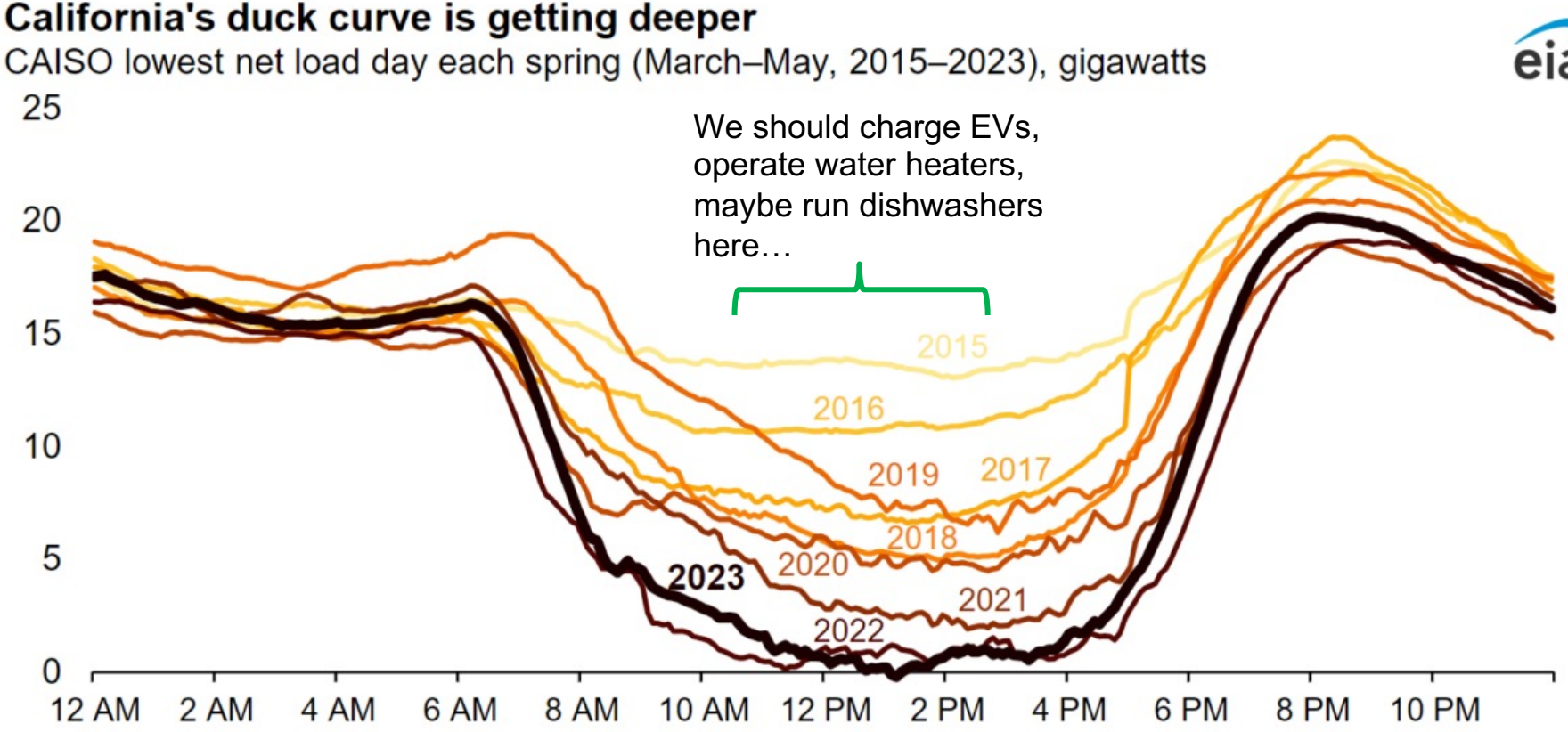


Image: Energy Information Administration

Immediate Actions

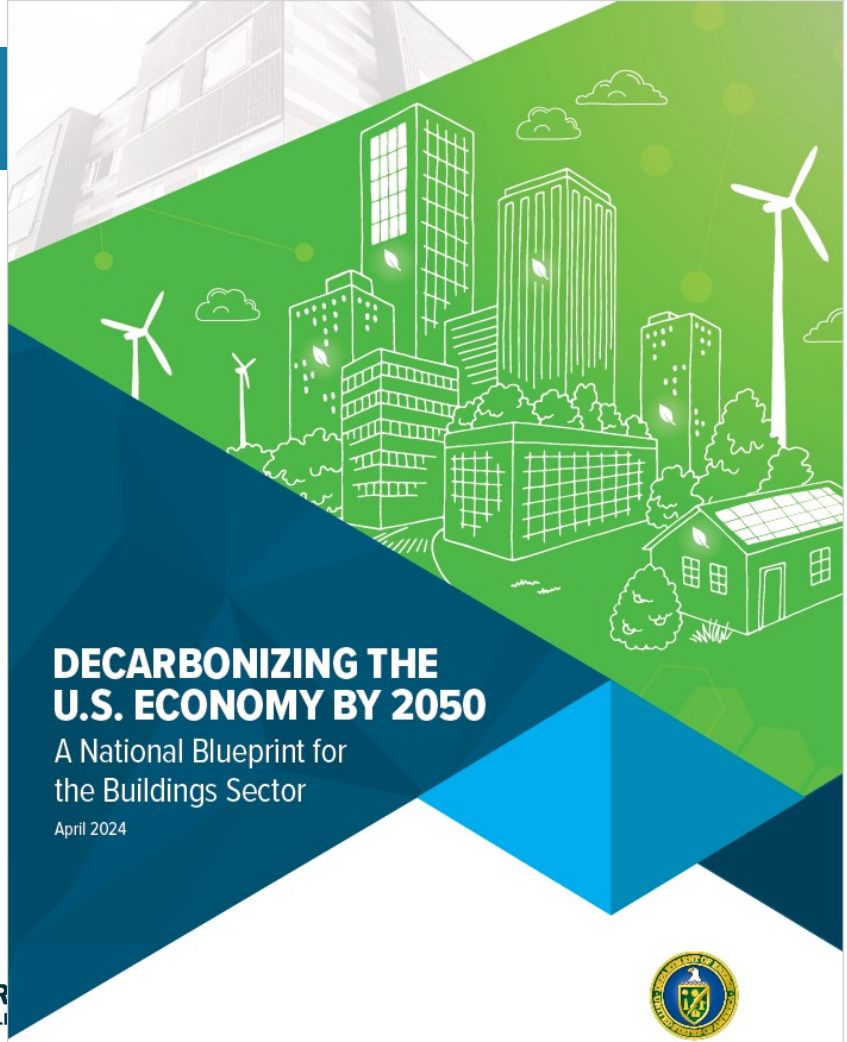
- **Make changes now.** Deploy available technology today and improve systems as they become available in the future. Don’t wait to solve all the issues or for perfect solutions. Get started immediately in the houses that are easy to electrify right now. Don’t do everything all at once – but have a plan, e.g., prewire for HP/HPWH now so that emergency replacement is easy. **Make every AC replacement a heat pump.**
- **Increase demand.** Give people what they want: available, affordable, easily financed, reliable, safe, and resilient systems. Incentivize demand with rebates.
- **Reduce risk.** Wherever possible, deploy proven technologies & existing mainstream products: insulation, air sealing, heat pumps, electric cooking and clothes drying. Include health, safety, & comfort in value proposition. Create guides for home owners and trades.
- **Support workforce.** Overcome the workforce shortage by offering a compelling value proposition for workers and employers: solid pay and benefits, and a strong steppingstone to longer-term career opportunities. Help contractors to change business practices.

Immediate Actions

- **Increase affordability**. Use Low Power Electrification approaches and cost compression. Focus on CO_2 reduction strategies. Work with utilities on better rate structures and Green Book requirements.
- **Enable equitable and accessible options**. Meet the needs of disadvantaged communities, multifamily housing, manufactured housing, and renters.
- **Make new products available**. Work with equipment manufacturers on better form factors, low GWP refrigerants, noise regulation, lower power devices, emerging technologies: circuit sharing/pausing, better controls and controls access.
- **Simplify Regulation**. Work with local authorities to allow low power electrification approaches.

(Near) Future Innovations Needing Policy Support

Low power, low GWP heat pump solutions
Low power cooking and clothes drying solutions
Integrated control platforms that address and control all levels of the system, including appliances, branch circuits and panel boards.
Load control with modulation capability – include V2G
Communication-ready appliances and equipment.
Devices that can be paused mid-cycle and then resumed seamlessly.
Load control solutions that can respond to local grid conditions.
Database for “power rating” of appliances similar to “energy rating”.
More integrated battery/thermal storage devices to enable low power in, high power out PLUS resiliency.
Including embodied CO_2.



LBNL-2001540

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March 2023

doi.org/10.20357/B7XG7T

Questions?