Better Buildings
U.S. DEPARTMENT OF ENERGY

Better Buildings Residential Network
Peer Exchange Call Series

Carrying the Load: What Is the State of Load Flexibility and Energy Efficiency?

March 11, 2021

U.S. DEPARTMENT OF ENERGY

Agenda and Ground Rules

- Agenda Review and Ground Rules
- Opening Poll
- Residential Network Overview and Upcoming Call Schedule
- Featured Speakers
  - **Erika Gupta**, U.S. Department of Energy
  - **Teja Kuruganti**, Oak Ridge National Laboratory
  - **Saul Griffith**, Otherlab
- Open Discussion
- Closing Poll and Announcements

Ground Rules:

1. **Sales of services and commercial messages are not appropriate** during Peer Exchange Calls.
2. Calls are a safe place for discussion; **please do not attribute information to individuals** on the call.

The views expressed by speakers are their own, and do not reflect those of the Dept. of Energy.

Better Buildings Residential Network

Join the Network

Member Benefits:

- Recognition in media and publications
- Speaking opportunities
- Updates on latest trends
- Voluntary member initiatives
- One-on-One brainstorming conversations

Commitment:

- Members only need to provide *one number*: their organization's number of residential energy upgrades per year, or equivalent.

Upcoming Calls (2nd & 4th Thursdays):

- Mar 25: *Smart Range Hoods vs. Indoor Air Quality: Coming to Kitchens Near You Soon*
- Apr 08: *Automation: Where is the Balance between Humans and Machines to Save Energy?*
- Apr 22: *Earth Day Special: Electrification, Batteries, Storage & Residential Efficiency*

Peer Exchange Call summaries are posted on the Better Buildings website a few weeks after the call

For more information or to join, for no cost, email bbresidentialnetwork@ee.doe.gov, *or go to* energy.gov/eere/bbrn *& click Join*

Erika Gupta
U.S. Department of Energy

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Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

DOE Building Technologies Office EE and Flexible Loads Overview

Presenter: Erika Gupta, Emerging Technologies Program Manager, *Acting*

March 11, 2021

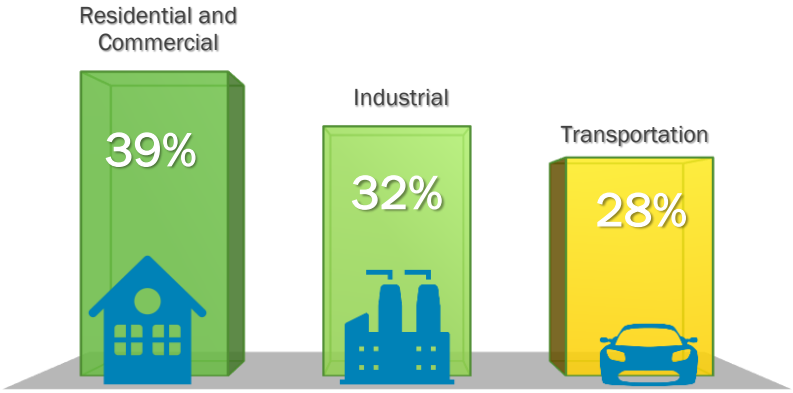
Administration Priorities

President Biden has established a specific target to **cut the U.S. building stock's carbon footprint in half by 2035** by creating incentives for deep building retrofits that combine appliance electrification, efficiency, and on-site clean power generation.

Taking that further, President Biden also wants to establish a "**new net-zero emissions standard for all new commercial buildings by 2030**"

Overview of U.S. Homes and Buildings

Our Homes and Buildings Use More Energy than Any Other Sector



The U.S. building stock is comprised of ~126 million commercial buildings and housing units totaling 329 billion ft. sq.

More than 80% of structures are at least 20 years old.

5.6 million commercial buildings totaling **92 billion square feet**

121 million housing units totaling **237 billion square feet**

36% of homes produce **rental income** for their owners

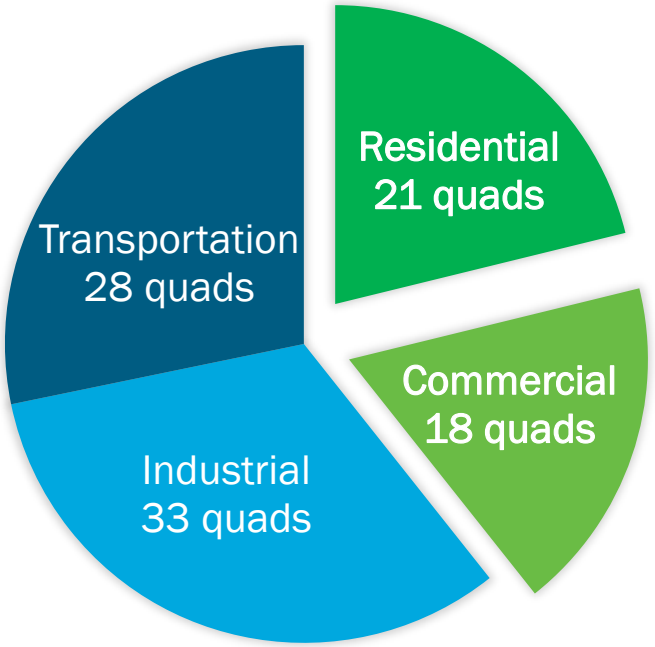
Buildings' energy utility bill is **~$412B annually,** much of which is wasted

87 million Americans are **invested in real estate** through retirement and investment funds

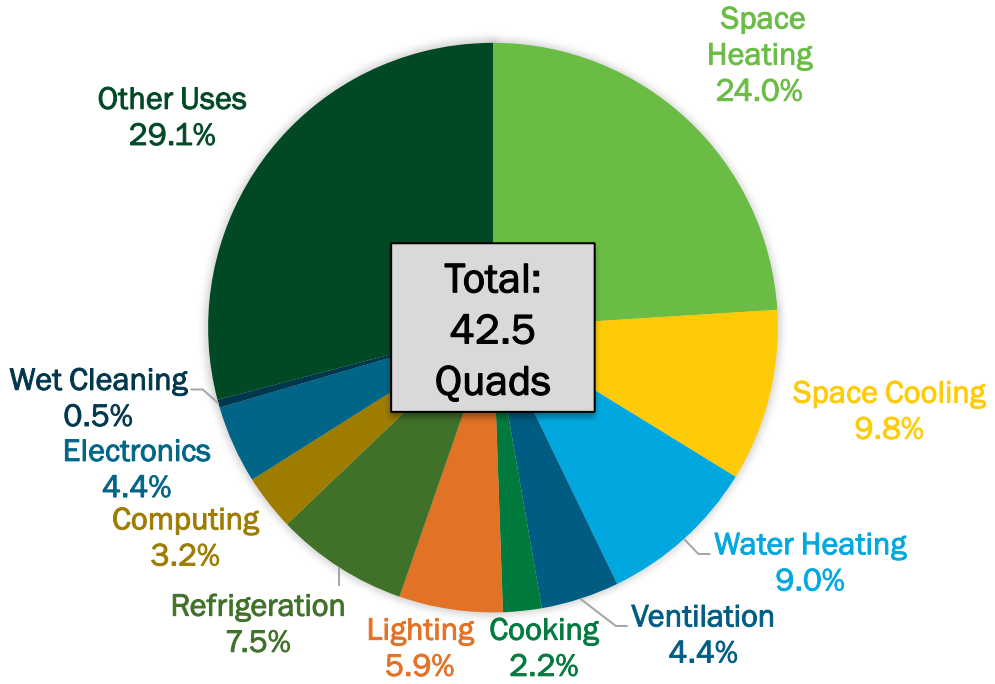
Source: EIA Monthly Energy Review; U.S. Energy Information Administration (CBECS 2012/RECS 2015); NAREIT Reits by the Numbers; Harvard University (The State of the Nation's Housing 2019)

U.S. Energy and Electricity Consumption by Sector

Energy Use



Building Energy Use



Buildings Energy Use: 39% of U.S. total

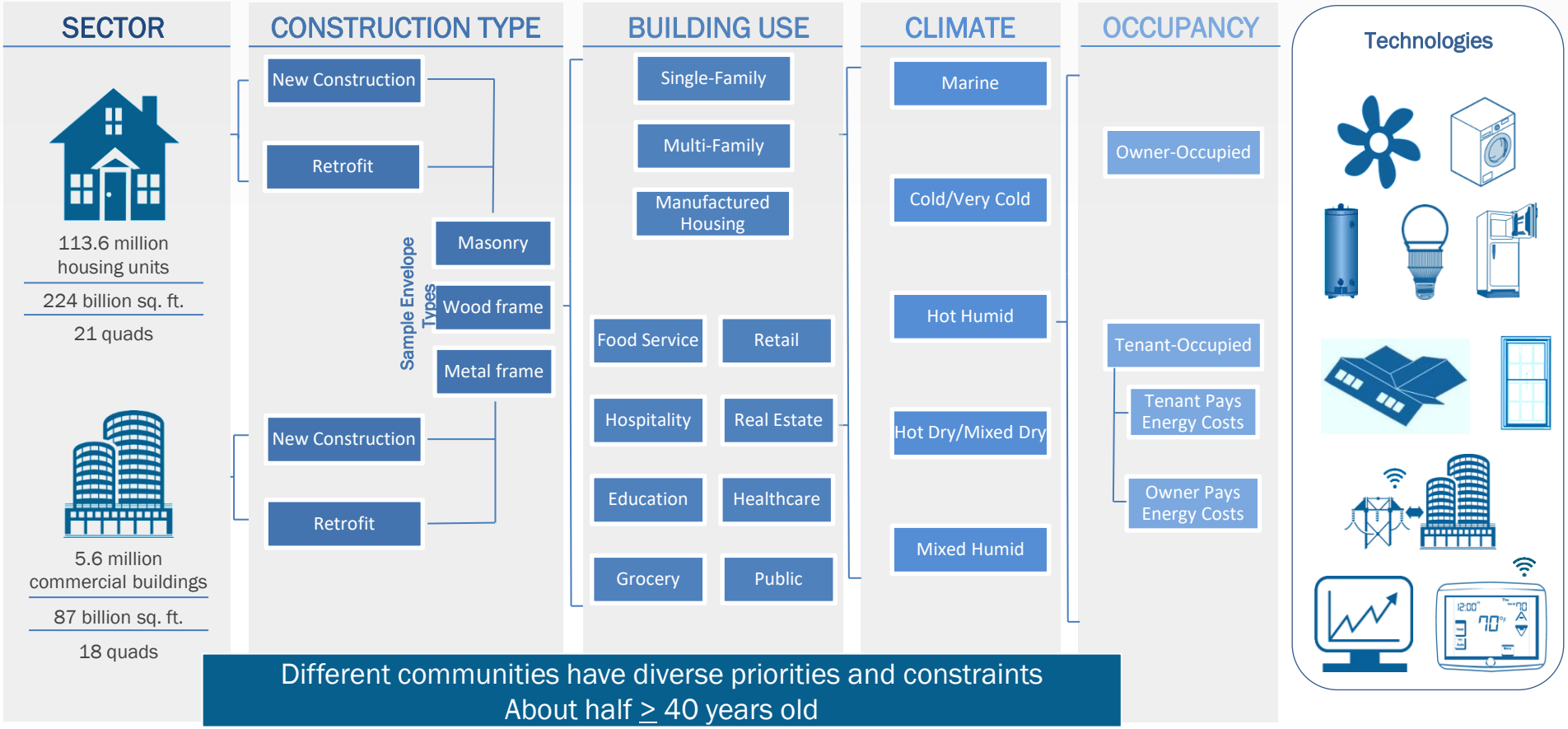
Buildings Electricity Use: 74% of U.S. total

Buildings Peak Electricity Demand: ~80% of regional total

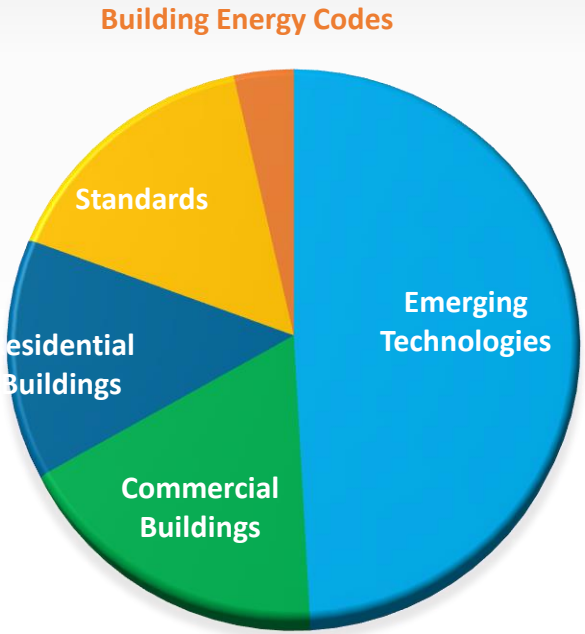
Building Energy Utility Bill: $412 billion per year

Sources: US EIA (Monthly Energy Review, Annual Energy Outlook 2020, Electric Power Monthly, Natural Gas Summary)

US buildings market is large, complex, diverse: many challenges, multiple solutions needed



BTO works on the entire spectrum of Market Transformation: from R&D to Integration & Deployment to Standards & Codes



BTO invests across the market transformation spectrum to make homes and buildings more efficient, affordable and comfortable, and to make the US more sustainable, secure and prosperous.

R&D
R&D in next-gen technology: Lighting, HVAC, Windows & Envelope, Grid-interactive Efficient Buildings (GEB), Building. Energy Modeling, Sensors & Controls

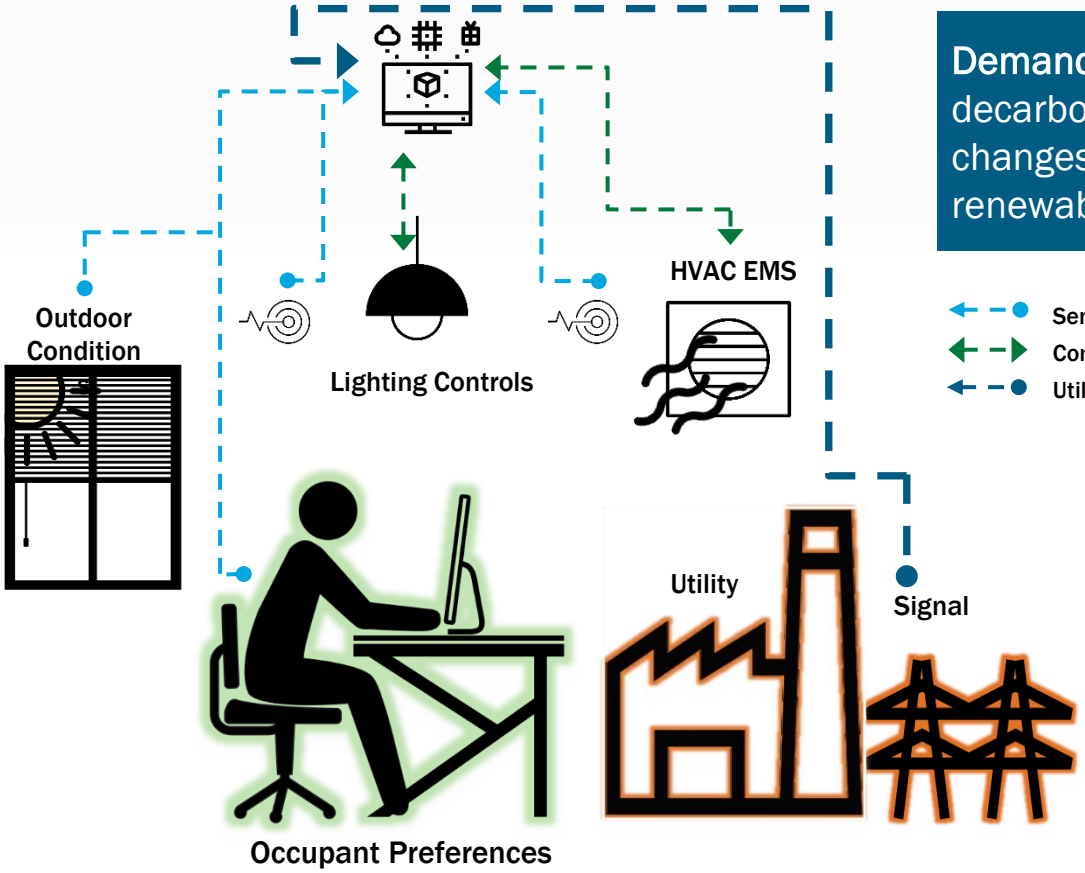
Integration & Deployment
Technology validation, field & lab testing, decision tools, market integration, demonstration, market transformation

Codes & Standards
Codes & standards development and technical analysis, standards and test procedures promulgation

John Cymbalsky Joan Glickman
Amy Jiron Erika Gupta
David Nemtzow

David Nemtzow, Director
Lucy DeButts & Jeremiah Freeman
Ops Team

Grid-interactive Efficient Buildings: advancing demand flexibility



Demand flexibility is needed for a lower-cost decarbonization transition, supporting changes on the grid resulting from both renewable integration and electrification

Sensor/Occupant Inputs
Control Signal
Utility Communication

Applicable to Other Technologies, e.g.:

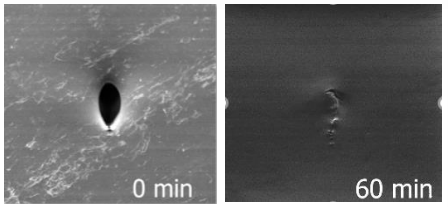
For more information please visit:
energy.gov/eere/buildings/GEB

Groups of GEBs Can Provide Added Value

Advanced Building Construction (ABC) Initiative

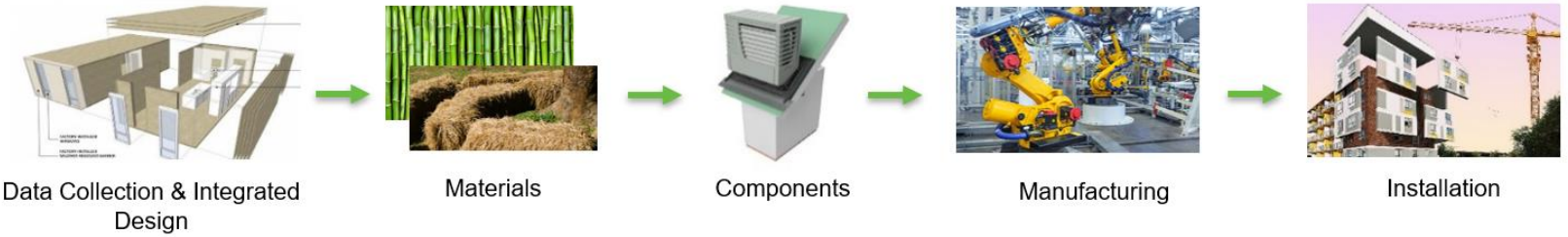
Integrating energy efficiency solutions into highly productive U.S. construction practices for new buildings and retrofits to help advance high-performance buildings at scale.

Example: Self-healing materials



- ✓New building materials
- ✓3D printing
- ✓Modular construction
- ✓Digitization
- ✓Robotics
- ✓Workforce development

Workforce Development



For more information please visit: energy.gov/eere/buildings/advanced-building-construction-initiative

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Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

LET'S WORK TOGETHER!

www.energy.gov/eere/buildings

Erika Gupta

erika.Gupta@ee.doe.gov

Teja Kuruganti
Oak Ridge National Laboratory

U.S. DEPARTMENT OF
ENERGY

OAK RIDGE National Laboratory

Carrying the Load -- What Is the State of Load Flexibility and Energy Efficiency?

Teja Kuruganti

Oak Ridge National Laboratory

Email: kurugantipv@ornl.gov

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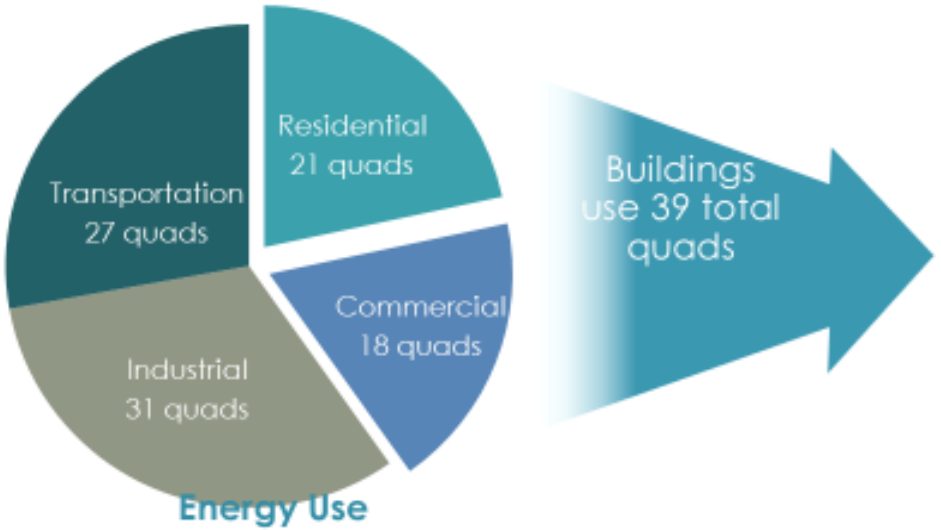
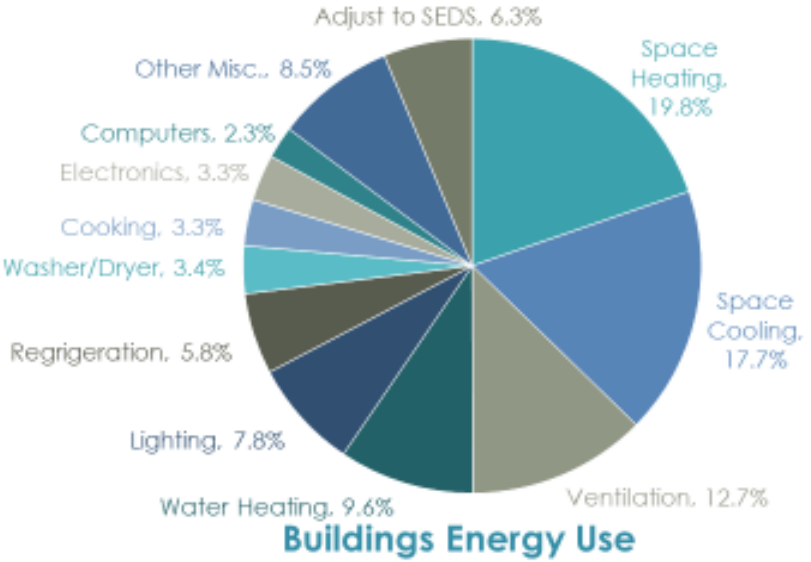
U.S. DEPARTMENT OF ENERGY

U.S. Energy Consumption by Sector





Buildings are a high priority for improving the nation's energy productivity and electric grid resilience

Buildings Energy Use	Buildings Electricity Use	Buildings NG Use	U.S. Building Energy Bill	Buildings Greenhouse Gas Emissions
40% of U.S. total	**75% of U.S. total (~80% during peak demand)**	**35% of U.S. total (~60% including power generation)**	**$380 billion per year**	**40% of U.S. total**

OAK RIDGE National Laboratory

Sources: EIA Annual Energy Outlook 2017

Smart Neighborhood Initiatives

First-of-a-kind, two smart home communities testing energy efficiency, distributed energy resources, and building(s)-to-grid integration

Georgia Power Smart Neighborhood™

- 46 townhomes
- Atlanta, Georgia
- **Homeowner owned solar + storage**
- Grid integration of solar, storage, HVAC, water heating & EV charging

Alabama Power SMART NEIGHBORHOOD®

- 62 single-family homes
- Birmingham, Alabama
- **Utility owned, grid-connected microgrid**
- Grid integration of microgrid, water heating & HVAC

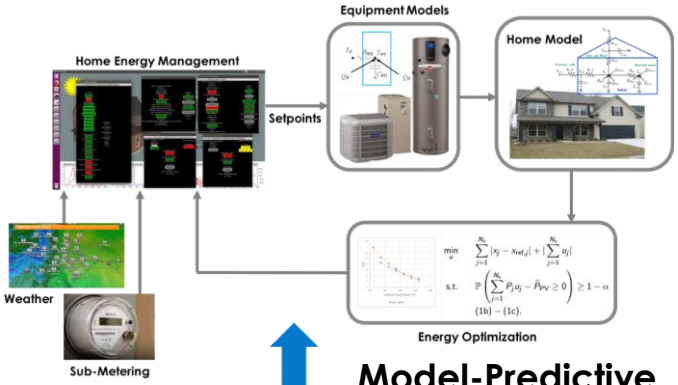
Leveraging in-home technologies
Smart thermostats, Solar Panels, Battery storage, Vivint security & home automation

Gaining a better understanding of
Energy Efficiency, Distributed Energy Resources and Home Automation on residential energy loads of the future

Utilizing external research partners
Electric Power Research Institute (EPRI) and U.S. Department of Energy's Oak Ridge National Laboratory

Grid Interactive Energy Efficient Buildings

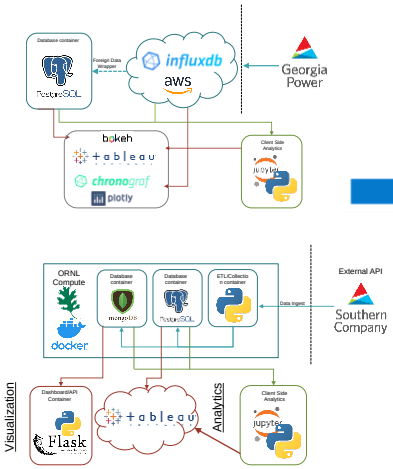
It is a balancing act to effectively manage resource efficiency and Grid Reliability



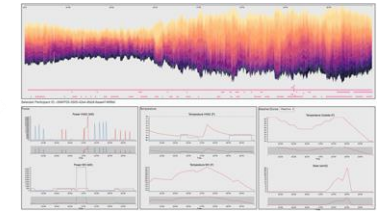
Model-Predictive Control

Field - Sensors and Controls

Data

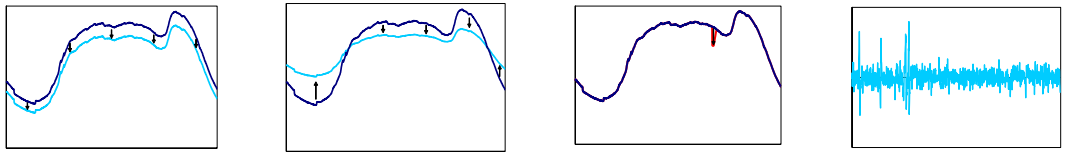


Analytics



Situational Awareness

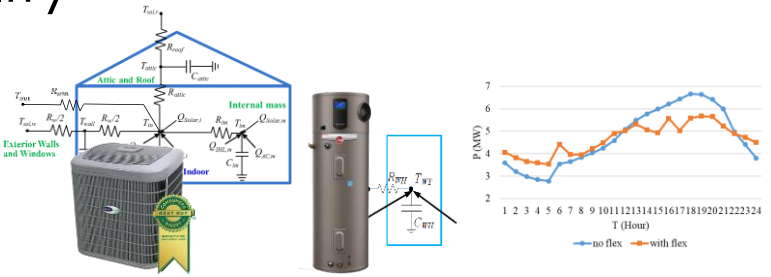
Grid Services



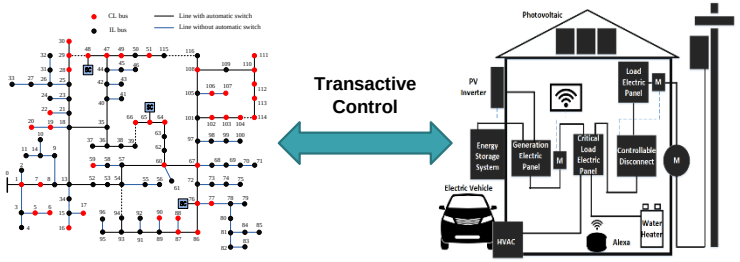
Energy Efficiency | Adaptive Load Shape | Reliability response | Regulation response

Key Advances to Address Scalability

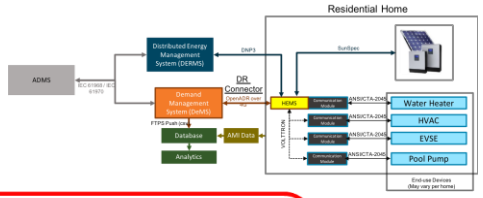
- **Models -** Online learning-driven models
  - Characterize devices based on available sensor data
  - Forecast energy-use based on disturbances and constraints



- **Controls** - Grid-interactive Building Controls
  - Clouds-in-the-loop – Latency and Reliability
  - Optimize resources for comfort and grid support



- **System Integration** – Overlay Architectures
  - Diverse set of requirements in these two domains
  - Coordinate power flow, operations and economics



Artificial Intelligence | Cloud Computing | Connectivity

Technology convergence drives opportunity

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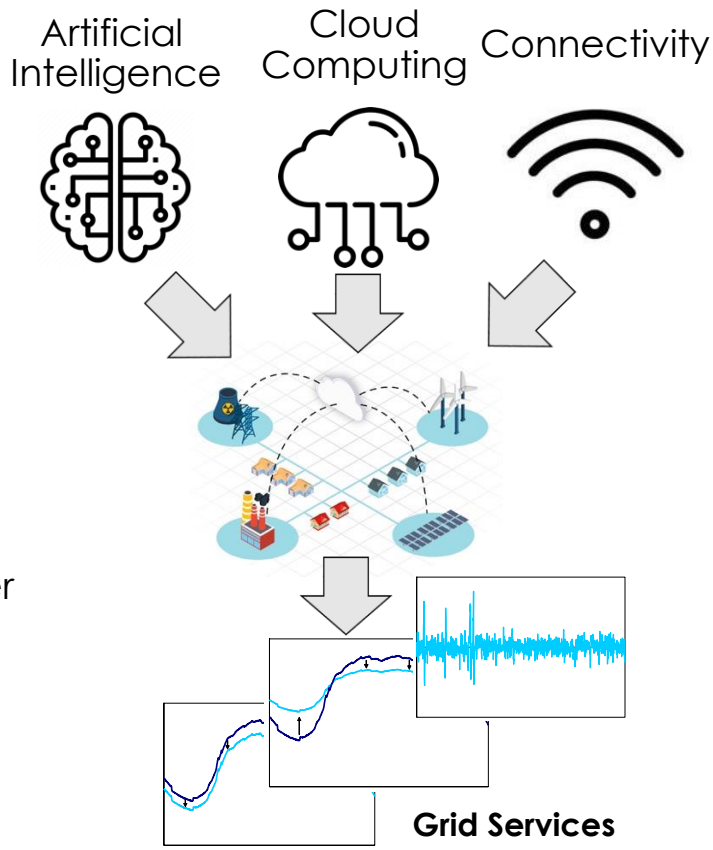
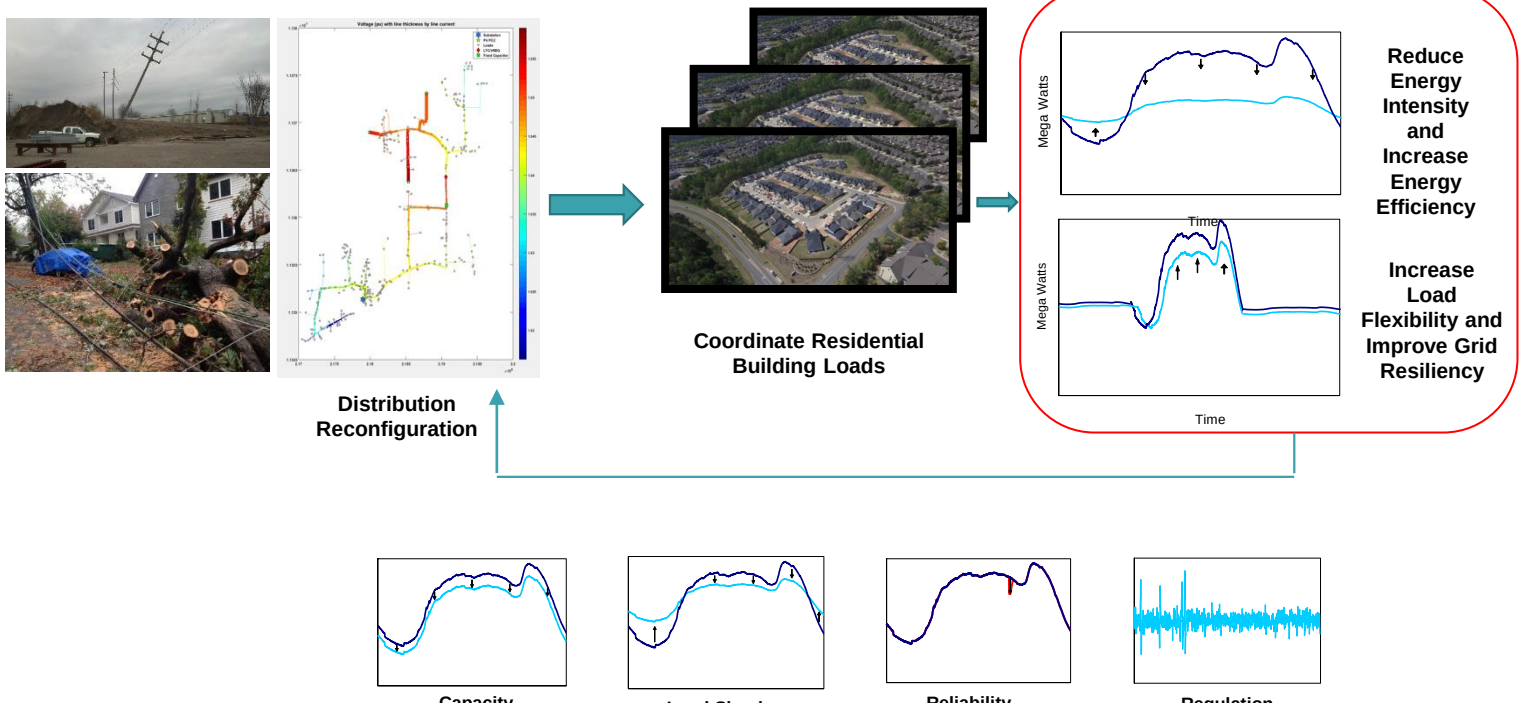
Scaling Edge-to-Utility Architecture

- **Technology convergence -** drives opportunity
  - Wide-area situational awareness
  - Proactive decision-making that is needed for improving resilience
- **Data management** and communications
  - Federating large numbers of IoT-driven end-use devices
  - Data-centric architectures
- **Wide-Area control**
  - Robust and distributed feedback control systems
  - Cloud-in-the-loop control – Tolerance to latency and jitter
- **Federated learning**
  - Granular spatiotemporal data from networks of devices
  - Online distributed learning



Improve Resilience – Engaging Building Loads/DERs



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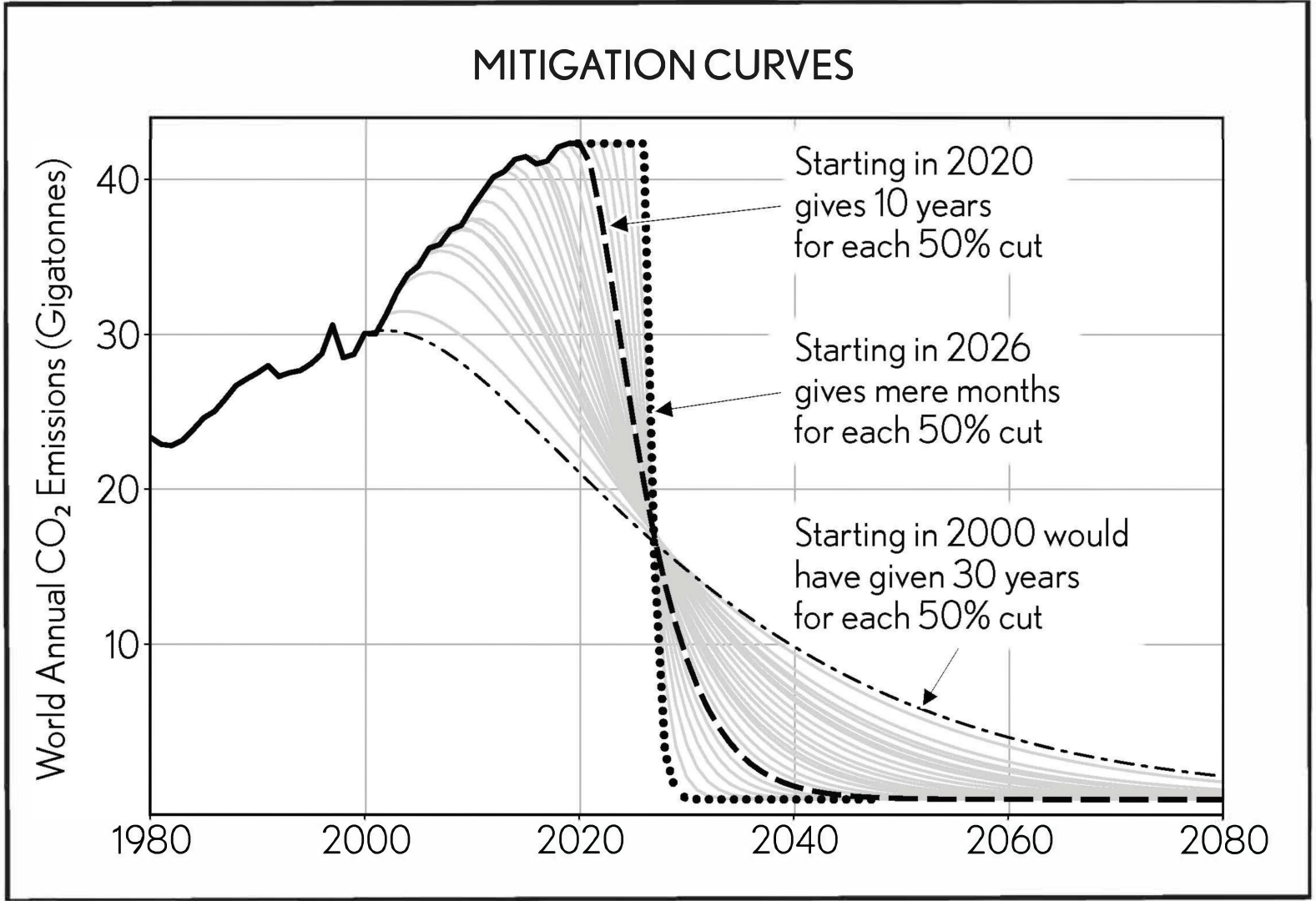
Saul Griffith
Otherlab

U.S. DEPARTMENT OF ENERGY

REWIRING AMERICA

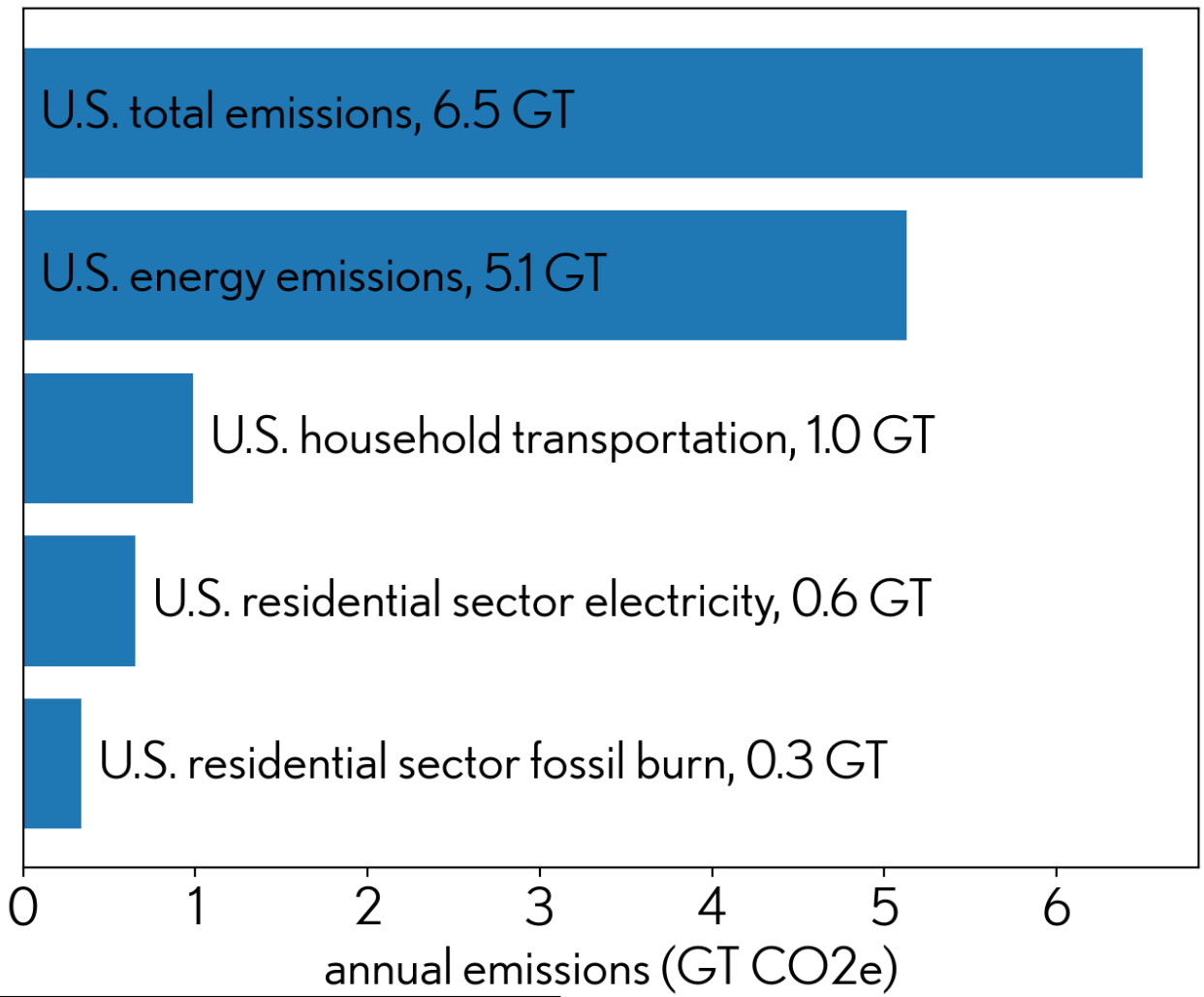
1 Billion Machines.

Climate change mitigation from the kitchen table out.


MITIGATION CURVES
World Annual CO_2 Emissions (Gigatonnes)
40
30
20
10
1980
2000
2020
2040
2060
2080
Starting in 2020
gives 10 years
for each 50% cut
Starting in 2026
gives mere months
for each 50% cut
Starting in 2000 would
have given 30 years
for each 50% cut

U.S. Emissions

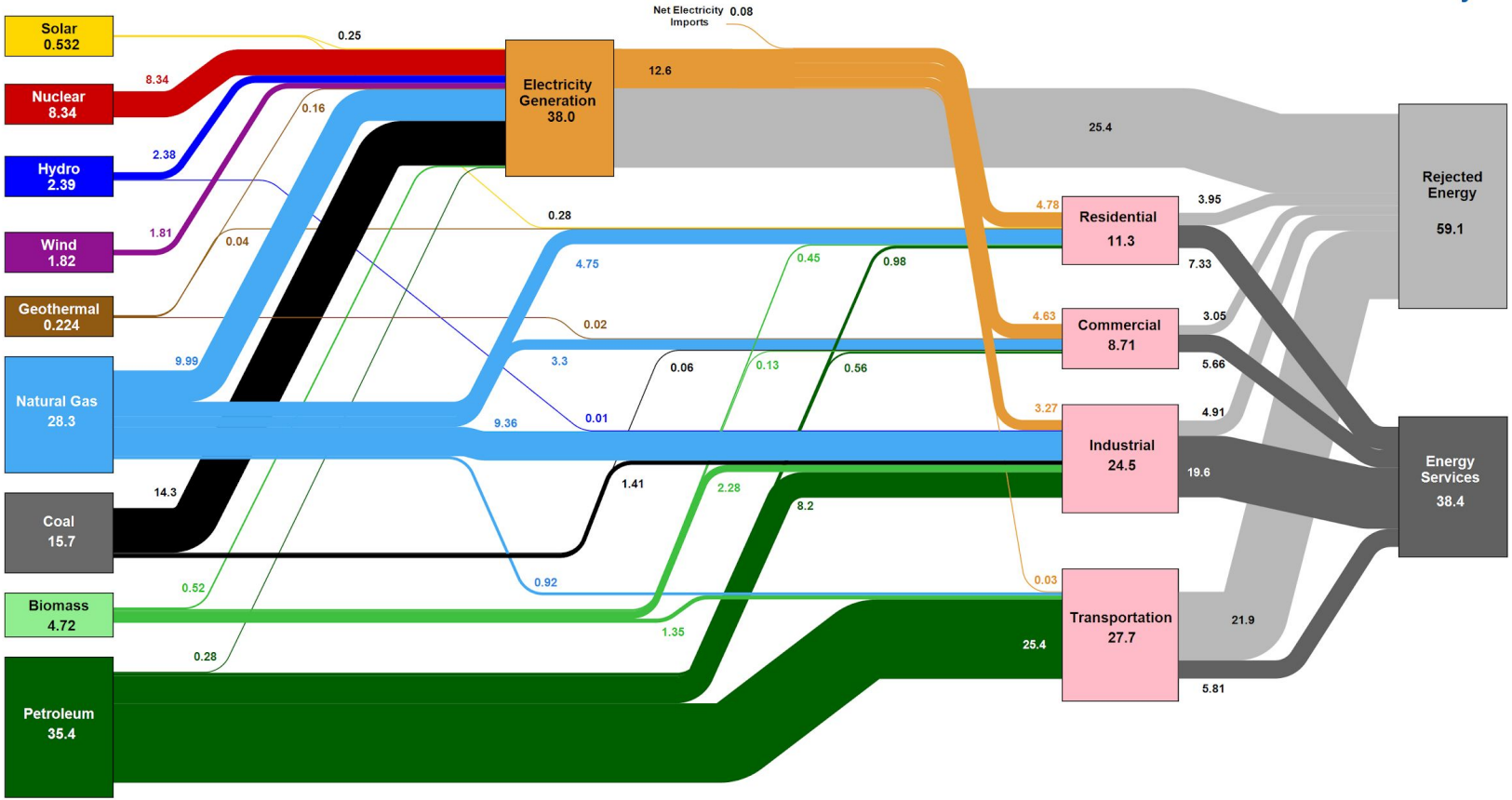
Decisions we control in our households are responsible for 42% of energy–related greenhouse gas emissions.[1]. These include our transportation, electricity, and direct fossil fuel combustion. But that is not the story we are told.



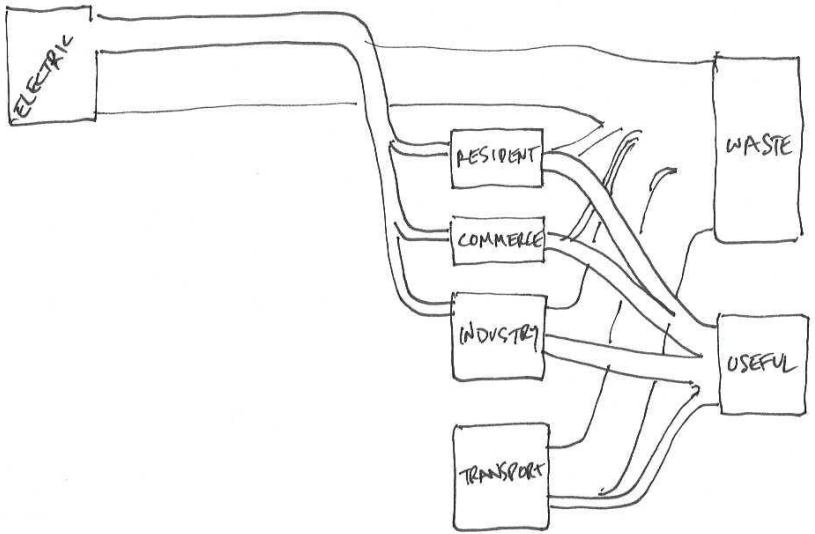
[1] EPA GHGs inventory

Estimated U.S. Energy Consumption in 2015: 97.5 Quads

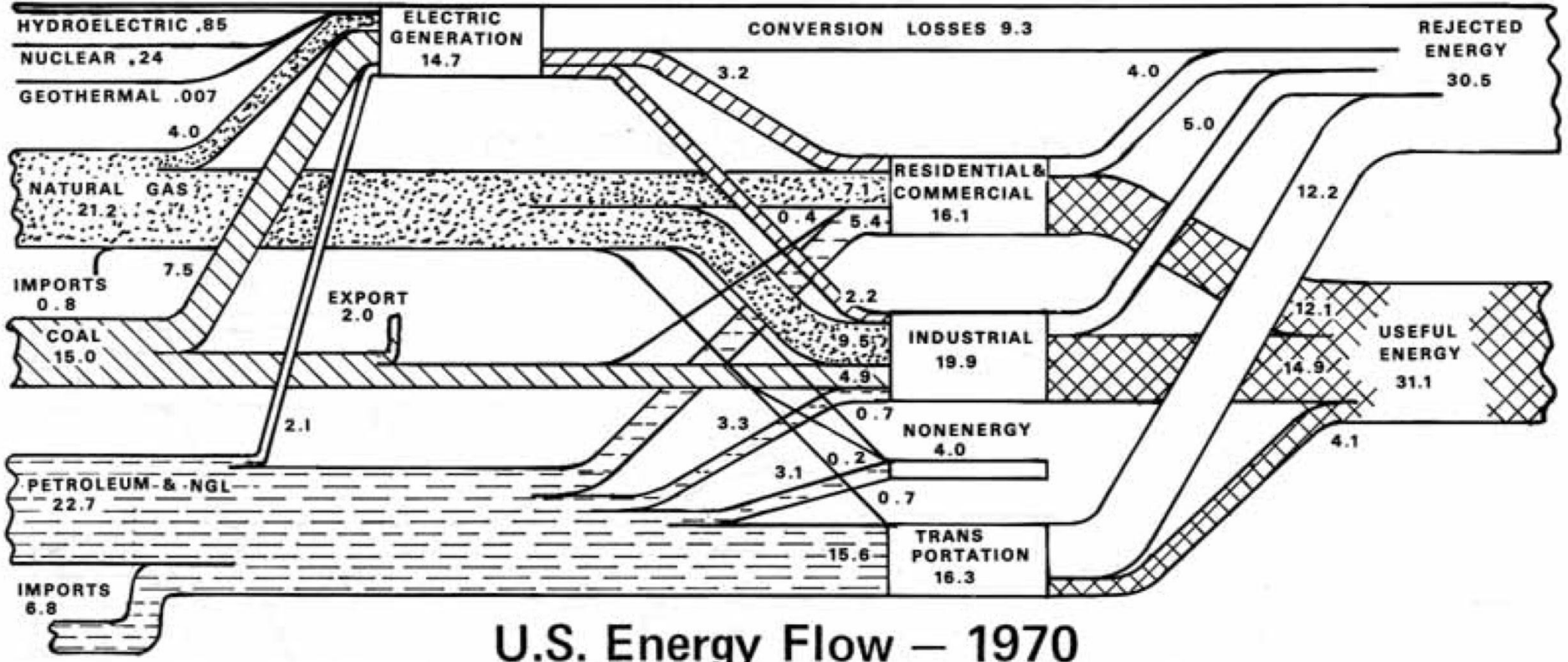
Lawrence Livermore National Laboratory



Source: LLNL March, 2016. Data is based on DOE/EIA MER (2015). If this information or a reproduction of it is used, credit must be given to the Lawrence Livermore National Laboratory and the Department of Energy, under whose auspices the work was performed. Distributed electricity represents only retail electricity sales and does not include self-generation. EIA reports consumption of renewable resources (i.e., hydro, wind, geothermal and solar) for electricity in BTU-equivalent values by assuming a typical fossil fuel plant heat rate. The efficiency of electricity production is calculated as the total retail electricity delivered divided by the primary energy input into electricity generation. End use efficiency is estimated as 65% for the residential sector, 65% for the commercial sector, 80% for the industrial sector, and 21% for the transportation sector. Totals may not equal sum of components due to independent Rounding. LLNL-MI-410527



These abstractions: “sectors”, were invented in the 1970’s

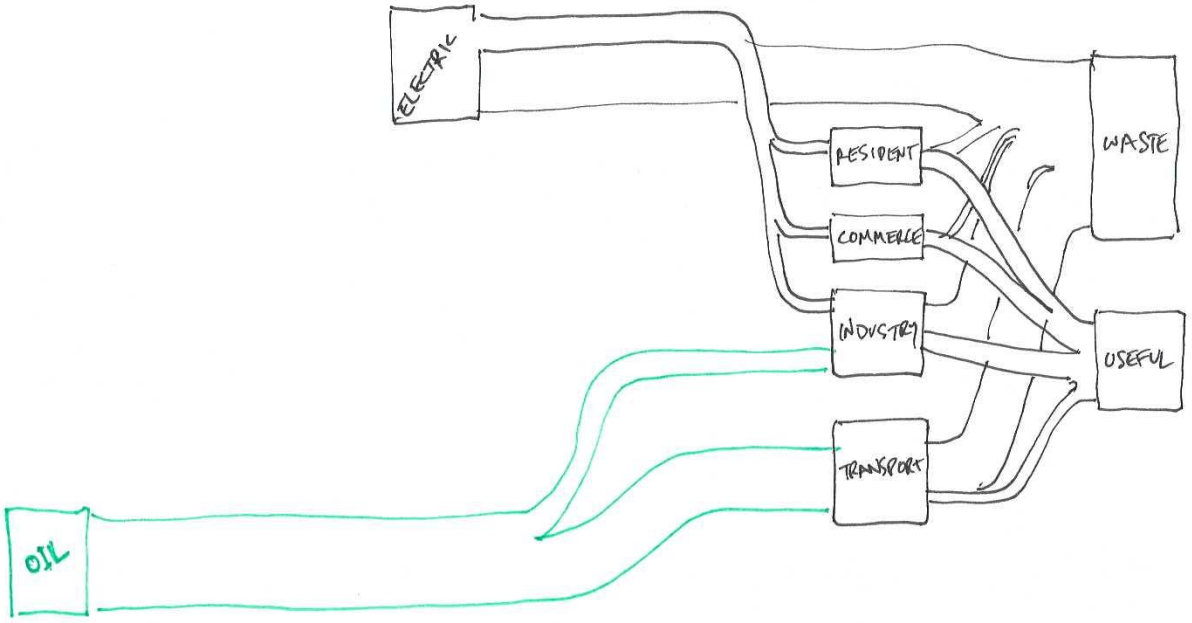


U.S. Energy Flow — 1970

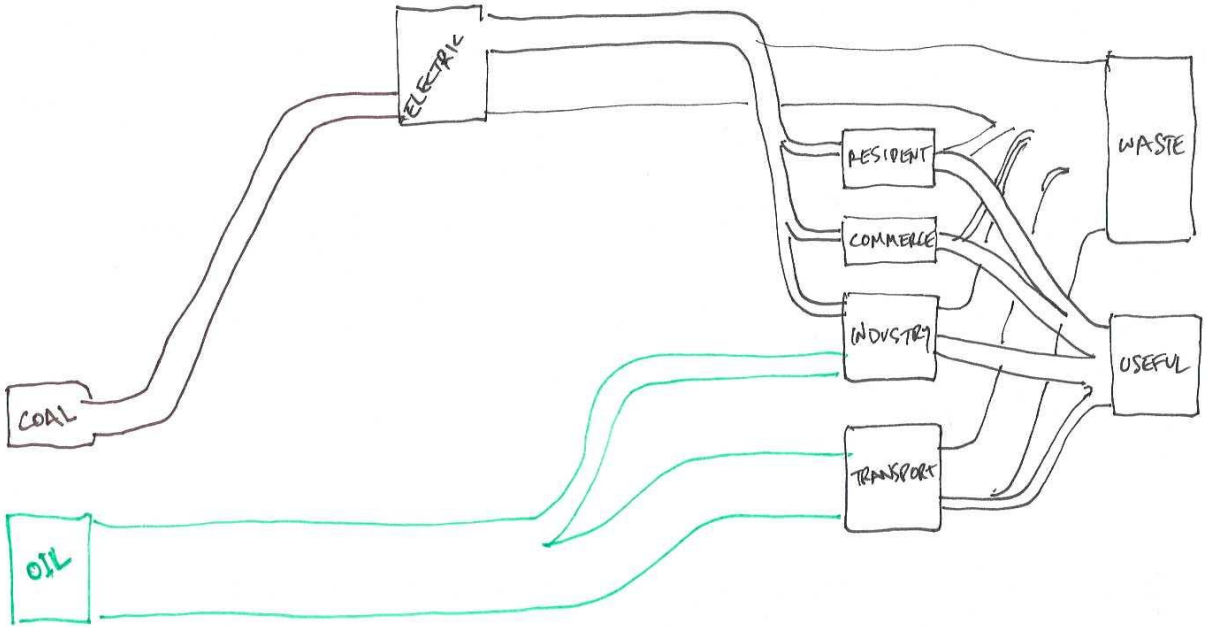
All values $\times 10^{15}$ Btu (2.12×10^{15} Btu = 10^6 bbl/day oil)

Total energy consumption = 67.5×10^{15} Btu

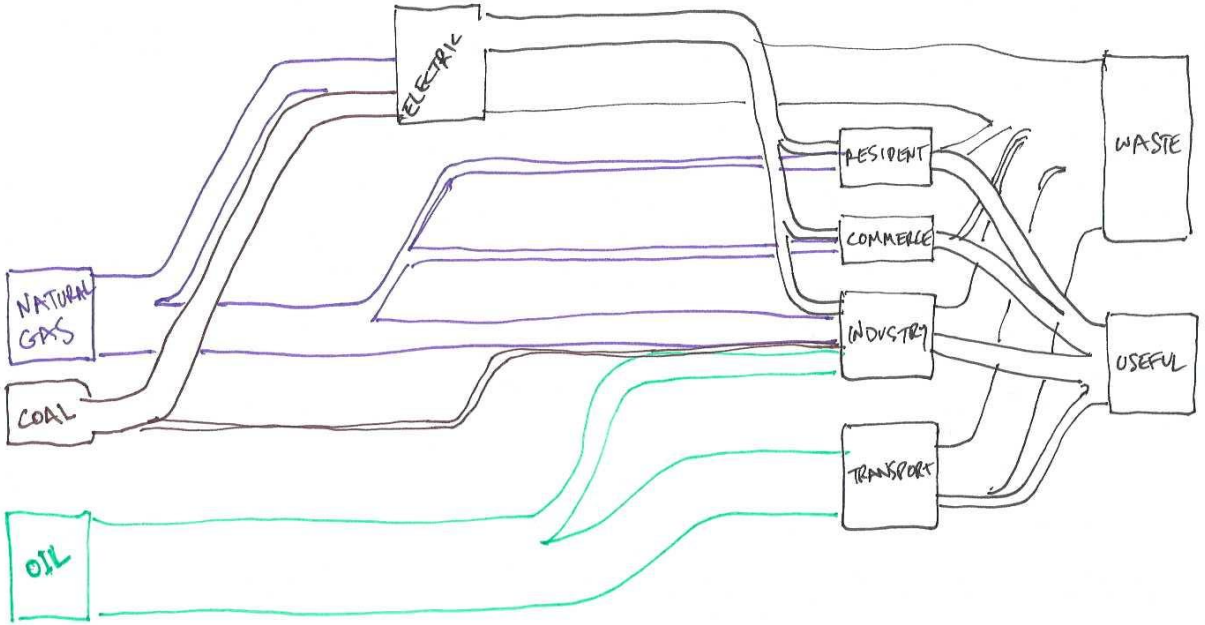
LAWRENCE LIVERMORE LABORATORY



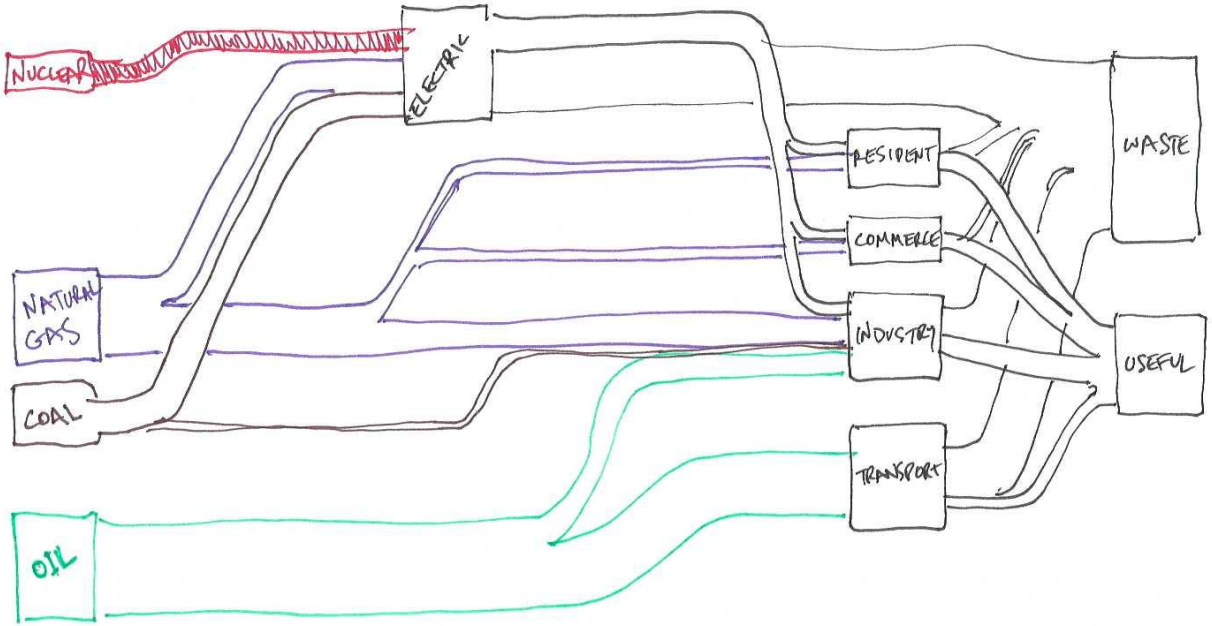
To help politicians understand and respond to the oil crisis.



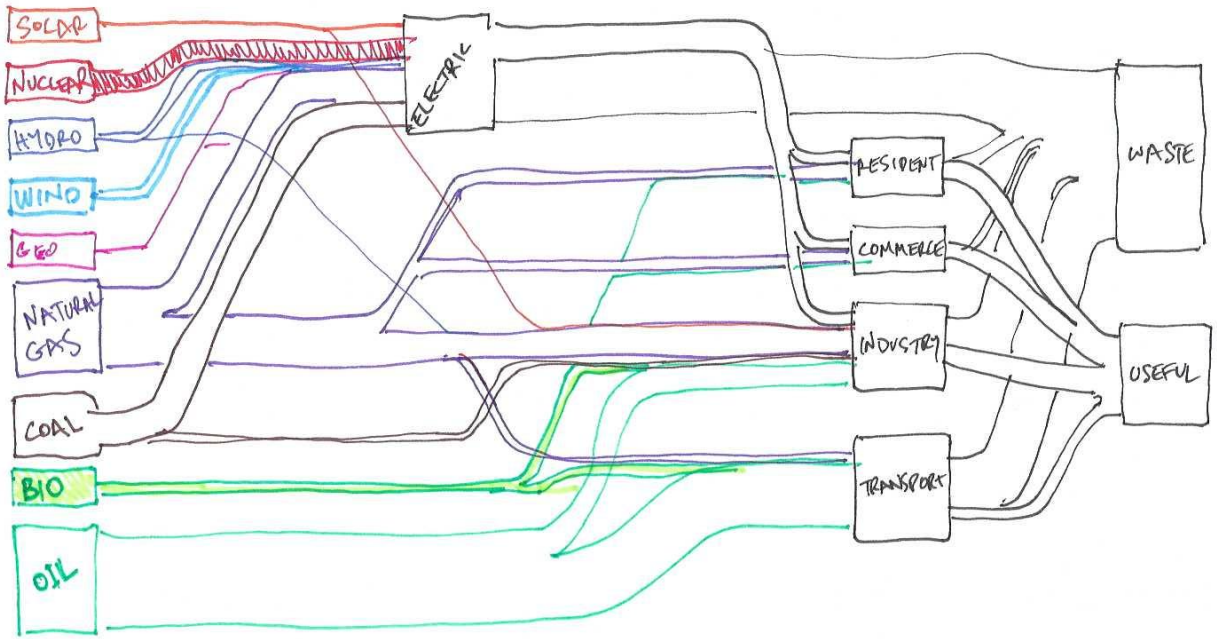
And gave us insight into our coal use... principally for generating electricity



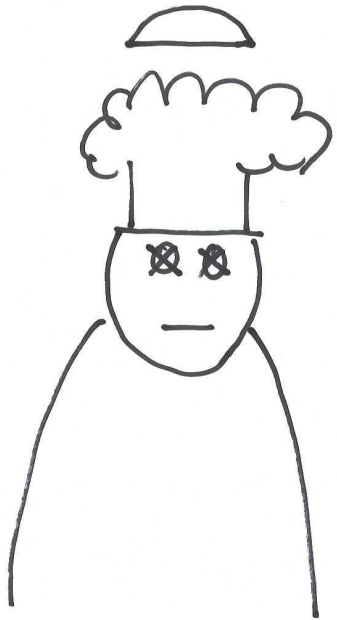
And our natural gas use, for heat and electricity



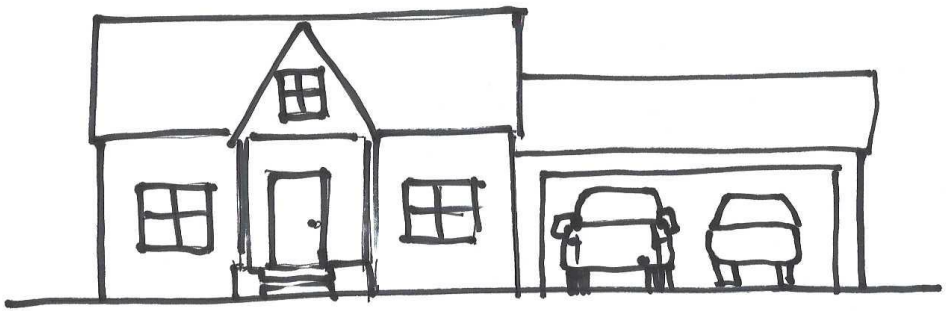
As well as our nuclear generated electricity



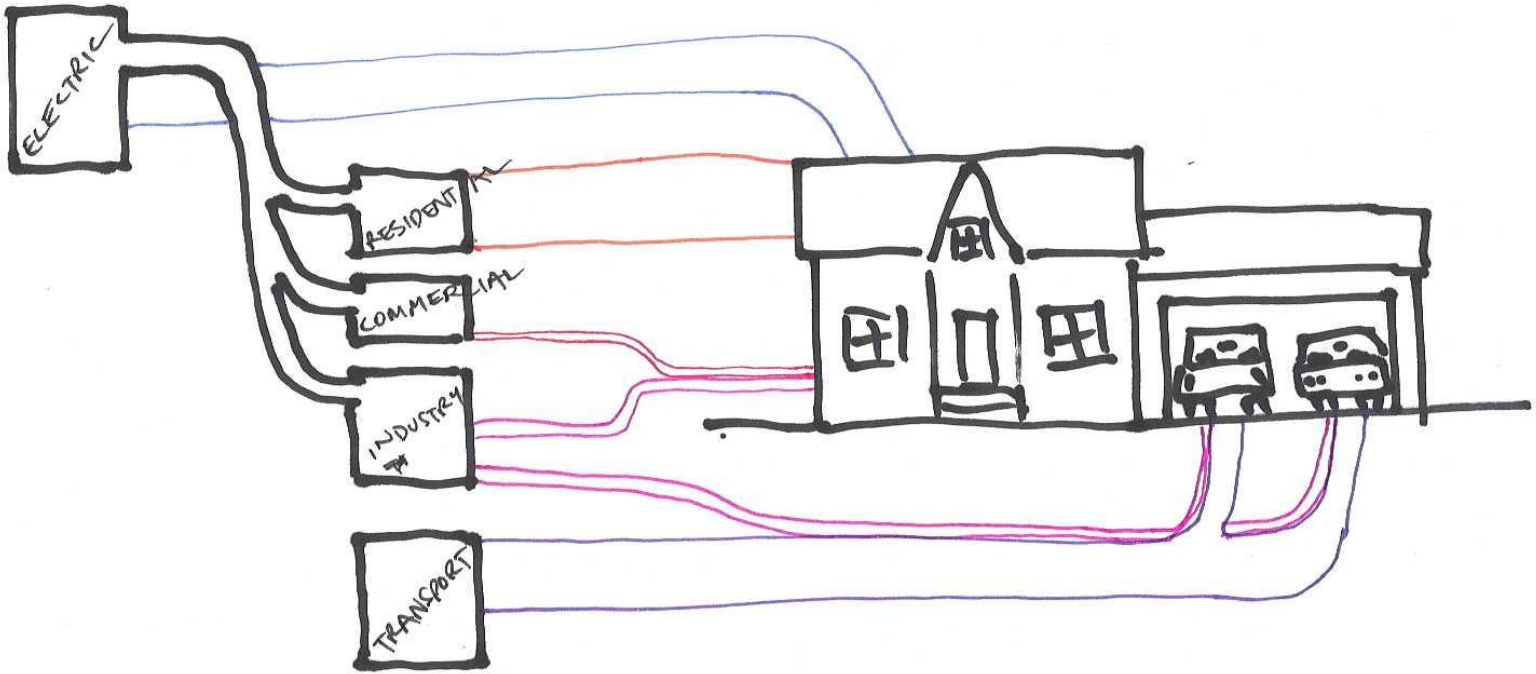
And more recently increasing renewables.



It’s complicated for experts let alone citizens.



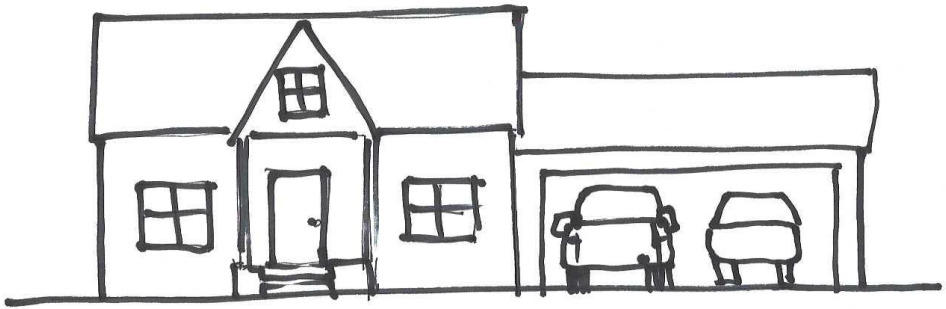
People it turns out... think in terms of their households.



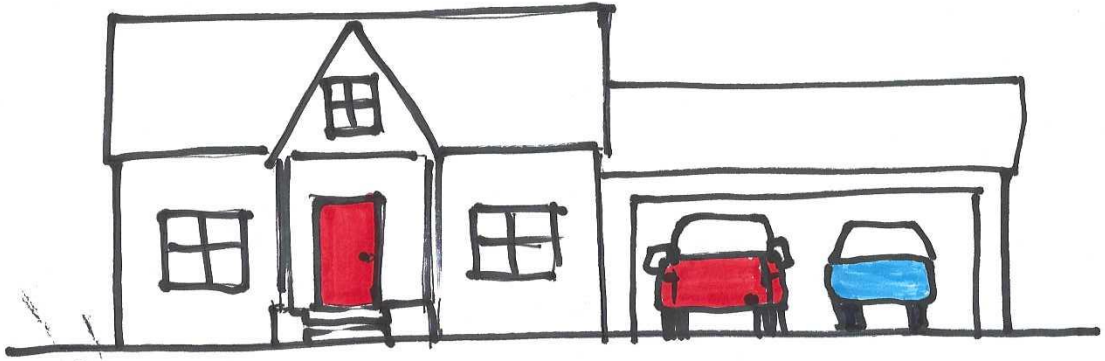
And our households are interconnected to all sectors.

The vehicles of our households are more than half of our transportation energy.
Our homes consume ~36% of our electricity
Fuels used in our house are transported by transport sector and refined and mined in industry sector.

42% of our emissions are the result of fuels used in our homes.
More than 60% if we include emissions associated with our businesses (commercial sector) which has similar emissions profiles : building heat and electricity, and vehicles associated with the activity of the buildings.



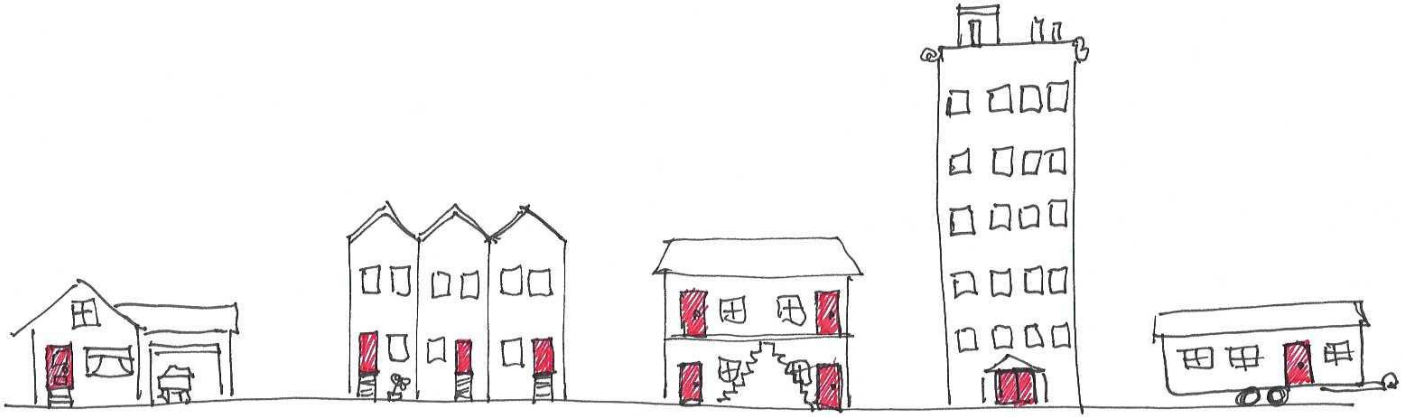
Framing the conversation around the household makes sense as electrification will connect our vehicles, reshape our HVAC systems and with rooftop solar contribute significantly to the expansion and cleaning of the grid.



There are 121 million households in the U.S. With an average of 2.6 people...
And 1.88 cars.

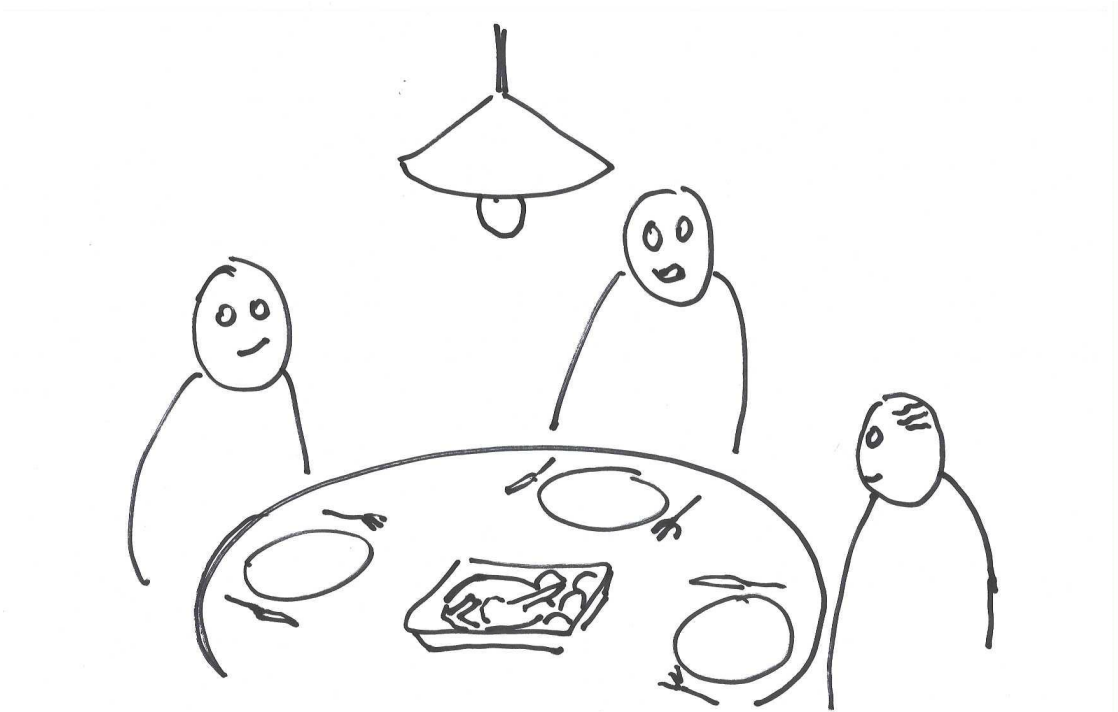
But not every household is the same...

There are many different homes



	Single Family Detached	Single Family Attached	2-4 Unit Multifamily	5+ Unit Multifamily	Mobile homes
Millions of homes	73.9	7.0	9.4	21.1	6.8

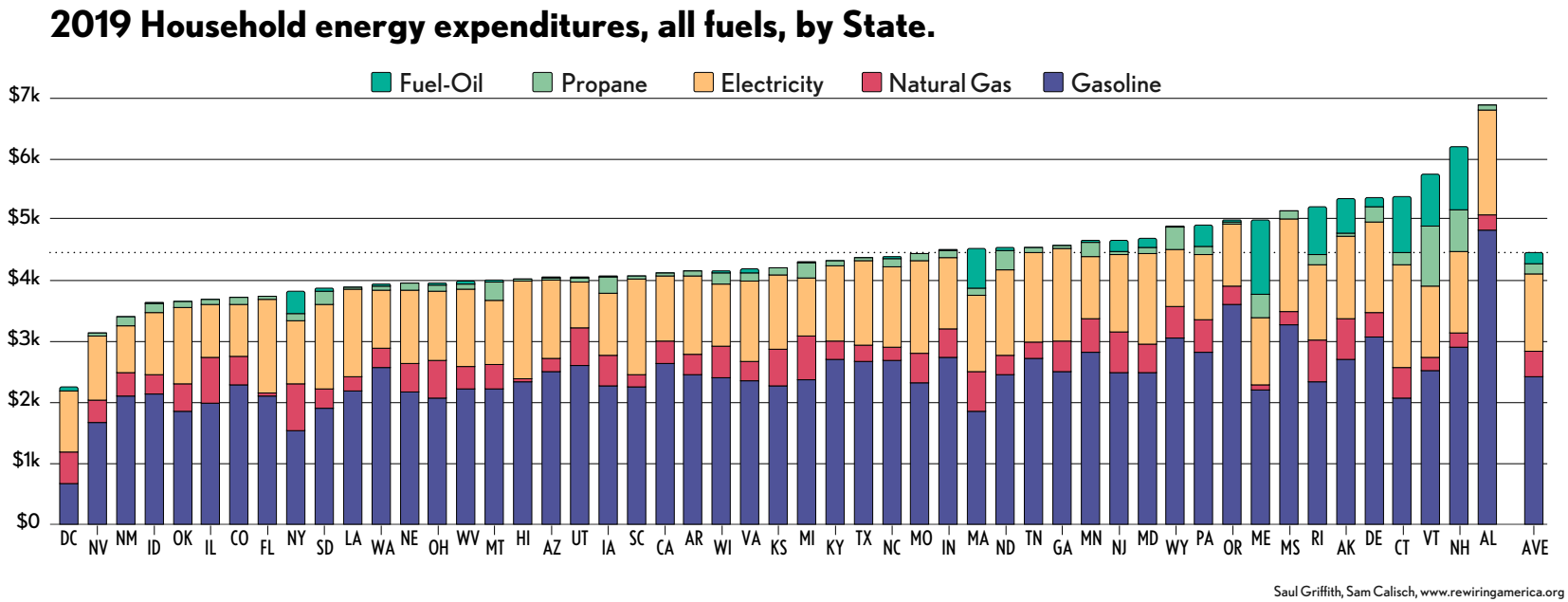
Millions of homes. Data source : https://www.eia.gov/consumption/residential/data/2015/hc/php/hc2.1.php



Our homes may be quite different shapes and sizes…
And our expenditures very different…
But we enjoy surprisingly similar things and energy uses.

Existing Energy Costs per Household

The average household spends around $4,470 annually on energy. (Data from SEDS, NHTS, RECS).

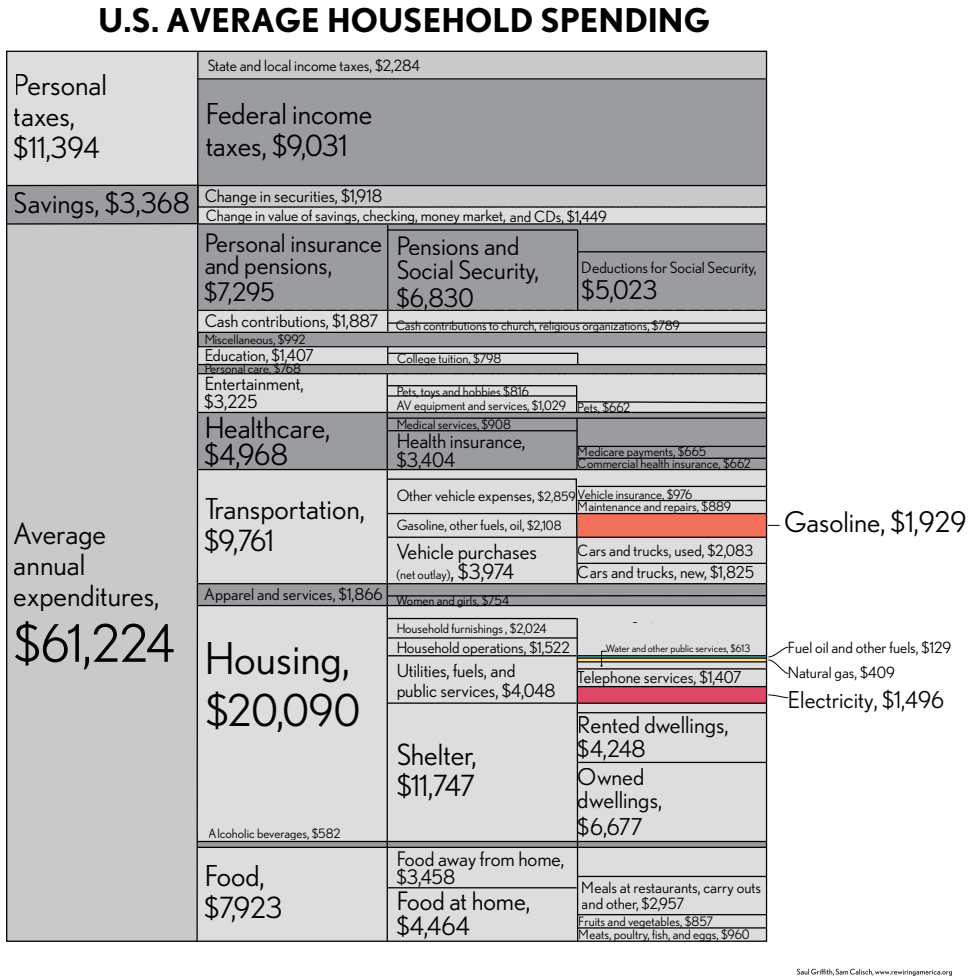


In New England, the mid-Atlantic, and colder northern states, we use substantial amounts of energy heating. Hot places like Hawaii use significant energy in air conditioning. In rural places like Alabama, people tend to drive a lot and buy more gasoline.

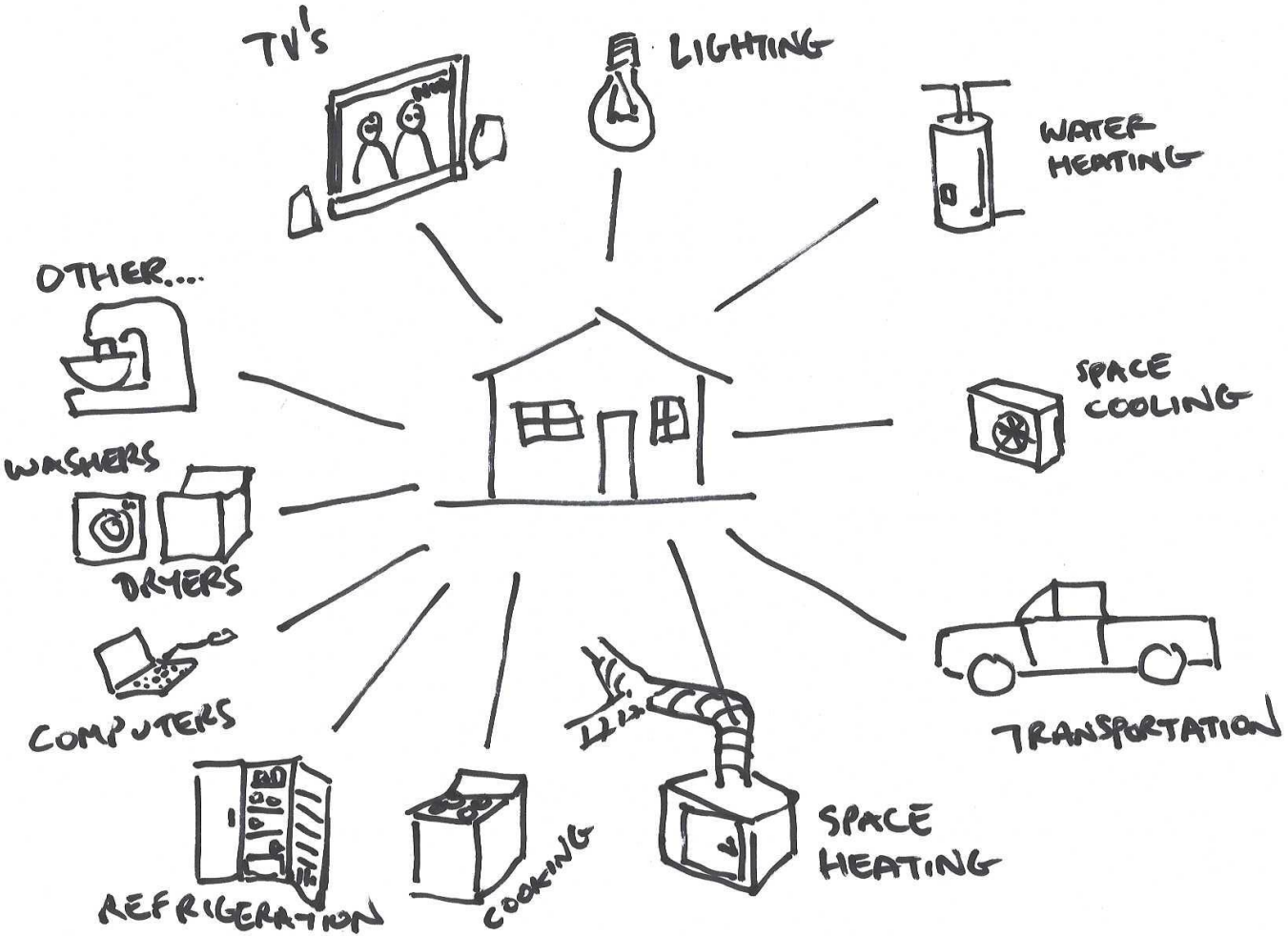
Household Expenditures

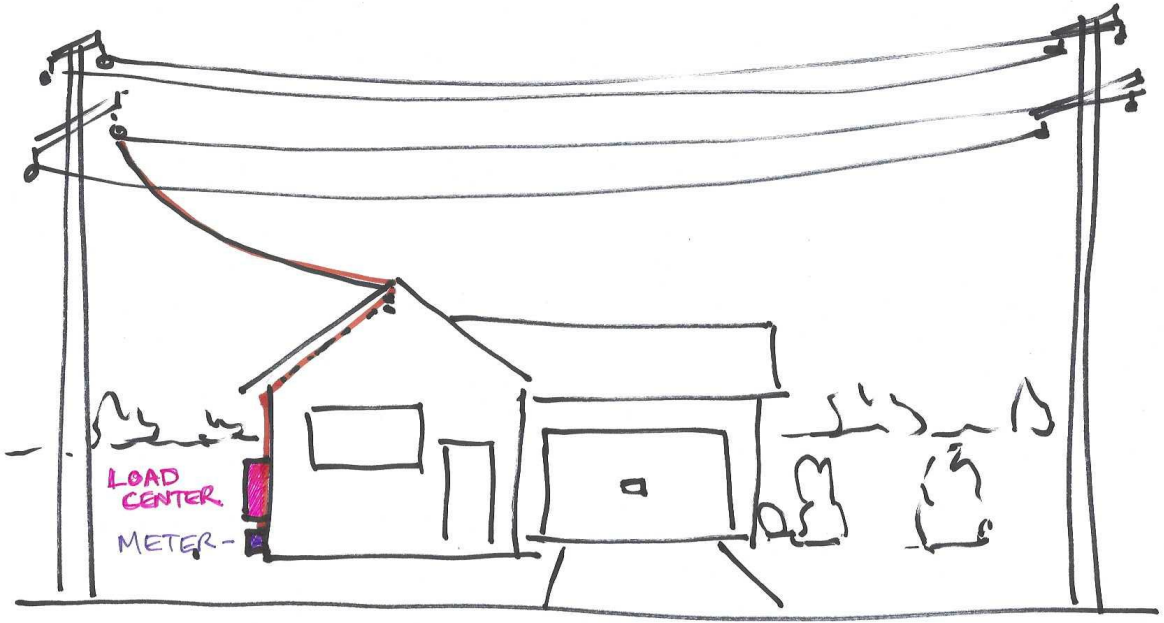
Our direct uses of energy and fossil fuels — gasoline, electricity, natural gas, propane, and heating oil — are shown at right in context with our other expenditures.[4]

We spend more on electricity ($1,496) than we do on education ($1,407). We spend more on natural gas ($409) than dental services ($315). And we spend more on gasoline ($1,929) than we do on meat, poultry, fish, eggs, fruit and vegetables combined ($1,817).



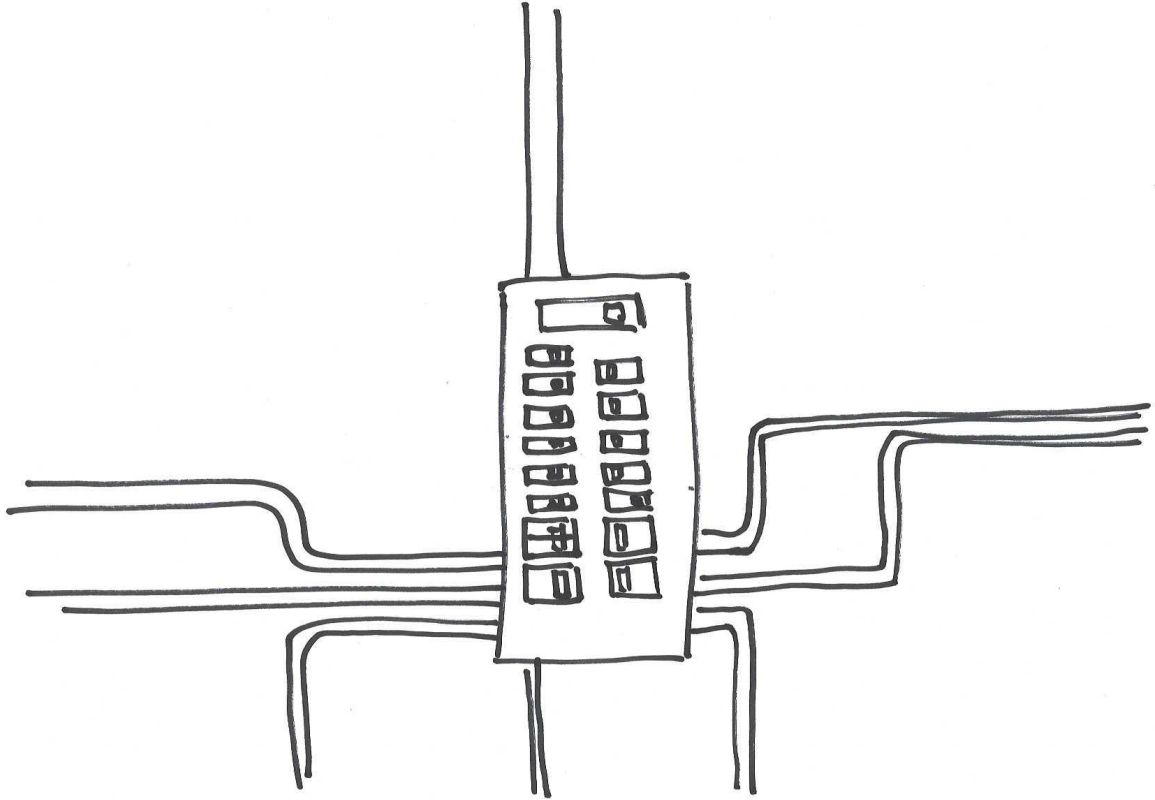
[4] Data from Bureau of Labor Statistics, Consumer Expenditure Survey


TV's
LIGHTING
WATER HEATING
OTHER....
SPACE COOLING
WASHERS
DRYERS
COMPUTERS
TRANSPORTATION
REFRIGERATION
COOKING
SPACE HEATING

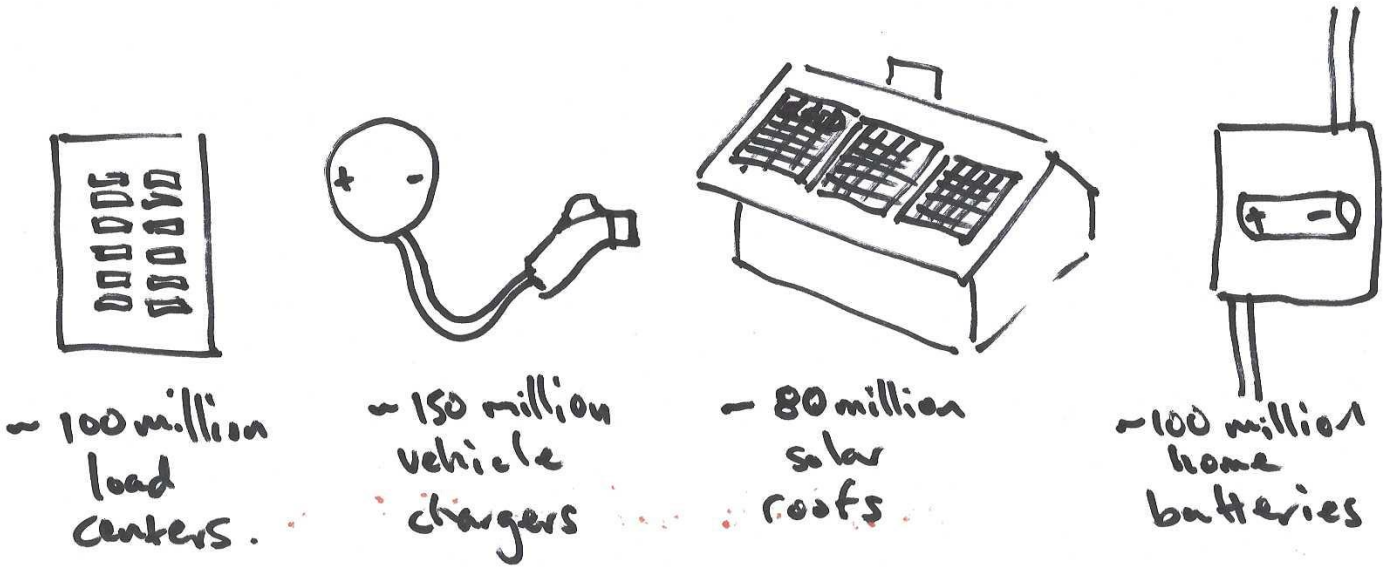


To eliminate all of those emissions we must electrify the whole household...

There are 550 million fossil-fueled machines we need to electrify



Which will require some new household infrastructure...



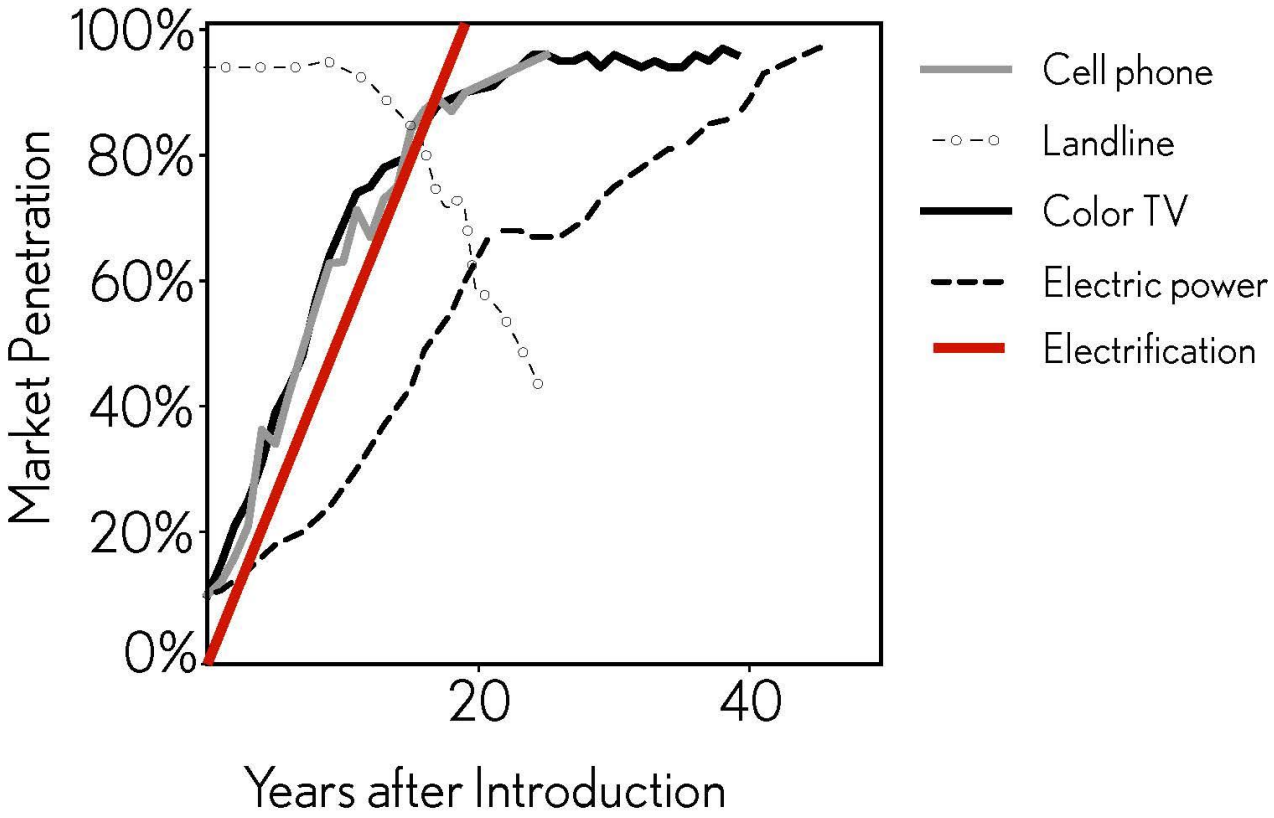
Which is another 430 million machines ...

Is the

1 Billion

machines between us and zero emissions

ELECTRIFICATION ADOPTION RATES NEEDED



But we must start immediately

Focusing on the electrification of machines is critical because any machine we buy now that isn't electric will continue emitting for many years to come.

Average lifetimes of select machines:

- Cars and light trucks : 20-25 years
- Furnaces : 15-20 years
- Gas Water Heaters : 8-12 years
- Electric Water Heaters : 10-15 years
- Kitchen ranges : 13-15 years
- Clothes Dryers : 10-13 years
- Load Center : 20-25 years

The grid is greening rapidly (75% of newly installed generation in 2020 was renewable[2]) so these investments get greener over time.

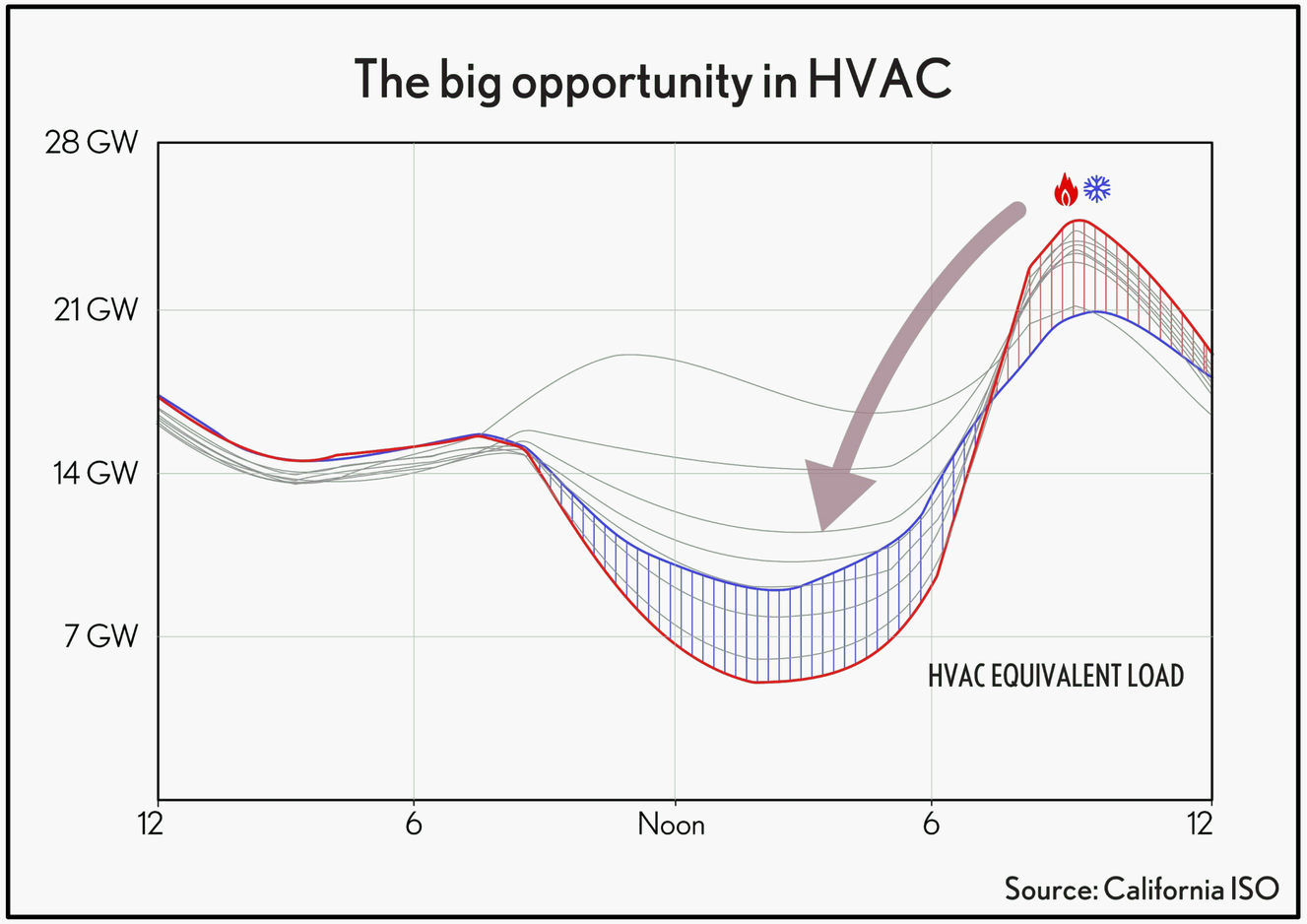
[2] U.S. EIA, *Monthly Electric Generator Inventory.*

What can shift, and batteries everywhere ?

End use	Share of 2019	Share of 2030*	Storable/Shiftable	Peak power	Cycle energy/16h window	Enables 110V
Space cooling	16%	10.00%	Yes, thermal	4kW	20-30 kWh	Y
Space heating	15%	13.20%	Yes, thermal	8kW	20-50 kWh	Y
Water heating	12%	6.00%	Yes, thermal	4kW	2-5 kWh	Y
Refrigeration	6%	3.00%	Yes, therm/ electric	200W	0.2-0.4 kWh	N/A
Lighting	5%	2.00%	Yes, Electric	2kW	0.16 kWh	N/A
Clothes dryers	4%	6.00%	Yes, Electric	5kW	2.5-5 kWh	Y
Televisions etc.	4%	2.00%	Yes, Electric	N/A	2 kWh	N/A
Computers etc.	2%	2.00%	Yes, Electric	N/A	2 kWh	N/A
Fans and pumps	2%	2.00%	Yes, Electric	400W	1-2 kWh	N/A
Freezers	1%	0.50%	Yes, Electric	100W	0.75-1.5 kWh	N/A
Cooking	1%	7.00%	Yes, Electric	6kW	3 kWh	Y
Clothes washers	1%	0.50%	Yes, Electric	1kW	1 kWh	N/A
Dishwashers	1%	0.50%	Yes, Electric	1kW	1 kWh	N/A
Other uses**	31%	28.00%	NO (home battery)	N/A		N/A
Vehicle charging	N/A	17.00%	Yes, V2G	8kW		N

Table 1: *Residential electricity end uses today and in 2030 under a deep electrification scenario, with estimates of peak power and battery capacity required for a 16 hour load shift. *2030 Share from model of Households Savings Report, Saul Griffith and Sam Calisch. Rewiring America, 2020. **Includes small electric devices, heating elements, exterior lights, outdoor grills, pool and spa heaters, backup electricity generators, and motors not listed.*

The Big Opportunity in HVAC



Electrification and Flexible Load Shifting

For existing and new construction homes

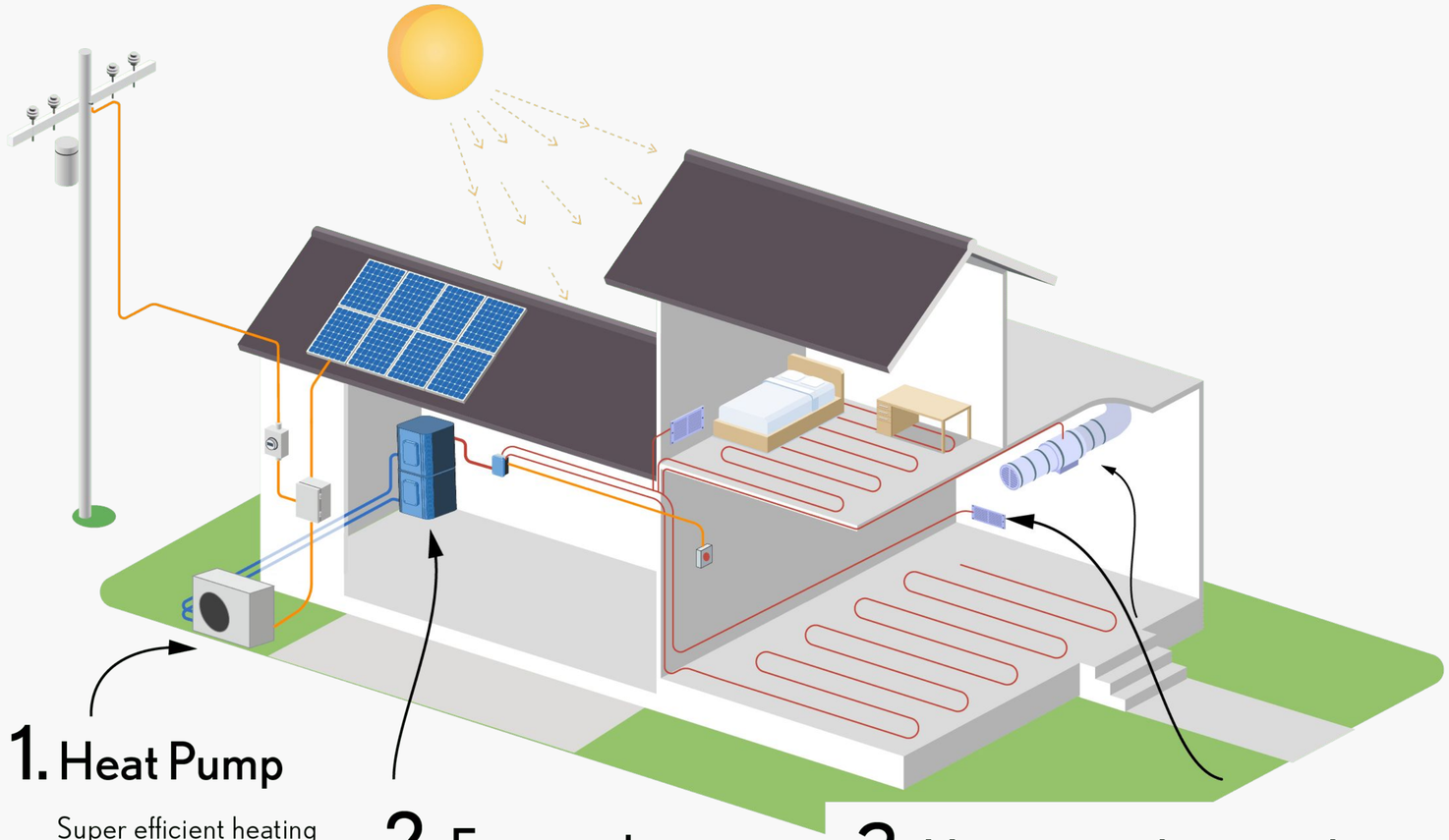
An equity and resilience solution

Addressing .5 GT CO2 in the US alone (RMI) generated by space heating and water heating, annually

By creating a massive, grid-scale distributed battery
for renewables

Source(s): https://rmi.org/insight/the-economics-of-electrifying-buildings/

Sensible Thermal Storage System



1. Heat Pump

Super efficient heating powered by the grid or roof-top solar.

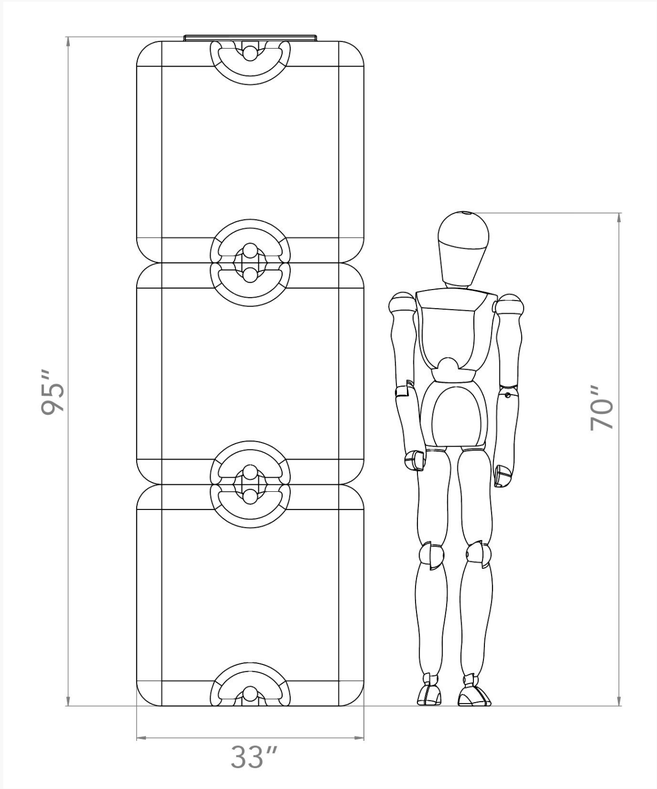
2. Energy storage

Space saving modular energy storage

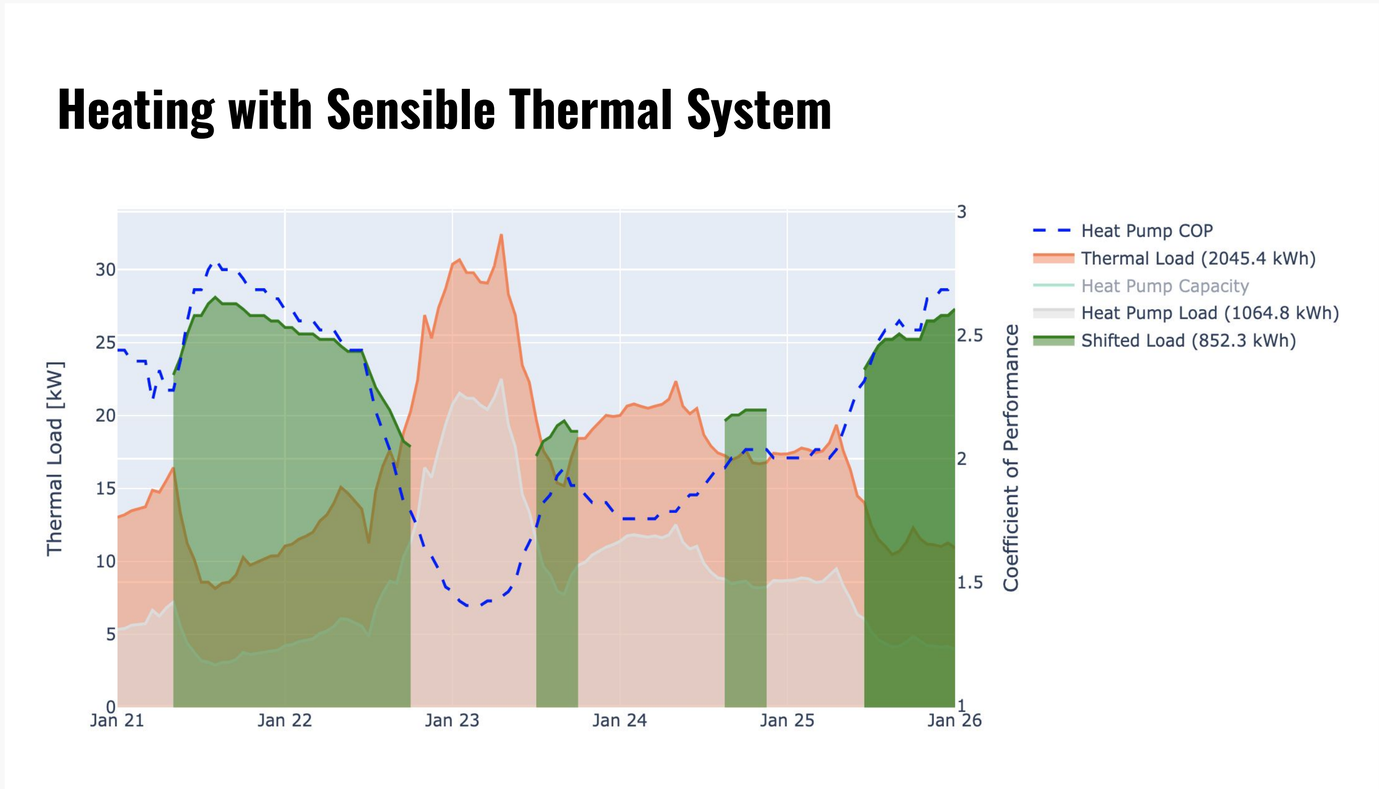
3. Heating and air conditioning

Existing ductwork or hydronic system integrates seamlessly with the Sensible system

Intellectual Property



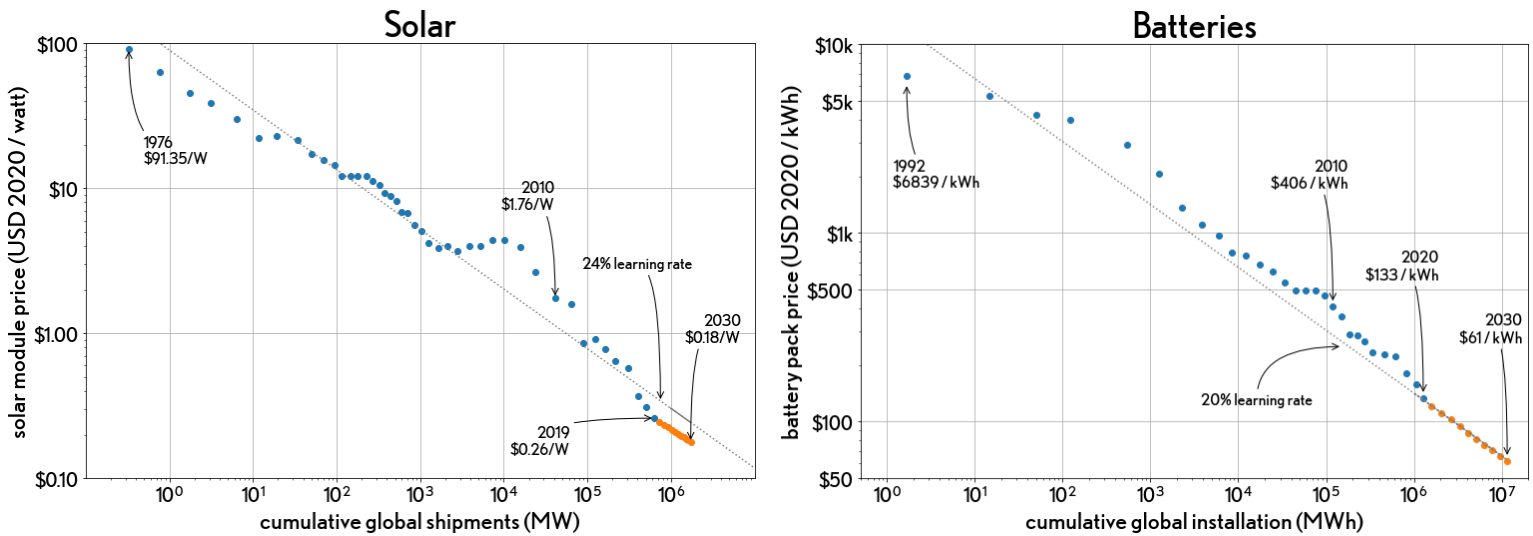
Integrated quick connections and system-in-a-package design allows for rapid, low cost installation.



Utility and solar compatible software adaptively charges thermal storage based on usage predictions to help customers save money and reduce their CO2 footprint.

What will this do to future prices?

Massive industrial scale has driven down the cost of photovoltaics and batteries faster than all predictions.



Batteries in appliances.

***Table 1**: Comparing total electrified residential energy by end-use. Some larger users (HVAC) require professional installation, and aren't good candidates for appliance integration. Some users are too small to warrant battery integration. The list of "goldilocks" candidates includes refrigerators, TVs, clothes dryers, ranges, freezers, dehumidifiers, and microwaves. Data from RECS. *Estimates for the ratio of peak hourly load to the average hourly load, derived from ResStock models.*

End use	Household kWh/year	Share	Amenable to battery integrated appliance	Req. 240V?	Peak hourly to Average*
Space heat	3985	31%	NO, requires prof. install., Thermal storage	Yes	7.6
Water heat	2368	19%	NO, requires prof. install., Thermal storage	Yes	4.2
AC	1812	14%	NO, requires prof. Install., Thermal storage	Yes	8.0
Lighting	1104	8%	NO, not centralized	No	2.6
Refrigeration	750	6%	YES, commodity appliance, homeowner install	No	1.3
TV + Periph.	738	6%	YES, commodity appliance, homeowner install	No	2.2
Clothes Dry	583	5%	YES, commodity appliance, homeowner install	Yes	39
Range	481	4%	YES, commodity appliance, homeowner install	Yes	3.9
Ceiling fan	194	2%	YES, commodity appliance, homeowner install	No	2.1
Freezer	173	1%	YES, commodity appliance, homeowner install	No	1.3
Dehumidifiers	130	1%	YES, commodity appliance, homeowner install	No	2.1
Microwave	116	1%	YES, commodity appliance, homeowner install	No	2.1
Hot tub	70	<1%	NO, <100kWh/year	Yes	3.5
Clothes wash	64	<1%	NO, <100kWh/year	No	39
Pool heat	28	<1%	NO, <100kWh/year	Yes	3.6

Eg. Cooking.

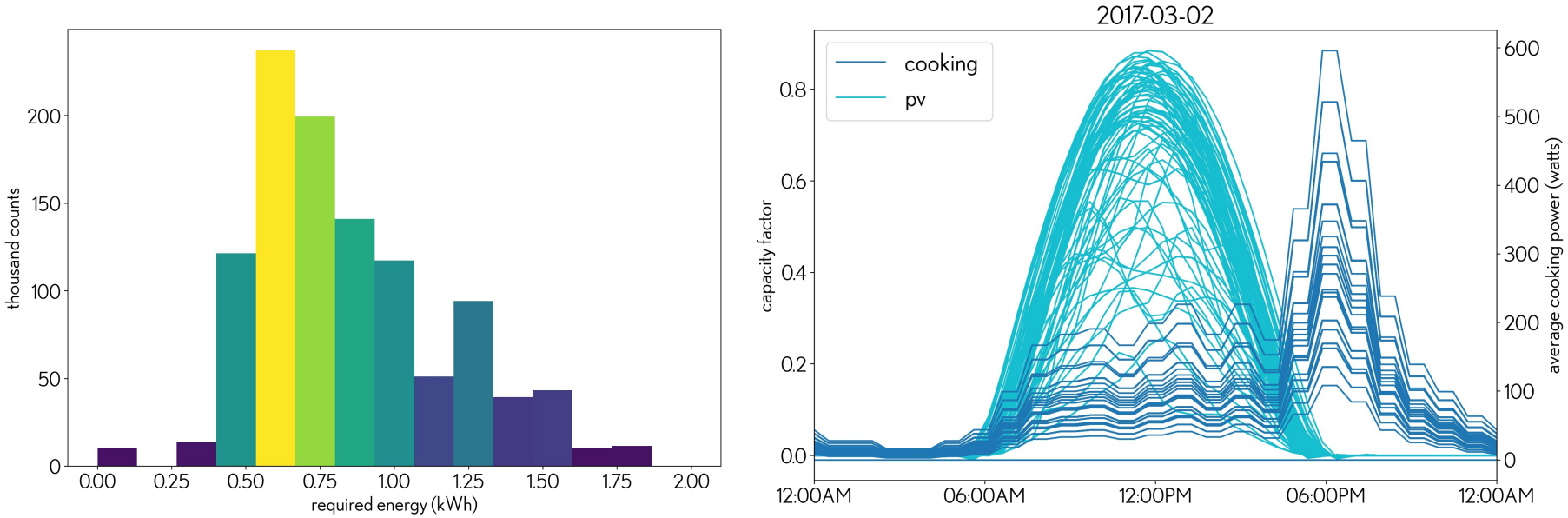
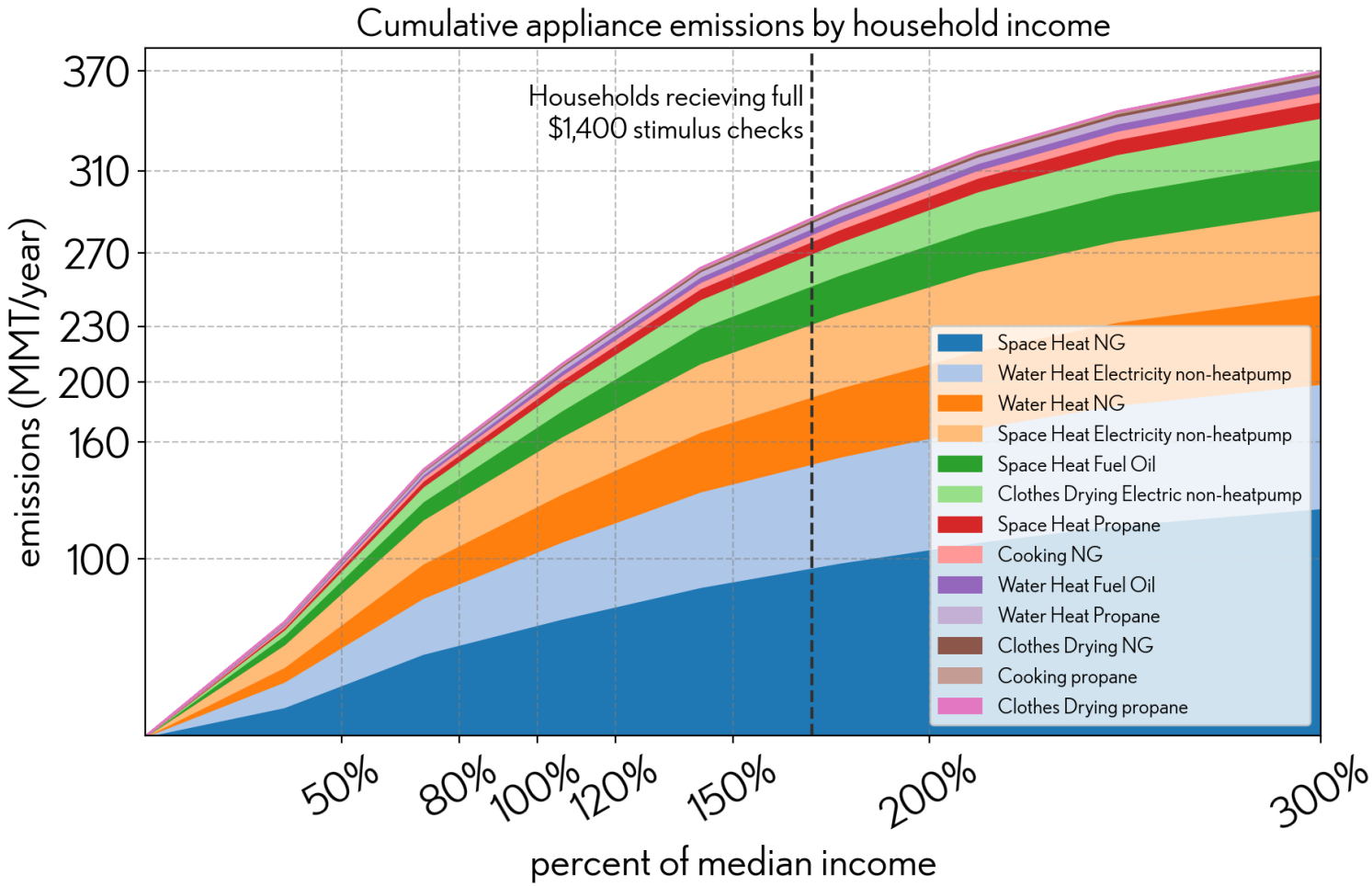


***Figure 1**: Modeling time-resolved residential solar potential and residential cooking demands. a) Histogram energy used for cooking dinner over 3000 homes and 365 days of the year, showing battery capacity required to meet this demand, b) PV capacity factor versus cooking loads for a given day, over a population of 109 houses spread across TMY3 locations. The mismatch between supply and demand is evident. Drawn from the NASA MERRA2 dataset, and NREL ResStock models.*

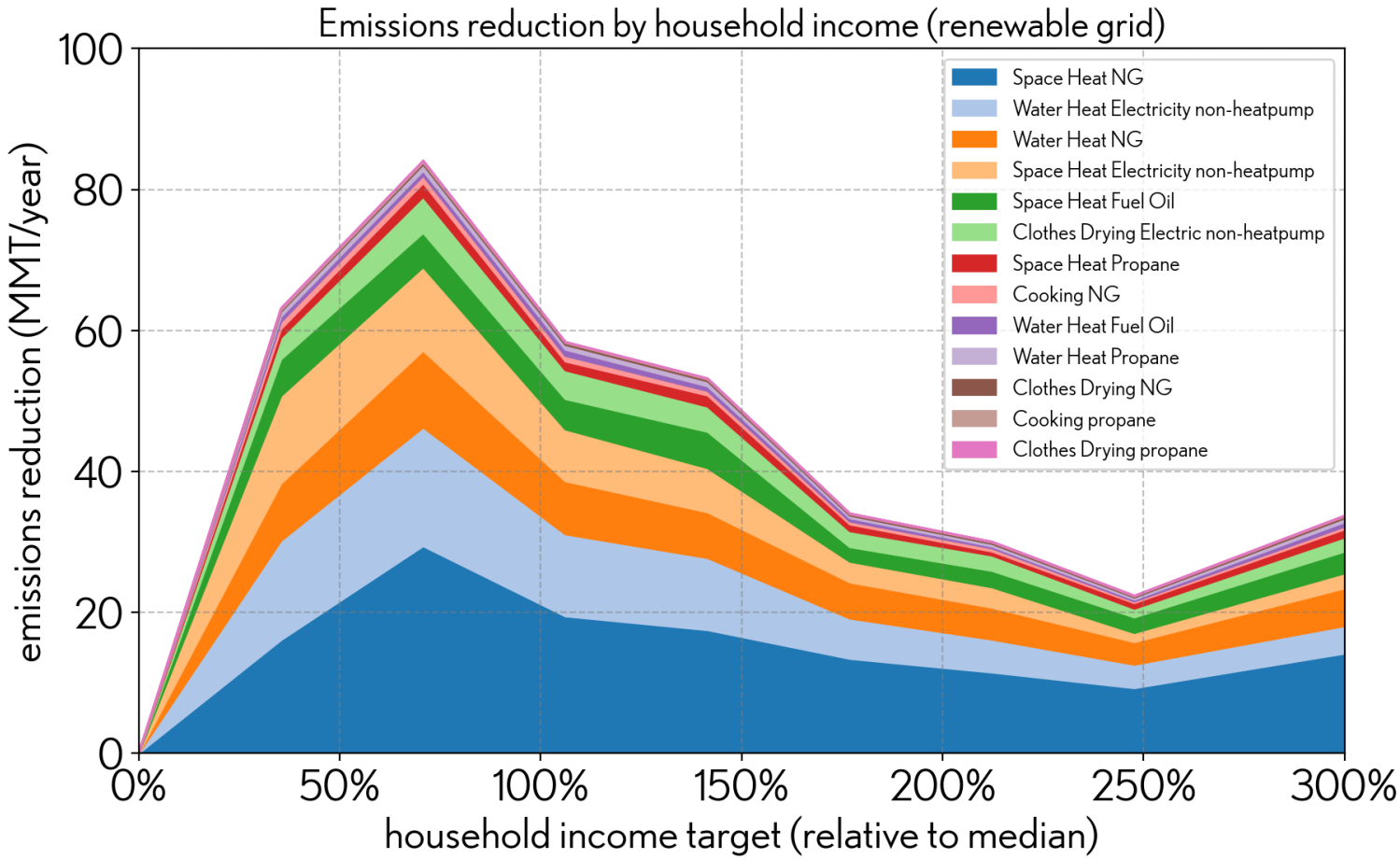
Household emissions by income bracket

By helping households in lower income brackets electrify, we can mitigate a significant portion of residential emissions. For example, if we help every household receiving a full COVID-19 stimulus check, we address 80% of these emissions.



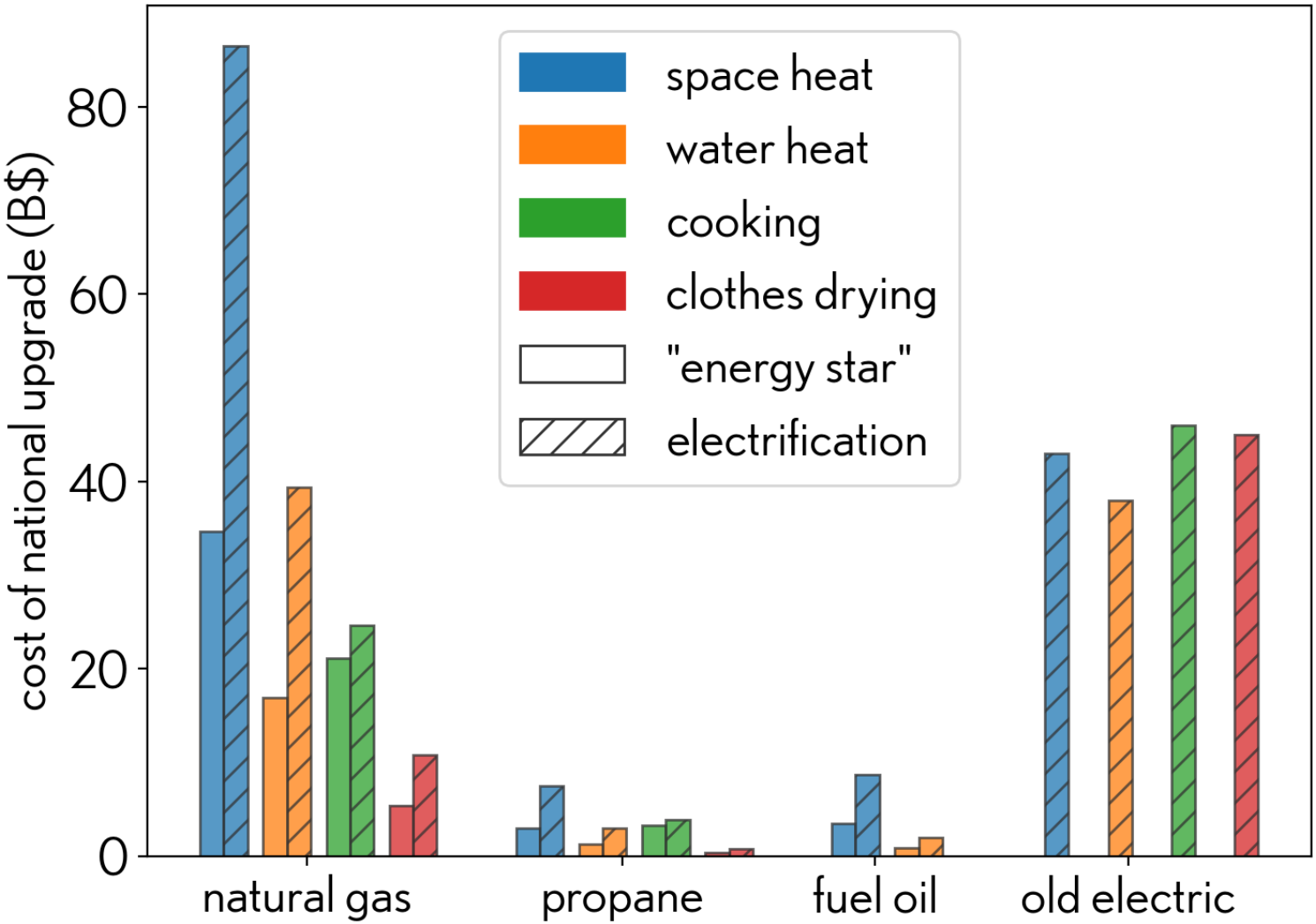
LMI households should be the focus

Focusing on LMI households also has a disproportionate impact on emissions reductions.



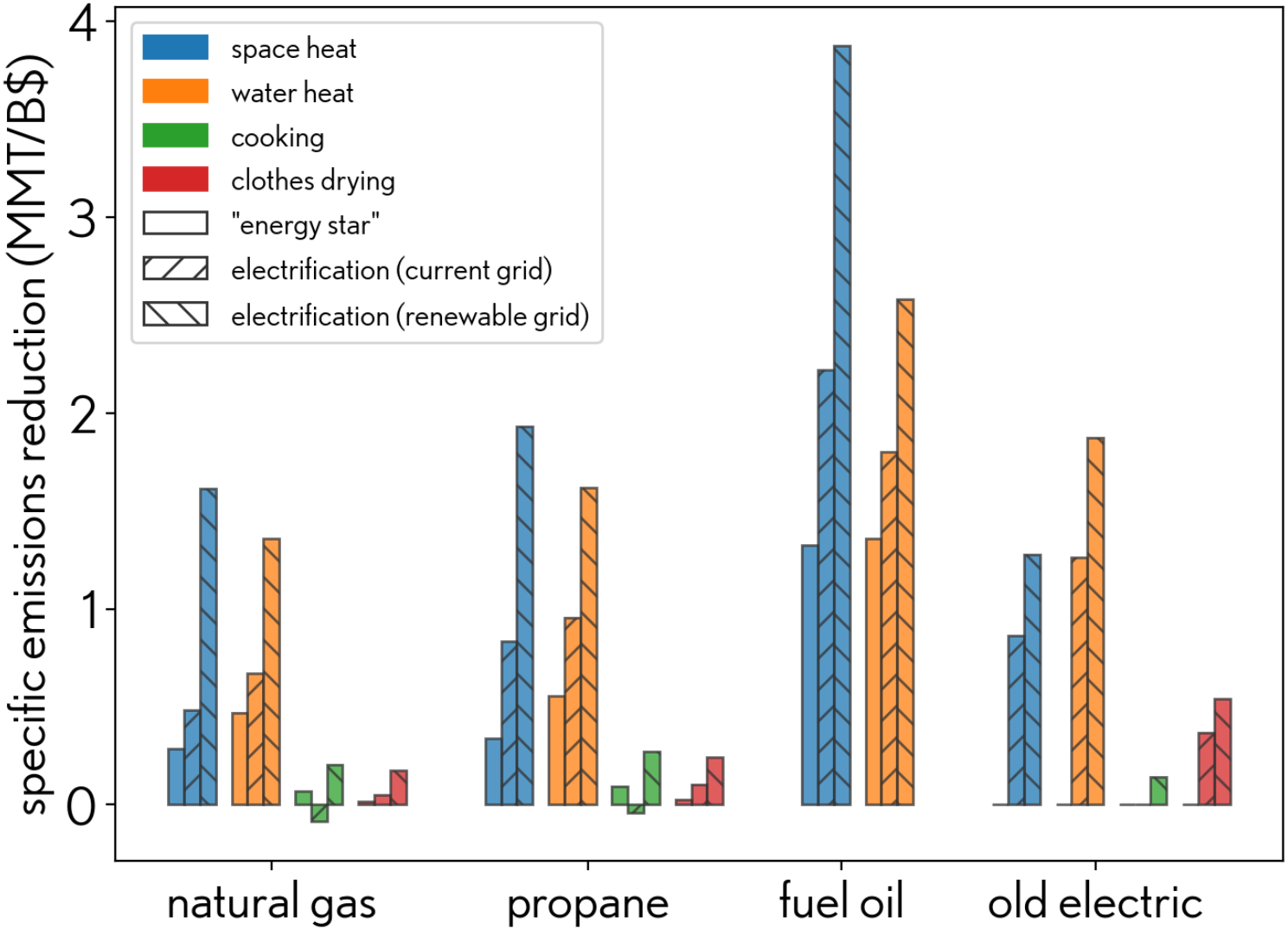
Costs

Modern electric appliances do generally cost more than their fossil fuel equivalents.



How far do the dollars go?

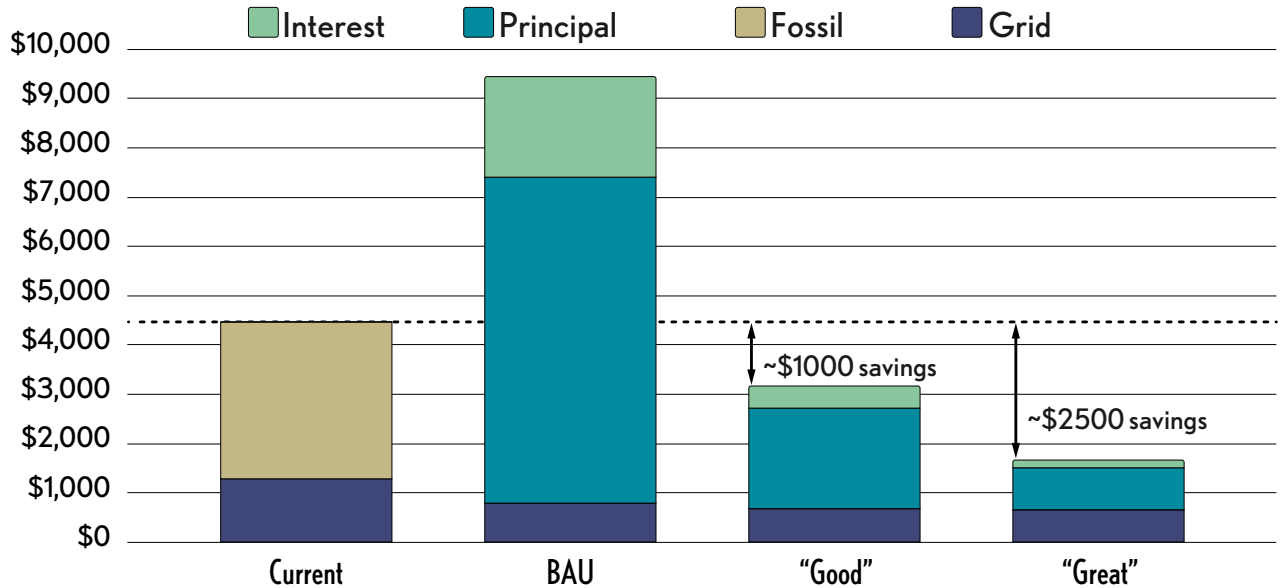
But for emissions cut per dollar spent, electricity is the clear winner again.



Electrification saves households money

In many markets, electrification will save households money on their bills today, especially with cheap solar and falling costs of EVs[3]. In all markets, those savings are achieved through manufacturing, regulatory and financing cost reductions.

Total household energy costs before and after electrification



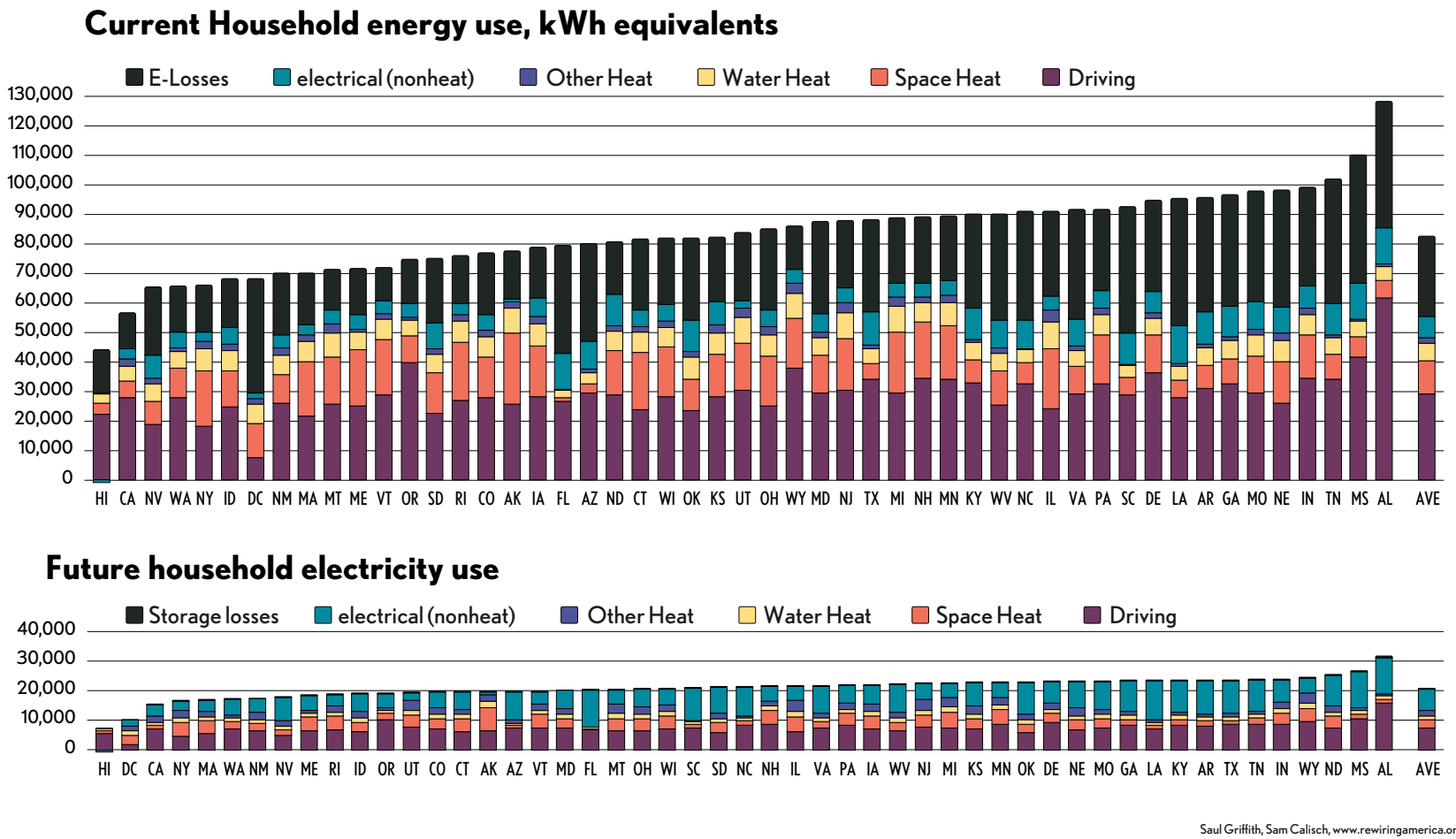
Saul Griffith, Sam Calisch, www.rewiringamerica.org

For homes with sufficient credit and discretionary income, financing can overcome the current high upfront cost of electrification. For LMI households, a national rebate program will be critical in overcoming the current cost barriers.

[3] See our household savings report for details.

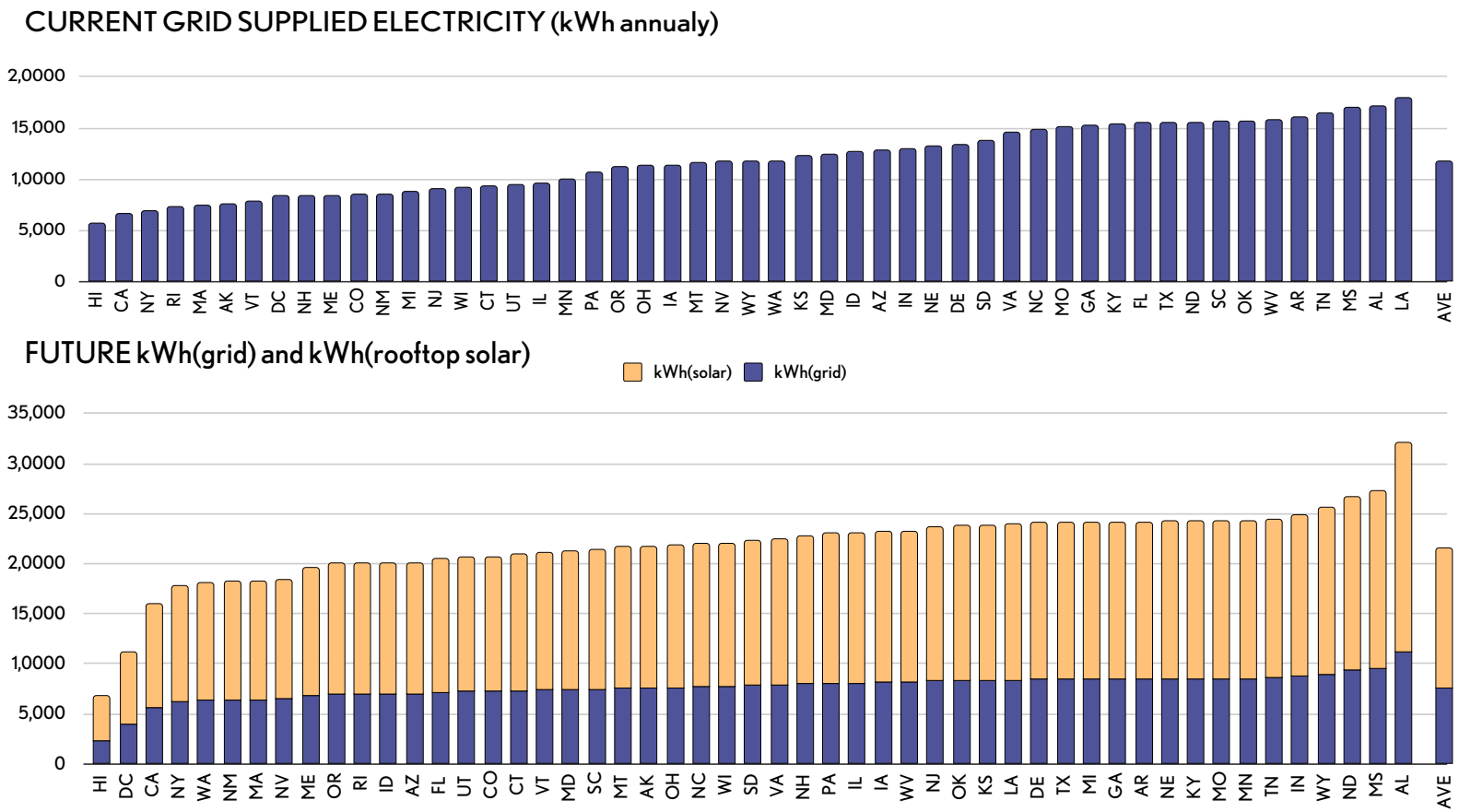
Current and future household energy consumption, by state

We see some variation state–to–state, but going electric saves significant energy across the board.



Rooftop solar and the grid

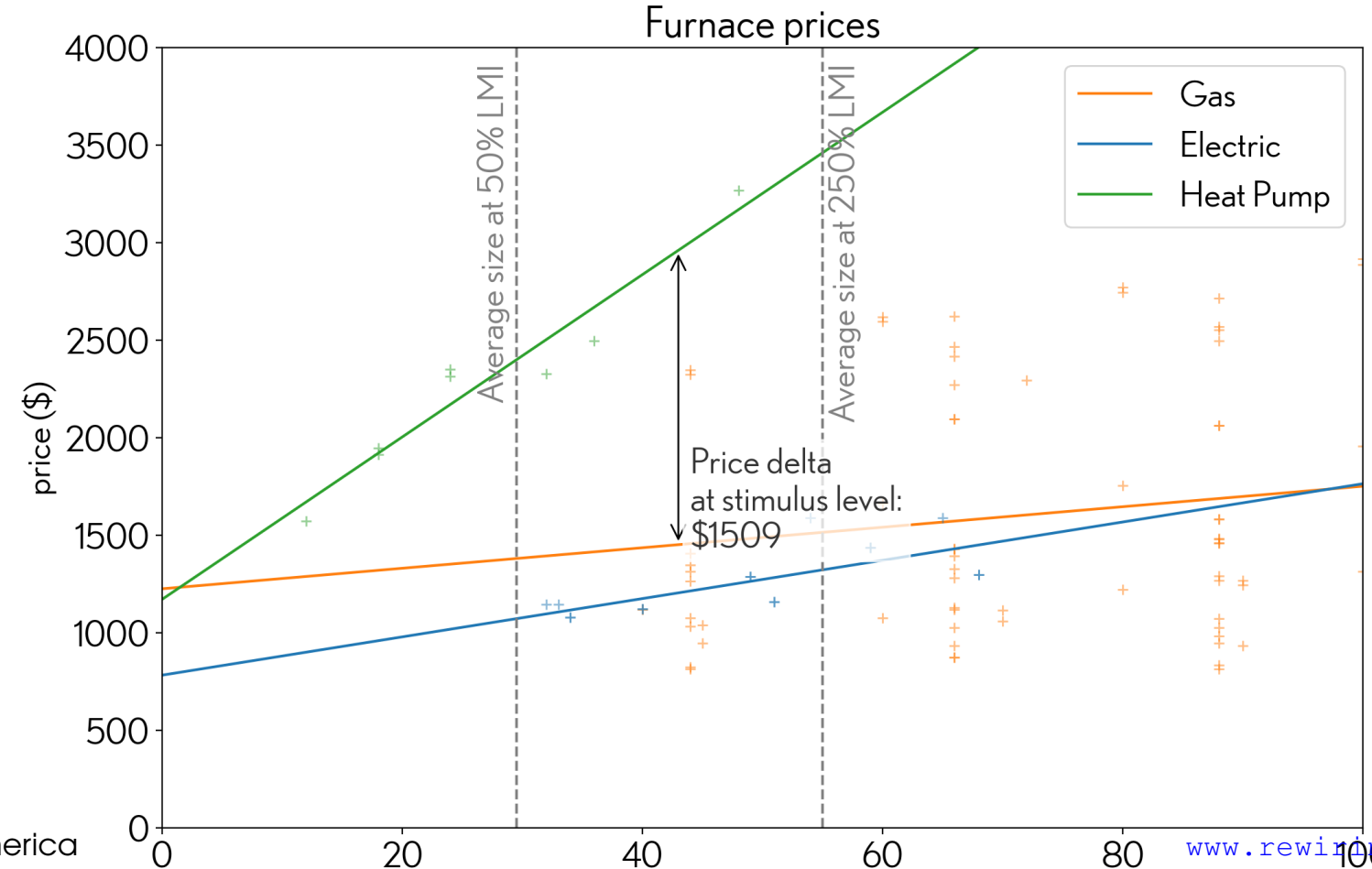
This electrification program will install ~1100 GW of rooftop solar, which is within the total rooftop potential of the U.S.[14].



[14] NREL's 2016 report, Rooftop Solar Photovoltaic Technical Potential in the United States, finds over 1100GW potential even using a very conservative 16% module efficiency.

Designing the rebates

We calculate rebate size with the goal of bringing cost parity between fossil fuel appliances and electric replacements. In order to have one rebate number per appliance, we analogize household income to appliance size, assuming that wealthy households tend to buy larger and more expensive appliances. For space heating, for example, we believe a $1,500 rebate brings heat pumps to cost parity or better for all households receiving a $1,400 stimulus check.



About Rewiring America

Rewiring America was founded in 2020 to outline the detailed efforts required for decarbonization for a better than 2 degree goal, and the accompanying economic benefits.

Households report: How we electrify everything and save every household thousands of dollars a year.

Jobs Report: Creating 25 million near term and 10 million long term jobs decarbonizing America by electrifying everything.

Rewiring America: A handbook for winning the climate fight

Electrify An Optimist's Playbook for Our Clean Energy Future, MIT Press, 2021.

New Virtual Sessions from Solar Decathlon on Innovative Homes and Energy Careers

The Solar Decathlon announced a new webinar series starting in September that will include virtual tours of innovatively designed homes and address a variety of topics from the rise in zero energy homes to clean energy careers.

U.S. DEPARTMENT OF ENERGY
SOLAR DECATHLON

Register for Upcoming Session and Watch Prior Sessions at solardecathlon.gov/virtual_sessions.html

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Resources to help improve your program and reach energy efficiency targets:

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- Quick Answers - provide answers and resources for common questions.
- Proven Practices posts - include lessons learned, examples, and helpful tips from successful programs.
- Technology Solutions NEW! - present resources on advanced technologies, **HVAC** & **Heat Pump Water Heaters**, including installation guidance, marketing strategies, & potential savings.

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