# No Place Like Home

*Fighting climate change (and saving money) by electrifying America's households*

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We have been told that solving climate change will be hard, complicated, and expensive — and that we'll need a miracle to do it.

None of that need be true.

We can fight climate change starting right in our own homes, where decisions about which fuels we use are responsible for ~42% of our energy–related carbon emissions. But most households can't do it by themselves. We critically need a healthy mix of sound policy, low–cost financing, industrial commitment, and steady technological progress to support climate success.

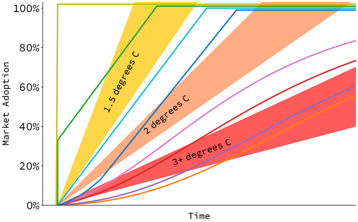
This analysis shows how households can swap their fossil fuel-burning machines for electric ones, using technology that exists today, and cut their energy bills in the process.

We can solve climate change together, starting in our own homes.

# Climate Context

The world has dragged its feet on addressing climate change and so we now find ourselves requiring nearly perfect execution to hit a climate target under 2° C (3.6° F) of warming.

We need the fastest possible adoption rates of the technologies that eliminate our emissions. Neither a carbon tax nor a "free market" solution is fast enough any more.


The only viable option is a rapid build–up of industrial capacity, a prolonged period of high market adoption rates, and a steady ramp–down of fossil fuel use over the next 20 years.

# Households today

Decisions we control in our households are responsible for 42% of energy–related greenhouse gas emissions.[1]

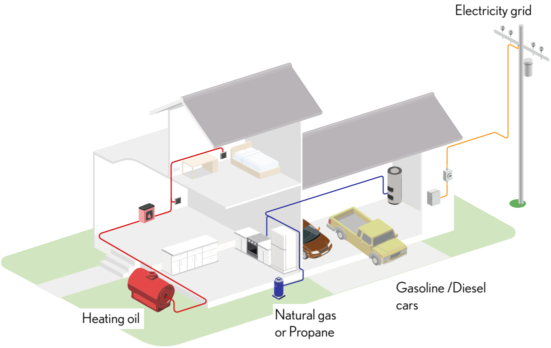
We all cook and eat. We all like to be warm or cool. We need refrigeration. We enjoy the convenience of personal motor vehicles. Running hot water is no longer viewed as a luxury in America, but as a right (and air conditioning is close behind!). Today, American homes use around 25 kWh per day of electricity. In most places, we heat our homes, and the cost of that heat ranges from a few hundred dollars a year in mild climates to thousands of dollars in places like New England. Nearly all households have at least one car. Most average two, and drive them each more than 10,000 miles per year at a fuel economy of about 22 mpg.[2]

[1] See details from the EPA GHGs inventory in Appendix.

[2] Data from National Household Travel Survey, U.S. Dept. of Transportation.

# Households today

This is a picture of the fuel–burning infrastructure used to power households today: Gasoline or diesel power most cars. Natural gas, fuel oil, or propane heat most homes. Natural gas is frequently used for cooking. Electricity lights up every home.



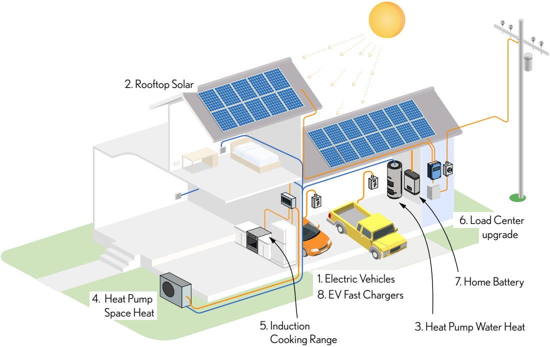
# An electrified, decarbonized household

It is possible with the technology we have now to electrify our households. We can decarbonize our driving with electric cars, and charge them cleanly with solar on our rooftops and renewable electricity from the grid. Where most homes now burn methane in the kitchen to run the stove, we can switch to electric induction for cooking — which is cleaner, often faster, and healthier, since unlike "natural" gas, it doesn't release toxic fumes. We can use electric water heaters, or better still, heat pump hot water heaters that more efficiently provide us with hot showers and warm water. A heat pump, potentially with energy storage cheaply attached, can replace our furnace or other heating systems with electricity. We can buy electric clothes dryers to replace natural gas ones. To make this all work, we need to install a bigger load center, wire in electric car chargers, and attach a battery capable of running the loads in the house for a half day or so. Together these things electrify our households.

Electrification is the only viable pathway to decarbonizing a household.

# Household decarbonization infrastructure upgrade

What does this electrification upgrade infrastructure look like?




These are electric versions of the ∼ half–dozen pieces of "life infrastructure" that we buy every 10 or so years. These are the critical household purchasing decisions climate–wise, and they are all currently capital–intensive, with high up–front costs.[3]

[3] Air conditioning is also a critical piece of household infrastructure. As it is already electric, it is not included in this analysis apart from the savings caused by lower electricity costs.

# What households spend on energy

In order to figure out how we can afford to decarbonize American households, we need to look at how the costs of these electric household infrastructure purchases relate to how much we currently spend on energy.

Today, the average American household spends about $4,470 per year on the fuels that underpin our lifestyles.

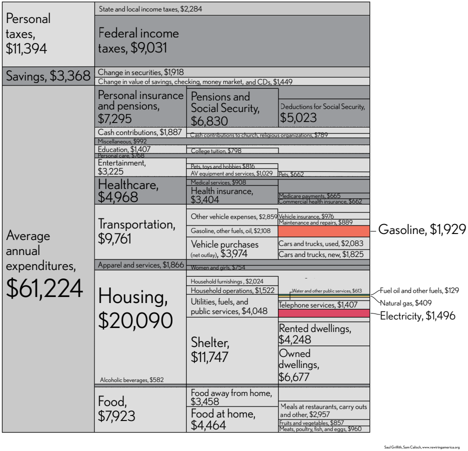
Households in much colder or much hotter places spend more, because of heating and air conditioning, and rural or suburban households often spend more because they drive more.

# 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).

**U.S. AVERAGE HOUSEHOLD SPENDING**




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

# More specific household energy costs, by state

Defining the "average household" in a country as geographically broad as the U.S. is difficult. Some people use lots of heating oil to heat their homes; in other places, they only need air conditioning.

We use existing, comprehensive, public data sets to model current energy uses and energy costs per household, broken down by state to give us local insight:

- Typical prices for each fuel — electricity, natural gas, fuel oil, gasoline, diesel, and propane — are built from 5 and 10–year rolling averages of Energy Information Administration (EIA) State Energy Data System (SEDS):

  https://www.eia.gov/state/seds/

- Typical consumption for transportation is determined from the National Household Travel Survey (NHTS) database:

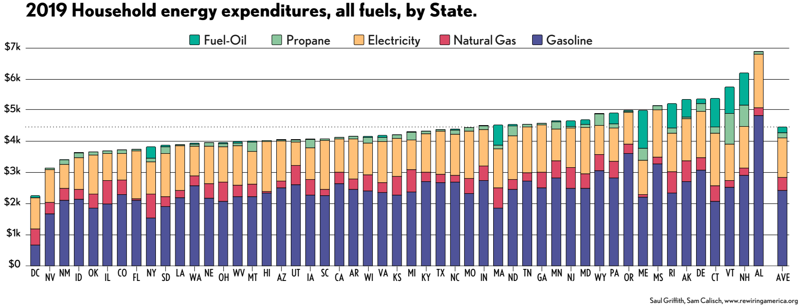
  https://nhts.ornl.gov/

- Typical consumption for residential electricity, natural gas, and heating fuels are determined from EIA Residential Energy Consumption Survey (RECS):

  https://www.eia.gov/consumption/residential/data/2015/

# 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.

# An electrification model of the future

We build a model of future household energy use, which assumes that future behaviors will be similar to current behaviors, only electrified. We take the existing energy uses and fuel types in the home and convert them to their electrical equivalents.

No "efficiency" measures such as insulation retrofits or smaller vehicles have been assumed here. These could provide additional energy savings and would need to be analyzed individually for cost benefits.

With this model we determine the energy cost of running all of our future electrified homes.

Same–sized homes. Same–sized cars. Same levels of comfort. Just electric.

# An electrification model of the future

- For converting current fuel–based heat to electric heat–pump heat, heat pump performance (COP) is determined from published manufacturers data, and NREL TMY3–based estimates of climate. COP of existing infrastructure is determined from fuel use data from RECS and historical sales data from the EIA.
- For converting energy consumption in gasoline cars to electric cars we compare fuel use between similarly–sized vehicles (from the DOE's fueleconomy.gov), and derive a conversion of 8.5kWh of electricity for each gallon of fuel, which holds across differently sized vehicles.
- Other fuel uses, for example in cooking, are converted using a conservative COP of 1 for both the original fuel and the electric replacement. In many cases, like cooking, the electrical equivalents are actually more efficient.
- We assume 15% of the household energy use requires electrical storage to balance supply and demand, and we assume 90% round–trip efficiency for battery storage of that energy. We also include a modicum of grid–purchased renewable electricity to further balance supply and demand.

# Current households vs. electrified

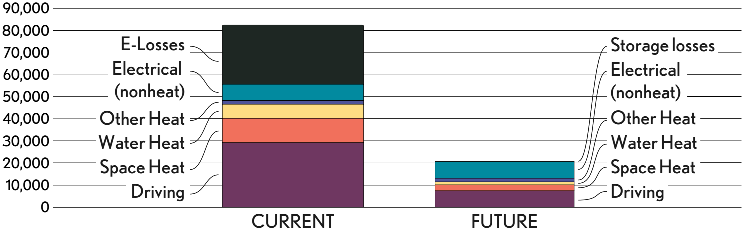
The electrified U.S. household uses substantially less energy than current homes.

One area of enormous savings is the elimination of thermoelectric losses in electricity generation, assuming we will provide our future loads with renewables.

The efficiency of electric cars over internal combustion engine (ICE) vehicles also generates substantial savings.

Similarly, we show the substantial savings derived from the high efficiency of heat pumps for space and water heating.

**Annual average energy use per U.S. household, kWh equivalents**

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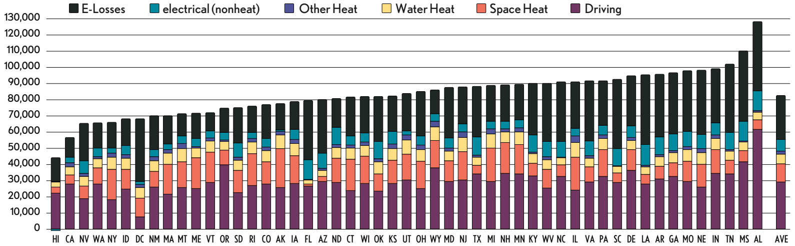
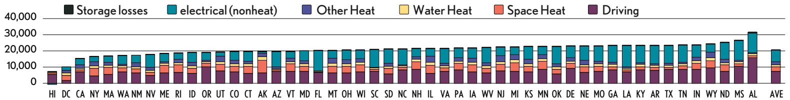
# Current and future household energy consumption, by state

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

**Current Household energy use, kWh equivalents**




**Future household electricity use**

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# If we save so much energy, why can't we save money?

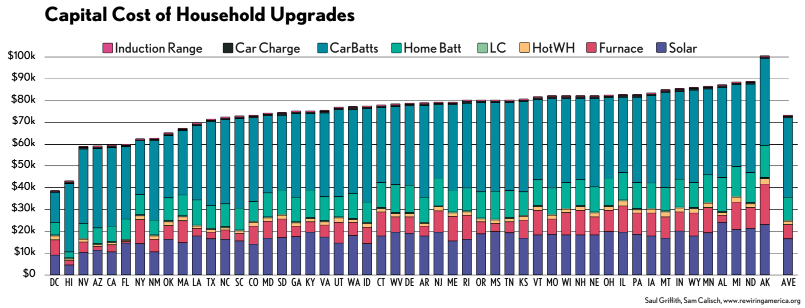
Clean, electrified technologies have high up-front costs, but very low fuel costs in the future. Fossil fuel machines are cheaper at point of sale, but require constant refilling with expensive fuels.

Because of this, electrification requires us to spend more money on changing the infrastructure of our lives. Most Americans don't have the cash on hand for this. But if this equipment were financed, can the savings be larger than the loan payments?

**What are the costs of the technology and financing that would allow households to decarbonize and save money in all 50 states?**

# Today, a household electrification upgrade is expensive

Using price estimates[5] to find the difference between fossil-fueled and electric infrastructure, we find that today it would cost a household around $70,000 to completely decarbonize, something only the wealthiest households can afford. Below, we show the capital costs by state, using the electrification plan described above.




We need to prioritize lowering these costs using regulatory reform and industrial scaling. We also need to prioritize financing to help American households afford these items.

[5] Data from BloombergNEF, NREL, Homewyse, and Fixr

# Three scenarios for change

We examine three scenarios, starting with what's possible today, and progressing towards more aggressive changes:

- **"Business as Usual"** - Does it work currently in the U.S.? We assume currently–available, unsubsidized costs and an interest rate of 5% for financing all items.
- **"Good"** - Does it work using global best practices? We includes regulatory improvements and an interest rate of 2.9% for financing, comparable to current mortgage rates.
- **"Great"** - Does it work if we make it a national priority? We includes cost reductions through larger scale of production, regulatory optimization, technology improvements, and a 2% interest rate.

# Modeling the transition

The table below summarizes the most important model parameters[6]:

| | BAU | "Good" | "Great" |
|---|---|---|---|
| Rooftop Solar Costs ($/W) | 3.00 | 1.50 | 1.00 |
| Battery Costs ($/kWh) | 250 | 120 | 75 |
| Heat Pump COP (ave) | 2.7 | 2.9 | 3.1 |
| Interest Rate (%) | 5.0 | 2.9 | 2.0 |

For reference, Australia already installs rooftop solar at around U.S. $1.20/W, and the DOE's Sunshot program is on track to systematically bring costs down to less than $1.00/W. Batteries are available at $120/kWh in packs, and scaling predicts prices below $75/kWh by 2030.[7] While car loans are currently around 5% currently,[8] mortgage rates are commonly under 3%[9], and the FHA and Fannie Mae are precedents for federally–guaranteed, low–interest loans in the national interest.

[6] Additionally, capital costs of household appliances (heat pumps, etc.) experience a decrease, and lifetimes (and hence financing period) increase in the Good and Great models. For example battery lifetimes increase from 7 to 12 years.

[7] Data from BloombergNEF (1, 2) and Kittner, et al.

[8] See the Fed's G19 Consumer Credit Report

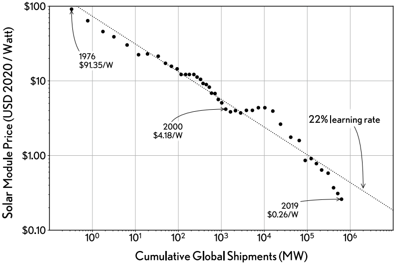
[9] See the CFPB's Rate Explorer and Mortgage Market Activity and Trends

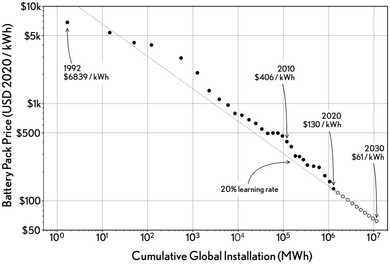
# Costs are falling, and massive scale is key

As a natural trend of huge industrial scale, clean energy solutions are getting exponentially cheaper.

With every doubling in delivered solar modules, the price is dropping 22%. The same watt of electricity that cost $4 in 2000 now costs just $0.26,[10] and at the scale of this study, just $0.18.

For battery storage, every doubling reduces price 20%. The battery pack that cost $1,000 in year 2000, now costs $130,[11] and at the scale implied by this study, just $65 (even lower than we have assumed).



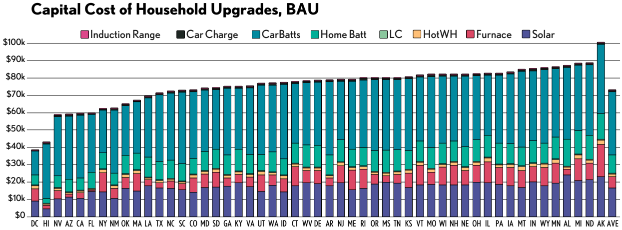



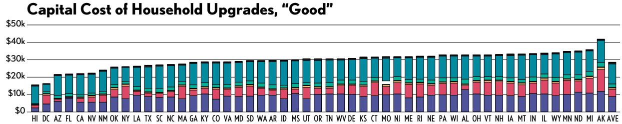

[10]Data from IEA PVPS, NREL (1, 2) and Haegel, et al.

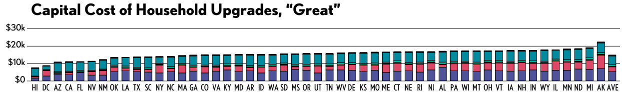
[11]Data from BloombergNEF (1 2) and Kittner, et al.

# Modeled capital cost reductions

The industrial scale just mentioned, as well as regulatory optimization (such as the Australian rooftop solar experience), drive the large capital cost reductions of the Good and Great scenarios.

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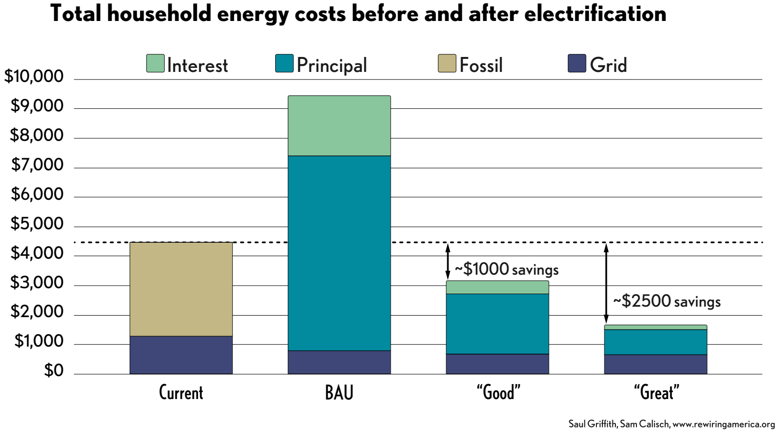
# It comes down to financed capital costs vs. fuel costs

We know what we need to build to decarbonize each household. We have modeled how far the cost of all these goodies can fall, and now we can see whether the right financing will help every household save money.

**Is the cost of financing the future upgrade lower than the cost of the fuels today?**

# Energy costs: Fuels today vs. financing tomorrow



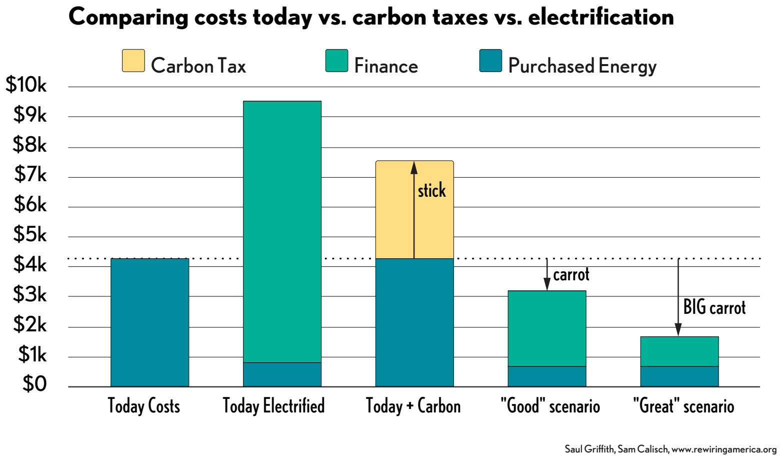
# A remarkable result

We can now see a tantalizing pathway to an economic win in every household. While clearly "Business as Usual" is not an economic win, the Good and Great scenarios net massive savings.

The average U.S. household will save more than $1,000 per year once we achieve Good, and more than $2,500 per year once we achieve Great.

To get there, we need to prioritize reductions in three areas: soft costs through regulatory reform, hard costs through massive industrial scale and steady technological progress, and finance costs through government–backed loans.

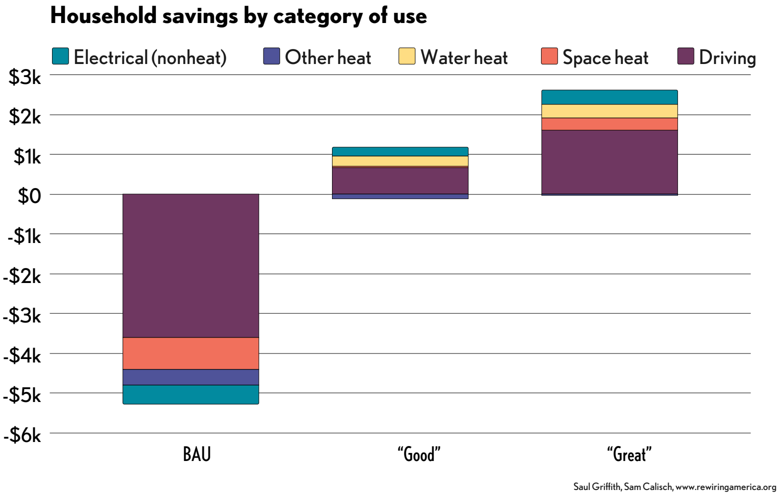
# Electrification and decarbonization costs today




We can compare this approach to the commonly-proposed carbon tax mechanism, seeing that while a carbon tax acts as a "stick" for households, electrification can be a (big) "carrot."

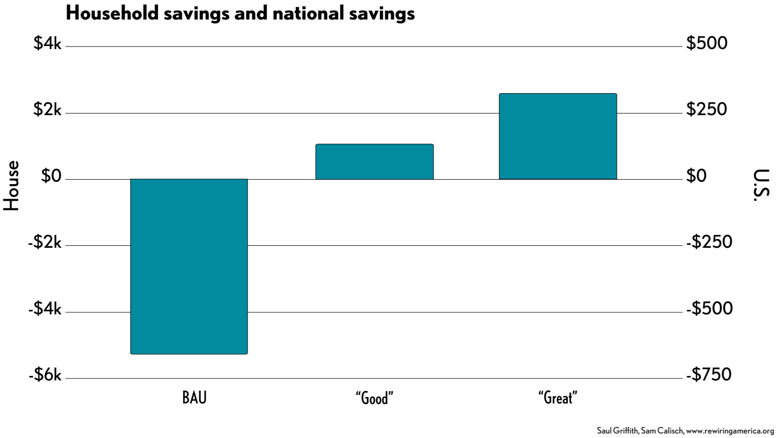
# Savings by category

Savings can be assigned to the category of energy use. The biggest savings are derived from driving and heating.



# Households save thousands, the U.S. saves hundreds of billions

All of these households saving money adds up to large savings on a national scale. In the Great scenario, more than $320 billion dollars in household savings will flow into the larger economy!

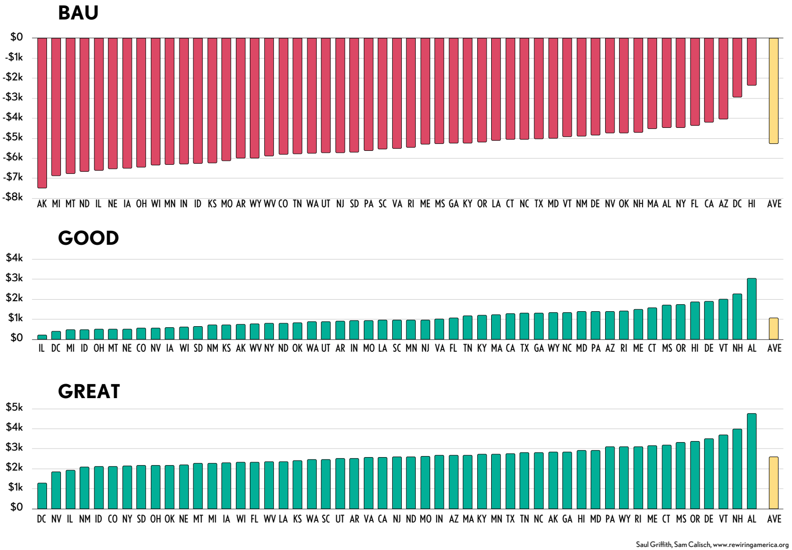


# But what about me? How does it pencil out where I live?

The improvement in household costs depends on a lot of factors: whether people already use a lot of energy, whether their state is hot or cold, and how much they drive where they live. The good news is that everyone can win once we get to the Good scenario. If we achieve what is possible in the Great scenario, all homes will save a couple thousand dollars a year, and in some states homes stand to save as much as $4,000-$5,000.

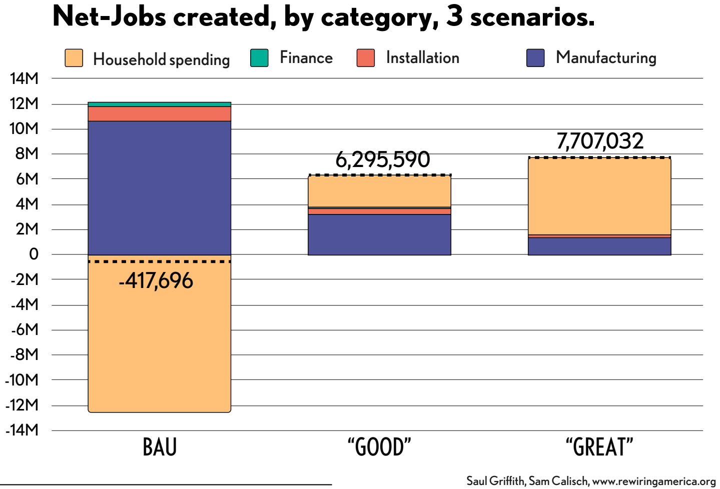
| State | "Good" | "Great" |
|---|---|---|
| Pennsylvania | $1,400 | $3,100 |
| Florida | $1,100 | $2,300 |
| Ohio | $500 | $2,200 |
| Arizona | $1,400 | $2,700 |
| Nevada | $600 | $1,900 |
| Maine | $1,500 | $3,200 |
| Colorado | $600 | $2,100 |

# Annual savings by household, by state



# What is the effect of this stimulus on jobs?

As many as 25 million jobs will be created in the U.S. by an aggressive climate plan.[12] The household transformation outlined here will create more than 7.7 million of those new jobs.[13]




[12]We have analyzed this previously in the Rewiring America Jobs Report.

[13]We use data from Implan to analyze the number of net new jobs created.

# Policy critically impacts the type and quality of jobs

We need to lower capital and soft costs to have the most impact on the economy. If we don't, we create the most jobs in installation and manufacturing, but households don't save money. Decreased household spending eliminates jobs elsewhere in the economy.

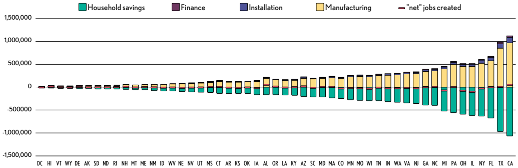
With increased savings in capital and installation costs, more varied and local jobs are created through increased household spending enabled by energy cost savings.

We are only modeling jobs in the residential sector and the household portion of the transportation sector. We have previously done an analysis demonstrating that there will be additional jobs in the commercial sector, industrial sector, and the remainder of the transportation sector, peaking in total at as many as 25 million new jobs.

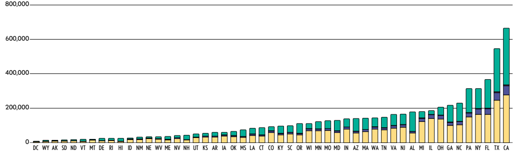
**The more aggressively and quickly we ramp up on a project like this, the sooner those jobs are created.**

# Where are those jobs created?

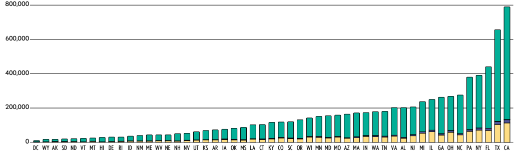
**Jobs created by state, BAU**




**Jobs created by state under "Good" scenario**




**Jobs created by state under "Great" scenario**

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# About those jobs...

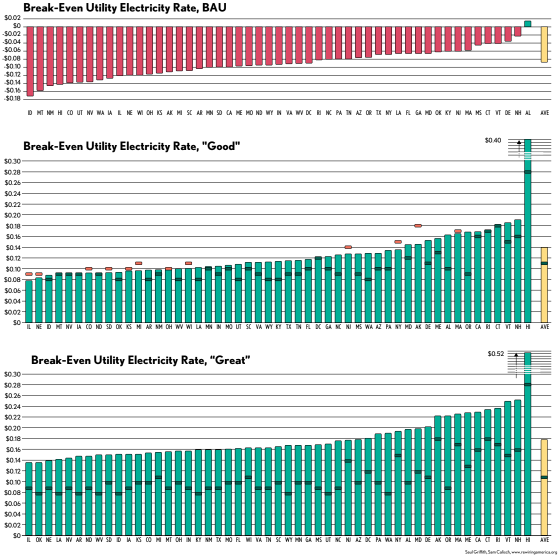
- Making this transition will create many jobs that are necessarily local and impossible to export. They are jobs on rooftops installing solar, jobs in basements installing heat pumps, and jobs in garages installing load centers and car chargers.
- Which states or countries get the manufacturing jobs is a question of industrial policy and state incentives.
- Which states or countries get the financing jobs is a question of policy and state incentives.
- The jobs generated by household savings are likely to be mostly local. For this reason, saving households money helps local economies.
- The policy choices around financing rates and regulatory environments largely determine whether the spoils go to the corporations, the utilities, the banks, or to households and communities.

# Can we do it through grid–delivered electricity alone?

Much of the household savings comes from the very low cost of electricity enabled by cheap rooftop solar. But not every household is a detached single–family house with a large roof, so for many households the question will be whether this transition will be economically viable at the cost of grid electricity.

To study this, we calculate the *break–even grid price*, or the price at which the grid would have to deliver electricity to have total household energy costs break even compared to today.

# Can we do it through grid–delivered electricity alone?



# Break–even scenarios for grid prices by state

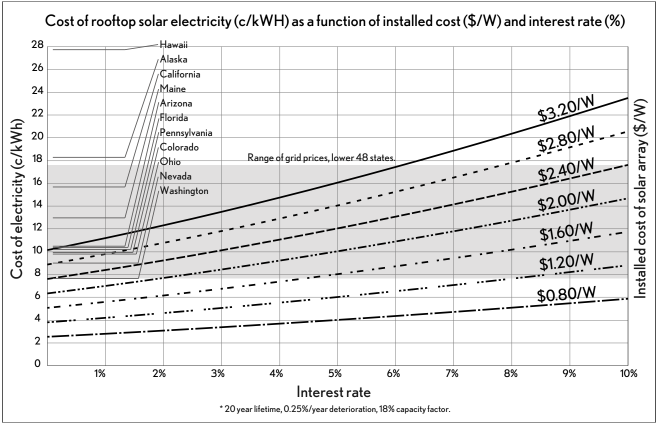
In the Good scenario, the majority of states break even at current grid prices. In the Great scenario, all states break even. In the Good and Great scenarios, the utilities have 3 and 7 cents per kWh of headroom to provide the household electrification upgrade as a service.

This implies that utility financing of the end–use electrical loads can work out once we have the cost reductions in place due to scale and regulatory reform.

There is ample opportunity for utilities to be a critical and profitable part of the solution.

# Can we do it through grid–delivered electricity alone?

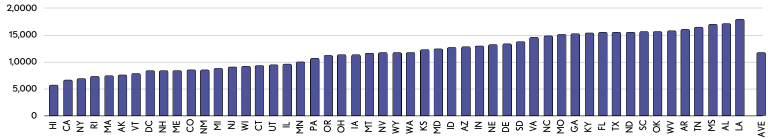
With low interest and low installation costs, rooftop solar still beats current grid prices in every market. So, while the grid can power electric households and save money, the greatest savings are realized by leveraging rooftop solar wherever possible.



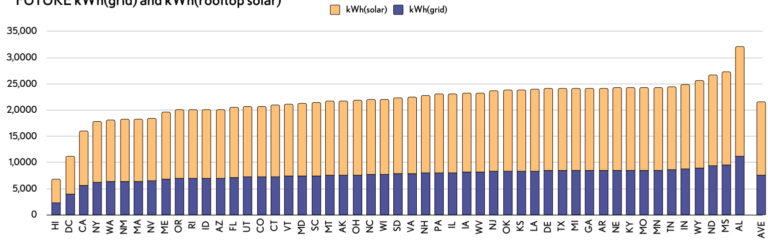
# Rooftop solar and the grid

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

CURRENT GRID SUPPLIED ELECTRICITY (kWh annualy)




FUTURE kWh(grid) and kWh(rooftop solar)




[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.

# What interest rates are required?

How critical is low–cost financing to make the switch to electrification?

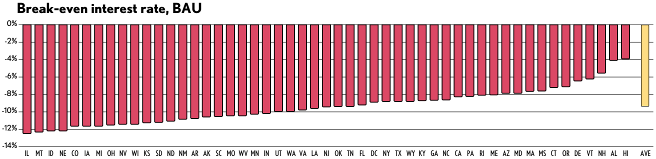
The *break–even interest rate* is the rate at which financed household electrification costs are the same as today's cost of household energy.

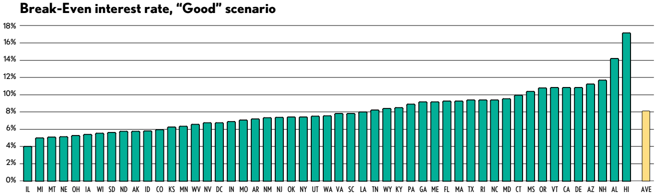
We can compare these required interest rates with those currently available to households. Remember that car loans are currently around 5%[15] and mortgage rates are commonly under 3%.[16]

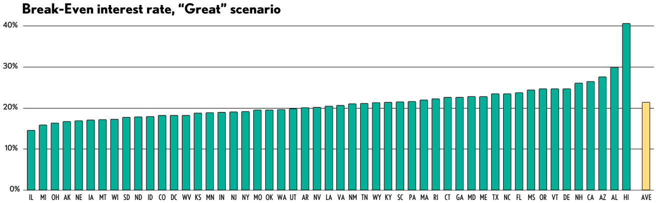
[15] See the Fed's G19 Consumer Credit Report

[16] See the CFPB's Rate Explorer and Mortgage Market Activity and Trends

# What interest rates are required?

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# What interest rates are required?

Because of the unfavorable costs of the BAU scenario, negative interest rates would be required to complete the electrification.

In the Good scenario, however, all interest rates are positive and are above mortgage rates. Many are still below the financing rates for households with poor credit scores, or for financing consumer appliances. In the Great scenario, allowable interest rates are considerably higher, well above car loan rates, with many in the realm of credit card rates.

Once we have achieved the great scenario, we can see there is plenty of room for run–of–the–mill interest rates (i.e., those where lenders can make a sure profit).

With both utility rates and interest rates, as the electrification transition drives down capital costs, the economics only get better in the future.

# What does this mean for national research priorities?

Though this analysis will be accused of picking technology winners, that isn't the point. It shows a pathway with existing technologies that is a baseline for climate success. New technologies only improve this situation.

This work suggests that the majority of our applied research should be on practical details — steady improvements in battery density and life, increasing COP of heat pumps, low or no emission refrigerants for heat pumps, small increases in solar efficiency, materials and industrial automation that supports lowering the cost of all components, and practical issues like minimizing installation costs.

Moonshots are politically popular, and while we should certainly shoot for breakthroughs, but we should emphasize that we can get to our goal with the technology we have now. If we need moonshots, they are in other sectors that are more difficult to decarbonize — industry, agriculture, and the material economy in particular.

# Equity

We only succeed in fighting climate change if all households can afford to transition to the new economy. It is the poorest households that have the most to gain from household energy savings.

This analysis suggests guaranteed low interest pathways that work well for home–owners and landlords, and which have precedent in the FHA and Fannie Mae programs of the New Deal stimulus of 1936.

We suggest that expanding the low cost of financing to the critical pieces of household infrastructure is key to climate success.

We additionally underscore the need for policy mechanisms that assist low–and–moderate–income (LMI) households and those with low credit scores. This could mean direct rebates, utility rate–based financing, point–of–purchase financing, or other creative policy solutions.

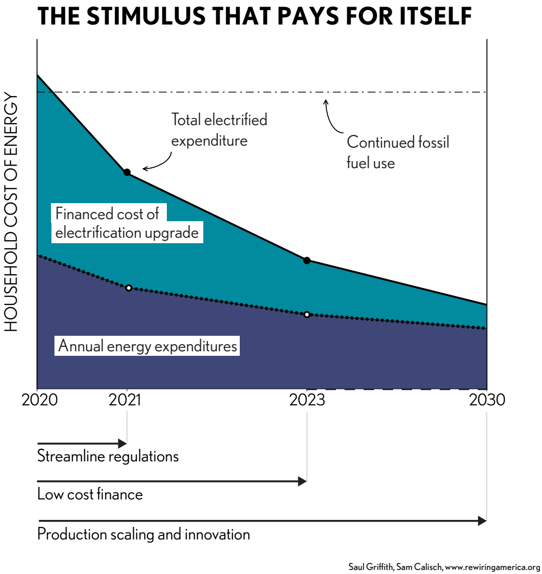
## The big conclusions

- If we do a "Good" job we can decarbonize more than 40% of the economy through our household energy consumption, while saving more than $1000 per year per household
- With an optimal regulatory environment, low cost financing, huge industrial scale and steady technology improvements we can save more than $2500 per year per household
- We don't need any miracle technologies to completely decarbonize American households
- Decarbonizing our households would eliminate around 40% of emissions
- If we apply the same technologies and approaches to the commercial sector, it would eliminate around 65% of emissions
- Regulatory reform and restructuring of monopoly control of energy services is absolutely necessary
- In the short term (0-10 years), low–cost financing is critical
- Massive scale of industrial ramp-up will lower costs significantly
- 5-10 years out, the critical technology costs will be low enough that grid electricity prices will be competitive and subsidized financing won't be necessary (but it would still be nice!)

# Policy–relevant conclusions

From a policy perspective, it is critical that we do these things:

- Optimize building codes and regulatory environment such that rooftop solar and electrification retrofit costs are not artificially high
- Make low–cost financing available at point of purchase, as these are typically infrequent and stressful purchasing decisions
- Guarantee grid neutrality to optimize costs and demand response and storage
- Scale up industrial and finance capabilities
- Find mechanisms that enable all households to afford access to these low cost energy solutions. We do not succeed if decarbonization is limited to people with a high FICO score
- We should prioritize steady iteration of existing technologies alongside "moonshot" programs in the national research agenda


THE STIMULUS THAT PAYS FOR ITSELF
HOUSEHOLD COST OF ENERGY
Total electrified expenditure
Continued fossil fuel use
Financed cost of electrification upgrade
Annual energy expenditures
2020
2021
2023
2030
Streamline regulations
Low cost finance
Production scaling and innovation
Saul Griffith, Sam Calisch, www.rewiringamerica.org

# Your family, your household

*Let's summarize the impact of the U.S. succeeding at a project like this:*

A regular family, living in the suburbs of Philadelphia, currently pays around $4,900 a year for energy — about $2,800 for gasoline, $1,070 for electricity, and the balance in heating fuels. To cut fossil fuels, this home would need an electrification upgrade that would cost about $80,000 today, but if we follow this recipe of regulatory reform, massive industrial scale, low–cost financing, and consistent innovation, this can actually be made a money saving proposition. Financed at 2% (Great), this would enable the household to save $3,093 a year on their all–in energy costs. Very likely someone in that household would be placed in one of the nearly 400,000 jobs created under this plan in their state alone. This proud job installing and enabling American technologies to be our new domestic infrastructure would afford a strong middle–class income and household financial security, while critically protecting our environment and climate for the children living under that solar–powered roof.

# But wait, there's more

This analysis only looked at the economic benefits that immediately flow to U.S. households in lowered costs of energy.

It is now understood that lifetime electric vehicle maintenance costs are half that of internal combustion engine cars, mainly due to fewer moving parts and fluids to change.[17] On average, that's $500 per household extra annual savings from going electric.

It is widely understood now that our health is negatively affected by burning fossil fuels in the home.[18] We will realize additional household savings in lowered healthcare costs as we have better air quality in our dining rooms and driveways.

No fossil fuels also means improved air and water quality, no oil spills, no gas explosions, and no mountain–top removal for fossil fuel extraction — in addition to the climate benefits.

**There is much to look forward to in our electric future. The future can indeed be awesome.**

[17] See Consumer Reports: Electric Vehicle Ownership Costs.

[18] See this RMI report on health effects from gas stove pollution

# A reminder of the urgency

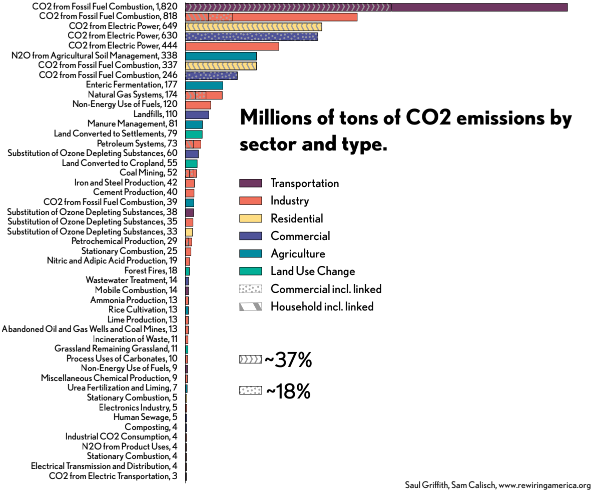
It is worth reminding ourselves that to realistically hit a climate target under 2°C, and certainly if we wish to hit a safer target like 1.5°C, we need urgent and bold actions:

- An immediate ramp–up of our industrial production of critical materials and machinery — electric vehicles, heat pumps, solar modules, batteries, wind turbines, and associated equipment for a much larger and more connected electrical grid. Each needs approximately a 10X increase in the rate of production. The speed needs to be similar to the "Arsenal of Democracy," the ramp–up of production of critical war materials for WWII.
- Simultaneously, we need to train a workforce for the manufacturing, distribution, and installation of these technologies.
- We need very high, if not 100% adoption rates of these technologies as we retire our existing energy using machinery, including our fossil power plants.
- We need financing mechanisms that enable everyone to participate. This financing needs to be available every time someone buys a car, a pickup truck, a water heater, a furnace or space heater, or when they are retrofitting their house with solar.
- We need a grid that delivers 3-4 times as much electricity as today, and that allows everyone to both buy and sell energy services.
- We need regulatory reform that allows these clean technologies to be the lowest–cost option in every market.

# Appendices:
# Down the rabbit hole (extra materials)

# Greenhouse Gas Emissions of households (and commercial businesses)

Figure 1: Greenhouse gas emissions in households, including personal vehicles, residential energy consumption, and industrial energy consumption associated with delivering fuels to households.



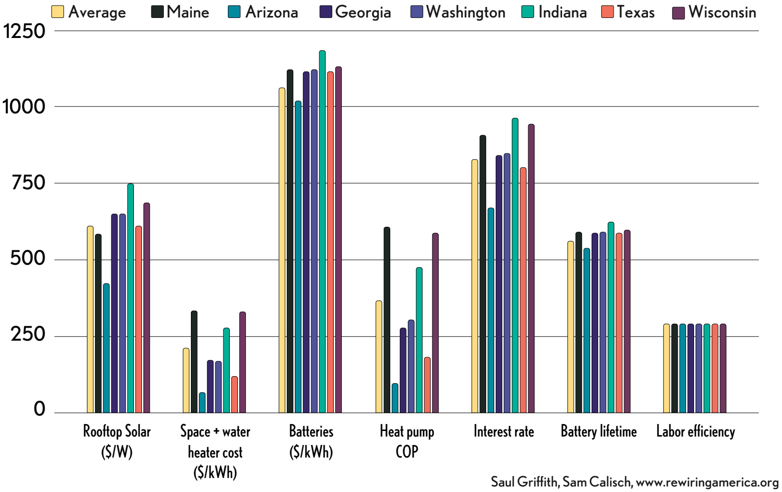
# Greenhouse gas emissions of a household

**This study looks at the 42% of energy related emissions that occur from energy decisions we control in our households.**

Greenhouse gas emissions and energy consumption statistics are often difficult to comprehend because we typically account for them by sector: Industrial, Residential, Commercial, or Transportation. We also sometimes talk about the "electricity sector" that feeds into all of the other sectors. Yet many of the emissions of one sector are actually realized in another. For example, a huge amount of energy (and emissions) is used in the industrial sector to produce and deliver the fuels that we use in our cars and homes. If we take all of the uses of energy in a household and trace them back to their emissions, irrespective of in which sector they occurred, we get a more complete picture. Around 37% of our emissions are from our households, including all of our electricity, all of our heat, and all of our driving. Similarly, around 18% of our emissions come from commercial buildings. If we were to consider the costs of making our homes, our vehicles, and all of our appliances, those emissions would be higher still, as these manufacturing costs and embodied energy are realized in the industrial sector. Approximately 2% of U.S. energy goes into making our cars and trucks before they have even driven a mile.

# What is the sensitivity to the various components?

Sensitivity analysis shows us the critical components to achieve this vision: cheap rooftop solar, cheap batteries, low interest, and high performance heat pumps.



# Savings correlated to state-wide characteristics

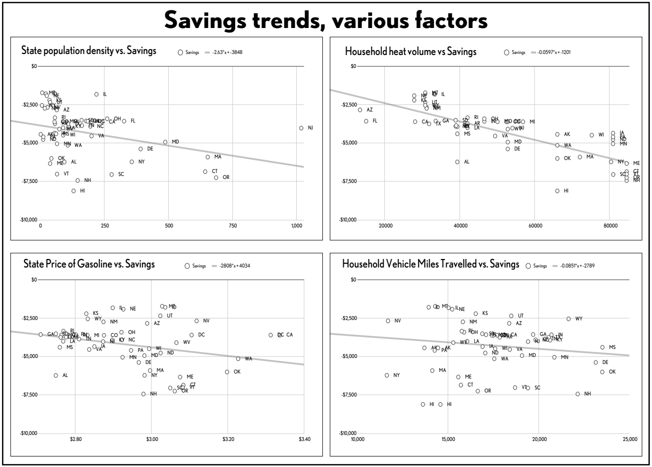



Figure 2: Correlations for various components by state characteristics.

# Savings correlated to state-wide characteristics

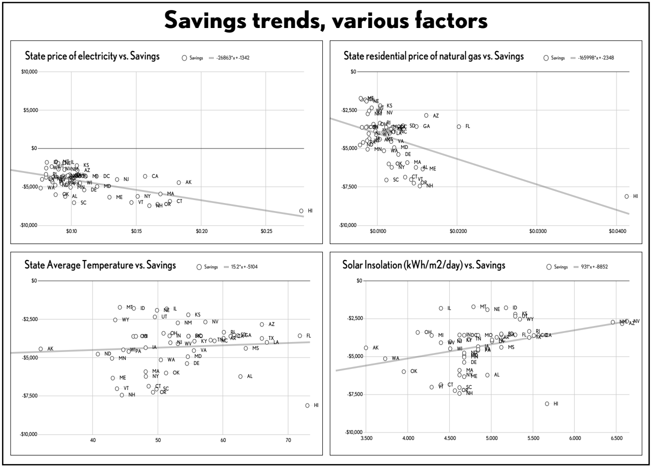



Figure 3: Correlations for various components by state characteristics.

# Existing electrical load of households vs. future electrical load

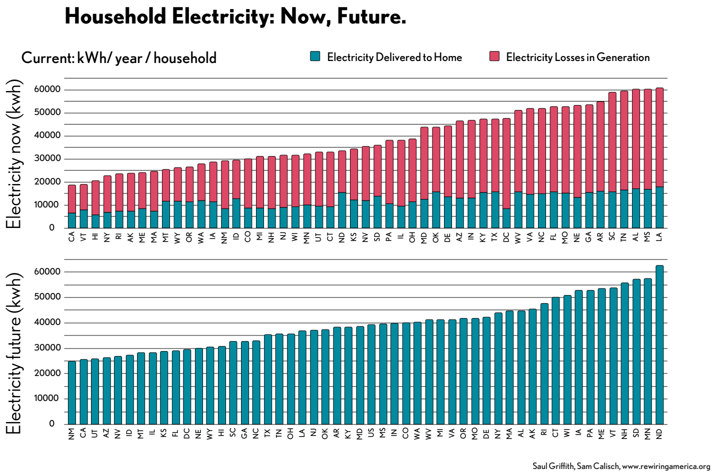



Figure 4: Current electrical load, and current electrical generation waste, and future total electrical load, electrified households.

# People per household by state

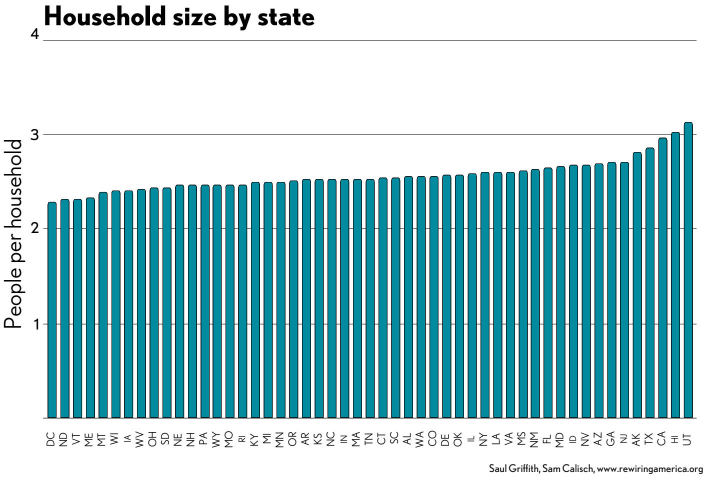



Figure 5: Number of people per household by state.

# Vehicle Miles Travelled per household, by state

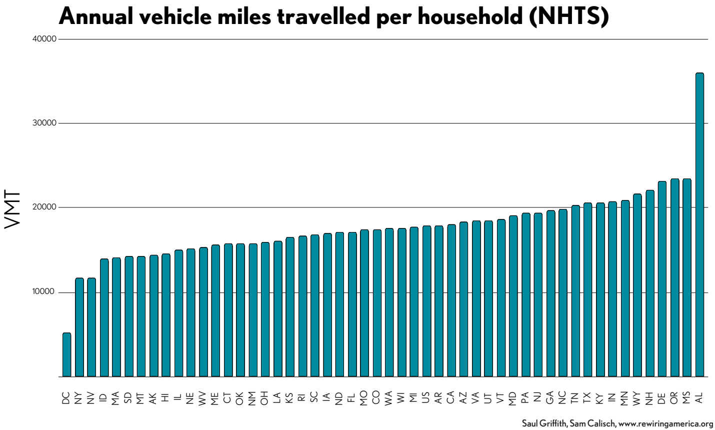
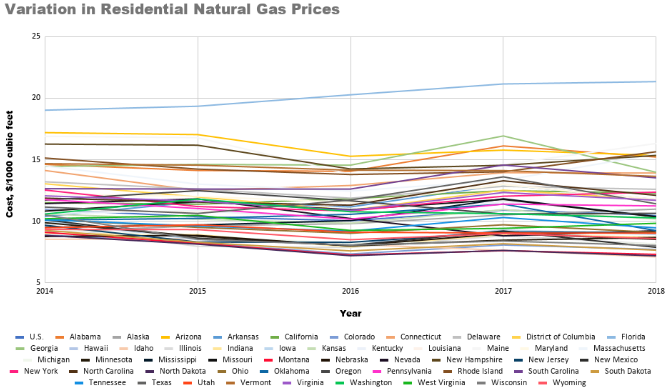
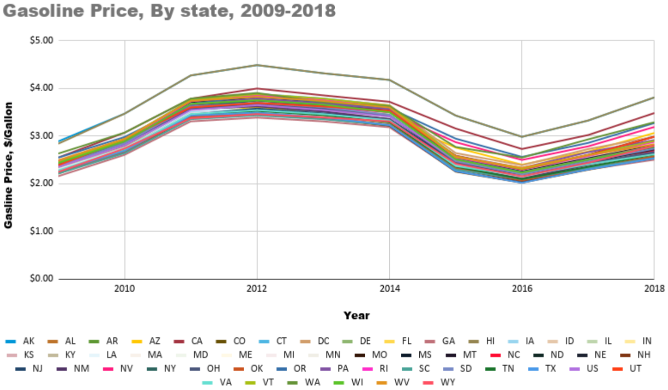



Figure 6: Vehicle miles travelled per household, current.

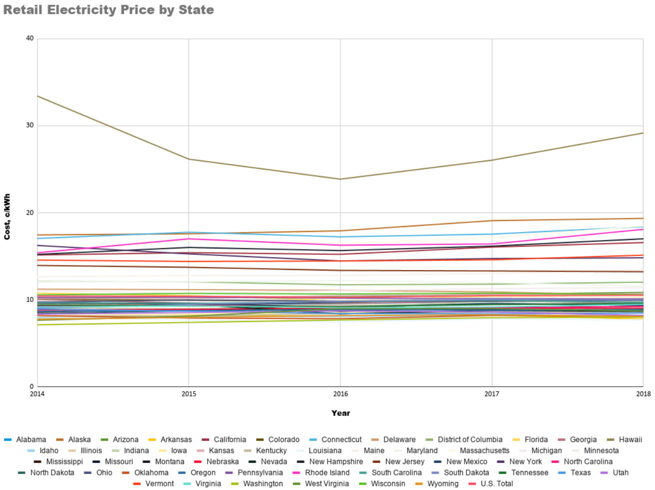
# Price history of natural gas in U.S.



# Price history of gasoline in U.S.



# Price history of electricity in U.S.



# Price history of propane in U.S.

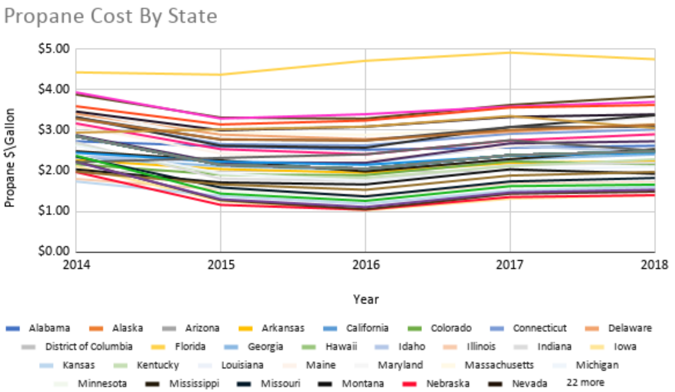



Figure 7: **Retail prices of fuels to households:** (a) Residential Natural Gas Prices by state, 2014-2018, (b) Retail Gasoline Prices by State, 2009-2018, (c) Residential Cost of Electricity by state, 2014-2018, (d) Propane Prices by State, 2014-2018, (e) Heating Oil Prices by State, 2009-2018

# Price history of heating oil in U.S.

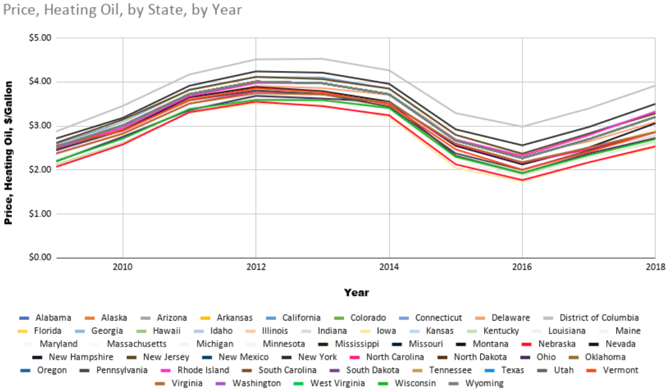



Figure 8: **Retail prices of fuels to households:** (a) Residential Natural Gas Prices by state, 2014-2018, (b) Retail Gasoline Prices by State, 2009-2018, (c) Residential Cost of Electricity by state, 2014-2018, (d) Propane Prices by State, 2014-2018, (e) Heating Oil Prices by State, 2009-2018

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