Rewiring America

A kitchen-table out and bottom-up solution to climate change



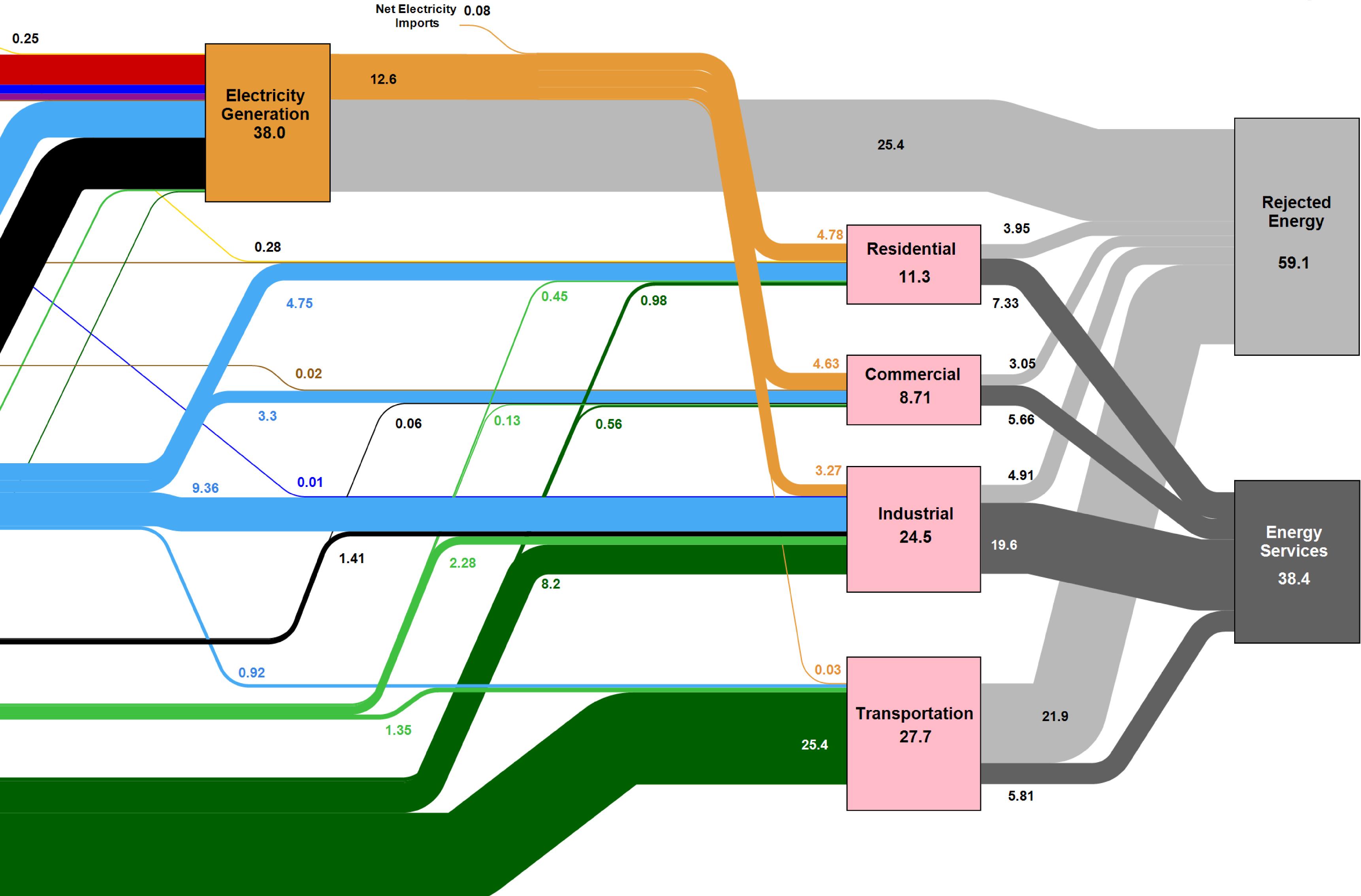
Our last shot at a good climate outcome:

Massive Electrification

Solar 0.532	
Nuclear	8.34
8.34	0.16
Hydro	2.38
Hydro 2.39	
	1.81
Wind 1.82	
Geothermal	
0.224	
	9.99
Natural Gas	
28.3	
	14.3
Coal	
15.7	
	0.52
Biomass	0.32
4.72	
	0.28
Petroleum	
35.4	

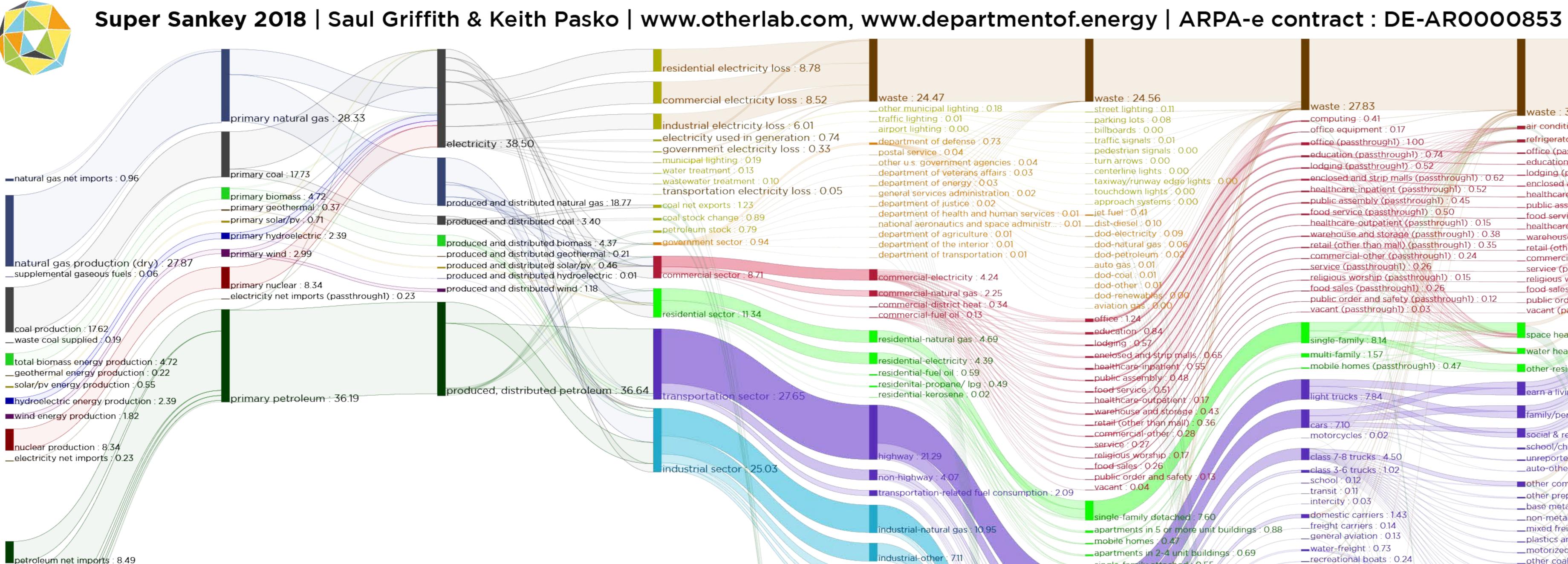
Source: LLNL March, 2016. Data is based on DOE/EIA MER (2015). If this information or a reproduction of it is used, credit must be given to the Lawrence Livermore National Laboratory and the Department of Energy, under whose auspices the work was performed. Distributed electricity represents only retail 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

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









total petroleum field production : 23.18 ■renewable fuels and oxygenate plant net ... : 2.00 petroleum processing gain : 1.89 __petroleum adjustments : 0.62

_____single-family attach

nt-duty vehicles / 14.97

- freight trucks 5.52 _____commercial light trucks : 0.55 __buses 0.26
- air:1717
- water : 0.97
- pipeline fuel natural gas : 0. ____rail: 0.52
- —construction and mining equipment : 0.96
- __agricultural equipment / 0.60
- __industrial equipment : 0.35
- _recreational equipment : 0.19

manufacturing : 18.30

non-manufacturing 5.89

industrial-electricity : 3.53

industrial-petroleum : 1.39

industrial-coal : 1

waste : 27.83 ____computing : 0.41 ____office equipment : 0.17 ____office (passthrough1) 1.00 education (passthrough1): 0.74 _lodging (passthrough1) : 0.52 enclosed and strip malls (passthrough1): 0.62 healthcare-inpatient (passthrough1): 0.52 ____public assembly (passthrough1) : 0.45 __food service (passthrough1) : 0.50 healthcare-outpatient (passthrough1) : 0.15 __warehouse and storage (passthrough1): 0.38 ___retail (other than mall) (passthrough1) : 0.35 ____commercial-other (passthrough1) : 0.24 service (passthrough1) 0.26 religious worship (passthrough1) : 0.15 food sales (passthrough1): 0.26 public order and safety (passthrough1) : 0.12 vacant (passthrough1) : 0.03

single-family : 8.14

multi-family : 1.57 _mobile homes (passthrough1) : 0.47

light trucks 7.84

cars : 7.10 motorcycles : 0.02

class 7-8 trucks 4.50 class 3-6 trucks 1.0 ___school : 0.12 __transit : 0.11 _intercity: 0.03 domestic carriers : 1.43 __freight carriers : 0.14 ___general aviation : 0.13 water-freight 0.73 __recreational boats : 0.24 __freight-rail: 0.47

chemicals : 6.31

__passenger : 0.05

petroleum and coal products : 4.17 paper : 2.09 primary metals 1.64 food : 1.11 nonmetallic mineral products : 0.83 wood products : 0.39 __fabricated metal products : 0.35 __transportation equipment : 0.32 plastics and rubber products : 0.29 ___machinery : 0.17 __computer and electronic products : 0.16 textile mills 0.10 beverage and tobacco products : 0.10 printing and related support : 0.09 electrical equip., appliances, and compo...: 0.07 miscellaneous 0.06 furniture and related products : 0.04 textile product mills 0.03 apparel: 0.01 leather and allied products : 0.00 mining: 3.00 construction : 1.62

agriculture : 1.17 ____data centers : 0.24

waste : 30.03

air conditioning : 1.29 refrigerators : 1.16 __office (passthrough2): 0.52 education (passthrough2): 0.25 _lodging (passthrough2): 0.24 enclosed and strip malls (passthrough2) healthcare-inpatient (passthrough2) _public assembly (passthrough2) : 0.15 _food service (passthrough2) : 0.27 healthcare-outpatient (passthrough2): 0.08 warehouse and storage (passthrough2): 0.1 retail (other than mall) (passthrough2) 0. commercial-other (passthrough2): 013 service (passthrough2): 0.09 _religious worship (passthrough2) 0.06 _food sales (passthrough2) : 0.07 _public order and safety (passthrough2) : 0.0 vacant (passthrough2)/04

space heating : 5.98

water heating : 2.30

other-residential 3.04

earn a living 5.19

family/personal business :

social & recreational : 3.64 _school/church: 0.66 unreported : 0.48 _auto-other : 0.08

other commodities : __other prepared foodstuffs, and/fats and ... __base metal in primary or semi-finished f...: 0.32 ____non-metallic mineral products / 0.30/ __mixed freight 0.30 ___plastics and rubber :/ ____motorized and other vehicles (includes p...: 0.22 __plumbing, heating, and air-conditioning ...: 0.19 ____other coal and petroleum products, not e.... 0.21 ___electrical contractors and other wiring: 0.12 ____basic chemicals : 02 ___waste and scrap 0 ____meat, poultry, fish, seafood, and their: 0.19 ____pulp, newsprint, paper and paperboard : 0.18 ____gravel and crushed stone (excludes dolom...: 0.17__painting and wall covering contractors : 0.03 __agricultural products (excludes animal f...: 0.17 __international shipping //0.62 __domestic shipping / 0.10

NAICS 325 Chemicals

NAICS 324 Petroleum and Coal Products NAICS 322 Paper NAICS 331: Primary Metals -NAICS 311 Food -NAICS 327 : Nonmetallic Mineral Product _NAICS 321 Wood Products _NAICS 336 : Transportation Equipment semiconductors and related devices : 0.09 NAICS 312 : Beverage and Tobacco Products oil and natural gas extraction : 1.83 beneficiation and processing : 0.59 __extraction : 0.32 __materials handling : 0.26 specialty trade contractors : 0.98 heavy and civil engineering construction : 0.42 _construction of buildings : 0.22 _____crops : 0.49 livestock : 0.30

waste : 37.99 other appliances : 1.40 ventilation : 0.79 lighting : 1.56 cooking : 1.13

washing: 0.53 _electronics : 0.46

5-19 miles : 5.44

20-50 miles : 4.14

50+ miles : 3.83 0-5 miles 1

NAICS 325 : Chemicals

NAICS 324 : Pet eum and Coal Products

NAICS 322 : Paper

NAICS 331 : Primary Metals ...

-NAICS 31

___NAICS 321 : Wood Products . NAICS 336 : Transportation Equipment semiconductors and related devices (pass...: 0.09 NAICS 312 : Beverage and Tobacco Products __grinding : 0.49 _crushing: 0.05 separations : 0.05

digging: 0.08 drilling: 0.07

dewatering: 0.03 _blasting: 0.02 ____diesel equipment : 0.21 electric equipment : 0.05 ____site preparation contractors : 0.24

__drywall and insulation contractors : 0.08 _all other specialty trade contractors : 0.08 __poured concrete foundation and structure...: 0.04 __roofing contractors: 0.04 ____finish carpentry contractors : 0.03 other building equipment contractors : 0.02 masonry contractors : 0.02 other building finishing contractors : 0.01

flooring contractors : 0.01

framing contractors : 0.01 tile and terrazzo contractors : 0.01 other foundation, structure, and buildin...: 0.01 glass and glazing contractors : 0.01 siding contractors : 0.01 highway, street, and bridge construction : 0.22 water and sewer line and related structu...: 0.06

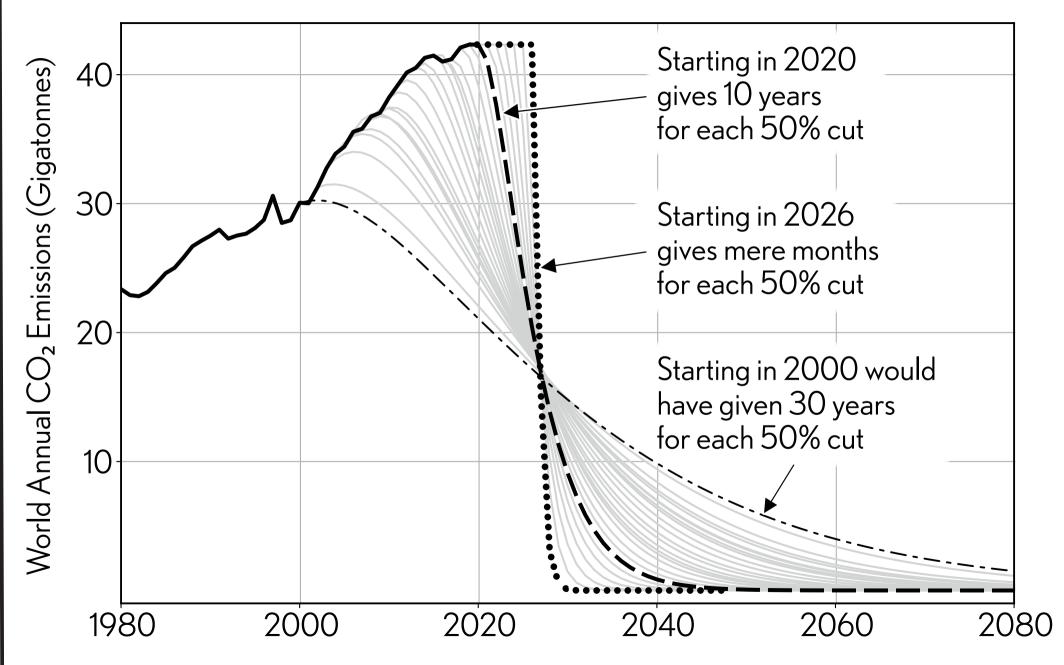
oil and gas pipeline and related structu...: 0.05 other heavy and civil engineering constr...: 0.03 land subdivision : 0.00 commercial and institutional building co...: 0.10 residential remodelers : 0.05 new single-family housing construction (...: 0.03 new housing for-sale builders : 0.03 industrial building construction : 0.0

new multifamily housing construction (ex...: 0.00 ____major field crops : 0.28 vegetables and fruits : 0.08 greenhouse and nursery : 0.02 beef and cattle ranching : 0.08 dairy cattle and milk production : 0.04 cattle feedlots : 0.02 hog and pig farming: 0.02

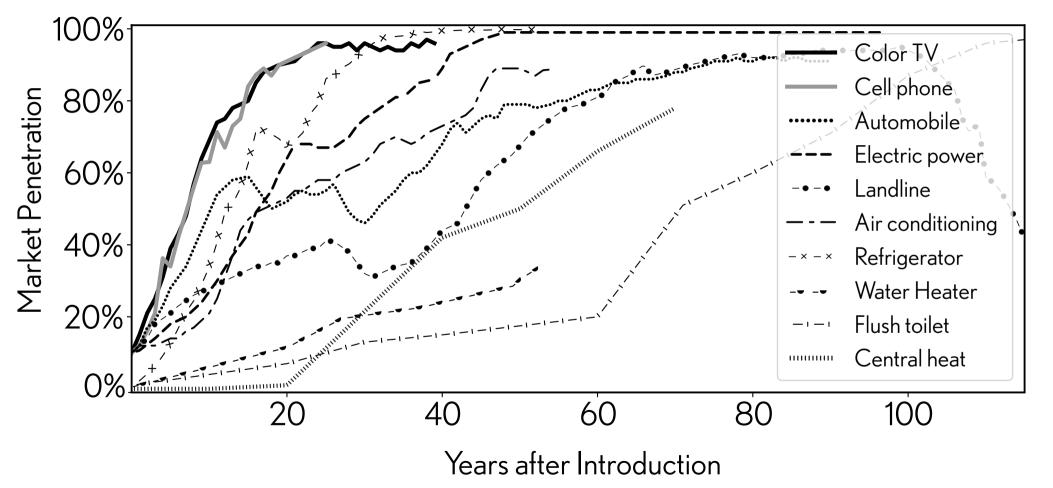
poultry and egg production : 0.02 aquaculture and other : 0.02

waste : 53.94 waste : 53.94 waste : 56.11 process heating : 2.68 energy materials in products : 4.53 machine drive : 1.02 __other process use : 0.21 process energy : 4.48 electro-chemical processes 0.16 _process cooling and refrigeration : 0.16 end use not reported : 5.64 chp and/or cogeneration process : 1.77 boiler fuel : 2.55 —conventional boiler use : 0.77 nonprocess energy : 0.53 __facility hvac : 0.31 facility lighting : 0.08 other facility support : 0.05 onsite transportation : 0.04 other nonprocess use : 0.01 conventional electricity generation : 0.01 NAICS 327 : Nonmetallic Mineral Products structural steel and precast concrete co...: 0.01 power and communication line and related...: 0.05

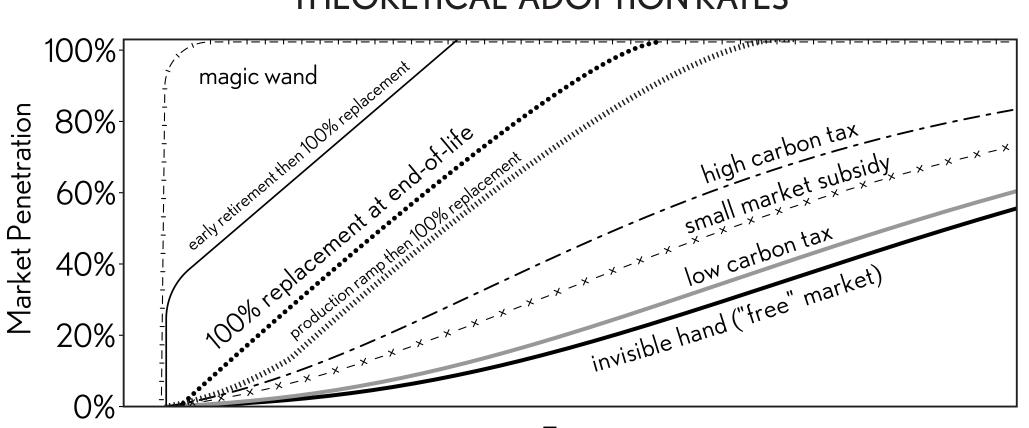
MITIGATION CURVES



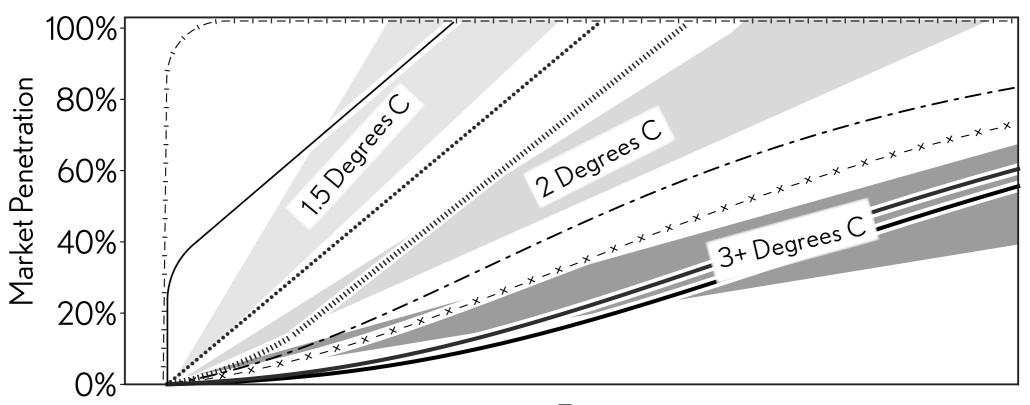
TECHNOLOGY ADOPTION RATES HISTORICALLY



THEORETICAL ADOPTION RATES



THEORETICAL ADOPTION RATES VS. CLIMATE OUTCOMES



Time

			and dec makes it	nitment to arbonizat t substanti ır energy (i ia
	Electricity generation without fossil fuels eliminates ~25 percent of our primary energy needs.	Electrification of cars, light trucks and freight trucks eliminates ~16 percent of our primary energy needs.	Electrification of heating using heat pumps for homes offices and some industry eliminates 6-7% more.	The 6% of our energy use that currently finds, mines, refines, and transports fossil fuels won't be needed.	L a e a n e 5
Before: 100 Quads Required	75 Quads	59 Quads	53 Quads	47 Quads	

electrification ion ally easier to demands.

LED lighting (1.5%) and industrial efficiency and advanced manufacturing eliminates another 5%.

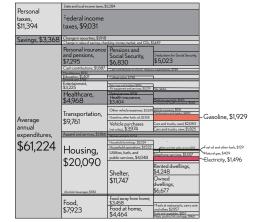
42 Quads

After : 42 Quads Needed.

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

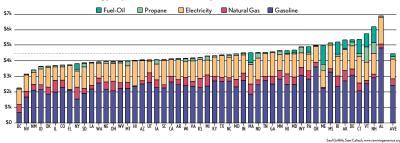
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⁴Data from Bureau of Labor Statistics, Consumer Expenditure Survey

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Existing Energy Costs per Household

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

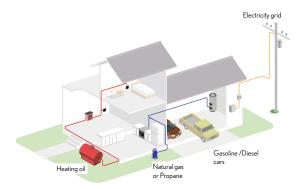


2019 Household energy expenditures, all fuels, by State.

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.

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.



Household decarbonization infrastructure upgrade

What does this electrification upgrade infrastructure look like?



These are electric versions of the \sim 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

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³Air 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.

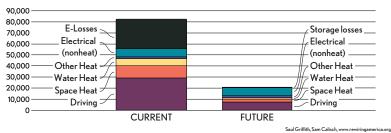
Current households vs. electrified

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.

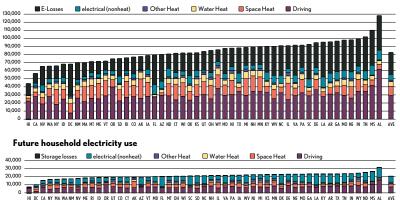


Annual average energy use per U.S. household, kWh equivalents

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Current and future household energy consumption, by state

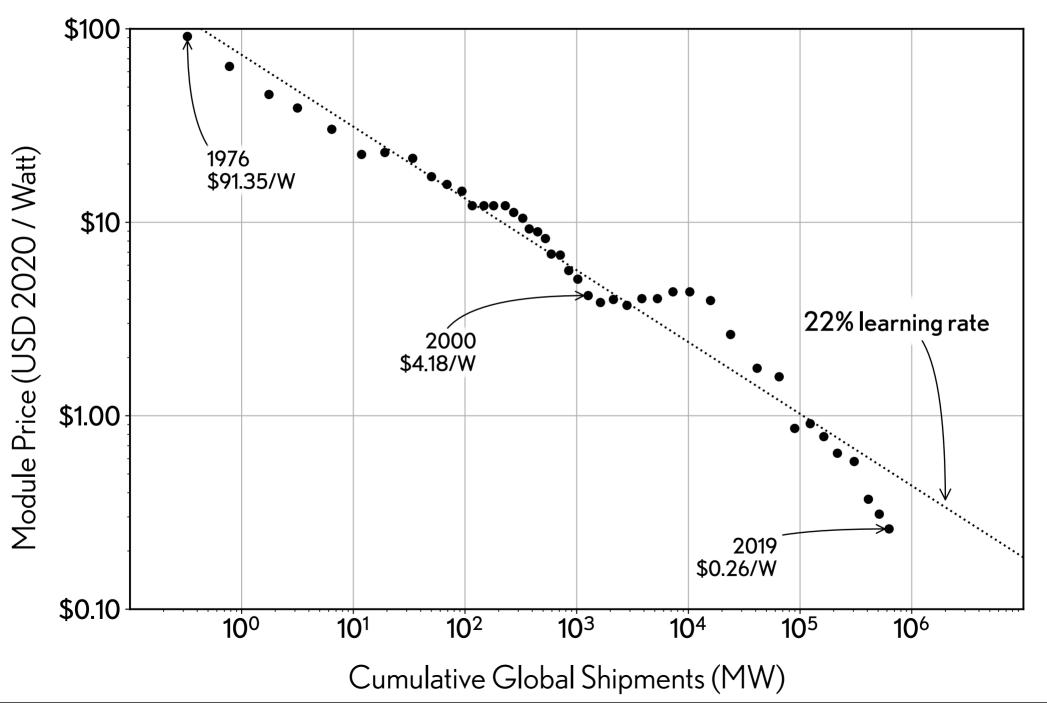
We see some variation state-to-state, but going electric saves significant energy across the board.



Current Household energy use, kWh equivalents

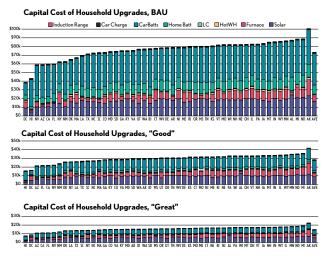
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COST OF SOLAR OVER TIME



Modeled capital cost reductions

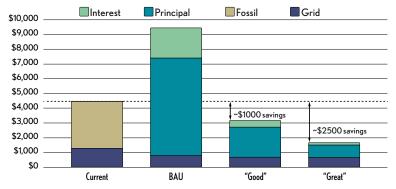
The industrial scale just mentioned, as well as regulatory optimization (such as the Australian rooftop solar experience), drive the large capital cost reductions of the Good and Great scenarios.



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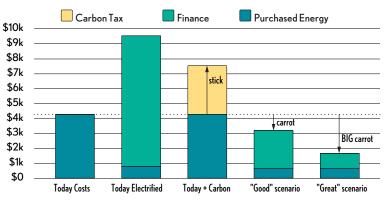
Energy costs: Fuels today vs. financing tomorrow

Total household energy costs before and after electrification



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Electrification and decarbonization costs today



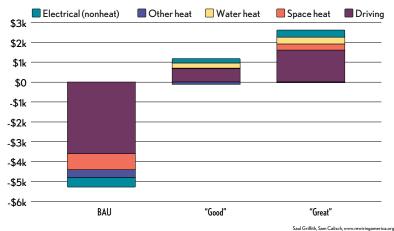
Comparing costs today vs. carbon taxes vs. electrification

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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."

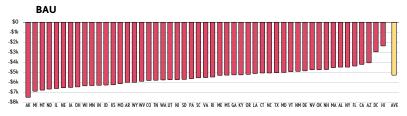
Savings by category

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

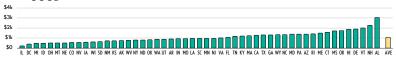


Household savings by category of use

Annual savings by household, by state



GOOD

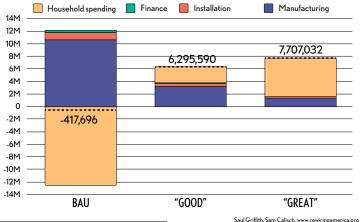




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What is the effect of this stimulus on iobs?

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 iobs.¹³



Net-Jobs created, by category, 3 scenarios.

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

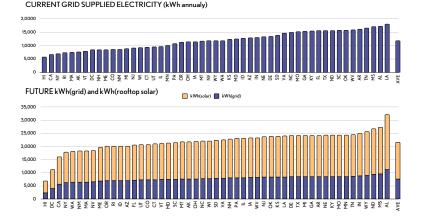
¹³We use data from Implan to analyze the number of net new jobs created.

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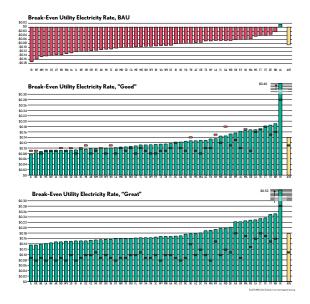
Rooftop solar and the grid

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

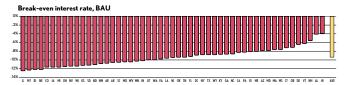


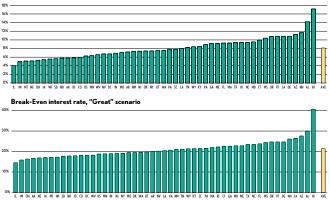
¹⁴NREL's 2016 report, Rooftop Solar Photovoltaic Technical Potential in the United States, finds over 1100GW potential even using a very conservative 16% module efficiency. Saul Griffith and Sam Calisch

Can we do it through grid-delivered electricity alone?



What interest rates are required?





Break-Even interest rate, "Good" scenario

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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.

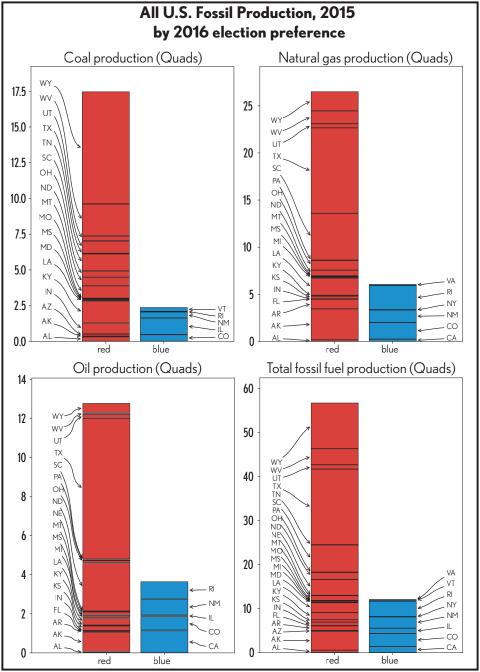
CO2 from Fossil Fuel Combustion, 1.820 CO2 from Fossil Fuel Combustion, 818 CO2 from Electric Power, 649 CO2 from Electric Power 630 CO2 from Electric Power 444 N2O from Agricultural Soil Management, 338 CO2 from Fossil Fuel Combustion, 337 CO2 from Fossil Fuel Combustion, 246 Enteric Fermentation, 177 Natural Gas Systems, 174 Non-Energy Use of Fuels, 120 Landfills, 110 Manure Management, 81 Land Converted to Settlements, 79 Petroleum Systems, 73 Substitution of Ozone Depleting Substances, 60 Land Converted to Cropland, 55 Coal Mining, 52 Iron and Steel Production, 42 Cement Production, 40 CO2 from Fossil Fuel Combustion, 39 Substitution of Ozone Depleting Substances, 38 Substitution of Ozone Depleting Substances, 35 Substitution of Ozone Depleting Substances, 33 Petrochemical Production, 29 Stationary Combustion, 25 Nitric and Adipic Acid Production, 19 Forest Fires, 18 Wastewater Treatment, 14 Mobile Combustion, 14 Ammonia Production, 13 Rice Cultivation, 13 Lime Production, 13 A bandoned Oil and Gas Wells and Coal Mines 13 Incineration of Waste, 11 Grassland Remaining Grassland, 11 Process Uses of Carbonates, 10 Non-Energy Use of Fuels, 9 Miscellaneous Chemical Production, 9 Urea Fertilization and Liming, 7 Stationary Combustion, 5 Electronics Industry, 5 Human Sewage, 5 Composting 4 Industrial CO2 Consumption, 4 N2O from Product Uses, 4 Stationary Combustion, 4 Electrical Transmission and Distribution, 4 CO2 from Electric Transportation, 3

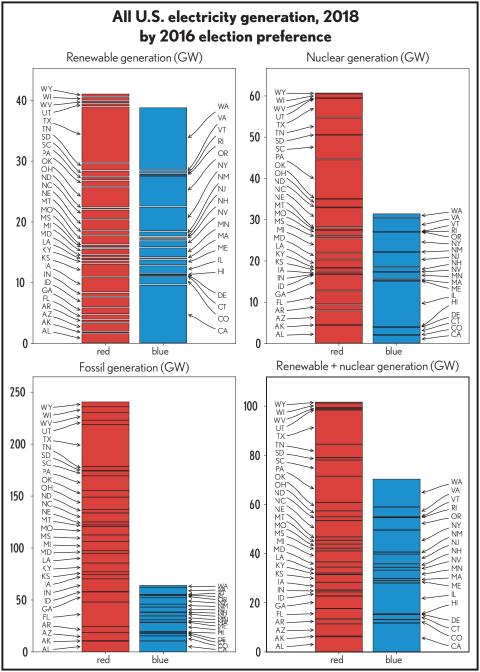
Millions of tons of CO2 emissions by sector and type.



∞∞~37% ∞∞~18%

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U.S. land area (million square miles) by 2016 electoral preference

