U.S. Energy Production & Consumption

John C. Bean

Outline

U.S. Energy factoids worth remembering

Different types of energy used in the U.S. (and elsewhere)

U.S. **Electrical Energy** production & consumption:

- Sources of this Electrical Energy, including rapid changes over the last 20+ years
- State-by-state breakdown of Electrical Energy sources & trends
- Analysis of alternate scenarios for reducing Greenhouse Gas (GHG) linked Electricity

U.S. **Total Energy** production & consumption:

- Understanding the dauntingly complex U.S. government reports
- Energy reductions if particular fossil-fuel technologies were replaced by electric technologies
  - Expansion of green Electric Grid capacity required to support those particular conversions
- Plausibility of expanding green Electric Grid capacity to eliminate ~ **ALL** GHG emissions

Putting U.S. power consumption into perspective:

- Worldwide data and maps on per-capita energy consumption

(Extensively expanded & rewritten: February 2023)

U.S. Energy Production & Consumption

To **figure out how** to build a sustainable energy system, we must learn more about

the pieces of today's energy system - and how they **now** work together

and about alternative pieces - and how they might **more sustainably** work together

But while a decade ago major change seemed necessary by 2050,

global warming now indicates the need for major change within even **this** decade

Calling for not only invention, but rapid R&D, commercialization & deployment

To assess the **scale** of necessary change, and the **rate & impact** of recent changes,

this noteset focuses on the amounts, types, and trends in recent U.S. Energy use

Image adapted from: http://determinedtosee.com/?p=1032

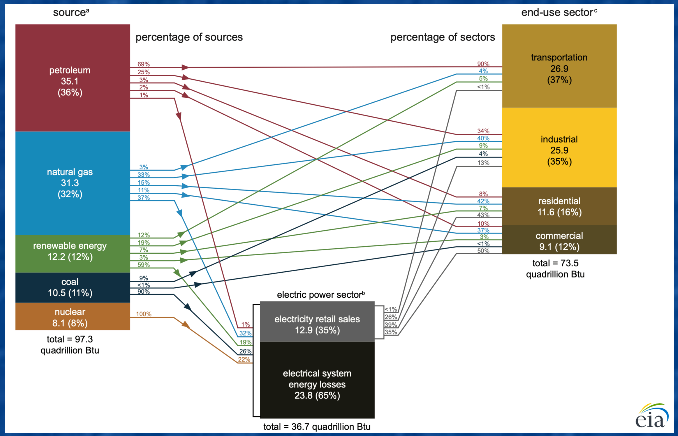
*But which **type** of energy?*

Our high school science teachers talked about **all sorts** of energy, including:

potential, kinetic, chemical, thermal, electrostatic, electromagnetic . . .

The U.S. (and other countries) similarly make use of **all sorts of energies**

as "explained" in this purportedly clarifying U.S. government figure: [1]



"U.S. Energy Facts Explained"

https://www.eia.gov/energyexplained/us-energy-facts/

Rather than making a frontal assault upon this (boggling) figure,

let's begin with the energy most directly affecting us as citizens & consumers:

Electrical Energy - the one delivered to us by electrons flowing through wires

(a.k.a. "**Electricity**")

How much Electrical Energy does the U.S. produce / consume?

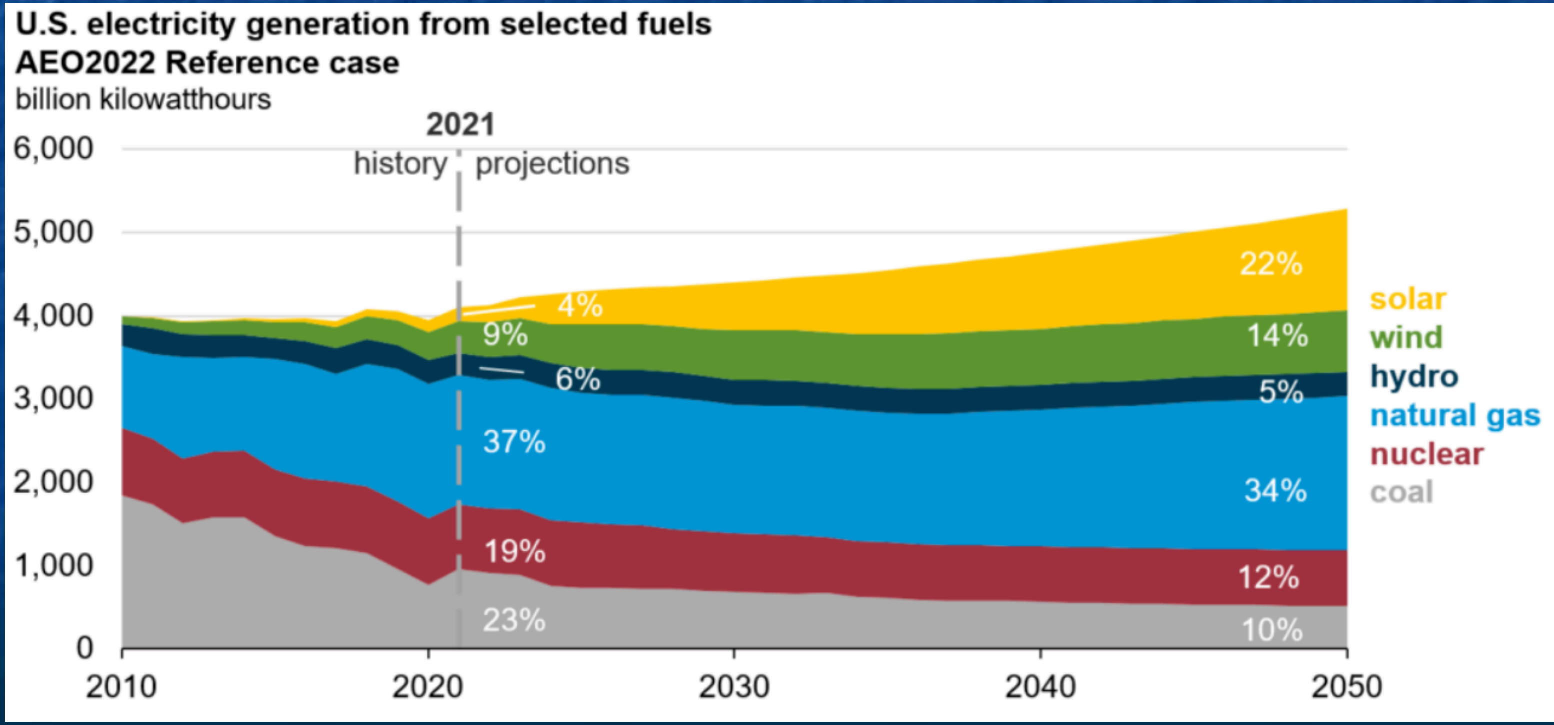
The **U.S. Energy Information Administration (EIA)** offers some key factoids & snapshots:

AVERAGE U.S. HOUSEHOLD Electrical POWER use in 2021: 886 kW-hrs / month [1]

(886 kW-hrs) / (30 x 24 hrs) => ~ **1-¼ kilowatts**

TOTAL U.S. annual Electrical ENERGY production (projected to 2050): [2]

2021 Total ~ 4000 billion kW-h / yr ~ **4 x 10^{15} W-h / yr**



1) EIA FAQs 2023: https://www.eia.gov/tools/faqs/faq.php?id=97&t=3
2) EIA Annual Energy Outlook 2022 - Narrative, p17: https://www.eia.gov/outlooks/aeo/narrative/pdf/AEO2022_Narrative.pdf

Calling for a quick refresher on metric unit multipliers:

Especially for the very rarely used (and thus seldom remembered) LARGEST multipliers:

K **or k = kilo** = thousand = 1,000 = 10^3

M = mega = million = 1,000,000 = 10^6 (not to be confused with: **m = milli** = 10^{-3})

G = giga = billion = 1,000,000,000 = 10^9

T = tera = trillion = 1,000,000,000,000 = 10^{12}

Q or q = quad = quadrillion = 1,000,000,000,000,000 = 10^{15}

Then, from the preceding figure (inserting 10^{15} = quad = Q):

U.S. ANNUAL ELECTRICAL ENERGY production: ~ 4 QW-h

And because AVERAGE ELECTRICAL POWER = ANNUAL ELECTRICAL ENERGY / 1 YEAR

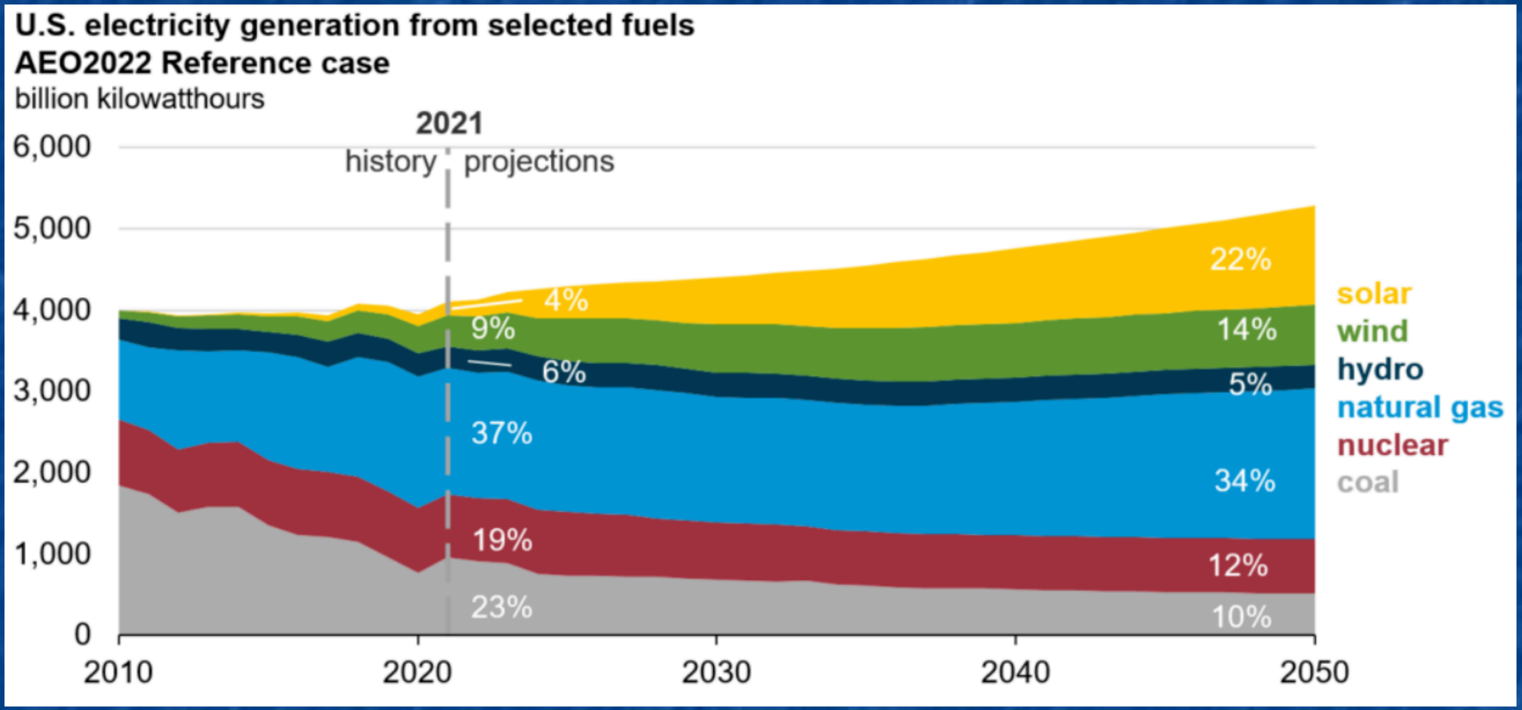
using: hour / year = 1 h / (24 x 365 h) = 1 / 8760 and: 4 QW / 8760 = 0.00046 QW

U.S. AVERAGE ELECTRICAL POWER generation: ~ 1/2 TW

But U.S. Electrical Energy looks a LOT LESS GREEN than we often hear!

According to that EIA figure, the 2021 breakdown of U.S. Electrical Energy sources was:

2021: **23% Coal** / **37% Natural gas** / **19% Nuclear** / **~ 19% Renewables** [1]



Further, based on their knowledge of the U.S. power industry, the EIA predicts very slow greening:

2050: **10% Coal** / **34% Natural gas** / **12% Nuclear** / **~ 41% Renewables**

(with ***particularly*** weak growth of wind power: 55% over the 29 years 2021 to 2050)

*1) **~ 19% Renewables** because this figure's "selected fuels" do not include renewable biomass fuel*

More detailed & recent data are provided by the EIA's ***Electricity Data Browser***

Which has the advantage of being updated both monthly and yearly

But the disadvantage of data presentation via only often-hard-to-digest numerical tables

Screenshot from its webpage (link - also spelled out at the bottom of this page):

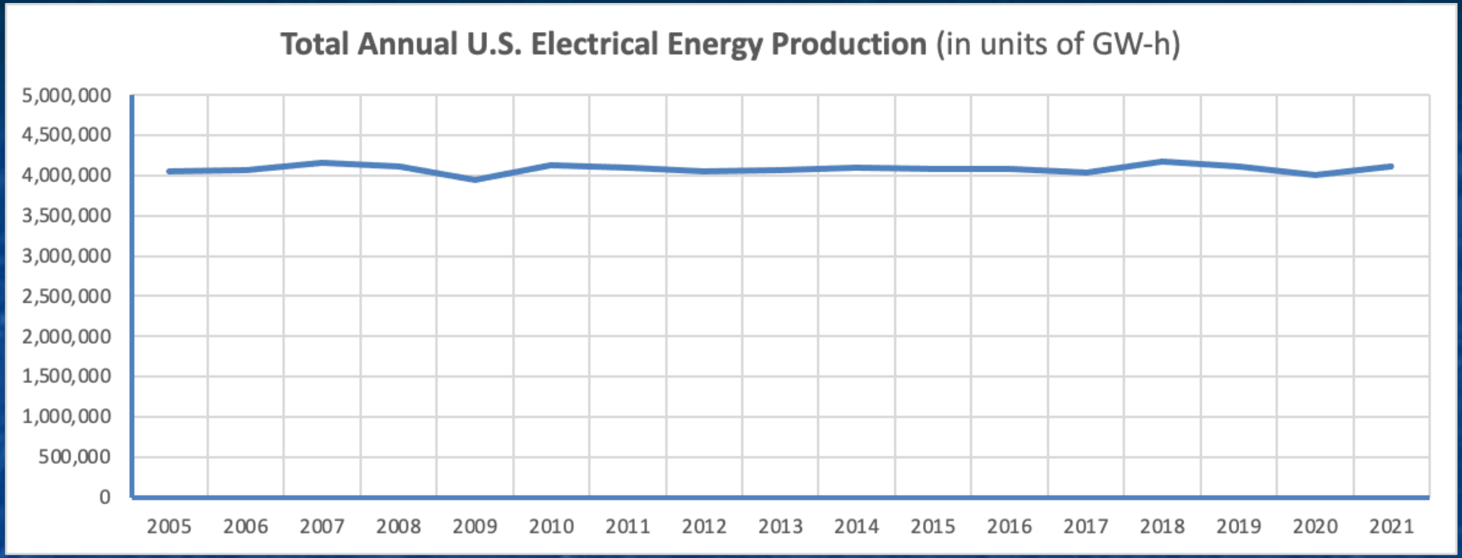
eia + Sources & Uses | + Topics | + Geography | Search eia.gov

Pin | API | 2001 – 2021 | Annual | Quarterly | Monthly

	2018	2019	2020	2021
Net generation for all sectors (thousand megawatthours)				
United States				
All fuels	4,180,988	4,130,574	4,009,767	4,108,303
Coal	1,149,487	964,957	773,393	897,885
Petroleum liquids	16,245	11,522	9,662	11,665
Petroleum coke	8,981	6,819	7,679	7,511
Natural gas	1,471,843	1,588,533	1,626,790	1,579,361
Other gases	13,463	12,591	11,818	11,397
Nuclear	807,084	809,409	789,879	778,188
Conventional hydroelectric	292,524	287,874	285,274	251,585
Other renewables				
Wind	272,667	295,882	337,938	378,197
All utility-scale solar	63,825	71,937	89,199	115,258
Geothermal	15,967	15,473	15,890	15,975
Biomass (total)	61,832	57,507	54,712	54,252
Wood and wood-derived fuels	40,936	38,543	36,219	36,463
Other biomass	20,896	18,964	18,493	17,790
Hydro-electric pumped storage	-5,905	-5,261	-5,321	-5,112
Other	12,973	13,331	12,855	12,140
All solar	93,365	106,894	130,721	164,422
Small-scale solar photovoltaic	29,539	34,957	41,522	49,164

https://www.eia.gov/electricity/data/browser/

The top line yields my plot of Total Annual U.S. Electrical Energy Production:



Which, for over twenty years, has been remarkably constant at ~ **4.1 QW-h**

"Remarkably" because, in the same period, U.S. population grew by over 13% [1]

and inflation-corrected U.S. Gross Domestic Product (GDP) grew by over 75% [2]

How was stable electrical energy use achieved? Commonly cited factors include:

Widespread conversion from incandescent to LED lighting (5-8X more energy efficient)

Improved home construction, including much more energy efficient "heat pumps"

1) U.S. Census: https://www.census.gov/data/tables/time-series/dec/popchange-data-text.html
2) https://www.macrotrends.net/countries/USA/united-states/gdp-gross-domestic-product

Annually I also add EIA Electricity Data Browser data to an Excel spreadsheet:

And use it to convert production numbers into percentages of total electrical energy:

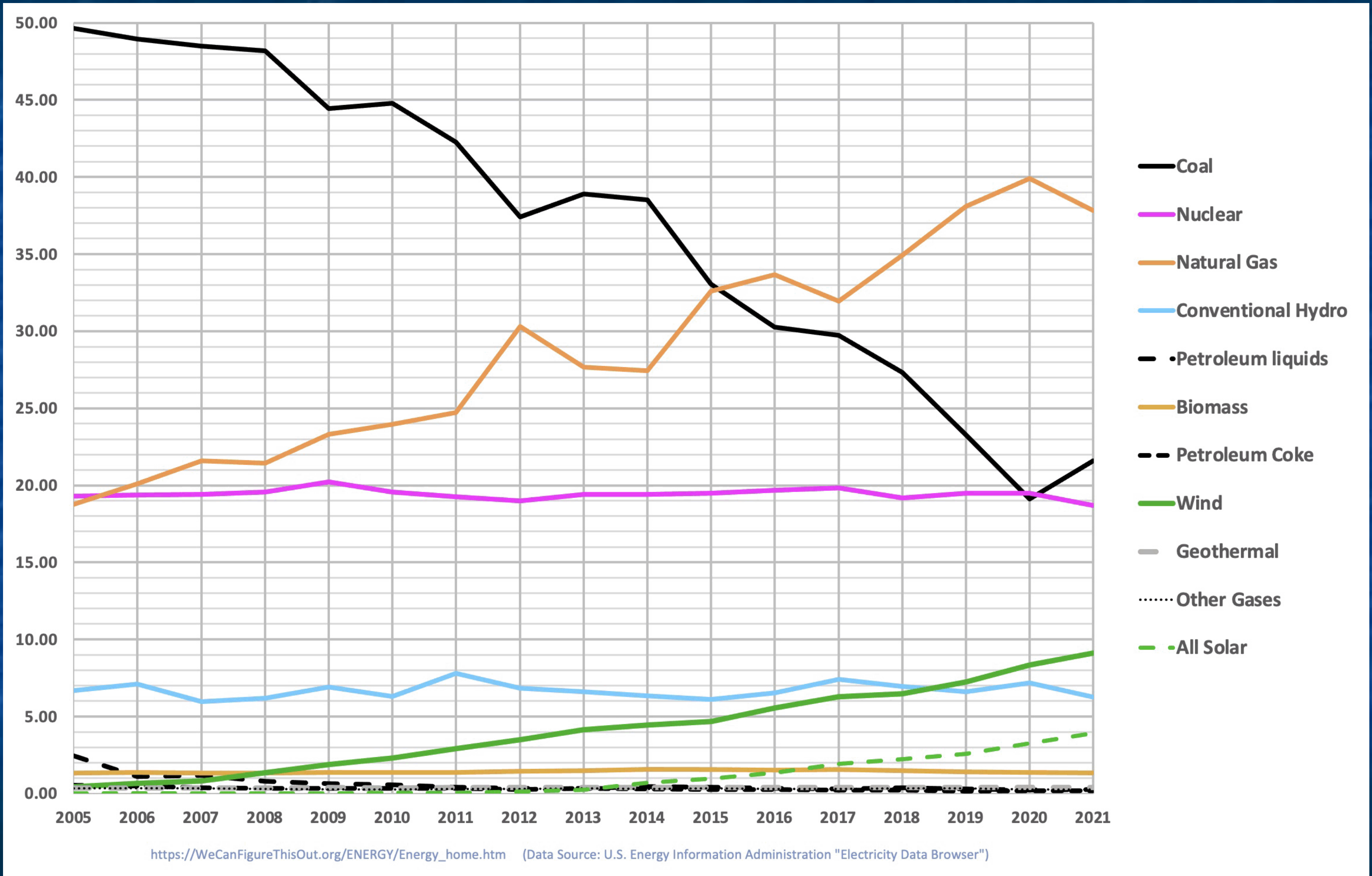
Percentage of Total Generation for that year (sorted by 2005 order)

	2005	2006	2007	2008	2009	2010	2011	2012	2013
Coal	49.63	48.97	48.51	48.21	44.45	44.78	42.28	37.40	38.89
Nuclear	19.28	19.37	19.40	19.57	20.22	19.56	19.27	19.01	19.41
Natural Gas	18.76	20.09	21.57	21.43	23.31	23.94	24.72	30.29	27.66
Conventional Hydro	6.67	7.12	5.95	6.19	6.92	6.31	7.79	6.82	6.61
Petroleum liquids	2.46	1.09	1.19	0.77	0.66	0.57	0.39	0.33	0.34
Biomass	1.34	1.35	1.34	1.34	1.38	1.36	1.38	1.42	1.50
Petroleum Coke	0.55	0.48	0.39	0.35	0.33	0.33	0.34	0.24	0.33
Wind	0.44	0.65	0.83	1.34	1.87	2.29	2.93	3.48	4.13
Geothermal	0.36	0.36	0.35	0.36	0.38	0.37	0.37	0.38	0.39
Other Gases	0.33	0.35	0.32	0.28	0.27	0.27	0.28	0.29	0.32
All Solar	0.01	0.01	0.01	0.02	0.02	0.03	0.04	0.11	0.22

	2014	2015	2016	2017	2018	2019	2020	2021
Coal	38.53	33.05	30.26	29.71	27.32	23.26	19.10	21.58
Nuclear	19.42	19.48	19.67	19.83	19.18	19.49	19.50	18.69
Natural Gas	27.45	32.59	33.65	31.95	34.91	38.09	39.91	37.82
Conventional Hydro	6.32	6.09	6.54	7.40	6.95	6.59	7.19	6.25
Petroleum liquids	0.45	0.42	0.32	0.31	0.39	0.28	0.24	0.27
Biomass	1.56	1.56	1.53	1.55	1.47	1.41	1.38	1.33
Petroleum Coke	0.29	0.27	0.27	0.22	0.21	0.17	0.19	0.18
Wind	4.43	4.66	5.54	6.27	6.48	7.23	8.33	9.12
Geothermal	0.39	0.39	0.39	0.39	0.38	0.39	0.42	0.39
Other Gases	0.29	0.32	0.31	0.31	0.32	0.33	0.28	0.27
All Solar	0.70	0.95	1.34	1.90	2.22	2.58	3.27	3.93

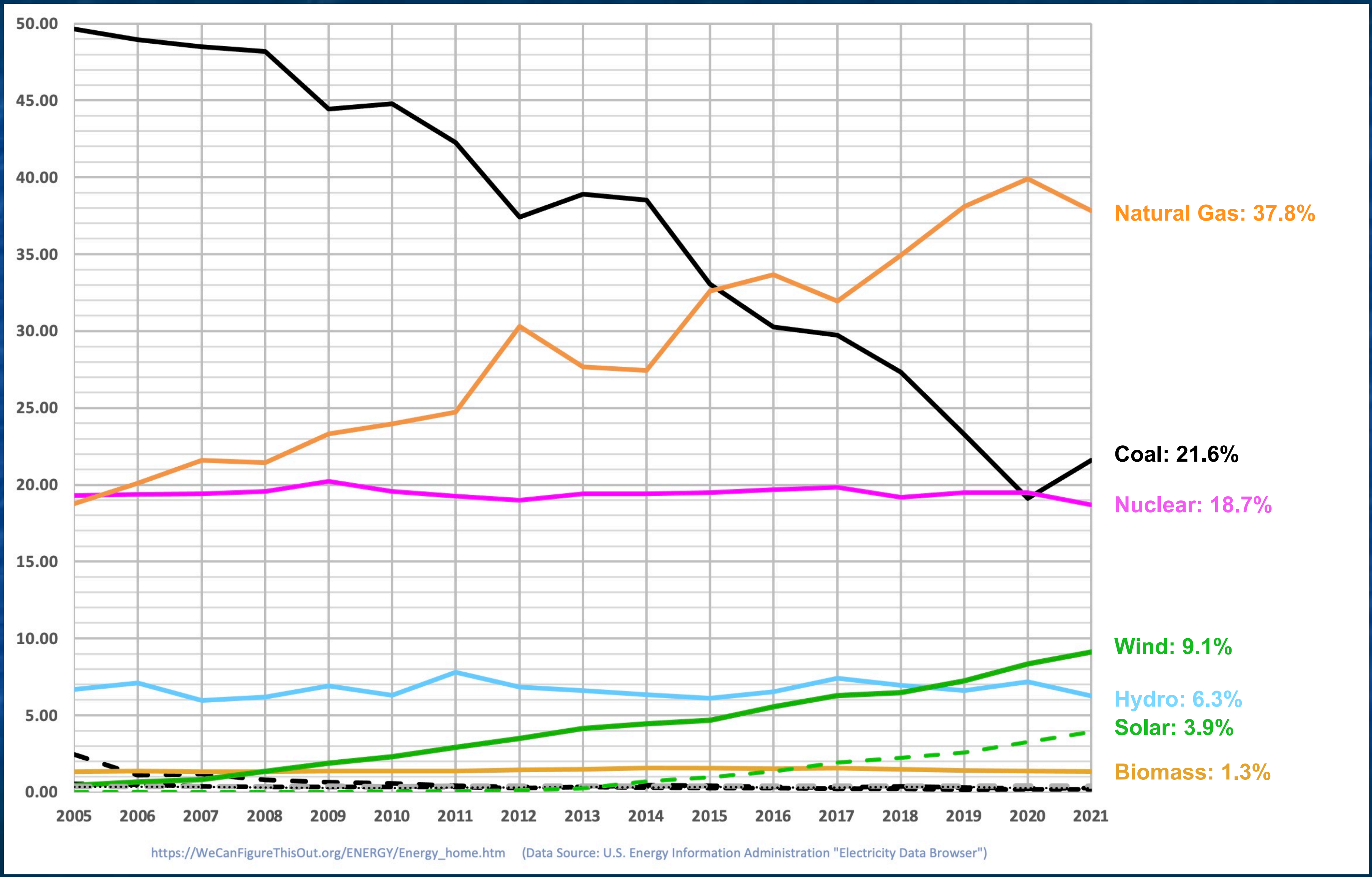
(My complete speadsheet is available on this webnote set's Resources Webpage)

From which I plot: ***Percentage of U.S. Electrical Energy vs. Energy Source***



(Line colors chosen to resemble later Washington Post figures)

Or calling out latest reported percentages for the largest sources:



U.S. Electricity IS getting cleaner - but nowhere near as fast as often reported

The best news is that use of **coal** (our dirtiest fuel), has declined by ~ 60%

But ~ two thirds of that decline was offset by growing use of **natural gas (NG)**

which, contrary to massive disinformation campaigns, IS FAR FROM GREEN

Compared to coal power power plants, NG power plant GHG emissions are only

~20% lower (for "OCGT" NG plants) to ~ 40% lower (for "CCGT" NG plants) [1]

Further, while 39% of our electricity now comes from non-GHG emitting power plants

two thirds of that non-GHG electricity is from nuclear & hydroelectric power plants

The former being completely unacceptable to many people

The latter being increasingly threatened by climate change droughts

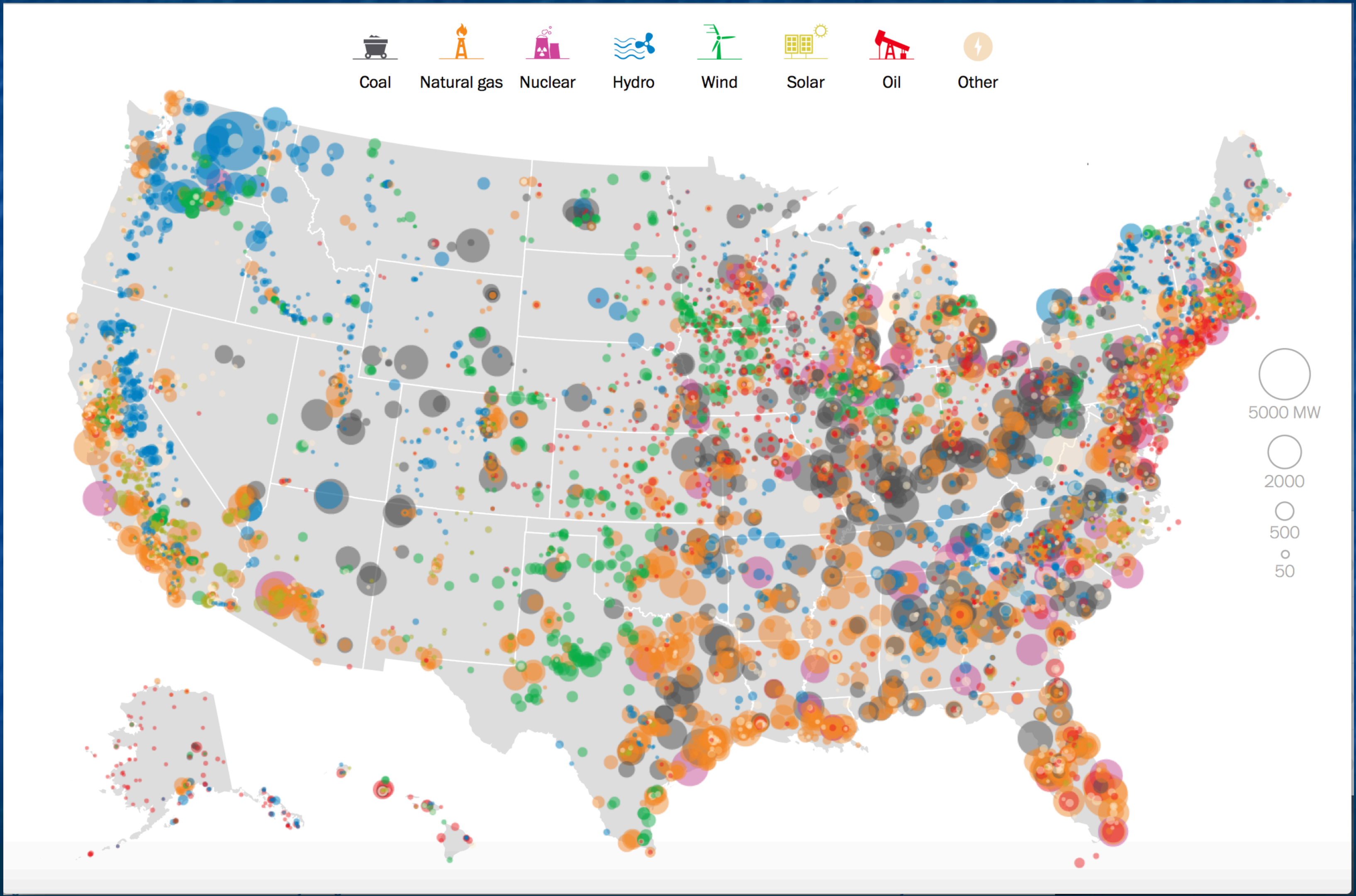
Leaving the only unambiguous (but far less impressive) clean electricity gain as being

15 year growth of **wind + solar electricity** from near 0% to 13% (9.1 + 3.9%)

1) As fully explained in my noteset: FOSSIL FUELS (pptx / pdf / key)

How do the Sources of U.S. Electricity vary across the U.S.?

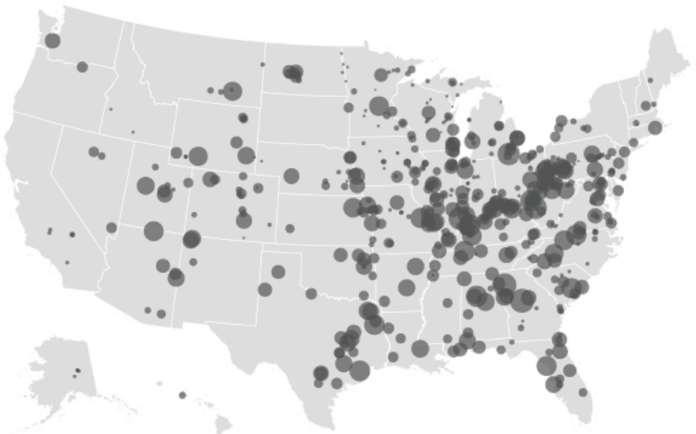
The Washington Post's 2015 Geographic Breakdown of U.S. Electricity: [1]



1) http://www.washingtonpost.com/graphics/national/power-plants/

Coal (34% of U.S. power) and Natural Gas (30%):

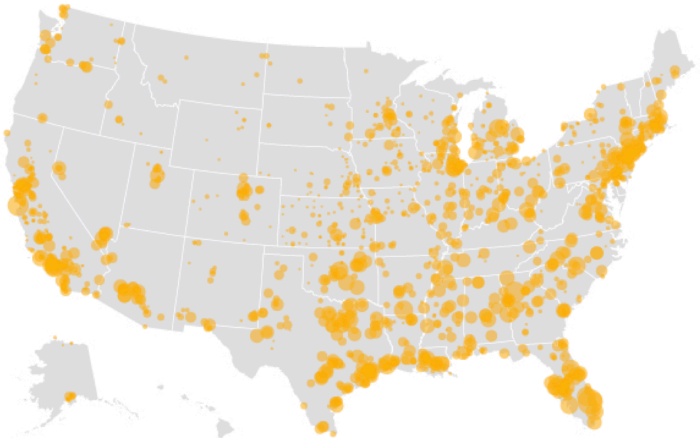
Coal-powered electric plants



There are 511 coal-powered electric plants in the U.S. They have generated 34 percent of the nation's electricity this year.

The leading fuel for electricity generation in the country, coal is most popular in the Midwest, Appalachia and the East Coast, but is also the primary source in Wyoming, Utah, Montana and Arizona. It generated the vast majority of the nation's electricity in the late 1980s but now creates one-third with natural gas gaining steadily. Coal is the chief source of electricity in 22 states and creates a majority of the electrical power in 14 states.

Natural gas

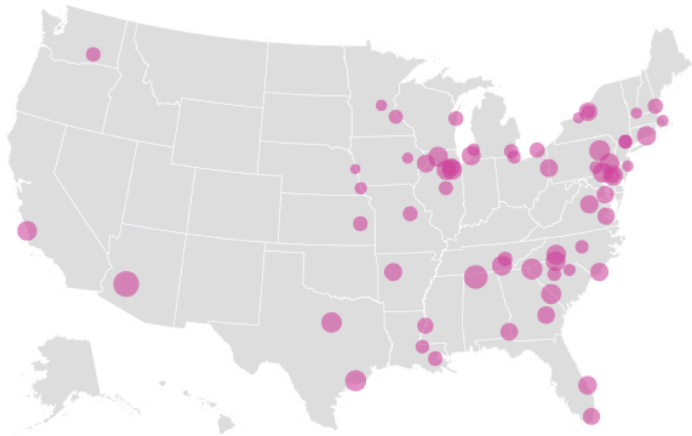


There are 1,740 natural gas-powered electric plants in the U.S. They have generated 30 percent of the nation's electricity this year.

Advances and expansion of fracking in the past decade have unlocked vast supplies of natural gas from shale deposits all over the country. Natural gas is the predominant source of power in 15 states including all of the Gulf of Mexico states, Virginia, Georgia, New York, Massachusetts, Nevada and California.

Nuclear (20%) and Hydroelectric (7%):

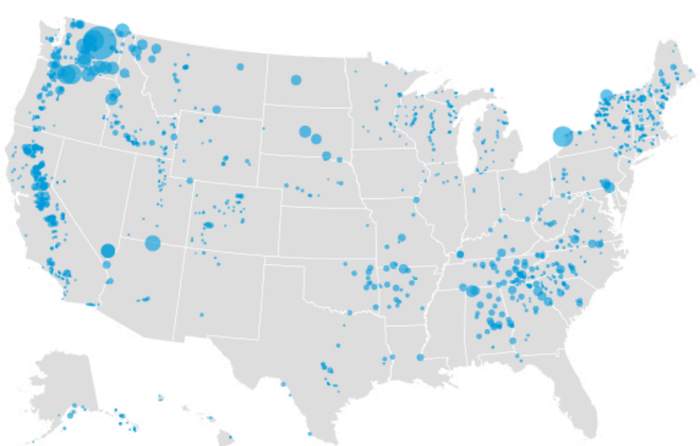
Nuclear



There are 99 reactors at 63 nuclear electric plants in the U.S. They have generated 20 percent of the nation's electricity this year.

Five new nuclear plants are under construction following decades of pause after the initial push in the 1970s and 1980s driven by the first oil shock. Only South Carolina, Illinois, Pennsylvania, Connecticut and New Hampshire get a plurality of their power from nuclear. Twenty states have no nuclear electricity generation at all.

Hydro

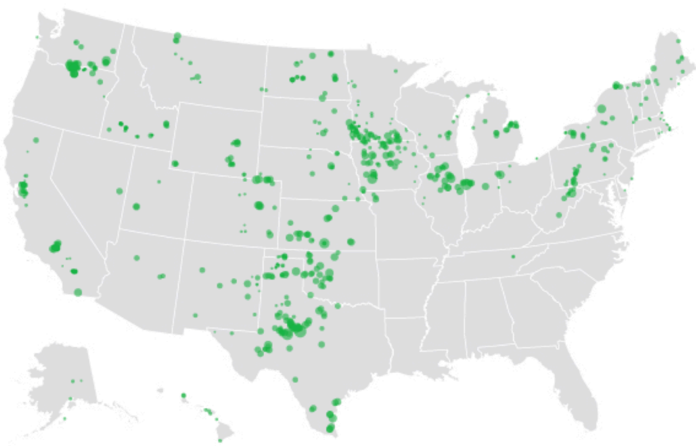


There are 1,436 hydroelectric plants in the U.S. They have generated 7 percent of the nation's electricity this year.

Washington, Oregon and Idaho lead the nation in power from hydroelectric plants. It's a feast-or-famine source, providing 48 percent or more of the power in five states, but less than 10 percent of the electricity in 40 states. Government-run plants generate most of the power.

Wind (5%) and Solar (1%):

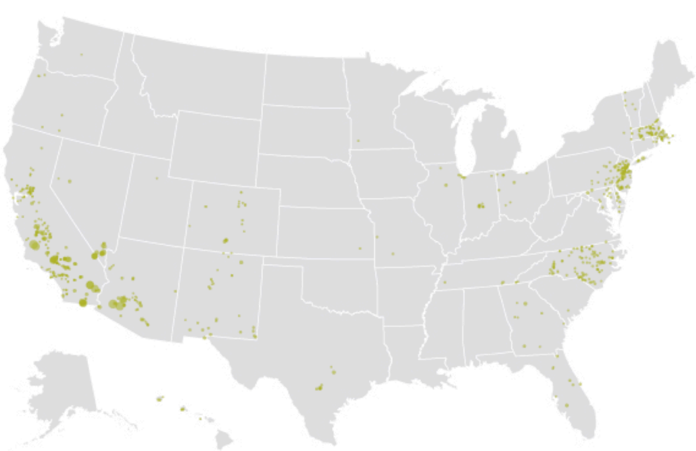
Wind



There are 843 wind-powered electric plants in the U.S. They have generated 5 percent of the nation's electricity this year.

Wind is the fastest growing source, finding a home in the Great Plains where wind blows reliably across wide open spaces. Iowa and South Dakota get one third of their power from wind, followed by Kansas, Vermont and North Dakota.

Solar



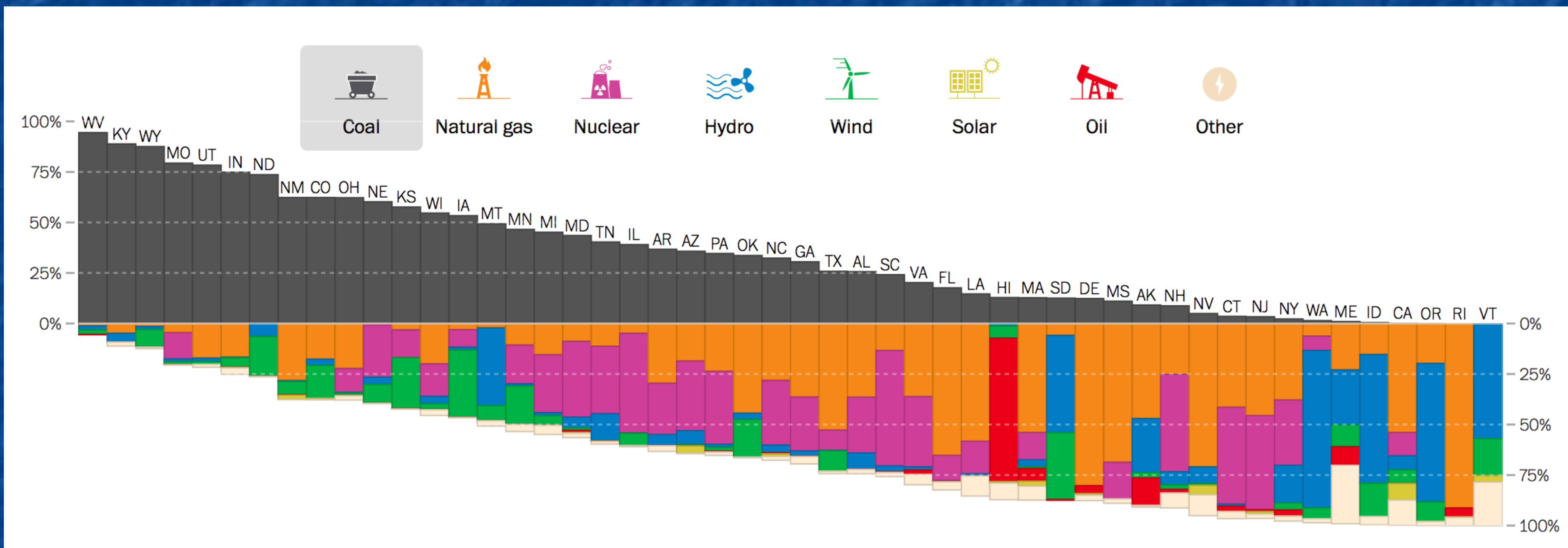
There are 772 solar-powered electric plants in the U.S. They have generated 1 percent of the nation's electricity this year.

Sun power is predominantly in the Southwest where the sun shines the most. Thirty-nine states have no solar generating plants. California gets 8 percent of its electricity from solar and Nevada gets 5 percent, followed by Vermont and Arizona with 4 percent each.

Is there truth to some state claims of being exceptionally green?

This 2015 Washington Post figure certainly pegs **West Virginia** as the least green

But the greenest, **Vermont**, succeeds only by importing **Quebec's** hydropower



West Virginia

Utah

Ohio

Idaho

Maryland

Pennsylvania

Texas

Virginia

Massachusetts

New Hampshire

Washington

California

Vermont

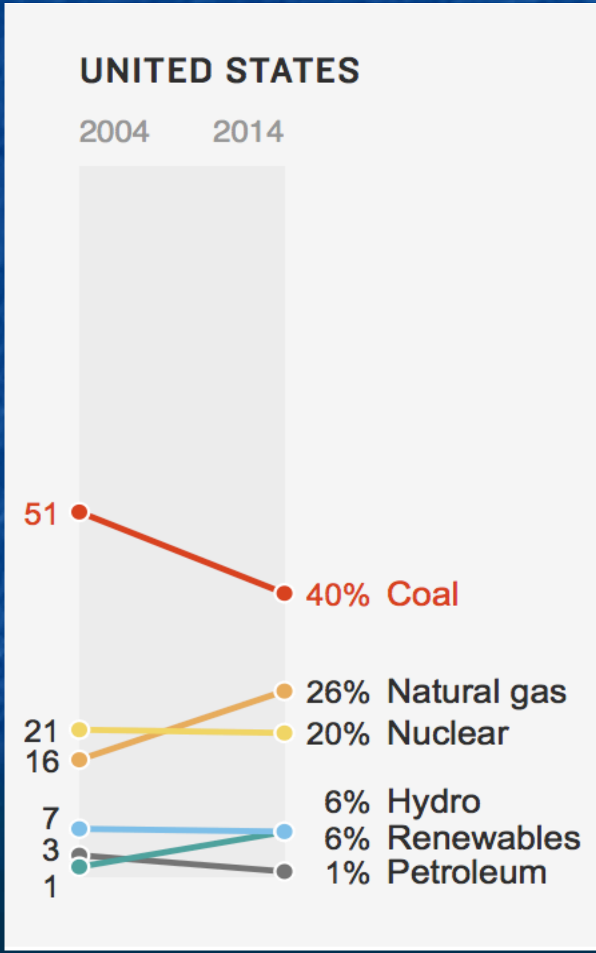
Source: http://www.washingtonpost.com/graphics/national/power-plants/

Ten Year Trends in State-by-State Sources of Electrical Energy:

Drawn from this National Public Radio article:

"Coal, Gas, Nuclear, Hydro? How Your State Generates Power" [1]

The 2004-2014 trend for total U.S. electrical power:



Then, on the five slides that follow, the trends for

Alabama through Georgia

Hawaii through Maryland

Massachusetts through New Jersey

New Mexico through North Carolina

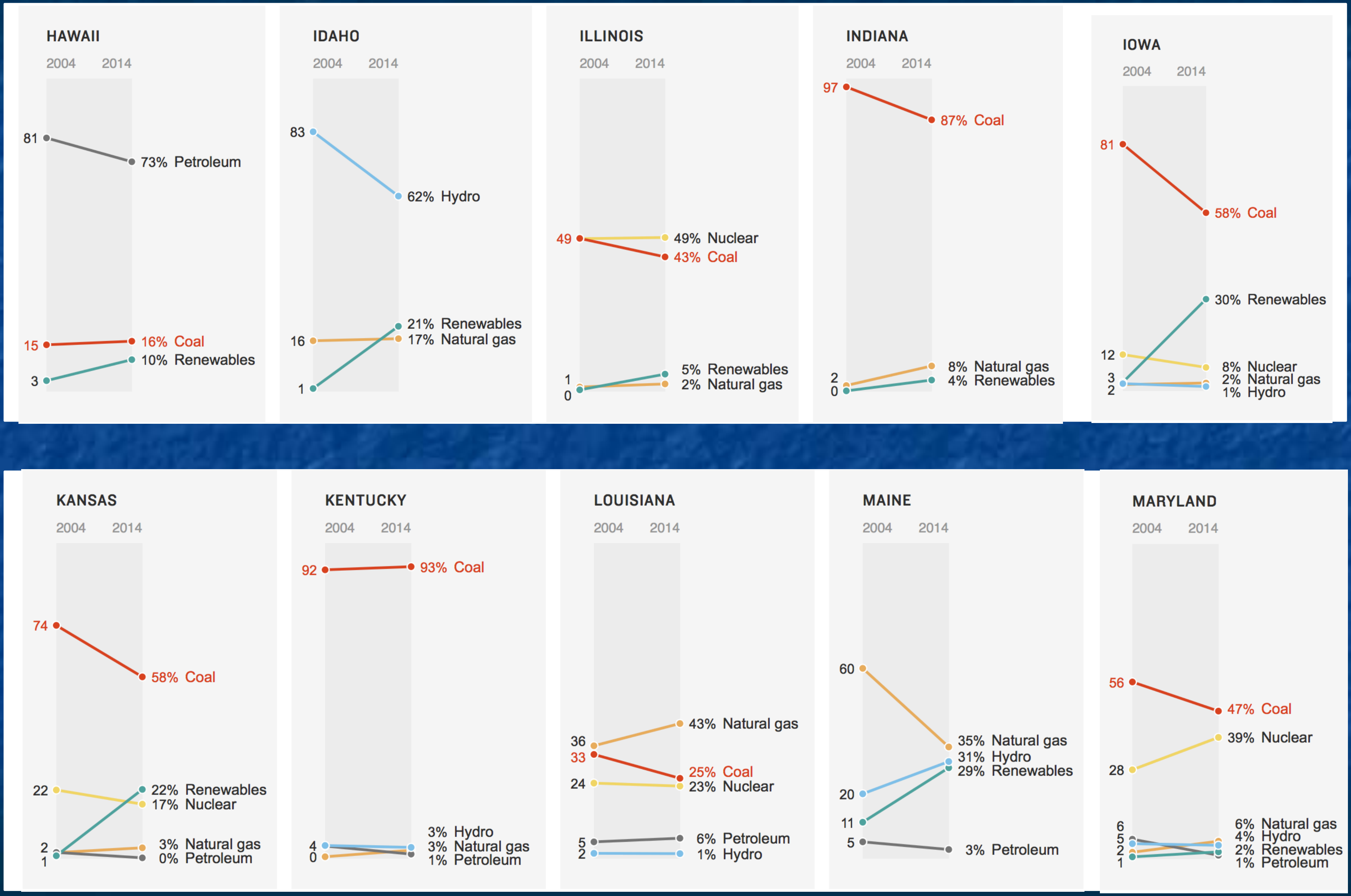
South Carolina through Wyoming

1) http://www.npr.org/2015/09/10/319535020/coal-gas-nuclear-hydro-how-your-state-generates-power?utm_source=facebook.com&utm_medium=social&utm_campaign=npr&utm_term=nprnews&utm_content=20150910

Alabama through Georgia:

http://www.npr.org/2015/09/10/319535020/coal-gas-nuclear-hydro-how-your-state-generates-power?utm_source=facebook.com&utm_medium=social&utm_campaign=npr&utm_term=nprnews&utm_content=20150910

Hawaii through Maryland:



http://www.npr.org/2015/09/10/319535020/coal-gas-nuclear-hydro-how-your-state-generates-power?utm_source=facebook.com&utm_medium=social&utm_campaign=npr&utm_term=nprnews&utm_content=20150910

Massachusetts through New Jersey:

http://www.npr.org/2015/09/10/319535020/coal-gas-nuclear-hydro-how-your-state-generates-power?utm_source=facebook.com&utm_medium=social&utm_campaign=npr&utm_term=nprnews&utm_content=20150910

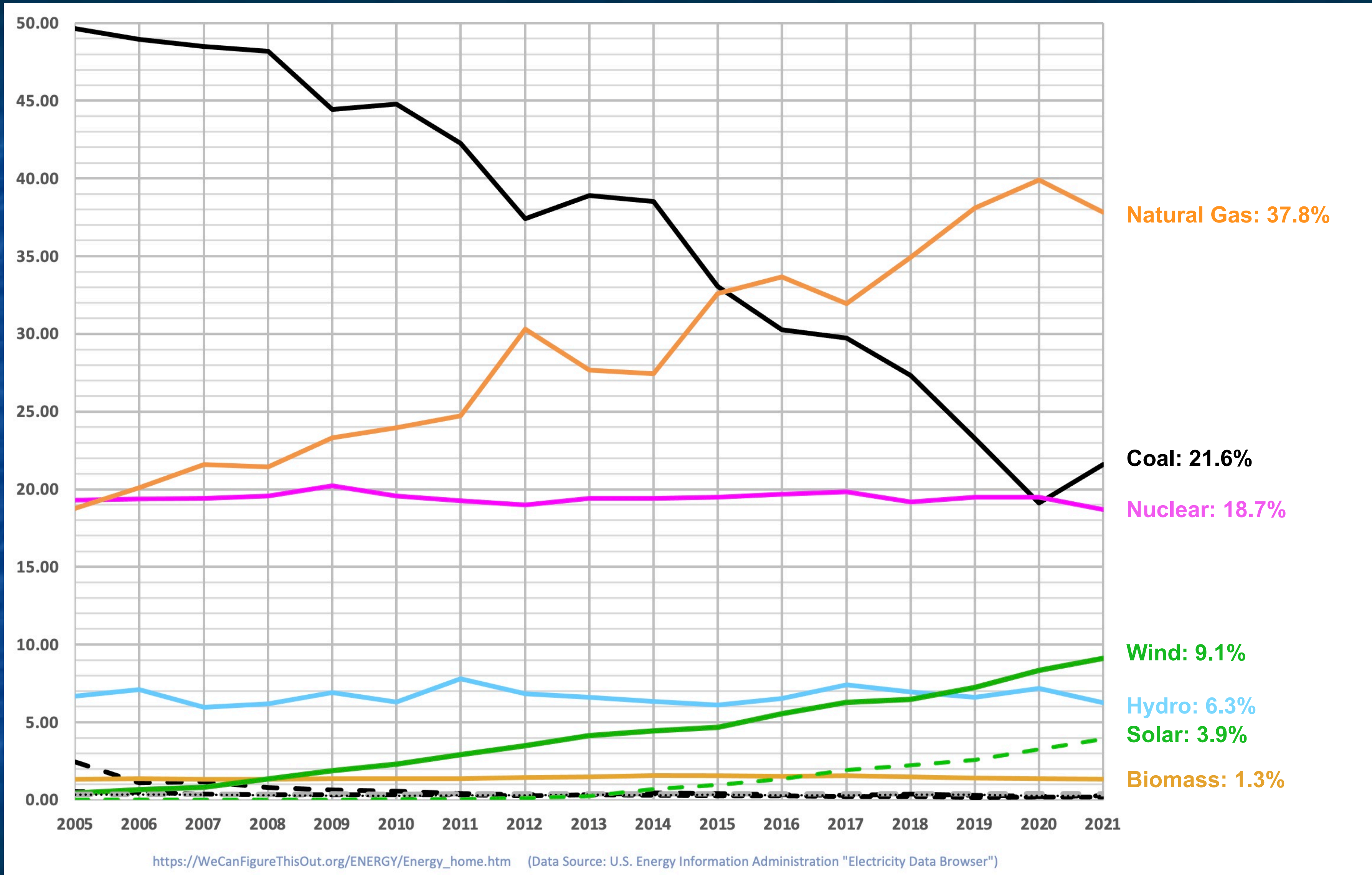
New Mexico through South Carolina:

http://www.npr.org/2015/09/10/319535020/coal-gas-nuclear-hydro-how-your-state-generates-power?utm_source=facebook.com&utm_medium=social&utm_campaign=npr&utm_term=nprnews&utm_content=20150910

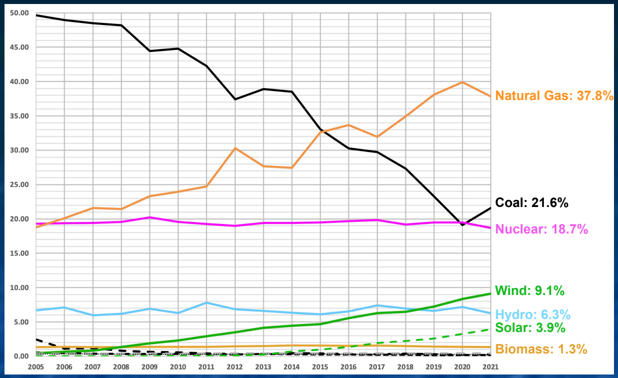
South Carolina through Wyoming

http://www.npr.org/2015/09/10/319535020/coal-gas-nuclear-hydro-how-your-state-generates-power?utm_source=facebook.com&utm_medium=social&utm_campaign=npr&utm_term=nprnews&utm_content=20150910

How could we make U.S. Electrical Energy more sustainable?



Alternate scenarios:



Analyzing the most recent data:

Coal + Natural Gas = (37.8 + 21.6 = 59.4)% of 4.1 QW-h = 2.5 QW-h

Coal + Natural Gas + Nuclear = (37.8 + 21.6 + 18.7 = 78.1)% of 4.1 QW-h = 3.2 QW-h

Nuc + Hydro + Wind + Solar + Bio = (18.7 + 6.3 + 9.1 + 3.9 + 1.3 = 39.3)% of 4.1 QW-h = 1.6 QW-h

Hydro + Wind + Solar + Bio = (6.3 + 9.1 + 3.9 + 1.3 = 20.6)% of 4.1 QW-h = 0.84 QW-h

Wind + Solar + Bio = (9.1 + 3.9 + 1.3 = 14.3)% of 4.1 QW-h = 0.59 QW-h

Changing to this:	**Would require this growth:**	**of these sources:**
0% (Coal + NG)	(59.4 + 39.3) / 39.3 => **2.5X**	Nuc + Wind + Hydro + Solar + Bio
0% (Coal + NG) + fixed (Nuclear)	(59.4 + 20.6) / 20.6 => **3.9X**	Hydro + Wind + Solar + Bio
0% (Coal + NG) + fixed (Nuc + Hydro)	(59.4 + 14.3) / 14.3 = **5.2X**	Wind + Solar + Bio
0% (Coal + NG + Nuclear)	(78.1 + 14.3) / 14.3 => **6.5X**	Wind + Solar + Bio

First scenario includes 2.5X growth of both Nuclear (intensely controversial) & Hydro (impossible?)

Second scenario includes 3.9X growth of Hydro (impossible?)

*Which is why later notesets **thoroughly analyze** both Nuclear & Hydro Power!*

Having examined ***U.S. Electrical Energy Production & Consumption***

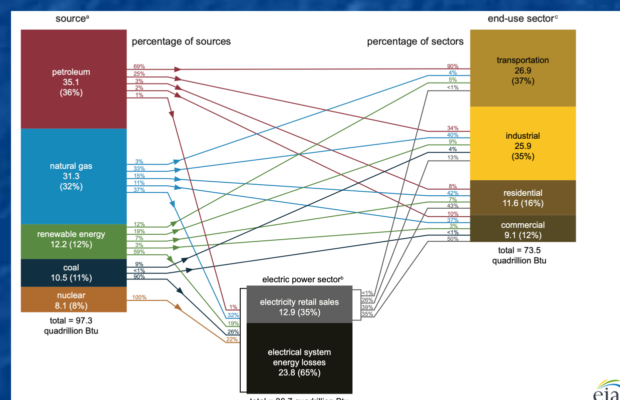
Let's now turn to ***U.S. TOTAL Energy Production & Consumption***

Addressing questions such as:

What is the **size** of our non-electrical energy use?

How does that break down into climate-sustainable vs. non-sustainable parts?

How might non-sustainable parts be most expeditiously reduced or eliminated?



"U.S. Energy Facts Explained"

https://www.eia.gov/energyexplained/us-energy-facts/

Taking us back to that EIA figure which, in addition to its obviously complexity,

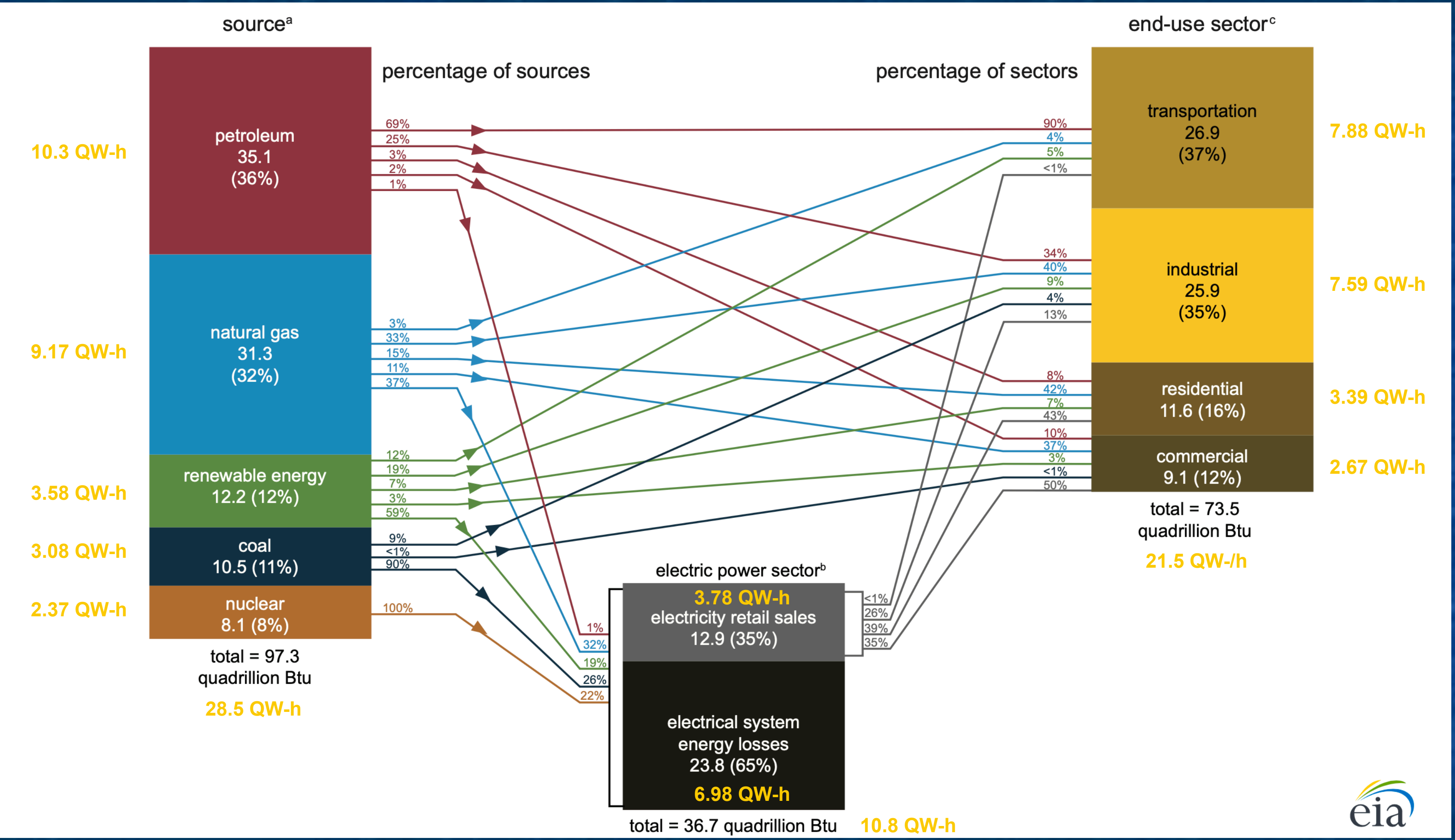
uses only an obscure, pre 20th century, UK based unit

(reputedly derived from the energy released by 1 burning wooden match):

The British Thermal Unit (BTU)

Here brought into the modern era by my addition of metric unit equivalents:

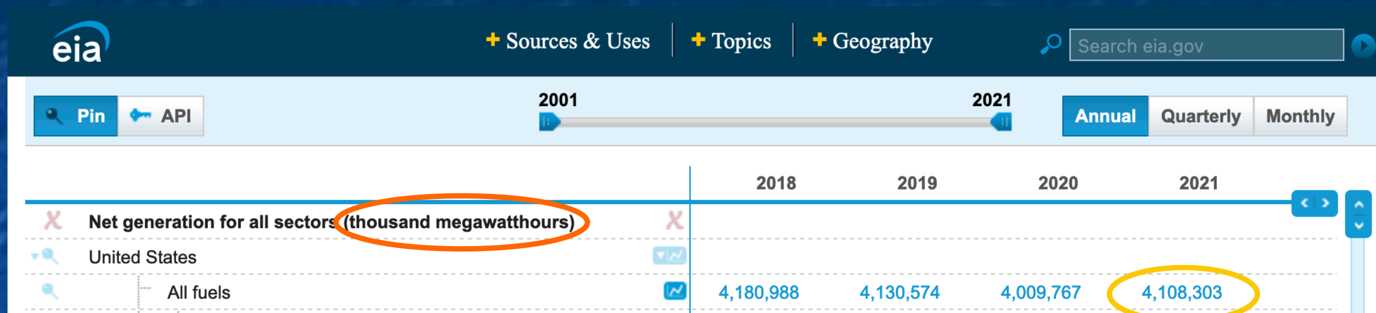
Using the conversion: [1-5] 1 BTU = 0.2931 W-h => 1 quadrillion BTU = 0.2931 QW-h



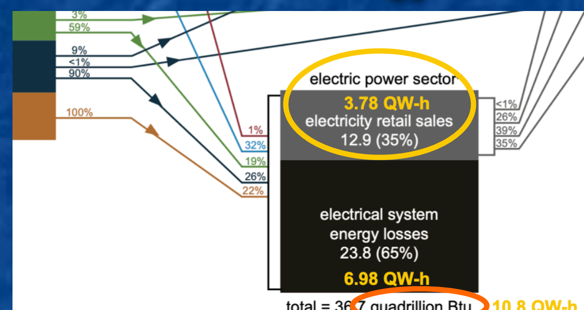
1) https://en.wikipedia.org/wiki/British_thermal_unit
2) https://www.rapidtables.com/convert/power/BTU_to_Watt.html
3) https://www.freeconvert.com/unit/btu-to-watt-hours
4) https://www.unitconverters.net/power/btu-it-hour-to-watt.htm
5) https://learnmetrics.com/convert-btu-to-watt/

Digression: NASA got clobbered mixing unit systems [1] - the EIA "missed that memo"

From the 2021 EIA **Electricity Data Browser** used early in this note set: [2]



From the immediately preceding 2021 EIA U.S. **Energy Facts Explained**: [3]



4.108 is significantly different than 3.78

Raising some doubts about EIA data accuracy & internal data sharing [4]

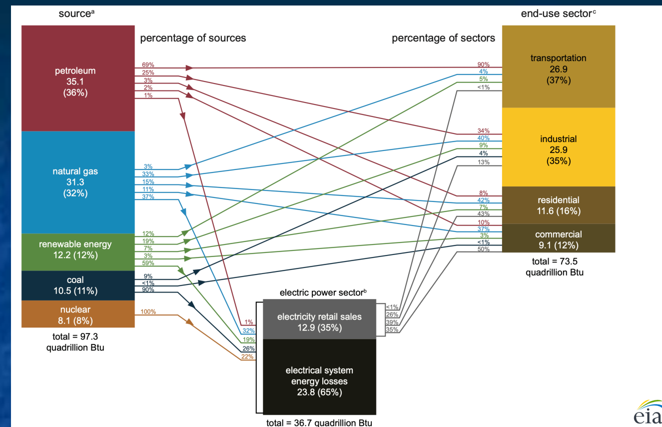
*1) **Mars Probe Lost Due to Simple Math Error** - Los Angelas Times (1 October 1999):
https://www.latimes.com/archives/la-xpm-1999-oct-01-mn-17288-story.html*

2) https://www.eia.gov/electricity/data/browser/

3) https://www.eia.gov/energyexplained/us-energy-facts/

4) Confirming the advisability of always "figuring it out" for yourself (or at least double checking the "experts")

Returning to the whole figure: Why must it be so complex?



THE MAIN REASON: It tracks two very differently behaving types of energy:

1) Electrical Energy: Which can be transported easily and efficiently,

and at its final point-of-use converts its energy with very high efficiency:

e.g., electric motors convert electrical to kinetic energy at near 100% efficiency

or electric heaters convert electrical to thermal energy at 100% efficiency

2) Hydrocarbon Chemical Combustion Heat Energy: Which is transported in myriad ways,

and at its point-of-use converts its heat energy in many different low efficiency ways, e.g.:

Fossil-fuel power plants convert heat to output electrical energy at ~ 33% efficiency [1]

Fossil-fuel cars & trucks convert heat to vehicle kinetic energy at ~ 20% efficiency [2]

*1) See noteset: Generic Power Plant & Grid (pptx / pdf / key)   2) See noteset: **Greener Cars and Trucks** (pptx / pdf / key)*

Result: Electrical Energy tracking is easy / Combustion Heat Energy tracking is hard:

Because some **applications** use combustion heat energy directly (e.g., in furnaces)

While other **applications** use electricity generated by conversion from combustion heat energy,

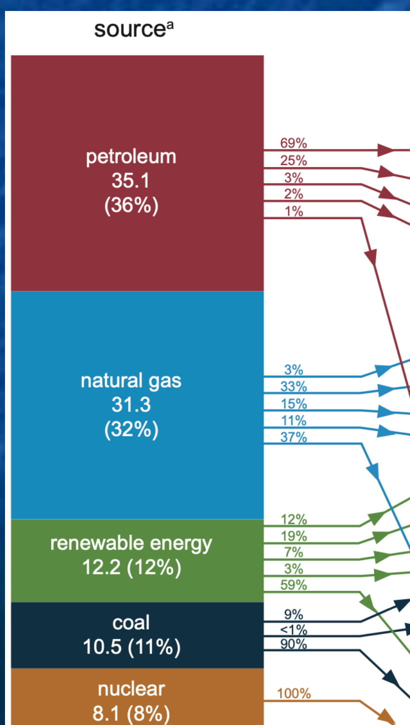
done at some intermediate point (often, but not always, in a "Power Sector" power plant)

With that conversion efficiency depending strongly upon the exact technology used,

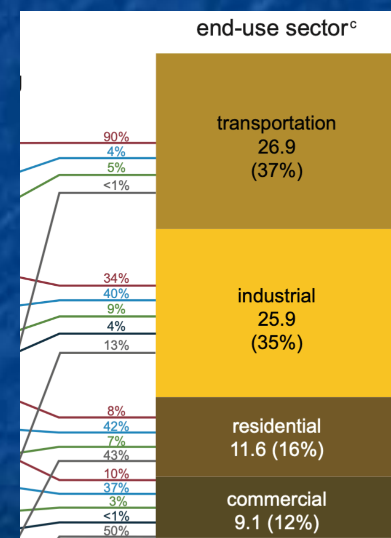
AND that conversion efficiency falling well below 100% (i.e., with **heavy** energy wastage)

Leading to these arrow-connected divisions

Energy Sources

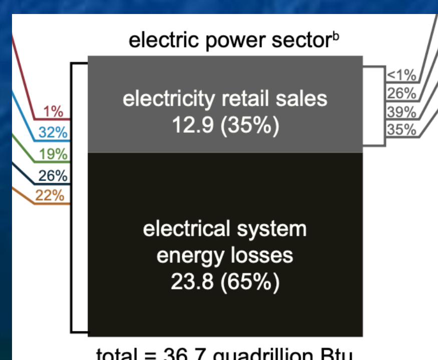


End Use Applications



"Electric Power Sector"

(?????)



*What exactly does the EIA **INCLUDE** within its center "**Electric Power Sector**"?*

The Electricity Grid? YES & NO: It's the far right electricity output arrows

Power plants burning fossil-fuels to generate electricity? YES

Making descending red, blue, black input arrows chemical heat energy

Power plants fissioning uranium to generate electricity? NO

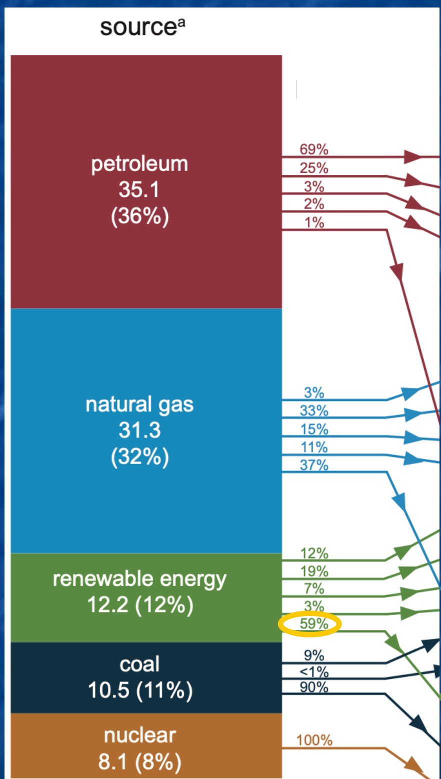
Because nuclear energy is sourced & converted in the **same** plant (vs. hydrocarbons sourced but then converted in **separate** plants)

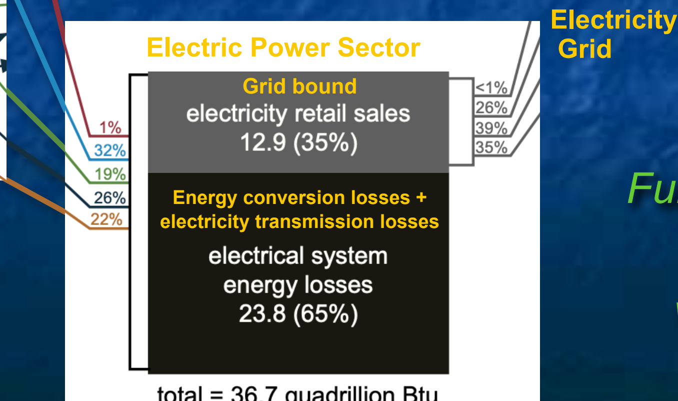
Making nuclear's brownish descending input arrow electrical energy

But making the descending green renewable arrow very confusing because:

Wind, solar & hydro plants directly output electrical energy

While biomass/biofuel plants output chemical energy only converted to electricity by entirely separate plants in the"electric power sector"





Further, if only 59% of renewable energy goes to the Electric Power Sector where does the remaining 41% go?

Its destination is revealed only by careful study of a 265-page supporting EIA document [1]

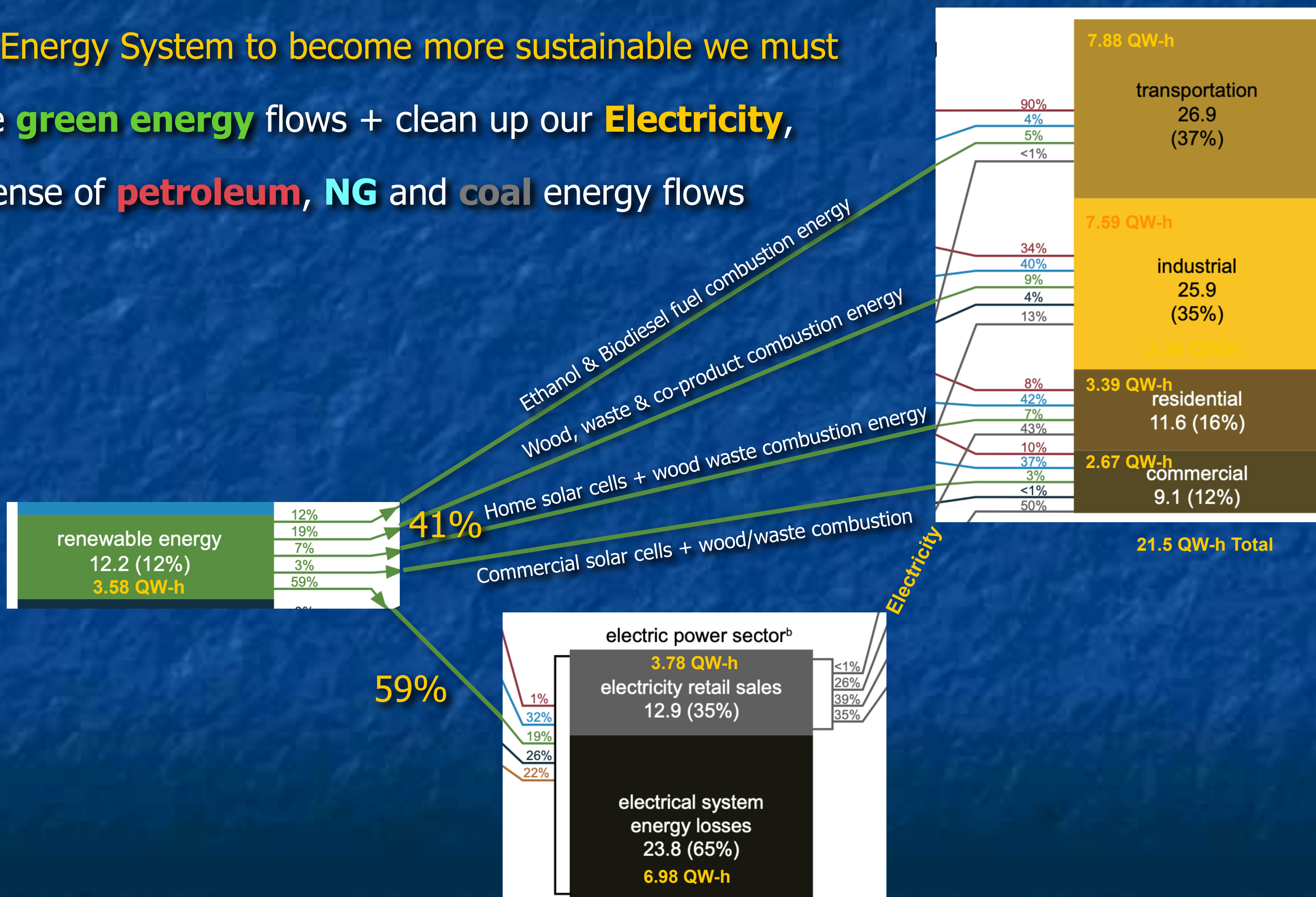
Drawing from that study's **eleven** chapters and **five** appendices,

the complete division of 2021 U.S. renewable energy is identified below

For our TOTAL Energy System to become more sustainable we must

grow those **green energy** flows + clean up our **Electricity**,

at the expense of **petroleum**, **NG** and **coal** energy flows

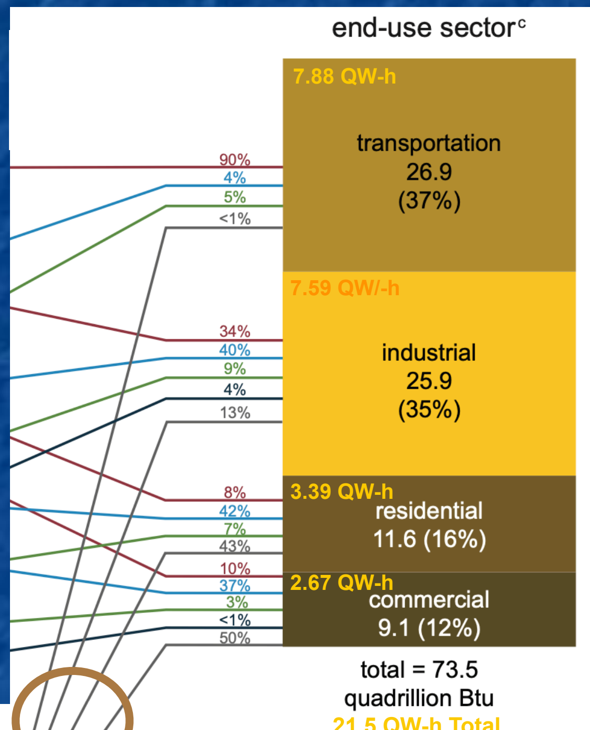


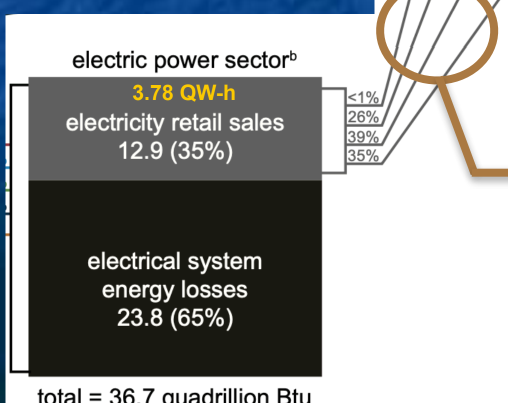
1) ***Monthly Energy Review, April 2022***: *https://www.eia.gov/totalenergy/data/monthly/archive/00352204.pdf*

*How much of **Total U.S. Energy** is tied to **Greenhouse Gas (GHG)** emissions?*

2021 Electricity is 59.4% tied to GHG emissions: 3.78 QW-h = 2.25 QW-h + 1.53 QW-h

End-Use Sector Electricity inputs must similarly divided 59.4% / 40.6%, ultimately yielding:





Total tied to **GHGs:**	Total not tied to **GHGs:**	
~ **7.4 QW-h**	~ **0.4 QW-h** [1]	
~ **6.5 QW-h**	~ **1.1 QW-h** [2]	
~ **2.6 QW-h**	~ **0.8 QW-h** [3]	
~ **2.1 QW-h**	~ **0.6 QW-h** [4]	
~ **18.6 QW-h**	~ **2.9. QW-h**	**Total**

Incoming Electrical Energy alone = 3.78 QW-h => 2.25 QW-h + 1.53 QW-h

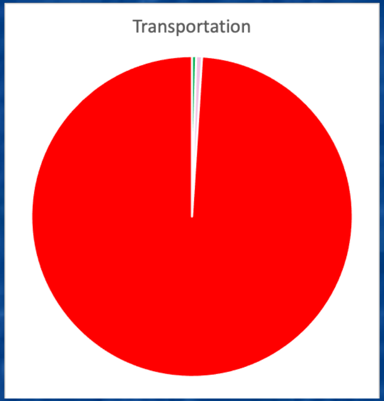
1) (90 + 4 + .594 x 0)% vs (5 + .406 x 0)% => 94% vs 5%
2) (34 + 40 + 4 + .594 x 13)% vs (9 + .406 x 13)% => 85.7% vs 14.3%
3) (8 + 42 + .594 x 43)% vs (7 + .406 x 43)% => 75.5% vs 24.4%
4) (10 + 37 + 0 + .594 x 50) vs (3 + .406 x 50) => 76.7% vs 23.3%

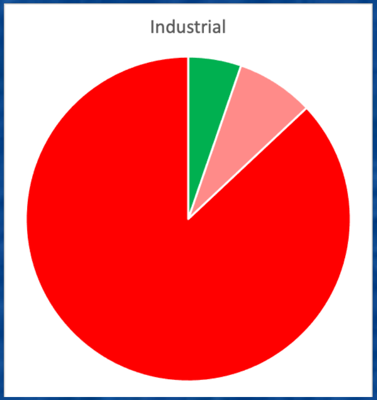
Or displaying those 2021 U.S. energy data in Pie Charts:

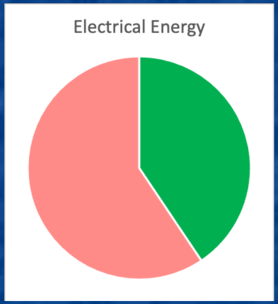
With pie chart areas scaled to be proportional to the energies they represent:

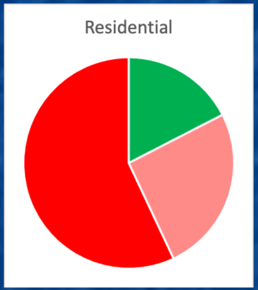
Electrical Energy Generation:

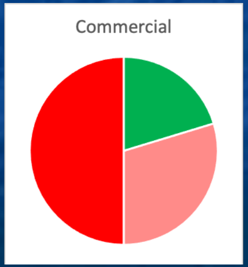
Energy Consumption (including green / red electrical + other red energy sources):











Link to the Excel worksheet in which I generated those pie charts:

https://wecanfigurethisout.org/ENERGY/Web_notes/Introduction/US_Energy_Production_and_Consumption_Supporting_Files/US Energy Pie Charts for 2021 worksheet.xlsx

Key observations regarding ***U.S. TOTAL Energy Consumption***

Total Energy use is over **5X** larger than **Electrical Energy** use alone (21.5 / 3.78)

Total Energy is also now 86.5% GHG emission based (18.6 / 21.5) versus its Electrical Energy component which is now 59.4% GHG emission based (2.25 / 3.78)

Earlier we calculated that eliminating 2.25 QW-h of GHG-linked **Electrical Energy** required:

2.5X growth of ALL non-GHG Electricity sources or

even greater growth of deepest-green Wind + Solar + Bio

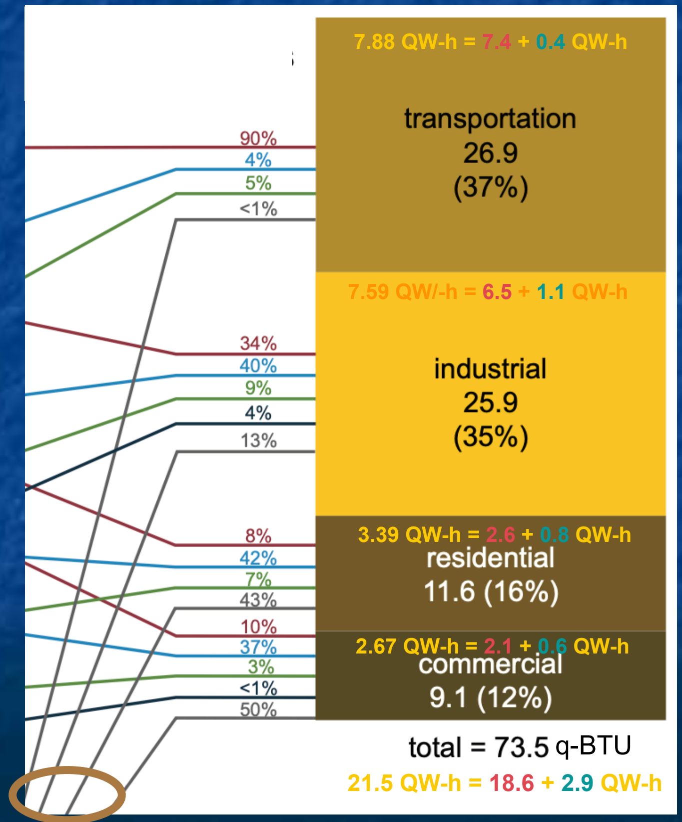
But **Total Energy**'s GHG-linked input is instead 18.6 QW-h which even excluding dirty electricity's 2.25 QW-h leaves 16.35 QW-h

Some suggest a strategy of just growing clean electricity to the point that it could replace not only dirty electricity's 2.25 QW-h, but also total energy's remaining dirty 16.35 QW-h [1]

But that would seem to require net clean electricity growth of:

(18.6 / 1.53) = **12X**

Which I don't see that happening in a climate-acceptable time frame



3.78 QW-h = 2.25 + 1.53 QW-h incoming Electricity

1) Forget 'Reduce, Reuse, Recycle' - The Atlantic, 25 Feb 2022:
https://www.theatlantic.com/newsletters/archive/2022/02/saul-griffith-electrify-everything-solution-save-humanity/622911/

But improvement would be easier than those numbers suggest because . . .

Many tasks require dramatically more Fossil-fuel Energy than Electrical Energy

For such tasks, a conversion eliminating 1 unit of fossil fuel

would require much less than 1 unit of replacement electrical energy

Meaning not all of that dirty 18.6 QW-h total energy need be replaced 1:1 with clean electricity

Three particularly effective AND timely conversions might be based on the following:

- Cars & trucks deliver fossil fuel energy to vehicle motion energy at efficiencies of 13 - 25%

  vs. electric car energy conversion efficiencies of 70 - 75% [1]

- Furnaces transfer fossil-fuel energy to building air at efficiencies of 80 - 95%

  vs. electric heat pump efficiencies of 300 to 400% [2]

  Which is achieved by **NOT directly converting** electric energy into heat

  but by instead using it to **move** heat from outside air (or water) to inside air

- Water heaters transfer fossil-fuel energy to water at efficiencies of ~ 60%

  vs. electric heat-pump water heaters achieving efficiencies of up to 400% [3]

1) See my noteset: Greener Cars & Truck (pptx / pdf / key)

2) See my noteset: Energy Consumption in Housing (pptx / pdf / key)

3) Based on corrected U.S. Department of Energy document (link)

Using those observations to generate some (admittedly crude) rules:

Regarding Transportation:

1) For electric vehicles replacing fossil-fuel **cars & trucks**:

1 unit of Electrical Energy could replace ~ 4 units of Fossil-fuel Energy

Regarding Residences:

2) For electric heat pumps replacing fossil-fuel **air ventilation furnaces**:

1 unit of Electrical Energy could replace ~ 3.5 units of Fossil-fuel Energy

This rule applies ONLY to air ventilation furnaces because electric heat pumps cannot effectively heat other things to well above room temperature

3) For electric heat pump water heaters replacing fossil-fuel **water heaters**:

1 unit of Electrical Energy could replace ~ 5 units of Fossil-fuel Energy

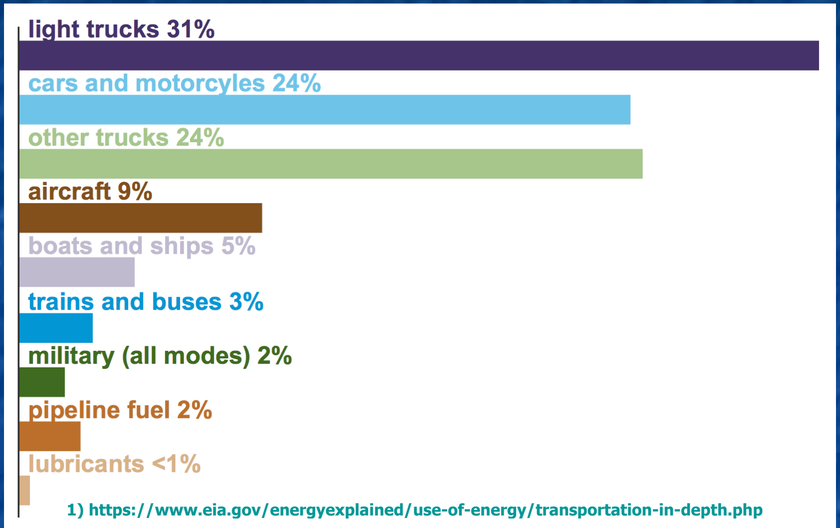
NEXT STEPS: Figuring out WHERE such fossil-fuel replacements are most plausible / likely

Calculating AMOUNT of energy saved via those fossil-fuel to electric conversions

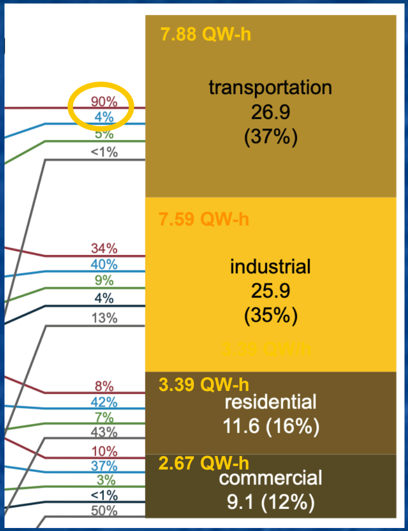
Applying my Transportation Vehicle Rule 1:

From my **Energy in Transportation** (pptx / pdf / key) notes,

2020 EIA breakdown of U.S. Transportation Energy Use: [1]



2021 figure from above:



From the left, most plausible targets for electric vehicles = Light trucks, cars & motorcycles = 55%

Reasons for not including other targets are given in my **Energy in Transportation** noteset

From the right, U.S. Transportation's net fossil-fuel input = (90 + 4)% of 7.88 QW-h = **7.4 QW-h**

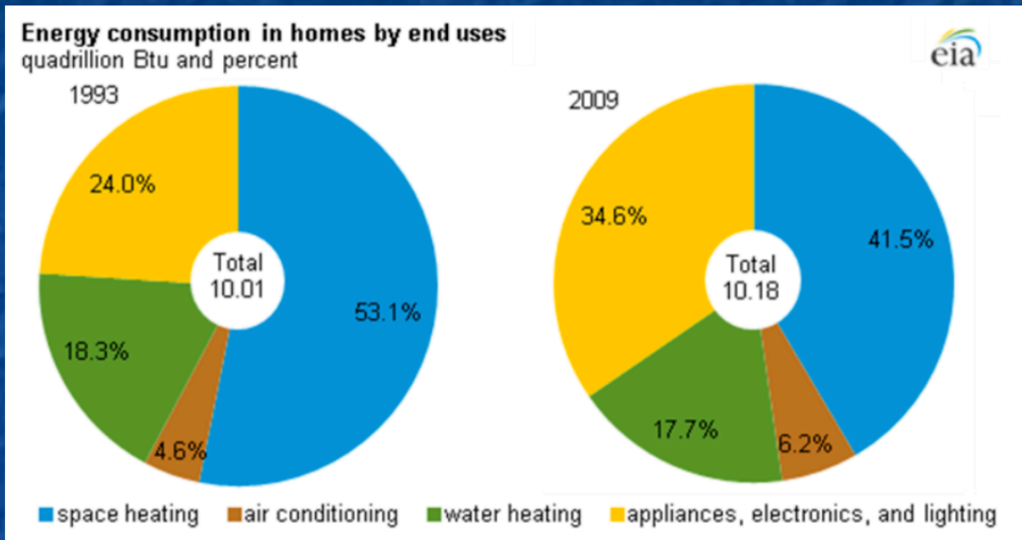
Target vehicle fossil-fuel energy use is now = 55% of 7.4 QW-h = **4.1 QW-h**

Applying rule 1 above, replacement electrical energy use = 4.1 QW-h / 4 = **1.0 QW-h**

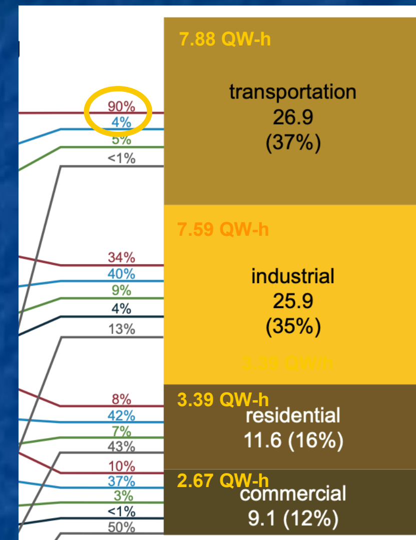
Rule 1 based net change in **U.S. Energy Consumption** = (1.0 - 4.1) QW-h = **- 3.1 QW-h**

Applying my Residential Rules 2 & 3 is considerably more complicated:

From my **Energy in Housing** (pptx / pdf / key) notes, an EIA breakdown of U.S. Home Energy categories: [1]



2021 figure from above:



Having found no more recent breakdown, I'll make do with the above center 2009 percentages:

41.5% air heating / 17.7% water heating / 6.2% air cooling / 34.6% appliances + electronics + lights

Which seems reasonable given small 2009 to 2021 change in Total Home Energy (10.18 vs. 11.6)

Multiplying the 2009 percentages by the 2021 Total Home Energy of **3.39 QW-h** (11.6 q-BTU)

For categories impacted by my rules 2 & 3, I get approximate 2021 energy uses of:

1.4 QW-h air heating / **0.6 QW-h** water heating

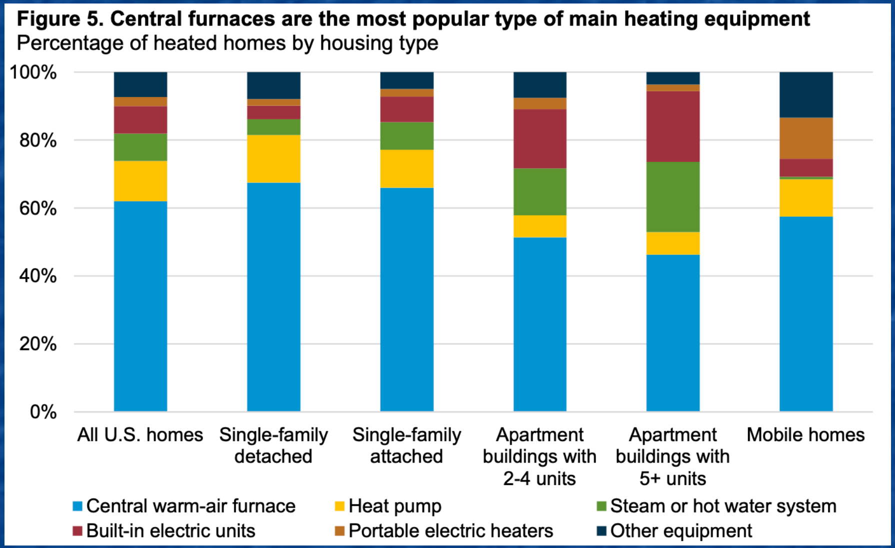
1) DOE (EIA) Energy Data Facts - Residential: https://rpsc.energy.gov/energy-data-facts

But in those two categories, what fractions are ALREADY cleaned up?

The EIA's 2015 Residential Energy Consumption Survey (RECS) [1]

gives some (but, surprisingly, far from all of the useful) answers

Concerning Rule 2's home air heating conversion to heat pumps:



1) https://www.eia.gov/consumption/residential/reports/2015/overview/index.php

~ 70% of U.S. homes are still use fossil-fueled furnace, steam or hot water heating

Multiplying last slide's 1.4 QW-h total heating energy by that percentage => **1.0 QW-h**

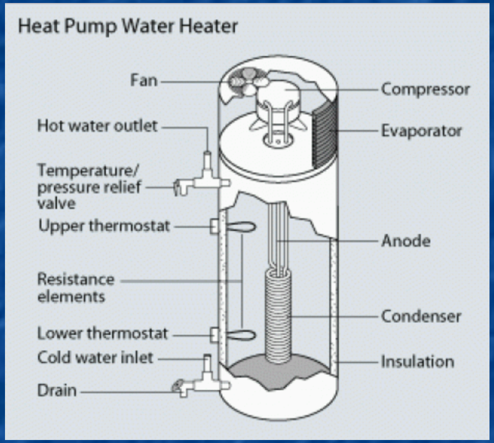
Invoking Rule 2 replacement by electric heat pumps => 1.0 QW-h / 3.5 = **0.3 QW-h**

Rule 2 based net change in **U.S. Energy Consumption** = (0.3 - 1.0) QW-h = **- 0.7 QW-h**

Concerning Rule 3 conversion to Heat Pump Water Heaters:

Beyond the most basic DOE / EIA explanations of how they work, [1]

these are so new that I found no DOE or EIA data on their extent of U.S. use



1) https://www.energy.gov/energysaver/heat-pump-water-heaters

But my decades of home ownership + Habitat for Humanity home construction

+ **This Old House** viewership suggest their deployment is still very small

So I'll assume ~100% of the U.S. **0.6 QW-h** water heating energy is still fossil-fueled

Rule 3 replacement by electric heat-pump water heaters => 0.6 QW-h / 5 = **0.12 QW-h**

Rule 3 based net change in **U.S. Energy Consumption** = (0.12 - 0.6) QW-h = **- 0.5 QW-h**

Summarizing savings due to Rule 1-3 fossil-fuel to electricity conversions:

But first sticking my neck out by inserting one more bold (but plausible) assumption that:

Rule 1-3 Fossil-fuel to Electricity conversions could produce comparable

Commercial sector and **Residential sector changes in** energy use, yielding this:

Sector	**2021 EIA Energies**	**Rule 1-3 changes**	**Revised Energies**
Transportation	7.88 = 7.4 + 0.4 QW-h	- 4.1 + 1.0 QW-h	4.78 = 3.3 + 1.4 QW-h
Residential	3.39 = 2.6 + 0.8 QW-h	- 1.6 + 0.43 QW-h	2.22 = 1.0 + 01.23 QW-h
Commercial	2.67 = 2.1 + 0.6 QW-h	~ (- 1.6 + 0.43) QW-h	~1.53 = ~0.5 + ~1.03 QW-h
Subtotal	13.9 = 12.1 + 1.8 QW-h		~8.53 = ~4.8 + ~3.66 QW-h

In these three (of four) sectors, fossil-fuel to electricity substitutions thus offer:

A **39% decrease in energy use**

AND a shift from (87% GHG-based / 13% green) to (56% GHG based / 46% green)

Based upon adoption of ONLY TWO already well-known & well-developed technologies:

Electric motor driven road vehicles **Heat-pump driven air and water heaters**

Revised estimate of Green-Electricity growth needed to drive out ~ all GHG-based energy

EIA data lead us to this earlier breakdown of 2021 Total U.S. Energy Consumption:

Sector:	**2021 EIA Energies:**
Transportation	7.88 = 7.4 + 0.4 QW-h
Residential	3.39 = 2.6 + 0.8 QW-h
Commercial	2.67 = 2.1 + 0.6 QW-h
Industrial	7.59 = 6.5 + 1.1 QW-h
Total	21.5 = 18.6 + 2.9 QW-h

Revised Subtotal for first three Sectors based upon above Rule 1-3 substitutions:

=> ~8.53 = ~4.8 + ~3.66 QW-h

Yielding revised all-sector Total:

16.1 = 11.3 + 6.59 QW-h

To eliminate revised 11.3 QW-h of GHG energy, today's 1.53 QW-h of green Electricity would have to grow by ~ (11.3 / 1.53) = **7X** (instead of the 12X calculated earlier)

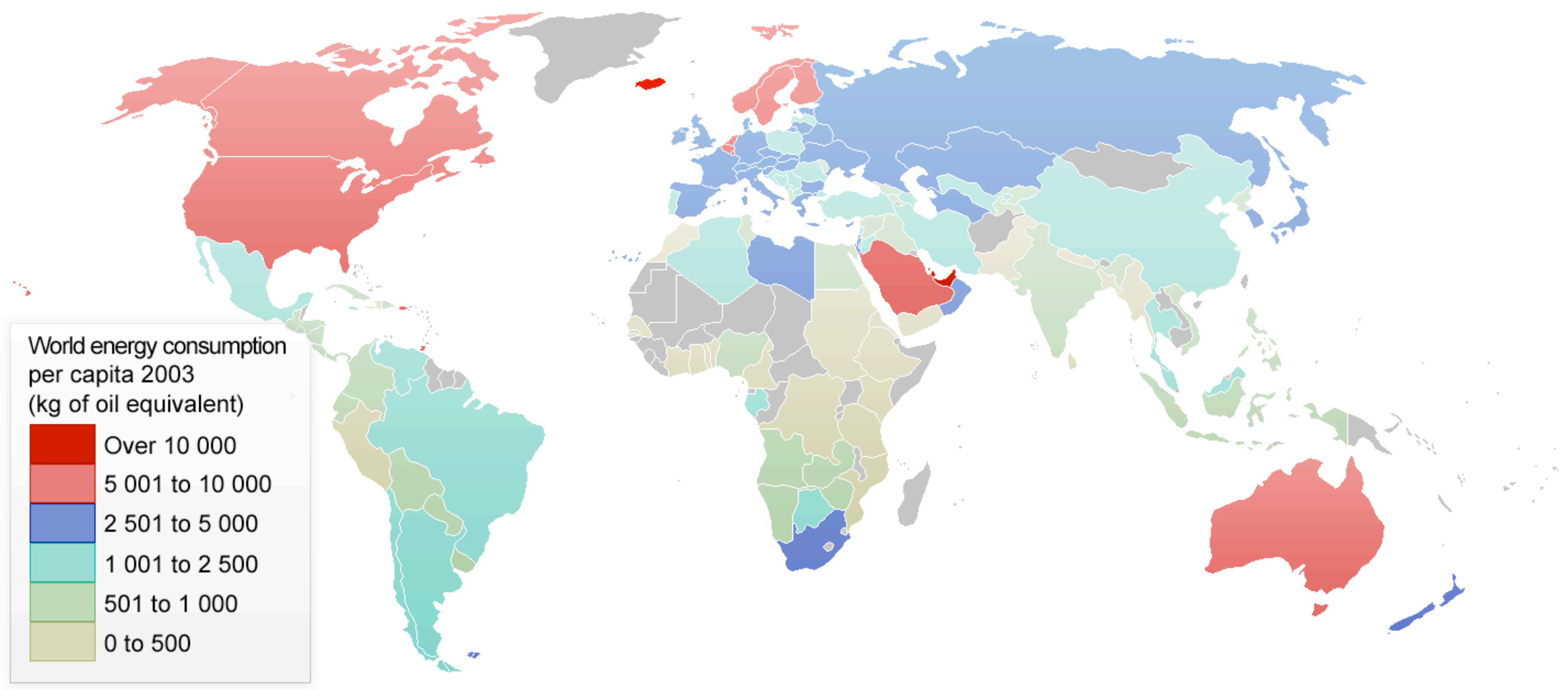
Fossil-fuel to Electricity substitutions in the final **Industrial** sector would further reduce GHG generation, but require greater growth of green electricity

Contradicting media reports that **3X** growth alone might provide a U.S. path to full sustainability [1]

1) Page 5: Forget 'Reduce, Reuse, Recycle' - The Atlantic, 25 Feb 2022 (link)

*Finally: Putting **Total U.S. Energy Consumption** into a global perspective:*

International Energy Agency 2003 map of per-capita energy consumption: [1]

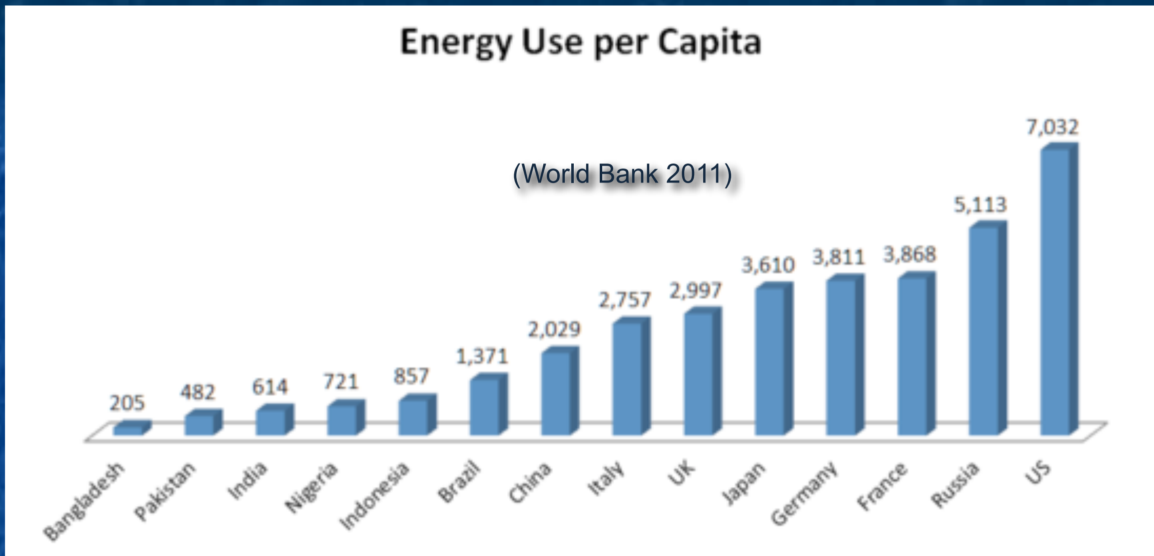


Energy Conversion: 1 kg of oil equivalent ("koe") => 11.63 kW-h [2]

1) http://en.wikipedia.org/wiki/List_of_countries_by_energy_consumption_per_capita
2) https://www.unitjuggler.com/convert-energy-from-koe-to-kWh.html

More recent data on per capita energy consumption:

An abbreviated bar graph (in kg oil equivalent per capita):



Or, in rank order:

Iceland	16882.5
Trinidad and Tobago	15913.3
Qatar	12799.4
Kuwait	12204.3
Luxembourg	8342.5
Brunei Darussalam	8308.4
United Arab Emirates	8271.5
Bahrain	7753.7
Canada	7379.6
Oman	7187.7
United States	7164.5
Finland	6787.2
Norway	6637.4
Singapore	6455.7
Saudi Arabia	6167.9

Figures: http://en.wikipedia.org/wiki/List_of_countries_by_energy_consumption_per_capita

Very affluent but much more energy-thrifty countries:

Germany	4003.3
France	4030.5
Japan	3898.4

~ 50% of U.S. Energy use!

Prompting this website's later recurring discussions about how,

with often surprisingly little inconvenience or pain,

the U.S. could substantially reduce its present day energy wastage

In conclusion: We Americans have a history of profligate energy use

Comparably profligate countries have tended to fall in two groups:

1) Affluent countries able to afford the exceptional heating or cooling energy desirable in their exceptionally hot or cold climates, such as:

Australia, Canada, Finland, Iceland, Norway & Sweden

2) Countries with particularly abundant & accessible native energy sources, including:

Middle-eastern OPEC oil-exporting countries

Iceland, with its uniquely abundant Geothermal energy sources

AND the U.S. with its abundant oil, natural gas and coal reserves

With abundant fossil-fuels AND moderate climate, through almost the end of the twentieth century we Americans paid very little attention to energy efficiency

Facing climate change, this noteset exposes the major challenges we now confront

But like many "energy experts" I remain cautiously optimistic because I see so many tools

Some that we Americans had - until recently - largely ignored (e.g., solar & wind energy),

Plus a large number still in development but with many progressing dramatically

Thus, echoing others, I see our real challenge as finding the will to run with these tools

Credits / Acknowledgements

Some materials used in this class were developed under a National Science Foundation "Research Initiation Grant in Engineering Education" (RIGEE).

Other materials, including the WeCanFigureThisOut.org "Virtual Lab" science education website, were developed under even earlier NSF "Course, Curriculum and Laboratory Improvement" (CCLI) and "Nanoscience Undergraduate Education" (NUE) awards.

This set of notes was authored by John C. Bean who also created all figures not explicitly credited above.

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