U.S. Energy Production & Consumption

John C. Bean

Outline

U.S. energy production & consumption

Typical household consumption / Total U.S. electrical power production

How this has (or has not) been changing:

The still surprisingly small role of renewables in the U.S.

How states differ in the ways they produce energy

And how this has been changing

How our consumption varies during the day

The surprising importance of residential consumption

"Follow the Heat!"

Putting U.S. power consumption into perspective:

Worldwide data and maps of per-capita power consumption

(Written / Revised: October 2019)
To figure out how we might build a truly sustainable future energy system, we are about to dive into the science of "electricity" and into the technologies underlying the pieces of such a puzzle. But it makes sense to first discuss the likely scale of such systems. And if "sustainability" includes sustaining a form of technological society, that scale will have to resemble that of today's energy systems. Hence today's description of current U.S. Energy production & consumption.
But first a short digression / confession:

Less technology-inclined students often skip the following two note sets:

Which explain what **electricity** really is, and its often **very weird** behavior

Yes, that is a geeky topic, and I understand your possible hesitancy

But energy systems confront that "weird behavior" over and over and over

And that behavior will thus be a thread running through this entire class

So I urge you, **strongly**, to read through those note sets

If you do, you'll discover that **this** note set's title contains a redundancy

Because: Electrical power production = Electrical power consumption

And that stems from the fact that, while electrons are **things**,

**Electricity is instead a process**: The process of electron flow

And you can't freeze a process without stopping and destroying that process
What you can do is try to store electrons

In the hope that you might then later release them to create electricity.

But nature abhors accumulations of negative (or positive) charge, and thus tries to balance negative electron and positive proton numbers.

And given that proton numbers are fixed (as locked inside the nuclei of atoms), nature tries, really hard, to similarly lock in electron numbers.

We can slightly upset this balance in things called "capacitors."

But they work at only minute scales, and thus store very few electrons.

Electricity storage thus normally involves converting it to another form of energy.

E.g., by using electricity to pump water up a hill (creating "potential energy")

Then later sending that water down that hill to create "hydroelectricity."

But, at large scales, such conversions are very difficult and very expensive.
Once electrical power is produced
it must be transported
and used
within milliseconds!

This immediacy makes electricity, as a product, essentially unique

In the language of economics: Supply must ABSOLUTELY equal demand

And if it doesn't, your electrical grid is just milliseconds away from blacking out!

OK, with my confession + argument for the study of electricity now out of the way:

How much energy do we in the U.S. use?
U.S. Energy Information Agency (EIA) Data:

AVERAGE U.S. HOUSEHOLD electrical power use in 2015: 901 kW-hrs / month

(901 kW-hrs) / (30 x 24 hrs) => 1-¼ kilowatts (A very useful number to remember)

TOTAL U.S. electrical power generation projected to 2040:

<= Now ~ 4 ¼ trillion kW-h / yr

1) EIA FAQs 2017: https://www.eia.gov/tools/faqs/faq.php?id=97&t=3
2) EIA Annual Energy Outlook 2015, p31: http://www.eia.gov/forecasts/aeo/er/pdf/0383er%282013%29.pdf
Massaging that figure's data a bit:

Reminding ourselves of metric multipliers:

\[ k = \text{kilo} = \text{thousand} = 1,000 = 10^3 \]

\[ M = \text{mega} = \text{million} = 1,000,000 = 10^6 \]

Not to be confused with: \( m = \text{milli} = 0.001 = 10^{-3} \! \)

\[ G = \text{giga} = \text{billion} = 1,000,000,000 = 10^9 \]

\[ T = \text{tera} = \text{trillion} = 1,000,000,000,000 = 10^{12} \]

Then, from the preceding figure, total 2017 U.S. electrical generation translates into:

\[ = \frac{4}{4} \text{trillion kW-h / yr} = 4.25 (10^{12}) (10^3) \text{ W h / (365 x 24 h)} \]

\[ = 485 x (10^9) \text{ W} \sim \frac{1}{2} \text{TW} \]

**Average U.S. Electricity Generation = \( \frac{1}{2} \text{Tera-Watt} \)**

(Another very useful number to remember)
That U.S. power is a lot less green than most people believe!

According to the figure, the 2011 breakdown was:

42% Coal / 25% Natural gas / 19% Nuclear / 13% Renewables
And those probably weren't the "renewables" you were expecting:

Breakdown of renewable contribution in 2012 (based on EIA data): ¹

<table>
<thead>
<tr>
<th>Renewable Type</th>
<th>Fraction of Renewables</th>
<th>Fraction of Total Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydroelectric</td>
<td>58%</td>
<td>7.5%</td>
</tr>
<tr>
<td>Wind</td>
<td>26.9%</td>
<td>3.5%</td>
</tr>
<tr>
<td>Biomass</td>
<td>11%</td>
<td>1.4%</td>
</tr>
<tr>
<td>Geothermal</td>
<td>3.2%</td>
<td>0.4%</td>
</tr>
<tr>
<td>Solar</td>
<td>0.8%</td>
<td>0.1%</td>
</tr>
</tbody>
</table>

Excluding hydro, renewables contributed only 5.6% of 2012 U.S. electricity!

Biomass (sawdust + corn husks + manure) = 1.4% vs. Solar = 0.1% !!!

¹ en.wikipedia.org/wiki/Renewable_energy_in_the_United_States (based on: www.eia.gov/electricity/data.cfm#generation)
² = Renewable fraction of second column x 13% total renewable fraction from preceding page's figure
Things DID improve significantly by 2016:

Preceding 2012 data:
- Natural gas = 25%
- Coal = 42%
- Nuclear = 19%
- Renewables (total) = 5.6%
  - Hydro = 11%
  - Wind = 3.4%
  - Biomass = 1.4%
  - Solar = 0.1%
  - Geothermal = 0.4%

2016 EIA data: 1
- Natural gas = 33.8%
- Coal = 30.4%
- Nuclear = 19.7%
- Renewables (total) = 14.9%
  - Hydropower = 6.5%
  - Wind = 5.6%
  - Biomass = 1.5%
  - Solar = 0.9%
  - Geothermal = 0.4%
- Petroleum = 0.6%
- Other gases = 0.3%
- Other nonrenewable sources = 0.3%

But excluding hydro, renewables still contributed only 8.4% of 2016 U.S. electricity

With solar energy's contribution going from miniscule to tiny: 0.1% => 0.9%

THE BIG CHANGE = Swapping one fossil fuel for another (coal => natural gas)

Which DID, nevertheless, produce a significant decrease in the U.S. carbon footprint!

1) EIA FAQs 2017: https://www.eia.gov/tools/faqs/faq.php?id=427&t=3
The EIA provides greater detail in their "Electricity Data Browser"

Which I tracked down at this link (spelled out at the bottom of this page):

I entered last ten years of that EIA data into an Excel spreadsheet:

And then converted production numbers to percentage of total electrical energy:

<table>
<thead>
<tr>
<th>Percentage of Total Generation for that year (sorted by 2008 order)</th>
</tr>
</thead>
<tbody>
<tr>
<td>------</td>
</tr>
<tr>
<td>Coal</td>
</tr>
<tr>
<td>Natural Gas</td>
</tr>
<tr>
<td>Conventional Hydro</td>
</tr>
<tr>
<td>Wind</td>
</tr>
<tr>
<td>Biomass</td>
</tr>
<tr>
<td>Petroleum liquids</td>
</tr>
<tr>
<td>Geothermal</td>
</tr>
<tr>
<td>Petroleum Coke</td>
</tr>
<tr>
<td>Other Gases</td>
</tr>
<tr>
<td>Utility Scale Solar</td>
</tr>
</tbody>
</table>

(My spreadsheet is available on this lecture's Resources Webpage)
Plotting that: **Percentage U.S. Electrical Energy vs. Energy Source**

(Line colors chosen to match the following Washington Post figures)
The Washington Post's 2015 Geographic Breakdown of U.S. Electricity:

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%):

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.

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.
Pulling together all of the preceding data on U.S. Electrical Power:

<table>
<thead>
<tr>
<th></th>
<th>EIA 1993</th>
<th>EIA 2011</th>
<th>EIA 2012</th>
<th>WP 2015</th>
<th>EIA 2018</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Coal</strong></td>
<td>53%</td>
<td>42%</td>
<td></td>
<td>34%</td>
<td>27.4%</td>
</tr>
<tr>
<td><strong>Natural Gas</strong></td>
<td>13%</td>
<td>25%</td>
<td></td>
<td>30%</td>
<td>35.1%</td>
</tr>
<tr>
<td><strong>Petroleum</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Nuclear</strong></td>
<td>19%</td>
<td>19%</td>
<td></td>
<td>20%</td>
<td>19.3%</td>
</tr>
<tr>
<td><strong>Hydro</strong></td>
<td></td>
<td></td>
<td>7.5%</td>
<td>7%</td>
<td>7.0%</td>
</tr>
<tr>
<td><strong>Wind</strong></td>
<td></td>
<td></td>
<td>3.5%</td>
<td>5%</td>
<td>6.6%</td>
</tr>
<tr>
<td><strong>Solar</strong></td>
<td>0.1%</td>
<td>1%</td>
<td></td>
<td></td>
<td>1.6%</td>
</tr>
<tr>
<td><strong>Biomass</strong></td>
<td>1.4%</td>
<td></td>
<td></td>
<td></td>
<td>1.5%</td>
</tr>
<tr>
<td><strong>Geothermal</strong></td>
<td>0.4%</td>
<td></td>
<td></td>
<td></td>
<td>0.4%</td>
</tr>
<tr>
<td><strong>All Renewable</strong></td>
<td>11%</td>
<td>13%</td>
<td></td>
<td></td>
<td>17.1%</td>
</tr>
<tr>
<td>(excluding nuclear)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

EIA = U.S. Energy Information Agency / WP = Washington Post
But is there truth to some state claims of being exceptionally green?

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

But greenest **Vermont** succeeds only by importing **Quebec's** hydropower.
Combination of State-by-State Data with Ten Year Trends:

From the National Public Radio article:

Coal, Gas, Nuclear, Hydro? How Your State Generates Power

Here is the trend for total U.S. electrical power:

On the five slides that follow are the trends for:

Alabama through Georgia

Hawaii through Maryland

Massachusetts through New Jersey

New Mexico through North Carolina

South Carolina through Wyoming
Alabama through Georgia:
Hawaii through Maryland:

Massachusetts through New Jersey:

- Massachusetts 2004: 58% Natural gas, 19% Nuclear, 9% Coal, 6% Renewables, 3% Petroleum, 2% Hydro
  2014: 51% Coal, 30% Nuclear, 11% Natural gas, 6% Renewables

- Michigan 2004: 58, 15, 13, 3
  2014: 66, 24, 20, 1

- Minnesota 2004: 26, 12, 11, 1
  2014: 26, 23, 18, 7

- Mississippi 2004: 42, 27, 21, 7
  2014: 60% Natural gas, 20% Nuclear, 12% Coal, 7% Hydro

- Missouri 2004: 86, 9, 11, 3
  2014: 83% Coal, 4% Nuclear, 4% Natural gas, 1% Hydro

- Montana 2004: 65, 33, 7, 2
  2014: 64, 32, 26, 0

- Nebraska 2004: 63, 32, 26, 3
  2014: 63% Natural gas, 26% Nuclear, 18% Coal, 7% Hydro

- Nevada 2004: 48, 43, 18, 4
  2014: 43, 42, 22, 3

- New Hampshire 2004: 43, 42, 22, 4
  2014: 48% Nuclear, 45% Natural gas, 22% Natural gas, 10% Renewables

- New Jersey 2004: 50, 27, 22, 2
  2014: 48% Nuclear, 45% Natural gas, 22% Natural gas, 10% Renewables

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:

- **NEW MEXICO**
  - 2004: 89, Coal 64%, Natural gas 27%, Renewables 9%
  - 2014: 9, Coal 9%, Natural gas 27%, Renewables 9%

- **NEW YORK**
  - 2004: 61, Coal 40%, Natural gas 32%, Nuclear 19%, Renewables 4%
  - 2014: 33, Coal 39%, Natural gas 32%, Nuclear 19%, Hydro 4%
  - 2016: 2, Coal 4%, Hydro 2%, Renewables 4%

- **NORTH CAROLINA**
  - 2004: 94, Coal 94%, Natural gas 18%, Renewables 2%
  - 2014: 94, Coal 75%, Hydro 7%
  - 2016: 5, Coal 18%, Natural gas 12%, Renewables 18%

- **NORTH DAKOTA**
  - 2004: 94, Coal 94%, Natural gas 18%, Renewables 2%
  - 2014: 94, Coal 75%, Hydro 7%
  - 2016: 5, Coal 18%, Natural gas 12%, Renewables 18%

- **OHIO**
  - 2004: 67, Coal 67%
  - 2014: 67, Coal 67%
  - 2016: 11, Coal 18%, Natural gas 12%, Nuclear 12%

- **OKLAHOMA**
  - 2004: 56, Coal 43%, Natural gas 38%, Renewables 17%
  - 2014: 66, Coal 43%, Natural gas 38%
  - 2016: 7, Coal 43%, Natural gas 38%

- **OREGON**
  - 2004: 55, Coal 55%, Natural gas 45%
  - 2014: 55, Coal 36%
  - 2016: 4, Coal 36%

- **PENNSYLVANIA**
  - 2004: 53, Coal 53%
  - 2014: 40, Coal 53%
  - 2016: 12, Coal 55%

- **RHODE ISLAND**
  - 2004: 98, Coal 98%
  - 2014: 98, Coal 95%
  - 2016: 5, Coal 95%

- **SOUTH CAROLINA**
  - 2004: 11, Coal 2%
  - 2014: 11, Coal 2%
  - 2016: 1, Coal 2%

There's one more important characteristic of U.S. power:

Our daily cycles in electricity consumption (and price):

Consumption must, of course, fall drastically in the middle of the night.

But you'd think it would peak near midday, when we are all hard at work.

It actually peaks in **early evening**:

Source: https://www.eia.gov/todayinenergy/detail.php?id=12711 (to which I've added the yellow lines)
Which hints at the importance of **RESIDENTIAL** power consumption

As confirmed in this U.S. Department of Energy (DOE) explanation of power cycles:

(Figure is from the must-have DOE document: **U.S. Electricity Primer**)
As also seen in this 2014 EIA breakdown of U.S. energy:

From which I generated this more readable U.S. energy consumption pie-chart:

- Exports (fuels): 12.01%
- Commerce: 17.93%
- Residential: 21.13%
- Transportation: 27.01%
- Industrial: 31.48%

1) EIA 2014 - http://www.eia.gov/todayinenergy/detail.cfm?id=16511&src=Total-b1
Why is residential consumption so large?

Well, for a long time we have been building remarkably energy inefficient homes

(See my later lecture on Housing)

But here it's also important to note that ENERGY comes in many different forms

But, eventually, almost all of it ends up moving/vibrating atoms & molecules

We call that form of energy HEAT

So if you really want to search out where energy is being used,

my rule (corrupting a famous Watergate quote) is to:

**Follow the money heat!**

And it so happens that we produce/use/move a LOT OF HEAT in our homes:

Heating & cooling air / heating & cooling food / heating dishes, laundry . . .

And we do that mostly in the evenings => U.S. evening power bump!
Finally: Putting U.S. consumption into a global perspective:

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

http://en.wikipedia.org/wiki/List_of_countries_by_energy_consumption_per_capita
More recent data on per capita energy consumption:

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

<table>
<thead>
<tr>
<th>Country</th>
<th>Energy Use per Capita (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iceland</td>
<td>16882.5</td>
</tr>
<tr>
<td>Trinidad and Tobago</td>
<td>15913.3</td>
</tr>
<tr>
<td>Qatar</td>
<td>12799.4</td>
</tr>
<tr>
<td>Kuwait</td>
<td>12204.3</td>
</tr>
<tr>
<td>Luxembourg</td>
<td>8342.5</td>
</tr>
<tr>
<td>Brunei Darussalam</td>
<td>8308.4</td>
</tr>
<tr>
<td>United Arab Emirates</td>
<td>8271.5</td>
</tr>
<tr>
<td>Bahrain</td>
<td>7753.7</td>
</tr>
<tr>
<td>Canada</td>
<td>7379.6</td>
</tr>
<tr>
<td>Oman</td>
<td>7187.7</td>
</tr>
<tr>
<td>United States</td>
<td>7164.5</td>
</tr>
<tr>
<td>Finland</td>
<td>6787.2</td>
</tr>
<tr>
<td>Norway</td>
<td>6637.4</td>
</tr>
<tr>
<td>Singapore</td>
<td>6455.7</td>
</tr>
<tr>
<td>Saudi Arabia</td>
<td>6167.9</td>
</tr>
</tbody>
</table>

Or, in rank order:

Much lower ranked but nevertheless affluent countries:

- Germany 4003.3
- France 4030.5
- Japan 3898.4

~ 50% of U.S.!
We North Americans are profligate energy consumers

But, yes, our Canadian cousins have hung right in there with us!

We're in a club whose other members are either the world's oil producers

Or where something really strange is going on:

Iceland: Cold as heck + most abundant/cheap geothermal in the world?

Finland: Damn cold (=> saunas?), but how on earth can they afford it?

Trinidad and Tobago: I haven't a clue

So not only are we climate change bad guys

But maintaining our economy/lifestyle is going to be particularly difficult

About 75% more difficult than for even economic leader, Germany!

http://en.wikipedia.org/wiki/List_of_countries_by_energy_consumption_per_capita
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This set of notes was authored by John C. Bean who also created all figures not explicitly credited above.

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