Electricity Past & Future

By John Benson

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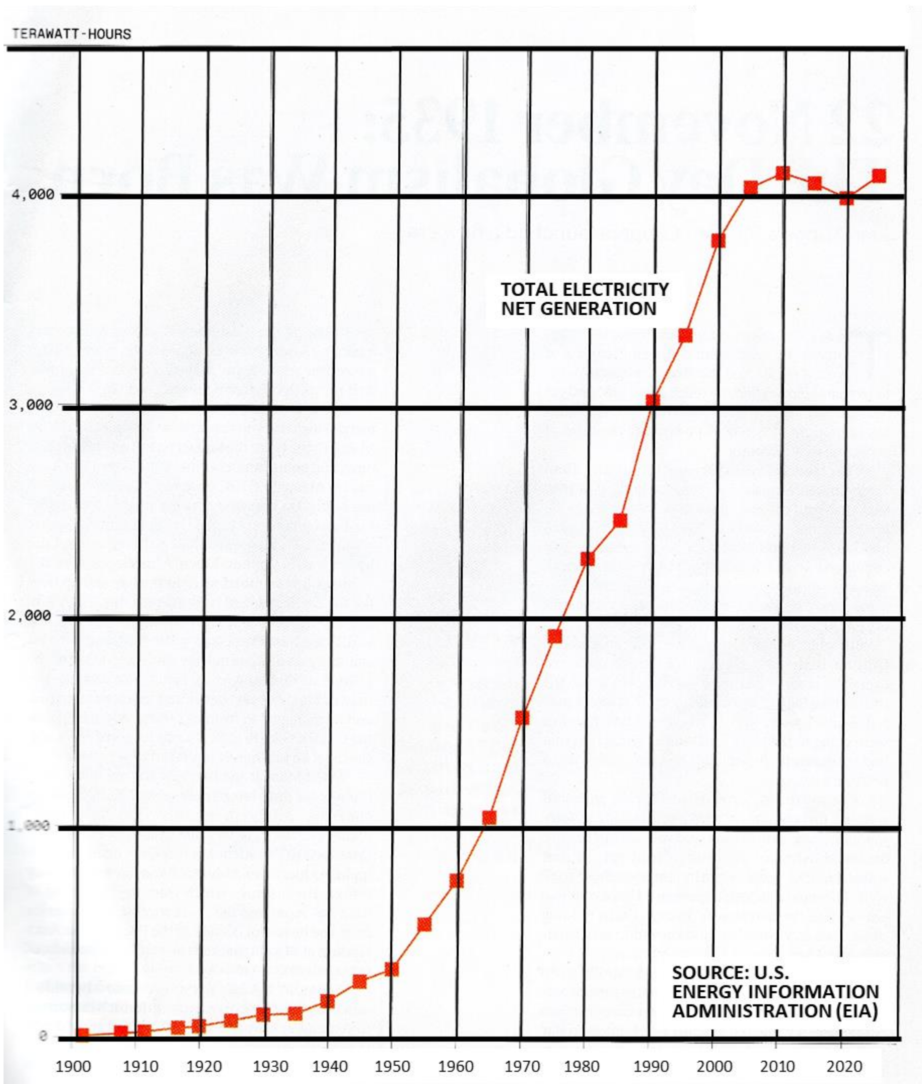
1. Introduction

My June IEEE Spectrum had an interesting chart in it (below).



This is obviously the U.S. Electric consumption over time. There was also some interesting commentary on this, some of which I've excerpted in section 2 below. But what I'm really interested in is what this tells us about the future, which is mainly covered in section 3 below.

2. The Past

One hundred forty years ago, Thomas Edison began generating electricity at two small coal-fired stations, one in London (Holborn Viaduct), the other in New York City (Pearl

Street Station). Yet although electricity was clearly the next big thing, it took more than a lifetime to reach most people. Even now, not all parts of the world have easy access to it. Count this slow rollout as one more reminder that fundamental systemic transitions are protracted affairs.[1]

Such transitions tend to follow an S-shaped curve: Growth rates shift from slow to fast, then back to slow again. I will demonstrate this by looking at a few key developments in electricity generation and residential consumption in the United States, which has reliable statistics for all but the earliest two decades of the electric period.

In 1902, the United States generated just 6 terawatt- hours of electricity, and the century-plus-old trajectory shows a clear S-curve. By 1912, the output was 25 TWh, by 1930 it was 114 TWh, by 1940 it was 180 TWh, and then three successive decadal doublings lifted it to almost 1,600 TWh by 1970. During the go-go years, the 1930s was the only decade in which gross electricity generation did not double, but after 1970 it took two decades to double, and from 1990 to 2020, the generation rose by only one-third.

As the process began to mature, the rising consumption of electricity was at first driven by declining prices, and then by the increasing variety of uses for electricity. The impressive drop in inflation-adjusted prices of electricity ended by 1970, and electricity generation reached a plateau, at about 4,000 TWh per year, in 2007.

The early expansion of generation was destined for industry-above all for the conversion from steam engines to electric motors-and for commerce. Household electricity use remained restrained until after World War II.

In 1900, fewer than 5 percent of all households had access to electricity; the biggest electrification jump took place during the 1920s, when the share of dwellings with connections rose from about 35 percent to 68 percent. By 1956, the diffusion was virtually complete, at 98.8 percent…

It took a long time for new appliances to make a difference, because there were significant gaps between the patenting and introduction of new appliances- including the electric iron (1903), the vacuum cleaner (1907), the toaster (1909), the electric stove (1912), the refrigerator (1913)-and their widespread ownership. Radio was adopted the fastest of all: Seventy-five percent of households had it by 1937.

The same dominant share was reached by refrigerators and stoves only in the 1940s-dishwashers by 1975, colorTVs by 1977, and microwave ovens by 1988. Again, as expected, these diffusions followed more or less orderly S-curves.

Rising ownership of these and a range of other heavy electricity users drove the share of residential consumption to 25 percent by the late 1960s, and to about 40 percent in 2020…

But what really caused the consumption of electricity to slow down? Certainly the number of “appliances” have continued to proliferate: Personal Computers, digital video recorders, wall-sized televisions, to name a few, all developed their major markets after the year 2000. Mostly the power-down was caused by the increasing efficiency of all

[1] Vaclav Smil, IEEE Spectrum, Crosstalk, “Electricity’s Slow Rollout,” June, 2022 Paper Issue, Although there is an on-line version of this, IEEE Membership is required to receive the magazine paper version or access the full on-line version.

appliances, and this was aided by something called the Rosenfeld Effect. To understand this, see the earlier post described and linked below.

The Godfather of Energy Efficiency: *There has been much discussion of Energy Efficiency lately. Every time I see a discussion of energy efficiency, my thoughts go to a gentleman that shares a title with this paper, which I am posting to scratch this itch (and give myself a nice Thanksgiving present).*

His name is Dr. Arthur Rosenfeld, and I had the honor to work with him on a couple of projects shortly after Y2K.

https://energycentral.com/c/um/godfather-energy-efficiency

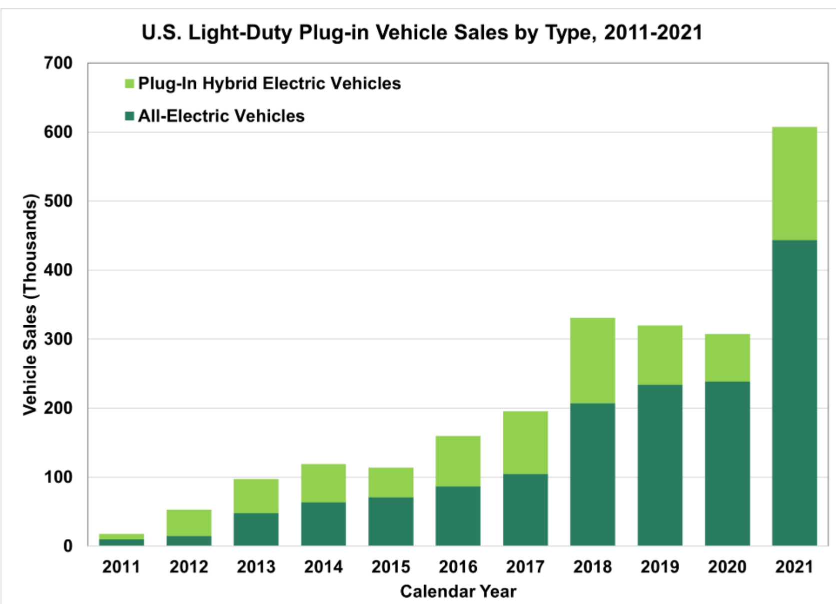
One more thing is described by the above chart: Since 2020 the electricity consumption has started increasing, what's going on there? To find out, read the next section.

3. The Future Renaissance

In the above chart we are seeing just the beginning of a really major increase, and this one will benefit everyone. Although the other new sources of consumption I will describe below are already happening, I expect the first subsection below is what we are already seeing in the above chart's tweak upward since 2020.

3.1. The Electric Vehicle (EV) Revolution

See the chart from Energy.gov below.[2]



Note that the Pandemic flattened our curve a bit, but it came roaring back in 2021 with over 400,000 pure EVs, and over 150,000 plug-in hybrids. Total quarterly sales in Q2 2022 of pure EVs was almost 200,000 units. Keeping all of these EVs charged is likely a

[2] Energy.gov, "Energy Saver, "New Plug-in Electric Vehicle Sales in the United States Nearly Doubled from 2020 to 2021," March 1, 2022, https://www.energy.gov/energysaver/articles/new-plug-electric-vehicle-sales-united-states-nearly-doubled-2020-2021

large part of the recent bump up we see in the chart in the Introduction, and it clearly is just accelerating.

The additional EV incentives provided by the Inflation Reduction Act of 2022 include: *The $7,500 tax credit can be availed for new clean energy vehicle purchases by those whose income is under $300,000 for joint filers, $225,000 for heads of households and $150,000 for others… The tax credit would run through Dec. 31, 2032. To be eligible for the tax credit, the vehicle should be made in North America. There are retail price caps of $80,000 for vans, SUVs and pickup trucks; $55,000 for others, including sedans... Batteries have to contain a certain level of critical minerals extracted or processed in any country the U.S. has a free trade agreement with or are recycled in North America.*[3]

The bill also seeks to do away with the previous mandate that required qualified vehicles to have solely plug-in electric drive motors and the 200,000-vehicle per manufacturer cap.

The last deletion will help Tesla greatly, and Chevy a bit.

3.2. The Second, Third & Fourth EV Revolutions

The current revolution, as described in subsection 3.1 is pretty strictly limited to light road-going electric vehicles, but this will not be the last revolution as described below.

3.2.1. Heavy Road Vehicles

A limited number of medium and heavy road vehicles are already starting to circulate on our roads. See the earlier post below for details.

Electric Trucks and Buses in California: *This paper is much longer that I like to post, but I thought it better to leave it together rather than splitting it. It is not just for my normal reader, but also for stakeholders of private and public organization that are involved in the title subject. Mostly in California, but also outside of our state. For more details, read on.*

This post will take a deep dive into California requirements and incentives for medium and heavy electric trucks, buses and related technologies, and look at why California is doing this. This paper will also dive into truck and bus manufacturers and their products. And finally, we will review U.S. federal incentives for electric trucks and buses.

https://energycentral.com/c/ec/electric-trucks-and-buses-california

These vehicles are already starting to ramp up big-time, and this will continue for the next five years. Generous government incentives impending government restrictions on internal combustion (see section 2.1 and 2.2 in the above linked paper) plus reasonable availability of models of all types of heavy EVs (see section 2.3 and 3 in the above linked paper) will continue to drive volume upward.

[3] Shanthi Rexaline, Benzinga via MSN, "What Does The New Senate Deal Mean For Tesla, Toyota And Other Automakers?" July 28, 2022, https://www.msn.com/en-us/money/news/what-does-the-new-senate-deal-mean-for-tesla-toyota-and-other-automakers/ar-AA1042Bj?ocid=msedgntp&cvid=c6592e6e8e614448a9a475a1f16c019d

3.2.2. Electric Aero Vehicles

Current aero-electric vehicles are limited to short-hop duty, and none of them have entered commercial service yet, but at least one is getting really close. Read the recent post below for details.

Air Taxis, Starting to Takeoff? *A bit over three years ago, I wrote a post on flying EVs. Although there are some flying EVs (as there were then), these have hardly become mainstream, but the title version of these appear to (very slowly) taking off, and the amount of funds being pumped into them by major firms are taking off, big-time.*

This post will review how air taxis from the earlier post have developed and review the current crop of air taxis most likely to quickly (and perhaps inexpensively) whisk you over the traffic in the next few years.

https://energycentral.com/c/ec/air-taxis-starting-takeoff

Although the first U.S. production air taxy will take off in a year or two, the volume of these will not start to take off until after 2030.

3.2.3. Electric Marine Vessels

As I'm writing this I just posted "Oceanic Solutions – Ships and Shipping" A few weeks ago. Section 4 of this paper describes a solution under development that may create large battery-electric ocean-going vessels. This paper is described and linked at the end of subsection 3.5, below.

Marine EVs will probably not achieve significant volume until well into the 2030s, but see section 3.5 below for an indirect source of increasing load.

3.3. Commercial & Residential Environmental Heating

Although this application increase the load substantially in a decade or two, it has yet to really take off. Also there are two distinct roads to heating here:

1. Biomethane fired heat
2. Heat pumps

The first can be used immediately, but does not require as high an electrical load per BTU heat as the second one does. The production of biomethane does require some electric energy, however there are several production-methods and each has a different electricity demand profile.

3.3.1. Biomethane Fired Heat

Since most heating is done by natural gas (a.k.a. geologically sourced methane plus higher molecular weight hydrocarbons (ethane, butane, etc.) that can be present in this natural gas), transitioning to biomethane is strictly a financial transaction, but with the caveat that the supply / production of biomethane needs to be ramped up. My home state (California) is currently trying to do this.

February 24, 2022 - The California Public Utilities Commission (CPUC), in ongoing efforts to support clean energy, today set biomethane procurement targets for utilities to reduce short-lived climate pollutant (SLCP) emissions.[4]

The decision establishes a biomethane procurement program that is carefully crafted to help achieve the state's SLCP goals, which call for a 40 percent reduction in methane and other SLCPs by 2030. Renewable gas procurement will reduce otherwise uncontrolled methane and black carbon emissions in our waste, landfill, agricultural and forest management sectors. These sectors are responsible for more than 75 percent of the state's methane emissions, according to California Air Resources Board 2019 data. Reducing SLCPs, which are a far more potent greenhouse gas than carbon dioxide, is one of the most effective ways to slow the pace of climate change.

Senate Bill 1440 (Hueso, 2018) authorizes the CPUC to adopt biomethane procurement targets or goals for the gas utilities it regulates, and Senate Bill 1383 (Lara, 2014) requires California to reduce emissions of methane by 40 percent below 2013 levels by 2030. The biomethane will displace some of the fossil fuel natural gas that utilities supply to their customers.

The decision establishes short-term and medium-term procurement goals, including:

- *The short-term 2025 biomethane procurement target is 17.6 billion cubic feet of biomethane, which corresponds to 8 million tons of organic waste diverted annually from landfills. Each utility will be responsible for procuring a percentage of the total in accordance with its proportionate share of natural gas deliveries.*

- *The medium-term 2030 target for biomethane procurement is 72.8 billion cubic feet per year. This higher amount will help the state achieve its goal to reduce methane emissions 40 percent by 2030. It reflects approximately 12 percent of current residential and small business (known as "core gas customers") gas usage in 2020.*

- *Because biomethane from dairies is currently incentivized in other state programs, under the decision it may be procured to satisfy only the medium-term target, after the utility has procured sufficient biomethane from organic waste diverted from landfills to divert its share of 8 million tons of organic waste. For the medium-term goal, there is a ceiling on dairy biomethane of 4 percent of total biomethane procurement. Measures are required to avoid adverse environmental impacts to air and water quality from any dairies that provide biomethane…*

I would guess that eventually the CPUC will establish a premium price to be paid to biomethane producers, and paid by biomethane consumers (either individually or en masse). I believe that all of the major natural gas pipelines in California can already transport biomethane in the same way that electric transmission lines can transport renewable electricity (financial transaction for purchasers / consumers plus supply contract with gas-specification for producers).[5]

[4] California Public Utilities Commission (CPUC) Press Release, "CPUC Sets Biomethane Targets for Utilities," https://www.cpuc.ca.gov/news-and-updates/all-news/cpuc-sets-biomethane-targets-for-utilities

[5] There are two links to sites that explore this: https://www.bioenergyca.org/policy/biogas/ and https://www.cpuc.ca.gov/-/media/cpuc-website/files/uploadedfiles/cpuc_website/content/utilities_and_industries/energy/energy_programs/gas/natural_gas_market/ccstworkshop.pdf

As the above method of supplying biomethane matures it will probably be used as an interim solution to reduce net greenhouse gas emissions from gas fired heaters.

3.4. Heat Pump

A large majority of current "air conditioning" (cooling) technology uses heat pumps. The text below is from the Wikipedia Article on heat pumps as modified by your author.

A heat pump is a device that can heat or cool a facility by transferring thermal energy using a refrigeration cycle. Units that only provide cooling are referred to as air conditioners.

When in the heating mode, a refrigerant at outside temperature is pressurized. As a result, the refrigerant becomes hot (boosts the temperature by adding the pressurization energy). The heat can then be used by an inside heating system.

After being moved outdoors again, the refrigerant is decompressed (evaporated). It has lost some of its energy and becomes colder than the environment. It can now take up heat-energy from the atmosphere or the ground before the process repeats. Compressors, fans, and pumps run with electric energy.

When in the cooling mode the heat pump (or air conditioner) operates exactly as described above, but in reverse – it absorbs heat indoors and rejects this heat outdoors.

There is a version of hot water heaters that use heat pumps. Operation is as described above in the heating mode.

Common types are air source heat pumps (as described above), ground source heat pumps, water source heat pumps and exhaust air heat pumps, which vary depending on the outside "source" the heat pump uses to absorb and reject heat…

When used for space heating, heat pumps are typically much more energy efficient than simple electrical resistance heaters.

Because of their high efficiency and the increasing share of fossil-free sources in electrical grids, heat pumps can play a key role in electrification, the energy transition, and climate change mitigation. With 1 kWh of electricity, they can transfer 3 to 6 kWh of thermal energy into or out of a building. The carbon footprint of heat pumps depends on how electricity is produced. Heat pumps could satisfy 90% of global heating needs with a lower carbon footprint than gas-fired condensing boilers.

Efficiency of heat pumps: There are several metrics for this.

EER (energy efficiency ratio) = BTU/h of output ÷ Watts of Energy Input[6]

The nice thing with EER is you can measure it in real-time if you know the watts being used and the BTUs being produced. No conversions needed, no fancy math. Measured EER is an easy snapshot, but rated EER is another matter, based only on RATED conditions. It doesn't take into account seasonal temperature or runtime variations.

COP (coefficient of performance) = BTU/h output ÷ BTU/h of Energy Input

[6] Bryan Orr, HVAC School. "EER & COP vs. SEER & HSP," Nov 30, 2020, https://hvacrschool.com/eer-cop-vs-seer-hspf/

In other words, COP is the same as EER, but you convert the input to BTU/h from watts by multiplying watts by 3.413. That one is also easy but has one more step of math added in. The same issue is that it is a snapshot of performance and is based on only one set of operating conditions.

SEER (Seasonal Energy Efficiency Ratio) = BTU/h output ÷ Watts of Energy Input, Averaged over an entire cooling season.

So, SEER is just like EER, but it would theoretically be the average EER if you measured it all through the cooling season and then averaged it. The PROBLEM is that it isn't the same everywhere, so it is still based on a set of conditions meant to replicate an average.

HSPF (Heating seasonal performance factor) = BTU/h output ÷ Watts of Energy Input, Averaged over an entire heating season

This equation makes HSPF exactly like the SEER, but it's the winter (heating season) version where the EER is calculated and then averaged out. The same challenge exists in that not all places have the same set of operating conditions.

The solution lies in understanding each efficiency measure and the requirements of the particular market you work in to provide your customers with the best possible products to serve their needs. If you live in a market with very high outdoor temps like Phoenix, AZ, you want to look at the extended performance data on the equipment you see and find systems that continue to perform well at high temperatures.

Author's comment: There is one more consideration here, when in the cooling mode (or when using an air conditioner) a heat pump performs one more job that is important in humid areas: it dehumidifies the inside air by condensing the humidity into liquid water as it passes over the cooling coils. This is why HVAC systems need a drip-line to be run outside or to the sewer. The physics / thermodynamics / comfort calculations for this are really complex, and I've already geeked-out enough with the above information.

3.5. Green Hydrogen, Ammonia and Methanol

All three of the substances in the subsection-title share three things:

1. All three can be used as fuel to generate other types of energy (motion, heat electricity, etc.).
2. All three are used as feedstock to to produce other compounds or substances (hydrogen to produce ammonia, ammonia as fertilizer to produce plants, all three to produce a wide range of organic compounds and polymers).
3. All three are directly or indirectly produced using mostly electric energy.

Thus all three will continue to be important in the future. The only difference vs. now is that they will increasingly be produced using electricity rather than petroleum-industry feedstock.

For additional reading on these substances, see the following three recent posts:

An Electrifying Chameleon: *Hydrogen. That is what this post is about. It all started with an article about a new method to produce it that looks really promising. But then we got to the question of what "color" is the hydrogen it produces. I frequently use the terms* *green hydrogen, gray hydrogen and sometimes blue hydrogen. Green hydrogen is produced via electrolysis using renewable electricity, but what is renewable electricity?*

This post will look at green hydrogen, and more specifically, the above question (what is renewable electricity?). Then it will look at the new method to produce hydrogen that I found.

https://energycentral.com/c/cp/electrifying-chameleon

Release the Crackers: *This paper will investigate why ammonia is probably the best carrier for hydrogen, possibly can be used directly as a fuel, and the latest developments in ammonia technology including crackers.*

https://energycentral.com/c/ec/release-crackers

Oceanic Solutions – Ships and Shipping: *Much of the world's goods travel by container ships, the primary subject of this paper. A current challenge is modifying these vessels such that they operate sustainably. This paper will review two potential solutions: a short-term solution, and a limited solution.*

See Section 3 of the paper linked below for green methanol.

https://energycentral.com/c/ec/oceanic-solutions-%E2%80%93-ships-and-shipping