Transitioning to EV's and Green Energy: Will The Lights Stay On?

Executive Summary

The California Air Resource Board (CARB) has recently created rules forcing vehicle manufacturers to completely convert all new light vehicles sales to zero emission vehicles (ZEV's) by 2035 while simultaneously removing fossil-based generation from the grid. Several other states including Washington and New York intend to follow. The Biden administration has set similar goals using executive orders.

Considering these rules and goals, and largely ignoring the problems of energy distribution and costs, this paper focuses on the demands placed on electrical power generation, and attempts to provide the reader with both a sense of the scale of the challenge, and an informed, data-driven opinion of the risks of these policies. Here are the key findings:

- Policy driven increases in demand for EV's could cause national electricity demands to significantly increase with predictions ranging from 5-8% over current production by 2030, to 12-17% by 2035. The higher predictions generally assume a federal level of policy support similar to California's CARB rules, while the lower predictions assume organic growth.
- For the last decade, electrical energy generation (and demand) has been nearly flat for the U.S. and for California. What's changed is how electricity is generated -- the primary fuel mix. In the U.S. natural gas generation has increased to offset decreases in coal generation with some help from wind and solar, while in California, increases in solar generation have been largely offset by drought-induced decreases in hydro. The industry isn't sized for growth.
- In 2021 60% of U.S. electricity generation came from the reliable energy sources of gas and coal. While, after a more than a decade of investments, only 13% came from unreliable wind and solar. In that same year California natural gas accounted for 49% of in-state electricity generation. Reliable sources can almost always produce their rated power when needed.
- Policy-induced growth far in excess of historical rates will likely lead to supply chain issues that would significantly increase costs for raw materials. This is already happening for the polysilicon used to make solar panels, and for the lithium used in batteries. This will drive up the cost of: EV's; solar panels; and battery storage, extensive amounts of which are required to make wind and solar more reliable (but not reliable).
- The administration's goals of 25GW solar energy generation on BLM land, and of 30GW offshore wind generation combined would only power 12% of the nation's vehicles as EV's, or alternatively, reduce fossil-fuel energy production by only 7%. The federal government owns most of the prime solar land in the southwest, and controls all offshore leases.
- Washington State fossil generation accounts for 23% of the state's energy mix. The state appears to be on track to replace fossil fuels, but not to do that and fuel EVs.
- New York State fossil generation accounts for 47% of the state's energy mix. The state's plans and goals are well short of what's needed for net-zero goals, much less fueling EV's.

- California is currently ahead of the curve in terms of adding utility and small-scale solar capacity at a rate greater than predicted increases in demand from EV's, but will likely start to fall behind when the state implements mandated reductions in gas-generated power in accordance with their net-zero goals. Today, California generates only 69% of the state's energy needs, and is occasionally unable to meet peak energy demands.
- Given current economic headwinds, it's not obvious that public and private utilities will be able to increase energy production as quickly as needed, or predicted, as new energy projects become less viable with: increased project financing costs due to higher interest rates; higher construction costs due to high inflation; and longer waits in Interconnection Queues.
- **Based on historical growth rates in wind and solar, both of which have already benefited from policy support in terms of grants, rebates and tax incentives, the simultaneous and aggressive goals of transitioning to EV's, and away from carbon-based electricity generation, is likely to fail in California and New York, and on national level -- if attempted.**

To put the federal goals in perspective, if only 15% of the nation's vehicles are EV's by 2030, as predicted by McKinsey (Philipp Kampshoff, 2022), then to offset the 5% increased energy demand without burning more fossil fuels requires adding new green-energy generation capacity equal to more than 4 Grand Coulee Dams, or 15 Diablo Canyon-sized nuclear plants.

If at some point the federal government follows California's lead and adopts similar rulemaking, then it would be useful to consider a scenario where 50% of the nation's vehicles are EV's and 100% of the reliable gas and coal electricity generation has been retired. In this scenario the total new green-energy generation required would be 3,200 billion kWh/year, equal to: 80% of today's total energy generation; 56 Grand Coulee dams; or 194 Diablo Canyon-sized nuclear plants. To produce this much energy with solar alone would require exclusive use of 11.3 million acres, an area approaching half of the farmland in California. If the energy was produced only by onshore wind, which has lower energy density than solar, non-exclusive use of 132 million acres would be required, an area 25% larger than the entire state of California, the third largest state in the nation (hence the push for offshore wind generation). There will likely be increasing environmental and NIMBY concerns and lawsuits given the scale, slowing the rate at which solar and wind generation can be implemented.

It is the opinion of this author that reaching both the EV, and net-zero generation goals with California's level of enthusiasm is unlikely to succeed. In a best-case scenario, supply chain issues and slow consumer adoption of EV's at the national level will limit EV growth to rates that won't overly stress power systems as fossil-based energy is slowly removed – if removed at all. Net-zero goals incorporate Renewable Energy Certificates, which can be used to greenwash brown energy. Other tactics, such as credits for low-income assistance programs can also be used to offset fossil generation, keeping fossil generation online.

If, however, the federal government follows California's lead and mandates EV's while simultaneously ridding the grid of fossil-fuel based electrical generation, then what's more likely to happen is: a less reliable grid; more expensive energy; higher transportation costs; and a lower quality-of-life for most U.S. citizens, especially those with limited means. That, and the lights go out.

Introduction

The California Air Resource Board (CARB) has recently created rules forcing vehicle manufacturers to completely convert all new light vehicles sales to zero emission vehicles (ZEV's) by 2035 with 68% of new vehicles being ZEV's in 2030. Several of the 17 other states currently following CARB standards have signaled their intent to implement the new rules including New York and Washington. In 2021 California also codified its goal (AB-1279) to reach net zero carbon emissions by 2045, and cut greenhouse gas emissions by at least 85%. More recently Senate bill 1020 was signed into law which requires 90% of retail electrical and 100% of government electrical from renewable carbon-free sources in 2035.

In August, 2021 the Biden administration issued Executive Order 14037 setting a *goal* that 50 percent of all new passenger cars and light trucks sold in 2030 be zero-emission vehicles, including battery electric, plug-in hybrid electric, or fuel cell electric vehicles. It also directs the Secretary of Transportation and the Administrator of the EPA to consult with the Secretaries of Commerce, Labor, and Energy on ways to achieve the goals. Policy support of the goal might ultimately include tax incentives, grants for research projects, restrictions on oil and gas production, or EPA regulations. The administration also issued Executive Order 14057 directing the federal government to buy ZEV's and carbon-free electricity.

The publicly stated goal of EV proponents is to convert to zero-emission vehicles powered by green-energy sources. With that in mind this paper assumes that: we still drive the same number of miles each year, and that we continue to buy, and own vehicles at the same rate. To simplify the analysis, we will also ignore energy greenwashing schemes which may mask brown-energy generation with renewable energy and carbon certificates, or credits. Net-zero goals will be interpreted as "*zero means zero"*, as marketed.

The road to net-zero emissions for light vehicles (cars, light trucks, etc.) is challenging. There are many potential obstacles to Electric Vehicle adoption such as:

- Vehicle range and charging times
- Vehicle price, especially for EV's with enough range to compete with gas vehicles
- Raw materials for EV motors and batteries: cost, source, availability, and environment concerns
- (Fast) Charging station availability (rural areas, street, multi-family dwellings, work, school, etc.)
- Electricity costs at Level 3 commercial charging stations
- Coming state mileage/road taxes to replace lost gas and diesel tax revenue

In spite of the challenges, the state of California has imposed new rules on the sale of light vehicles. Under the new CARB rules, 35% of new vehicles sales must be zero emission by 2026, 68% by 2030, and 100% by 2035. Currently, out of more than 36 million vehicles registered in California, only 1.3 million are EV's. Assuming the state is successful in implementing the CARB rule, the number of EV's could increase to almost 17 million in 2035, nearly half of all registered vehicle. Of course it's also possible that many Californian's won't buy new EV's and will instead keep their old cars longer than normal, or import used gas and diesel vehicles from other states. If California is serious, it will no doubt find a way to disincentivize residents from taking advantage of those options.

A single gallon of gas contains enough energy to easily propel a mid-sized car at highways speeds for 30 miles. That's a lot of energy, and we use a lot of gasoline in the USA. So, if we want to replace gasoline and diesel fuel with electricity generated from renewable resources, then it's important to ask; how much electricity do we need; where will it come from, and can we realistically increase reliable, green-energy production to meet the goals and rules for EV sales? If we end up burning more fossil fuels to generate electricity to power EV's, then there's really no benefit to using EV's in terms of reducing green-house emissions.

The power grid in the U.S. is extremely reliable, so much so that most people never give a thought to having sufficient power to operate anything that they choose to plug into a wall outlet, including EV's. However, EV's consume significantly more energy than a new toaster or big-screen TV. An average EV is similar to one half of an average home, so it's not unreasonable to ask if our electrical generation and distribution systems will continue to be reliable if there is rapid growth in the number of EV's on the road. The question of reliability is even more important given goals of transitioning from reliable fossil-fuel based electricity generation to unreliable solar and wind generation.

This paper largely focuses on California based on: the number of vehicles, the new rules on EV sales and carbon emissions, and on California being a leader in the conversion to renewable energy. Also, California has already demonstrated that their energy grid is marginal. The state was forced to import 31% of their electricity in 2021, and in Sept, 2022 their electrical systems could not handle the peak demands of air conditioners. This occurred in the early evening as people came home from work on a warm day, and the setting sun eliminated solar energy production. Ironically, Californian's were asked to refrain from charging their EV's in the early evening only a few days after the new CARB rules were announced. In 2021 solar power supplied only 12% of California's total energy needs, 19% if you include small-scale generation (e.g. home solar). One has to wonder how much worse the shortages will be when less reliable solar energy accounts for an even greater percentage of California's energy mix

The *Average EV*: Comparing Gas and Electric Vehicles

The California CARB rules don't limit choices to battery-electric vehicles (BEV's) only, they also allow plug-in hybrids (PHEV) and alternative non-polluting fuels such as hydrogen. In the state, BEV's currently outsell PHEV's by a factor of five or more. In this paper we'll focus on BEV's and PHEV's and treat both as battery-only. The CARB rules will limit the number of PHEV's a manufacture can sell. Also, starting in 2026 PHEV's are required to have a minimum range of 40 miles, so it seems reasonable to assume that most daily driving is likely to be on battery. Other ZEV types (e.g. hydrogen) are not likely to be a significant factor in the next decade.

We're all very familiar with the miles-per-gallon metric (MPG) used for both gas and diesel powered vehicles. With electric vehicles there is a similar metric of miles-per-kilowatt-hours (mi/kWh). There's an alternative electric vehicle metric of MPGe, which is a useless marketing gimmick designed to make consumers feel good when comparing electric to gas-powered vehicles. Both the MPG and mi/kWh metrics are often inverted. For example, we might specify how many gallons it takes to drive one mile, or 100 miles.

The ever popular Ford F150 pickup comes in both gas and electric versions. Using this truck as an example, we have the following EPA estimates :

- Gas: 4 gal/100 miles or 25 miles/gallon (MPG)
- Electric: 48 kWh/100 mi or 0.48 kWh/mi or, inverting, 2.1 mi/kWh

If we know how many miles are driven in a year then we can easily compute how much gas or electricity will be used. While the F150 Lightning is very popular, it uses almost twice as much electricity per mile as a Tesla 3. As with gas vehicles, how much energy is required to fuel an EV depends on the vehicle, driving style, and on outside temperatures. For the analysis in this paper we'll use the following parameters which assumes that we're only changing fuel technologies, not lifestyles.

- Average number of miles driven (US) **14,263 miles/year** (KBB)
- EV average energy consumption: **0.35 kWh/mile** (ecosavings.com based on EPA estimates, not actual)
- Multiplying we predict that the "***average EV*" will consume 4,935 kWh/year** (or close to half of the average home consumption of 11,000 kWh/year)

Today's use model for EV's is more likely to be that of a second car, or one used primarily for urban commuting. With the CARB rules the use model for EV's will become similar to today's gas-powered vehicles meaning: greater driving distances in rural areas, more utility (e.g. light trucks), more passengers and their stuff, vacation trips, etc. This is the motivation for the "*average EV*".

Electrical Energy Primer

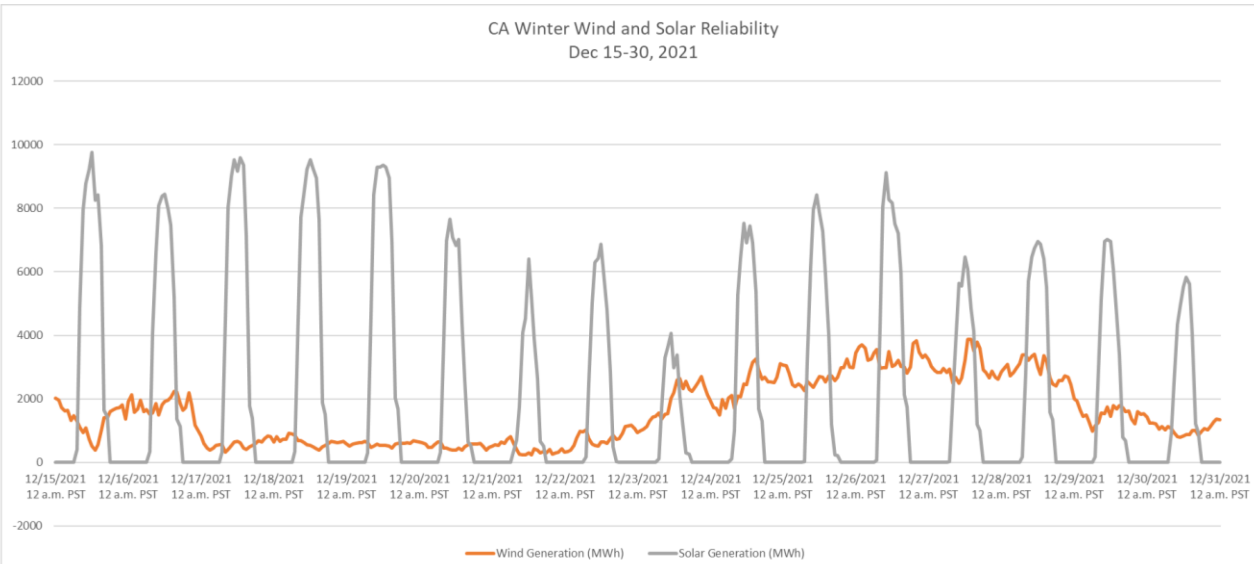
Electricity consumption is quantified in terms of *power* and *energy*. Electrical power is rated in Watts and represents the rate at which energy is consumed, or delivered. Electrical energy is expressed in Watt-hours. For example, your home *energy* bill is based on the number of kilowatt-hours consumed. If you own a 1000 Watt space heater, then you'll be billed for 1kWh (1000 Watt-hours) for every hour that you use the heater at maximum output. If you use the space heater for 5 hours, then you'll be billed for 5 kWh of energy. Similarly, if you have our *average EV* that consumes 0.35 kWh/mi and you drive 100 miles, you'll be charged for 35 kWh of energy when you recharge the batteries. Electricity residential costs per kWh vary by region but in June 2022 were: 10 cents in Washington State, 22 cents in New York, 29 cents in California, and 44 cents in Hawaii. Public charging stations can be as high as 40-70 cents/kWh --not great news if you can't charge at home.

The terminology is the same with electricity generation. For a power plant with a power capacity of 100 MW (100 million Watts), then the maximum amount of energy it can produce in one hour is 100 MWh. (megawatt-hours). The maximum amount of energy a 100MW plant can generate in one year is 100 MW-year. However, we almost always work in Watt-hours, so, 100MW for an hour*24hours/day*365days/year = 876,000 MWh per year or equivalently 876 GWh/year (gigawatt-hours per year).

The actual amount of net energy production in a power plant is always less than the maximum because of downtime for maintenance, lack of fuel (sun, wind, water, natural gas), grid problems, or lack of demand (idled). For many power sources the net production is also less than total production because some of the energy generated is consumed in the process of producing the energy; running cooling pumps for example. Using the 2,240 MW Diablo Canyon Nuclear facility as an example, we would expect that over 8,760 hours in a year it would produce 19,622 GWh. In 2021 it actually produced 16,477 GWh. For that reason, we attempt to use actual net energy whenever possible in this paper. If the plant consistently produced 16,500 GWh each year then we might express the average production as 16,500 GWh/year.

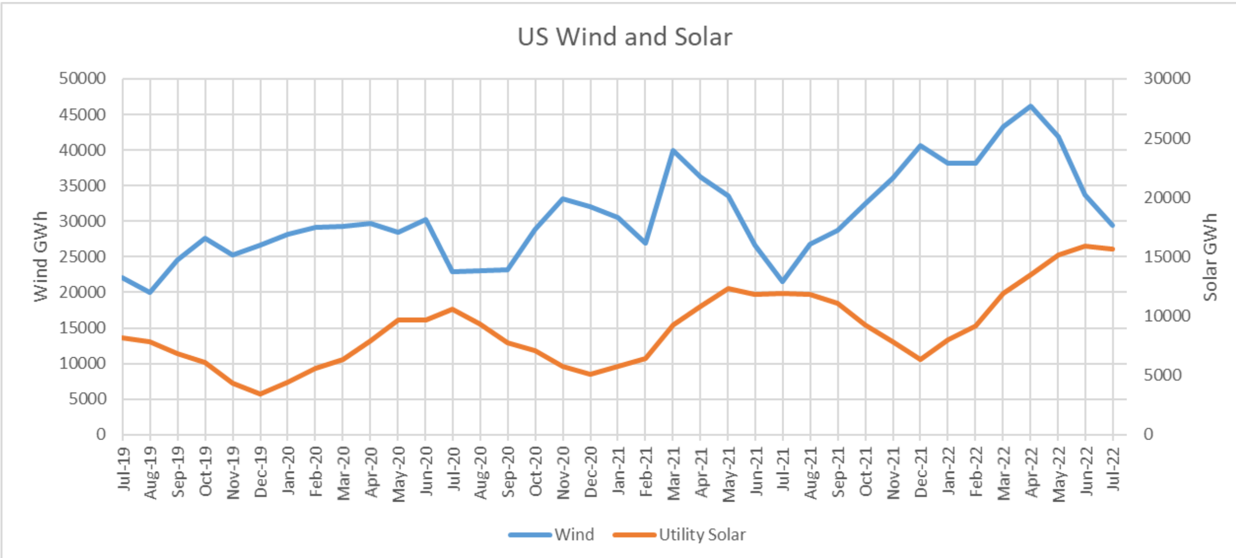
The transportation of energy across space, and time, results in losses. Transmission lines and transformers all have losses. If you want to store energy for later consumption, for example in a battery storage system, compressed air storage system, or pump-back lake, then there are losses associated with those technologies as well. The round-trip efficiency for the Tesla Powerwall 2 battery storage system is specified as 90%. For simplicity, we will ignore energy system inefficiencies which might consume 5% of the energy, keeping in mind that, with storage, those losses could be significantly greater (e.g. 5% transmission + 10% storage).

Wind and solar power sources are not reliable. Short-term output varies with weather and day-night cycles. In the graph below, the effects of cloudy weather can be seen in the daily solar output, along with close to a week of windless days. Long-term output varies by season and longer-term weather trends. Short term variations can potentially be handled by battery storage. For example, the problems California had with peak power demands might be solved with more battery storage.



Seasonal variations are more challenging for electrical energy. Battery storage might help for a few hours, or a couple of days, but not for weeks or months. The Moss Landing battery energy storage system (BESS), the largest in the world, is rated as 400MW/1,600 MWh. Meaning, it can deliver about 1/6th of the power of the Diablo Canyon nuclear facility, for about 4 hours, then it's done until recharged.

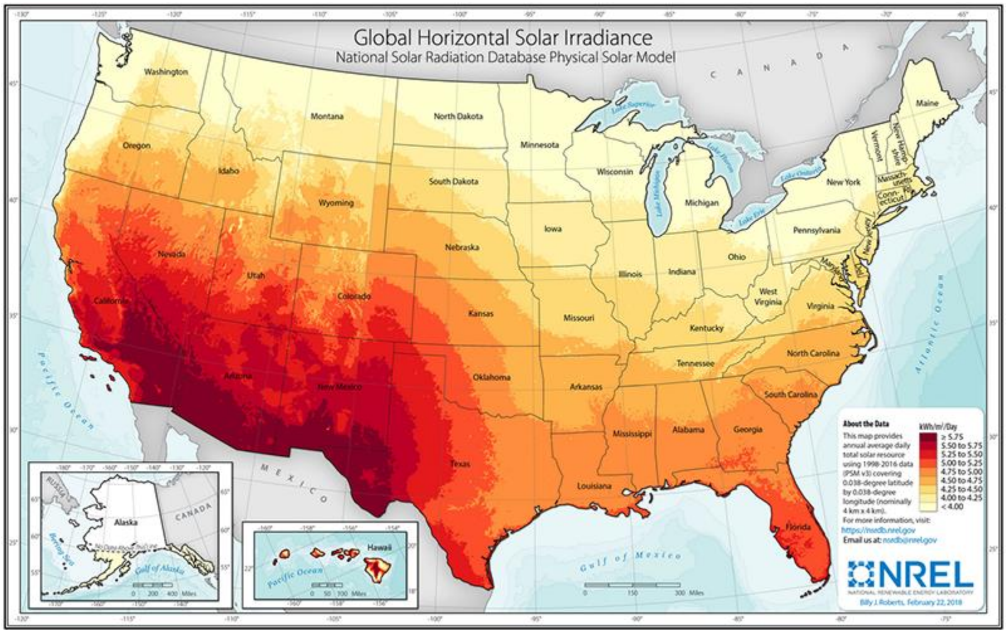
This next graph illustrates the challenges with variability over longer periods in time. Solar power on a monthly basis is quite predictable, but also highly variable with the minimum generation in winter only about 1/3 of the peak generation in summer -- even in California. Onshore wind energy is obviously less predictable than solar, and when aggregated over the US, is generally lower in the summer, and peaking in spring. Looking from Mar-21 to Jul-21 the monthly wind energy generation dropped by almost 50%.



Today, solar only accounts for 4% of US electricity production so when the sun goes down, or it's cloudy, then 4% is the maximum loss of the grid's generating capacity. Wind (all onshore) is currently 9% of total production. Keeping the lights on will be increasingly difficult when wind and solar become a significant portion of the energy mix, and there are fewer fossil-fueled plants that can be brought on line to smooth out the variations.

Care is required when reading press releases about new energy plants, especially with wind and solar, as maximum power capacity is always what's given, not net energy generation. For example, the Solar Gen II facility in California has a rated power capacity of 163 MW. If we multiply by the number of hours in a year we get 1,428 GWh/year of energy production. However, actual production is closer to ¼ of that amount at 384 GWh/year. The reason is that the sun doesn't shine with the same intensity through the day and is especially dim at night. This reduction is known as the Capacity Factor, which in this case is 27%. For the Diablo Canyon Nuclear Plant, the Capacity Factor is much higher at 84%.

Not all locations are equally blessed when it comes to solar power -- the amount of usable solar radiation in Seattle is significantly less than Phoenix. In Phoenix the solar energy falling on one square meter of area might be 6-7 kWh per day (solar-electric.com) while in Seattle there would be about half of that at 3-4 kWh per day per square meter. Converting that energy from solar radiation to electricity incurs significant losses. PV solar panel efficiency is currently only about 15%-20%, so a solar panel with an area of one square meter in Seattle might produce, on average, 0.5 kWh per day, or enough to move our *average EV* 1.7 miles per day. Of course, in Seattle, most of the solar energy is produced in the summer. With short days and cloudy weather, winter production is near zero.



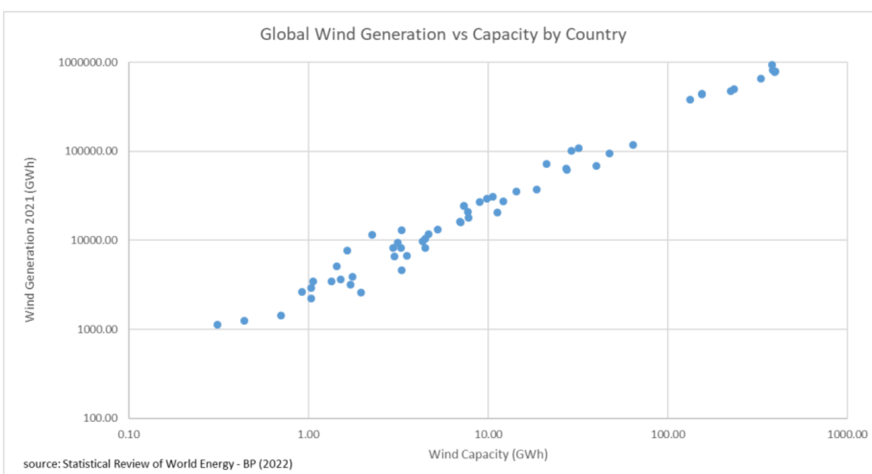
Another consideration for solar is the amount of land used. The [BLM estimate] is that 8.5 acres is needed to generate 1 megawatt of power from photovoltaic solar (PV) panels. This seems reasonable considering the 2 PV facilities listed in the table below. The first facility uses concentrated solar power (CSP) technology, not PV.

California Solar Facility	Capacity (MW)	Area (Acres)	Area (km^2)	acre/ MW	Generation (MHh/year)	Capacity Factor	Density (GWh/km$^{2/}$/year)	Type
Genesis Solar	250	1950	7.89	7.8	540,091	24.7%	68.4	CSP
Adobe Solar	20	160	0.65	8.0	46,569	26.6%	71.9	PV
Solar Gen II	163	1451	5.87	8.9	384,216	26.9%	65.4	PV

Another important efficiency metric relates to the amount of energy produced by an area of land, that is energy density. This takes into account not only the efficiency of the panels, but other factors such as: panel spacing, roads, buildings, and other facility areas used for maintenance. While 70 GWh/km^2 per year is a reasonable number for these installations, other CA installations are currently producing 80 GWh/km^2. Obviously this number will be much less for facilities in northern states.

Wind energy is also not equally distributed across the US and usually has seasonal variations. Comparing the NREL [solar]() and [wind]() maps it's easy to see why Wyoming has 42 times more wind generation than solar in 2021 (8,500 GWh vs. 200 GWh). It's also easy to see the potential for off-shore wind generation.

Wind variability affects the relationship between capacity and generation. Looking at global wind generation vs wind capacity in the plot below (each point is the wind capacity vs production for a country) we see that there's a very linear relationship. From the slope we can estimate a Capacity Factor of 25%. For 1 GW of capacity, estimated annual generation would be 1GW * 8760hours/year * 0.25 = 2,190 GWh/year. Offshore capacity factors are higher due to higher winds. For the [UK](), the offshore capacity factor is 42%. Of course, off-shore wind generation is more expensive to install and maintain.



In terms of wind power and energy density there's quite a bit of variability. One NREL estimates that wind farms average 3MW/km^2. Given a capacity factor of 25%, the annual generation would be 6GWh/km^2, or about 8 percent of a PV solar facility. However, while occupying large areas, wind farm use is not exclusive. That said, many oppose the loss of scenery, and there are environmental concerns, especially with bird kills.

Load flexibility is one of the tools utilities plan to use to avoid having to add peak generation capacity. In other words, don't charge your EV or run the dishwasher during times of peak energy demand. From a power distribution perspective load shifting to non-peak times is useful. Much of the grid is sized to handle peak loads, so there is excess distribution capacity at non-peak times.

For the most part, load flexibility, or shifting, does not increase the energy supply, it simply smooths out the power demands. It can appear to increase energy supply if power generation sources are underutilized; a gas generating plant doesn't always operate at full power. This also happens with both wind and solar when supply exceeds demand (or cheaper sources of power are available). In that case, wind turbines are idled, or solar generated electricity is not allowed onto the grid (curtailed), or is exported to another state only to be replaced with brown energy later in the evening. Perhaps you've driven past a wind farm on a windy day and noticed that only a few of the wind turbines were spinning.

Battery storage can be thought of as production shifting; capturing excess energy produced when the wind is blowing or the sun is shining and then delivering that energy at a later time when there's increased demand. Utility-scale battery energy storage systems (BESS) are expensive ($/kWh), and home units even more so. The Tesla Powerwall II+ costs $8,500 and provides 13.5kWh of storage. If the average home uses 11,000 kWh/year, then on an average day, the home uses 30 kWh, more than twice the Powerwall II+'s capacity. So, battery systems today are useful for shifting energy by a few hours, but not so much for dealing with a week of cloudy weather.

While this paper is not focused on energy transmission, every new energy sources must request connection to the grid. This obviously requires studies and analysis to ensure that the grid can handle the new energy distribution from the source to the intended customer, and what upgrades are needed, if any. This is a process that can take several years. In-process projects are listed in "interconnection queues". According to Berkley labs, only 23% of the projects in interconnection queues from 2000-2016 were actually built.

Finally, a word on electrical units. In this paper, and elsewhere, you'll see energy and power expressed different ways depending on scale. Here are some useful conversions for power (W) and energy (Wh).

- 1000 W = 1 kW (kilowatt)
- 1000 kW = 1 MW (megawatt)
- 1000 MW = 1 GW (gigawatt) but is sometimes written as 1 thousand MW, or 1 million kW
- 1000 GW = 1 TW (terawatt) but is sometimes written as 1 billion kW

For example, annual U.S. electricity consumption for the last decade has been about 4000 billion kWh each year, which sounds more impressive than 4000 TWh, and is perhaps easier to relate to since we all pay for kWh on our utility bills.

A Sense of Scale

Now that we understand what energy is, and how much a EV is likely to use in a year we can begin to understand the scale of the problem. Let's start with existing energy production including major sources of California's in-state utility generation, and a couple of other examples as well.

A useful way to get a sense of scale is to imagine that, for each source of energy in the table below, 100% of that energy is used to fuel a single type of demand such as homes, or in this example EV's. Having established that our *average EV* will consume 4,935 kWh/year we can easily compute the number of EV's supported by each energy source.

ENERGY SOURCE	Capacity MW	Delivered GWh (2021)	EV's SUPPORTED
CA Diablo Canyon Nuclear Plant	2,240	16,477	3,338,806
CA Utility Solar		33,260	6,739,618
CA Wind (Total)		15,173	3,074,571
CA total natural gas power	41,000	97,431	19,742,865
CA Large Hydro		12,036	2,438,907
CA Geothermal		11,116	2,252,483
CA Total		185,493	37,587,234
WA Grand Coulee Dam	6,809	56,068	11,361,307
Single Home Solar (typical 6 kW system)	0.0060	0.0096	1.22

Primary source: energy.ca.gov

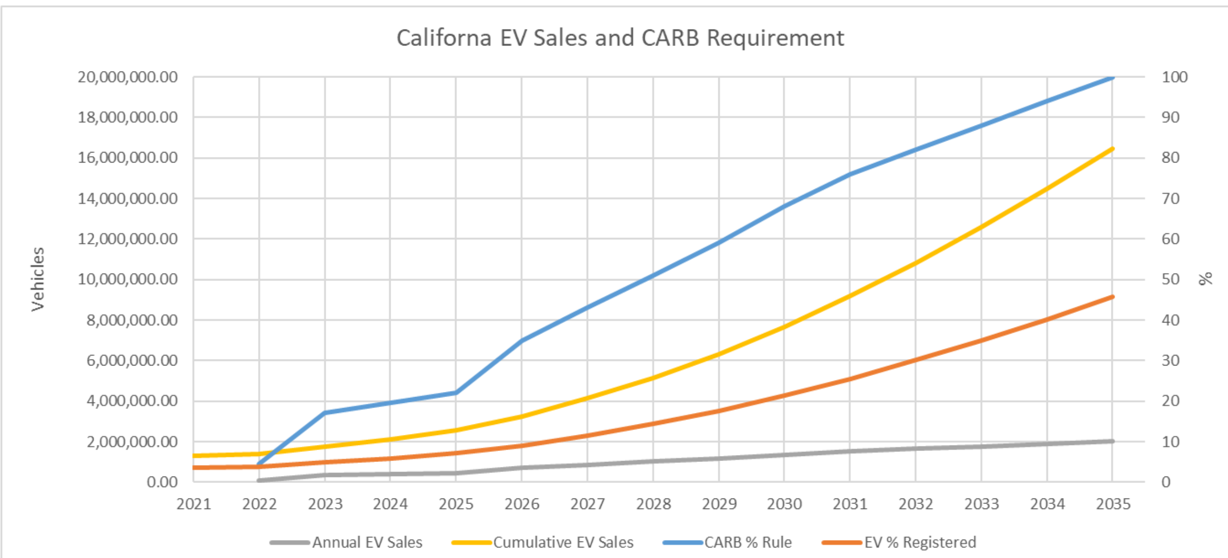
The were 36.5 million vehicles registered in California in 2019 (CA DMV). This is an interesting number in that it's very close to the same number of vehicles that can be supported using all major in-state utility-grade energy production sources. Put another way, if all of California's vehicles were suddenly switched to EV's, then there's just enough in-state utility energy to operate them all. Homes, businesses and government operations would need to use rooftop solar, or imported power.
Another interesting number is 2 million. That's the number of new vehicles registered in California each year; it's a fairly steady number. The Diablo Canyon Nuclear Facility, which Gov. Newsom recently elected to keep running, has enough capacity to support 3.3 million vehicles, or a little over one and a half years' worth of new-EV sales in 2035 -- when all new vehicles sales are ZEV's. The 2021 utility-scale wind and solar renewables combined would support five years of new CA vehicle sales, as would Grand Coulee dam, the largest electricity generating plant in the US.

The average 6 kW home solar installation should, comfortably fuel one *average EV*, with a little left over for the house. In a different way of computing this, the average EV consumes about half as much energy as the average home. So if the solar installation provides enough energy for the home to be completely off grid, it might possibly power two vehicles, but not the home. Of course, if you live in an apartment, you're unlikely to have the roof space required for everyone in the complex to have a 6kW system. What about putting solar cells on the EV? Thinking back to our Seattle/Phoenix example, a one meter-square panel on the roof of your *average EV,* in California, might be good, on average, for 2-3 miles of travel per day depending on location and panel efficiency. Just don't park in the shade!

The *average vehicle* will require the annual production from 62 square meters, or 664 square feet of southwest utility-grade solar. This is a little more than 25'x25', or the area occupied by 20 sheets of 4'x8' plywood. This includes all land use, not just the solar panels.

California's EV and Net-Zero Transitions

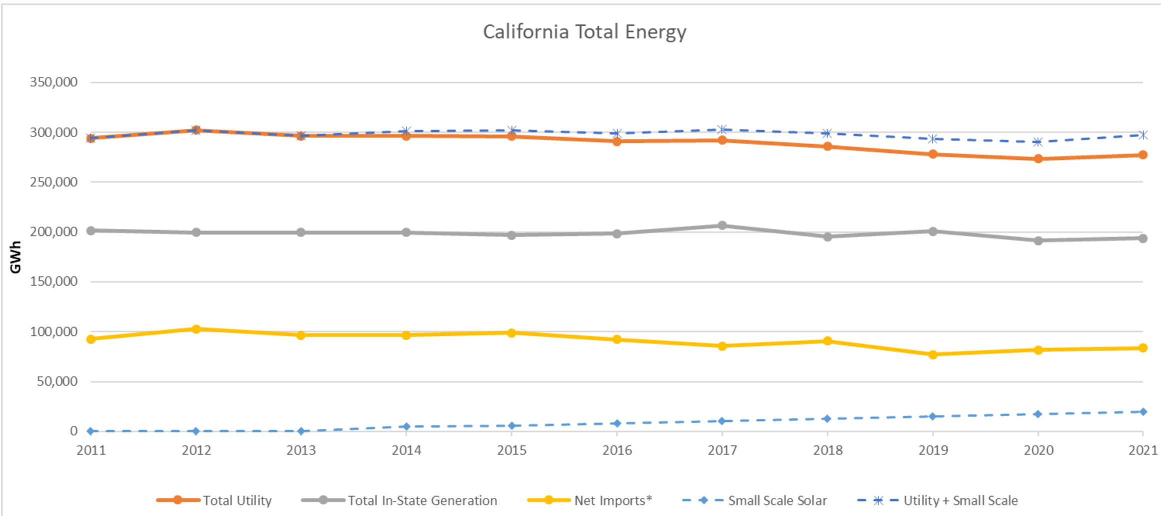
New vehicle sales in California have been very steady at 1.9 - 2.2 million per year (source energy.ca.gov). Using historical ZEV registrations, the CARB mandate percentages, and assuming that new vehicle sales remain constant at 2 million/year we can predict the cumulative number of ZEV's registered in California. **Throughout this paper this will be referred to as the *California Model*. It predicts that about 21% of all vehicles will be EV's in 2030, increasing to near 45% in 2035**



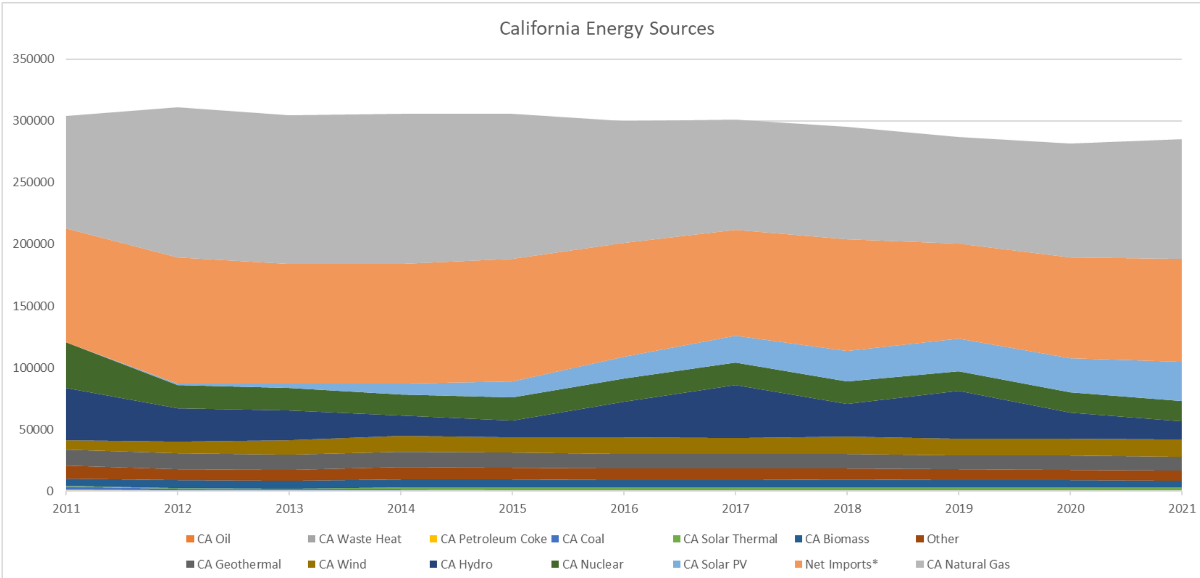
The prediction of 16.5 million ZEV's in 2035, or 45% of all registered vehicles, is not the result of a direct mandate requiring that half of all registered vehicles be EV's, but is instead the result of the cumulative effect of each year's new vehicles sales, and the sales gas/EV mix rules. For example, if the mandate was 10% the first year and 20% the second, then first year sales would be 200,000, second year sales would be 400,000, and the cumulate sales after the first two years would be 600,000 or 1.6% of all registered vehicles. If new vehicle sales drop below 2 million/year as a result of consumers hanging on to their old gas vehicles, or importing used gas vehicles from other states, then the predicted sales shown in the plot will be wrong. Right or wrong, the assumptions are that CARB and Gov. Newsom are serious, and that there's sufficient state-wide consumer demand for EV's, and supply, to enable new-vehicle sales to remain unchanged at 2 million/year. The *California Model* is admittedly simple, but also useful for getting a sense of scale because it's easy to understand, minimizes bias, and it doesn't require any data other than the rules, an assumption about annual sales, and a starting point – current EV registrations.

From the predicted sales of *average EV's,* the 2030 energy requirements will be approximately 38,000 GWh, increasing to 81,500 GWh for 2035. This represents a need to increase all in-state utility power production by 43% over 2021. If energy is produced by in-state renewables, then California wind/solar utility power will have to nearly double by in 8 years, and triple in 12. Of course 2035 is only the start of the 100% ZEV rule with slightly less than half of California's cars then fueled by electricity (or hydrogen).

Let's see if California is on a trajectory that will achieve that kind of energy growth.



Looking at the [total-utility and in-state utility production]() from a historical perspective we can see that total utility generation has been dropping. While in-state utility generation has been in a slight decline, imports have declined more than 10% from the 2012 peak. Looking further at the small-scale (non-utility) solar, we can see that it pretty much offsets the decline in imports. So, overall, there has been no net change in energy consumption for a decade; not an encouraging trend.



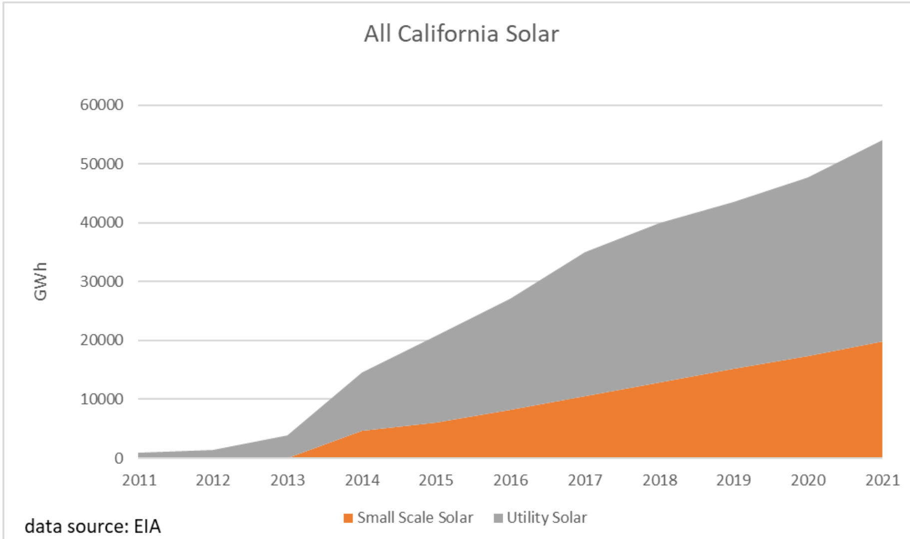
Looking more closely at the utility sources of California's energy, we can make the following observations:

- Natural Gas and imports provided 68% of California's energy in 2021
- It has taken only 10 years for utility solar to increase from nothing to 31,000 GWh/year, and, with the help of declining hydro, becoming the third largest energy source in 2021
- Hydro, another renewable energy source, has declined from a peak of 43,000 GWh/year to 14,500 GWh/year essentially offsetting the gains in solar. When the drought causing the decline in hydro power ends, generation should increase, as it did in 2016-2017
- Wind energy production has been flat for a decade and was less than half of solar in 2021. Solar dominates California's new electricity generation capacity.

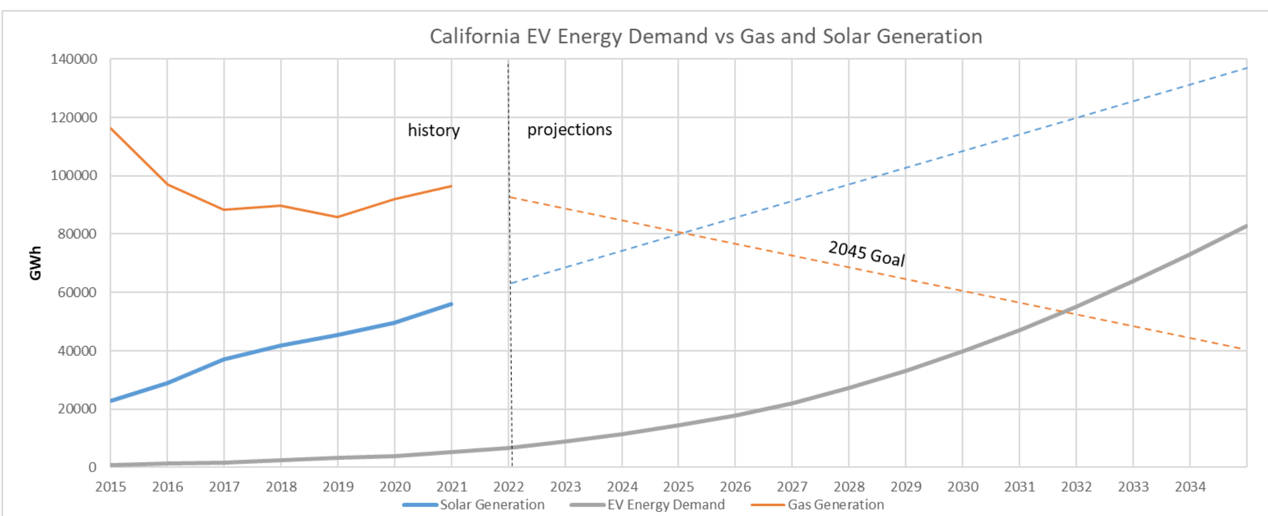
California has heavily promoted residential and commercial small-scale solar generation. They've even mandated solar on new homes. Growth in that sector has been surprisingly steady driven by both tax credits and net electricity metering (NEM). While federal tax credits for home solar systems had been decreasing and were set to expire in 2023, the federal Inflation Reduction Act bumps the credit back up to 30% and extends the timeframe to 2032. The NEM program which allows homeowners to sell excess energy back to the utilities is currently in a state of flux. Proposals for NEM 3.0 have included selling at discounted rates for homeowners and a monthly fee, both of which reduce the incentive for homeowners to install expensive solar systems. A decision on net metering was expected in late Sept,2022, but is now expected to be delayed until after the November elections.

While home solar installations may not be used to power EV's directly, they do serve to offset demand for utility-generated power so it's appropriate to include all sources of solar when attempting to answer the question of whether or not the lights will stay on.

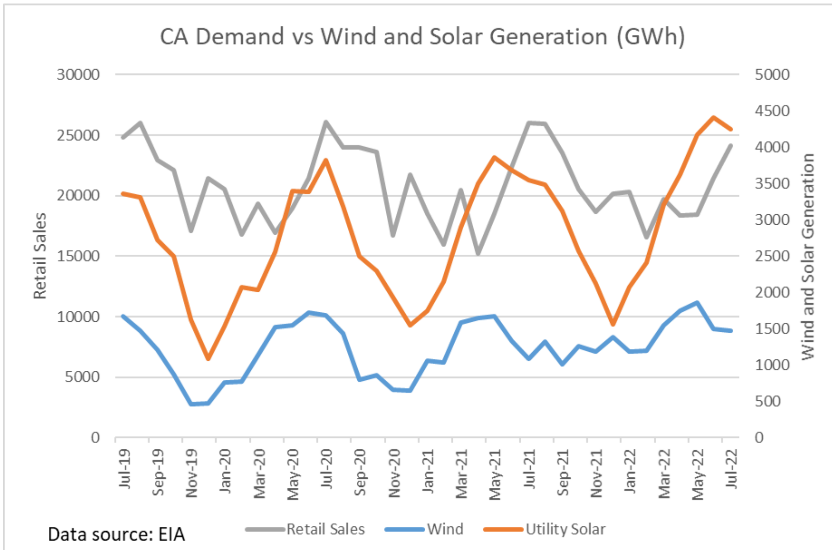
In the next graph we can see that there is significant growth in both utility and small-scale solar, and that the growth has been very steady, adding about 6,000 GWh of new energy each year. It's important to remember that this historical growth was encouraged by policy support in the form of rebates and tax incentives, for small-scale, net metering.



As shown in the graph below, the rate of solar energy growth looks promising compared to EV electricity demands -- until one considers the simultaneous requirement to remove fossil fueled generation from the grid. While solar generation has been steadily increasing, natural gas electricity generation will need to simultaneously decrease to meet the 2035 and 2045 net-zero goals. To simplify the analysis, the illustrated goal is to have eliminated gas fueled electricity production by 2045. When looking at the graph below, keep in mind that almost none of the 56,000 GWh solar produced in 2021 went to fueling EV's. It's the rate of change (slope) that's most important; solar growth is faster than EV demand until about 2030, but the removal of gas generation largely offsets solar growth. The question is, will California add solar power fast enough to offset increased demand from EV's *and* reduced generation from retiring gas-generated electricity?



While looking at annual generation is useful, it's also important, especially with wind and solar, to look at output variations over shorter time intervals. Clearly, battery storage can be used to shift peak solar output during the day, to peak demand in the early evening. It's less clear if battery storage is economically feasible for dealing with even a short stretch of cloudy, or calm days. The bigger problem is seasonal variations as can be seen in the next graph.



As we would expect in California, electricity demand (retail sales) peaks in the late summer with increased use of air conditioning. Looking at the solar output we can see that there are two problems. First, peak solar output occurs in the May-Jun timeframe, while peak demand last from July into September. The second problem is that the seasonal drop in demand during the winter months is only about 30%, while the drop in solar power generation is closer to 65%. So, if California wants to depend primarily on solar power, then the solar capacity required is determined not by annual, or even peak-summer demands, but by winter demands, which might result in excess spring capacity; for which there is no market. Importing power in the winter might be a problem as winter is when peak demand occurs in colder, northern states. It appears that in-state wind power has a seasonal pattern similar to solar, so adding more wind in California won't necessarily help mitigate the winter decline in solar.

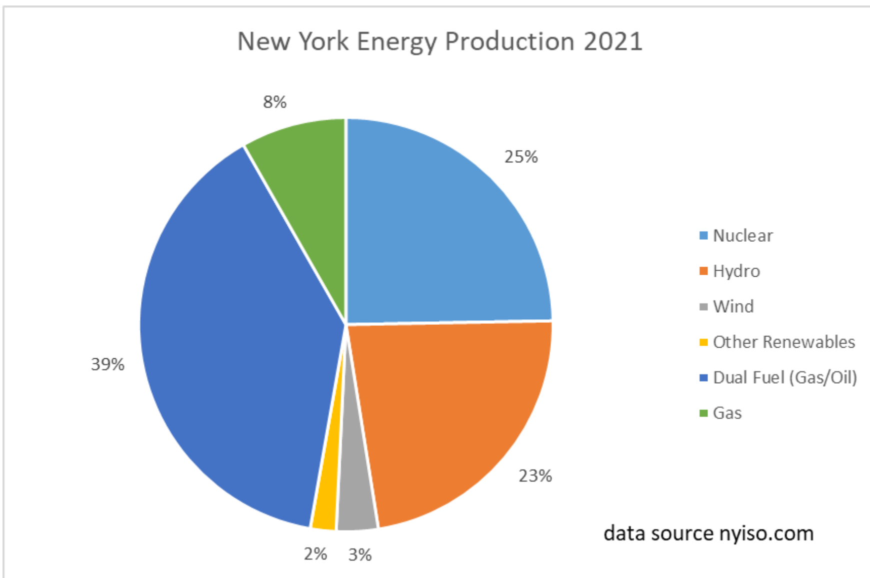
In summary, Californian's can replace natural gas electricity production with solar, or, they can replace gas vehicles with EV's. Both goals are not likely to be simultaneously achieved without significantly increasing the rate at which new solar generation is added (and adding storage for reliability) and/or significantly reducing energy consumption (e.g. driving fewer EV miles).

A Quick Look at New York and Washington States

New York wants to have a zero-emission grid by 2040. For Washington, the target is 2045, the same as California. This is important because New York State gets 47% of its electricity by burning fossil fuels. California is slightly worse at 49%. In Washington, the largest source of hydro power in the nation, fossil fuels account for 17% of its in-state generation and 23% of its consumption. **The point of this is that all three states have a stated goal of eliminating reliable carbon-emission power while simultaneously significantly increasing electricity demand with forced transitions to EV's.**

New York

From data contained in the [NYISO 2021-2040 System & Resource Outlook Report]() we learn that 47% of New York's electricity is generated using fossil fuels, or about 60,000 GWh in 2021.



New York's goal is 70% renewable energy in 2030. This will require 41,000 GWh/year of new production. Add to this 4,400 GWh/year to fuel 21% of their 4.2 million light vehicles for a requirement of 45,400 GWh/year.

To retire all fossil generation by 2040 will require 60,000 GWh/year of generation plus at least 10 GWh/year to power half of the state's vehicles as EV's, totaling 70,000 GWh/year.

New York has a goal of 6,000 MW of solar by 2025. Using a Capacity factor of 13%, 6GW translates to 8,000 GWh/year which would be a 4000 GWh increase over 2021 where a little less than 4,000 GWh were produced, of which only 30% came from utility-scale facilities.

Operational windfarms have been producing about 4,400 GWh/year, a modest increase from 4,000 GWh since 2014. However, New York has 4.3 GW of offshore wind under development, and has a goal of 9GW by 2035. Using a 42% Capacity Factor, the planned development adds 15,800 GWh/year with a goal of increasing to 33,000 GWh in 2035.

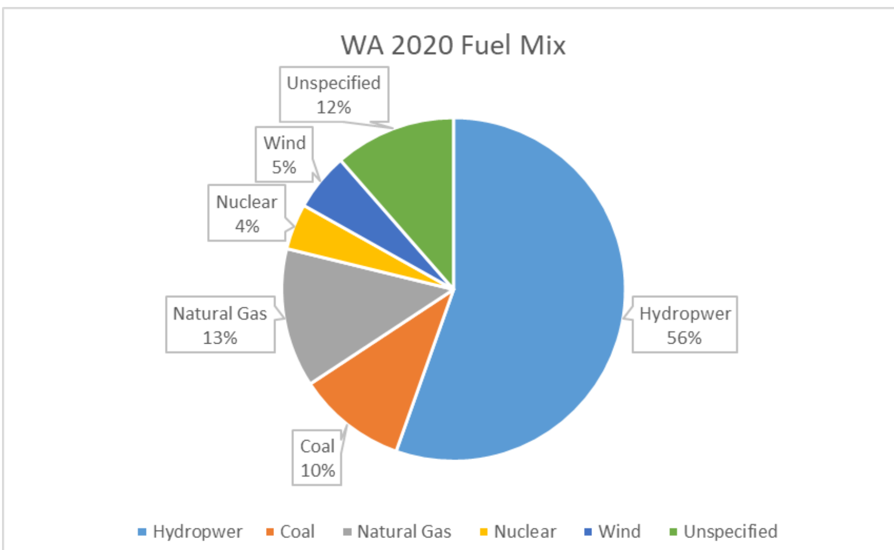
So, ignoring the fact that New York imports nuclear power from Ontario, power that is going away, in total, New York needs 70,000 GWh/year to go 100% renewable, and has goals for 37,000 GWh/year of new solar and wind generation, or about half of what's required.

The NYISO report contains some interesting scenarios on how to achieve the green-energy goals. The authors also recognize the challenges:

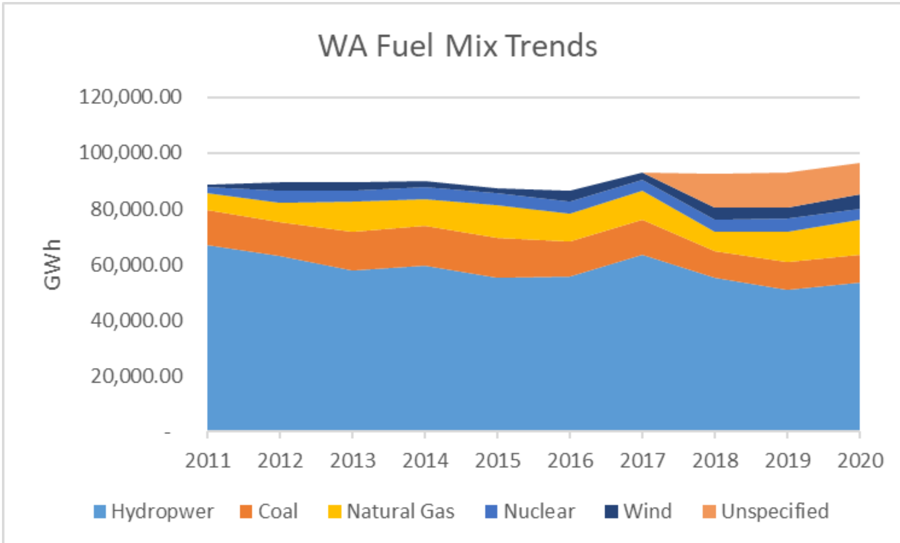
> *By 2030, roughly seven years from the publication of this report, an estimated 20 GW of additional renewable generation must be in-service to support the energy policy target of 70% renewable generation by 2030. For reference, 12.9 GW of new generation has been developed since wholesale electricity markets began more than 20-years ago in 1999. Over the past five years, 2.6 GW of renewable and fossil-fueled generators came on-line while 4.8 GW of generation deactivated. This Outlook demonstrates the need for an unprecedented pace of project deployment that will require significant labor and materials available for New York over a long period of time.*

Washington

In 2019 Washington's Governor Inslee signed into law the Clean Energy Transformation Act (CETA) which commits Washington to an electricity supply free of greenhouse gas emissions by 2045. It has several transition milestones, the first being the complete elimination of coal-generated electricity in 2025. This bill already had utility districts scrambling to figure out how to keep the lights on. The ZEV transition will make the transition harder by increasing demand. For example, in 2020 Puget Sound Energy (PSE), the state's largest utility, used coal to provide 23% of energy demands and natural gas to provide 27% for a combined 50%. For the entire state, 23% of the electricity came from natural gas and coal generation.



In 2019 Washington state law was changed to incorporate an unspecified power source category. From the graph below we see that hydro, gas and coal all appear to drop when unspecified appears in 2018. We can also see that hydro power has been generally decreasing, while gas generation hit an all-time high in 2020 at 12,600 GWh, this in spite of CETA goals. With the help of the new "unspecified" category, coal has been decreased from a 2015 peak of 14,400 GWh, to 10,000 GWh in 2020.

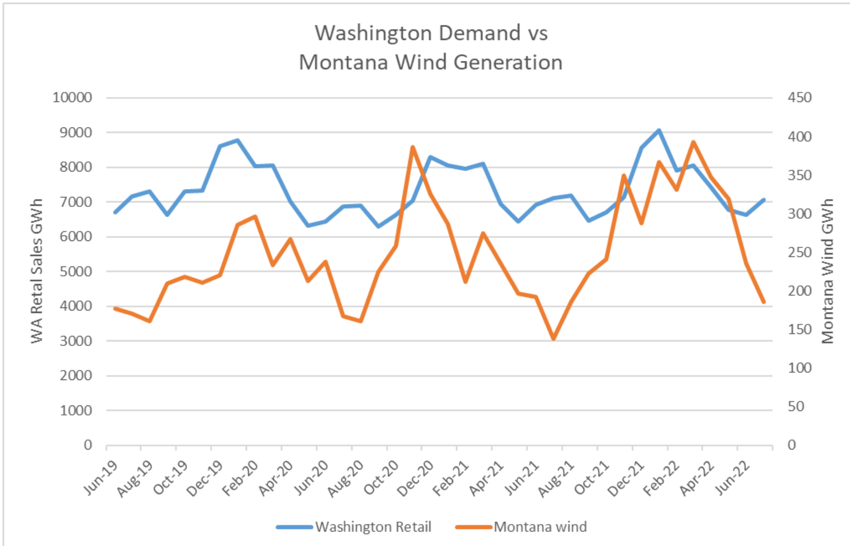


Using the *California Model*, Washington State, with 2.9 million registered vehicles, will have 1.3 million EV's by 2035 requiring 6,400 GW/year for fuel.

Based on [PSE's Interconnection Queue](), which is a list of projects that might connect to the grid, there are about 1,230 GW of in-state solar and wind power projects under study, or in more advanced stages of planning. Using a 25% capacity factor, in-state projects, would only produce 2,700 GWh/year. Interestingly, the in-state projects only account for 15% of the power listed, the other 85% is mostly wind power projects in Montana, which is where PSE currently generates a significant amount of power from a coal plant. Using PSE (21% of Washington energy) to estimate completed new power projects for the entire state, then a likely optimistic estimate for the amount of new generation would be 23,000 GWh -- not quite enough to eliminate 22,600 GWh of coal and gas (2020) plus 6,400GW/year of fuel for EV's.

The estimate of new power is likely high because PSE generated 50% of its electricity using coal and natural gas, more than double state's 23% for the same year. PSE needs more green projects than other utility districts.

Looking at Washington demand and Montana wind generation we can see why Montana wind is a desirable choice for the winter heating and lighting of Washington homes and businesses. Montana generates more wind energy in the winter.



Washington seems to be in reasonable shape in terms of plans to eliminate fossil generation. However, the recent additional requirement for EV's could create a few new headaches for Washington's energy planners, even with all of the greenwashing gimmicks in the Clean Energy Transformation Act.

A Nationwide Perspective

Let's assume that the nation's 290 light million vehicles were instantly transformed to average EV's increasing energy demand by 1,400 TWh/year. But wait! Almost 60% of our electrical energy production comes from fossil fuels, so let's get rid of that too. Now we find that we're left with only 1,600 TWh/year of generation and 5,400 TWh/year of demand. The lights just went out. The point is that, to keep the lights on, we have to continually balance the increased energy demands caused by EV's with the growth in renewable electrical energy and the loss of fossil-fuel based electricity generation.

McKinsey & Company recently published an article titled "Building the electric-vehicle charging infrastructure America needs" This article, while primarily about the needs for charging stations, an important topic, also includes estimates for the number of EV's expected to be on the road by 2030.

The article notes:

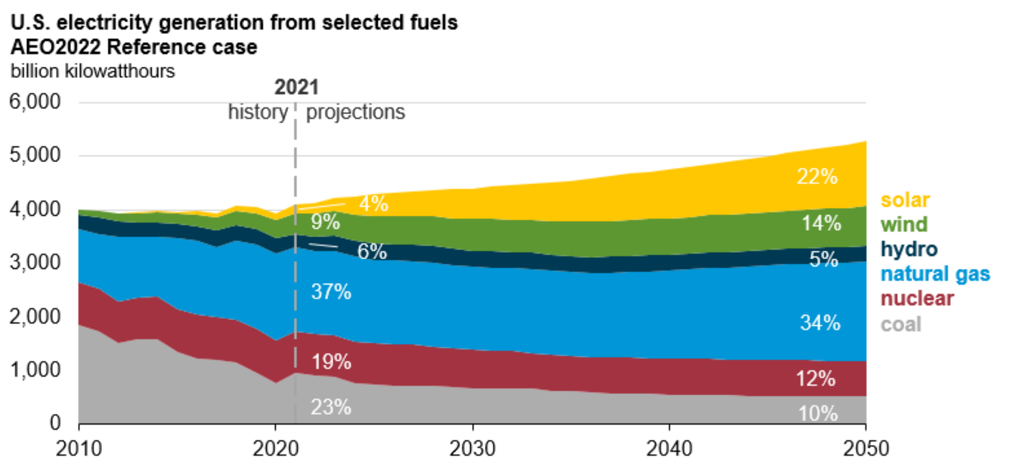
- The federal government has set a target: half of new passenger cars and light trucks sold in 2030 should be ZEVs—a category that includes both battery-electric vehicles (BEVs) and plug-in hybrid electric vehicle
- In a scenario in which the nation reaches the federal ZEV sales target, we estimate that the country's fleet of EVs would grow from less than three million today to more than 48 million in 2030—about 15 percent of all vehicles on the road in the United States.
- Annual demand for electricity to charge them would surge from 11 billion kilowatt-hours (kWh) now to 230 billion kWh in 2030, approximately 5 percent of current total electricity demand in the United States

Note: Using our *average EV*, McKinsey's 48 million vehicles would use 237 billion kWh/year, which is very close to and only slightly higher than McKinsey's own 230 billion kWh prediction for 2030.

McKinsey's prediction of 48 million vehicles is could be high primarily because the federal target doesn't have the legal weight of a CARB rule, at least not yet, so demand will be largely driven by consumer enthusiasm based on perceived costs and conveniences, not on the administration's goals. EV's are a great option for many people, but they're not the right solution for everyone.

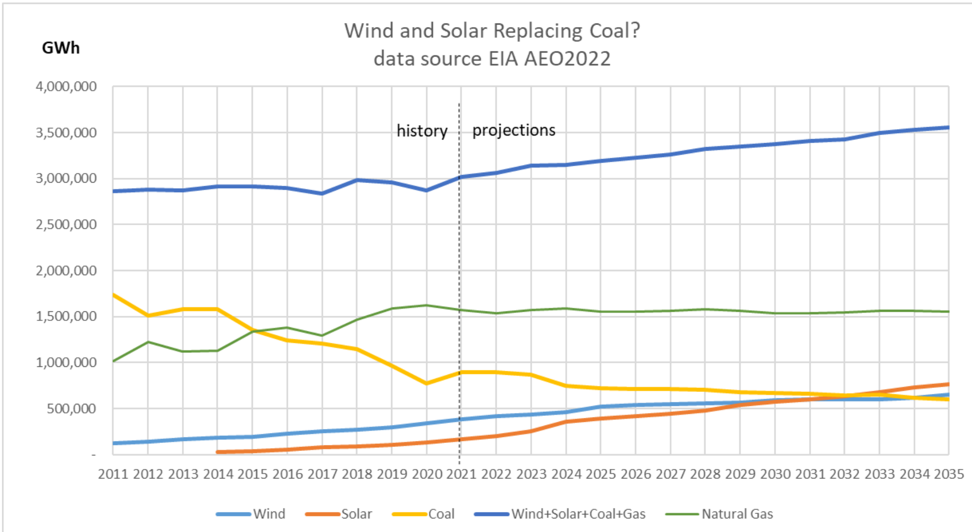
The McKinsey article largely brushes over the power requirements which are "only 5 percent of current total electricity demand". So, is there a problem on the horizon with U.S. energy generation?

Looking at the graph below which is from the U.S. Energy Information Administration's (EIA's) [Annual Energy Outlook 2022] (AEO2022), we can see that total power generation in the US has been relatively flat at 4000 TWh/year for the last decade. While there has been a significant decrease in energy produced from coal, that loss of generation has been offset mostly by increases in fossil gas generation, followed by wind and solar. Looking at the EIA's predictions, it's obvious that they are very bullish on solar, and somewhat surprisingly, are not predicting declines in natural gas and coal electricity generation. In fact, they predict constant natural gas generation out to at least 2035.



Source: U.S. Energy Information Administration, *Annual Energy Outlook 2022* (AEO2022) Reference case
Note: Solar includes both utility-scale and end-use photovoltaic electricity generation.

Unstacking the data in the graph above, and focusing on gas coal, solar, and wind out to 2035, we can see that wind and solar energy are, somewhat miraculously, able to suddenly reverse the declines in coal power production (with help from gas prior to 2021). This is largely due to the sudden flattening of coal's rate of decline. Predicted solar growth also appears to accelerate just before wind growth starts to falter. With these minor miracles, U.S. wind and solar production are projected to increase net energy production by 300,000 GWh in 2030. In 2035 the net increase is just shy of 500,000 GWh. *Note: one should always be slightly suspicious of "hockey stick" shaped projections, i.e. those with sharp inflection points.*

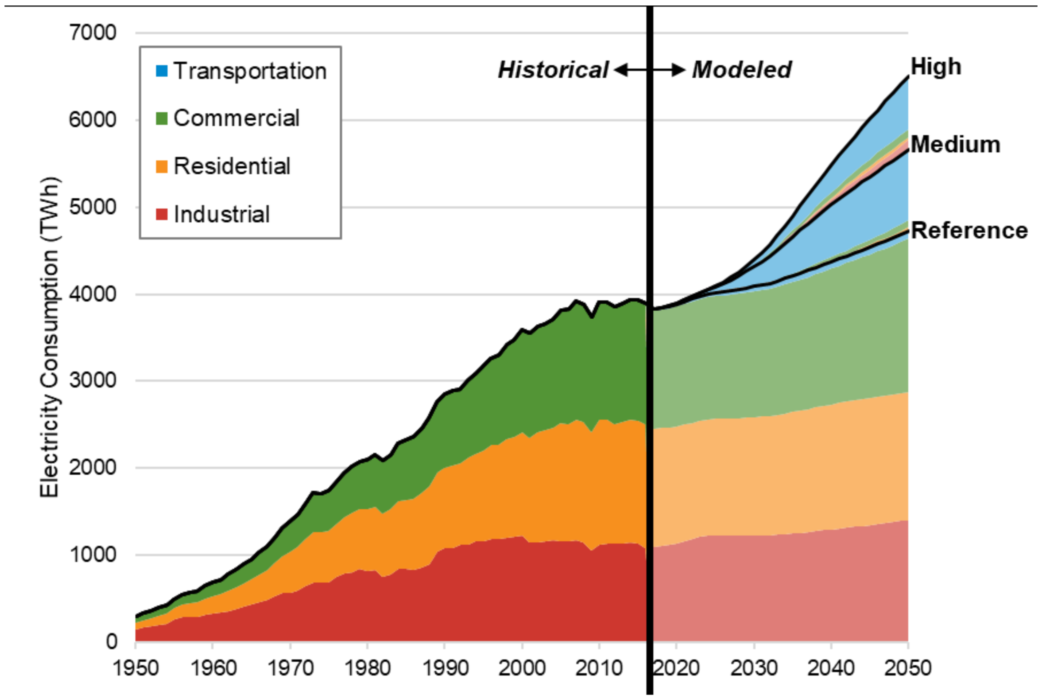


The EIA green-energy projections seem a bit optimistic, but not completely unreasonable based on the demonstrated wind and solar growth prior to 2022 and new incentives. However, the historical growth includes small-scale solar installations with estimated values, not measured. Many home solar systems fail to produce the expected energy based on installed capacity due to installation constraints and shadowing, so, any estimates based solely on installed capacity and location could be biased high. Some coal generation may be necessary to deal with the wind and solar reliability issues, so perhaps that projection is reasonable as well. That said, keeping coal and gas plants active is politically undesirable. Also, keeping generating capacity around is expensive, especially when operated well below capacity and only for peak demands.

There are currently around 290 million light vehicles registered in the U.S. Let's assume that the federal government follows California's lead and implements the same EV rules. In that event, using the *California Model*, 21% of all registered vehicles will be EV's in 2030, and in 45% in 2035. Is this likely? Probably not, but it's also a possibility with strong-arm policy support including ZEV mandates, and other policy changes that significantly increase gas and diesel prices, such as restricted leasing of federal land for oil production, carbon taxes, and restrictive pipeline policies.

Having established that our *average EV* will consume 4,935 kWh/year, it's easy to compute that in 2035 the nation's 130.5 million EV's will consume 644,000 GWh, which is much higher than the EIA's 500,000 GWh increase in production.

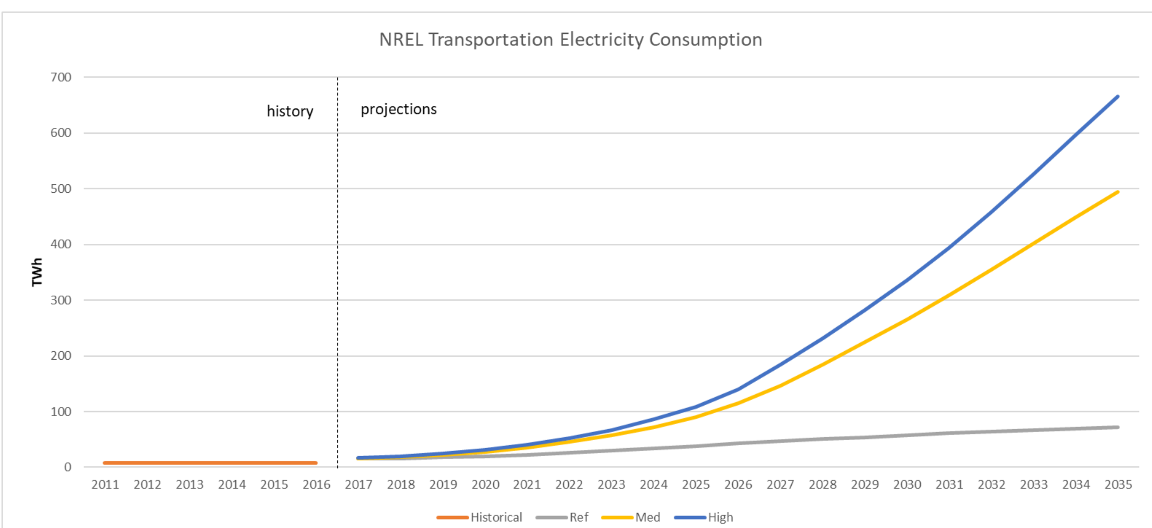
In 2018 the National Energy Renewal Lab (NREL) released a report titled "Electrification Futures Study: Scenarios of Electric Technology Adoption and Power Consumption for the United States", which contained the following chart.



The NREL describes the three scenarios as:

- **Reference scenario**: the least incremental change in electrification through 2050, which serves as a baseline of comparison to the other scenarios.2
- **Medium scenario**: a future with widespread electrification among the "low-hanging fruit" opportunities in electric vehicles, heat pumps and select industrial applications, but one that does not result in transformational change.
- **High scenario**: a combination of technology advancements, policy support and consumer enthusiasm that enables transformational change in electrification.

Here's the same data focusing only on transportation, and only out to 2035. The historical data is primarily public transit and light-rail.



In this table we have the EIA's prediction for net energy generation increases along with the various EV demand predictions. Red indicates that consumption exceeds generation capacity.

Year		2030 (GWh)	2035 (GWh)
Generation	EIA Net Energy Production Increase Predictions	300,000	500,000
Consumption	California Model (assumes federal mandates)	300,500	644,000
	McKinsey (assumes federal goals)	230,000	
	NREL Reference	58,000	72,000
	NREL Medium	266,000	456,000
	NREL High	336,000	667,000

Comparing the EIA's predictions for net energy production increases with the various predictions for EV energy demand it's reasonable to conclude that **the U.S. probably won't have an energy shortage problem and the lights will stay on through 2035 provided:**

- **The federal government doesn't follow California's lead in mandating sales quotas**
- **Car manufacturers continue supply enough gas and diesel vehicles to meet demand**
- **EIA Forecasts are accurate:**
    - **Solar and Wind production growth continues, and even accelerate**
    - **Fossil Gas electrical generation remains flat**
    - **Coal electrical generation levels off with only slight declines**

The EIA's predictions on gas and coal appear problematic given the political pressure for eliminating fossil-fuel based electrical energy generation. If gas and coal generation start to go away, grab a flashlight.

We're going to need more land!

Again, trying to get a sense of scale, it's instructive to ask just how much space is required for solar generated power to fuel half of the nation's cars. Let's assume that all of the panels are installed in the sunny southwest. We'll use California solar projects as a reference for predictions.

Existing California Solar Plants and 2021 production:

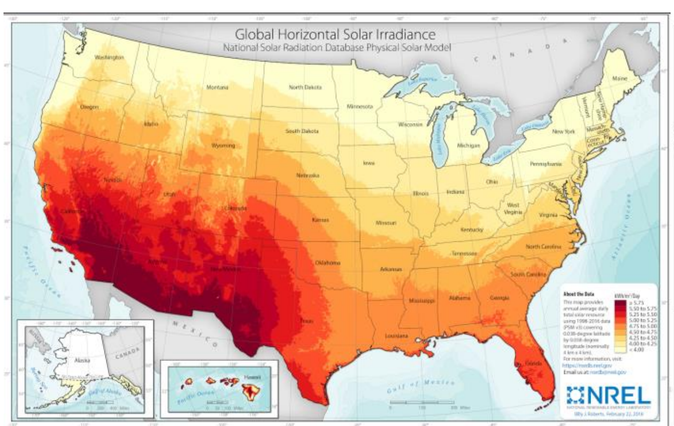
- **Genesis Solar Energy Project**
    - 1950 acres or 7.9 km^2
    - 540,091 MWh (CSP)
    - **68.3 GWh/year/km^2**

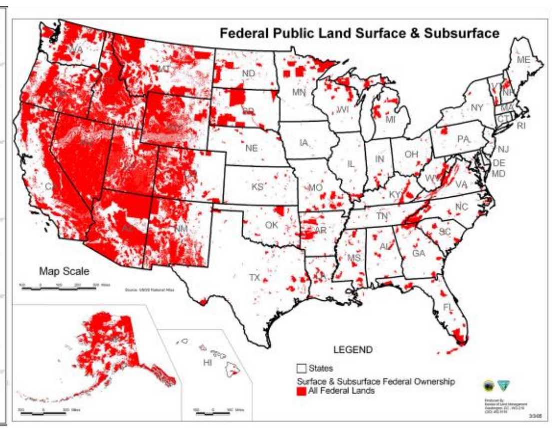
- **Adobe Solar**
  - 160 acres or .65 km^2
  - 46,569 MWh (PV)
  - **76.w GWh/year/km^2**
- Solar Gen II
  - 1451 acres or 5.9 km^2 over three facilities (Arkansas, Sonora, Alhambra)
  - 384,216 MWh (PV)
  - **65 GWh/year/km^2**

When location and all of the extra space for maintenance access, other equipment, and other inefficiencies are taken into account, a practical metric for solar facility land efficiency might be 70 GWh/year/km^2. Some photovoltaic plants in Southern California can produce more than 80 GWh/year/km^2.

Using 70 GWh/year/km^2 we can estimate that to power half of the nation's cars (145 million) with solar-generated electricity would then require facilities occupying 10,200 square kilometers, 2.3 million acres, or 3,500 square miles, an area about the size of Yellowstone National Park. That said, 2.3 million acres is small compared to the 24 million acres of farmland in California. However most of the farmland was put into production before 1970, with the peak of approximately 35 million acres occurring in 1969. The EPA was created in 1970. The point being that it was easier to develop land for other uses 50 years ago.

Of course all of the solar wouldn't be built in at a single location. If all of the projects were similar to California's Adobe Solar Project in terms size, 160 acres, then to fuel 145 million EV's there would likely be more than 14,000 solar generation sites. Deployed on that scale there will could be significant, and growing resistance to the solar projects by environmentalist and NIMBY residents which could limit the rate at which projects can be completed by filing NEPA lawsuits. While some of that solar can be installed on roofs and other existing structures, most will replace farmland and natural habitat with fields of solar arrays. Unlike wind energy, converting farmland to solar largely prevents growing food and other crops. While there's a lot of empty desert in the southwest, most of it owned by the federal government, the desert isn't truly empty, it's just sparsely populated with insects, plants and animals, many of which will likely need protection. In areas with more precipitation, solar farms can may require deforestation leading to soil erosion and stormwater runoff problems.





From the Bureau of Land Management's website we learn "Across the 245 million acres (3521 km^2) of public land it manages, the BLM has prioritized a combined total of roughly 870,000 acres for solar energy development within its land use plans". That's enough land to power about 56 million cars (20% of the nation's current 290 million cars). The BLM's has created 19 solar energy zones (SEZ's) distributed across 6 states: Arizona, California, Colorado, Nevada, New Mexico, and Utah.

OK, so land has been prioritized. What's the reality? From 2010 to December, 2021 BLM has permitted 37 projects, 23 of which are operating and 11 of which are pending construction, and only 3 of those include storage. The total capacity for both operational and planned projects is 6.9 GW. Total acreage: 57,300. So, while 870,000 acres have been prioritized, 29,000 acres (117 km^2) are currently producing electricity, and only 21,000 acres (85 km^2) are pending construction. The projects that are pending construction will add capacity for only 1.2 million EV's, or 0.4% of the nation's light vehicles.

The Biden administration wants to issue permits for 25 GW of renewable power on public lands by 2025. This will require Department of the Interior to significantly up their game given they've permitted less than 7 GW in the last decade. Also worth noting, the permitted projects will still require EPA approval and grid Interconnection Agreements. Assuming slightly higher efficiency in the future, the 25 GW capacity will occupy 207,500 acres (840 km^2) and will would support 4% of the nation's light vehicles, or reduce the nation's coal and gas electricity generation by less than 2%. Still not very impressive.

Offshore leasing for wind farms is the domain of the Bureau of Ocean Energy Management (BOEM). Current offshore wind capacity is very small, 0.042 GW, perhaps enough to power 30,000 EV's, or 0.01% of the nation's vehicles.

The Biden administration has set a goal of 30 GW of offshore wind capacity by 2030. Using a 42% capacity factor, predicted 2030 generation would be 110,500 GWh, enough to power less than 8% of the nation's vehicles, or to reduce the nation's coal and gas production by less than 5%. Note: New York's offshore projects are included in this goal.

It's obvious that the administration's goals for energy production on federal land fall well short of what's required to support EV goals, much less the elimination of fossil-fuel electricity generation. Combining offshore wind and solar goals, there would be enough energy to either power 12% of the nation's vehicles as EV's, or to reduce fossil-fuel energy production by 7%. It's important to remember that these are only goals.

Energy Distribution

While the focus of this paper is on electricity generation, there are several important distribution issues worth mentioning

All of the new solar and wind facilities need to be connected to the grid. This means new power corridors from the generation sites, when not co-located with existing substations, to some location where they can tie into the grid. In other words, more land, more permits, and fewer unmolested vistas.

Wind and solar generation changes energy distribution from a geographic perspective. Solar installations are much more efficient in the southwest where not only is there more sunlight, but there are large open land areas. This is already helping fuel California fuel EV's. The eastern seaboard is a different story. Not only is there less sunlight, but finding hundreds of thousands of acres of open land for solar facilities might be challenging. This begs the question, are the nation's grids capable of distributing wind and solar generated electricity to the areas with the greatest increases in demand?

Here's one example where the answer is no. The [BPA's 2022 Cluster study] identified then need for $2 billion in direct capital costs to increase transmission capacity across the Cascade Mountains due to "Renewable mandates such as Oregon House Bill 2021 and Washington's Clean Energy Transformation Act".

The process of getting new power generation on a grid starts with an Interconnect Request (IR) and ends with an Interconnect Agreement (IA). An excellent study by Lawrence Berkeley National Laboratory discusses the growth in new requests, and the effects that has had on amount of time it takes to go from IR to IA. In 2021, the median duration from IR to IA was about 3 years; the time to commercial operation was about 5 years. With the flood of new EV rules and net-zero goals one might expect that more projects will get added to the Interconnection Queues and that project times will increase.

Overall energy consumption and generation has been flat for the last decade. It's unlikely that the existing infrastructure is capable of handling significant increases in peak demand. This includes not just the high-tension power lines, but also lines and transformers at the residential level. If an EV is equivalent to half of a home in terms of consumption, and half of the homes have EV's, then that represents 25% more electricity consumption in the neighborhood. There are typically 5-10 houses connected to the final transformers in the distribution system. What happens if every home on a given transformer buys one or two EV's? Well, it means that the chances of a local outage increases due to blown breakers, or exploding transformers. The utilities will likely become more aggressive in managing your energy consumption profile to manage peak loads. This means: variable pricing; controlling when you can run your appliances, or charge your car; load limits (taking over your thermostat); and if all of that fails, load shedding and rolling blackouts. Will all utilities have the resources to implement load management at the residential transformer level? Probably not.

As California has so recently demonstrated, peak demand occurs on warm days after the sun goes down, yet peak solar generation is closer to noon. This suggests that to minimized utility battery storage requirements and losses, EV's should really be charging during the day when most people are at work, or school, the implication being charging stations need to be where most of the EV's are parked during the day, with sufficient stations for at least 1/3 of the EV's.

In Washington state, the Snohomish County PUD recently installed ***two*** $52,000, 62.5kW level-3 fast chargers outside their building. These, the fastest of chargers, can charge a vehicle in 45 minutes. A $154,000 state grant *partially covered the project costs*. How many of these are we going to need?

Final Thoughts

If governments are successful in replacing most internal-combustion vehicles with electric vehicles, and in eliminating fossil fuels from the primary energy mix for power generation in the timelines envisioned, then the quality of life for all but the wealthiest will be significantly degraded. Energy will become very expensive and unreliable. As energy costs drive the costs of all goods and services, inflation will be unrelenting, and not just for transportation and home energy bills.

About the Author

Robert Cutler has an M.S. Degree in Electrical Engineering from the University of Washington and has 40 years of research and development experience in instrumentation, measurement science, data analytics and machine learning.