Price Trends in Solar Photovoltaic Systems 2010-2020

A Brief Review of a 2021 Research Report by NREL

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NREL (The National Renewable Energy Laboratory) is located in Golden, Colorado and frequently interacts with other national labs such as Lawrence Berkeley and their branch in Bozeman, Montana. I recently reviewed their research covering ten years of pricing data for residential, commercial, and industrial scale solar photovoltaic electricity systems, including battery storage. The full report is available on the CaliforniaGeo website, **HERE**.

There are various data summaries that have characterized solar PV costs as having fallen precipitously in the past decade (probably due to volume production/sales and greater competition among manufacturers). By review, I learned that the installation price I paid for my own 7.4KW AC system was far higher than the posted data by 2020.

However, this is the nature of acquiring a technology in a small market at an earlier part of its growth. I have enjoyed 8 years of reduced operating costs and secured a 30% federal tax credit for the project. Waiting for lower prices and betting on the continuation of tax incentives might not have turned out well. *[Until the Inflation Reduction Act was passed, tax credits for renewables were frequently "on the block," while generous historical tax incentives for conventional electric production resources continued.]*

I have chosen to feature some of the graphics from the NREL report (with additional labeling by me to enhance their understanding to the layman).

Table ES-1. Benchmark Assumptions

Unit	Description	
Values	2019 U.S. dollars (USD)[a]	
System Sizes	PV systems are quoted in direct current (DC) terms; inverter prices are converted by DC-to-alternating current (AC) ratios; storage systems are quoted in terms of kilowatt-hours or megawatt-hours (kWh or MWh) of storage or the number of hours of storage at peak capacity.	
PV Sector	**Description**	**Size Range**
Residential	Residential rooftop systems, monocrystalline silicon modules	4kW–7 kW
Commercial	Commercial rooftop with ballasted racking and fixed-tilt ground-mounted systems, monocrystalline silicon modules	100 kW–2 MW
Utility-scale	Ground-mounted systems, monocrystalline silicon modules, fixed-tilt and one-axis tracking	5–100 MW

[a] The dollar-per-watt total cost values are benchmarked as three significant figures, because the model inputs, such as module and inverter prices, use three significant figures.

Inversion-Conversion-

Since conventionally delivered electricity is AC (alternating current) and photovoltaic cells generate DC (direct current), a process must be utilized to make this power compatible with common electric devices and for export to utility grids.

This is accomplished with an inverter, with a small loss in the product. All systems in this NREL study used inverter systems for this purpose. RV owners may be familiar with a related process called a power "converter" that turns AC electric power from a shore connection or generator into DC power to charge up their mobile batteries.

The latest companion technology to solar PV in all three categories above is battery storage (which can only take place with DC power). Lithium-ion batteries have migrated well-past their origins within cordless shop tools. They now store power for households, cars, trucks, buses, and aircraft. For the electrical utilities who construct large scale PV arrays, these are becoming matched in capacity with on-site battery storage; sometimes also with nearby wind turbines driving the battery charging, too. The benefit is two-fold for the utility. First, the site can be designed to optimize the solar and or expected wind production to serve a daily load and continue inverted battery delivery into the night. Second, the dispatching of power from grid-scale DC batteries via an inverter system is the fastest response time known.

Scale-

The cost of solar PV is highly dependent on the size of the installation. Large projects cost far less per unit of output. But if we consider transmission challenges of getting electricity to users, then, rooftop residential capacity is the most efficient use of the power because it is consumed close to where it is generated. Losses occur for every mile of transmission and by substations near cities that transform the highest voltage into the common secondary voltage we residents use.

Table ES-2. Comparison of Q1 2019 and Q1 2020 PV System Cost Benchmarks

Sector	Residential PV	Commercial Rooftop PV	Utility-Scale PV, One-Axis Tracking
Q1 2019 benchmarks in 2019 USD/W_{DC}	$2.77	$1.76 -36%	$1.02 -63%
Q1 2020 Benchmarks in 2019 USD/W_{DC}	$2.71	$1.72	$1.01
Drivers of cost decrease	• Higher module efficiency (from 19.2% to 19.5%) • Decrease in BOS hardware and supply chain costs	• Higher module efficiency • Lower material & equipment costs in some categories	• Higher module efficiency • Lower material & equipment costs in some categories • Movement of land acquisition cost from upfront capital expenditures into operation & maintenance
Drivers of cost increase	• Higher labor wages • Higher module costs	• Higher labor wages • Higher module costs	• Higher labor wages • Higher steel prices • Higher module and inverter costs

Economy of Scale reduces costs

Hardware costs remained relatively flat, year-on-year, in Q1 2020, as shown in Figure ES-1, resulting in no change to the percentage of non-hardware, or "soft," costs.[2] Figure ES-2 shows the contribution of soft costs to total costs over time.[3] Also, soft costs and hardware costs interact. For instance, module efficiency improvements have reduced the number of modules required to construct a system of a given size, thus reducing hardware costs. This trend has also reduced soft costs from direct labor and related installation overhead.

In terms of grid load and getting through peak periods during maximum demand in heat waves, batteries installed close to generation resources can be of help. One way for residents or commercial users to remain less affected by time-of-use peak charges, or demand charges at any time, is to install battery storage that can supply a strategized load capacity at their site. It also helps when local outages take place. Local solar generation cannot be exported for utility credit when power is out (to protect linemen working on local lines) but a battery system might be isolated from the meter while still satisfying household loads for a time.

Bill's 2014 Residential Solar PV system was $3.52/watt DC & $4.05/watt AC

Based on our bottom-up modeling, the Q1 2020 PV cost benchmarks are:

- $2.71 per watt DC ($W_{DC}$) (or $3.12/$W_{AC}$) for residential PV systems
- $1.72/$W_{DC}$ (or $1.96/$W_{AC}$) for commercial rooftop PV systems
- $1.72/$W_{DC}$ (or $1.91/$W_{AC}$) for commercial ground-mount PV systems
- $0.94/$W_{DC}$ (or $1.28/$W_{AC}$) for fixed-tilt utility-scale PV systems
- $1.01/$W_{DC}$ (or $1.35/$W_{AC}$) for one-axis-tracking utility-scale PV systems
- $26,153–$28,371 for a 7-kW residential PV system with 3 kW/6 kWh of storage and $35,591–$37,909 for a 7-kW residential PV system with 5 kW/20 kWh of storage
- $2.07 million–$2.13 million for a 1-MW commercial ground-mount PV system colocated with 600 kW/2.4 MWh of storage
- $171 million–$173 million for a 100-MW PV system colocated with 60 MW/240 MWh of storage.

I'd like to explain the last three bullets in the previous graphic illustration. When PV production is paired with storage, the listing shows "5KW/20kWH of storage." This means that when the battery is fully charged with no additions or other outgoing loads, that battery can satisfy a 5,000-watt demand (instant, intermittent, or continuous) until a total of 20 kilowatt hours has been consumed. It's like a car's horsepower compared to 2 gallons of gas remaining in the tank.

These are hard mathematical limits, so residents who want (during an outage) to supply an all-electric home with cooking, refrigeration, air conditioning, water heating, and several "teenager" showers may want to calculate loads versus capacity very carefully.

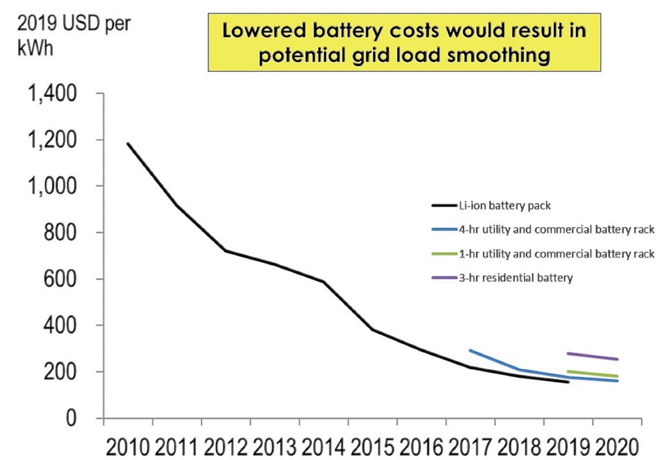

Figure 9. Ex-factory gate prices (spot prices) for Li-ion batteries by product, from Bloomberg New Energy Finance (2018-19) data

In addition to usefulness, the cost of batteries has been falling. More of them are being installed in every size of solar PV installation. If a consumer wants to operate a home or business and doesn't want to install solar, they can still add a battery and charge it using grid power whenever there is no outage. Those with or wanting electric vehicles take note.

Back-up generators take individual effort and fuel maintenance—batteries will work without direct attention.

Many times, manufactured production of equipment "at scale" results in lower costs. It's a "Two-fer" when the item (in this case solar PV panels) are increasingly efficient or effective. This could result in more output or fewer panels—resulting in lower costs or less space required.

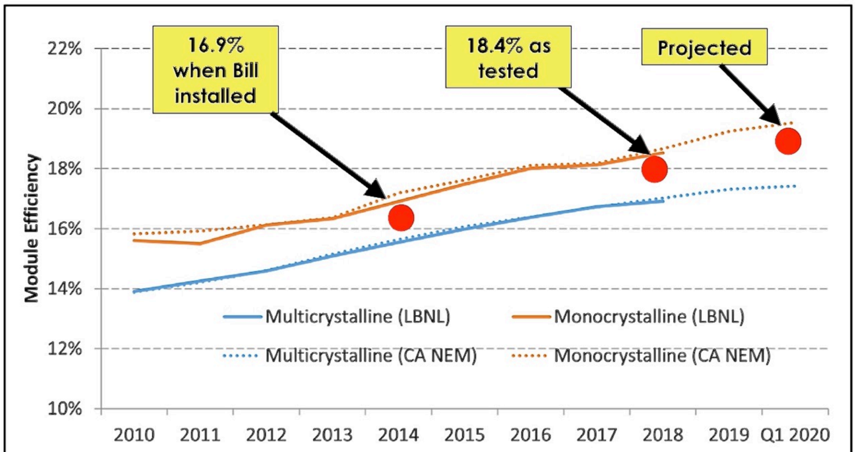

Figure 1. Capacity-weighted average module efficiency trends from the Tracking the Sun LBNL and *CA NEM* data sets, 2010-2020

LCOE (Levelized Cost of Energy)-
This is a financial principle that has guided electrical utilities and their regulators for decades. It's a mathematical approach to answer the question, "Is this investment worth it?" The answer is based on a prediction, but that's helpful, at least. The construction cost and all reasonably expected maintenance and repairs are estimated for 20 years forward and then divided by the number of kilowatt hours of expected generation during that time.

The result is **a "level" look at the cost of generated power for the next 20 years**. Utilities have a responsibility to look for the least predicted future cost of power on behalf of their ratepayers, and regulators are watching. Could there be errors? Sure. Hydroelectric facilities and fossil-fired plants may experience less than expected rainfall or far higher fuel prices over which the utility has no control. *[In case you missed it, this is why LCOE is more dependable for renewable sources because the fuel is free and there's no dependence on weather events.]*

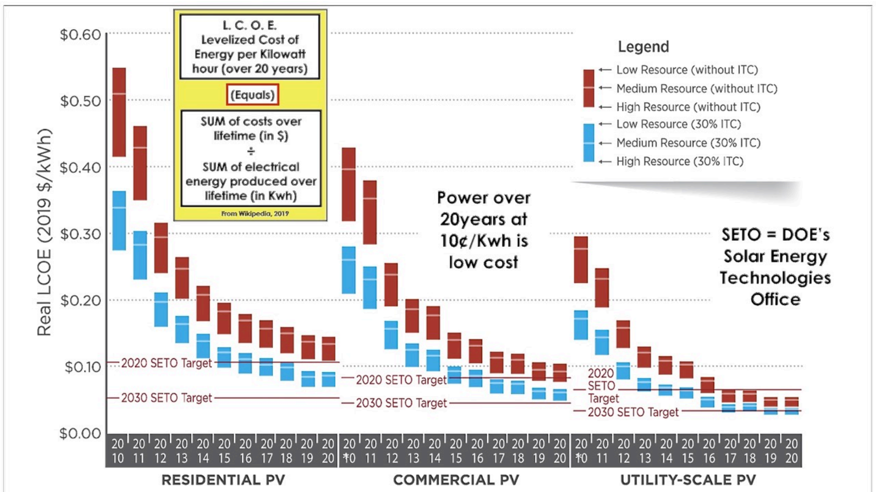

Figure 54. NREL PV LCOE benchmark summary (inflation-adjusted), 2010–2020

LCOE is calculated for each scenario under a low CF (New York City), medium CF (Kansas City), and high CF (Phoenix), but all other values remain the same. Appendix A provides a detailed discussion of the changes made to the models between last year's versions (Fu, Feldman, and Margolis 2018) and this year's versions.

As seen at left, all three sizes of solar installations have fallen over time.

Residents don't often calculate to this detail, but at right, you can see that self-generation at a cost of 5.3¢ per Kwh by 2030 would please anyone in my neighborhood who's paying close to 40¢ in 2023. Tax credits (that are supposed to last for nine more years) help make this possible, although there is grumbling from a current majority party in Congress about reducing that and other climate spending priorities.

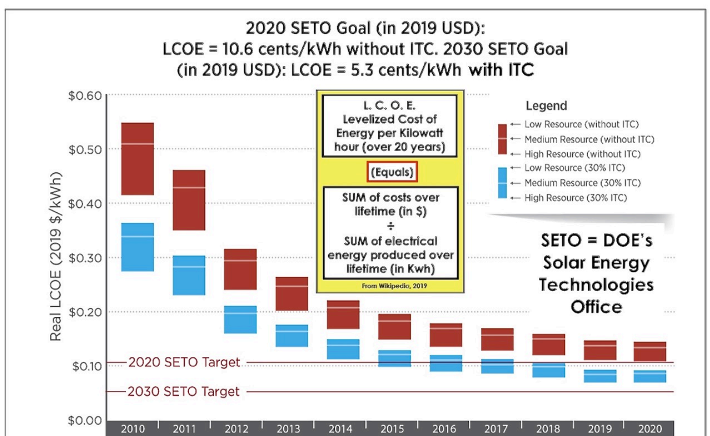

Figure 19. LCOE for residential PV systems, by region, with and without ITC, 2010–2020

We updated our methods and model this year; 2019 and 2020 LCOEs are higher than they would have been using previous models. Appendix A provides a detailed discussion of the changes made to the models between the previous version (Fu, Feldman, and Margolis 2018) and this year's version. LCOE is calculated for each scenario under a range of CFs, but all other values remain the same.

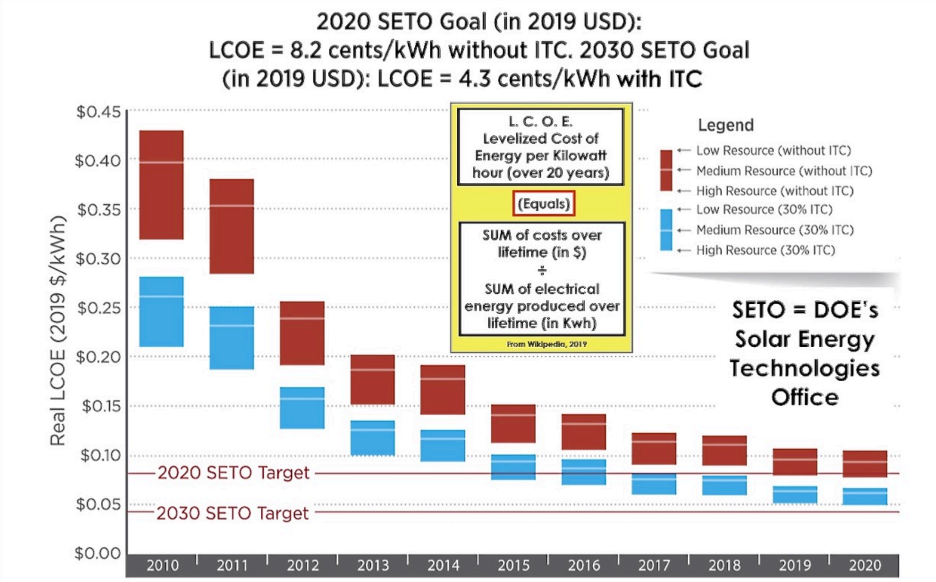

Figure 27. LCOE for commercial rooftop PV systems, by region, with and without ITC, 2010–2020

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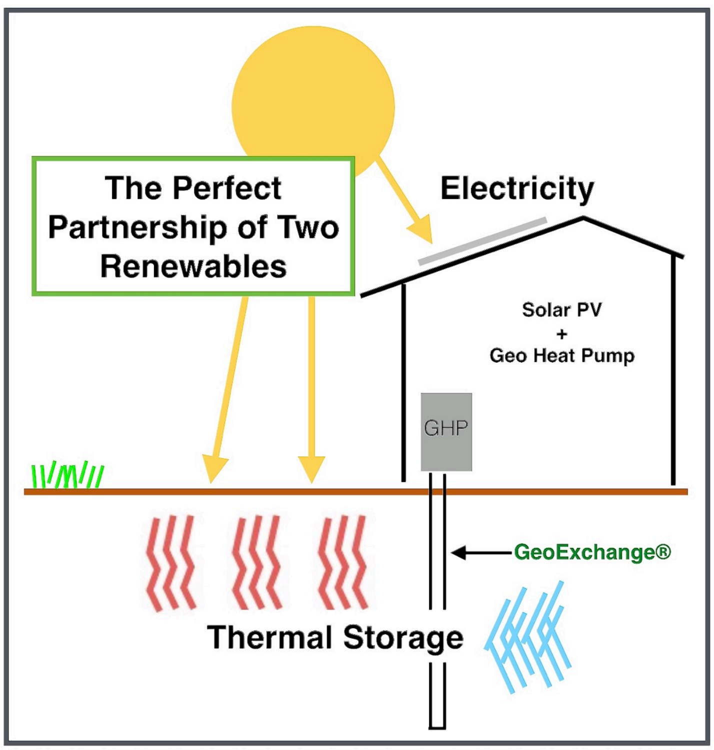
Commercial rooftop solar does even better with the ITC than residential by 2030. Large buildings with flat roofs are a favorite for placing lots of solar panels. They make it more likely the facility will be all-electric and contribute no greenhouse gases. Two of my favorites are the [Delta Americas warehouse-office complex]() in Milpitas, CA and the [IKEA facility in Centennial, CO.]()



Part of the driving force for Solar PV (as well as wind resources) is the increased drumbeat for de-carbonization, which is climate-productive. But many consider their electric bills too high for full electrification at home. I will make a suggestion. Geo heat pumps do more with a kilowatt hour of electricity than anything else. And, if you're generating rooftop solar and use a geo heat exchanger underneath your land, you're experiencing a double-whammy of renewability.

Lower HVAC consumption, no outside equipment or noise, no need for evaporative water for cooling, no possibility of contributing to urban heat islands, and longer lasting equipment; it's cost-effective green comfort without carbon!

I'd like to thank NREL for its diligence in paying attention and crunching the numbers for us.

—Bill Martin