Getting to 95

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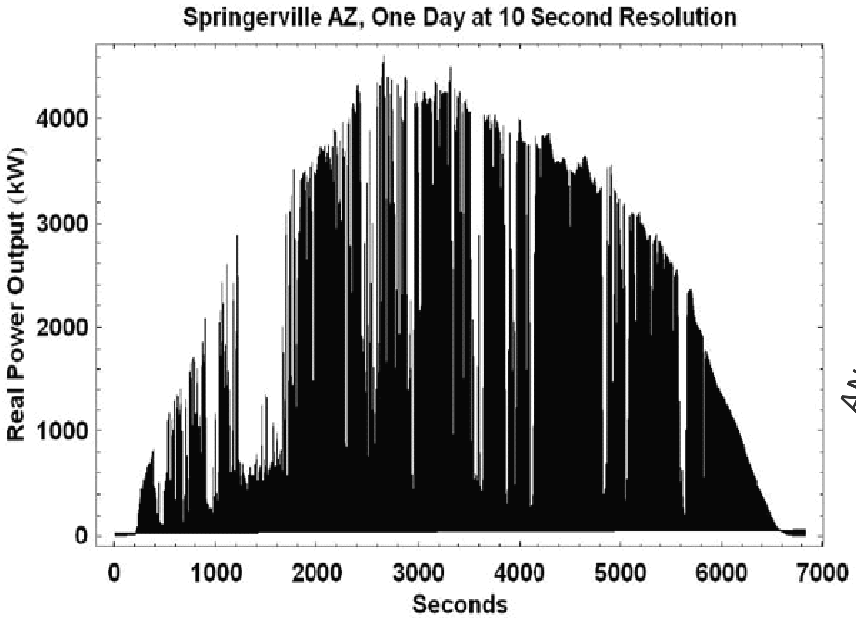
*Life is **5%** what happens and 95% how you react!" — Charles R. Swindoll*

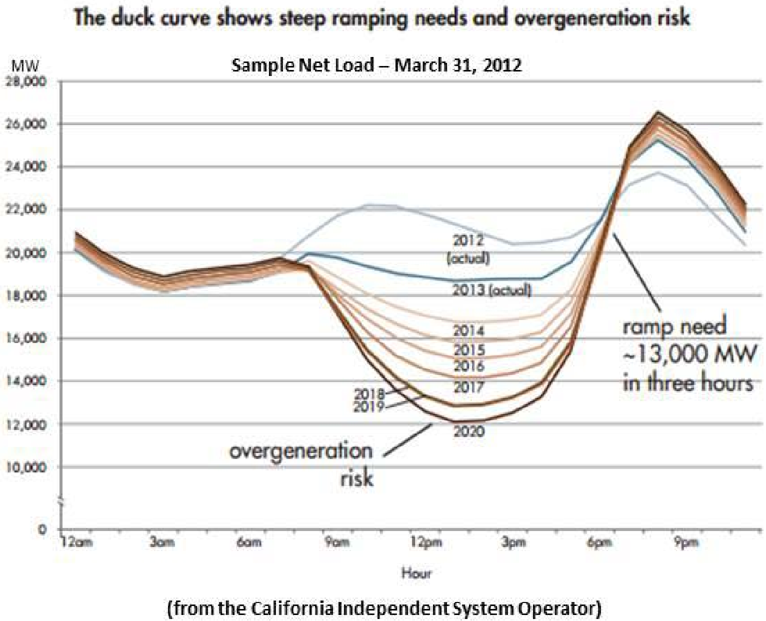
NREL/PR-5D00-82894

THIS LOOKS SCARY



Output from a single photovoltaic (PV) plant

AND THIS



System-level impacts to “net load”

De-Risking Solar Integration

What makes a "modern" DER?

Legacy DER
(IEEE Std 2003 version)

Core functions

- Power generation or DC/AC conversion
- (inverters) maximum power point tracking

"Good Citizen" Behavior

- Safety (e.g. anti-islanding protection)
- Tripping & reclose coordination (limited)
- Interconnect integrity (EMI, surge protection)
- Integration with area EPS grounding
- Synchronization limits for frequency, voltage, and phase angle
- Power quality (e.g. flicker, harmonics)

+

Modern DER
(IEEE Std 2018 version)

- **Voltage Regulation**
- **Interoperability**
- **Ride-Through**
- **Islanding Capability**

Modern "Good Citizen" Behavior

Safety

- Visible-break isolation device
- Anti-islanding
- Inadvertent energization of area EPS.

General

- Interconnect integrity
  - Protection from electromagnetic interference
  - Surge withstand.
- Integration with area EPS grounding
- Synchronization limits for frequency, voltage, and phase angle (IEEE 67 criteria okay for some types of synchronous generators[1]).

Power Quality

- Limitation of DC current injection
- Limitation of DER-caused voltage fluctuations
  - Flicker (revised method)
  - Rapid voltage changes (new).
- Limitation of current distortion
- Limitation of overvoltage contribution
  - Temporary overvoltage
  - Transient overvoltage.
- Harmonics.

Protection

- Response to short-circuit faults:
  - IEEE Std 1547-2018 requires the DER to cease to energize and trip
- Open phase conditions
- Coordination with area EPS circuit reclosing.
- Response to abnormal grid conditions:
  - Appropriate to ensure grid stability (*e.g.*, voltage and frequency ride-through capabilities) while maintaining safety of utility personnel

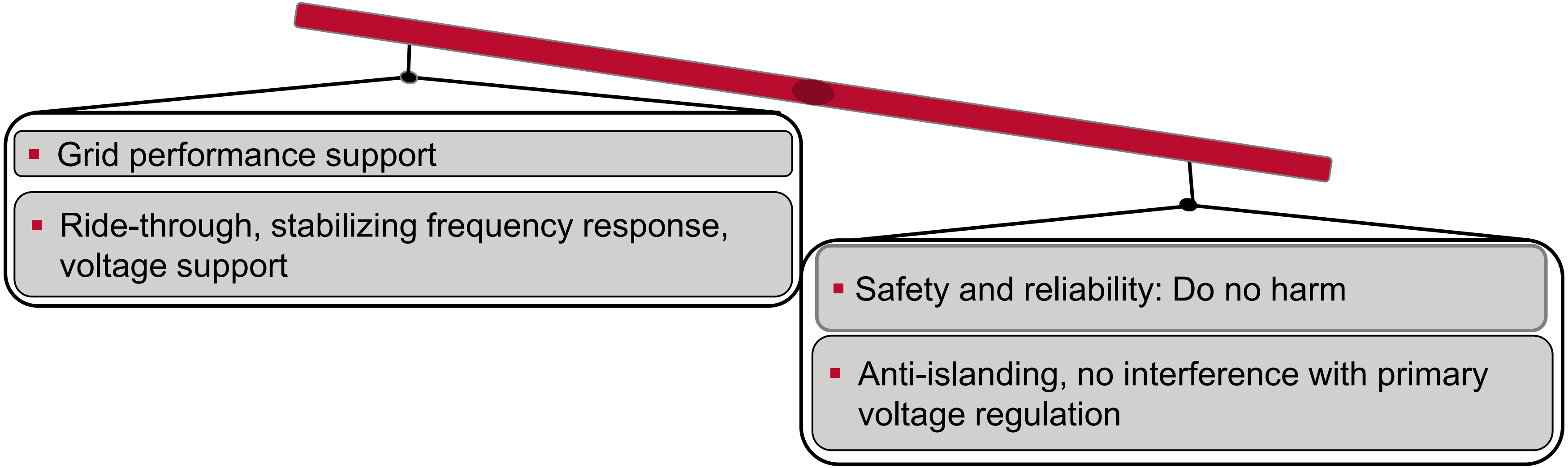
NOTE: Different requirements in IEEE Std 1547-2018 are set such that *no specific technology is given preference*, and the standard is technology neutral.

[1]For example, round rotor synchronous generators with ratings 10 MVA and larger and salient pole synchronous generators with ratings 5 MVA and larger may use the synchronization criteria described in IEEE 67, which are tighter than the ones specified here, and can therefore meet the requirements of this standard.

Reference: Mahmud, Rasel, and Michael Ingram. 2022. *Background Information on the Protection Requirements in IEEE Std 1547-2018*. Golden, CO: National Renewable Energy Laboratory. NREL/TP-5D00-78704. https://www.nrel.gov/docs/fy22osti/78704.pdf

Addressing Grid Planning and Operation Challenges

Increasing DER penetration was a major driver for revising IEEE 1547.



Slide credit: IEEE 1547-2018

IEEE 1547-2018 Active Voltage Regulation Requirements

Performance Categories (Grid support under normal grid conditions)		Mandatory Voltage Regulation Capabilities				
		Constant Power Factor Mode	Constant Reactive Power Mode (“reactive power priority”)	Voltage-Reactive Power Mode (“volt-VAR”)	Active Power-Reactive Power Mode (“watt-VAR”)	Voltage-Active Power Mode (“volt-watt”)
Category A	Meets minimum performance capabilities needed for area EPS voltage regulation Reasonably attainable by all state-of-the-art DER technologies	✓	✓	✓	Not required	Not required
Category B	Meets all requirements in Category A plus: Supplemental capabilities for high DER penetration, where the DER power output is subject to frequent large variations Attainable by most smart inverters	✓	✓	✓	✓	✓

IEEE 1547-2018: “The DER shall provide voltage regulation capability by changes of reactive power. The approval of the Area EPS Operator shall be required for the DER to actively participate in voltage regulation.”

The area EPS operator shall specify the required voltage regulation control modes and the corresponding parameter settings. Modifications of the settings and mode selected by the EPS operator shall be implemented by the DER operator (min 44% injecting, 25% absorption (low), 44% (high)).

Settings can be adjusted locally or remotely.

Reference: Narang, David, Rasel Mahmud, Michael Ingram, and Andy Hoke. 2021. *An Overview of Issues Related to IEEE Std 1547-2018 Requirements Regarding Voltage and Reactive Power Control.* Golden, CO: National Renewable Energy Laboratory. NREL/TP-5D00- 77156. https://www.nrel.gov/docs/fy21osti/77156.pdf.

Grid Support Requirements for Abnormal Grid Conditions

Ride-Through:
Ability to withstand voltage or frequency disturbances

Required

1. Voltage ride-through
2. Frequency ride-through
3. Rate-of-change (ROCOF)
4. Voltage phase angle change
5. Frequency droop.[1][2]

Other allowed capabilities

- Inertial response[3]
- Dynamic voltage support[4]

Driver for New Ride-Through Requirements: Potential for Widespread DER Tripping

- Transmission faults can depress distribution voltage over very large areas.
- Sensitive voltage tripping (i.e., 1547-2003) can cause massive loss of DER generation.
- Resulting bulk power system event could be greatly aggravated.
- System frequency is defined by the balance between load and generation.
- Frequency is the same across entire interconnection; all DERs can trip simultaneously during disturbance.
- Impact is the same whether or not DER is on a high-penetration feeder.

IEEE 1547-2018 mandates BOTH:
Tripping requirements, and ride-through requirements.

Ride-through is not a "setting"; it is a capability of the DER:
i.e., it is the DER's robustness.

Tripping points are adjustable over an allowable range.
Range does not allow DER tripping to seriously compromise BPS security.

Tripping points are specified by the area EPS operator (utility) within constraints of the regional reliability coordinator.

[1]Frequency response is capability to modulate power output as a function of frequency.
[2]Mandatory capability for Categories II and III under high frequency conditions, Mandatory for Categories II and III under low frequency conditions, optional for Category 1
[3]Inertial response is capability for DER to modulate active power in proportion to the rate of change of frequency.
[4]Dynamic voltage support provides rapid reactive power exchanges during voltage excursions

Based on a slide Dr. Jens Boemer

IEEE 1547-2018 Ride-Through Requirements

Performance Categories (Grid support under abnormal grid conditions)		Mandatory Ride-Through Capabilities						
		Voltage Ride-Through	Frequency Ride-Through	Rate-of-Change-of-Frequency (ROCOF) Ride-Through	Voltage Phase Angle Change Ride-Through	Frequency Droop (freq-power)	Inertial Response	Dynamic Voltage Support
Category I	Essential bulk system needs Attainable by all state-of-the-art DER technologies	✓	✓	✓ (.5 Hz/s)	✓	Low freq. optional	Permitted	Permitted
Category II	Full coordination with all bulk system power system stability/ reliability needs (e.g., NERC) Coordinated with existing reliability standards to avoid tripping for a wider range of disturbances (than Category I)	✓	✓	✓ (2.0 Hz/s)	✓	✓	Permitted	Permitted
Category III	Designed for all bulk system needs and distribution system reliability/power quality needs Coordinated with existing requirements for very high DER levels (e.g., CA, HI)	✓	✓	✓ (3.0 Hz/s)	✓	✓	Permitted	Permitted

[1]Frequency response is the capability to modulate power output as a function of frequency.
[2]Mandatory capability for categories II and III under high-frequency conditions, mandatory for categories II and III under low-frequency conditions, optional for Category 1
[3]Inertial response is the capability for the DER to modulate active power in proportion to the rate of change of frequency.
Dynamic voltage support provides rapid reactive power exchanges during voltage excursions

Interoperability

Value of interoperability:

Situational awareness/monitoring

Control and advanced control (integration with DER management tools, aggregation)

Supports modeling and simulation.

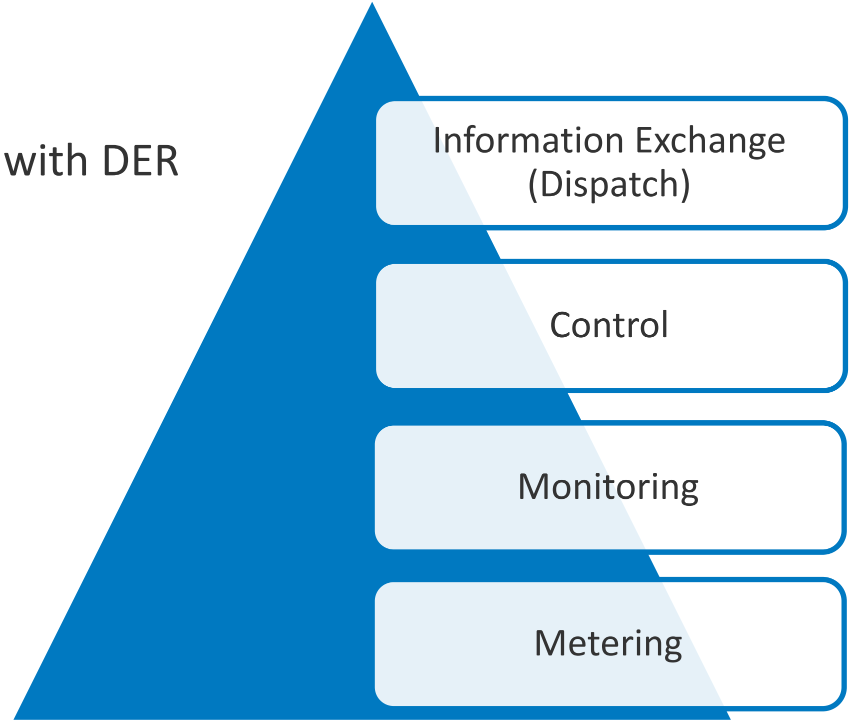
IEEE Std 1547-2018 requirements:

Communications requirements

Identified functions to communicate

Scope of interoperability

Communications protocols



Reference: Ingram, Michael, Rasel Mahmud, and David Narang (2021). *Informative Background on the Interoperability Requirements in IEEE Std 1547-2018*. Golden, CO: National Renewable Energy Laboratory. NREL/TP-5D00-77959. https://www.nrel.gov/docs/fy21osti/77959.pdf

Finding Information

NREL's IEEE 1547-2018 Resources Website

nrel.gov/grid/ieee-standard-1547

An online platform with educational resources to aid stakeholders in the successful adoption and implementation of IEEE 1547-2018.

Sponsored by:
Solar Energy Technologies Office

Partners and Advisors:

- Sandia National Laboratories
- Institute of Electrical and Electronics Engineers
- Electric Power Research Institute
- National Association of Regulatory Utility Commissioners
- National Rural Electric Cooperative Association
- Interstate Renewable Energy Council
- Regulatory Assistance Project
- Western Interstate Energy Board

Illustration by Fred Zietz, NREL

NREL's well-catalogued and publicly accessible online platform includes **presentations, industry white papers, and topic-specific NREL technical reports for utilities, states, solar developers, transmission operators, and other stakeholders.**

An NREL Guide for Authorities Governing Interconnection Requirements

A Guide to Updating Interconnection Rules and Incorporating IEEE Standard 1547-2018 presents a structured, step-by-step approach to help governmental authorities that oversee interconnection requirements and other stakeholders develop and update interconnection rules. The NREL-published report considers the incorporation of the new standard from both process and technical standpoints.

- Three main sections to report:

Step 1
Determining Context
(stakeholders and major drivers)

Step 2
Developing the Rule
(including updating technical requirements)

Step 3
Maintaining and Revising the Rule

- Key considerations include:
  - Has the governing authority sufficiently identified motivations for updating the interconnection rule? How do the identified technical requirements relate to the desired outcome?
  - Has the governing authority allowed for the use of DER capabilities (even if they are to be used in the future)?

Any state or local jurisdictions that are interested in adopting IEEE Standard 1547-2018 should consult this resource!

Find the full report on NREL's IEEE Resource Website or at nrel.gov/docs/fy22osti/75290.pdf.

Solar Industry

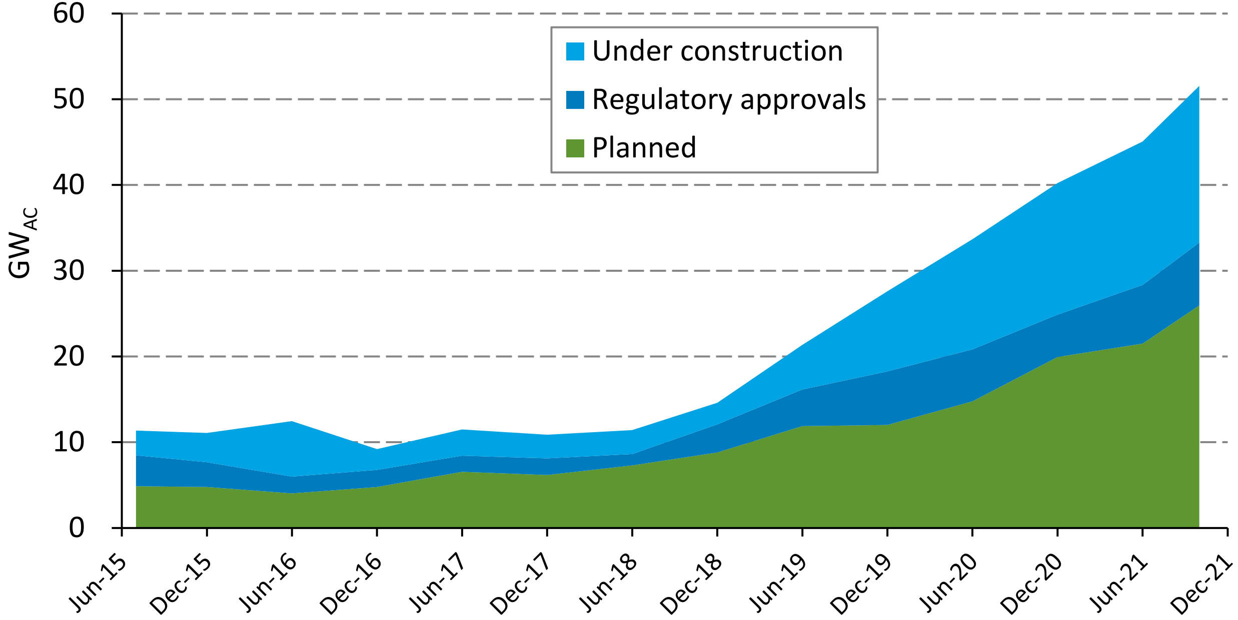
Excerpts from Winter 2021/2022 Update

Feldman, David, Krysta Dummit, Jarett Zuboy, Jenny Heeter, Kaifeng Xu and Robert Margolis. (2022). *Winter 2021/2022 Solar Industry Update. https://www.nrel.gov/docs/fy22osti/81900.pdf*

PV System Pricing

- **Despite supply chain shortages and component price increases, reported PV system prices from select states were relatively flat between H2 2020 and H2 2021.**
  - Prices were flat or declined slightly for system sizes smaller than 500 kW.
  - Prices increased slightly for system sizes larger than 500 kW.
- **When data are included from most of 2021, the median reported prices of residential PV+storage systems in select states were 8%–13% lower than full 2020 median values.**

EIA PV Project Planned Pipeline



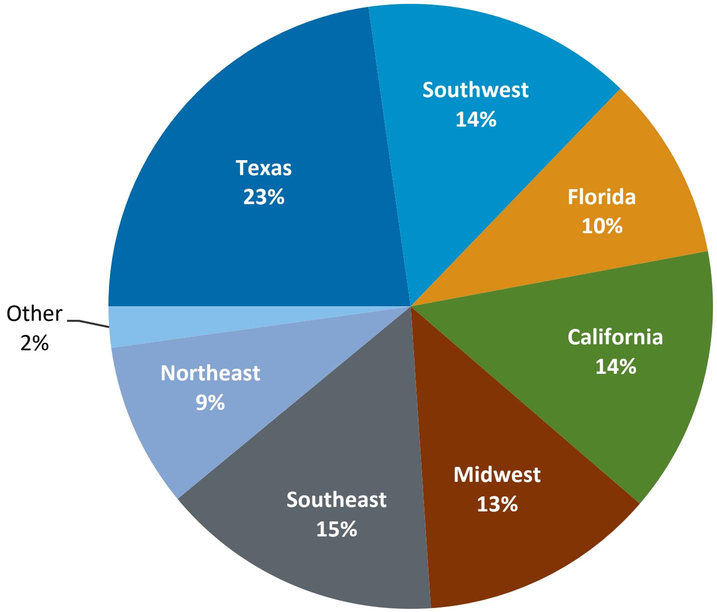
According to EIA data, the U.S. PV project pipeline of utility-scale PV projects continues to hit record highs, with 18 GW_{AC} of projects being under construction, 7 GW_{AC} having received regulatory approval, and 25 GW_{AC} planned as of October 2021.

Note: Pipeline is defined as all planned PV projects that have been submitted in EIA's Form 860M. All projects have a scheduled placed-in-service date between 2021 and 2030.

Source: EIA Form 860M/Preliminary Monthly Electric Generator Inventory ("Planned" June and October 2021).

U.S. Installation Breakdown

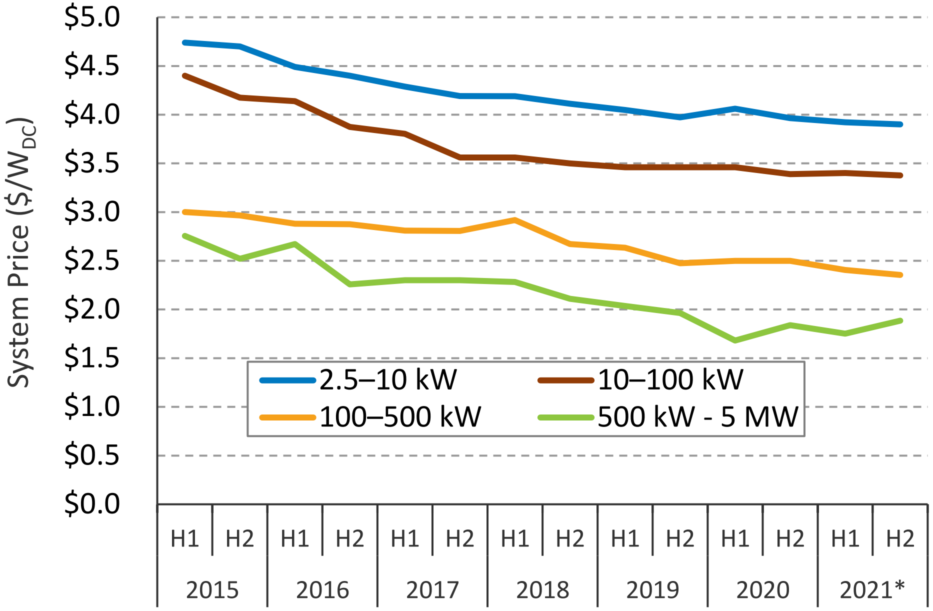
Q1–Q3 2021 U.S. PV Installations by Region (11.8 GW_{AC})



- Texas, Florida, and California installed over 1 GW each, and Virginia added over 780 MW_{AC} in Q1–Q3 2021—over half of total installations.
  - Texas installed nearly 2.7 GW_{AC}.
- Despite a concentration of PV installations in the top markets, diversification of growth continues across the United States.
  - Thirty-eight states installed >10 MW_{AC} of PV in Q1–Q3 2021, and 21 states installed >100 MW_{AC}.

Sources: EIA, "Electric Power Monthly," forms EIA-023, EIA-826, and EIA-861 (August 2021, February 2021, February 2019).

System Pricing from Select States



- From H2 2020 to H2 2021 YTD, the median-reported PV system price in Arizona, California, Connecticut, Massachusetts, and New York:
  - Fell 2% to $3.90/W for systems from 2.5 kW to 10 kW
  - Was flat at $3.38/W for systems from 10 kW to 100 kW
  - Fell 6% to $2.36/W for systems from 100 kW to 500 kW
  - Rose 2% to $1.88/W for systems from 500 kW to 5 MW.
- Prices for larger systems may be more affected by rising material costs, because they are more likely to have smaller margins and so are less able to absorb cost increases.

2021 YTD MW: Arizona (193), California (723), Connecticut (8), Massachusetts (182), New York (379)

* YTD; see source dates below

Note: System prices above $10/W and below $0.75/W were removed from the data set. There were not enough reported prices for systems above 5 MW in this data set to show a trend over time.

Sources: Arizona (varies, as late as 12/6/21), California NEM database (9/30/21); Connecticut (05/14/21), Massachusetts SREC (09/01/21) and SMART (12/3/21) programs; NYSERDA (11/30/21).

Infrastructure

Bipartisan Infrastructure Law

(aka Infrastructure Investment and Jobs Act or Public Law No. : 117-58)

- $62 billion to DOE, $16.2 billion to EERE (for comparison, the ARRA was $31 billion to DOE) which will impact solar energy in a variety of ways including directly through funding to SETO for fiscal year FY 2022–FY 2025:
    - $40 million for *SETO research, development, demonstration, and commercialization*
    - $20 million for *advanced solar energy manufacturing initiative*
    - $20 million for *solar energy technology recycling RD&D program*
    - Adding the viability of siting solar energy on current and former mine land to the Solar Energy Technology strategic vision report*
- And by
    - Increasing access to electricity ($17 billion)
    - Increasing demand for (clean) electricity (~$26 billion)
    - Emphasizing energy efficiency (~$4 billion)
    - Investing in the critical minerals/materials supply chain (~$1.4 billion)
    - Investing in cybersecurity for the energy sector ($550 million)
    - Investing in the workforce and an equitable transition (one council, one board, $750 million)
    - Establishing the Office of Clean Energy Demonstration (OCED) with ~$21 billion in funding.
- The Infrastructure Law is separate, and sometimes additive, from what Congress annually appropriates DOE. Because Congress has not yet passed a full-year appropriations bill, some funds awarded in the Infrastructure Law may be held up.

*$500 million (FY 2022–FY 2026) for clean energy demonstration projects (2/5 must be solar) on current and former mine lands, but that funding goes to the OCED.

Public Law No. :117-18

NREL's Community Efforts