



Documenting 15 Years of Reductions in U.S. Solar Photovoltaic System Costs

Vignesh Ramasamy, Jarett Zuboy, David Feldman, Meenakshi Narayanaswami, Michael Woodhouse, and Robert Margolis

National Renewable Energy Laboratory

**NREL is a national laboratory of the U.S. Department of Energy
Office of Energy Efficiency & Renewable Energy
Operated by the Alliance for Sustainable Energy, LLC**

This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.

Contract No. DE-AC36-08GO28308

Technical Report
NREL/TP-7A40-92536
January 2025



Documenting 15 Years of Reductions in U.S. Solar Photovoltaic System Costs

Vignesh Ramasamy, Jarett Zuboy, David Feldman, Meenakshi Narayanaswami, Michael Woodhouse, and Robert Margolis

Suggested Citation

Ramasamy, Vignesh, Jarett Zuboy, David Feldman, Meenakshi Narayanaswami, Michael Woodhouse, and Robert Margolis. 2025. *Documenting 15 Years of Reductions in U.S. Solar Photovoltaic System Costs*. Golden, CO: National Renewable Energy Laboratory. NREL/TP-7A40-92536. <https://www.nrel.gov/docs/fy25osti/92536.pdf>.

**NREL is a national laboratory of the U.S. Department of Energy
Office of Energy Efficiency & Renewable Energy
Operated by the Alliance for Sustainable Energy, LLC**

This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.

Contract No. DE-AC36-08GO28308

Technical Report
NREL/TP-7A40-92536
January 2025

National Renewable Energy Laboratory
15013 Denver West Parkway
Golden, CO 80401
303-275-3000 • www.nrel.gov

NOTICE

This work was authored by the National Renewable Energy Laboratory, operated by Alliance for Sustainable Energy, LLC, for the U.S. Department of Energy (DOE) under Contract No. DE-AC36-08GO28308. Funding provided by the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy Solar Energy Technologies Office under project 52925 (FY25–27 Supply Chain Analysis for SETO). The views expressed herein do not necessarily represent the views of the DOE or the U.S. Government.

This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.

U.S. Department of Energy (DOE) reports produced after 1991 and a growing number of pre-1991 documents are available free via www.osti.gov.

Cover Photos by Dennis Schroeder: (clockwise, left to right) NREL 51934, NREL 45897, NREL 42160, NREL 45891, NREL 48097, NREL 46526.

NREL prints on paper that contains recycled content.

Acknowledgments

We would like to acknowledge Paul Basore and Krysta Dummit (U.S. Department of Energy), as well as Nate Blair, Adam Warren, Heather Mirletz, and Brittany Smith (NREL), for reviewing this report. We also extend our gratitude to Susannah Shoemaker from the communications team at NREL for editing the report.

List of Acronyms

ac	alternating current
BESS	Battery Energy Storage System
BOS	balance of system
CPV	commercial photovoltaic
dc	direct current
DOE	U.S. Department of Energy
ILR	inverter loading ratio
kWh	kilowatt-hour
LCOE	levelized cost of electricity
MMP	modeled market price
MSP	minimum sustainable price
MW _{dc}	megawatts direct current
NREL	National Renewable Energy Laboratory
O&M	operations and maintenance
PERC	passivated emitter and rear cell
PII	permitting, inspection, and interconnection
PV	photovoltaic(s)
PVSCM	Photovoltaic System Cost Model
Q	quarter
RPV	residential photovoltaic
SETO	Solar Energy Technologies Office
UPV	utility-scale photovoltaic
USD	U.S. dollars
W _{dc}	watts direct current

Executive Summary

The U.S. Department of Energy’s Solar Energy Technologies Office (SETO) has played a key role in reducing photovoltaic (PV) system costs by supporting research, development, and deployment activities—addressing PV hardware costs as well as soft costs such as those related to installation labor, permitting, and customer acquisition. As part of this effort, SETO has sponsored annual benchmarking of PV system costs. This report highlights benchmark capital cost and levelized cost of electricity (LCOE) reductions from 2010 to 2024. It also shows PV-plus-storage benchmark cost trends from 2020 to 2024.

To contextualize the benchmarks, this report documents changes in system cost modeling methods that occurred over time to incorporate new data sources, changing market conditions, and technology advancements. The different methods must be accounted for when comparing benchmarks across years. For instance, earlier models did not account for soft cost details the way more recent models have. Still, the benchmarks provide valuable insights into PV system cost trends.

Purpose and Scope of Cost Benchmarks

Understanding the scope and limitations of the cost benchmarks in this report is essential to applying them appropriately. The cost benchmarks account for all key inputs associated with typical PV and energy storage system configurations, as well as their corresponding installation practices. These benchmarks are designed to provide representative estimates, rather than precise costs in any given location.

The primary objective of these cost benchmarks is to illuminate factors driving the long-term trajectories of PV and storage system costs. By identifying key system components that influence installed costs, the benchmarks highlight opportunities for cost reductions and inform strategies for innovation. Furthermore, these benchmarks play a crucial role in projecting future system prices, fostering transparency, and encouraging engagement with industry stakeholders.

These benchmarks are not intended to replace local or customer-specific market prices, nor should local market prices be used as substitutes for the benchmarks. For example, if a firm is seeking component prices for a specific location and time, it should consult multiple vendors to obtain accurate and current pricing. Additionally, cost benchmarks often differ from reported price data found in sources such as Lawrence Berkeley National Laboratory’s *Tracking the Sun* series. This disparity arises from the differing methods and objectives of these reports. Reported pricing is more likely to include cost categories not within the cost benchmarks’ scope, such as financing costs, roof upgrades, or service contracts; and to be based on national averages rather than representative configurations.

PV System Capital Costs, 2010–2024

Between 2010 and 2024, the cost benchmarks for PV systems in 2024 U.S. dollars (USD) decreased 65% for residential systems, 77% for commercial systems, and 83% for utility-scale

(one-axis tracking) systems (Figure ES-1).¹ A substantial portion of these reductions can be attributed to decreases in hardware costs, including modules, inverters, and balance of system (BOS) hardware, with module prices alone dropping by roughly 90% over this period.

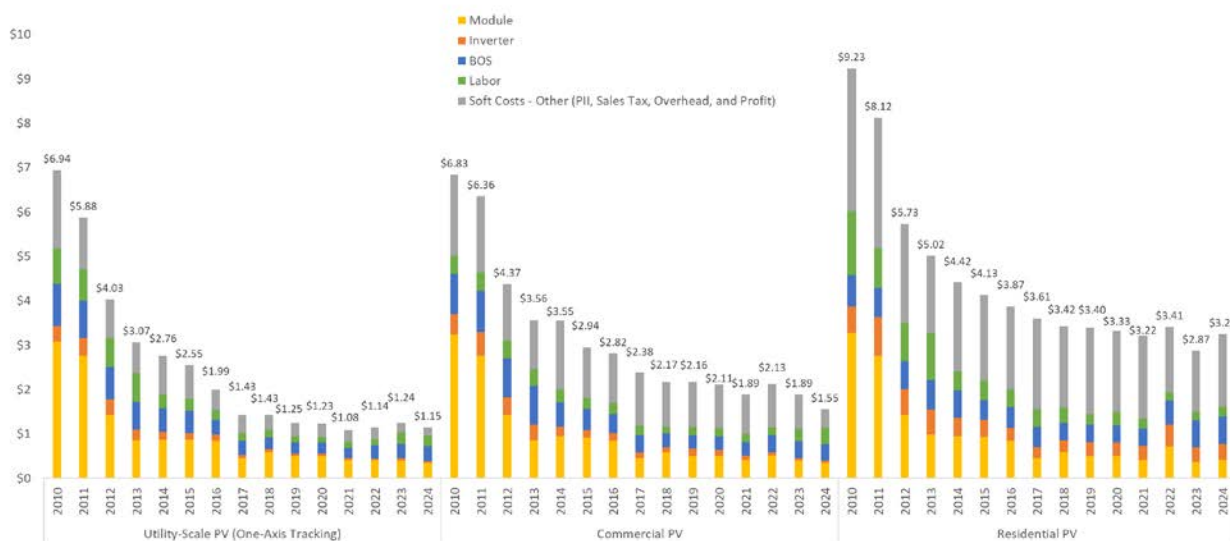


Figure ES-1. Installed PV system cost, 2010–2024, in \$/W_{dc} (2024 USD)

Note: Commercial PV costs in Figure ES-1 represent a 200-kW_{dc} rooftop application for 2010–2022 and a 3-MW_{dc} fixed-tilt ground-mount system from 2023–2024. Additionally, residential PV costs in Figure ES-1 account for different inverter types based on market share from 2010–2021 and include only microinverters from 2022–2024.

Pll = permitting, inspection, and interconnection

Although PV system costs consistently decreased across sectors from 2010–2021, system costs were relatively flat from 2021–2024; in some years, costs increased. Some of this can be explained by supply chain disruptions and labor shortages stemming from the COVID-19 pandemic. Additionally, increases in deployment have resulted in higher costs for land acquisition and interconnection studies as well as more expensive civil contracting requirements. Finally, changes in cost over time can be partially attributed to changes in cost modeling methods and variations in the collected input data.

It should be noted that for the first five benchmarked years, the data was collected in the fourth quarter of the previous year, while all subsequent benchmark data was collected in the first quarter of the calendar year, with the report typically published later in the year. This created a lag in the reported costs for each benchmarking year. Additionally, the costs were always adjusted from nominal to real USD for each benchmarking year, as the calendar year was often incomplete at the time of publication.

¹ Later versions of the annual benchmark reports have, in some cases, adjusted the cost values originally published in previous reports, to better demonstrate technology and cost trends over time. Therefore, the cost values are not always consistent from report to report. The PV system cost values represented in this report are taken from the following reports: DOE 2024; Feldman et al. 2021; Ramasamy et al. 2021; Ramasamy et al. 2022; Ramasamy et al. 2023.

PV-Plus-Storage System Capital Costs, 2020–2024

As shown in Figure ES-2, benchmarked ac-coupled PV-plus-storage system costs in 2024 USD decreased from 2020 to 2024 by 2% in the utility sector, 8% in the commercial sector, and 20% in the residential sector. Most cost reductions during this period can be attributed to reductions in lithium-ion battery costs and PV module costs. In contrast to PV systems cost trends, PV-plus-storage systems experienced the greatest cost reductions in the residential sector, followed by the commercial and utility sectors.

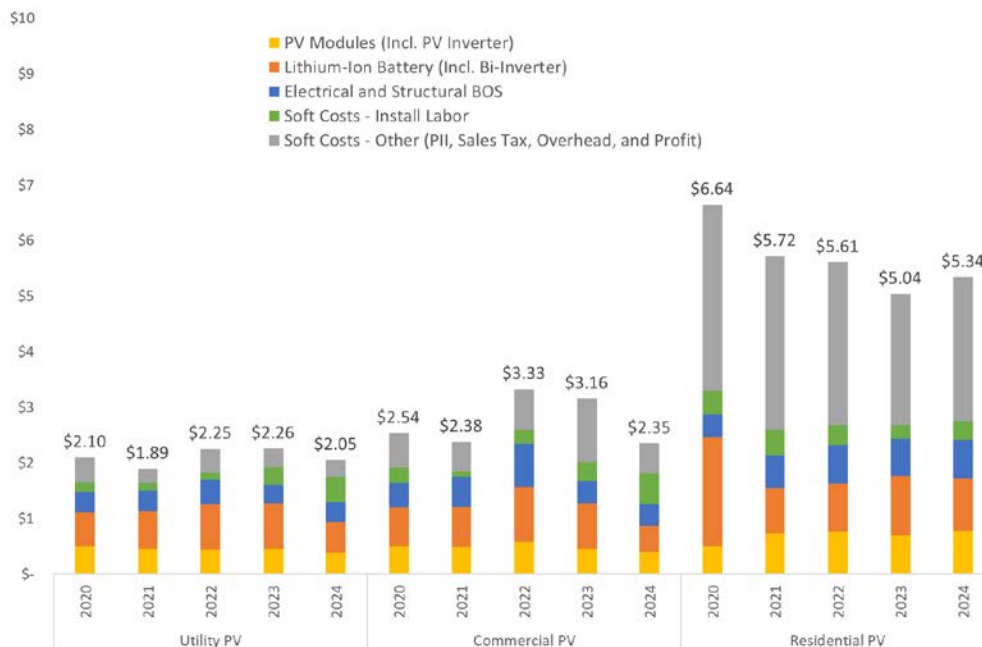


Figure ES-2. Installed cost of ac-coupled PV-plus-storage systems, 2020–2024, in $\$/W_{dc}$ (2024 USD)

PV LCOE, 2010–2024

Between 2010 and 2024, the benchmark LCOE in 2024 USD decreased by 86% for utility-scale PV systems, 84% for commercial PV systems, and 76% for residential PV systems (Figure ES-3). Reductions in installed PV system costs, combined with advancements in operations, system design, and technology, have influenced the cost of PV-generated electricity. When comparing benchmarked PV system LCOE to the LCOE targets established by SETO in 2010 (adjusted to 2024 USD), residential and commercial PV systems achieved their 2020 targets by 2020, while utility-scale PV systems met their 2020 target a year ahead of schedule, in 2019. In 2023, the adoption of community solar applications in the commercial sector cost modeling led to higher O&M costs due to additional subscriber management expenses. This increase led to a relatively high LCOE for the commercial sector in 2023 compared with 2024.

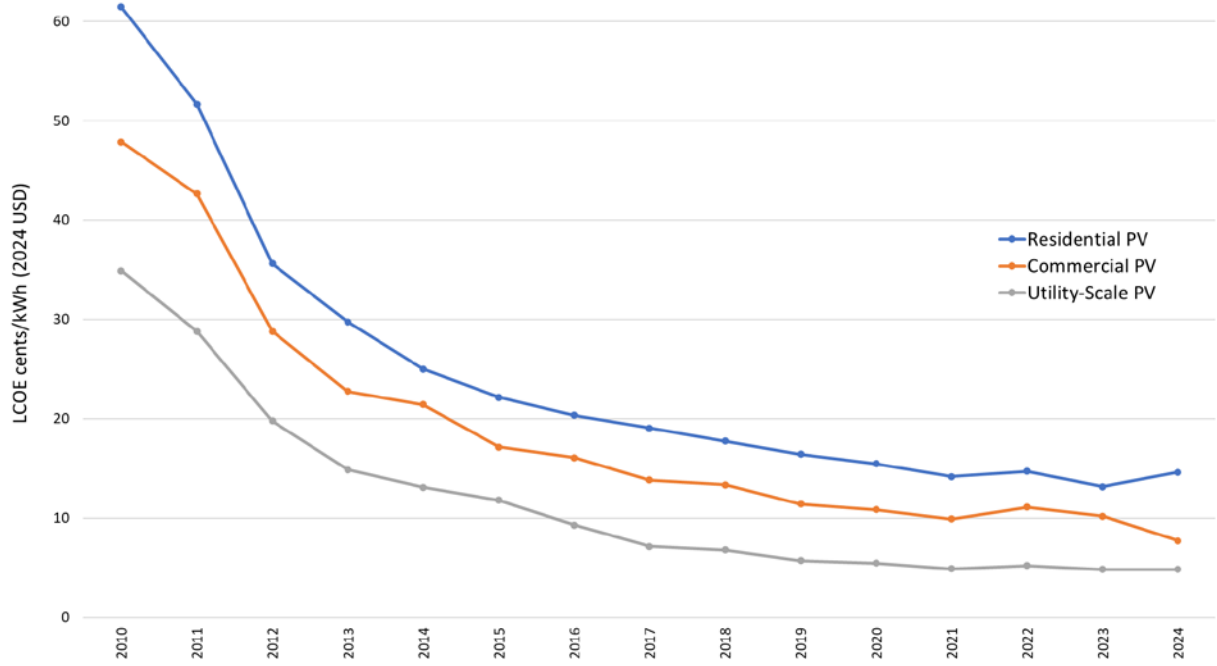


Figure ES-3. PV LCOE by sector, 2010–2024, in cents/kWh (2024 USD)

Table of Contents

Executive Summary	v
1 Introduction	1
2 Change in PV System Benchmark Parameters	2
2.1 PV Module	2
2.2 Inverter and Inverter Loading Ratio	3
2.3 PV System Size	5
2.4 Mounting	5
2.5 Residential Installer Type	5
3 Change in System Cost Modeling Methods	6
4 System Capital Costs, 2010–2024	8
5 PV System LCOE, 2010–2024	12
6 Conclusion	14
Appendix 1	15
References	20

List of Figures

Figure ES-1. Installed PV system cost, 2010–2024, in $\$/W_{dc}$ (2024 USD).....	vi
Figure ES-2. Installed cost of ac-coupled PV-plus-storage systems, 2020–2024, in $\$/W_{dc}$ (2024 USD)...	vii
Figure ES-3. PV LCOE by sector, 2010–2024, in cents/kWh (2024 USD)	viii
Figure 1. PV module efficiency across PV sectors, 2010–2024	3
Figure 2. Inverter loading ratio across sectors, 2010–2024	4
Figure 3. Installed PV system cost, 2010–2024, in $\$/W_{dc}$ (2024 USD).....	9
Figure 4. Soft cost as a proportion of total installed system cost by sector	10
Figure 5. Installed cost of ac-coupled PV-plus-storage systems, 2020–2024, in $\$/W_{dc}$ (2024 USD).....	11
Figure 6. PV system LCOE, 2010–2024, in cents/kWh (2024 USD).....	13

List of Tables

Table 1. PV and Battery System Capacity From 2020–2024	11
Table A-1. Installed PV System Cost ($\$/W_{dc}$, 2024 USD) 2010–2024.....	15
Table A-2. PV System LCOE (cents/kWh, 2024 USD) 2010–2024	15
Table A-3. Utility PV Installed System Cost Breakdown ($\$/W_{dc}$, 2024 USD) 2010–2024.....	16
Table A-4. Commercial PV Installed System Cost Breakdown ($\$/W_{dc}$, 2024 USD) 2010–2024	16
Table A-5. Residential PV Installed System Cost Breakdown ($\$/W_{dc}$, 2024 USD) 2010–2024	17
Table A-6. Residential PV LCOE Assumptions, 2010–2024.....	17
Table A-7. Commercial PV LCOE Assumptions, 2010–2024	18
Table A-8. Utility PV LCOE Assumptions, 2010–2024.....	18

1 Introduction

The U.S. Department of Energy’s (DOE’s) Solar Energy Technologies Office (SETO) has played a key role in reducing photovoltaic (PV) system costs by supporting research, development, and deployment activities—addressing PV hardware costs as well as soft costs such as those related to installation labor, permitting, and customer acquisition. As part of this effort, SETO has sponsored annual benchmarking of PV system costs.

This report highlights benchmark capital cost and levelized cost of energy (LCOE) trends from 2010 to 2024 across the U.S. residential, commercial, and utility-scale PV sectors. It also shows PV-plus-storage benchmark trends from 2020 to 2024. This historical overview charts progress in cost reductions over time. New annual benchmarks are made available on the SETO website.²

The SETO cost benchmarks have been developed using a bottom-up approach, in which individual hardware, labor, administrative, and overhead costs are estimated to provide nationally representative estimates of system costs. This approach differs from top-down approaches that are based on system-level average prices reported in the marketplace.³ By providing detailed estimates from an installed-cost perspective, bottom-up benchmarking facilitates transparent tracking of component-level costs and identification of component-level cost-reduction opportunities. The benchmarks are not intended to be a substitute for localized or customer-specific market prices, which require consultation with local vendors for accurate, site-specific data.

Sections 2 and 3 of the report describe how benchmarked system configurations and modeling methods have changed over time. Sections 4 and 5 present the historical benchmark results between 2010 and 2024, along with a discussion of key cost-reduction drivers. Section 6 provides a brief conclusion.

² Solar Photovoltaic System Cost Benchmarks: <https://www.energy.gov/eere/solar/solar-photovoltaic-system-cost-benchmarks>.

³ For example, Lawrence Berkeley National Laboratory’s *Tracking the Sun* series (<https://emp.lbl.gov/tracking-the-sun>) uses reported prices to track PV system costs over time. Reported prices typically include costs for items such as financing, roof upgrades, and service contracts, which are not part of SETO’s bottom-up benchmarks.

2 Change in PV System Benchmark Parameters

Between 2010 and 2024, the benchmarked configurations of PV systems across all three sectors evolved to reflect advancements in technology, system design, and installation practices. Until 2021, PV benchmarks were calculated as weighted average system costs, accounting for variations in market share by technology (e.g., inverter, mounting), installer type, installed system capacity across each state, locational costs, and so forth. However, due to the challenges of capturing the full extent of locational variability associated with soft costs, the benchmarking approach was revised. Recent benchmarks have focused on technologies with the largest market shares and the most common installation practices.⁴

To facilitate a consistent comparison over time, this report highlights the cost trends of the most relevant technologies in use today. For example, early utility-scale PV benchmarks primarily represented fixed-tilt systems, which dominated the market at the time. However, all utility-scale PV (UPV) cost values in this report assume single-axis tracking systems, reflecting their current prevalence. Similarly, microinverters were the only inverter type benchmarked in 2023 and 2024, whereas previous reports also benchmarked the cost of other inverter types, such as string inverters and dc optimizers, which were common during certain periods. This section provides context on how technology has evolved as well as the range of possible technology combinations and scenarios benchmarked in previous years.

2.1 PV Module

Until 2018, benchmarked PV systems predominantly used multicrystalline silicon modules, with efficiencies ranging from 14.5% to 19.1% for both UPV and commercial PV (CPV) systems and from 14.5% to 17.2% for residential PV (RPV) systems (Figure 1). Starting in 2019, the benchmarks transitioned to monocrystalline passivated emitter and rear cell (mono PERC) modules, which offered improved performance. By 2024, module efficiencies had steadily increased to 20.6% for both UPV and CPV systems and to 21.1% for RPV systems. Increases in module efficiency can help reduce costs by producing more power per square meter, which means that less labor and materials are required to produce the same amount of power. Notably, the UPV and CPV benchmarks for 2023 and 2024 also adopted bifacial mono PERC modules, further increasing energy production per square meter.

⁴ Later versions of the annual benchmark reports have, in some cases, adjusted the cost values originally published in previous reports, to better demonstrate technology and cost trends over time. Therefore, the cost values are not always consistent from report to report. The PV system cost values represented in this report are taken from the following reports: DOE 2024; Feldman et al. 2021; Ramasamy et al. 2021; Ramasamy et al. 2022; Ramasamy et al. 2023.

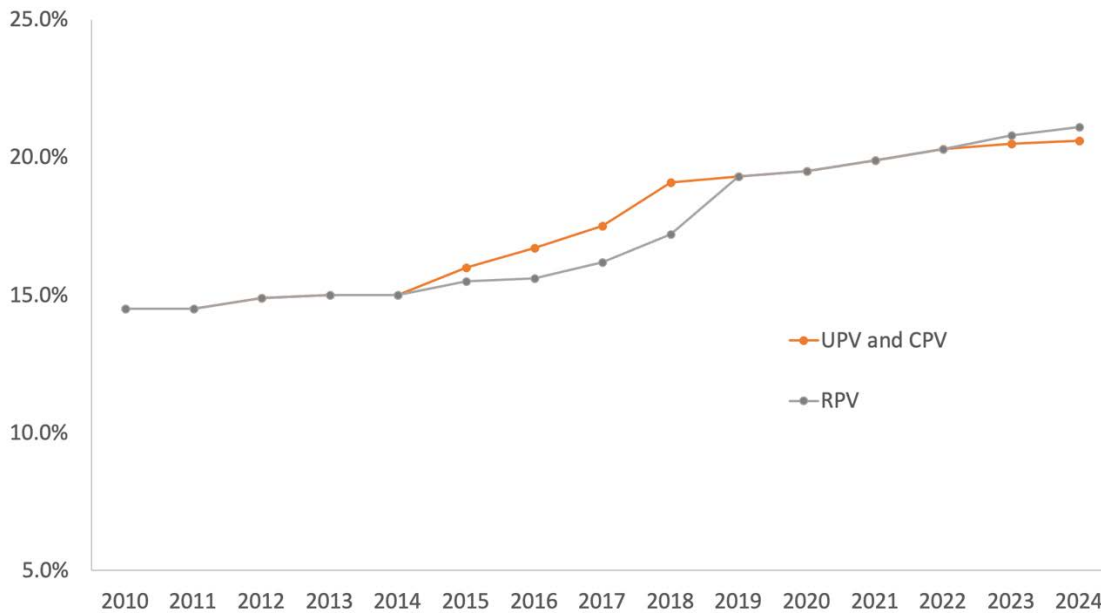


Figure 1. PV module efficiency across PV sectors, 2010–2024

Sources: DOE 2024; Ardani and Margolis 2011; Goodrich et al. 2012; Feldman et al. 2012; Davidson et al. 2014; Chung et al. 2015; Fu et al. 2016; Fu et al. 2017; Fu, Feldman, and Margolis 2018; Feldman et al. 2021; Ramasamy et al. 2021; Ramasamy et al. 2022; Ramasamy et al. 2023

2.2 Inverter and Inverter Loading Ratio

The benchmarked inverter types remained consistent for UPV systems (central inverters). For RPV and CPV systems, string inverters (single-phase for RPV, three-phase for CPV), microinverters, and dc optimizers were incorporated into the benchmark reports between 2010 and 2024. The 2020–2021 benchmark reports estimated RPV and rooftop CPV costs from 2010–2021 using an inverter market-share-weighted average between the three types of inverters. From 2022–2024, the RPV benchmark assumed the use of microinverters, and the CPV benchmark assumed the use of three-phase string inverters.

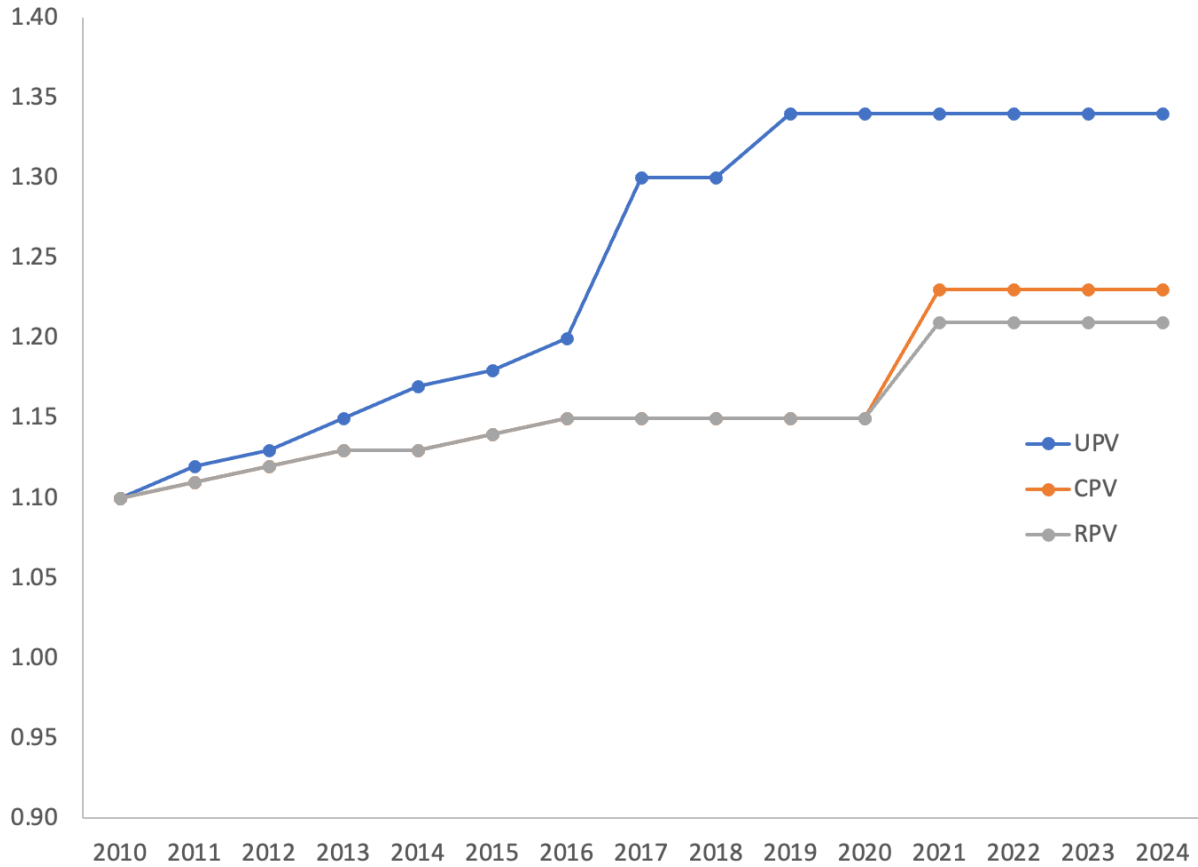


Figure 2. Inverter loading ratio across sectors, 2010–2024

Sources: DOE 2024; Feldman et al. 2021; Ramasamy et al. 2021; Ramasamy et al. 2022; Ramasamy et al. 2023

The inverter loading ratio (ILR) for benchmarked systems across all three sectors has increased since 2010, as shown in Figure 2. This upward trend in ILR has largely been driven by (1) technological advancements that facilitate more efficient use of inverter capacity and (2) the significant reduction in module prices, making it more cost-effective to oversize the dc array relative to the inverter capacity.

2.3 PV System Size

The benchmarked PV system size for the UPV sector remained stable at 100 MW_{dc} through 2024.⁵ However, between 2016 and 2021, a range of UPV system sizes, varying from 5 MW_{dc} to 100 MW_{dc}, were also included in the benchmark reports.⁶

In the CPV sector, initial reports benchmarked rooftop installations at a system size of approximately 200 kW_{dc}. However, recent reports shifted to benchmarking 3-MW_{dc} ground-mounted systems. From 2016 to 2021, the benchmarks encompassed a variety of CPV system sizes, both rooftop and ground-mounted, ranging from 100 kW_{dc} to 2 MW_{dc}.

Until 2022, the benchmark design for RPV systems was based on a 22-module configuration, which resulted in a steady increase in system size from 5 kW_{dc} to 7.9 kW_{dc}, driven by improvements in module efficiency. In 2023 and 2024, RPV system sizes were determined based on the typical installed system size across the United States, which was found to be approximately 8 kW_{dc}.

2.4 Mounting

The benchmarked mounting types for cost tracking across PV sectors, which include multiple types for UPV and CPV in certain years, were as follows: fixed-tilt racking systems for UPV systems from 2010–2021, single-axis tracking systems for UPV systems from 2010–2024, ballasted rooftop racking for CPV systems until 2022, and ground-mount fixed-tilt racking for CPV systems from 2020–2024. For RPV systems, flush-mounted systems on pitched roofs were consistently benchmarked from 2010–2024.

2.5 Residential Installer Type

Between 2017 and 2021, residential PV costs were benchmarked based on a soft cost model developed for two installer types: smaller, regional installers and large, national integrators. The final benchmark cost was based on the weighted average of different types of inverters and installers, weighted by their respective market shares. From 2022 to 2024 cost benchmarks were based on smaller, regional installers.

⁵ The original Q4 2010 benchmark report (Goodrich et al. 2012) assumed a UPV system size of 187.5 MW_{dc} to match EIA representative PV system benchmarking efforts at the time (EIA 2010), assuming an ILR of 1.25. However, later benchmarking reports revised the PV system size for historical benchmarks.

⁶ The 2023 and 2024 benchmark reports also have supplementary published Excel cost models for UPV, CPV, and RPV that allow users to vary certain input parameters, including system size, by a factor of up to two (up or down) to assess its cost impact. Therefore, these models are appropriate for UPV systems sized 50 MW_{dc} to 200 MW_{dc}, CPV systems sized 1.5 MW_{dc} to 6.0 MW_{dc}, and RPV systems sized 4 kW_{dc} to 16 kW_{dc}.

3 Change in System Cost Modeling Methods

Between 2010 and 2024, the benchmark modeling methods have undergone significant advancements—reflecting changes in market conditions, technological improvements, and analytical objectives. From 2010 to 2014, the modeling framework focused on high-level cost components, offering a broad overview of system costs without delving into individual cost categories. Beginning in 2015, the methods transitioned to a more granular bottom-up cost modeling approach, which remained in use until 2022. Key aspects of that approach included:

- **Material and Equipment Costs:** Estimation of material and rental equipment costs for site preparation, site staging, and BOS construction activities.
- **Economies of Scale:** Adjustments in cost calculations to reflect the influence of project size on component costs.
- **Mounting System Costs:** Incorporation of detailed analyses of snow and wind loading factors.
- **Labor Costs:** Specification of labor types, quantities, and activities for each installation step, adjusted for locational variations.
- **Soft Costs:** Detailed modeling of customer acquisition, sales, and marketing expenses; engineering and permitting, inspection, and interconnection (PII)-related costs; and overhead expenses for residential PV systems.
- **Market Shares and Weighting:** Weighted averages of system costs, considering inverter market shares, installer market shares, and state-specific installed capacities across the United States.
- **Unit Consistency:** Intrinsic unit-based cost estimations, ultimately converted to $\$/W_{dc}$ for standardized comparisons.

In 2022, two new types of metrics were introduced to enhance the relevance of the benchmarks for near-term market analysis and strategic policymaking:

- **Modeled Market Price (MMP):** Reflects installed system costs, accounting for short-term market distortions such as tariffs, supply chain disruptions, and other challenges due to events like the COVID-19 pandemic.
- **Minimum Sustainable Price (MSP):** Estimates system costs without considering short-term distortions, providing a baseline for long-term cost projections and policy decisions.

In 2023, the PV System Cost Model (PVSCM) was introduced to make the cost benchmarks simpler and more transparent, while also expanding them to cover PV product components not previously benchmarked.⁷ PVSCM can also facilitate sensitivity analysis based on key system parameters in their intrinsic units.

In 2024, the benchmarking effort expanded to include stakeholder input from two additional national laboratories: Lawrence Berkeley National Laboratory and Sandia National Laboratories. These laboratories, along with NREL—which had been performing benchmarking since 2010—

⁷ The versions of PVSCM corresponding with particular benchmark years can be downloaded from the NREL Data Catalog at <https://data.nrel.gov/submissions/221> (2023) and DOE’s Solar Photovoltaic System Cost Benchmarks page at <https://www.energy.gov/eere/solar/solar-photovoltaic-system-cost-benchmarks> (2024).

submitted cost data to SETO derived from separate sets of industry stakeholders as well as a weighting for the number of independent data sources used for each cost element. SETO integrated these data to produce benchmark values and ranges in PVSCM. The independent analyses and industry data from multiple laboratories were intended to improve the estimate of uncertainty in benchmark cost components.

4 System Capital Costs, 2010–2024

This section highlights the capital cost trends of systems assumed to use the PV technologies that are most relevant today, facilitating consistency in cross-year cost comparisons (as described in Section 2). Figure 3 shows benchmarked capital costs for all sectors in 2024 USD. Between 2010 and 2024, RPV costs⁸ decreased 65%, from \$9.23/W_{dc} to \$3.25/W_{dc}. The steep cost reductions in early years can be attributed to reductions in hardware costs, particularly PV module costs. Since 2020, technology improvements and supply chain growth have reduced costs to some extent, but overall system costs have remained relatively flat, with ups and downs caused by market dynamics like policy changes, tariffs, and supply chain constraints.

Costs for UPV systems, characterized by a 100-MW_{dc} single-axis tracking configuration, decreased 83%, from \$6.94/W in 2010 to \$1.15/W in 2024. These reductions were primarily driven by lower module costs, market maturation, economies of scale, and improvement in average module efficiencies.

Costs for CPV systems, as characterized in Figure 3, decreased 77%, from \$6.83/W in 2010 to \$1.55/W in 2024. The benchmarked CPV system in Figure 3 was a rooftop system through 2022 and a ground-mounted system in 2023 and 2024 (a community solar system in 2023 and a system integrating sheep grazing in 2024). These alternative designs were modeled in the more recent benchmarks to reflect the increasing diversification of the commercial sector. The shift from commercial rooftop benchmarking to commercial ground-mounted system benchmarking also led to an increase in structural BOS costs associated with larger ground-mounted systems.

⁸ The cost data used for comparison here reflect MMPs. Until 2021, PV benchmarks were calculated as weighted average system costs, accounting for variations in market share by technology (inverter, mounting, etc.), installer type, and installed system capacity across each state, as well as locational costs. However, due to the challenges of capturing all locational variability associated with soft costs, benchmarks were changed to be based on the technologies with the highest market shares and the practices most followed across all states.

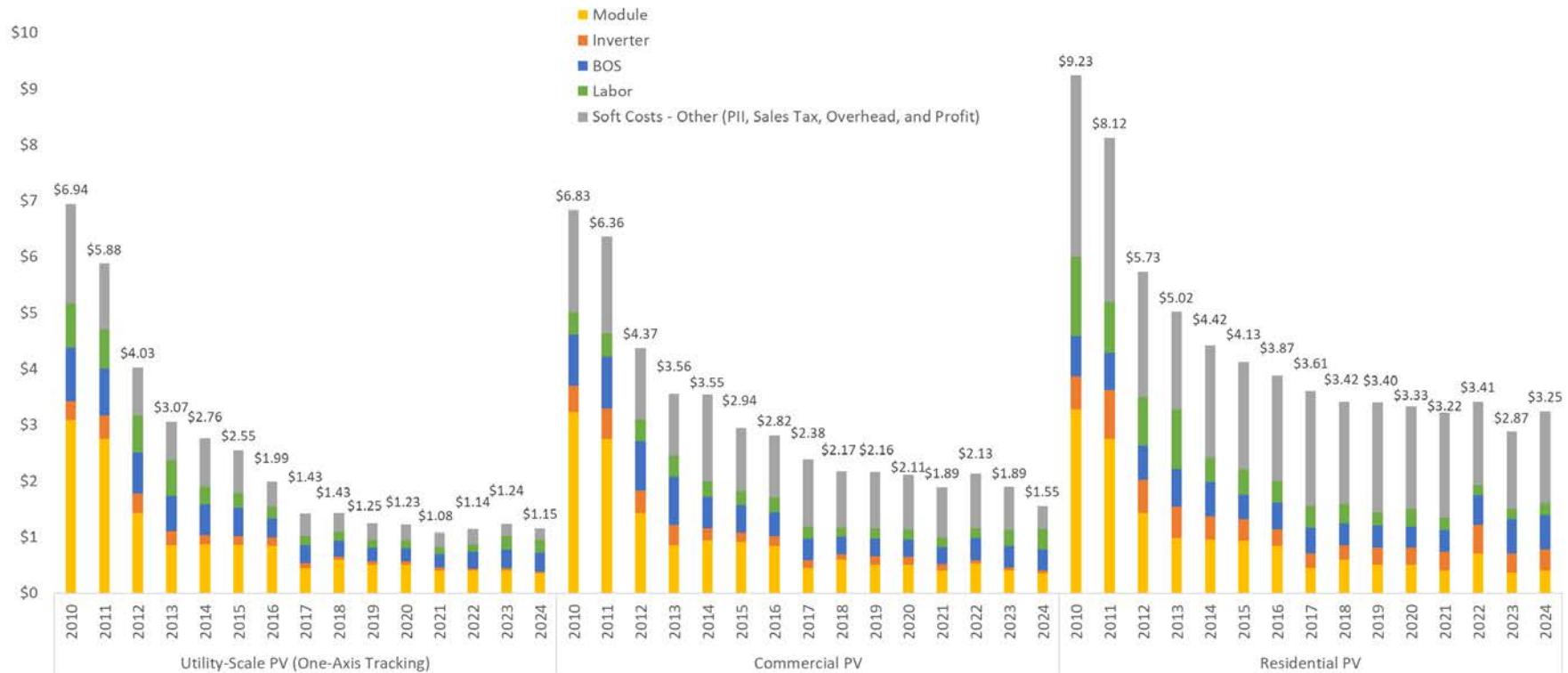


Figure 3. Installed PV system cost, 2010–2024, in \$/W_{dc} (2024 USD)

Note: CPV costs in Figure 3 represent a 200-kW_{dc} rooftop application from 2010–2022 and a 3-MW_{dc} fixed-tilt ground-mount system from 2023–2024. Additionally, residential PV costs account for different inverter types based on market share from 2010–2021 and include only microinverters from 2022–2024.

Sources: DOE 2024; Feldman et al. 2021; Ramasamy et al. 2021; Ramasamy et al. 2022; Ramasamy et al. 2023

Figure 4 illustrates the proportion of soft costs (labor and other soft costs) as a percentage of total installed system costs for each sector over time. RPV systems have had the highest soft cost shares, peaking at 68% in 2017, while approximately half of CPV system costs have been attributed to soft cost categories since 2014. UPV has maintained the lowest level of soft costs, stabilizing around 35%–40% after 2015. Starting in 2017, a detailed soft-cost analysis was conducted across all sectors, incorporating soft costs that had not previously been included. This led to an increase in the proportion of soft costs across sectors in 2017 (exacerbated by a 47% reduction in module costs from 2016 to 2017). Unlike other years, where the RPV inverter cost was based on the weighted average cost of different inverter types, the significant drop in the soft-cost percentage for RPV during 2022–2024 is attributed to the exclusive use of microinverters in those years. The higher hardware costs caused by microinverters reduced the relative proportion of soft costs. Soft cost reductions across all sectors have lagged behind hardware cost reductions, indicating that improvements in system procurement and deployment processes have not fully translated into proportional soft cost reductions.

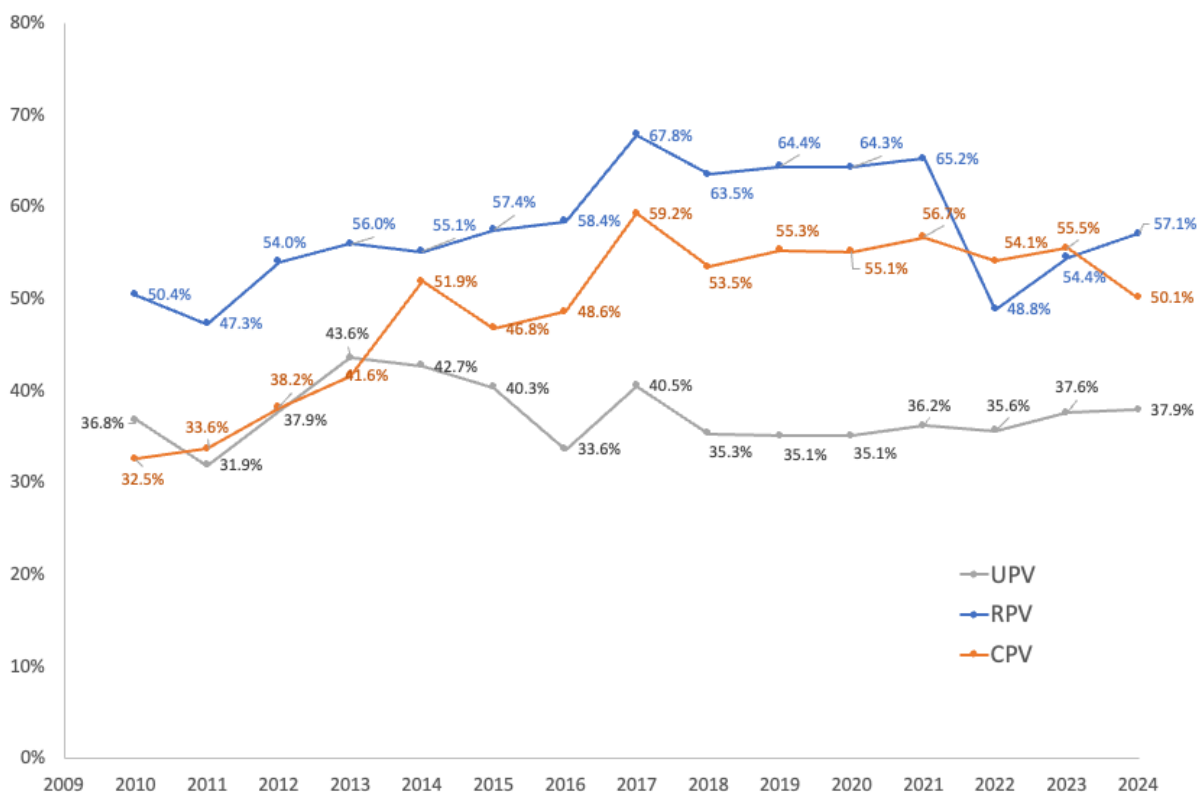


Figure 4. Soft cost as a proportion of total installed system cost by sector

As shown in Figure 5, ac-coupled PV-plus-storage system costs decreased from 2020 to 2024, by 2% in the utility sector, 8% in the commercial sector, and 20% in the residential sector. Most cost reductions during this period can be attributed to reductions in lithium-ion battery costs and PV module costs. In contrast to PV-only systems, PV-plus-storage systems experienced the greatest cost reductions in the residential sector. This was because there were very few residential systems incorporating battery energy storage prior to 2020.

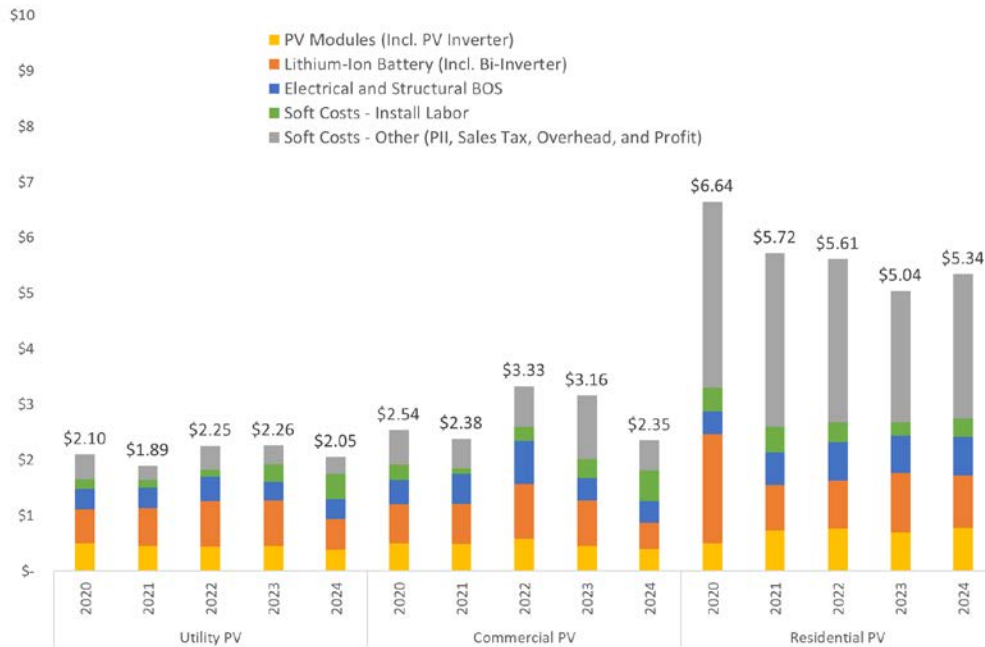


Figure 5. Installed cost of ac-coupled PV-plus-storage systems, 2020–2024, in \$/W_{dc} (2024 USD)

The following table illustrates the PV and battery system capacity from 2020–2024.

Table 1. PV and Battery System Capacity From 2020–2024

Year	Residential Sector	Commercial Sector	Utility-Scale Sector
2020 ⁹	7-kW _{dc} PV + 5-kW _{dc} 20-kWh BESS	1-MW _{dc} PV + 600-kW _{dc} 2400-kWh BESS	100-MW _{dc} PV + 60-MW _{dc} 240-MWh BESS
2021	7.2-kW _{dc} PV + 5-kW _{dc} 12.5-kWh BESS	1-MW _{dc} PV + 600-kW _{dc} 2400-kWh BESS	
2022	8-kW _{dc} PV + 5-kW _{dc} 12.5-kWh BESS	500-kW _{dc} PV + 300-kW _{dc} 1200-kWh BESS	
2023	8-kW _{dc} PV + 5-kW _{dc} 12.5-kWh BESS	3-MW _{dc} PV + 1.8-MW _{dc} 7.2-MWh BESS	
2024	8-kW _{dc} PV + 5-kW _{dc} 12.5-kWh BESS	3-MW _{dc} PV + 1.8-MW _{dc} 7.2-MWh BESS	

⁹ The 2020 benchmark report also included a 7-kW_{dc} PV system paired with a 3-kW_{dc}, 6-kWh ac-coupled BESS configuration.

5 PV System LCOE, 2010–2024

Figure 6 shows the LCOE trends over time for each sector in 2024 USD. The LCOE for RPV decreased 76%, from 61.5 cents/kWh in 2010 to 14.6 cents/kWh in 2024. Drivers include lower installed system costs, lower operations and maintenance (O&M) costs,¹⁰ improved module and inverter efficiency, and better financing terms. Since 2022, high interest rates have put upward pressure on residential PV LCOE.¹¹

For CPV systems, LCOE decreased 84%, from 47.9 cents/kWh in 2010 to 7.7 cents/kWh in 2024, largely due to advances in system design, including the adoption of mono PERC modules and larger inverter capacities. In 2023, the inclusion of community solar applications in the commercial sector's cost modeling resulted in higher O&M costs due to additional subscriber management expenses. This increase led to a relatively high LCOE for the commercial sector in 2023 compared with 2024.

UPV systems have consistently had the lowest LCOE, decreasing 86%, from 34.9 cents/kWh in 2010 to 4.8 cents/kWh in 2024, due to high-efficiency modules, single-axis tracking, and optimized system designs, including advanced power electronics and higher ILRs. The cost trajectory highlights significant economies of scale and reduced BOS costs over time. In 2022, PV became the largest source of capacity added to U.S. electricity grids (Bolinger et al. 2023).

¹⁰ Across all sectors, O&M costs decreased by roughly 80% between 2010 and 2024, largely due to lower material replacement costs. In 2023, CPV O&M costs were inflated because the benchmark was based on community solar, which includes additional customer management costs in the O&M cost.

¹¹ LCOE benchmarks for 2010 through 2019 assumed current financing costs (including use of the Investment Tax Credit) alongside calculations without the Investment Tax Credit, creating an inconsistency. Since 2020, we have transitioned to calculating LCOE based on long-term, steady-state financing assumptions, excluding the Investment Tax Credit and incorporating interest rates higher than the historically low rates observed in 2020.

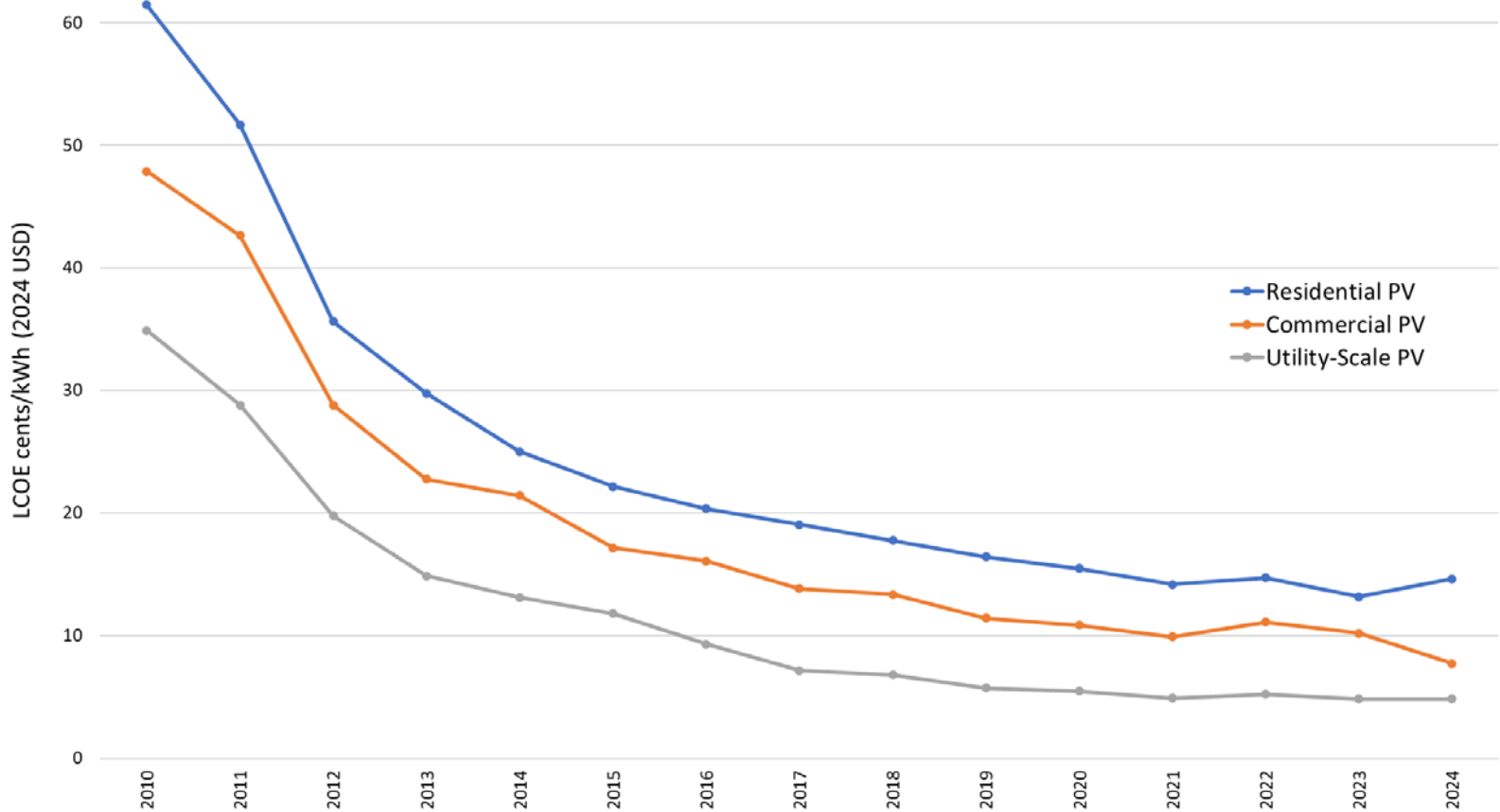


Figure 6. PV system LCOE, 2010–2024, in cents/kWh (2024 USD)

Sources: DOE 2024; Ramasamy et al. 2022

6 Conclusion

This report illustrates dramatic PV benchmark cost reductions in 2024 USD between 2010 and 2024. During this period, UPV system costs decreased 83%, CPV system costs decreased 77%, and RPV system costs decreased 65%. In addition, between 2020 and 2024, ac-coupled PV-plus-storage system costs decreased by 2% for UPV, 7% for CPV, and 20% for RPV. At the same time, LCOE decreased 86% for UPV, 84% for CPV, and 76% for RPV. These reductions highlight significant advancements in efficiency across sectors, driven by technology improvements, economies of scale, and streamlined processes. These efforts have laid the foundation for transformative advancements and widespread adoption of solar power.

Appendix 1

Table A-1. Installed PV System Cost (\$/W_{dc}, 2024 USD) 2010–2024

Overnight Installed PV System Cost \$/W _{dc} (2024 USD)	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
	(Q4 2009)	(Q4 2010)	(Q4 2011)	(Q4 2012)	(Q4 2013)	(Q1 2015)	(Q1 2016)	(Q1 2017)	(Q1 2018)	(Q1 2019)	(Q1 2020)	(Q1 2021)	(Q1 2022) MMP	(Q1 2023) MMP	(Q1 2024) MMP
Residential PV	\$9.23	\$8.12	\$5.73	\$5.02	\$4.42	\$4.13	\$3.87	\$3.61	\$3.42	\$3.40	\$3.33	\$3.22	\$3.41	\$2.87	\$3.25
Commercial PV	\$6.83	\$6.36	\$4.37	\$3.56	\$3.55	\$2.94	\$2.82	\$2.38	\$2.17	\$2.16	\$2.11	\$1.89	\$2.13	\$1.89	\$1.55
Utility-Scale PV	\$6.94	\$5.88	\$4.03	\$3.07	\$2.76	\$2.55	\$1.99	\$1.43	\$1.43	\$1.25	\$1.23	\$1.08	\$1.14	\$1.24	\$1.15

Note: Utility-scale PV costs represent a 100-MW_{dc} single-axis tracking system. Commercial PV costs represent a 200-kW_{dc} rooftop application from 2010–2022 and a 3-MW_{dc} fixed-tilt ground-mount system from 2023–2024. Additionally, residential PV costs account for different inverter types based on market share from 2010–2021 and include only microinverters from 2022–2024.

Table A-2. PV System LCOE (cents/kWh, 2024 USD) 2010–2024

LCOE cents/kWh (2024 USD)	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
	(Q4 2009)	(Q4 2010)	(Q4 2011)	(Q4 2012)	(Q4 2013)	(Q1 2015)	(Q1 2016)	(Q1 2017)	(Q1 2018)	(Q1 2019)	(Q1 2020)	(Q1 2021)	(Q1 2022) MMP	(Q1 2023) MMP	(Q1 2024) MMP
Residential PV	61.5¢	51.7¢	35.6¢	29.8¢	25.0¢	22.2¢	20.4¢	19.1¢	17.7¢	16.4¢	15.5¢	14.2¢	14.7¢	13.2¢	14.6¢
Commercial PV	47.9¢	42.6¢	28.8¢	22.7¢	21.4¢	17.2¢	16.1¢	13.8¢	13.3¢	11.4¢	10.8¢	9.9¢	11.1¢	10.2¢	7.7¢
Utility-Scale PV	34.9¢	28.8¢	19.8¢	14.9¢	13.1¢	11.8¢	9.3¢	7.1¢	6.8¢	5.7¢	5.5¢	4.9¢	5.2¢	4.8¢	4.8¢

Table A-3. Utility PV Installed System Cost Breakdown (\$/W_{dc}, 2024 USD) 2010–2024

UPV \$/W _{dc} (2024 USD)	(Q4 2009)	(Q4 2010)	(Q4 2011)	(Q4 2012)	(Q4 2013)	(Q1 2015)	(Q1 2016)	(Q1 2017)	(Q1 2018)	(Q1 2019)	(Q1 2020)	(Q1 2021)	(Q1 2022) MMP	(Q1 2023) MMP	(Q1 2024) MMP
Module	\$3.08	\$2.75	\$1.43	\$0.86	\$0.87	\$0.87	\$0.85	\$0.45	\$0.59	\$0.50	\$0.50	\$0.40	\$0.41	\$0.40	\$0.35
Inverter	\$0.35	\$0.41	\$0.35	\$0.24	\$0.16	\$0.15	\$0.15	\$0.08	\$0.06	\$0.06	\$0.06	\$0.05	\$0.03	\$0.05	\$0.03
BOS	\$0.96	\$0.84	\$0.73	\$0.63	\$0.54	\$0.51	\$0.33	\$0.32	\$0.28	\$0.25	\$0.24	\$0.24	\$0.30	\$0.33	\$0.33
Labor	\$0.79	\$0.70	\$0.66	\$0.64	\$0.31	\$0.27	\$0.21	\$0.18	\$0.16	\$0.14	\$0.14	\$0.13	\$0.14	\$0.25	\$0.24
Soft Costs	\$1.77	\$1.18	\$0.86	\$0.70	\$0.87	\$0.76	\$0.46	\$0.40	\$0.34	\$0.30	\$0.30	\$0.26	\$0.27	\$0.21	\$0.20
Total	\$6.94	\$5.88	\$4.03	\$3.07	\$2.76	\$2.55	\$1.99	\$1.43	\$1.43	\$1.25	\$1.23	\$1.08	\$1.14	\$1.24	\$1.15

Table A-4. Commercial PV Installed System Cost Breakdown (\$/W_{dc}, 2024 USD) 2010–2024

CPV \$/W _{dc} (2024 USD)	(Q4 2009)	(Q4 2010)	(Q4 2011)	(Q4 2012)	(Q4 2013)	(Q1 2015)	(Q1 2016)	(Q1 2017)	(Q1 2018)	(Q1 2019)	(Q1 2020)	(Q1 2021)	(Q1 2022) MMP	(Q1 2023) MMP	(Q1 2024) MMP
Module	\$3.23	\$2.75	\$1.43	\$0.86	\$0.94	\$0.91	\$0.85	\$0.45	\$0.59	\$0.50	\$0.50	\$0.40	\$0.52	\$0.40	\$0.35
Inverter	\$0.46	\$0.54	\$0.40	\$0.36	\$0.21	\$0.17	\$0.17	\$0.13	\$0.10	\$0.17	\$0.15	\$0.11	\$0.07	\$0.05	\$0.06
BOS	\$0.91	\$0.93	\$0.88	\$0.86	\$0.55	\$0.48	\$0.43	\$0.39	\$0.32	\$0.30	\$0.30	\$0.30	\$0.39	\$0.39	\$0.37
Labor	\$0.41	\$0.41	\$0.39	\$0.38	\$0.28	\$0.25	\$0.25	\$0.22	\$0.15	\$0.19	\$0.18	\$0.18	\$0.17	\$0.28	\$0.36
Soft Costs	\$1.82	\$1.72	\$1.28	\$1.10	\$1.56	\$1.13	\$1.12	\$1.20	\$1.01	\$1.01	\$0.98	\$0.89	\$0.98	\$0.77	\$0.42
Total	\$6.83	\$6.36	\$4.37	\$3.56	\$3.55	\$2.94	\$2.82	\$2.38	\$2.17	\$2.16	\$2.11	\$1.89	\$2.13	\$1.89	\$1.55

Table A-5. Residential PV Installed System Cost Breakdown (\$/W_{dc}, 2024 USD) 2010–2024

RPV \$/W _{dc} (2024 USD)	(Q4 2009)	(Q4 2010)	(Q4 2011)	(Q4 2012)	(Q4 2013)	(Q1 2015)	(Q1 2016)	(Q1 2017)	(Q1 2018)	(Q1 2019)	(Q1 2020)	(Q1 2021)	(Q1 2022) MMP	(Q1 2023) MMP	(Q1 2024) MMP
Module	\$3.28	\$2.75	\$1.43	\$0.99	\$0.95	\$0.93	\$0.85	\$0.45	\$0.59	\$0.50	\$0.50	\$0.40	\$0.71	\$0.36	\$0.40
Inverter	\$0.59	\$0.88	\$0.59	\$0.56	\$0.42	\$0.39	\$0.28	\$0.25	\$0.26	\$0.32	\$0.31	\$0.33	\$0.51	\$0.34	\$0.37
BOS	\$0.71	\$0.65	\$0.62	\$0.67	\$0.62	\$0.44	\$0.48	\$0.46	\$0.39	\$0.40	\$0.38	\$0.39	\$0.53	\$0.61	\$0.62
Labor	\$1.43	\$0.91	\$0.86	\$1.06	\$0.43	\$0.44	\$0.39	\$0.39	\$0.34	\$0.24	\$0.31	\$0.22	\$0.19	\$0.19	\$0.21
Soft Costs	\$3.22	\$2.93	\$2.24	\$1.75	\$2.00	\$1.93	\$1.87	\$2.05	\$1.83	\$1.96	\$1.83	\$1.88	\$1.48	\$1.37	\$1.64
Total	\$9.23	\$8.12	\$5.73	\$5.02	\$4.42	\$4.13	\$3.87	\$3.61	\$3.42	\$3.40	\$3.33	\$3.22	\$3.41	\$2.87	\$3.25

Table A-6. Residential PV LCOE Assumptions, 2010–2024

Metric	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021 ¹²	2022	2023	2024
Installed cost (\$/W _{dc})	\$9.23	\$8.12	\$5.73	\$5.02	\$4.42	\$4.13	\$3.87	\$3.61	\$3.42	\$3.40	\$3.33	\$3.22	\$3.41	\$2.87	\$3.25
System size (kW _{dc})	5.0	5.0	5.1	5.1	5.2	5.2	5.6	5.7	6.2	6.6	7	7.15	7.9	7.9	7.9
Inverter loading ratio	1.10	1.11	1.12	1.13	1.13	1.14	1.15	1.15	1.15	1.15	1.15	1.21	1.21	1.21	1.21
Annual degradation (%)	1.00	0.95	0.90	0.85	0.80	0.75	0.75	0.75	0.70	0.70	0.70	1.0	1.0	0.70	0.70
O&M expenses (\$/kW _{dc} -yr)	69	61	52	45	38	32	31	31	27	33	36	30	30	33	35
Pre-inverter derate (%)	90	90.1	90.2	90.3	90.4	90.5	90.5	90.5	90.5	90.5	90.5	85.9	85.9	85.9	85.9
Inverter efficiency (%)	94.0	94.8	95.6	96.4	97.2	98.0	98.0	98.0	98.0	98.0	98.0	96.0	96.0	96.0	96.0
Equity discount rate (real)	9	8.6	8.3	7.9	7.6	7.3	6.9	6.9	6.9	6.1	6.1	10.2	10.2	6.8	6.8
Inflation rate	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
Debt interest rate	5.5	5.4	5.3	5.2	5.0	4.9	4.8	4.8	4.8	4.0	4.0	4.5	4.5	7.0	7.0
Debt fraction	34.2	35.2	36.1	37.1	38.1	39	40	40	40	53.7	53.7	100	100	75.9	75.9

¹² The 2021 and 2022 Residential LCOE Benchmark assumed a 25-year cost recovery, as opposed to the 30-year cost recovery for all other years and market segments.

Table A-7. Commercial PV LCOE Assumptions, 2010–2024

Metric	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
Installed cost (\$/W _{dc})	\$6.83	\$6.36	\$4.37	\$3.56	\$3.55	\$2.94	\$2.82	\$2.38	\$2.17	\$2.16	\$2.11	\$1.89	\$2.13	\$1.89	\$1.55
System size (kW _{dc})	200	200	200	200	200	200	200	200	200	200	200	200	200	3,000	3,000
Inverter loading ratio	1.10	1.11	1.12	1.13	1.13	1.14	1.15	1.15	1.15	1.15	1.15	1.23	1.23	1.23	1.23
Annual degradation (%)	1.00	0.95	0.90	0.85	0.80	0.75	0.75	0.75	0.70	0.70	0.70	0.70	0.70	0.70	0.70
O&M expenses (\$/kW _{dc} -yr)	43	40	36	32	29	25	24	24	22	24	24	22	21	21	20
Pre-inverter derate (%)	90.5	90.5	90.5	90.5	90.5	90.5	90.5	90.5	90.5	90.5	90.5	90.5	85.9	85.9	85.9
Inverter efficiency (%)	95.0	95.6	96.2	96.8	97.4	98.0	98.0	98.0	98.0	98.0	98.0	96.0	96.0	96.0	96.0
Equity discount rate (real)	9.0	8.6	8.3	7.9	7.6	7.3	6.9	6.9	6.9	6.1	6.1	6.1	6.1	6.8	6.8
Inflation rate	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
Debt interest rate	5.5	5.4	5.3	5.2	5	4.9	4.8	4.8	4.8	4	4	5	5	7.0	7.0
Debt fraction	34.2	35.2	36.1	37.1	38.1	39.0	40.0	40.0	40.0	53.8	53.8	71.8	71.8	75.9	75.9

Table A-8. Utility PV LCOE Assumptions, 2010–2024

Metric	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
One-axis tracker installed cost (\$/W _{dc})	\$6.94	\$5.88	\$4.03	\$3.07	\$2.76	\$2.55	\$1.99	\$1.43	\$1.43	\$1.25	\$1.23	\$1.08	\$1.14	\$1.24	\$1.15
One-axis tracker annual degradation (%)	1.00	0.95	0.90	0.85	0.80	0.75	0.75	0.75	0.70	0.70	0.70	0.70	0.70	0.70	0.70
One-axis tracker O&M expenses (\$/kW _{dc} -yr)	36	33	31	29	26	24	24	22	16	20	20	22	21	24	23
One-axis tracker pre-inverter derate (%)	90.5	90.5	90.5	90.5	90.5	90.5	90.5	90.5	90.5	90.5	90.5	90.5	85.9	85.9	85.9
One-axis tracker inverter efficiency (%)	96.0	96.4	96.8	97.2	97.6	98.0	98.0	98.0	98.0	98.0	98.0	96.0	96.0	96.0	96.0
One-axis tracker inverter loading ratio	1.10	1.12	1.13	1.15	1.17	1.18	1.20	1.30	1.30	1.34	1.34	1.34	1.34	1.34	1.34
Equity discount rate (real)	7.4	7.2	7.0	6.9	6.7	6.5	6.3	6.3	6.3	5.1	5.1	5.1	5.1	5.9	5.9
Inflation rate	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5

Metric	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
Debt interest rate	5.5	5.3	5.2	5.0	4.8	4.7	4.5	4.5	4.5	4.0	4.0	5.0	5.0	7.0	7.0
Debt fraction	34.2	35.2	36.1	37.1	38.1	39	40.0	40.0	40.0	51.9	51.9	71.8	71.8	75.3	75.3

References

- Ardani, Kristen, and Robert Margolis. 2011. *2010 Solar Technologies Market Report*. Golden, CO: National Renewable Energy Laboratory. DOE/GO-102011-3318. <https://www.nrel.gov/docs/fy12osti/51847.pdf>.
- Bolinger, Mark, Joachim Seel, Julie Mulvaney Kemp, Cody Warner, Anjali Katta, and Dana Robson. 2023. “Utility-Scale Solar, 2023 Edition: Empirical Trends in Deployment, Technology, Cost, Performance, PPA Pricing, and Value in the United States.” Berkeley, CA: Lawrence Berkeley National Laboratory. https://emp.lbl.gov/sites/default/files/emp-files/utility_scale_solar_2023_edition_slides.pdf.
- Chung, Donald, Carolyn Davidson, Kristen Ardani, Ran Fu, and Robert Margolis. 2015. *U.S. Photovoltaic Prices and Cost Breakdowns: Q1 2015 Benchmarks for Residential, Commercial, and Utility-Scale Systems*. Golden, CO: National Renewable Energy Laboratory. NREL/TP-6A20-64746. <https://www.nrel.gov/docs/fy15osti/64746.pdf>.
- Davidson, Carolyn, Ted L. James, Robert Margolis, Ran Fu, and David Feldman. 2014. *U.S. Residential Photovoltaic (PV) System Prices, Q4 2013 Benchmarks: Cash Purchases, Fair Market Value, and Prepaid Lease Transaction Prices*. Golden, CO: National Renewable Energy Laboratory. NREL/TP-6A20-62671. <https://www.nrel.gov/docs/fy15osti/62671.pdf>.
- DOE. 2024. *Solar Photovoltaic System Cost Benchmarks*. U.S. Department of Energy Office of Energy Efficiency and Renewable Energy Solar Energy Technologies Office. <https://www.energy.gov/eere/solar/solar-photovoltaic-system-cost-benchmarks>.
- EIA. 2010. *Updated Capital Cost Estimates for Electricity Generation Plants*. Washington, D.C.: U.S. Energy Information Administration. <https://www.nrc.gov/docs/ML1034/ML103420319.pdf>.
- Feldman, David, Galen Barbose, Robert Margolis, Ryan Wiser, Naim Darghouth, and Alan Goodrich. 2012. *Photovoltaic (PV) Pricing Trends: Historical, Recent, and Near-Term Projections*. Golden, CO: National Renewable Energy Laboratory. DOE/GO-102012-3839. <https://www.nrel.gov/docs/fy13osti/56776.pdf>.
- Feldman, David, Galen Barbose, Robert Margolis, Ted James, Samantha Weaver, Naim Darghouth, Ran Fu, Carolyn Davidson, Sam Booth, and Ryan Wiser. 2014. “Photovoltaic System Pricing Trends: Historical, Recent, and Near Term Projections – 2014 Edition.” Golden, CO: National Renewable Energy Laboratory. NREL/PR-6A20-62558. <https://www.nrel.gov/docs/fy14osti/62558.pdf>.
- Feldman, David, Vignesh Ramasamy, Ran Fu, Ashwin Ramdas, Jal Desai, and Robert Margolis. 2021. *U.S. Solar Photovoltaic System and Energy Storage Cost Benchmark: Q1 2020*. Golden, CO: National Renewable Energy Laboratory. NREL/TP-6A20-77324. <https://www.nrel.gov/docs/fy21osti/77324.pdf>.

Fu, Ran, Donald Chung, Travis Lowder, David Feldman, Kristen Ardani, and Robert Margolis. 2016. *U.S. Solar Photovoltaic System Cost Benchmark: Q1 2016*. Golden, CO: National Renewable Energy Laboratory. NREL/TP-6A20-66532. <https://www.nrel.gov/docs/fy16osti/66532.pdf>.

Fu, Ran, David Feldman, Robert Margolis, Mike Woodhouse, and Kristen Ardani. 2017. *U.S. Solar Photovoltaic System Cost Benchmark: Q1 2017*. Golden, CO: National Renewable Energy Laboratory. NREL/TP-6A20-68925. <https://www.nrel.gov/docs/fy17osti/68925.pdf>.

Fu, Ran, David Feldman, and Robert Margolis. 2018. *U.S. Solar Photovoltaic System Cost Benchmark: Q1 2018*. Golden, CO: National Renewable Energy Laboratory. NREL/TP-6A20-72399. <https://www.nrel.gov/docs/fy19osti/72399.pdf>.

Goodrich, Alan, Ted James, and Michael Woodhouse. 2012. *Residential, Commercial, and Utility-Scale Photovoltaic (PV) System Prices in the United States: Current Drivers and Cost Reduction Opportunities*. Golden, CO: National Renewable Energy Laboratory. NREL/TP-6A20-53347. <https://www.nrel.gov/docs/fy12osti/53347.pdf>.

Ramasamy, Vignesh, David Feldman, Jal Desai, and Robert Margolis. 2021. *U.S. Solar Photovoltaic System and Energy Storage Cost Benchmarks: Q1 2021*. Golden, CO: National Renewable Energy Laboratory. NREL/TP-6A20-80694. <https://www.nrel.gov/docs/fy22osti/80694.pdf>.

Ramasamy, Vignesh, Jarett Zuboy, Eric O'Shaughnessy, David Feldman, Jal Desai, Michael Woodhouse, Paul Basore, and Robert Margolis. 2022. *U.S. Solar Photovoltaic System and Energy Storage Cost Benchmarks, With Minimum Sustainable Price Analysis: Q1 2022*. Golden, CO: National Renewable Energy Laboratory. NREL/TP-7A40-83586. <https://www.nrel.gov/docs/fy22osti/83586.pdf>.

Ramasamy, Vignesh, Jarett Zuboy, Michael Woodhouse, Eric O'Shaughnessy, David Feldman, Jal Desai, Andy Walker, Robert Margolis, and Paul Basore. 2023. *U.S. Solar Photovoltaic System and Energy Storage Cost Benchmarks with Minimum Sustainable Price Analysis: Q1 2023*. Golden, CO: National Renewable Energy Laboratory. NREL/TP-7A40-87303. <https://www.nrel.gov/docs/fy23osti/87303.pdf>.