Appendix B. PV System CAPEX and LCOE Benchmarks in 2020 USD

When comparing the results across periods, note that:

1. Values are inflation-adjusted using the Consumer Price Index (2020). Thus, historical values from our models are adjusted and presented as real USD instead of nominal USD.

2. Cost categories are aggregated for comparison purposes. Soft Costs—Others represents:

   A. PII

   B. Transmission line (if any)

   C. Sales tax

   D. EPC/developer overhead and profit.

3. The current versions of our cost models make a few significant changes from the versions used in our Q1 2020 (Feldman et. al. 2021) and Q1 2018 benchmarking reports (Fu et al. 2018a, Fu et al. 2018b). Appendix A details the changes made to the models between previous versions (Feldman et al. 2021) and this year's versions.

4. Our Q1 2019, Q1 2020, and Q1 2021 benchmarks use monocrystalline PV modules, whereas all previous benchmarks used multicrystalline PV modules. This switch reflects the overall trend occurring in the U.S. market.

5. Based on Wiser, Bolinger, and Seel (2020), which stated that most utility-scale PV projects do not own the land on which the PV system is placed, we reclassified land costs from an upfront capital expenditure (land acquisition) to an operating expenditure (lease payments) for 2019, 2020, and 2021. In previous editions of this report, we assumed a land acquisition cost of $0.03/W.

All previous benchmarks can be found at NREL's "Solar Technology Cost Analysis" web page at www.nrel.gov/solar/solar-cost-analysis.html.

We use the following equation to calculate LCOE of PV plus storage system as follows:

$$LCOE = \frac{E + \frac{F^n}{(1+R)^n} - \sum_{n-1}^{N} \frac{(D+DF)^n}{(1+Rn)^n} \times (T) + \sum_{n-1}^{N} \frac{(O+C+I)^n}{(1+Rn)^n} \times (1-T) - \frac{Rv^n}{(1+R)^n} \times (1-T) + \sum_{n-1}^{N} \frac{(P)^n}{(1+Rn)^n} \times (1-T)}{\left(\sum_{n-1}^{N} \frac{P \times (1-Dr)^n}{(1+R)^n} \times (1-B) + \sum_{n-1}^{N} \frac{P \times (1-Dr)^n}{(1+R)^n} \times (B) \times (1-Lp) + \sum_{n-1}^{N} \frac{G}{(1+R)^n} \times (1-Lg) \right) \times (1-T)}$$

Equation 1. LCOE of PV plus storage formula

E = Initial equity investment of solar and storage
I = Debt interest payments
P = Debt principal payments
C = Charging cost
F = Follow-on investments (inverter, battery replacements)
D = Depreciation of solar and storage (which may include depreciation from follow-on investments)
R = Real discount rate

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Rn = Nominal discount rate
T = Tax rate
O = O&M
Dr = Degradation of PV
Rv = Residual value
P = Initial annual system production
B = Percentage of generated solar electricity fed to battery
Lp = Roundtrip energy losses from PV-storage-grid
Lg = Roundtrip energy losses from grid-storage-grid
G = Annual electricity purchased from grid.

Table B-1 (CAPEX) and Table B-2 (LCOE) put our Q1 2021 benchmarking results (inflation-adjusted) in context with the results of previous National Renewable Energy Laboratory (NREL) benchmarking analyses.

Table B-1. Summary of NREL CAPEX (2020 $/W$_{DC}$)

Reporting Year (Benchmarking Date)	2010 (Q4 2009)	2011 (Q4 2010)	2012 (Q4 2011)	2013 (Q4 2012)	2014 (Q4 2013)	2015 (Q1 2015)	2016 (Q1 2016)	2017 (Q1 2017)	2018 (Q1 2018)	2019 (Q1 2019)	2020 (Q1 2020)	2021 (Q1 2021)
Residential (22-panel)	9.01	7.83	5.35	4.60	4.00	3.71	3.44	3.12	2.90	2.84	2.71	2.65
Commercial Rooftop (200-kW)	6.67	6.13	4.08	3.26	3.21	2.64	2.50	2.07	1.84	1.80	1.72	1.56
Utility-Scale (100-MW fixed-tilt)	5.69	4.83	3.17	2.39	2.19	2.12	1.67	1.15	1.13	0.97	0.94	0.83
Utility-Scale (100-MW one-axis tracking)	6.78	5.66	3.76	2.81	2.49	2.29	1.77	1.24	1.21	1.04	1.01	0.89

Table B-2. Summary NREL LCOE (2020 cents/kWh)

Reporting Year (Benchmarking Date)	Market Financing Rates												Steady-State Financing	
	2010 (Q4 2009)	2011 (Q4 2010)	2012 (Q4 2011)	2013 (Q4 2012)	2014 (Q4 2013)	2015 (Q1 2015)	2016 (Q1 2016)	2017 (Q1 2017)	2018 (Q1 2018)	2019 (Q1 2019)	2020 (Q1 2020)	2021 (Q1 2021)	2021 (Q1 2021)	2030 Goal
Residential PV (22-panel)														
LCOE (High resource)	42.1	35.4	24.4	20.5	17.2	15.2	13.9	13.1	12.2	11.3	11.1	10.6	9.7	—
LCOE (Medium resource)	51.6	43.4	29.9	25.0	21.0	18.6	17.1	16.0	14.9	13.8	13.7	13.0	11.9	5.4
LCOE (Low resource)	55.4	46.6	32.1	26.9	22.6	19.9	18.3	17.2	16.0	14.8	14.7	13.9	15.8	—
Residential PV-Plus-Storage														
LCOE (High resource)	—	—	—	—	—	—	—	—	—	—	16.6	25.4	16.7	—
LCOE (Medium resource)	—	—	—	—	—	—	—	—	—	—	20.1	23.6	20.5	—
LCOE (Low resource)	—	—	—	—	—	—	—	—	—	—	22.0	19.1	27.7	—
Commercial Rooftop PV (200 kW)														
LCOE (High resource)	32.3	28.8	19.5	15.3	14.5	11.6	10.8	9.4	9.0	8.0	7.8	7.4	6.8	—
LCOE (Medium resource)	40.2	35.8	24.2	19.1	18.0	14.4	13.5	11.6	11.2	9.6	9.4	9.1	8.3	4.3

	Market Financing Rates												Steady-State Financing	
LCOE (Low resource)	43.3	38.6	26.1	20.5	19.4	15.5	14.5	12.5	12.0	10.7	10.5	9.8	11.2	—
Commercial PV-Plus-Storage														
LCOE (High resource)	—	—	—	—	—	—	—	—	—	—	9.3	9.2	9.2	—
LCOE (Medium resource)	—	—	—	—	—	—	—	—	—	—	11.5	12.2	11.4	—
LCOE (Low resource)	—	—	—	—	—	—	—	—	—	—	12.3	14.3	15.6	—
Utility-Scale PV (100 MW One-Axis Tracking)														
LCOE (High resource)	22.8	18.8	12.9	9.8	8.6	7.7	6.1	4.7	4.4	3.7	3.7	3.6	3.2	—
LCOE (Medium resource)	29.3	24.2	16.6	12.5	11.0	9.9	7.8	6.0	5.7	4.8	4.8	4.6	4.1	2.0
LCOE (Low resource)	31.8	26.3	18.0	13.6	11.9	10.7	8.5	6.5	6.2	5.2	5.2	5.0	5.5	—
Utility-Scale PV-Plus-Storage														
LCOE (High resource)	—	—	—	—	—	—	—	—	—	—	6.5	6.9	6.0	—
LCOE (Medium resource)	—	—	—	—	—	—	—	—	—	—	8.5	8.9	7.7	—
LCOE (Low resource)	—	—	—	—	—	—	—	—	—	—	9.2	9.7	10.7	—