EIA Discussion on Capital Cost and Performance Characteristic Estimates for New Generating Technologies

EIA Electricity, Coal, and Renewables Long-Term Modeling Team

September 19, 2023

Meeting overview

- Statement on the *Annual Energy Outlook 2024*
- Overview of report
- Technology cases
- Comparison of overnight capital cost estimates
- Questions/discussion

Statement on the *Annual Energy Outlook* and EIA's plan to enhance long-term modeling capabilities

At the U.S. Energy Information Administration (EIA), a core aspect of our mission is to develop long-term projections of the U.S. energy system that inform decision makers at all levels. This work requires keeping pace with rapidly evolving energy markets, policies and regulations, macroeconomic trends, technology innovation, and resource availability.

EIA's National Energy Modeling System (NEMS), which we use to produce our Annual Energy Outlook (AEO), requires substantial updates to better model hydrogen, carbon capture, and other emerging technologies.

Our usual AEO publication schedule does not accommodate these necessary model enhancements, which require significant time and resources. As a result, EIA will not publish an AEO in 2024. This decision does not affect publications relying on our near-term modeling, such as the Short-Term Energy Outlook.

By retooling NEMS in 2024, the next AEO in 2025 will more comprehensively address existing laws and regulations in the Reference case, including up-to-date provisions in the Inflation Reduction Act and regulatory actions that could be finalized in the coming months.

We have also embarked on a longer-term effort to develop a flexible, next generation modeling framework that is better suited to address the ongoing changes in the U.S. energy sector.

We will continue to communicate with our stakeholders on these critical modeling issues and provide regular progress reports on our website.

Our plan ensures that the AEO will continue to provide a sound and independent long-term perspective on the U.S. energy sector for lawmakers, energy modelers, and other stakeholders.

Overview of report

- EIA commissions this study approximately every three years to provide reasonably comprehensive power-sector capital costs with known and consistent scope for technologies with narrowly defined, well-understood, and typical (but not necessarily average) plant characteristics.

- The study includes technologies with significant historical and recent additions (combined cycle, wind, solar), as well as technologies with few installations (nuclear, carbon capture and storage).

- Results may or may not line-up with statistical estimates, given differences in scope of estimation, statistical variation of actual plant characteristics, and temporal reporting issues.

Overview of technology cases

Technology	Description	Net nominal capacity (kW)	Capital cost ($/kW)	Net nominal heat rate (Btu/kWh)
Ultra-supercritical coal w/o carbon capture – greenfield	1 x 735 MW gross	650	$4,103	8,638
Ultra-supercritical coal 95% carbon capture	1 x 819 MW Gross	650	$7,355	12,293
Combustion turbine – simple cycle (aeroderivative)	4 x 54 MW gross aeroderivative simple cycle	211	$1,606	9,447
Combustion turbine – simple cycle	1 x H class simple cycle	419	$836	9,142
Combined-cycle 2x2x1	2 x 1 H class combined cycle	1,227	$868	6,266
Combined-cycle 1x1x1, single shaft	1 x 1 H class combined cycle	627	$921	6,226
Combined cycle 1x1x1, single shaft 95% carbon capture	1 x 1 H class combined cycle	543	$2,365	7,239
Bio energy 95% carbon capture	1 x 50 MW woody bubbling fluidized bed	50	$12,631	19,965
Advanced nuclear (brownfield)	2 x AP1000	2,156	$7,861	10,608
Small modular reactor nuclear power plant	6 x 80 MW small modular reactor	480	$8,936	10,046

Overview of technology cases

Technology	Description	Net nominal capacity (kW)	Capital cost ($/kW)
Geothermal	Binary cycle	50	$3,963
Hydroelectric power Plant	New stream reach development	100	$7,073
Onshore wind – large plant footprint	200 MW | 2.82 MW wind turbine generator	200	$1,484
Onshore Wind Repowering/Retrofit	150 MW | 1.5-1.62 MW wind turbine generator	150	$1,386
Fixed-bottom offshore wind: monopile foundations	900 MW | 15 MW wind turbine generator	900	$3,689
Solar PV w/ single axis tracking	150 MWAC	150	$1,502
Solar PV w/ single axis tracking + AC coupled battery storage	150 MWAC Solar 50 MW | 200 MWh Storage	150	$2,175
Solar PV w/ single axis tracking + DC coupled battery storage	150 MWAC Solar 50 MW | 200 MWh Storage	150	$2,561
Battery energy storage system	150 MW | 600 MWh	150	$1,744, ($436/kWh)

Comparison of technology case costs

- Estimation or plant characteristics may differ across these cases. We compare cases that are as similar as possible.

- Compared with:
  – Form EIA 860 construction cost data for electric generators installed in 2020
    - Form EIA 860 value is a capacity-weighted average of all projects installed, in 2020, of a given prime mover and are not representative of one specific design.
  – NREL Annual Technology Baseline (ATB) 2023
  – Lazard's 2023 Levelized Cost of Energy +
    - Low case technology represents older technology designs
    - High case technology represents modern technology designs
  – Lawrence Berkley National Laboratory (LBNL) *Land-Based Wind Market Report: 2023 Edition*
  – LBNL Utility-Scale Solar, 2022 Edition: Empirical Trends in Deployment, Technology, Cost, Performance, PPA Pricing, and Value in the United States

New coal without CCS—greenfield

Overnight capital cost—coal w/o carbon capture sequestration - greenfield
dollars per kilowatt (2023$/kW)

Ultra-supercritical coal without CO_2 capture

735 MW single steam generator and steam turbine with coal storage and handling systems

Nominal net capacity – 650 MW

Heat rate – 8,639 Btu/kWh

New coal with carbon capture sequestration

Overnight capital cost—coal w/ carbon capture sequestration
dollars per kilowatt (2023$/kW)

Note: S&L 2020 uses 90% CCS, compared with 95% for all other cases shown

Ultra-supercritical coal with CO_2 capture

819 MW single steam generator and steam turbine with coal storage and handling systems

95% CO_2 capture system

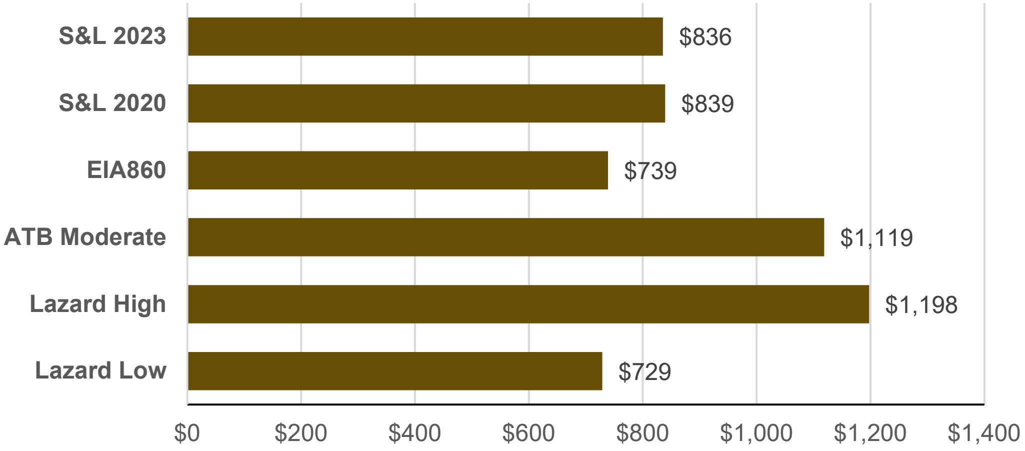
Amine-based carbon capture and sequestration (CCS)

Nominal net capacity – 650 MW

Heat Rate – 12,293 Btu/kWh

Natural gas combustion turbine—simple-cycle

Overnight capital cost—combustion turbine simple-cycle
dollars per kilowatt (2023$/kW)



Form EIA 860 value is a capacity-weighted average of all projects installed, in 2020, of a given prime mover and are not representative of one specific design.

Note: S&L2020 estimate based on 240 MW F-Frame simple-cycle combustion turbine.
ATB Moderate estimate based on 233 MW F-Frame simple-cycle combustion turbine.

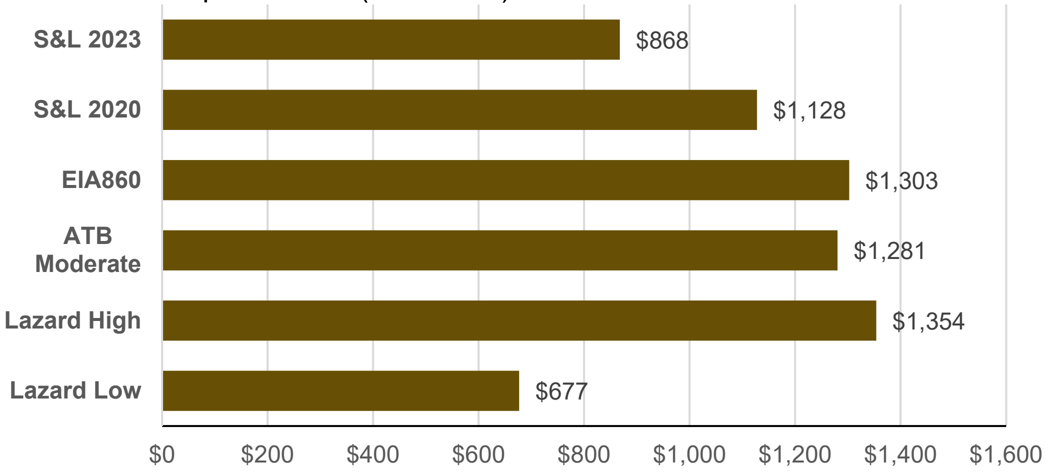
Combustion turbine simple-cycle

430 MW model H combustion turbine in simple-cycle configuration

Heat rate – 9,142 Btu/kWh

Natural gas combined—cycle 2x2x1

Overnight capital cost—combined-cycle 2x2x1
dollars per kilowatt (2023$/kW)



Form EIA 860 value is a capacity-weighted average of all projects installed, in 2020, of a given prime mover and are not representative of one specific design.

Note:S&L2020 estimate based on 1100 MW H-Frame combined-cycle combustion turbine.
ATB Moderate estimate based on 992 MW H-Frame combined-cycle combustion turbine.

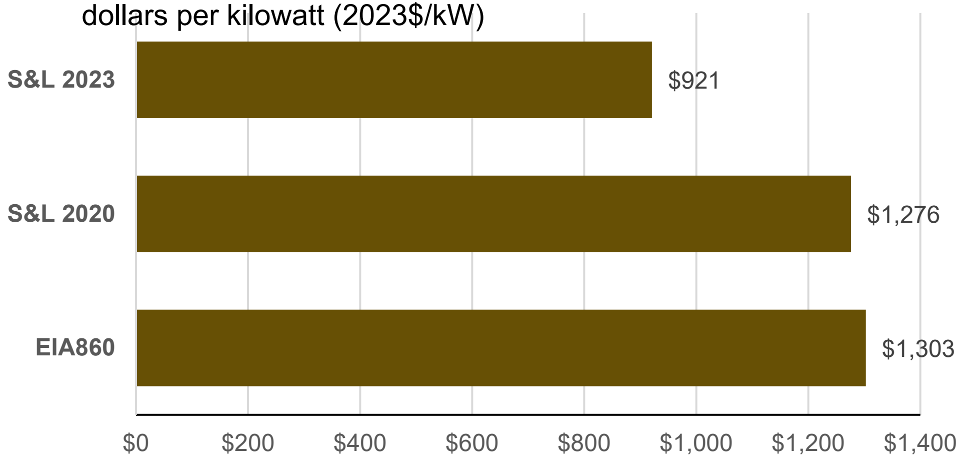
Combustion turbine combined-cycle 2x2x1

1,227 MW plant including two model H combustion turbines, two heat recovery steam generators (HRSGs) and one steam turbine generator (STG)

Heat rate – 6,266 Btu/kWh

Natural gas combined—cycle 1x1x1 without CCS

Overnight capital cost—combined-cycle 1x1x1 w/o CCS
dollars per kilowatt (2023$/kW)



Form EIA 860 value is a capacity-weighted average of all projects installed, in 2020, of a given prime mover and are not representative of one specific design.

Note: S&L2020 estimate based on 430 MW H-Frame combined-cycle combustion turbine

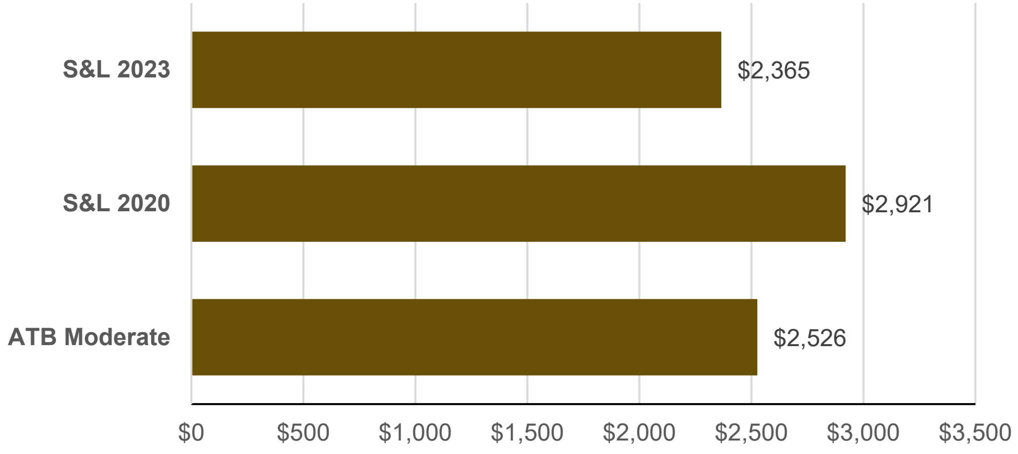
Combustion turbine combined-cycle 1x1x1, single shaft

627 MW plant including one model H combustion turbines, one heat recovery steam generators (HRSGs) and one steam turbine generator (STG)

Heat rate – 6,266 Btu/kWh

Natural gas combined-cycle 1x1x1 w/ CCS

Overnight capital cost—combined-cycle 1x1x1 w/ CCS
dollars per kilowatt (2023$/kW)



Note: S&L2020 estimate based on 430 MW H-Frame combined-cycle combustion turbine with 90% carbon capture system.
ATB Moderate estimate based on 877 MW H-Frame combined-cycle combustion turbine in a 2x2x1 array with 95% carbon capture system.

Combustion turbine combined-cycle 1x1x1, single shaft with CO_2 capture

543 MW plant including one model H combustion turbines, one heat recovery steam generators (HRSGs) and one steam turbine generator (STG)

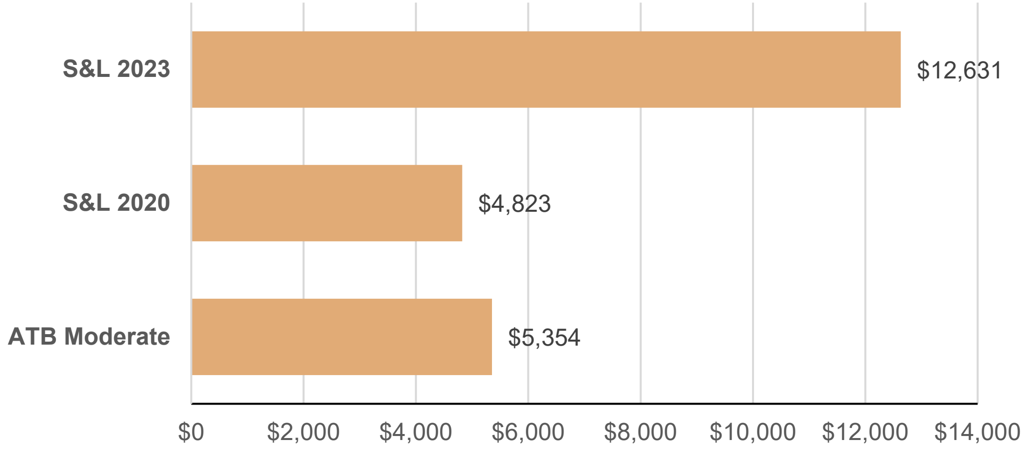
95% CO_2 capture system, no sequestration costs included

Nominal net capacity – 543 MW

Heat rate – 7,239 Btu/kWh

Biopower with carbon capture and storage

Overnight capital cost—biopower with carbon capture and storage
dollars per kilowatt (2023$/kW)



Note: S&L 2020 and ATB Moderate are dedicated biopower plants with no carbon capture system.

Biopower with carbon capture and storage (BECCS)

50 MW bubbling fluidized bed (BFB) boiler plant with single steam generator and condensing steam turbine with biomass storage and handling system.

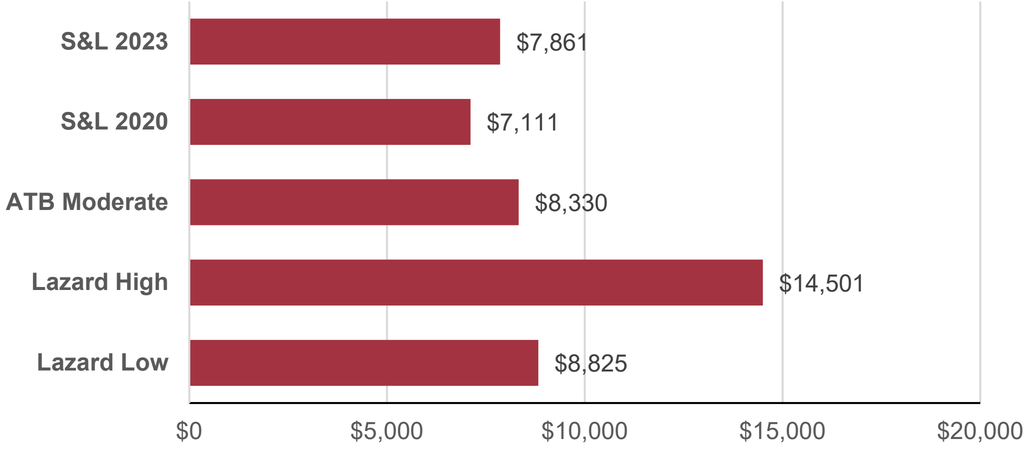
95% CO_2 capture system, no sequestration costs included

Nominal net capacity – 50 MW

Heat rate – 19,965 Btu/kWh

Advanced nuclear 2x AP1000—brownfield

Overnight capital cost—advanced nuclear—brownfield
dollars per kilowatt (2023$/kW)



Note: Lazard estimates rely on Vogtle units 3 and 4 costs for the range of cost estimates.S&L2023 also considered public data available for Vogtle in the estimate. However, the study recognizes that the Vogtle project had several issues that had significant financial repercussions that is more likely related to project planning than the technology.
Lazard estimates 69 month build time, compared with 52 months for S&L2023

Advanced nuclear—brownfield

2,156 MW plant with two AP1000 pressurized water reactors

Heat rate – 10,608 Btu/kWh

S&L2023 and S&L2020 estimates based off both domestic and international project costs due to limited recent U.S. data

Nuclear small modular reactor

Overnight capital cost—nuclear small modular reactor
dollars per kilowatt (2023$/kW)

Nuclear small modular reactor

480 MW plant of six small reactors each with a net capacity of 80 MW

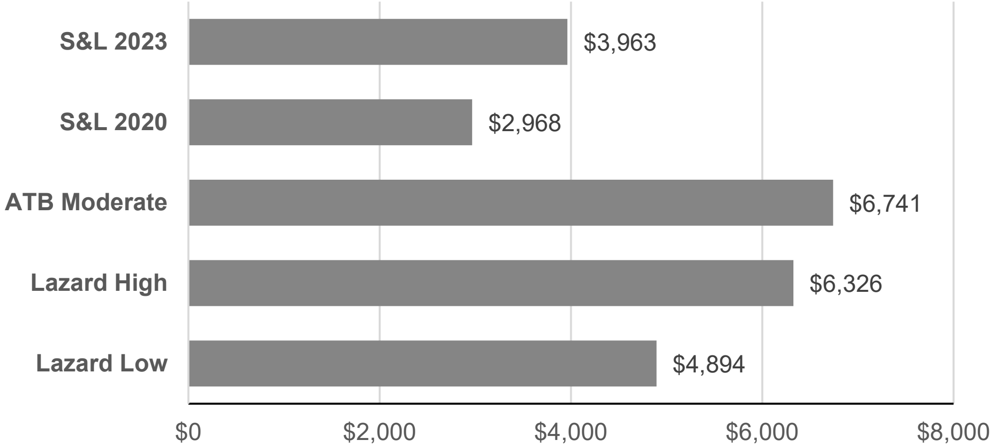
Heat rate – 10,046 Btu/kWh

Based on representative SMR plant, not a particular OEM

Light water reactor design

Geothermal

Overnight capital cost—geothermal binary cycle
dollars per kilowatt (2023$/kW)



Note: Geothermal costs are highly site-specific and variations in site cost data used for estimation can provide a range of results.

Geothermal binary cycle

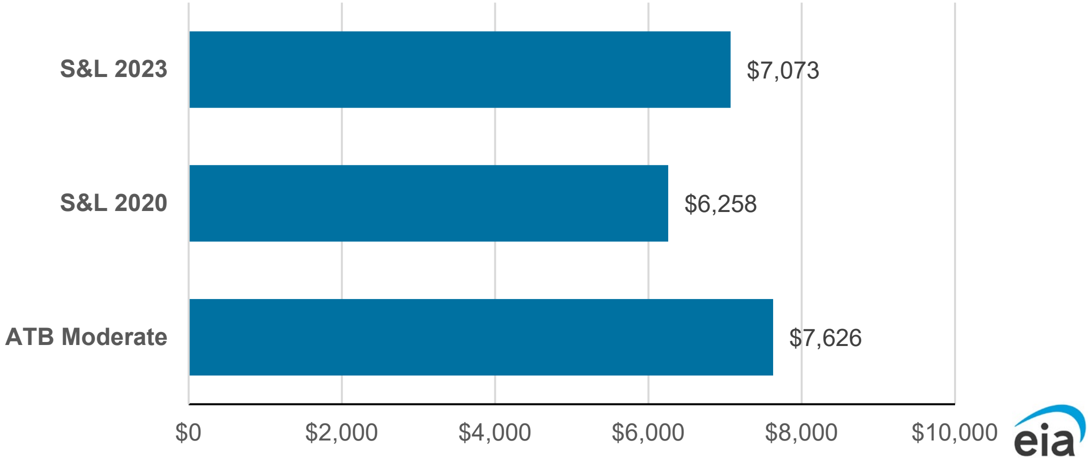
Two 30 MW turbine generators, heat exchangers, and fluid pumps

Net 50 MW

No exploration costs

Hydroelectric power plant—new stream reach

Overnight capital cost—hydroelectric power plant
dollars per kilowatt (2023$/kW)



Note: Hydroelectric costs are highly site-specific.

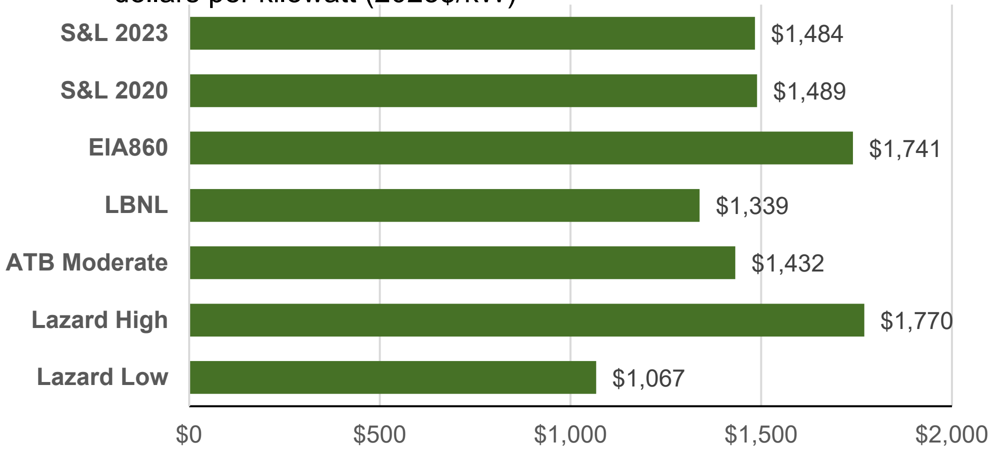
Hydroelectric new stream reach

100 MW *new stream reach development* with 30 feet of available head

Storage type includes a dam to store water in reservoir

Onshore wind

Overnight capital cost—onshore wind
dollars per kilowatt (2023$/kW)

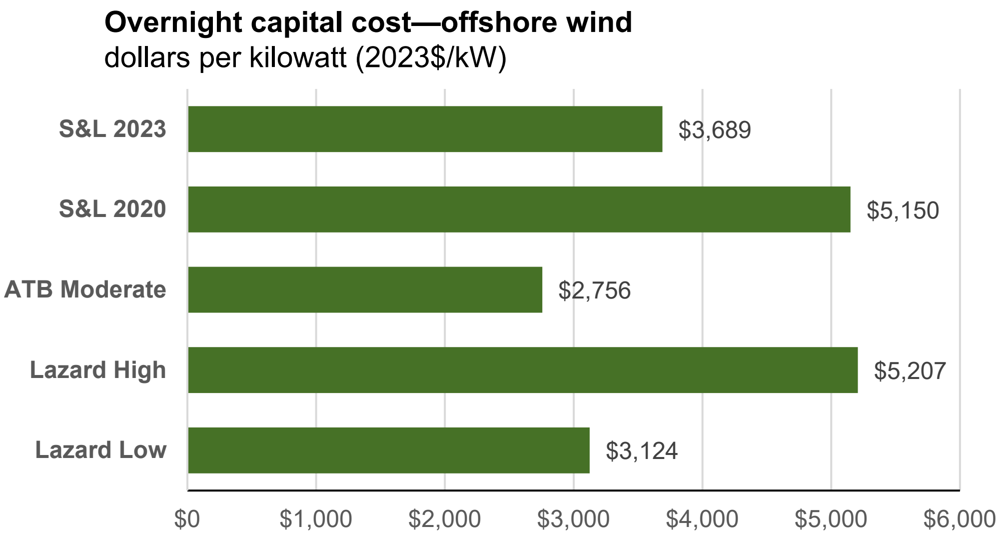


Form EIA 860 value is a capacity-weighted average of all projects installed, in 2020, of a given prime mover and are not representative of one specific design.

Onshore wind

200 MW project using 2.82 MW rated turbines with 125-meter rotor diameters and 90-meter hub height

Offshore wind



Note: S&L 2020 study assumed a 400 MW project with 10 MW turbines, compared to the 900 MW project with 15 MW turbines.

A large contributor to the difference in the S&L2020 and S&L2023 costs is the higher net capacity in the S&L2023 study in the denominator, which drives the $/kW overnight capital cost down compared to the 2020 study estimate.

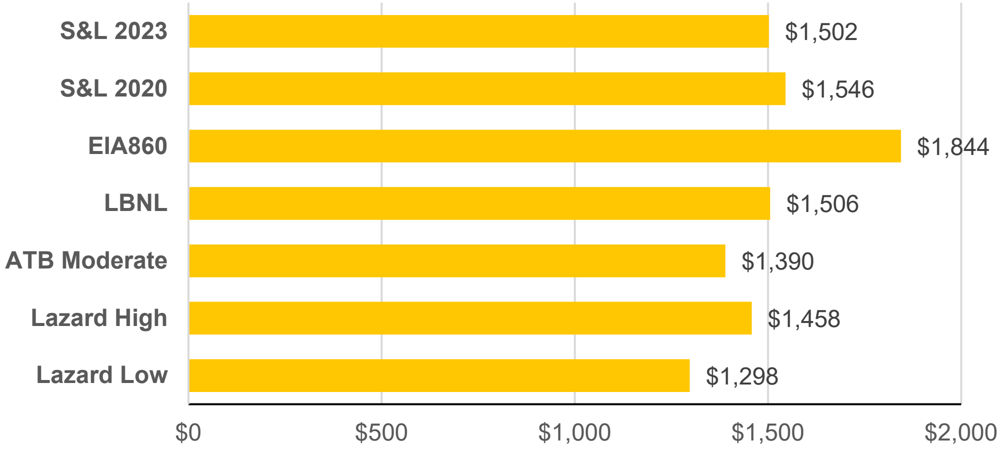
Offshore wind

900 MW project with 15 MW rated turbines, located 30 miles offshore in waters with depth of 100 feet, fixed-type monopile foundation

Onshore cable run of five miles also assumed and included

Solar PV with single axis tracking

Overnight capital cost—solar PV with single axis tracking
dollars per kilowatt (2023$/kW)



Form EIA 860 value is a capacity-weighted average of all projects installed, in 2020, of a given prime mover and are not representative of one specific design.

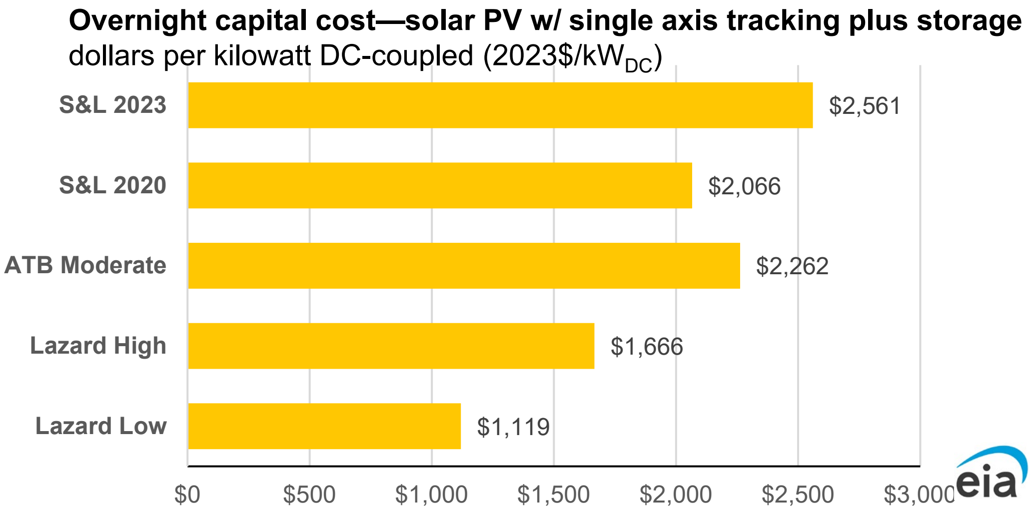
Note: ATB Moderate estimate based on a 100 MW_{DC} single axis tracking solar project.
S&L2020 estimate based on a 150 MW_{AC} single axis tracking solar PV project.

Solar PV with single axis tracking

150 MW_{AC} bifacial monocrystalline passive emitter and rear contact bifacial modules with single axis tracking

Inverter loading ratio of 1.3

Solar PV plus storage (DC-coupled)



Note: S&L2020 estimate is for an AC-coupled system.

Solar PV plus storage (DC-coupled)

150 MW$_{DC}$ solar PV plant with 200 MWh lithium-ion battery storage system

Inverter loading ratio of 1.6

Not compared:
Solar PV plus storage (AC-coupled)

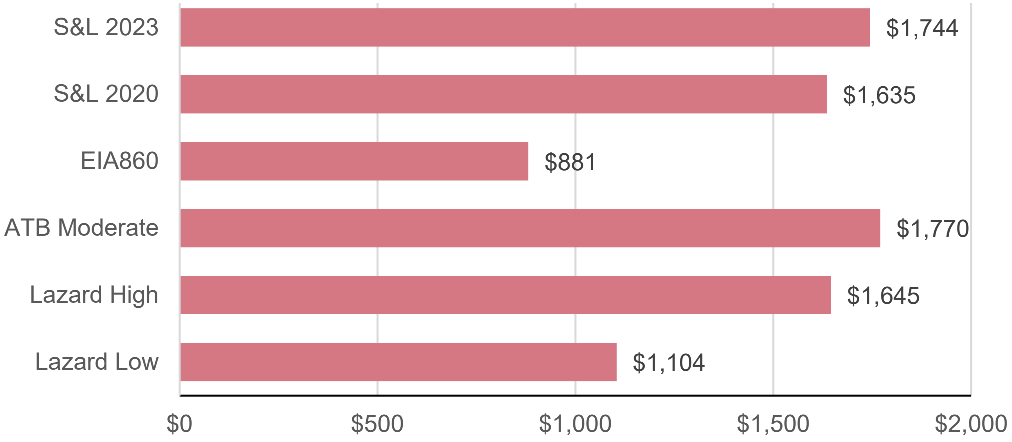
Same solar PV plant and BESS

Inverter loading ratio of 1.4

Overnight capital cost $2,175/kW

Battery storage four hour

Overnight capital cost—battery storage 4-hr
dollars per kilowatt (2023$/kW)



Form EIA 860 value is a capacity-weighted average of all projects installed, in 2020, of a given prime mover and are not representative of one specific design.

Battery energy storage system

150 MW power rating/ 600 MWh energy rating, lithium-ion battery that can provide 150 MW of power for four-hours

Follow-up work

- Working group for AEO2025 planned for late October
  - More comprehensive discussion of model enhancements for AEO2025

- Final *Estimates of Capital Cost and Performance Characteristics* report to be published January 2024

Contact information for EIA Electricity, Coal, and Renewables Modeling Team

• Chris Namovicz, Team Leader	Chris.Namovicz@eia.gov
• Laura Martin	Laura.Martin@eia.gov
• Manussawee Sukunta	Manussawee.Sukunta@eia.gov
• Augustine Kwon	Augustine.Kwon@eia.gov
• Cara Marcy	Cara.Marcy@eia.gov
• John Taber	John.Taber@eia.gov
• Richard Bowers	Richard.Bowers@eia.gov
• David Fritsch	David.Fritsch@eia.gov
• Kien Chau	Kien.Chau@eia.gov
• Vikram Linga	Vikram.Linga@eia.gov
• Kenneth Dubin	Kenneth.Dubin@eia.gov
• Ed Thomas	Edward.Thomas@eia.gov
• Singfoong Cheah	Singfoong.Cheah@eia.gov
• Nina Vincent	Nina.Vincent@eia.gov
• Alexander Felhofer	Alexander.Felhofer@eia.gov

For more information

U.S. Energy Information Administration homepage | www.eia.gov

Annual Energy Outlook | www.eia.gov/aeo

Capital Cost Study | https://www.eia.gov/analysis/studies/powerplants/capitalcost/

Short-Term Energy Outlook | www.eia.gov/steo

International Energy Outlook | www.eia.gov/ieo

Monthly Energy Review | www.eia.gov/mer

Today in Energy | www.eia.gov/todayinenergy

State Energy Profiles | www.eia.gov/state

Coal Data Browser | www.eia.gov/coal/data/browser

Questions