Annual Technology Baseline: The 2022 Electricity Update

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June 28, 2022

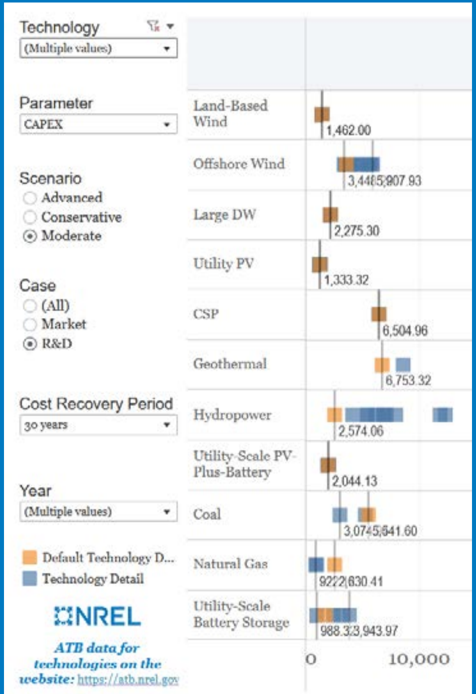
Webinar logistics slides are not included in this published version.

Slide numbering starts on this slide at #7.

Agenda

- Introduction and Overview
  - Why the ATB?
  - ATB Overview
- Updates
  - Technology-Specific Updates
  - Financial Cases and Methods
- Questions and Comments
- Breakout Groups

Why the ATB?



Annual Technology Baseline

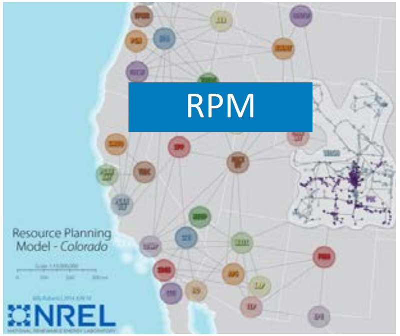
NREL Transforming ENERGY

About Technologies Data Contact

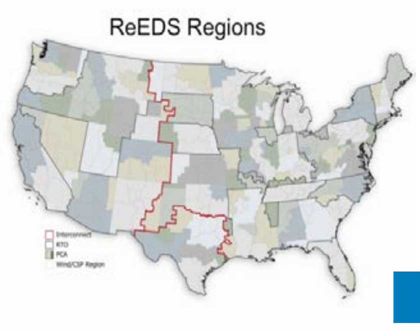
- Ever-changing technologies result in *conflicting reports of technology progress* based on inconsistent—and often opaque—assumptions.
- A *single data set is needed* to credibly and transparently assess the evolving state of energy technologies in the United States.
- The ATB enables *understanding of technology cost and performance across energy sectors* and thus informs electric sector analysis nationwide.

ATB Project Overview

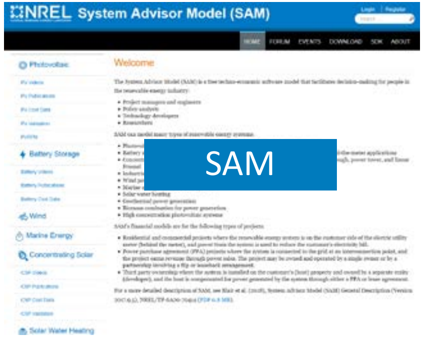
The ATB anchors key DOE and national lab analyses.



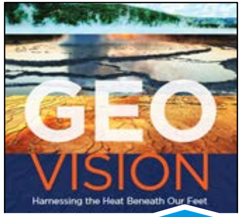
Resource Planning Model



Regional Energy Deployment System



System Advisor Model



Geothermal Vision

Hydropower Vision

Impacts of Tax Credit Extensions

Prospective RPS Cost, Benefits, and Impacts

Standard Scenarios

Storage Futures

Important Scenario Analyses Used ATB Projections

Now in its eighth year, the ATB is frequently used by planners, academics, analysts, and others.

Federal Agencies
Bureau of Land Management, U.S. Department of Energy and labs, U.S. Environmental Protection Agency

Grid Operators
North American Electric Reliability Corporation, Midcontinent Independent System Operator, Pennsylvania-New Jersey-Maryland Interconnection, New York Independent System Operator

Utilities
Hawaii Electric Company, Dominion Energy, Xcel Energy

Consultants
Rhodium Group, Navigant, M.J. Bradley & Associates, Analysis Group

Nonprofits
Resources for the Future, Environmental Defense Fund, Union of Concerned Scientists

Academia
Stanford University, University of Maryland, University of Texas, Duke University, University of Colorado, Colorado School of Mines

State Officials
Hawaii, Michigan, California

International
Chilean Ministry of Energy, Global Carbon Capture and Storage Institute, Institute, Canadian Institute for Integrated Energy Systems

Media
Utility Dive

These are examples of users—*not* a comprehensive list.

The ATB data are inputs for the Standard Scenarios.

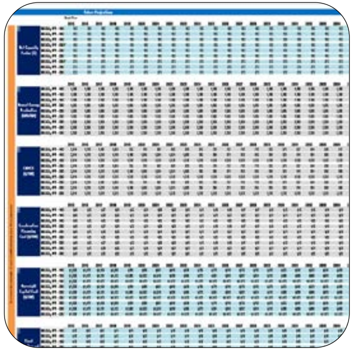
Annual Technology Baseline

Cost and performance assumptions for renewable and conventional technologies

Standard Scenarios

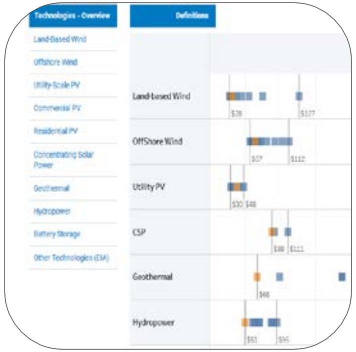
Ensemble of future scenarios of the U.S. electric power sector

The ATB includes a suite of products.



Spreadsheet

- Calculations
- Cost and performance projections, 2020–2050
- Capacity factor
- Operation and maintenance (O&M) costs
- Capital expenditures (CAPEX)
- Financing assumptions
- Levelized cost of energy (LCOE)



Web App

- atb.nrel.gov
- User guidance
- Additional analyses
- Methodologies
- Interactive charts
- Historical trends and comparison to other projections (e.g., EIA)

Interactive Charts

Tableau Workbook

Formatted Data

- Summary of selected data (no calculations)
- Interactive charts
- Visual exploration
- Cost and performance projections, 2020–2050
  - Capacity factor
  - O&M costs
  - CAPEX
  - Financing assumptions
  - LCOE
- Structured format

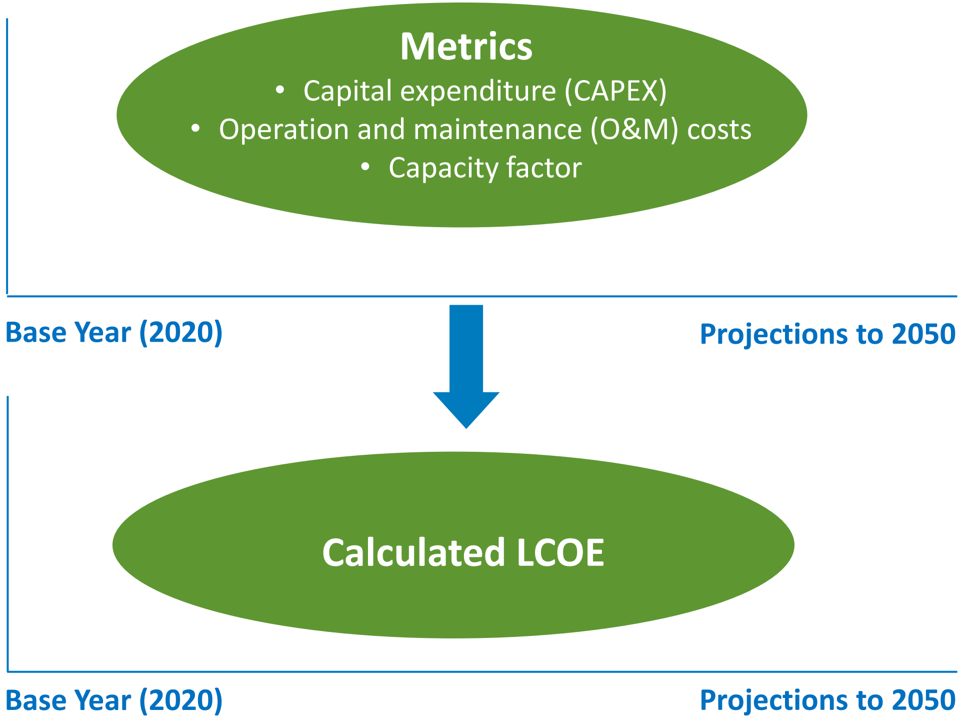
PowerPoint

- Webinar presentation
- Summary presentation

API

- Data published in Open Energy Data Initiative
- Programmatic access through AWS-S3
- **NEW: Jupyter notebook**

The ATB provides cost and performance data.



Cost and performance data are:

- Provided for each:
  - Year
  - Metric
  - Resource
  - Technology
  - Technology cost scenario
- Used to calculate LCOE.

LCOE is provided as a summary metric, but it is *not* used as an input to NREL models such as ReEDS, RPM, or SAM. Its limitations are described in the documentation. The user can select or specify financial assumptions for calculating LCOE.

Technologies Covered

Renewable Energy Technologies

New in 2022

Wind

- Land-based
- Offshore
- **NEW: Distributed**

Solar

- Utility photovoltaics (PV)
- Commercial and industrial PV
- Residential PV
- Utility PV-plus-battery
- Concentrating solar power (CSP)

Hydropower

- Non-powered dams (NPD)
- New stream-reach development (NSD)
- Pumped storage hydropower (**NEW: CAPEX**)

Geothermal (Flash and Binary)

- Hydrothermal
- Near-field enhanced geothermal systems (EGS)
- Deep EGS

Storage

- Utility-scale
- Commercial-scale
- Residential

Fossil Energy Technologies

Natural Gas

- Natural gas combined cycle (NGCC)
- NGCC-carbon capture and storage (90% CCS)
- Combustion turbine (CT)

Coal

- Integrated gasification combined-cycle (IGCC)
- Pulverized coal
- Pulverized coal w/ 90% CCS

Other Technologies

(Energy Information Administration, Annual Energy Outlook 2022)

Nuclear

- Pressurized water reactor (AP1000)
- **NEW: Small modular reactor (SMR)**

Biopower

- Dedicated (woody biomass)

Methodology Overview: Three Steps

1. Define resource bins for each technology

Group range of resources for contiguous United States into bins with common resource quality and characteristics, or develop representative plants.

2. Develop cost and performance data

Develop base year and projected values for Conservative, Moderate, and Advanced technology cost scenarios for CAPEX, capacity factor, and operation and maintenance (O&M).

3. Calculate LCOE

Use selected financial assumptions to calculate LCOE from CAPEX, capacity factor, and O&M.

Step 1: Define Technologies/Resource Bin Categories

Technology	Bins	Distinguishing Characteristics
Land-based wind	10	Annual average wind speed
Offshore wind	14	Annual average wind speed
Distributed wind	40	Turbine size, annual average wind speed
Utility-scale, commercial, residential PV, and utility-scale PV-plus-battery	10	Horizontal solar irradiance resource level
CSP	3	Direct normal solar irradiance
Geothermal	6[a]	Hydrothermal, EGS, binary or flash systems, reservoir temperature
Hydropower	12[a]	Non-powered dams, new stream-reach development, head, and design capacity
Pumped storage hydropower	15[a]	CAPEX
Utility-scale, commercial, residential battery storage	5	Storage duration
Natural gas	3	Combustion turbine, level of CCS
Coal	3	Pulverized coal, IGCC, level of CCS
Nuclear	2	Pressurized Water Reactor (AP1000) or SMR
Biopower	1	Dedicated

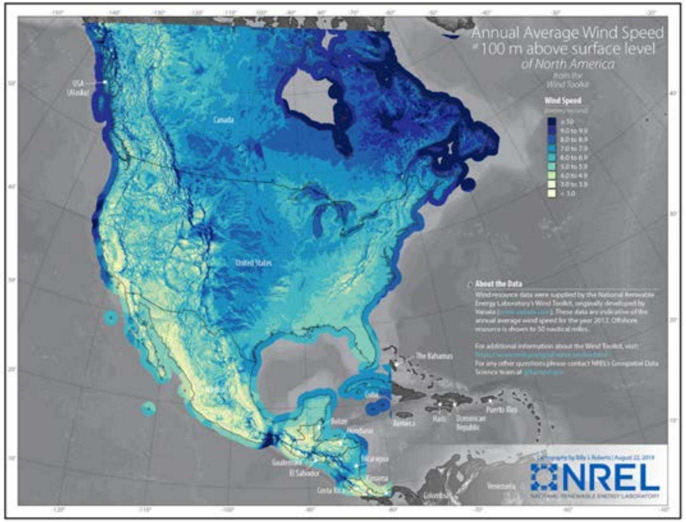
[a] Representative bins for the ATB only: the NREL Regional Energy Deployment System (ReEDS) implements a full site-specific supply curve.

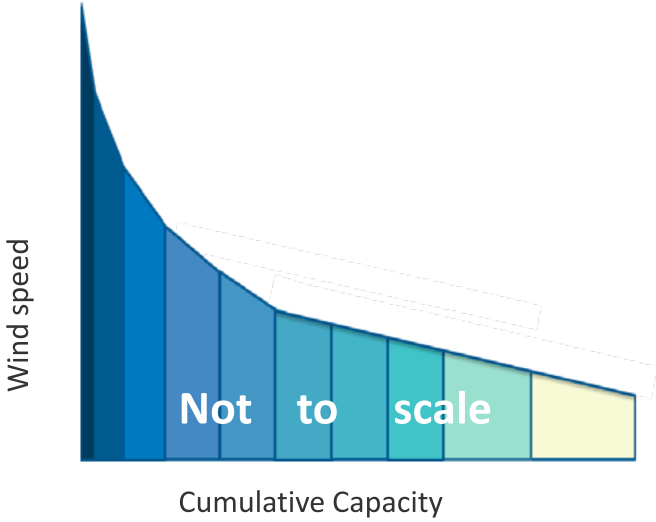
ATB Bins Technologies and Resources Based on Various Characteristics

Example: Wind ATB bins based on annual average wind speed

Annual average wind speed

ATB wind classes





https://www.nrel.gov/gis/assets/images/wtk-100-north-america-50-nm-01.jpg

Step 2: Develop Cost and Performance Data

Base Year (2020): Informed by market reports, market data, and bottom-up modeling

Projections: Generally, rely on bottom-up modeling and published studies; qualitatively harmonized to three scenarios of future technology innovation:

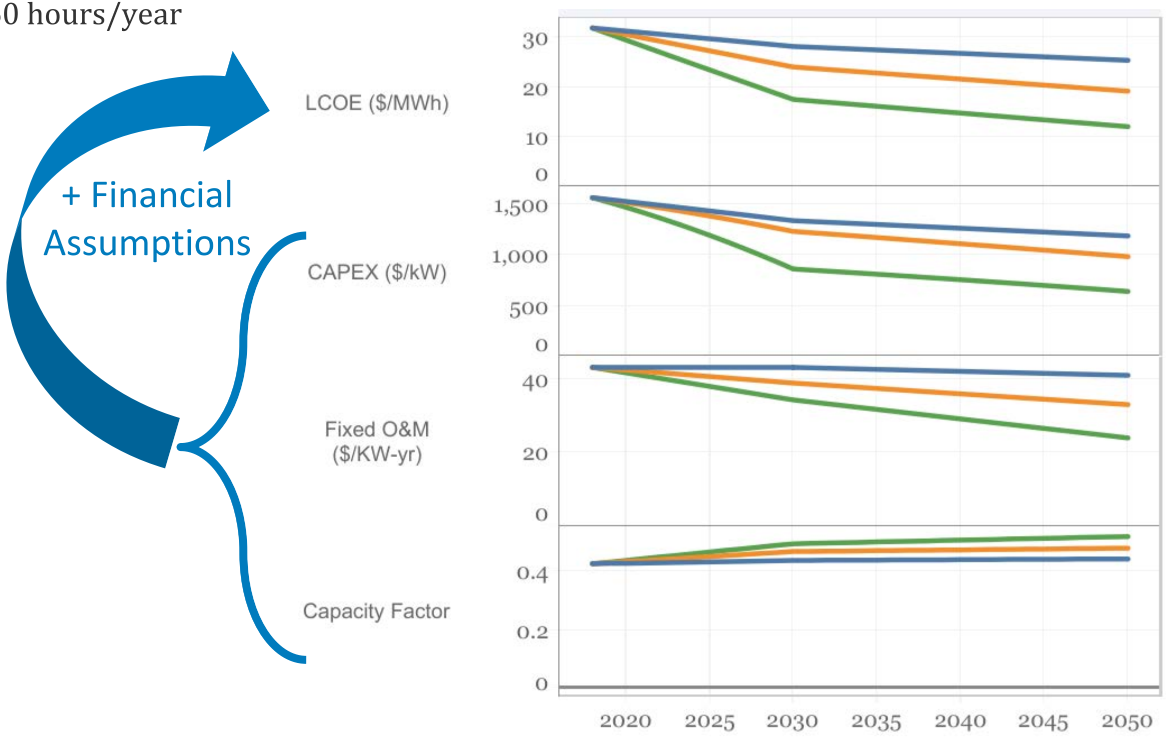
Conservative Technology Innovation	**Moderate** Technology Innovation	**Advanced** Technology Innovation
• Today's technology with little innovation • Continued industrial learning • Decreased public and private R&D	• Widespread adoption of today's cutting edge • Expected level of innovation • Current levels of public and private R&D	• Market success of currently unproven innovation • New technology architectures • Increased public and private R&D

Sources of Base Year (2020)

Technology	Source
Land-based wind power plants	*2020 Cost of Wind Energy Review* (Stehly and Duffy 2022) are used to estimate CAPEX based on central U.S. installations with wind speed for median of recently installed wind facilities; it is also used for O&M.
Offshore wind power plants	Bottom-up modeling (Beiter et al. 2016), methodology and data are updated to the latest cost and technology trends observed in the U.S. and European offshore wind markets (Beiter et al. 2020).
Distributed wind power plants	Base year costs and performances estimates are data obtained from NREL's 2020 Cost of Wind Energy study (Stehly and Duffy 2022).
Utility, residential, and commercial PV plants	CAPEX and O&M for 2020 are based on bottom-up cost modeling and market data from Feldman et al. (2021).
Concentrating solar power plants	Assumptions are based on recent assessment of the industry in 2022 and bottom-up CSP cost analysis for heliostat components (Kurup et al. 2022).
Geothermal plants	Bottom-up cost modeling uses Geothermal Electricity Technology Evaluation Model (GETEM) and inputs from the GeoVision BAU scenario (DOE 2019; Augustine et al. 2019).
Hydropower plants	NPD data are based on bottom-up 2020 cost analysis (Oladosu et al. 2021). NSD data from previous years based on Hydropower Vision study (DOE, 2016); bottom-up cost modeling is from O'Connor et al. (2015).
Utility scale PV-plus-battery	CAPEX assumptions for utility-scale PV-plus-battery are based on new bottom-up cost modeling and market data from Ramasamy et al. (2021)
Utility, residential, and commercial battery storage	Costs for utility-scale battery energy storage systems (BESS) are based on a bottom-up cost model using the data and methodology for utility-scale BESS in Ramasamy et al. (2021).
Pumped storage hydropower	Resource characterizations and capital costs are from Rosenlieb et al. (2022), which describes a national closed-loop PSH resource assessment. O&M costs are from Mongird et al. (2020).
Natural gas and coal	Estimates of performance and costs for currently available fossil-fueled electricity generating technologies are representative of current commercial offerings and/or projects that began commercial service within the past ten years (James et al. 2019).
Nuclear and biopower plants	Values from Annual Energy Outlook (EIA 2022) are reported.

Step 3: Calculate Levelized Cost of Energy (LCOE[a])

$$\text{Levelized Cost of Energy} = \frac{\text{Fixed Charge Rate} \times \text{Capital Expenditures} + \text{Fixed Operations and Maintenance Cost}}{\text{Capacity Factor} \times 8760\ \text{hours/year}}$$
$$+ \text{Variable Operations and Maintenance Cost}$$
$$+ \text{Fuel Cost}$$



LCOE is a summary metric with important limitations. See documentation at atb.nrel.gov .

Capacity factor refers to utilization for geothermal, hydropower, coal, gas, nuclear, and biopower.

[a]LCOE is for generation technologies only. Levelized cost of storage is not reported.

Technology-Specific Updates

https://atb.nrel.gov/electricity/2022/changes_in_2022

Updates by Technology

- **Land-Based Wind:** New base year report; no other major changes from 2021 ATB.
- **Offshore Wind:** Empirical market data are updated, leading to a lower CAPEX learning rate of 7.2%.
- **Distributed Wind:** This technology is new to the 2022 ATB.
- **Photovoltaics (all scales):** Initial cost metrics are informed by new benchmark results from Feldman et al. (2021) and projections are based on Ramasamy et al. (2021).
- **Concentrating Solar Power:** Component and system cost estimates for Base Year now include data from recent heliostat bottom-up analysis (Kurup et al. 2022).
- **Geothermal:** Data are updated to reflect lower fixed O&M in all cases and 100-MW enhanced geothermal system (EGS) plants in the advanced case.
- **Hydropower:** No changes from the 2021 ATB.
- **Utility-Scale PV-Plus-Battery:** Now includes an electricity cost for battery charging.
- **Battery Storage (all scales):** Base year CAPEX is updated consistent with new benchmark results in Ramasamy et al. (2021). Projections are revised based on a new literature survey (Cole et al. 2021).
- **Pumped Storage Hydropower:** Resource characterizations including capital costs are presented for the first time in the 2022 ATB. These are based on a national resource assessment for closed-loop PSH described by Rosenlieb et al. (2022).
- **Natural Gas and Coal:** Learning rates are updated to reflect EIA (2022).
- **Nuclear:** Small modular reactors are added based on EIA (2022).

Changes in **bold**. Main webinar session topics <u>**underlined**</u>.

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- Natural Gas and Coal: Learning rates are updated to reflect EIA (2022).
- Nuclear: Small Modular Reactors added based on EIA.

Land-Based Wind

Base Year

As in the 2021 ATB, capital expenditures (CAPEX) associated with wind plants installed in the interior of the country are used to characterize CAPEX for hypothetical wind plants with average annual wind speeds that correspond with the median conditions for recently installed wind facilities. The operation and maintenance (O&M) cost is also informed by a new report (Stehly and Duffy 2022); no variation of FOM with wind speed class is assumed.

Projections

As in the 2021 ATB, specific technology innovations are associated with each scenario. In the Moderate scenario, large segmented blades are transported by truck, enabling larger rotors. Segmentation enables higher hubs and larger turbines, and advanced controls enable higher capacity factors. In the Advanced scenario, even larger turbines and advanced rotor configurations increase turbine capacity, on-site manufacturing further increases hubs, and high-fidelity modeling and advanced controls are fully implemented.

Tyler Stehly

Land-Based Wind

Parameter
Multiple values

Scenario
All

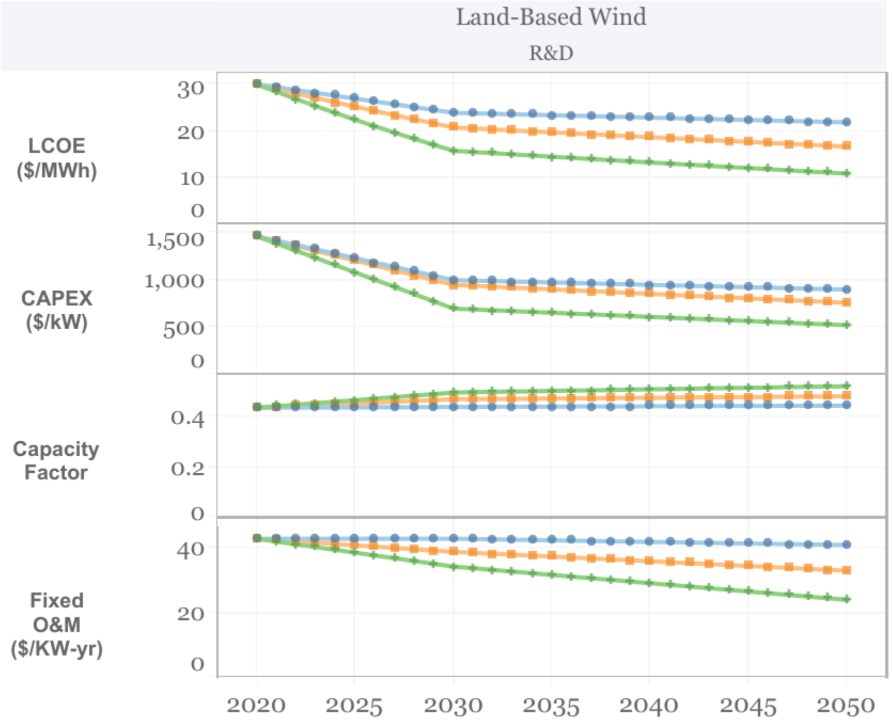
Financials
◯ Market
◉ R&D

Cost Recovery Period
30 years

Default Technology Detail

Land-Based Wind - Class 4

Technology Detail Filter
Default



data updated: 05/23/2022

Parameter value projections by scenario, financial case, cost recovery period, and technological detail

Select the parameter (LCOE, CAPEX, Fixed O&M, Capacity Factor, and FCR [fixed charge rate]), scenario, financial case, cost recovery period, and technological detail. The year represents the commercial online date. The default technology detail best aligns with recent or anticipated near-term installations.

NREL

ATB data for technologies on the website: https://atb.nrel.gov/

Land-Based Wind

Technology
Land-Based Wind

Parameter
Multiple values

Scenario
- [ ] Advanced
- [ ] Conservative
- [x] Moderate

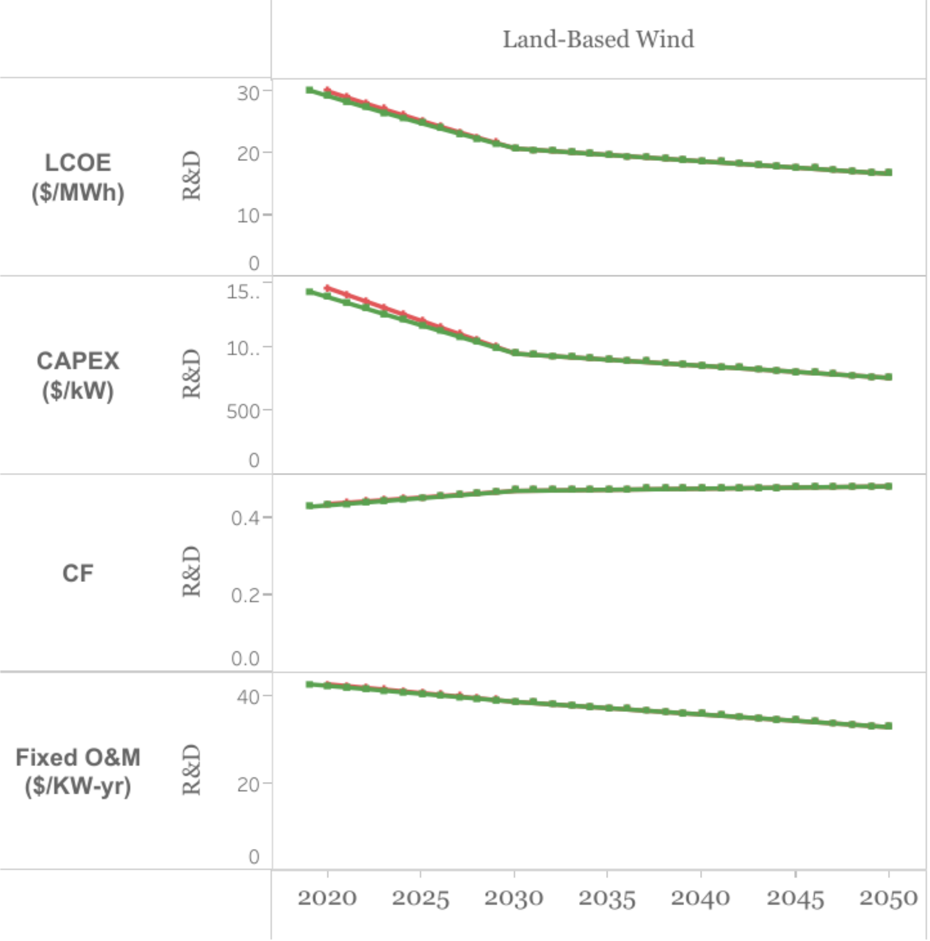
Atb Year
- [x] 2021
- [x] 2022

□ 2021
+ 2022

Technology Detail Filter
Default

CRP Years
30

Financials
- ○ Market
- ◉ R&D



ATB data for technologies on the ve..
website: https://atb.nrel.gov/

Offshore Wind

Base Year

As in the 2021 ATB, Base Year estimates are derived from a combination of bottom-up techno-economic cost modeling (Beiter et al. 2016) and experiential learning effects with economies of size and scale from higher turbine and plant ratings (Beiter et al. 2020).

Projections

CAPEX cost reduction trajectories are updated by updating the market data and global offshore wind deployment assumptions used to derive the experiential learning curves. As the learning curves predict future costs as a function of future offshore wind deployment, future costs in each of the ATB technology innovation scenarios are driven by different levels of deployment based on updated literature estimates. ITC assumptions are revised to include the 10-year safe harbor period.

Philipp Beiter, Patrick Duffy

Offshore Wind

Parameter
Multiple values

Scenario
All

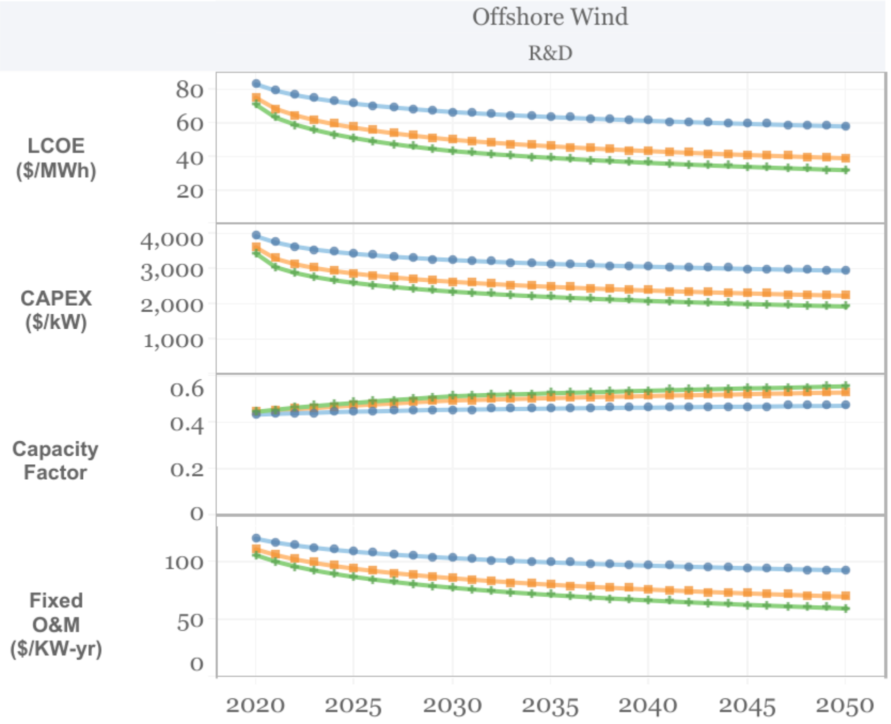
Financials
◯ Market
◉ R&D

Cost Recovery Period
30 years

Default Technology Detail

Offshore Wind - Class 3

Technology Detail Filter
Default



data updated: 05/23/2022

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NREL

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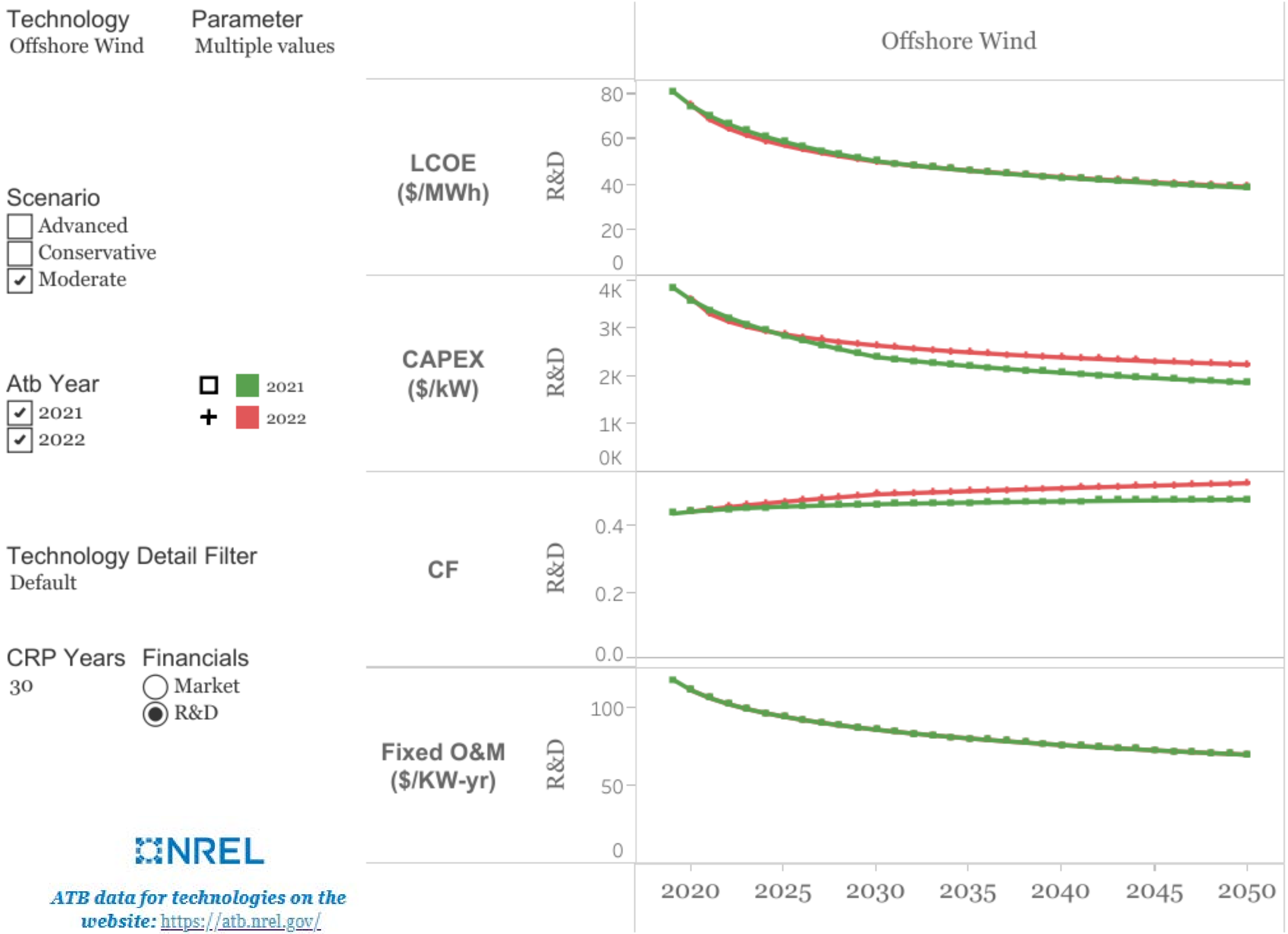
Offshore Wind



NREL

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Distributed Wind

Base Year

CAPEX is based on the Distributed Wind Futures Study and uses 2020 CAPEX and O&M costs from the Cost of Wind Energy study (Stehly and Duffy 2022).

Projections

CAPEX projections for distributed wind projects use methods from Lantz et al. (2016). 2020 costs are from the Cost of Wind Energy study (Stehly and Duffy 2022; DOE and NREL 2015). And updates are from the Distributed Wind Futures Study (McCabe et al. 2022).

Distributed Wind

Parameter
Multiple values

Scenario
All

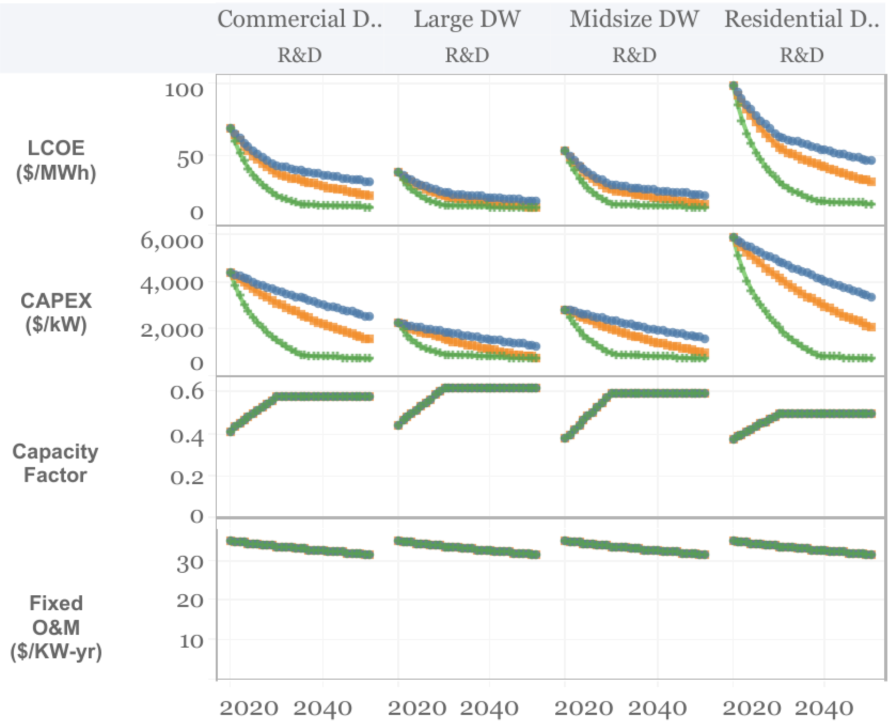
Financials
Market
R&D

Cost Recovery Period
30 years

Default Technology Detail

*

Technology Detail Filter
Default



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Parameter value projections by scenario, financial case, cost recovery period, and technological detail

Select the parameter (LCOE, CAPEX, Fixed O&M, Capacity Factor, and FCR [fixed charge rate]), scenario, financial case, cost recovery period, and technological detail. The year represents the commercial online date. The default technology detail best aligns with recent or anticipated near-term installations.

NREL

ATB data for technologies on the website: https://atb.nrel.gov/

Solar PV

Base Year

CAPEX for plants with a commercial operation date (COD) of 2020 are based on bottom-up modeling and market data from Feldman et al. (2021), the same source use by the 2021 ATB. For 2021 COD CAPEX, the new data are from Ramasamy et al. (2021). The O&M costs are based on modeled pricing for PV systems from those same sources.

Projections

The DC-to-AC ratio (or inverter loading ratio) for utility-scale PV is changed from 1.34 in the 2021 ATB to 1.28 in the 2022 ATB for the base year and future years. The straight-line improvements in cost metrics through 2030 are now calculated using the 2021 benchmarks from Ramasamy (et al. 2021) as the initial points.

Jarett Zuboy and David Feldman

Utility-Scale Solar PV

Parameter
Multiple values

Scenario
All

Financials
◯ Market
◉ R&D

Cost Recovery Period
30 years

Default Technology Detail

Utility PV - Class 5

Technology Detail Filter
Default

Parameter value projections by scenario, financial case, cost recovery period, and technological detail

Select the parameter (LCOE, CAPEX, Fixed O&M, Capacity Factor, and FCR [fixed charge rate]), scenario, financial case, cost recovery period, and technological detail. The year represents the commercial online date. The default technology detail best aligns with recent or anticipated near-term installations.

data updated: 05/23/2022

NREL

ATB data for technologies on the website: https://atb.nrel.gov/

Utility-Scale Solar PV

Technology
Utility PV

Parameter
Multiple values

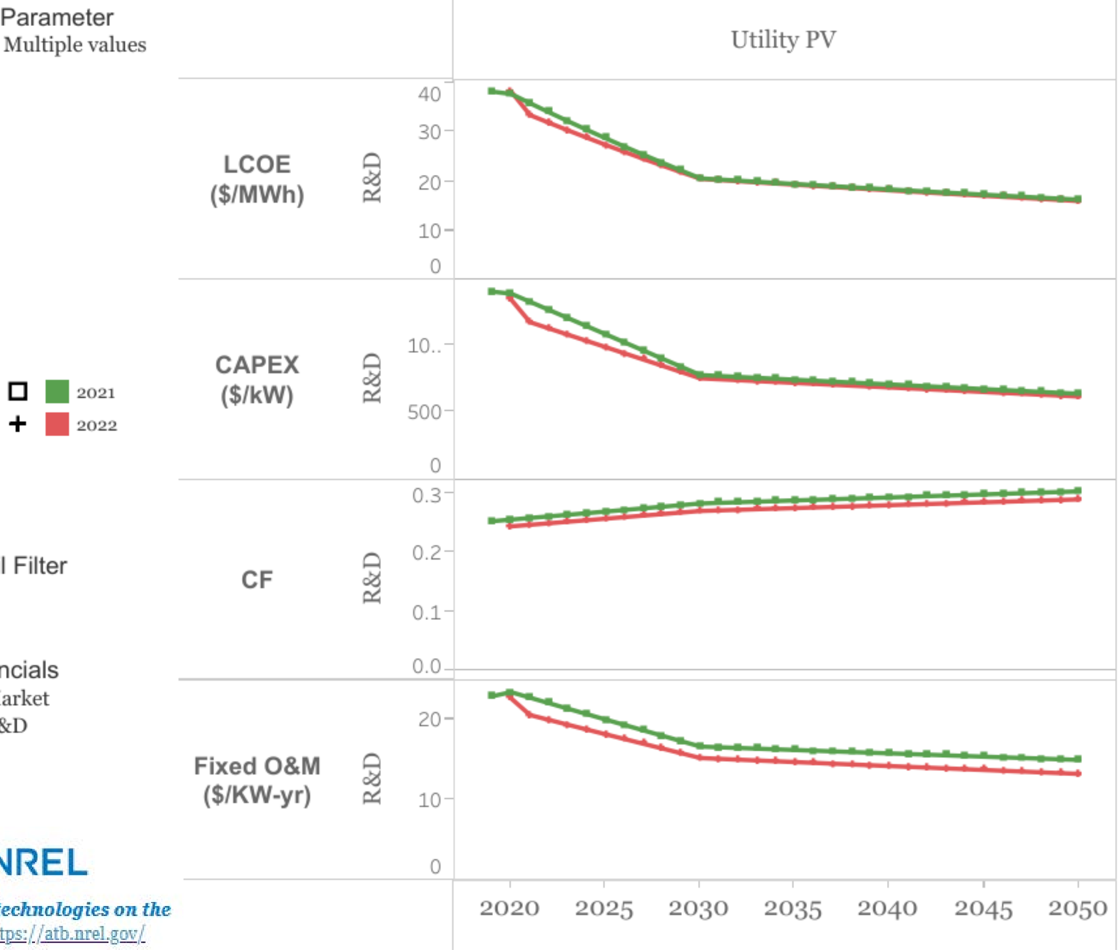
Scenario
- [ ] Advanced
- [ ] Conservative
- [x] Moderate

Atb Year
- [x] 2021
- [x] 2022

Technology Detail Filter
Default

CRP Years
30

Financials
- ◯ Market
- ◉ R&D



ATB data for technologies on the website: https://atb.nrel.gov/

Concentrating Solar Power

Base Year

CSP costs are based on cost estimates for CSP components from Kurup et al. (2022) that are available in Version 2021.12.02 of the System Advisor Model (SAM).

Projections

As in the 2021 ATB, the Moderate Scenario assumes a transition to a supercritical CO_2 cycle in the powerblock; advanced coatings on the receiver; improved tanks, pumps, and component configurations for the thermal storage unit; and improved heliostat installation and learning that are due to deployment in the solar field. The Advanced Scenario assumes higher-temperature supercritical CO_2; higher-temperature receiver; advanced storage compatible with higher temperatures' and low-cost, modular solar fields with increased efficiency.

Chad Augustine and Parthiv Kurup

Concentrating Solar Power

Parameter
Multiple values

Scenario
All

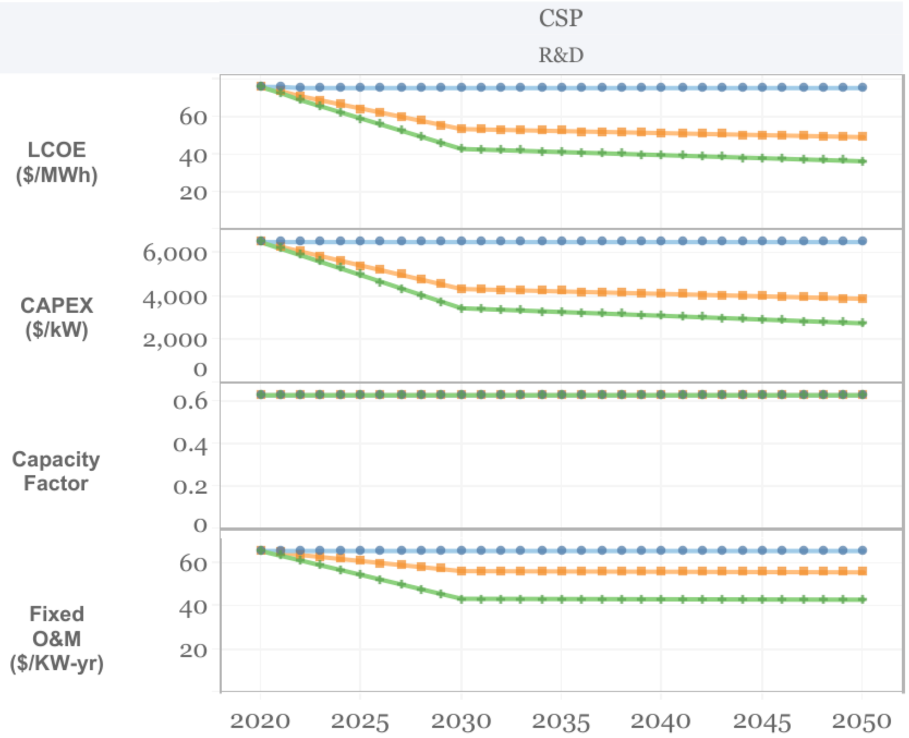
Financials
◯ Market
◉ R&D

Cost Recovery Period
30 years

Default Technology Detail

CSP - Class 2

Technology Detail Filter
Default



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ATB data for technologies on the website: https://atb.nrel.gov/

Concentrating Solar Power

Technology
CSP

Parameter
Multiple values

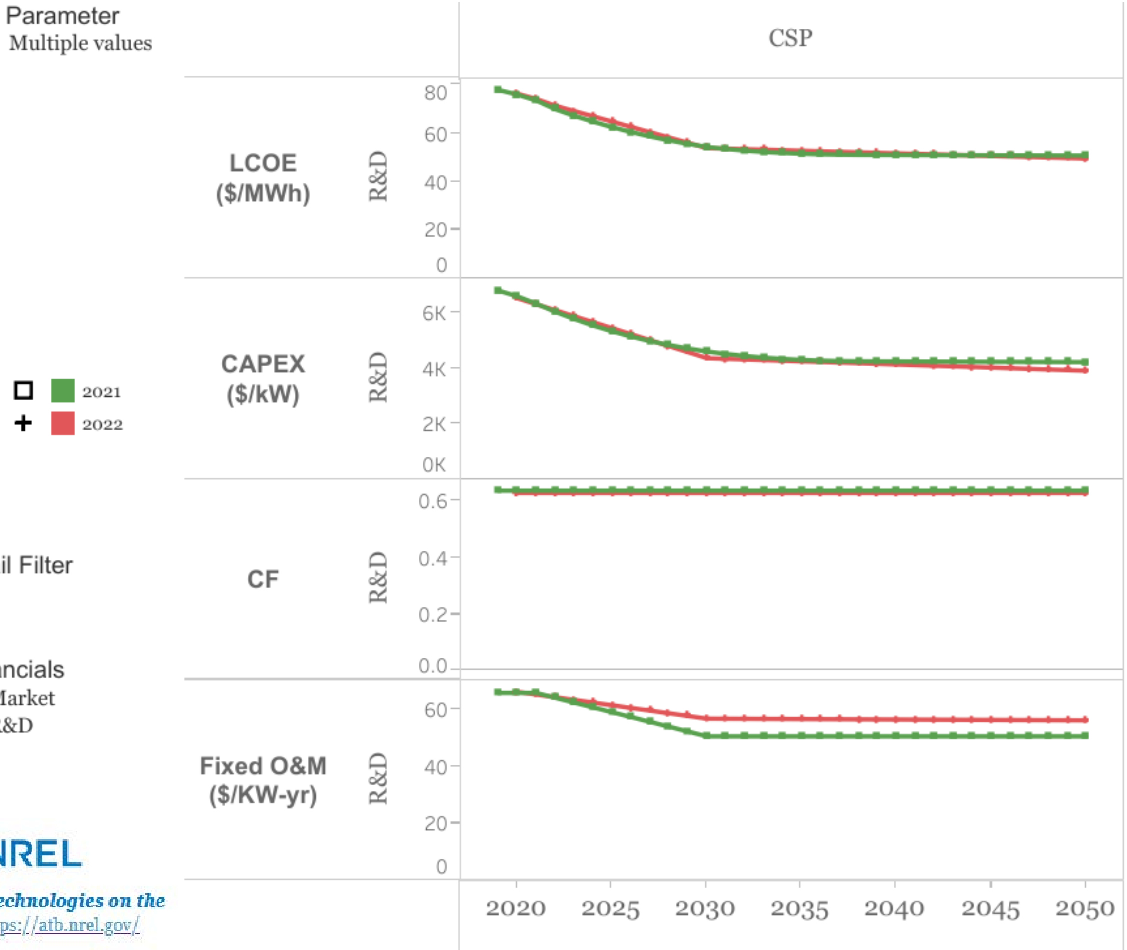
Scenario
- [ ] Advanced
- [ ] Conservative
- [x] Moderate

Atb Year
- [x] 2021
- [x] 2022

Technology Detail Filter
Default

CRP Years
30

Financials
- Market
- R&D (selected)



NREL

ATB data for technologies on the website: https://atb.nrel.gov/

Geothermal

Base Year

The lower O&M costs reflect results from additional empirical data. The lower CAPEX costs reflect shorter construction timelines. As in the 2021 ATB, estimates are based on bottom-up cost modeling using the Geothermal Electricity Technology Evaluation Model (GETEM) and inputs from the GeoVision Business-as-Usual (BAU) scenario (DOE 2019).

Projections

As in the 2021 ATB, the projection of future geothermal plant CAPEX for the Advanced Technology Innovation Scenario is largely based on the Technology Improvement scenario from the GeoVision Study (DOE 2019) and from Augustine et al. (2019). The Moderate Scenario is based on the Intermediate 1 Drilling Curve detailed as part of the GeoVision report to 2030 and on a minimum learning rate to 2050 as implemented in AEO2015 (EIA 2015). The Conservative Scenario assumes a minimum learning rate to 2050.

Jody Robins

Geothermal

Parameter
Multiple values

Scenario
All

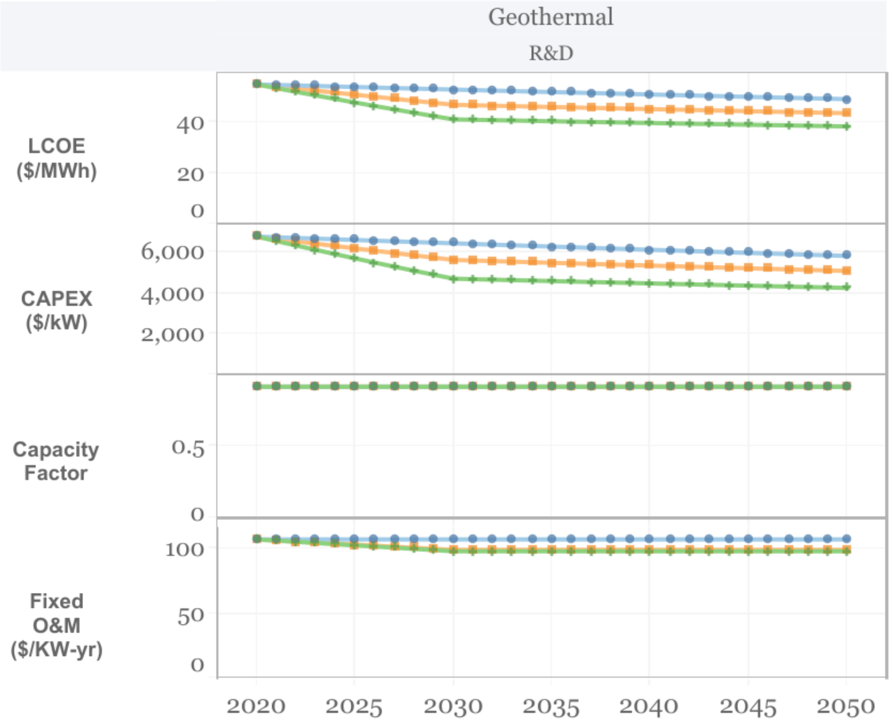
Financials
◯ Market
◉ R&D

Cost Recovery Period
30 years

Default Technology Detail

Geothermal - Hydro / Flash

Technology Detail Filter
Default



data updated: 05/23/2022

Parameter value projections by scenario, financial case, cost recovery period, and technological detail

Select the parameter (LCOE, CAPEX, Fixed O&M, Capacity Factor, and FCR [fixed charge rate]), scenario, financial case, cost recovery period, and technological detail. The year represents the commercial online date. The default technology detail best aligns with recent or anticipated near-term installations.

NREL

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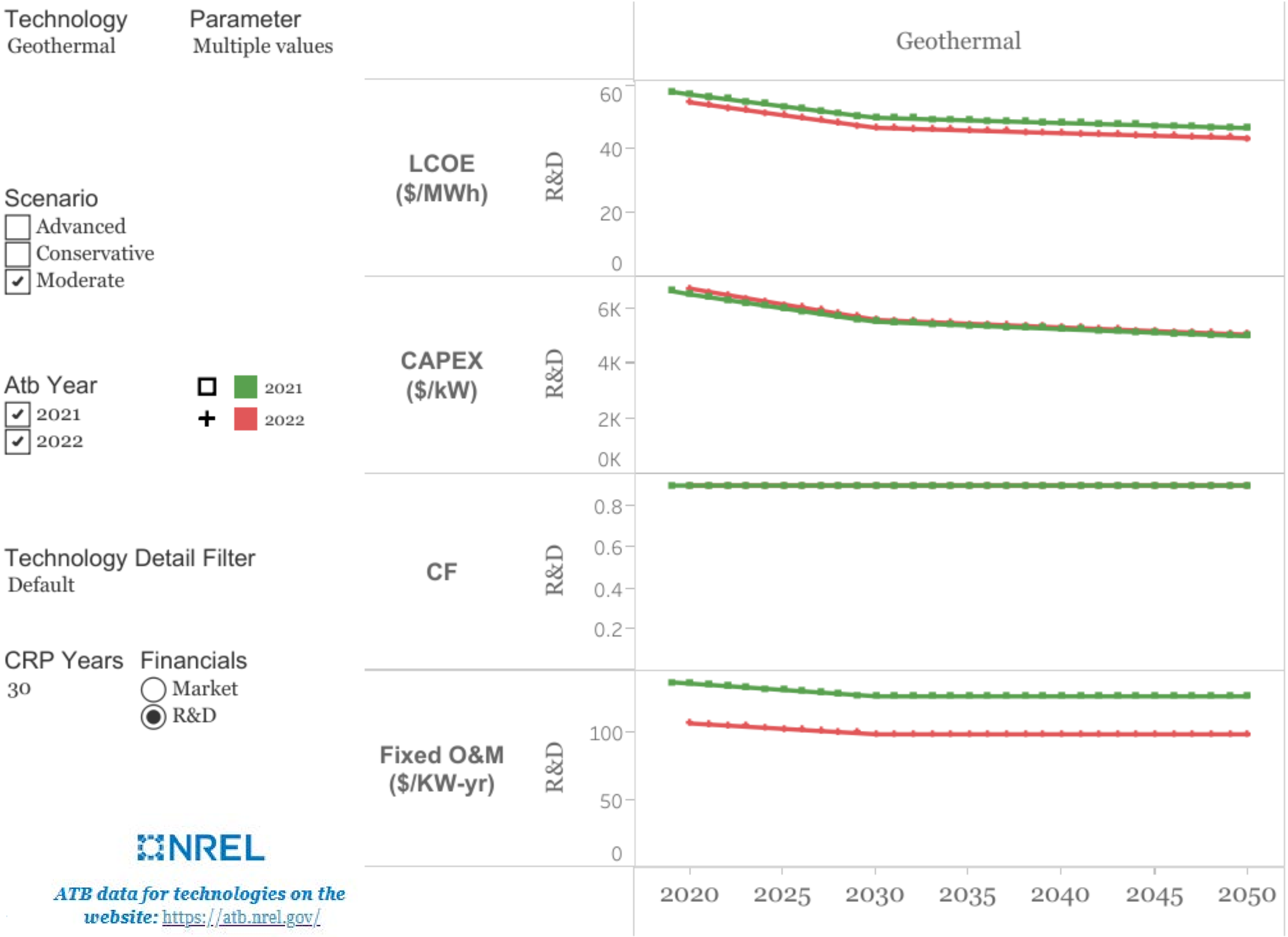
Geothermal



NREL

ATB data for technologies on the website: https://atb.nrel.gov/

Hydropower

Base Year

The 2022 ATB data are the same as those for the 2021 ATB. NPD data are based on a bottom-up modeling of reference sites using site-specific data (Oladosu et al. 2021). NSD data are based on projections developed for the Hydropower Vision study (DOE 2016) using technological learning assumptions and bottom-up analysis of process and/or technology improvements to provide a range of future cost outcomes (O'Connor et al. 2015).

Projections

The 2022 ATB data are the same as those for the 2021 ATB. The near-term (5-10 year) innovation case for NPD includes use of new materials for penstocks and use of matrix turbines to reduce the cost of civil works (Oladosu et al. 2021). NSD projections use a mix of U.S. Energy Information Administration (EIA) technological learning assumptions, input from a technical team of Oak Ridge National Laboratory researchers, and the experience of expert hydropower consultants.

‘Debo Oladosu

Hydropower

Parameter
Multiple values

Scenario
All

Financials
◯ Market
◉ R&D

Cost Recovery Period
30 years

Default Technology Detail

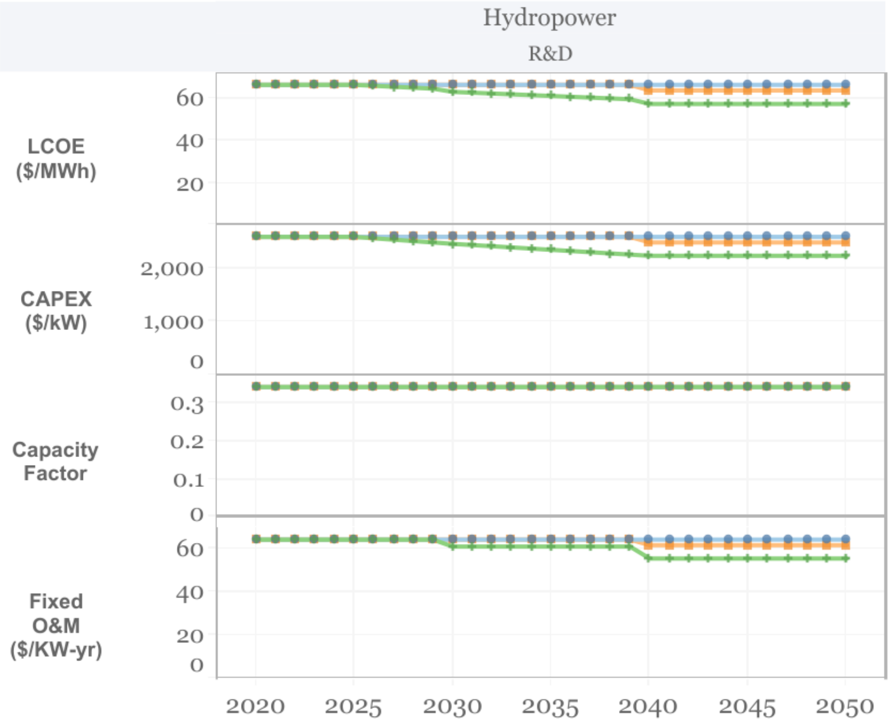
Hydropower - NPD 1

Technology Detail Filter
Default

data updated: 05/23/2022

NREL

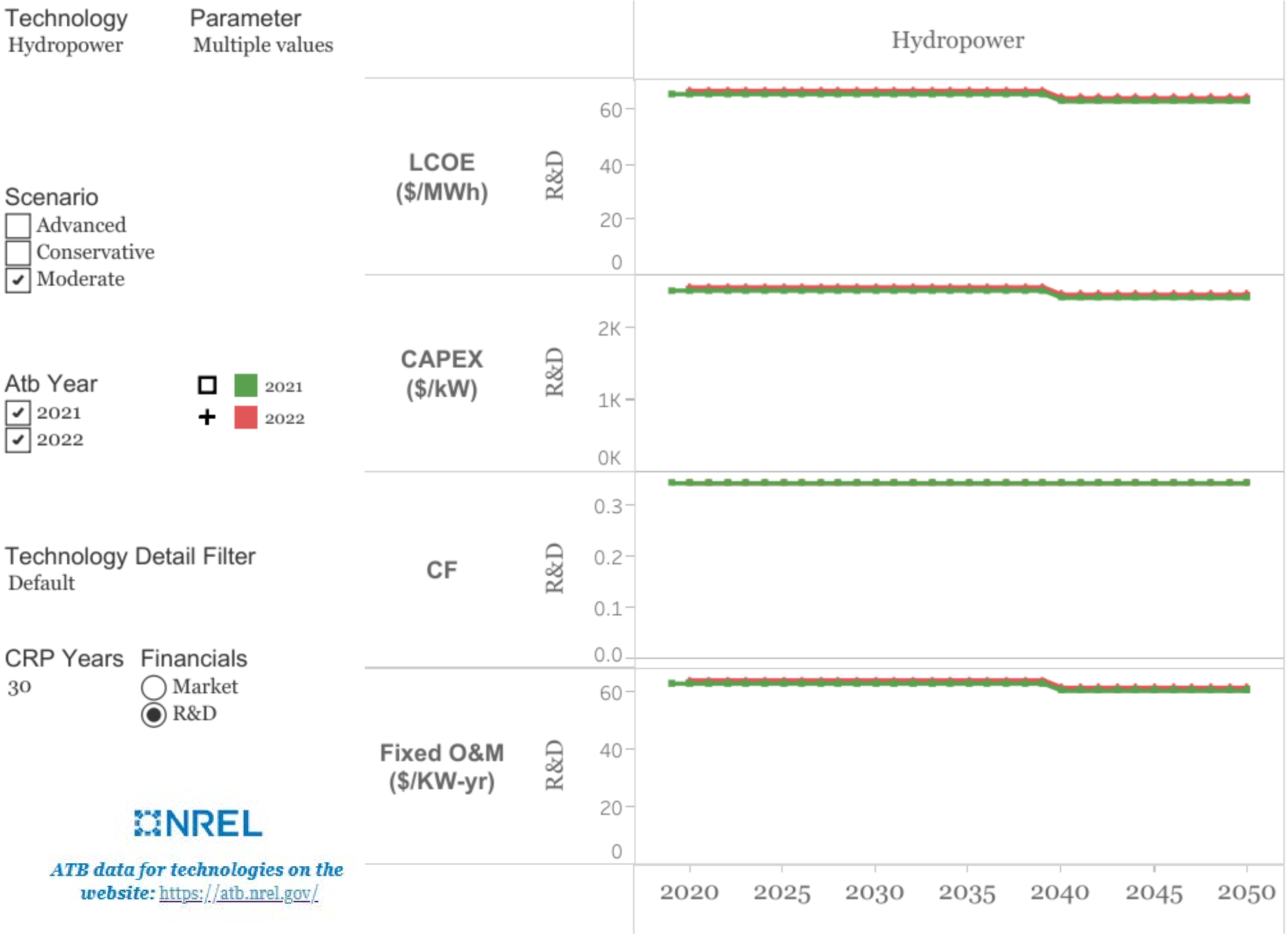
ATB data for technologies on the website: https://atb.nrel.gov/



Parameter value projections by scenario, financial case, cost recovery period, and technological detail

Select the parameter (LCOE, CAPEX, Fixed O&M, Capacity Factor, and FCR [fixed charge rate]), scenario, financial case, cost recovery period, and technological detail. The year represents the commercial online date. The default technology detail best aligns with recent or anticipated near-term installations.

Hydropower



NREL

ATB data for technologies on the website: https://atb.nrel.gov/

Utility-Scale PV-Plus-Battery

Base Year

CAPEX is based on new bottom-up modeling and 2021 Q1 market data from Ramasamy et al. (2021). The nameplate capacity of the battery is increased (from 50 MW to 71.5 MW) to allow for 55-MW_{DC} of usable stored energy. Interconnection and transmission costs now scale with the AC rating of the capacity. Battery replacements are now reflected in the fixed O&M costs, based on assumed battery degradation rates. Grid charging cost of $22/MWh is added to the default LCOE for the 25% of energy that comes from grid charging.

Projections

As in the 2021 ATB, PV-plus-battery projections in the 2022 ATB are driven primarily by CAPEX cost improvements but also by improvements in energy yield, operational cost, and cost of capital (for the Market+Policies Financial Assumptions Case). Projected technology costs are based on a new report (Feldman et al. 2021).

Caitlin Murphy and Vignesh Ramasamy

Utility-Scale PV-Plus-Battery

Parameter
Multiple values

Scenario
All

Financials
◯ Market
◉ R&D

Cost Recovery Period
30 years

Default Technology Detail

PV+Storage - Class 5

Technology Detail Filter
Default

data updated: 05/23/2022

NREL

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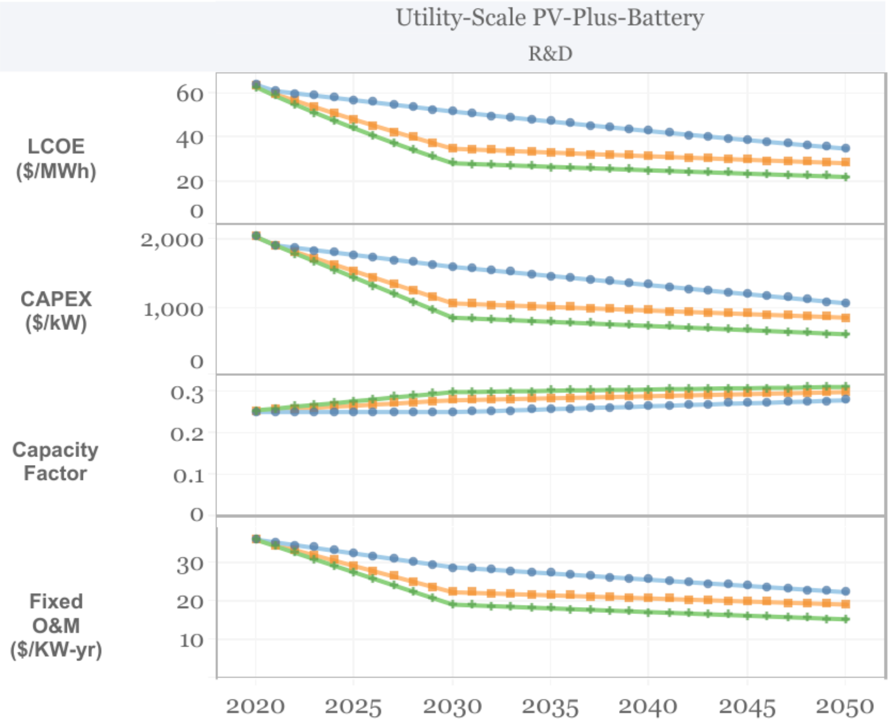


Parameter value projections by scenario, financial case, cost recovery period, and technological detail

Select the parameter (LCOE, CAPEX, Fixed O&M, Capacity Factor, and FCR [fixed charge rate]), scenario, financial case, cost recovery period, and technological detail. The year represents the commercial online date. The default technology detail best aligns with recent or anticipated near-term installations.

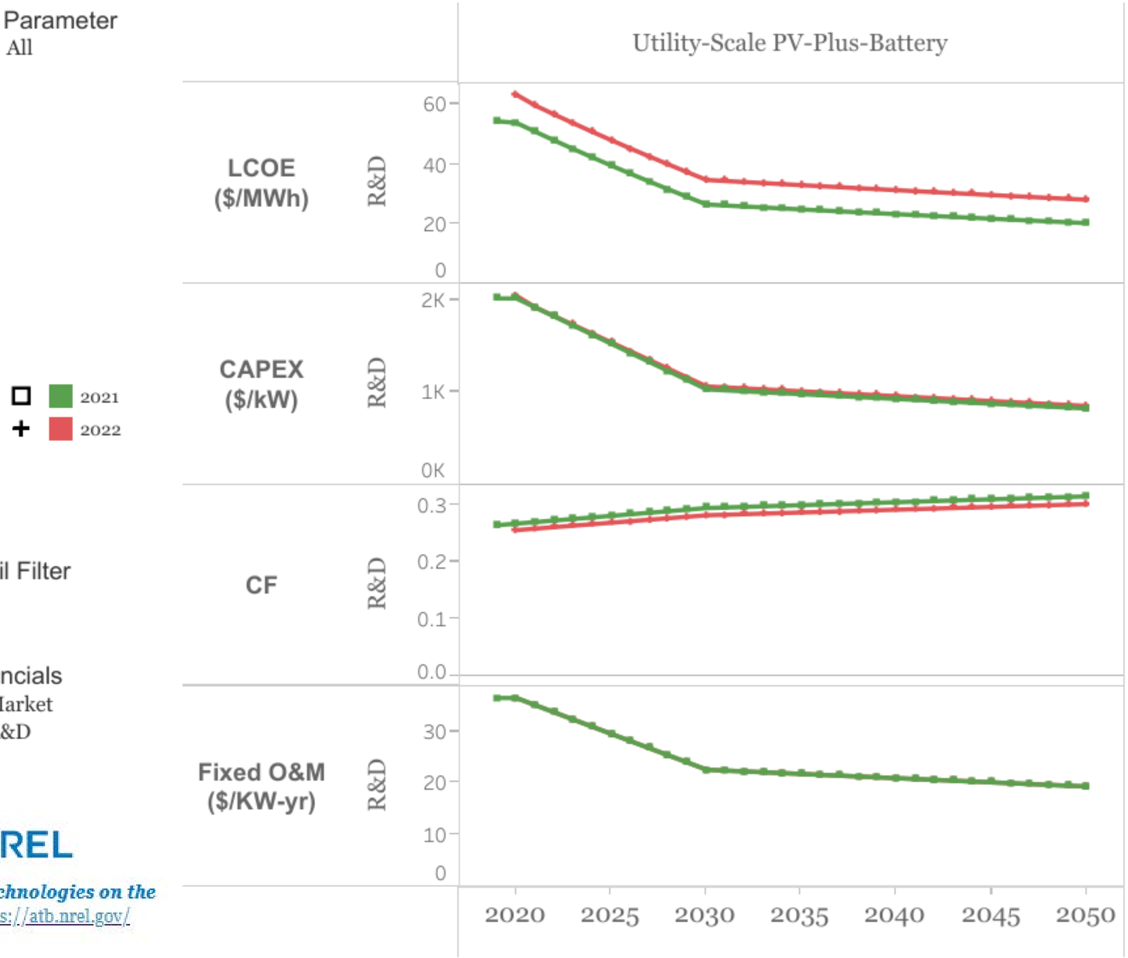
Utility-Scale PV-Plus-Battery

Technology
Utility-Scale PV-..

Parameter
All

Scenario
- [ ] Advanced
- [ ] Conservative
- [x] Moderate

Atb Year
- [x] 2021
- [x] 2022



Technology Detail Filter
Default

CRP Years
30

Financials
- ( ) Market
- (•) R&D

NREL

ATB data for technologies on the website: https://atb.nrel.gov/

Utility-Scale Battery Storage

Base Year

CAPEX is based on new bottom-up modeling and market data from a new report (Ramasamy et al. 2021).

Projections

As in the 2021 ATB, battery projections in the 2022 ATB are represented for utility-scale, commercial-scale, and residential-scale battery systems. Cost improvements are driven by a literature survey described by Cole et al. (2021). The literature survey incorporates more-rapid reductions in battery pack and cell costs while soft costs and costs related to other factors decline more slowly.

Nate Blair, Vignesh Ramasamy

Utility-Scale Battery Storage

Parameter
All

Scenario
All

Financials
◯ Market
◉ R&D

Cost Recovery Period
30 years

Default Technology Detail

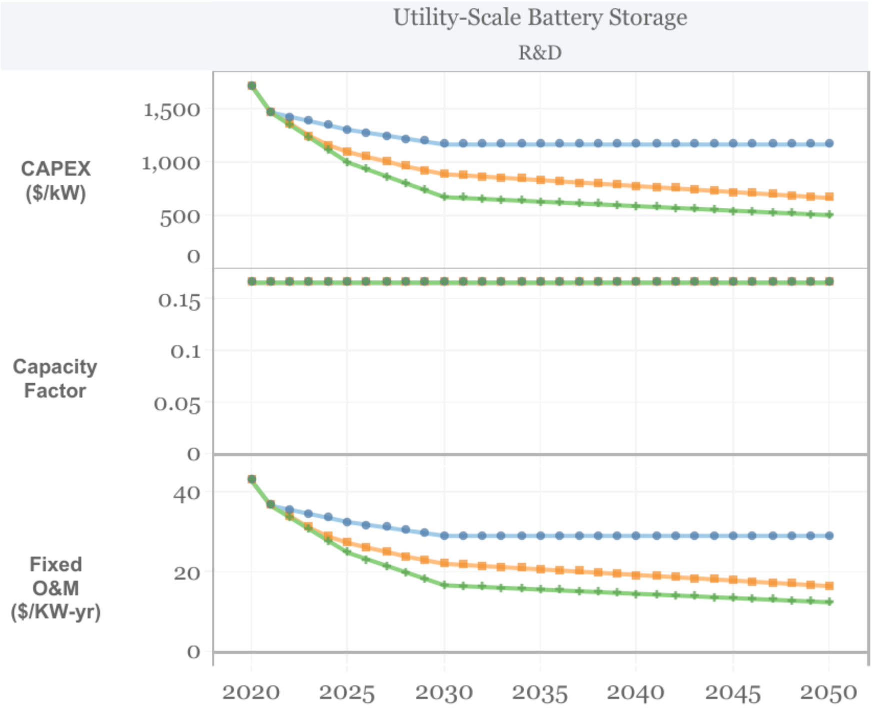
Utility-Scale Battery Storage - 4Hr

Technology Detail Filter
Default

data updated: 05/23/2022

NREL

ATB data for technologies on the website: https://atb.nrel.gov/



Parameter value projections by scenario, financial case, cost recovery period, and technological detail

Select the parameter (LCOE, CAPEX, Fixed O&M, Capacity Factor, and FCR [fixed charge rate]), scenario, financial case, cost recovery period, and technological detail. The year represents the commercial online date. The default technology detail best aligns with recent or anticipated near-term installations.

Utility-Scale Battery Storage

Technology
Utility-Scale Bat..

Parameter
All

Scenario
- [ ] Advanced
- [ ] Conservative
- [x] Moderate

Atb Year
- [x] 2021
- [x] 2022

□ 2021
+ 2022

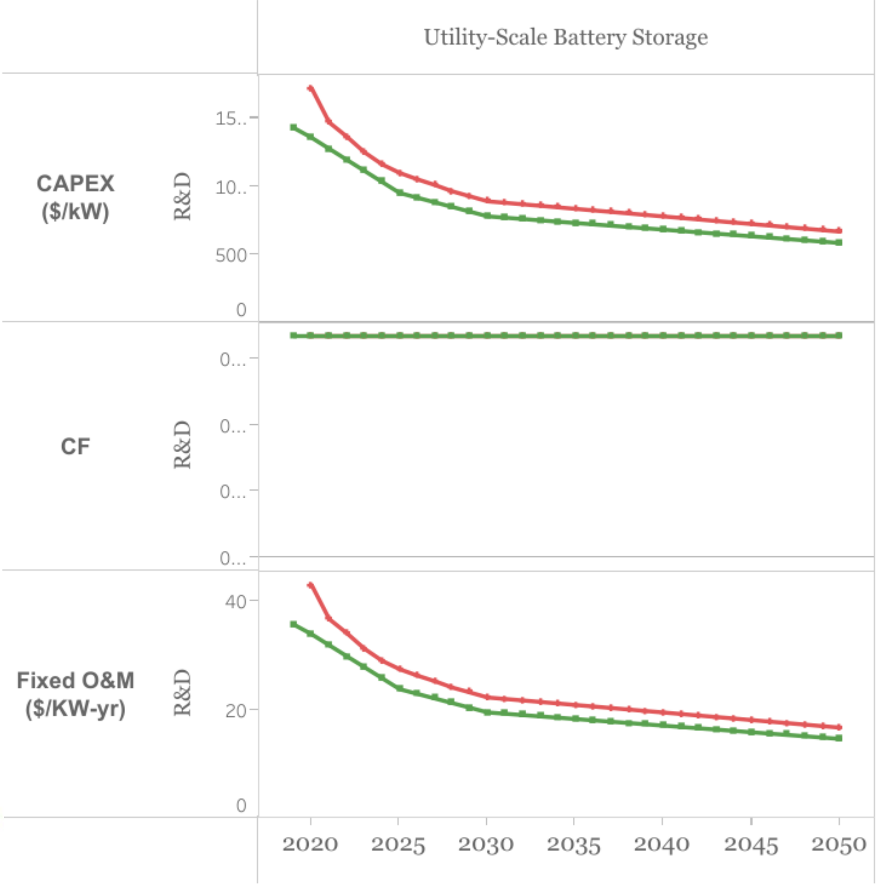
Technology Detail Filter
Default

CRP Years
30

Financials
- ○ Market
- ● R&D

NREL

ATB data for technologies on the website: https://atb.nrel.gov/



Pumped Storage Hydropower

Base Year

Resource characterizations including capital costs are presented for the first time in the 2022 ATB. These are based on a national resource assessment for closed-loop PSH described by Rosenlieb et al. (2022). And a first-of-its-kind U.S. data set has site-level information that could be useful beyond the ATB. See:

- "Closed-Loop Pumped Storage Hydropower Supply Curves," NREL, https://www.nrel.gov/gis/psh-supply-curves.html.
- Evan Rosenlieb, Donna Heimiller, and Stuart Cohen. *Closed-Loop Pumped Storage Hydropower Supply Curves* (Golden, CO: NREL, 2022). NREL/TP-6A20-81277, https://www.nrel.gov/docs/fy22osti/81277.pdf.

Projections

Projected cost reductions in the Advanced Scenario are based on innovations in modularity, materials, pumps and turbines, and closed-loop concepts as described by DOE (2016).

Stuart Cohen

Pumped Storage Hydropower

Parameter
All

Scenario
All

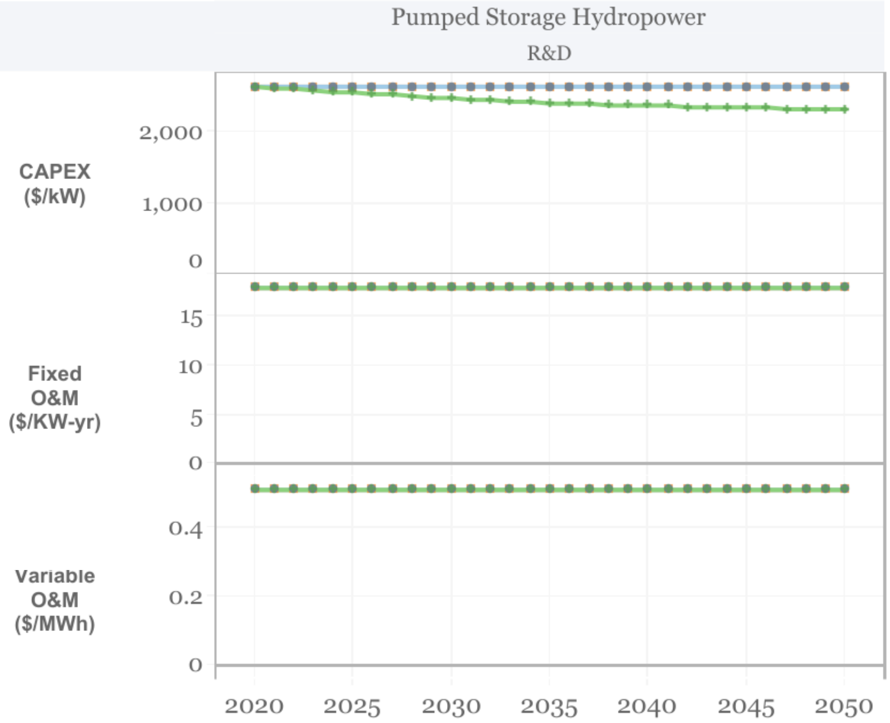
Financials
◯ Market
◉ R&D

Cost Recovery Period
30 years

Default Technology Detail

Pumped Storage Hydropower - Nation.

Technology Detail Filter
Default



CAPEX is shown for classes 1, 5, 10, and 15 when binned nationally by cost

data updated: 05/23/2022

Parameter value projections by scenario, financial case, cost recovery period, and technological detail

Select the parameter (LCOE, CAPEX, Fixed O&M, Capacity Factor, and FCR [fixed charge rate]), scenario, financial case, cost recovery period, and technological detail. The year represents the commercial online date. The default technology detail best aligns with recent or anticipated near-term installations.

NREL

ATB data for technologies on the website: https://atb.nrel.gov/

Fossil Energy

Base Year

As in the 2021 ATB, base year cost and performance data are based on (James et al. 2019).

Projections

Projections in the 2022 ATB are based on the rate of cost improvement from AEO2022 (EIA 2022).

Jeffrey Hoffmann

Fossil Energy Capital Cost Projections

Technology Alias
All

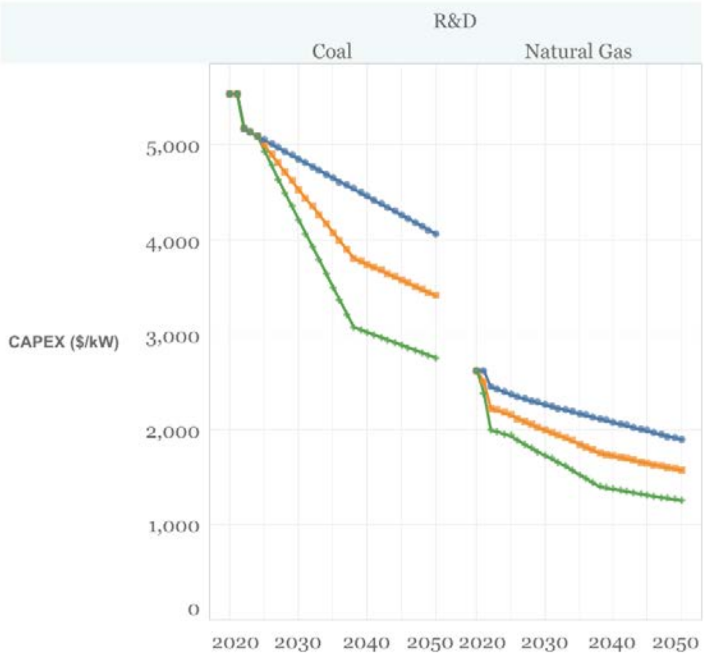
Parameter
CAPEX

Scenario
All

Financials
◯ Market
◉ R&D

CRP Years
30

Technology Sub-Group
Multiple values



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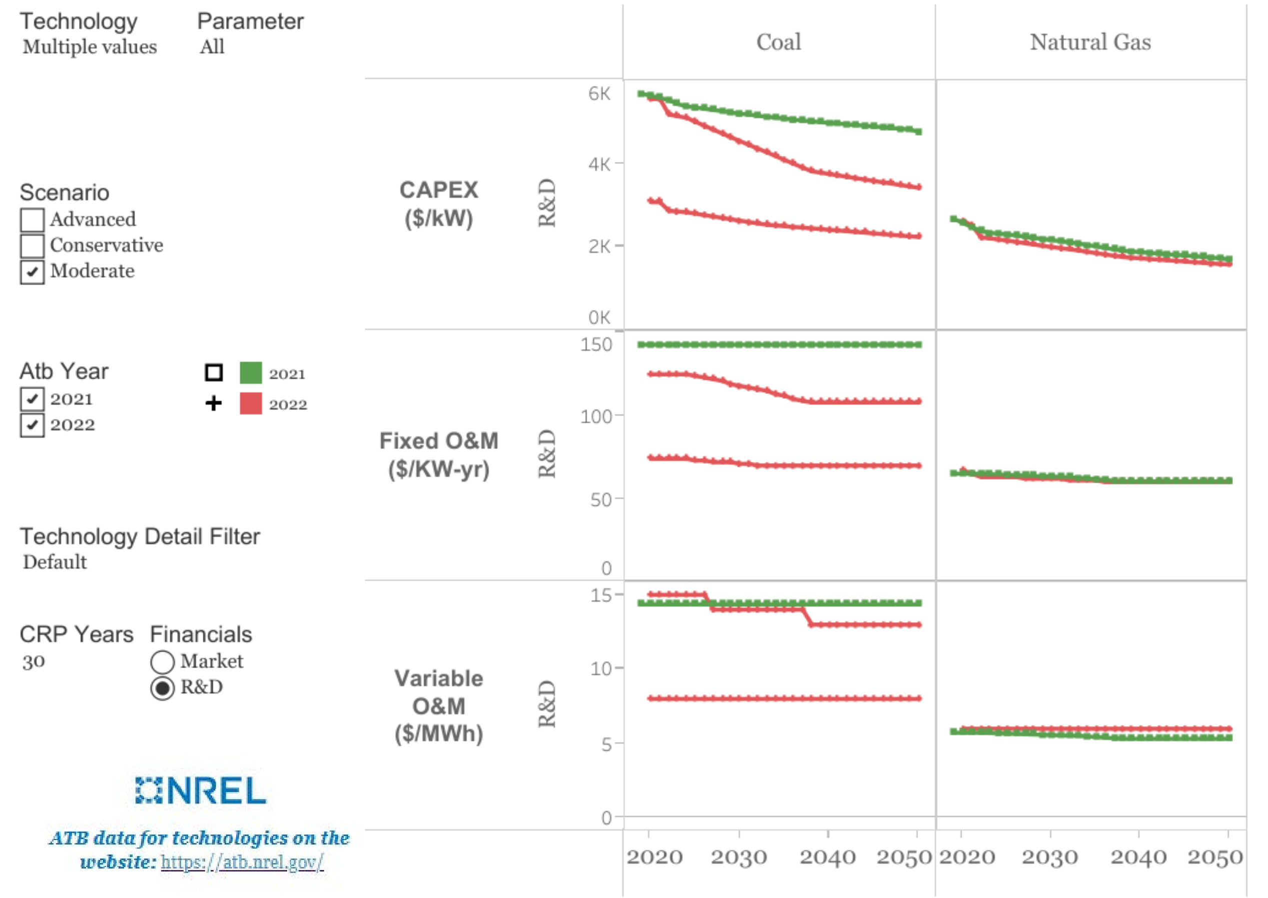
Parameter value projections by scenario, financial case, cost recovery period, and technological detail

Select the parameter (LCOE, CAPEX, Fixed O&M, Capacity Factor, and FCR [fixed charge rate]), scenario, financial case, cost recovery period, and technological detail. The year represents the commercial online date. The default technology detail best aligns with recent or anticipated near-term installations. Scenarios are labeled with ATB names but correspond to AEO scenarios.

Fossil Energy Capital Cost Projections



Financial Cases and Methods Updates

https://atb.nrel.gov/electricity/2022/financial_cases_&_methods

David Feldman

All-Technology Financial Changes in 2022 ATB

- Values are modified in the two financial cases (R&D and Market + Policies) to reflect current assessments and policies.
- Base year = 2020. Dollar year = 2020. Historical data include data reported in 2020.
- General approach is consistent with the 2021 ATB.

ATB does not track near-term cost variability.

The 2022 makes these clarifications about ATB limitations related to near-term cost variation :

- Sources of projections are clarified.
  - Projections are based on trend lines between historical data (base year = 2020) and long-term (2030 and 2050) estimated costs.
  - Values do not reflect every condition (e.g., local variation or recent market changes).

- The 2022 makes these clarifications about related ATB purpose:
  - "Develop and document transparent, normalized technology cost and performance assumptions **using published sources**."
  - "Reduce the lead time required when conducting scenario analysis **of 5- to 30-year futures**."

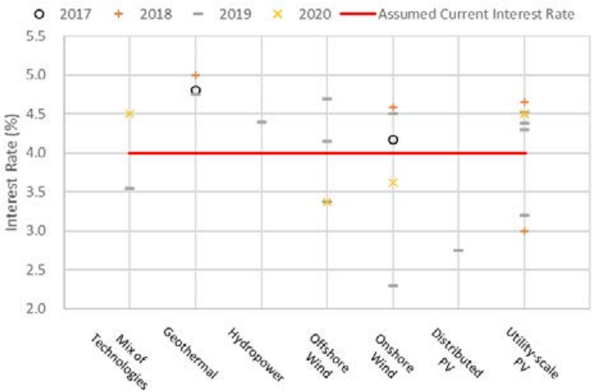
- "Current" is replaced with more precise wording.

The ATB does not include data about recent cost escalations.

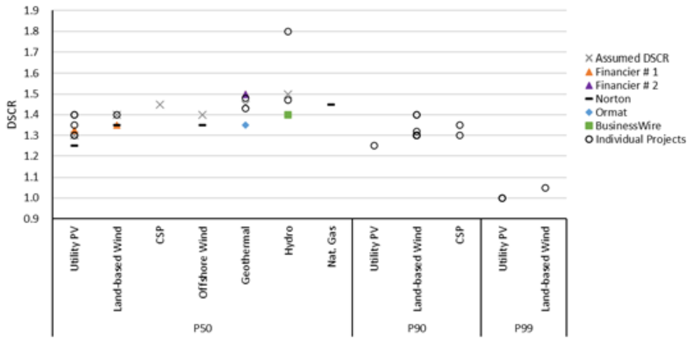
Define Financial Scenario, Collect Data, Run Models

- Collected data for renewable energy project financing owned by independent power producers with long-term power purchase agreements, as well as natural gas financial arrangements with quasi-merchant power contracts. (Represents the largest share of new projects in the United States, particularly for renewable energy.)
- Built cash flow model, with ATB and financing inputs, to determine project leverage over time. Methods, analysis, and data fully described by David Feldman, Mark Bolinger, and Paul Schwabe. *Current and Future Costs of Renewable Energy Project Finance Across Technologies*. (Golden, CO: NREL, 2020). NREL/TP-6A20-76881. https://www.nrel.gov/docs/fy20osti/76881.pdf.
- Developed values for two financial cases (R&D and Market + Policies) to reflect current assessments. "R&D" financial case assumes no tax credits and no change in interest rate.
- Financing costs for each technology are developed for (1) construction period and (2) operating period to account for different levels of risk.

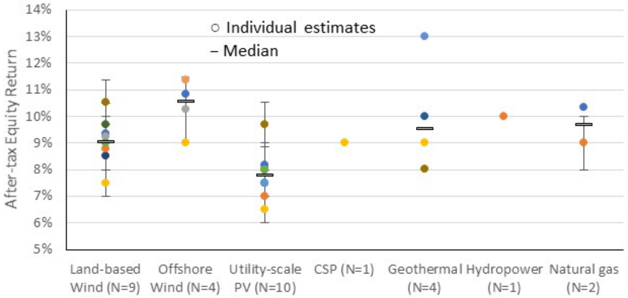
All-in term debt interest rates for loans initiated over time, by technology



DSCR data at different probability of exceedance levels, by technology



After-tax levered cost of equity, by technology



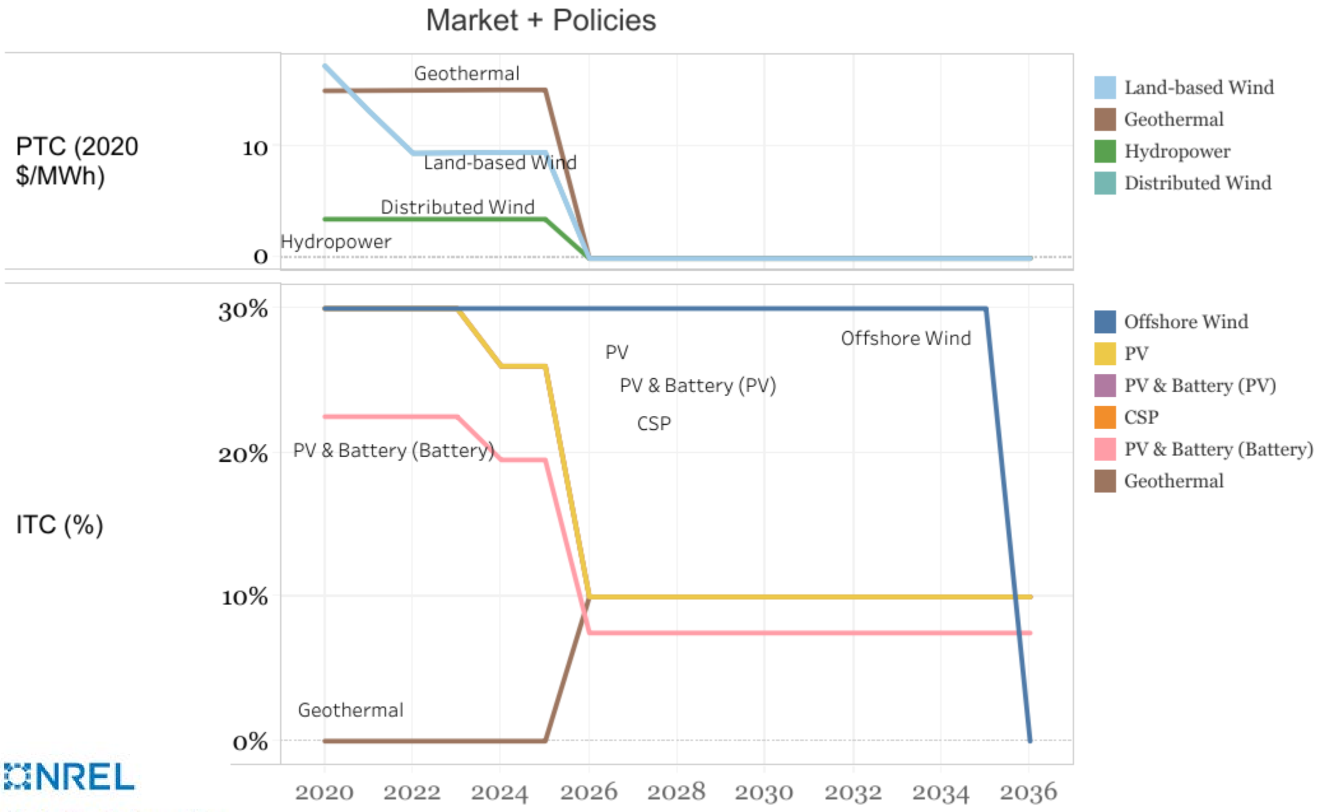
Comparing Financial Assumptions by Technology

The following slides compare financial assumptions that are used in calculating LCOE:

- ITC and PTC
- Term debt fraction
- Term-weighted average cost of capital (real)
- LCOE.

ITC and PTC

PTC applied to Distributed Wind



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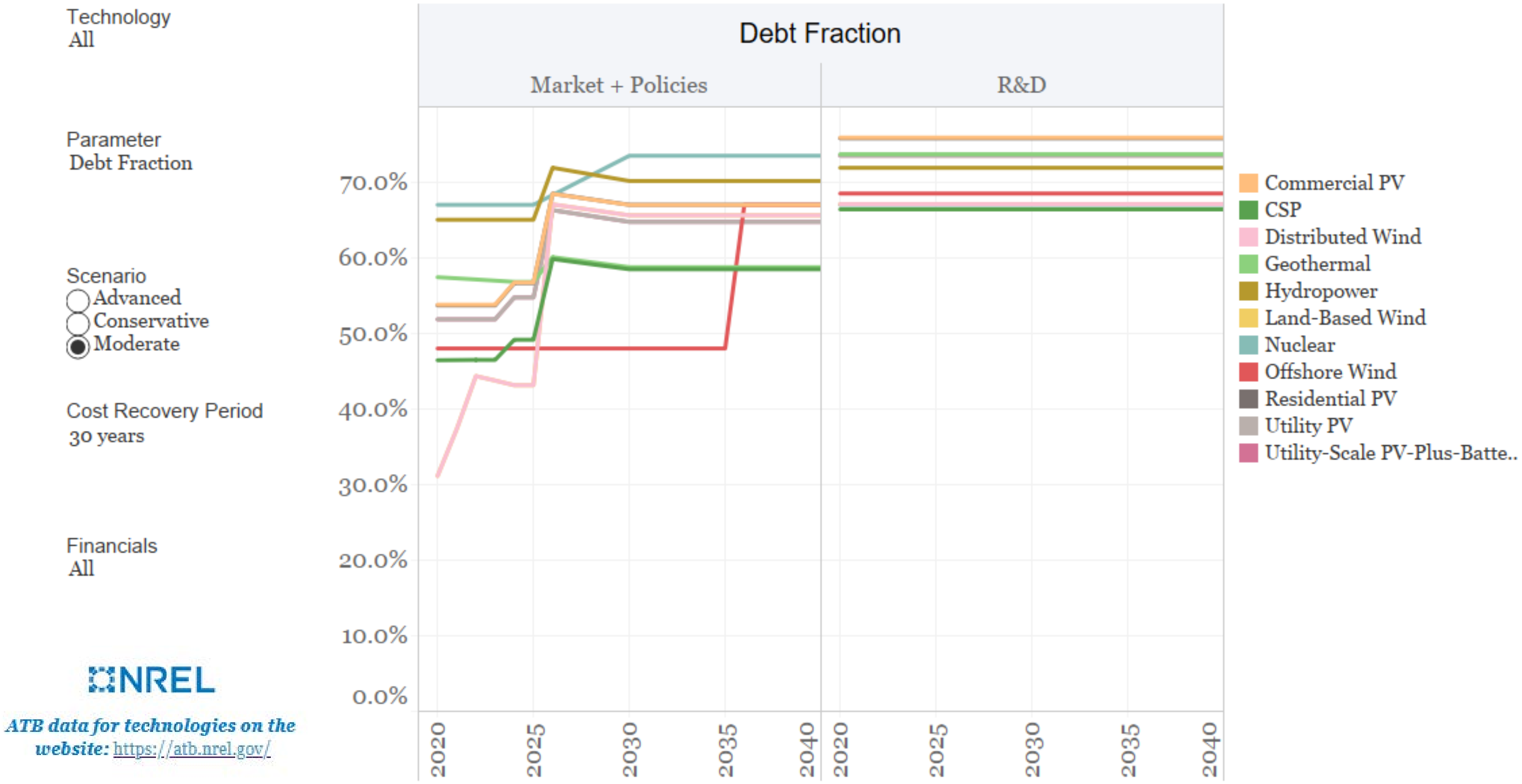
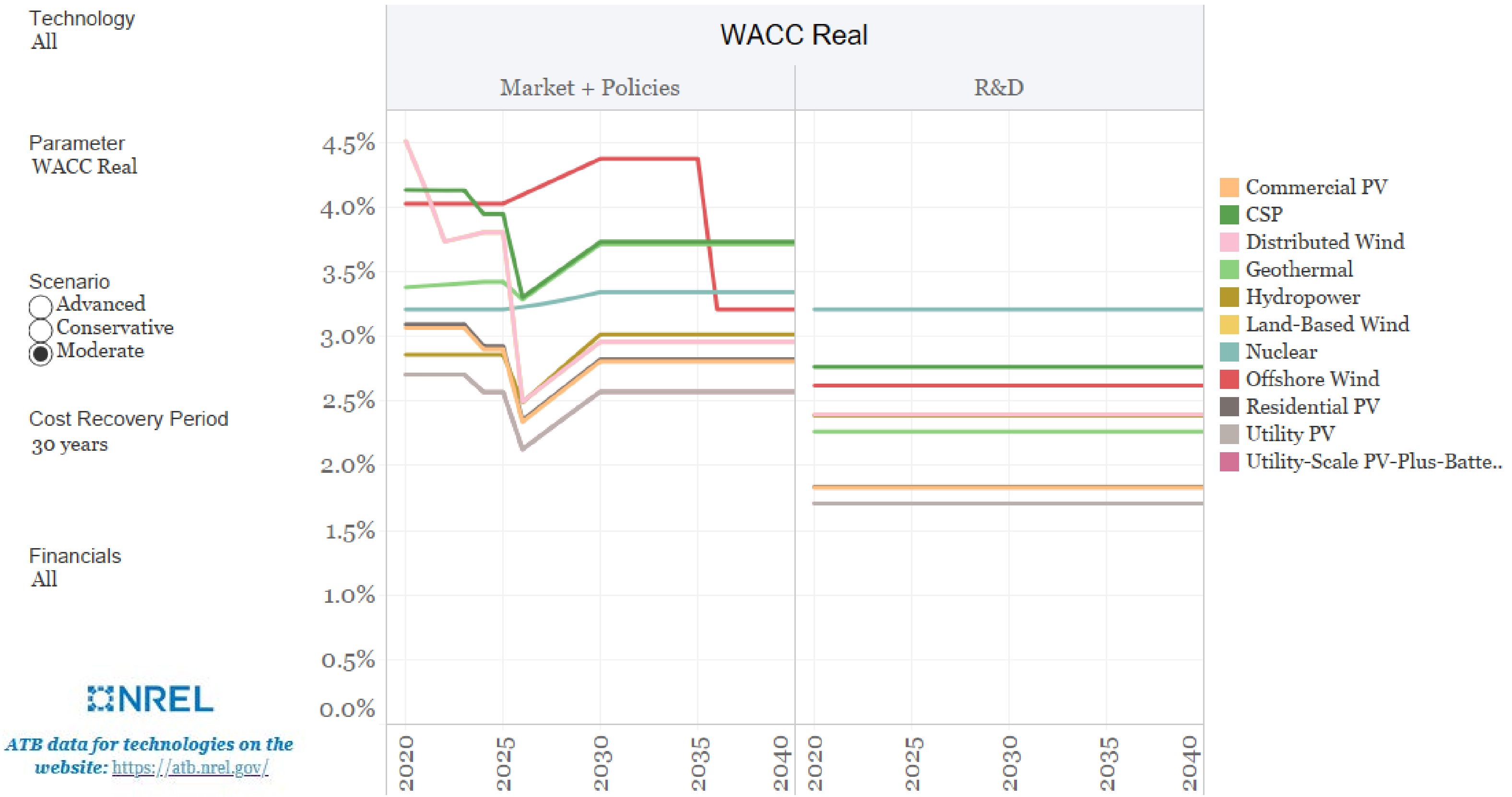
Term Debt Fraction by Financial Case



Term WACC (Real) by Financial Case



LCOE by Financial Case

Technology
Multiple values

- ● Land-based Wind
- ■ Offshore Wind
- ✚ Utility PV
- ✕ Commercial PV
- ✖ CSP
- ★ Geothermal
- ◆ Hydropower
- △ Distributed Wind
- ◁ Utility-Scale PV-Plus-Battery

Scenario
- [ ] Advanced
- [ ] Conservative
- [x] Moderate

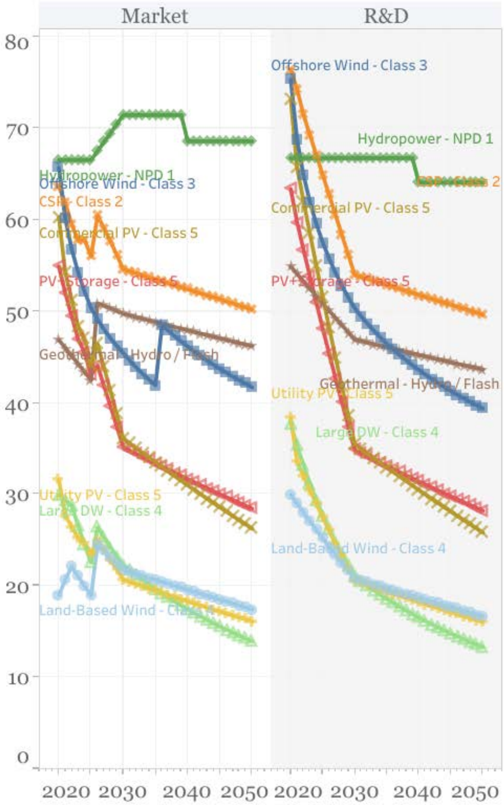
Parameter
LCOE

Cost Recovery Period
30 years

Technology Detail
All

Financials
All

LCOE ($/MWh)



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ATB data for technologies on the website:
https://atb.nrel.gov/

References

A complete list of references for the 2022 Electricity ATB can be found at https://atb.nrel.gov/electricity/2022/references.

Acronyms and Abbreviations

AEO	Annual Energy Outlook
API	application programming interface
ATB	Annual Technology Baseline
AWS	Amazon Web Services
BAU	business as usual
BESS	battery energy storage system
CAPEX	capital expenditure
CCS	carbon capture and storage
CSP	concentrating solar power
CT	combustion turbine
DOE	U.S. Department of Energy
DSCR	debt service coverage ratio
EGS	enhanced geothermal system
EIA	U.S. Energy Information Administration
FECM	Fossil Energy and Carbon Management (a U.S. DOE office)
GETEM	Geothermal Electricity Technology Evaluation Model
IGCC	integrated gasification combined cycle
ITC	investment tax credit
LCOE	levelized cost of energy
MW	megawatt
MWDC	megawatt-direct current
NGCC	natural gas combined cycle
NPD	non-powered dam
NREL	National Renewable Energy Laboratory
NSD	new stream-reach development
ORNL	Oak Ridge National Laboratory
O&M	operations and maintenance
PSH	pumped storage hydropower
PTC	production tax credit
PV	photovoltaic
RPM	Resource Planning Model
SAM	System Advisor Model
SMR	small modular reactor (a nuclear technology)

Acknowledgements

https://atb.nrel.gov/electricity/2022/about

- **Land-Based Wind:** Tyler Stehly, NREL
- **Offshore Wind:** Patrick Duffy and Philipp Beiter, NREL
- **Distributed Wind:** Parangat Bhaskar, NREL
- **Solar: Photovoltaics (PV):** David Feldman and Jarett Zuboy, NREL
- **Solar: Concentrating Solar Power (CSP):** Chad Augustine and Parthiv Kurup, NREL
- **Hydropower:** Gbadebo Oladosu, Oak Ridge National Laboratory (ORNL)
- **Geothermal:** Jody Robins, NREL
- **Fossil Technologies** (Data from DOE Office of Fossil Energy and Carbon Management source): Jeffrey Hoffmann, DOE-FECM
- **Battery Storage:** Vignesh Ramasamy and Nate Blair, NREL
- **Utility-Scale PV-Plus-Battery:** Caitlin Murphy and Vignesh Ramasamy, NREL
- **Pumped Storage Hydropower:** Stuart Cohen and Evan Rosenlieb, NREL
- **Nuclear and Biopower** (Data from U.S. Energy Information Administration source): Wesley Cole and Pieter Gagnon, NREL
- **Finance:** David Feldman, NREL
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Q&A

Thank you.

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