Annual Technology Baseline: The 2021 Electricity Update

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July 19, 2021

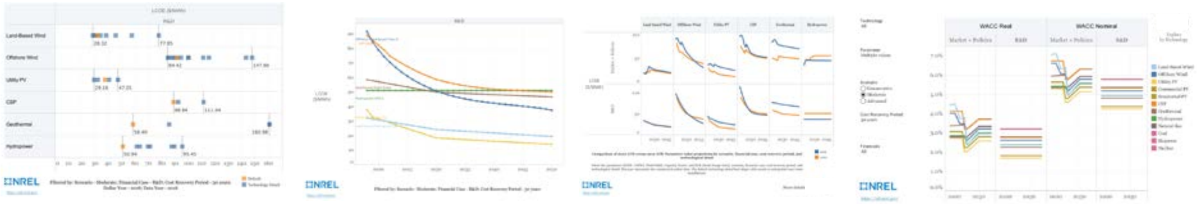
Agenda

- Why the ATB?
- ATB Project Overview
- Technology-Specific Highlights
- Financial Cases and Methods
- Questions and Comments

Why the ATB?

Annual Technology Baseline

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 targets analytic transparency and consistency.

Objective: develop and publish renewable energy technology cost and performance scenarios that are credible, comparable, and transparent, and reflect potential technology advancement

EERE[a] Analysis Consistency

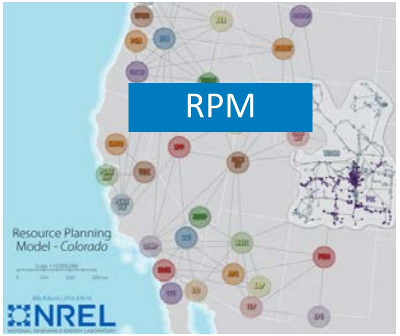
- Ensure consistent assumptions across technologies
- Provide comparability across EERE/national laboratory projects and publications

Third-Party Analysis

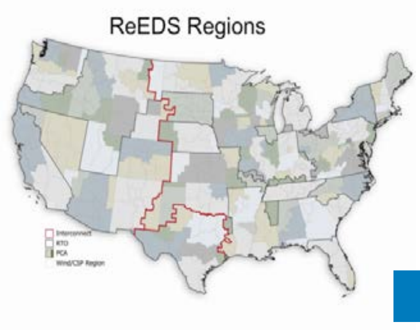
- Provide access to assumptions
- Leverage national laboratory expertise

[a] U.S. Department of Energy Office of Energy Efficiency and Renewable Energy (EERE)

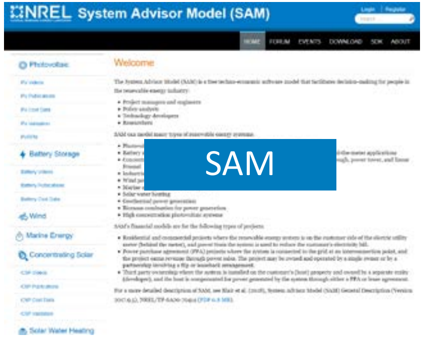
The ATB anchors key DOE and national lab analyses.



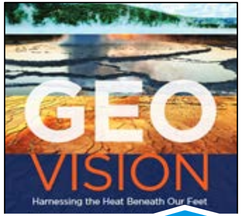
Resource Planning Model



Regional Energy Deployment System



System Advisor Model



Geothermal Vision

Hydropower Vision

Impacts of Tax Credit Extensions

Prospective RPS Cost, Benefits, and Impacts

Standard Scenarios

Impact of Storage on Electric System Planning

ATB Projections Used in Important Scenario Analyses

Now in its seventh 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)

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)

State Energy Offices
(Hawaii, Michigan)

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

Media
(Utility Dive)

The ATB data are inputs for the Standard Scenarios.

Annual Technology Baseline

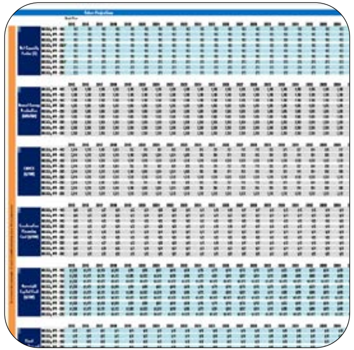
Cost and performance assumptions for renewable and conventional technologies

↓

Standard Scenarios

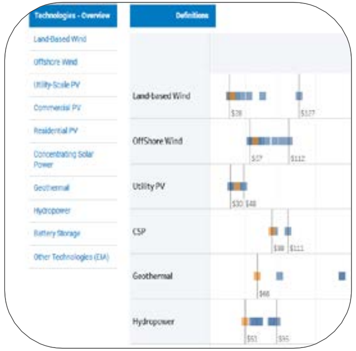
Ensemble of future scenarios of the U.S. electric power sector

The ATB includes a suite of products.



Spreadsheet

- Calculations
- Cost and performance projections, 2019–2050
- 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, 2019–2050
  - Capacity factor
  - O&M costs
  - CAPEX
  - Financing assumptions
  - LCOE
- Structured format

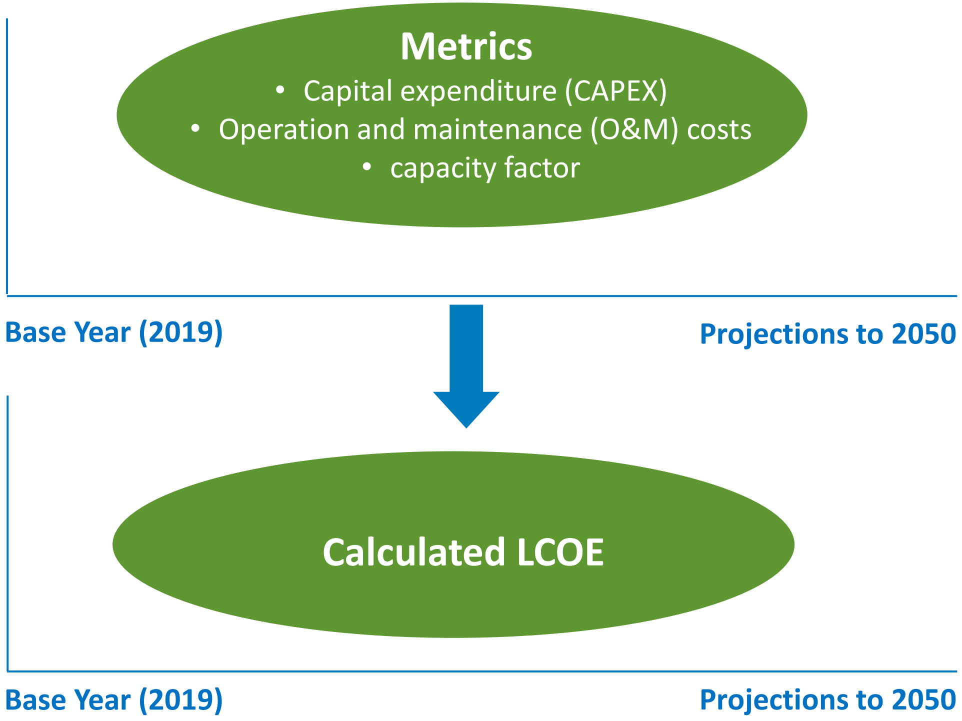
PowerPoint

- Webinar presentation
- Summary presentation

API

- Data published in Open Energy Data Initiative
- Programmatic access through AWS-S3

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 for each financial assumptions scenario.

LCOE is provided as a summary metric but is not used as a ReEDS model input. Its limitations are described in the documentation. The user can select or specify financial assumptions for calculating LCOE.

Technologies Covered

Renewable Energy Technologies (EERE/NREL)

Wind

- Land-based
- Offshore

Solar

- Utility 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

Geothermal (Flash and Binary)

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

Storage

- Utility-scale
- Commercial-scale
- Residential

Fossil with Carbon Capture and Storage Options (FE)

Natural Gas

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

Coal

- Supercritical pulverized coal (SCPC)
- SCPC w/ 36% CCS
- SCPC w/90% CCS
- Integrated gasification combined-cycle (IGCC)

Conventional (EIA AEO 2021)

Nuclear

- Gen 3

Biopower

- Dedicated

Methodology Overview: Three Steps

1. Define resource bins for each technology

Group range of resources for continental 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 Constant, Mid, and Low technology cost scenarios for CAPEX, capacity factor, and operation and maintenance (O&M)

3. Calculate LCOE (for selected technologies)

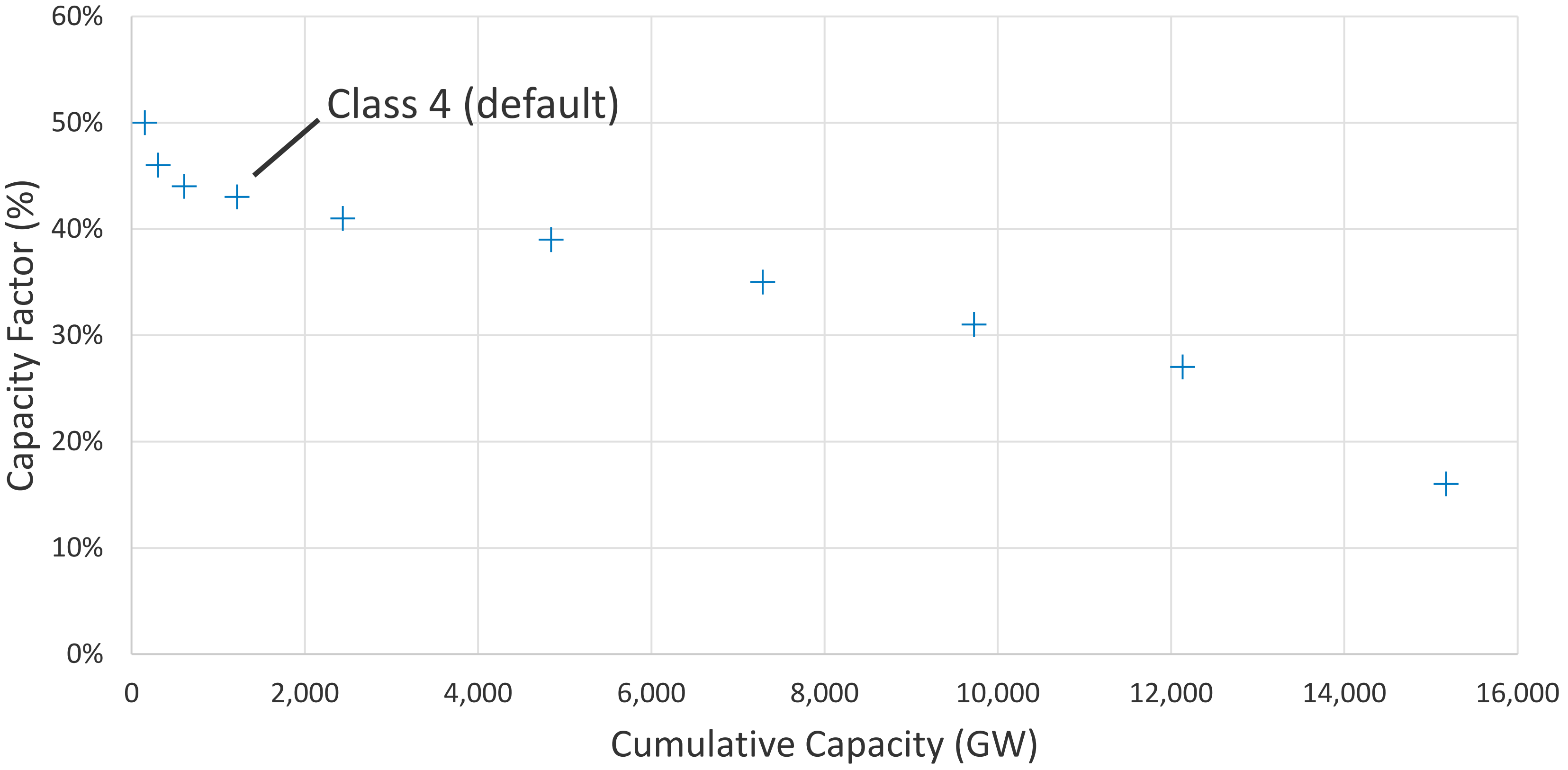
Use selected financial assumptions to calculate LCOE from CAPEX, capacity factor, and O&M

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
Utility-scale, commercial, residential PV, and utility-scale PV-plus-battery	10	Global horizontal solar irradiance
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	4	Resource categorization is forthcoming
Utility-scale, commercial, residential battery storage	5	Storage duration
Natural gas	6	Combustion turbine, IGCC, CCS
Coal	8	Pulverized coal, IGCC, CCS, Carbon capture rate
Nuclear	1	Not applicable
Biopower	1	Dedicated

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

Example of Technology/Resource Bins: Land-Based Wind



Step 2: Develop Cost and Performance Data

Base Year (2019): informed by market reports, market data, and bottom-up modeling

Projections: generally rely on bottom-up modeling and published studies; qualitatively harmonized to three projection scenarios:

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 (2019)

Technology	Source
Land-based wind power plants	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 (Stehly et al. 2020). The operation and maintenance (O&M) of $43/kW-yr is estimated in the 2019 Cost of Wind Energy Review (Stehly et al. 2020); no variation of fixed operation and maintenance expenses (FOM) with wind speed class is assumed. Capacity factors align with performance in Wind Speed Classes 2–7, where most installations are located.
Offshore wind power plants	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). Bottom-up estimates from the 2020 ATB are brought forward one year (2018 to 2019) using the learning methodology.
Utility, residential, and commercial PV plants	CAPEX for 2019 are based on new bottom-up cost modeling and market data from Feldman et al. (2021). O&M costs are based on modeled pricing for a 100-MW_{DC}, one-axis tracking system (Feldman et al. 2021). Resource classes were expanded from 5 to 10 and capacity factors are now based on weighted averages within specific global horizontal irradiance (GHI) bins.
Concentrating solar power plants	Bottom-up cost modeling are from Turchi et al. (2019) for the updates to the System Advisor Model (SAM) cost components.
Geothermal plants	Bottom-up cost modeling use Geothermal Electricity Technology Evaluation Model (GETEM) and inputs from the GeoVision Business-as-Usual (BAU) scenario (DOE 2019).
Hydropower plants	Non-powered dam (NPD) data are based on bottom-up new 2020 cost analysis (Oladosu et al. 2021). New stream-reach development (NSD) data are retained from previous years and were based on the Hydropower Vision study (DOE 2016), with bottom-up cost modeling from the *Hydropower Baseline Cost Modeling* report (O'Connor et al. 2015).

Sources of Base Year (2019) continued

Technology	Source
Utility scale PV-plus-battery	CAPEX for 2019 are based on new bottom-up cost modeling and market data from Feldman et al. (2021). O&M costs are based on modeled pricing for a 134-MW_{DC}, one-axis tracking system coupled with 50-MW, 4-hour battery storage (Feldman et al. 2021). The chosen configuration reflects recent and proposed utility-scale PV-plus-battery projects. Capacity factors and tax credits assume 75% of the energy used to charge the battery component is derived from the coupled PV (on an annual basis).
Utility, residential, and commercial battery storage	Current costs for utility-scale battery energy storage systems are based on a bottom-up cost model using the data and methodology for utility-scale battery energy storage systems in Feldman et al. (2021).
Pumped-storage hydropower	Resource characterizations with capital costs are forthcoming and will accompany the national closed-loop pumped-storage hydropower 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	These are Annual Energy Outlook (EIA 2021) reported costs.

Major Innovations Driving Projections (to 2050)

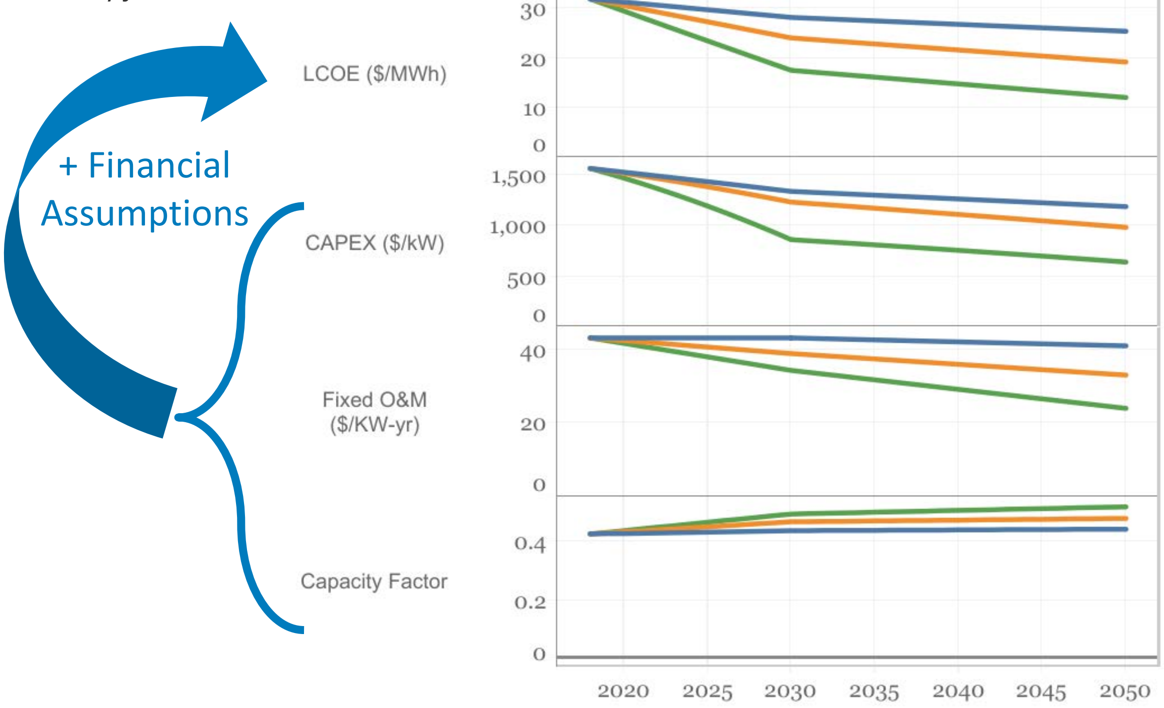
Land-based Wind	Offshore Wind	Solar Photovoltaics (including PV-battery)	Concentrating Solar Power	Geothermal	Hydropower	Battery Storage	Pumped-Storage Hydropower
Rotor, nacelle assembly	Turbine size	Module efficiency	Power block	Drilling advancements	Learning by doing	Significant market demand	Modularity
Tower	Supply chain	Inverter power electronics	Receiver	Enhanced geothermal systems development	Modularity	Improvements in chemistry	New materials
Science-based modeling	Size-agnostic innovation	Installation efficiencies	Thermal storage		New materials	Supply chain development	Automation/ digitization
		Energy yield gain	Solar field		Automation/ digitalization		Eco-friendly turbines
					Eco-friendly turbines		

Step 3: Calculate Levelized Cost of Energy (LCOE) (for selected technologies)

$$\text{Levelized Cost of Energy} = \frac{\text{Fixed Charge Rate} \times \text{Capital Expenditures} + \text{Fixed Operations and Maintenance Cost}}{\text{Capacity Factor} \times 8{,}760\ \text{hours/year}}$$
$$+ \text{Variable Operations and Maintenance Cost}$$
$$+ \text{Fuel Cost}$$

LCOE is a summary metric that combines the primary technology cost and performance parameters: capital expenditures, operations expenditures, and capacity factor. See documentation at atb.nrel.gov.

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



All-Technology Changes in 2021 ATB

- Modified values in the two financial cases (R&D and Market + Policies) to reflect current assessments and policies
- Base year = 2019
  Dollar year = 2019
  Historical data includes data reported in 2019.
- General approach consistent with 2020

Web Demonstration

- ATB Electricity Data Overview
  - 2019 Base Year
  - 2019–2050 trajectories
  - Filter by technology, parameter, scenario, cost recovery period, year, (tech. detail)
  - Downloads: slide deck, images, or Tableau workbook associated with each chart
- Example: Land-Based Wind
  - Technology-specific interactive chart
  - Scenario descriptions
  - Representative technology
- Annual Technology Baseline Data Download
- About

Technology-Specific Highlights

https://atb.nrel.gov/electricity/2021/changes_in_2021

Technology-Specific Summary

- **Concentrating Solar Power:** Component and system cost estimates for Base Year reference a 2017 industry survey and a 2018 cost analysis of recent market developments.
- **Pumped-Storage Hydropower:** This technology is new to the 2021 ATB.
- **Hydropower:** NPD data are based on new 2020 cost analysis.
- **Photovoltaics:** Projections are based on bottom-up techno-economic analysis of effects of improved module efficiency, inverters, installation efficiencies from assembly and design, all attributable to technological innovation. Resource categorization is split into 10 resource classes by irradiance instead of by representative location.
- **Land-Based Wind:** Projections are based on bottom-up technology analysis and cost modeling plus learning rates, with innovations that increase wind turbine size, improve controls, and enhance science-based modeling.
- **Offshore Wind:** Projections are based on experiential learning curves derived from market data and cost reductions associated with economies of size and scale.
- **Geothermal:** New data are now consistent with the GeoVision Study.
- **Utility-Scale PV-plus-Battery:** This technology is new to the 2021 ATB.
- **Battery Storage:** Updated projections are based on a new literature review.

Land-Based Wind

Parameter
Multiple values

Scenario
All

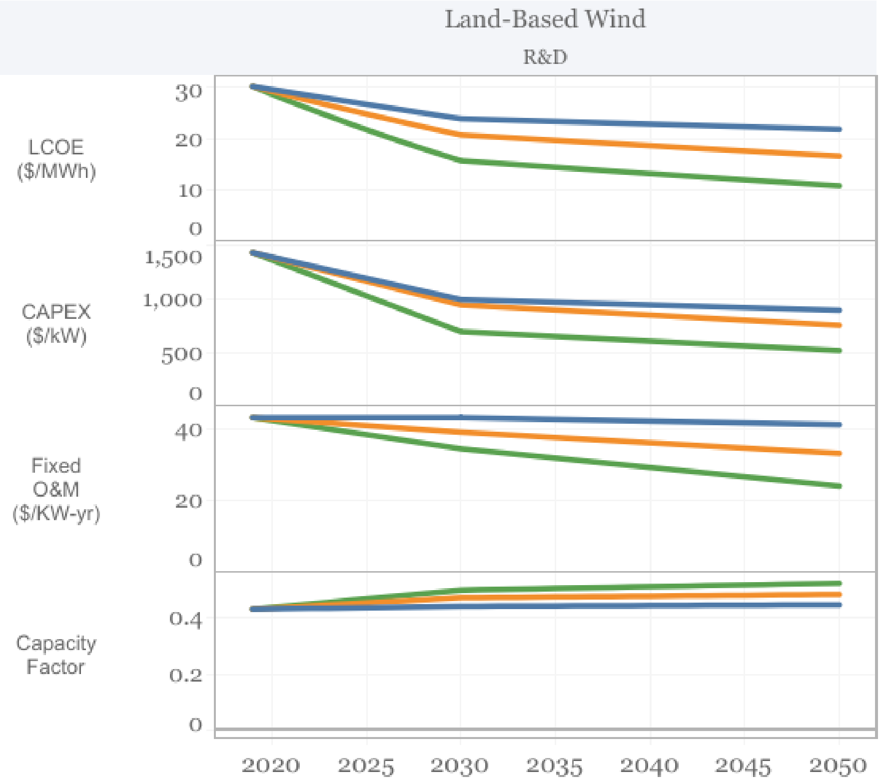
Financials
◯ Market + Policies
◉ R&D

Cost Recovery Period
30 years

Technology Detail
Default

Default Technology Detail

Land-based Wind Speed Class 4



Conservative
Moderate
Advanced

NREL

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.

Offshore Wind

Parameter
Multiple values

Scenario
All

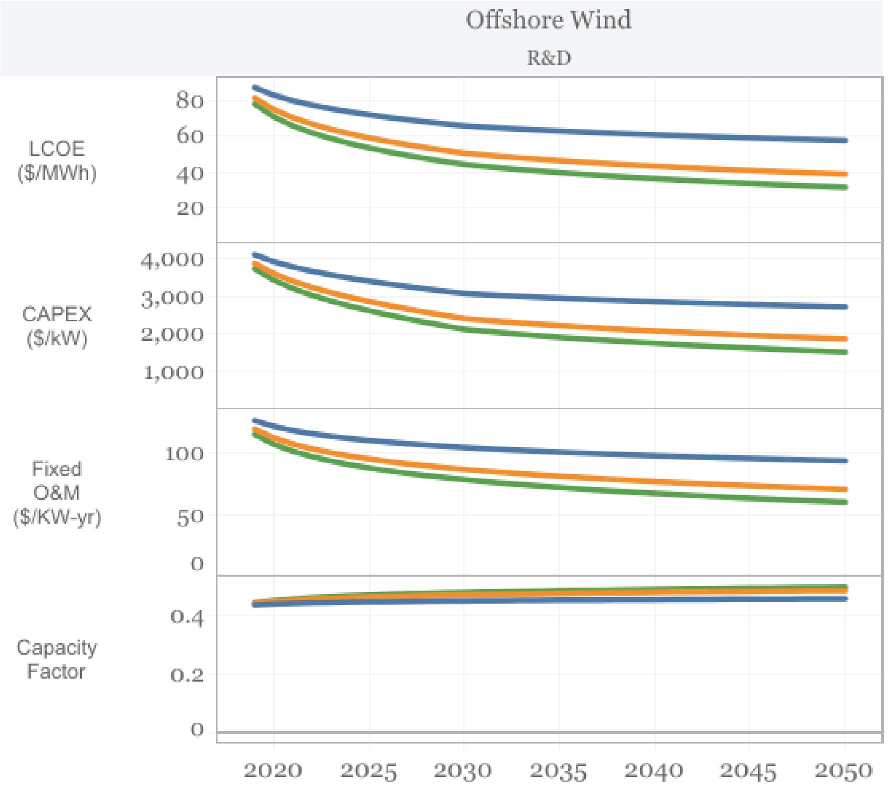
Financials
◯ Market + Policies
◉ R&D

Cost Recovery Period
30 years

Technology Detail
Default

Default Technology Detail

OffShore Wind Speed Class 3



NREL

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Solar PV

Parameter
Multiple values

Scenario
All

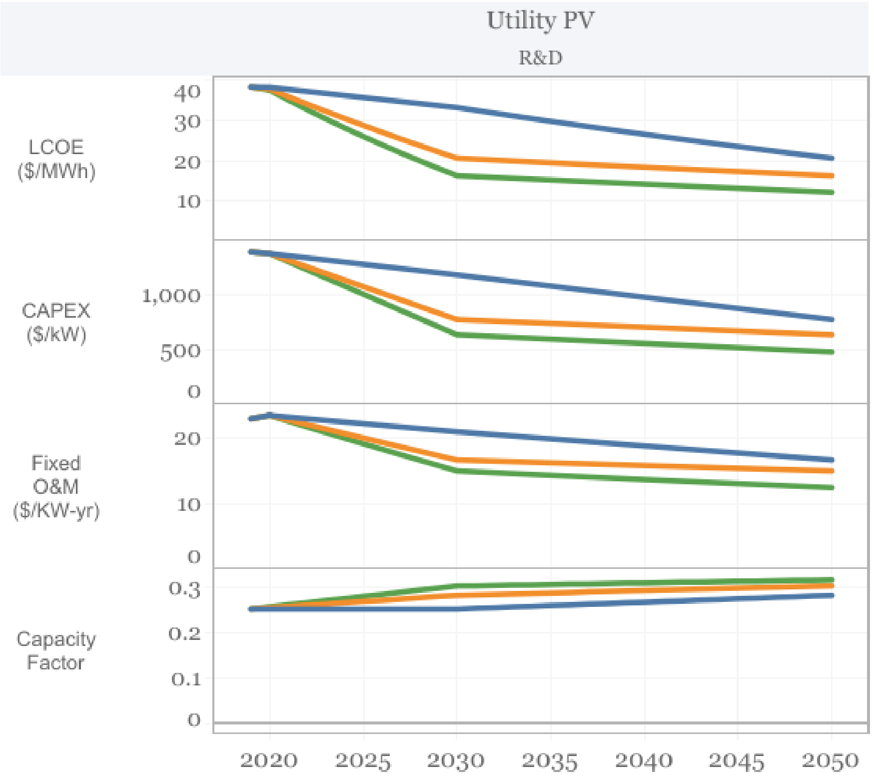
Financials
- ○ Market + Policies
- ◉ R&D

Cost Recovery Period
30 years

Technology Detail
Default

Default Technology Detail

Utility PV Class 5



- Conservative
- Moderate
- Advanced

NREL

https://atb.nrel.gov/

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

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Concentrating Solar Power

Parameter
Multiple values

Scenario
All

Financials
◯ Market + Policies
◉ R&D

Cost Recovery Period
30 years

Technology Detail
Default

Default Technology Detail

CSP Class 2

NREL

https://atb.nrel.gov/

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

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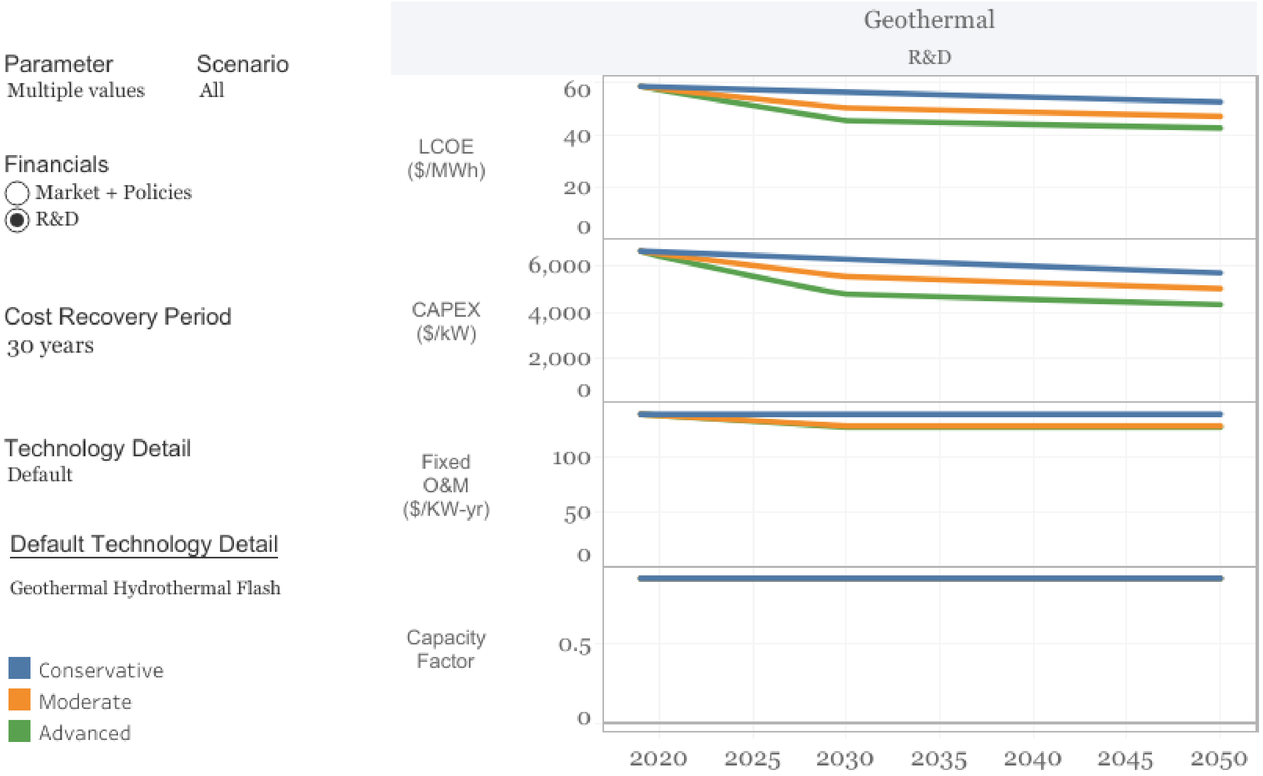
Geothermal



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

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https://atb.nrel.gov/

Hydropower

Parameter
Multiple values

Scenario
All

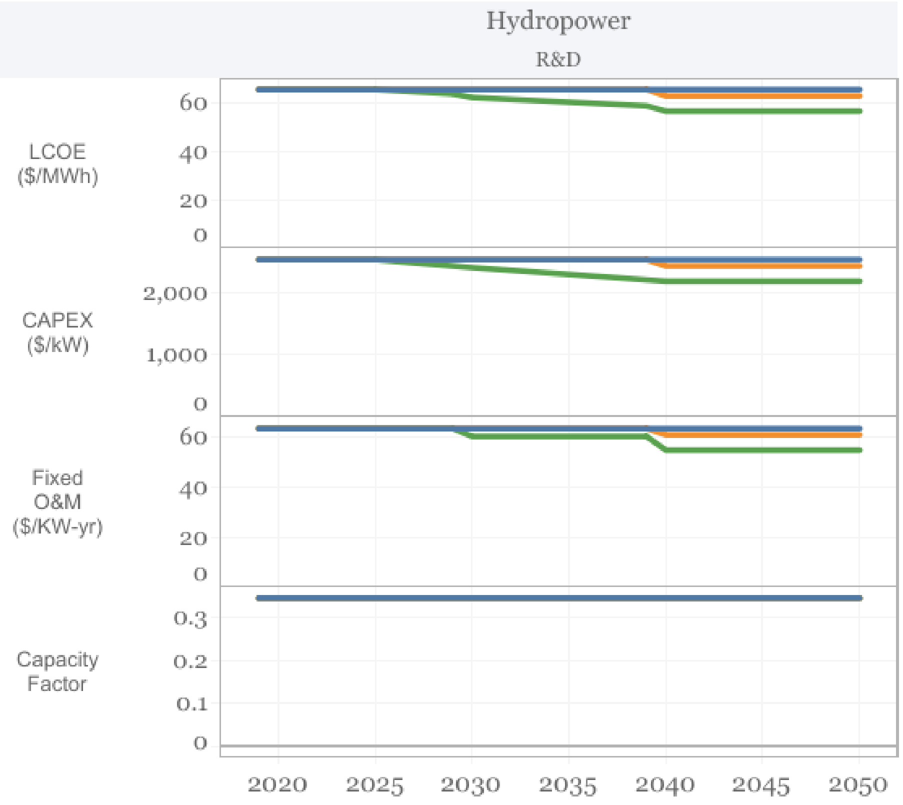
Financials
◯ Market + Policies
◉ R&D

Cost Recovery Period
30 years

Technology Detail
Default

Default Technology Detail

Hydropower NPD 1



Conservative
Moderate
Advanced

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

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NREL

https://atb.nrel.gov/

Battery Storage

Parameter
Multiple values

Scenario
All

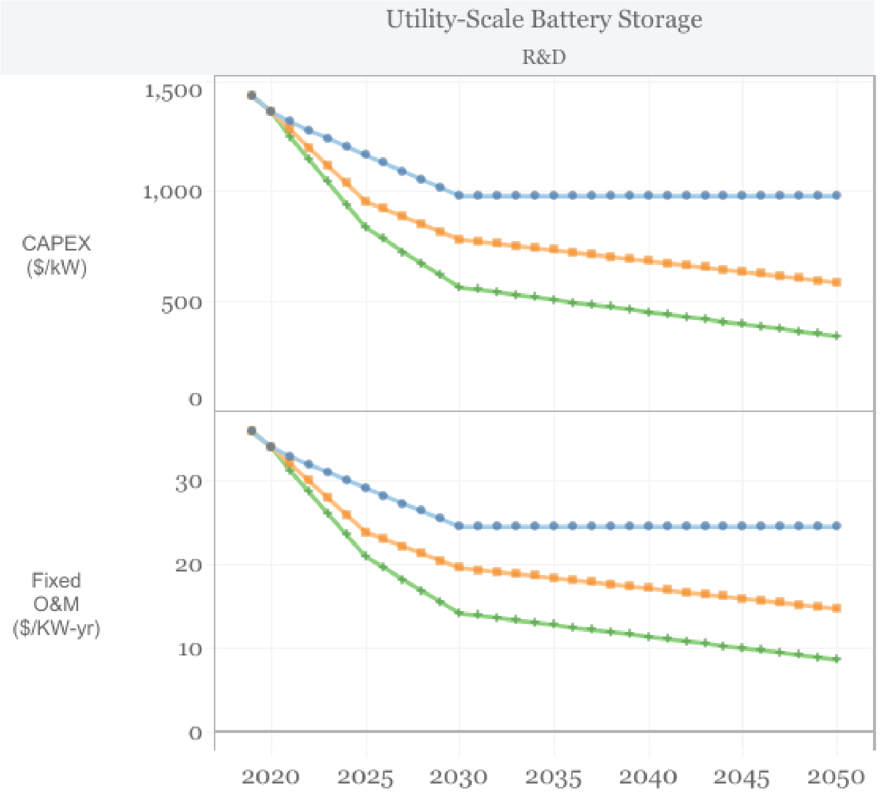
Financials
◯ Market + Policies
◉ R&D

Cost Recovery Period
30 years

Technology Detail
Default

Default Technology Detail

Utility-Scale Battery Storage 4Hr



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

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NREL

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

Utility-Scale PV-plus-battery

Parameter
Multiple values

Scenario
All

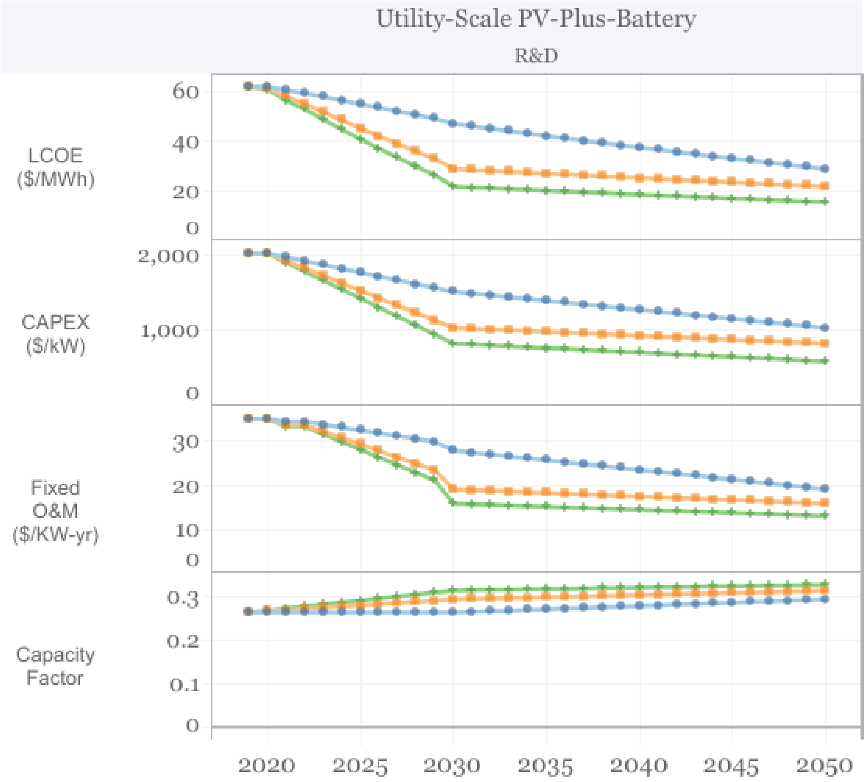
Financials
- ◯ Market + Policies
- ◉ R&D

Cost Recovery Period
30 years

Technology Detail
Default

Default Technology Detail

Utility-Scale PV+Battery Class 5



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

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NREL

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

Pumped-Storage Hydropower

To be added during 2021:

Capital costs and resource potential

Parameter
Multiple values

Scenario
All

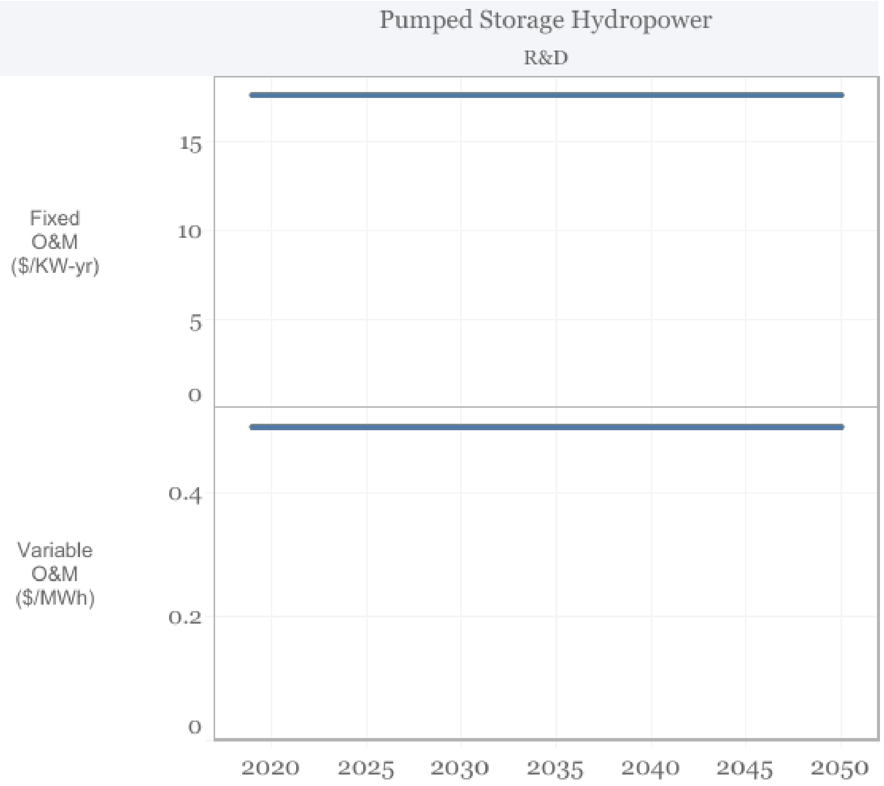
Financials
- ◯ Market + Policies
- ◉ R&D

Cost Recovery Period
30 years

Technology Detail
Default

Default Technology Detail

Pumped Storage Hydropower Class 3



Conservative
Moderate
Advanced

https://atb.nrel.gov/

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

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Fossil Energy Capital Cost Projections

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

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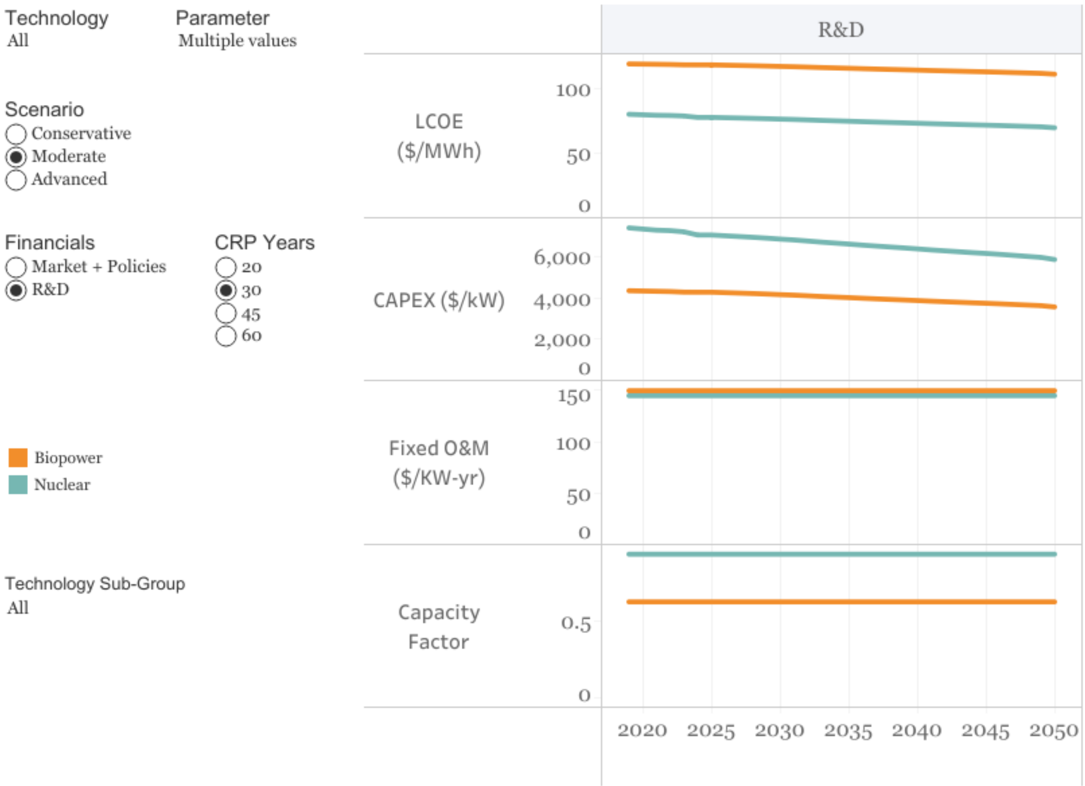
Biopower and Nuclear



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

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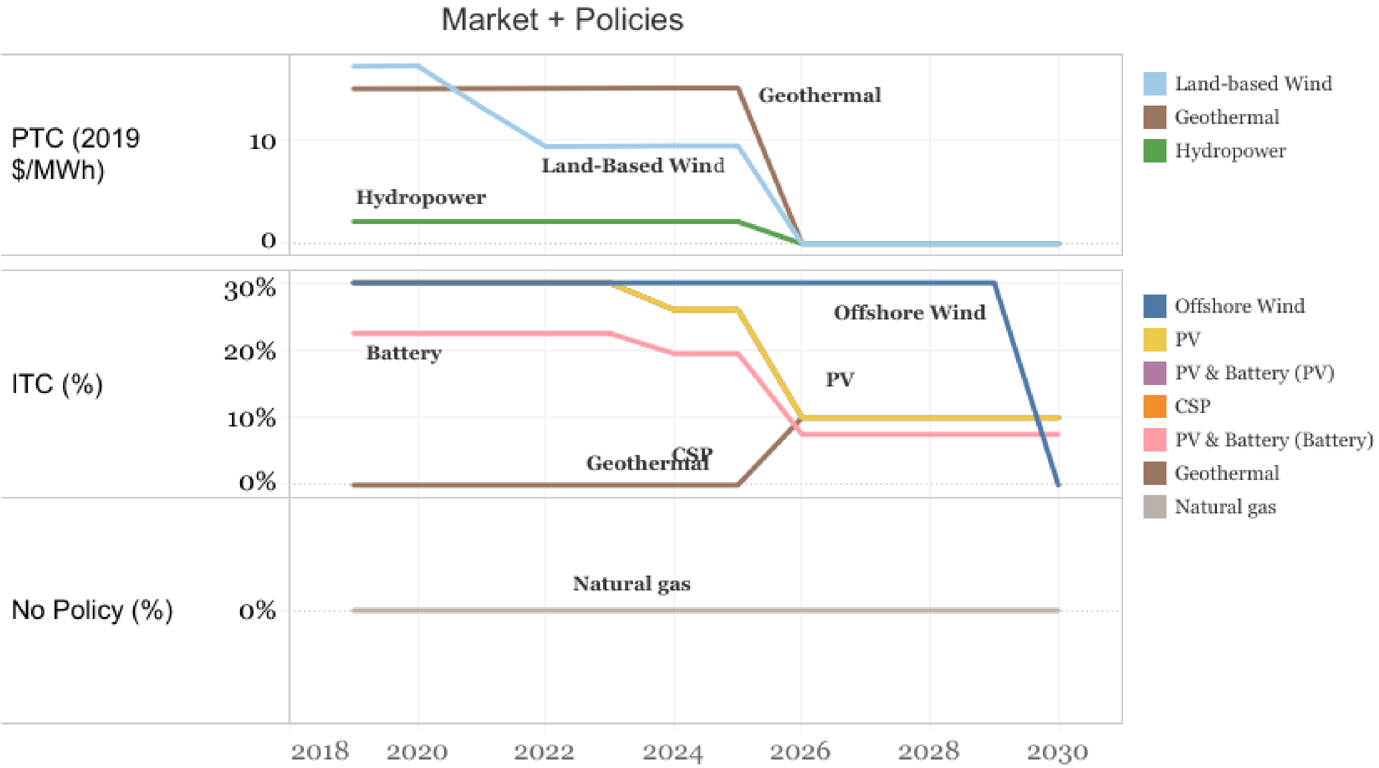
NREL

https://atb.nrel.gov/

Financial Cases and Methods

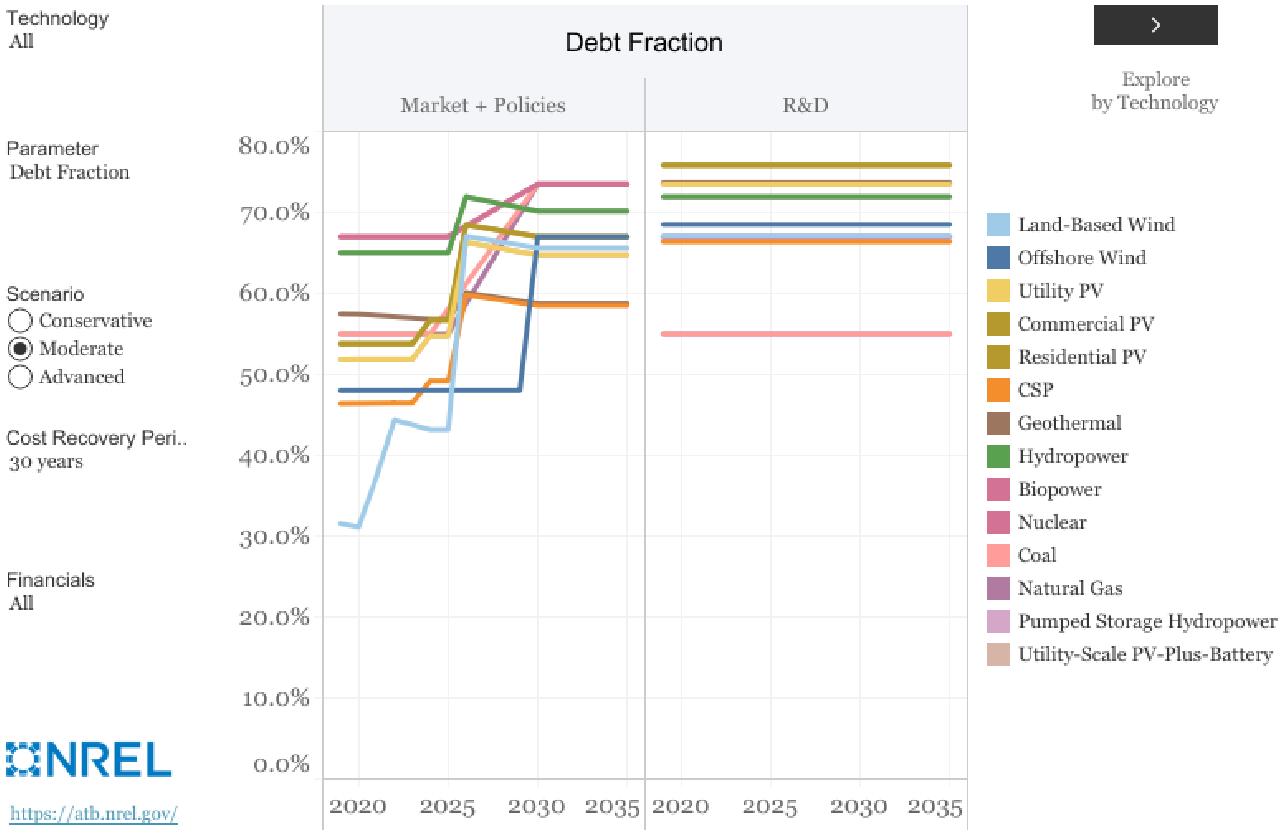
https://atb.nrel.gov/electricity/2021/financial_cases_&_methods

ITC/PTC by Year

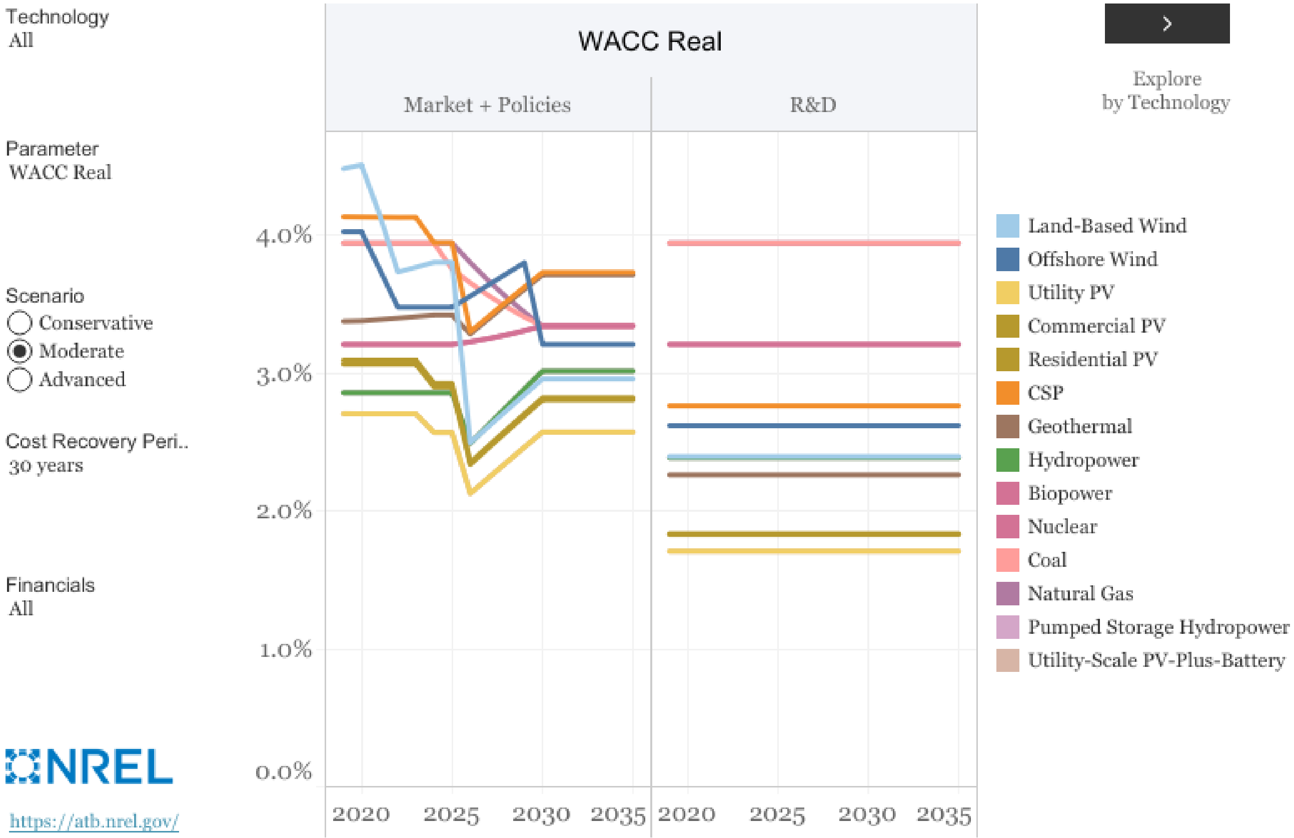


NREL https://atb2021.nrel.gov/

Term Debt Fraction by Financial Case



Term WACC (Real) by Financial Case



LCOE by Financial Case

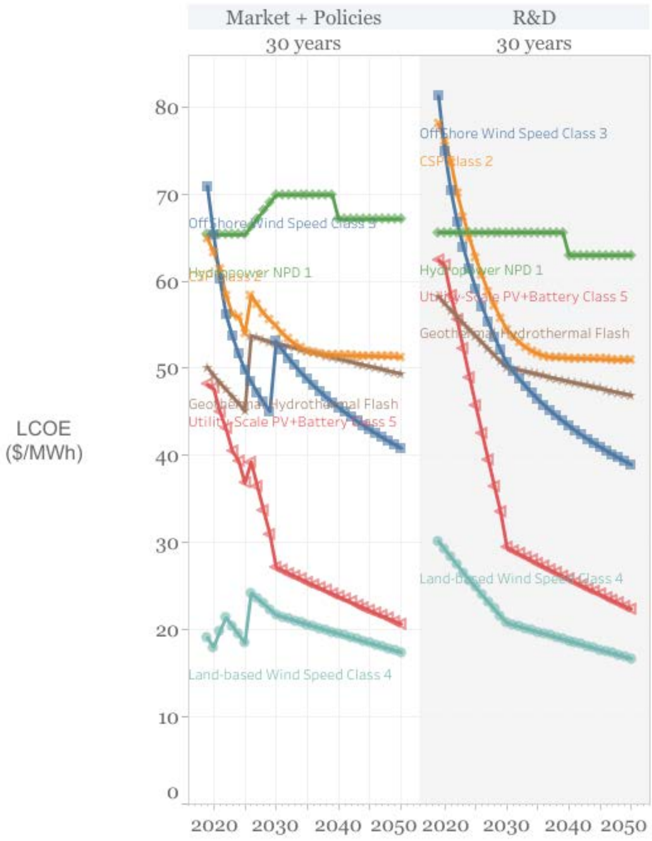
Technology
Multiple values

Parameter
LCOE

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

Financials
All

- ● Land-based Wind
- ■ OffShore Wind
- ✖ CSP
- ★ Geothermal
- ◆ Hydropower
- ◁ Utility-Scale PV-Plus-Battery



Cost Recovery Period
30 years

NREL

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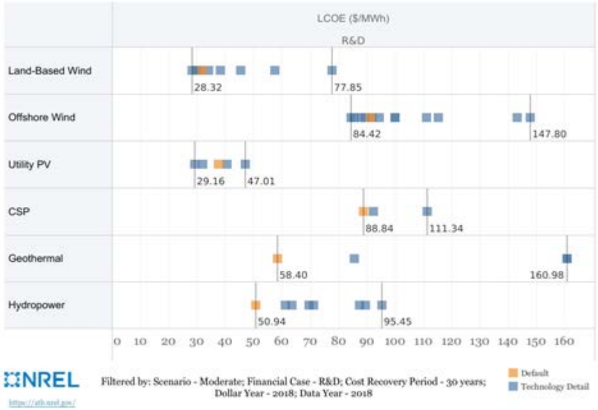
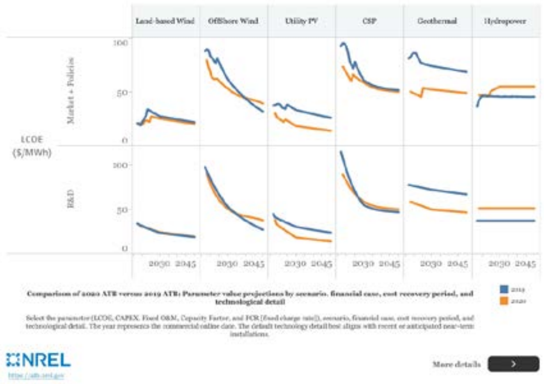
Conclusion

The Vision

The ATB, a **flagship analytic product**, facilitates access to **credible, consistent, transparent, timely, relevant, and public data** about current and future **energy technologies and systems** for a large and diverse audience.





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For a full list of ATB references, see https://atb.nrel.gov/electricity/2021/references.php.

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Acronyms and Abbreviations

AEO	Annual Energy Outlook
API	application programming interface
ATB	Annual Technology Baseline
AWS-S3	Amazon Web Services-Simple Storage Service
BAU	business as usual
CAPEX	capital expenditures
CT	combustion turbine
CCS	carbon capture and storage
CSP	concentrating solar power
CSV	comma-separated values
DOE	U.S. Department of Energy
DSCR	debt service coverage ratio
EERE	U.S. Department of Energy Office of Energy Efficiency and Renewable Energy
EGS	enhanced geothermal systems
EIA	U.S. Energy Information Administration
FE	DOE Office of Fossil Energy
GETEM	Geothermal Electricity Technology Evaluation Model
IGCC	integrated gasification combined cycle
IPP	independent power producer
LCOE	levelized cost of energy
NGCC	natural gas combined cycle
NPD	non-powered dam
NREL	National Renewable Energy Laboratory
NSD	new stream-reach development
ORNL	Oak Ridge National Laboratory
PPA	power purchase agreement
ReEDS	Regional Energy Deployment System Model
SAM	System Advisor Model
SCPC	supercritical pulverized coal
WACC	weighted average cost of capital