Annual Technology Baseline: The 2020 Electricity Update

Laura Vimmerstedt, Sertaç Akar, Philipp Beiter, Wesley Cole, David Feldman, Parthiv Kurup, Ashwin Ramdas, Greg Rhodes, Tyler Stehly, and Dana Stright (NREL)

Debo Oladosu (ORNL)

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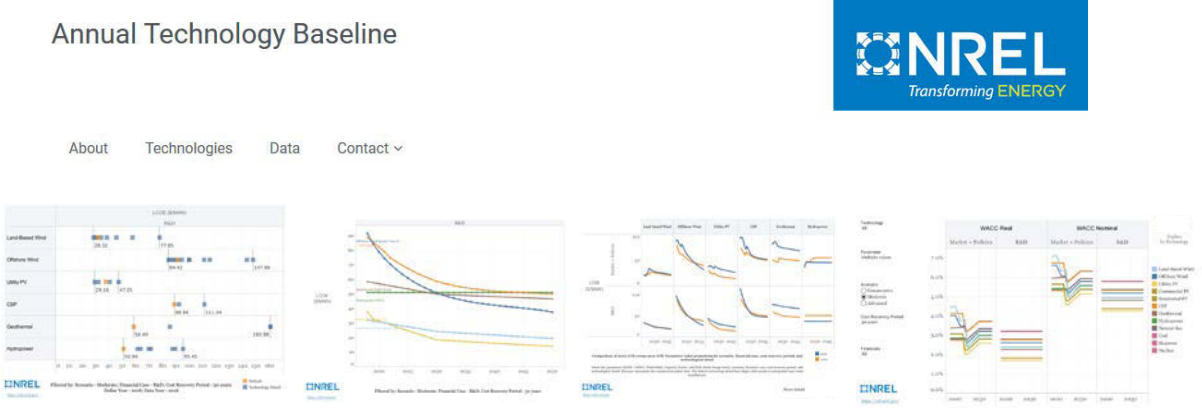
Agenda

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

Why the ATB?



- 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, transparent, and reflect potential technology advancement

EERE[a] Analysis Consistency

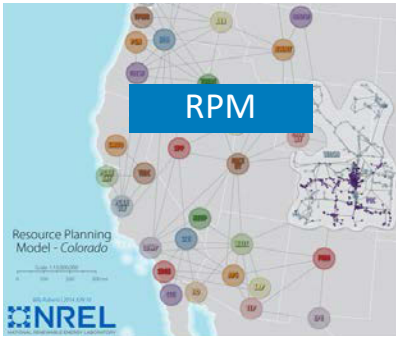
- Ensure consistent assumptions across technologies
- Provide comparability across EERE/national laboratory projects and publications

Third-Party Analysis

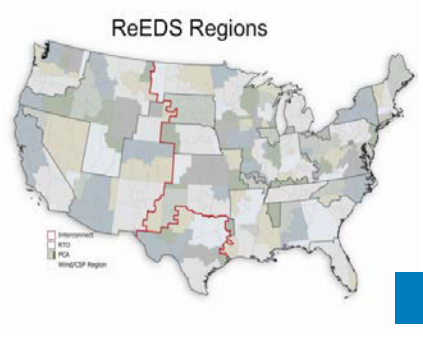
- Provide access to assumptions
- Leverage national laboratory expertise

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

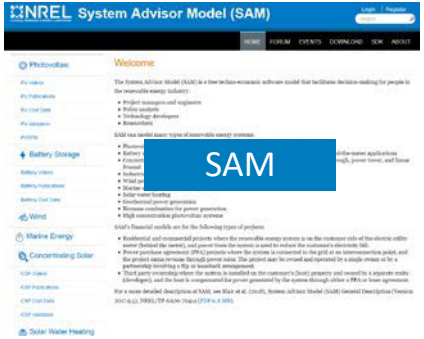
ATB anchors key DOE and national lab analyses.



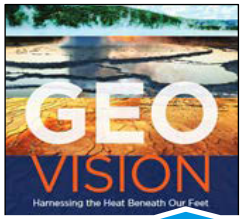
Resource Planning Model



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

Important Scenario Analyses Used ATB Projections

Now in its sixth 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.

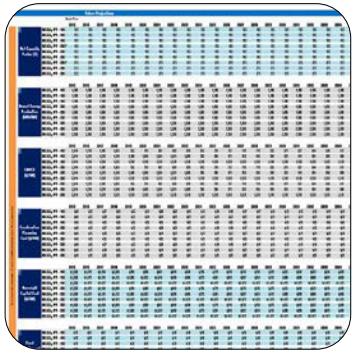
Annual Technology Baseline

Cost and performance assumptions for renewable and conventional technologies

Standard Scenarios

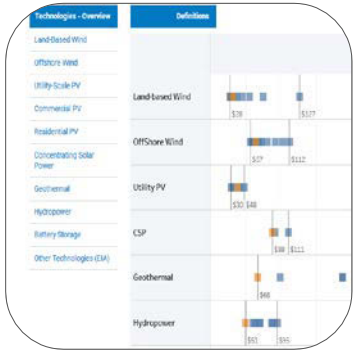
Ensemble of future scenarios of the U.S. electric power sector

The ATB includes a suite of products.



Spreadsheet

- Shows calculations
- Cost and performance projections, 2018–2050
- Capacity factor
- Operations 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

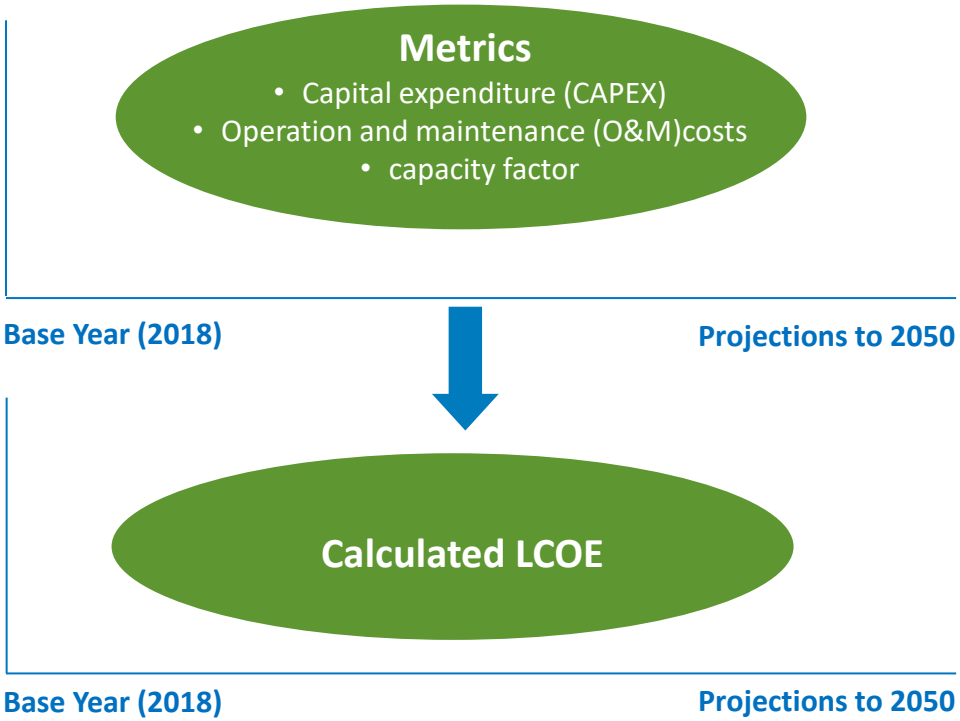
Formatted Data

- Summary of selected data (no calculations)
- Interactive charts
- Visual exploration
- Cost and performance projections, 2018–2050
  - Capacity factor
  - O&M costs
  - CAPEX
  - Financing assumptions
  - LCOE
- Structured format

PowerPoint

- Webinar presentation
- Tableau charts downloadable in PowerPoint form
- Summary presentation (coming soon)

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
- Concentrating solar power (CSP)

Hydropower
- Non-powered dams (NPD)
- New stream-reach development (NSD)

Geothermal (Flash and Binary)
- Hydrothermal
- Near-field enhanced geothermal systems (EGS)
- Deep EGS

Storage
- Utility-scale, four-hour battery storage

Conventional and Carbon Capture and Storage (EIA AEO 2020)

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

Conventional
- Integrated gasification combined-cycle (IGCC)
- 30% CCS

Nuclear
- Gen 3

Biopower
- Dedicated
- Cofired

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

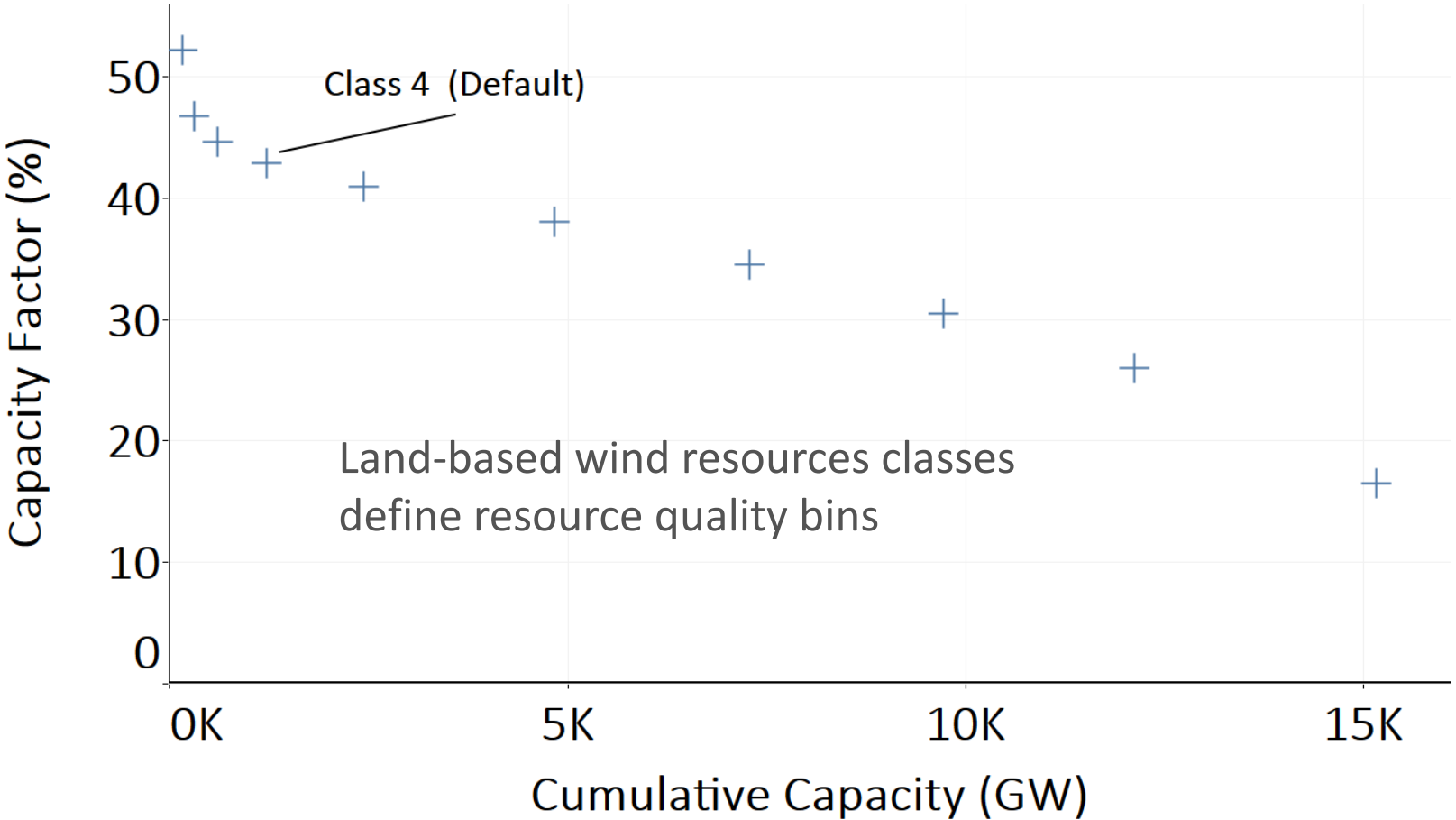
Use selected financial assumptions to calculate LCOE from CAPEX, capacity factor, and O&M

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, and residential PV	5	Horizontal solar irradiance resource level
CSP	3	Direct normal solar irradiance
Geothermal	6[a]	Hydrothermal, EGS, binary or flash systems, reservoir temperature
Hydropower	8[a]	Non-powered dams, new stream-reach development, head, and design capacity
Natural gas	6	Combustion turbine, IGCC, CCS, and choice of capacity factor
Coal	8	Pulverized coal, IGCC, CCS, and choice of capacity factor
Nuclear	1	Not applicable
Biopower	2	Dedicated or cofired

[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 (2018): 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 (2018)

Technology	Source
Land-based wind power plants	*2018 Cost of Wind Energy Review* (Stehly et al. 2019) used to estimated CAPEX based on central U.S. installations with wind speed for median of recently installed wind facilities; also used for O&M. Capacity factors align with performance in wind Classes 2–7, where most installations are located.
Offshore wind power plants	Bottom-up modeling (Beiter et al. 2016), methodology and data updated to the latest cost and technology trends observed in the U.S. and European offshore wind markets (Beiter et al. 2019; Musial et al. 2019)
Utility, residential, and commercial PV plants	CAPEX and O&M for 2018 and 2019 based on new bottom-up cost modeling and market data from Feldman et al. (Forthcoming). Capacity factors based on output from the System Advisor Model (SAM) using project-level assumptions from Feldman et al. (Forthcoming).
Concentrating solar power plants	Bottom-up cost modeling from Turchi et al. (2019) and an NREL survey of projects under construction for operation in 2018.
Geothermal plants	Bottom-up cost modeling using GETEM and inputs from the GeoVision BAU scenario (DOE 2019)
Hydropower plants	Hydropower Vision (DOE 2016), bottom-up cost modeling from Hydropower Baseline Cost Modeling (O'Connor et al. 2015)
Fossil, nuclear, and biopower plants	Annual Energy Outlook (EIA 2020) reported costs

Major Innovations Driving Projections (to 2050)

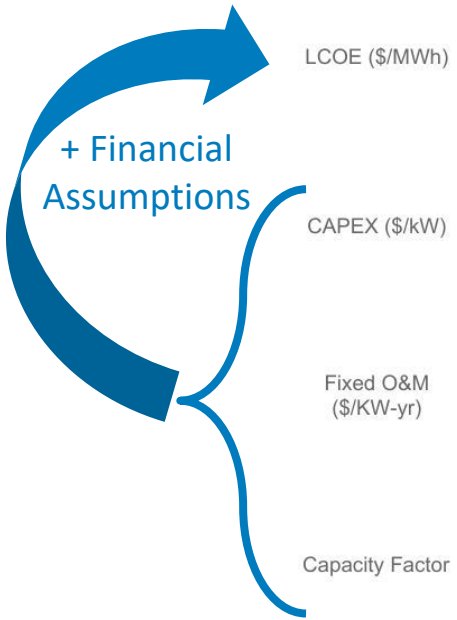
Land-based Wind	Offshore Wind	Solar Photovoltaics	Concentrating Solar Power	Geothermal	Hydropower
Rotor, Nacelle Assembly	Turbine Size	Module Efficiency	Power Block	Drilling Advancements	Learning by Doing
Tower	Supply Chain	Inverter Power Electronics	Receiver	EGS Development	Modularity
Science-Based	Size-Agnostic	Installation Efficiencies	Thermal Storage		New Materials
		Energy Yield Gain	Solar Field		Automation/ Digitalization
					Eco-Friendly Turbines

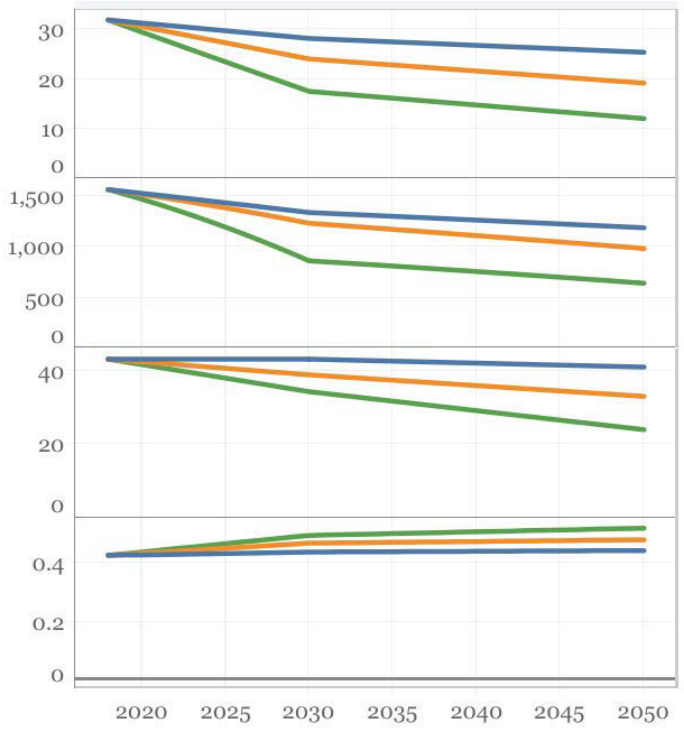
Step 3: Calculate Levelized Cost of Energy (LCOE)

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

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.





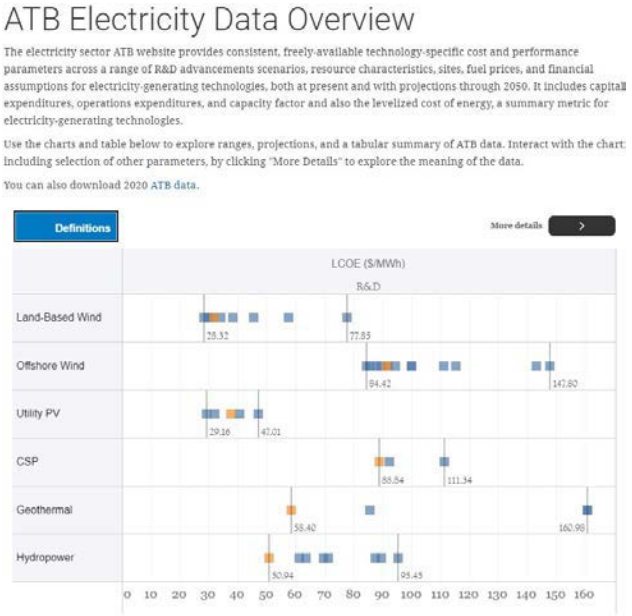
Cost and Performance Overview

All-Technology Changes in 2020 ATB

- Modified values in the two financial cases (R&D and Market + Policies) to reflect current assessments
- New products
  - Interactive charts are downloadable to PowerPoint
  - Tableau workbooks are downloadable individually from linked charts or the entire set as a zip file
  - Formatted data downloadable as CSV files
  - Summary PowerPoint (coming soon)
- Base year = 2018; Dollar year = 2018; Historical data includes data reported in 2018.

Web Demonstration

- ATB Project Overview
- Cost and Performance Overview
  - →Web demo (https://atb.nrel.gov/)
- Technology-Specific Highlights
- Financial Cases and Methods
- Questions and Comments



Web Demonstration

- ATB Electricity Data Overview
  - 2018 Base Year
  - 2018–2050 Trajectories
  - Filter by Technology, Parameter, Scenario, Cost Recovery Period, Year, (Tech Detail)
  - Downloads: PowerPoint, images, or Tableau workbook associated with each chart
- Example: Land-Based Wind
  - Technology-Specific Interactive Chart
  - Scenario Descriptions
  - Representative Technology
- 2020 vs. 2019 Changes
- Financial Cases and Methods
- Annual Technology Baseline Data Download
- About

Technology-Specific Highlights

https://atb.nrel.gov/electricity/2020/changes.php

Updates by Technology

- **Land-Based Wind:** projections based on bottom-up technology analysis and cost modeling plus learning rates, with innovations that increase wind turbine size, improve controls, and enhance operational performance through science-based modeling
- **Offshore Wind:** projections based on bottom-up techno-economic models and assessment of turbine and plant upsizing innovations, supply chain efficiencies and learning, and technology innovations identified through expert reviews
- **Utility-Scale Photovoltaics:** projections 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
- **Concentrating Solar Power:** component and system cost estimates for Base Year now reference a 2017 industry survey and a 2018 cost analysis of recent market developments.
- **Geothermal:** new data are now consistent with the GeoVision Study.
- **Lithium-Ion Battery Storage:** updated projections are based on a new literature review.

Land-Based Wind

Technology
Land-based Wind

Parameter
Multiple values

Scenario
- ○ Conservative
- ◉ Moderate
- ○ Advanced

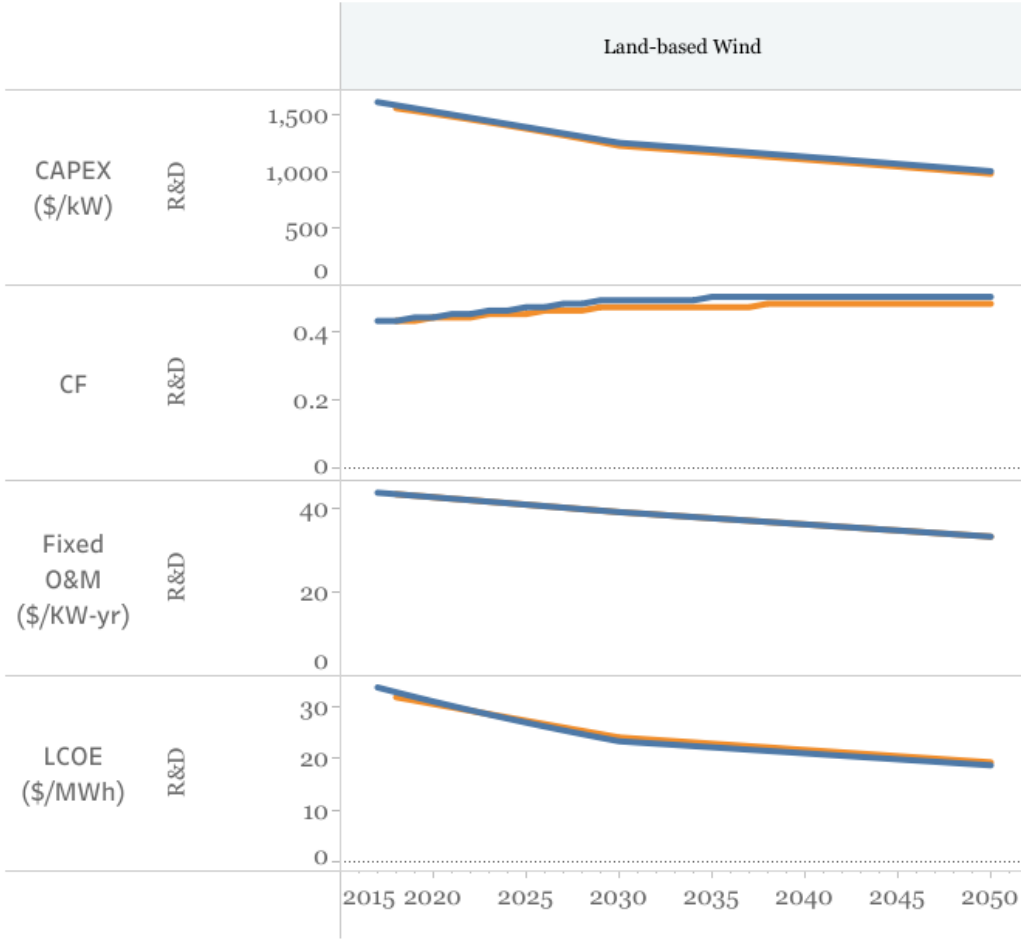
Atb Year
All

2019
2020

Technology Detail
Default

CRP Years
- ○ 20
- ◉ 30

Financials
- ○ Market + Policies
- ◉ R&D



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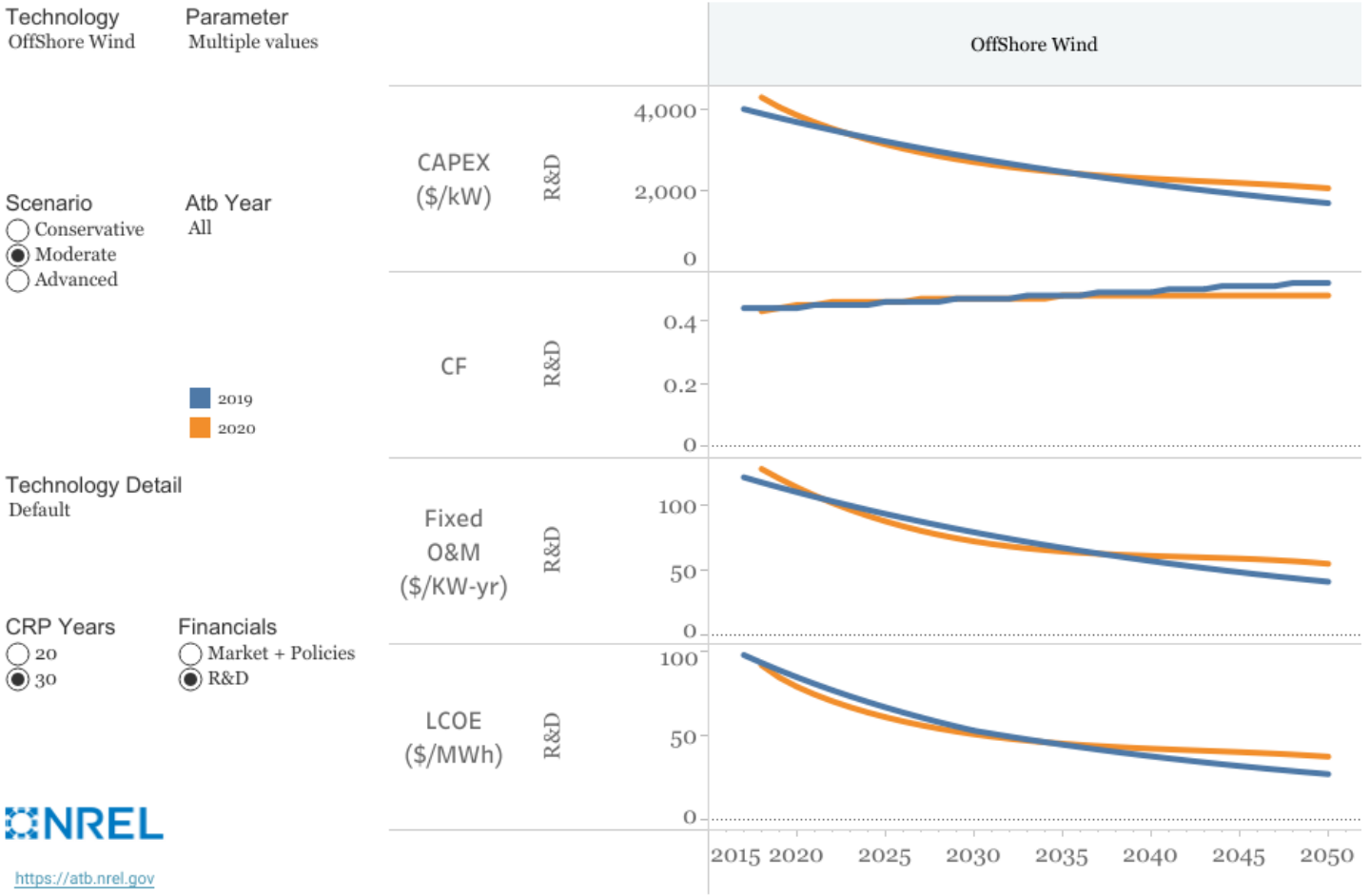
Offshore Wind



Utility-Scale Solar PV

Technology
Utility PV

Parameter
Multiple values

Scenario
- ○ Conservative
- ◉ Moderate
- ○ Advanced

Atb Year
All

2019
2020

Technology Detail
Default

CRP Years
- ○ 20
- ◉ 30

Financials
- ○ Market + Policies
- ◉ R&D

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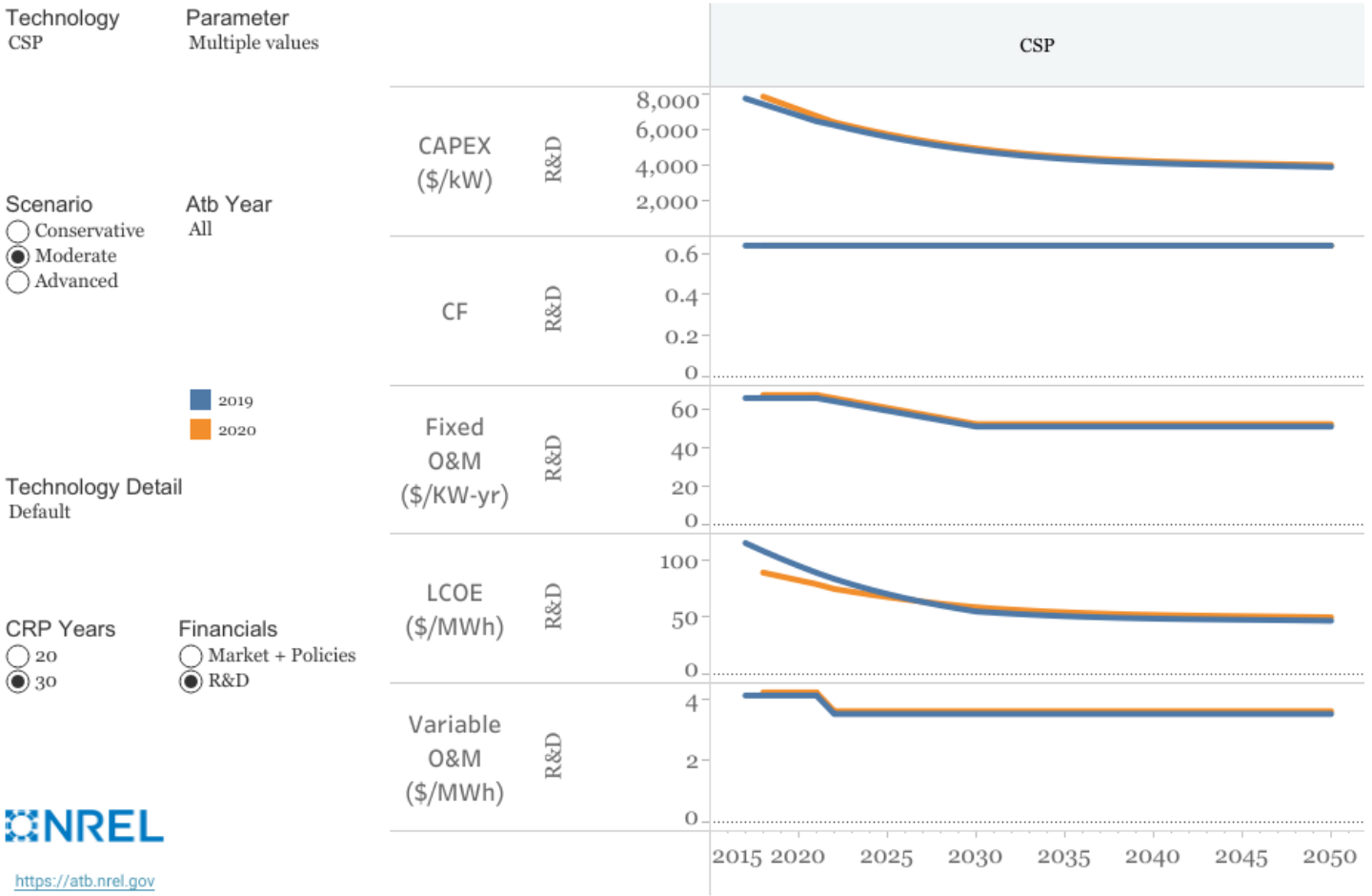
NOTE: 2019 values are in direct current units; 2020 values are in alternating current units.

Concentrating Solar Power



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Geothermal

Technology
Geothermal

Parameter
Multiple values

Scenario
- ○ Conservative
- ◉ Moderate
- ○ Advanced

Atb Year
All

2019
2020

Technology Detail
Default

CRP Years
- ○ 20
- ◉ 30

Financials
- ○ Market + Policies
- ◉ R&D

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Hydropower

Technology
Hydropower

Parameter
Multiple values

Scenario
- ○ Conservative
- ◉ Moderate
- ○ Advanced

Atb Year
All

- 2019
- 2020

Technology Detail
Default

CRP Years
- ○ 20
- ◉ 30
- ○ 100

Financials
- ○ Market + Policies
- ◉ R&D

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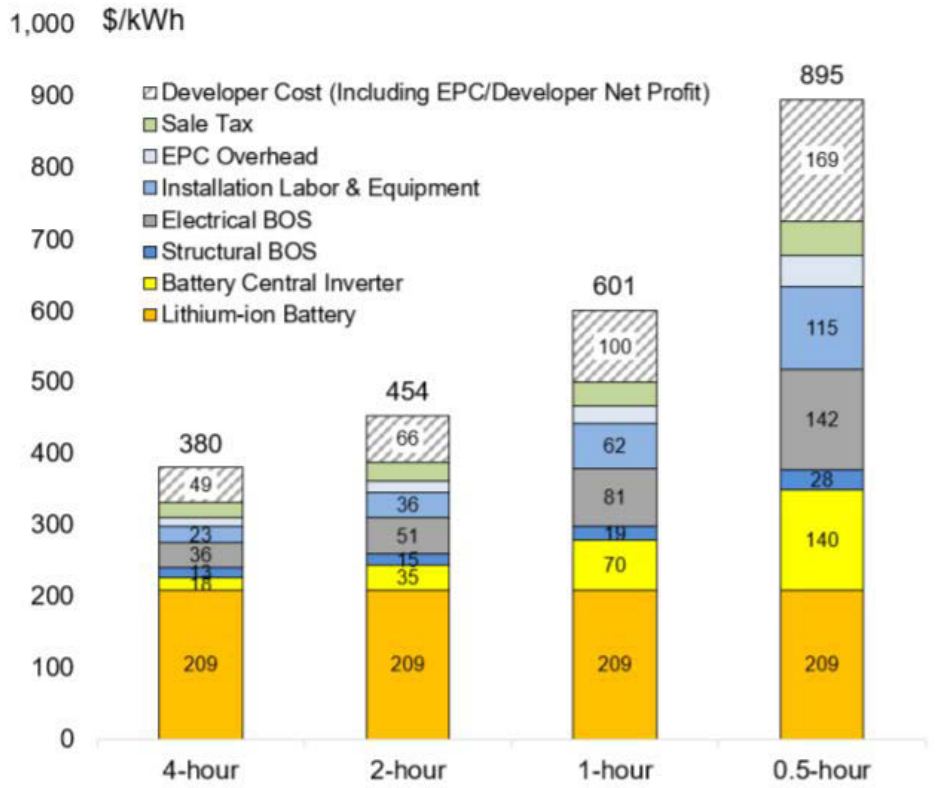
Battery Storage

A simple representation of the CAPEX scenarios used in ReEDS modeling for lithium-ion battery storage is included.



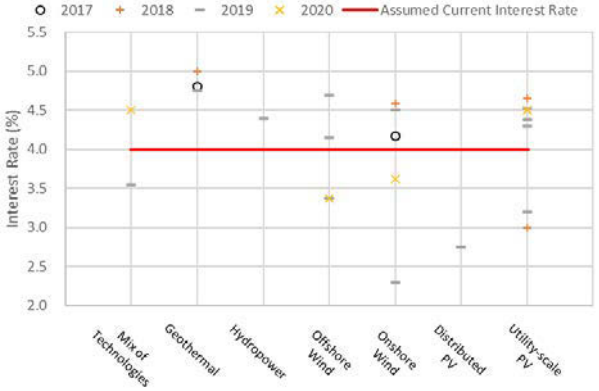
Financial Cases and Methods

https://atb.nrel.gov/electricity/2020/finance-impact.php

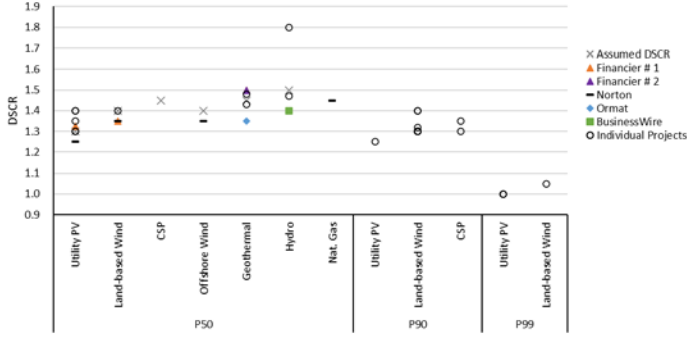
Define Financial Scenario, Collect Data, Run Models

- 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.
  - Full description of methods, analysis, and data are summarized in report: *Current and Future Costs of Renewable Energy Project Finance Across Technologies* (Feldman, Schwabe, and Bolinger 2020)
- Developed values for two financial cases (R&D and Market + Policies) to reflect current assessments. The "R&D" financial case assumes there are no tax credits and no change in interest rate.
- Financing costs for each technology were developed for 1) construction period and 2) operating period, to account for different levels of risk.

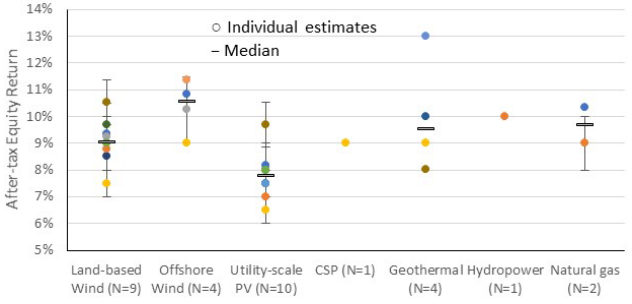
All-in term debt interest rates for loans initiated over time, by technology



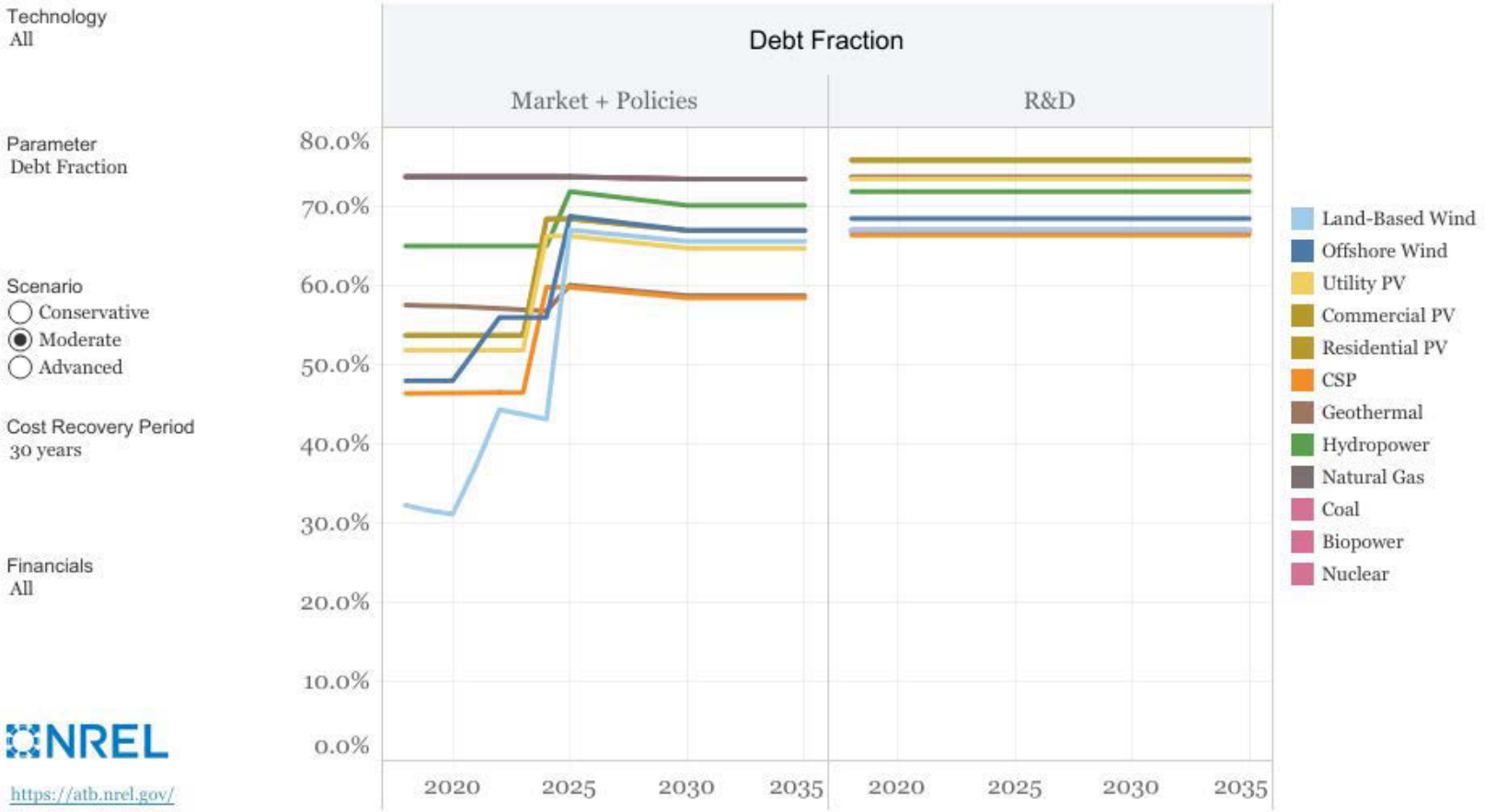
DSCR data at different probability of exceedance levels, by technology



After-tax levered cost of equity, by technology



Term Debt Fraction by Financial Case



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Term WACC (Real) by Financial Case

Technology
All

Parameter
WACC Real

Scenario
- ○ Conservative
- ◉ Moderate
- ○ Advanced

Cost Recovery Period
30 years

Financials
All

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LCOE by Financial Case

Technology
Multiple values

Parameter
LCOE

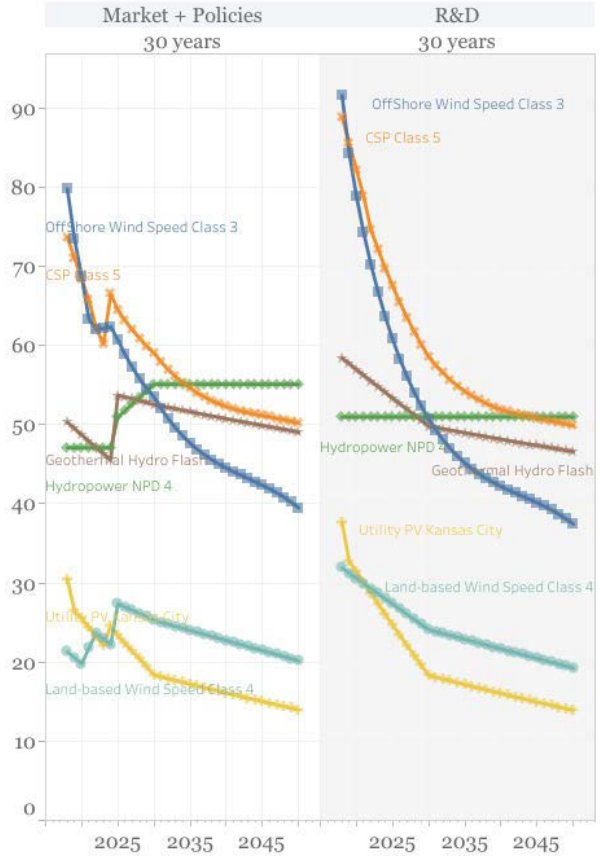
Scenario
- ○ Conservative
- ◉ Moderate
- ○ Advanced

Financials
All

Technology
- ● Land-based Wind
- ■ OffShore Wind
- ✚ Utility PV
- ✖ CSP
- ★ Geothermal
- ◆ Hydropower

Cost Recovery Period
30 years

LCOE ($/MWh)



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https://atb.nrel.gov/

Conclusion

The Vision

The ATB,

a flagship analytic product,

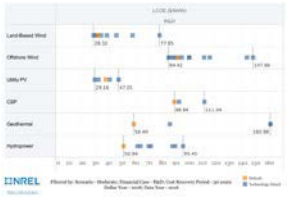
facilitates access

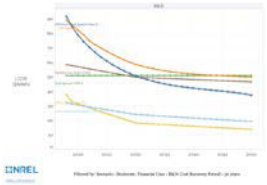
to credible, consistent, transparent, timely, relevant, and public data about

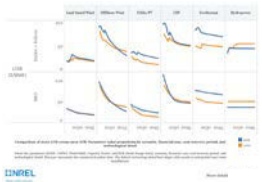
current and future energy technologies and systems

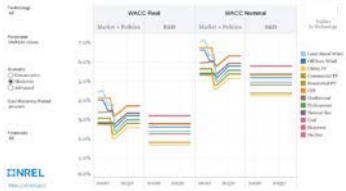
from a lab/DOE perspective

for a large and diverse audience.









Sign up for updates!

To receive occasional email updates and announcements about the Annual Technology Baseline, sign up at https://atb.nrel.gov/contact/register/

Thank you!

atb.nrel.gov

NREL/PR-6A20-76814

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References

For a full list of ATB references, see https://atb.nrel.gov/electricity/2020/references.php.

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Acronyms and Abbreviations

AEO	Annual Energy Outlook
ATB	Annual Technology Baseline
BAU	business as usual
CAPEX	capital expenditures
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
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
WACC	weighted average cost of capital