NREL
NATIONAL RENEWABLE ENERGY LABORATORY





2018 Annual Technology Baseline (ATB)

Laura Vimmerstedt, Chad Augustine, Philipp Beiter, Wesley Cole, David Feldman, Parthiv Kurup, Eric Lantz, Robert Margolis, Ashwin Ramdas, Tyler Stehly, and Craig Turchi (NREL),

Patrick O'Connor (ORNL)

Webinar – July 26, 2018

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Outline

- Project Overview
- Cost and Performance Summary
- Preview of 2018 Standard Scenarios

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

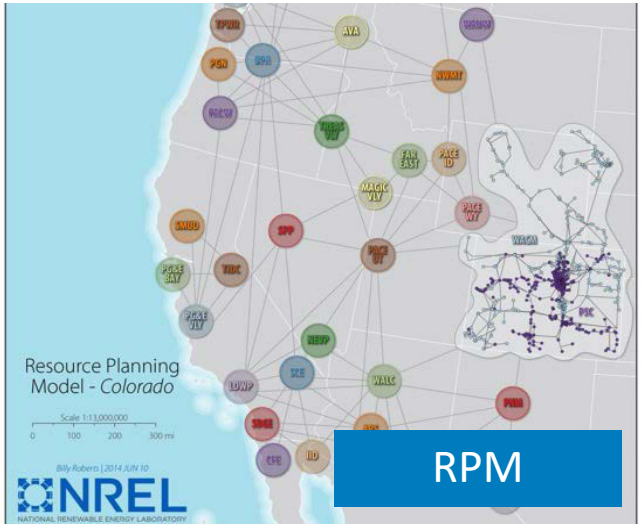
- Ensure consistent assumptions across technologies
- Provide comparability across EERE/national laboratory publications

Third Party Analysis

- Provides access to assumptions
- Leverages national laboratory expertise

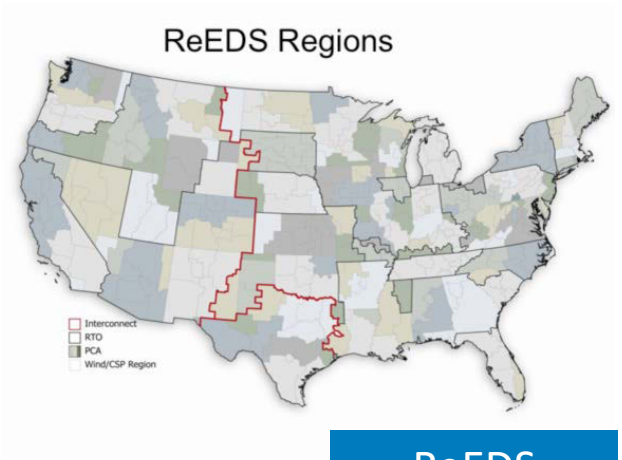
[a] U.S. Department of Energy Office of Energy Efficiency and Renewable Energy (EERE)

Now in its fourth year, the ATB is frequently used at NREL …



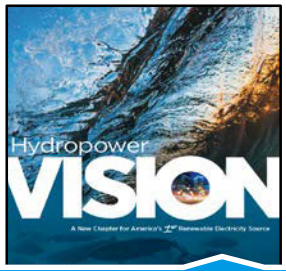
RPM

Resource Planning Model

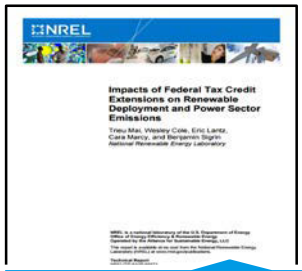


ReEDS

Regional Energy Deployment System



Hydropower Vision



Impacts of Tax Credit Extensions

Prospective RPS Cost, Benefits, and Impacts

2017 Standard Scenarios

Impact of Storage on Electric System Planning

Important Scenario Analyses Used ATB Projections

… and by planners, academics, analysts, and others.

Federal Agencies
(Bureau of Land Management, Department of Energy and Labs, 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)

Advocacy Groups
(Resources for the Future, Environmental Defense Fund, Union of Concerned Scientists)

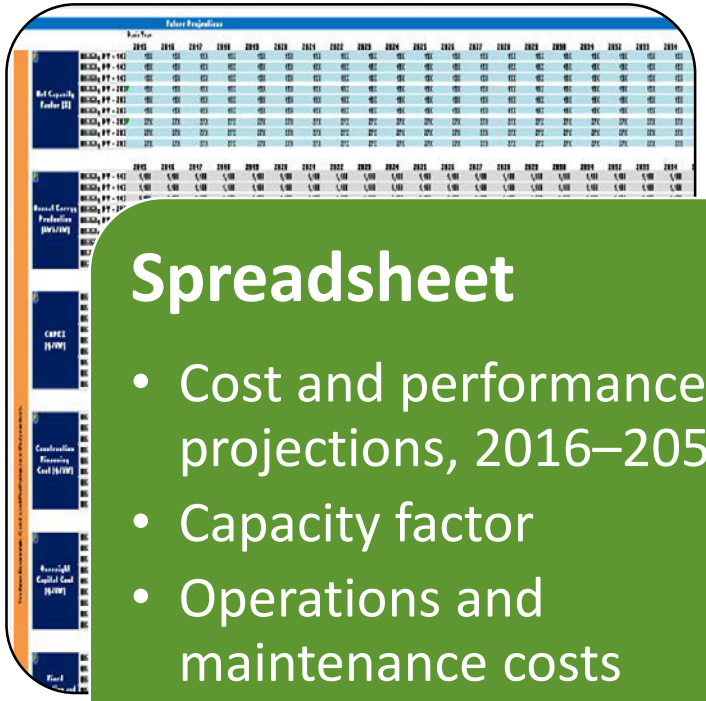
Academia
(Stanford University, University of Maryland, University of Texas, Duke University)

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 includes two products.



Spreadsheet

- Cost and performance projections, 2016–2050
- Capacity factor
- Operations and maintenance costs
- Capital expenditures (CAPEX)
- Financing assumptions
- Levelized cost of energy (LCOE)

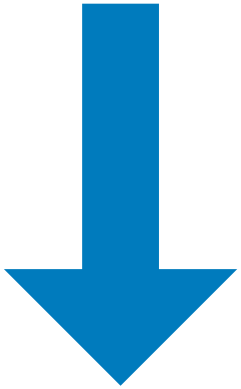
Web App (atb.nrel.gov)

- User guidance
- Additional analyses
- Methodologies
- Charts and figures
- Historical trends and comparison to other projections (e.g., EIA)

The ATB data are inputs for Standard Scenarios.

Annual Technology Baseline

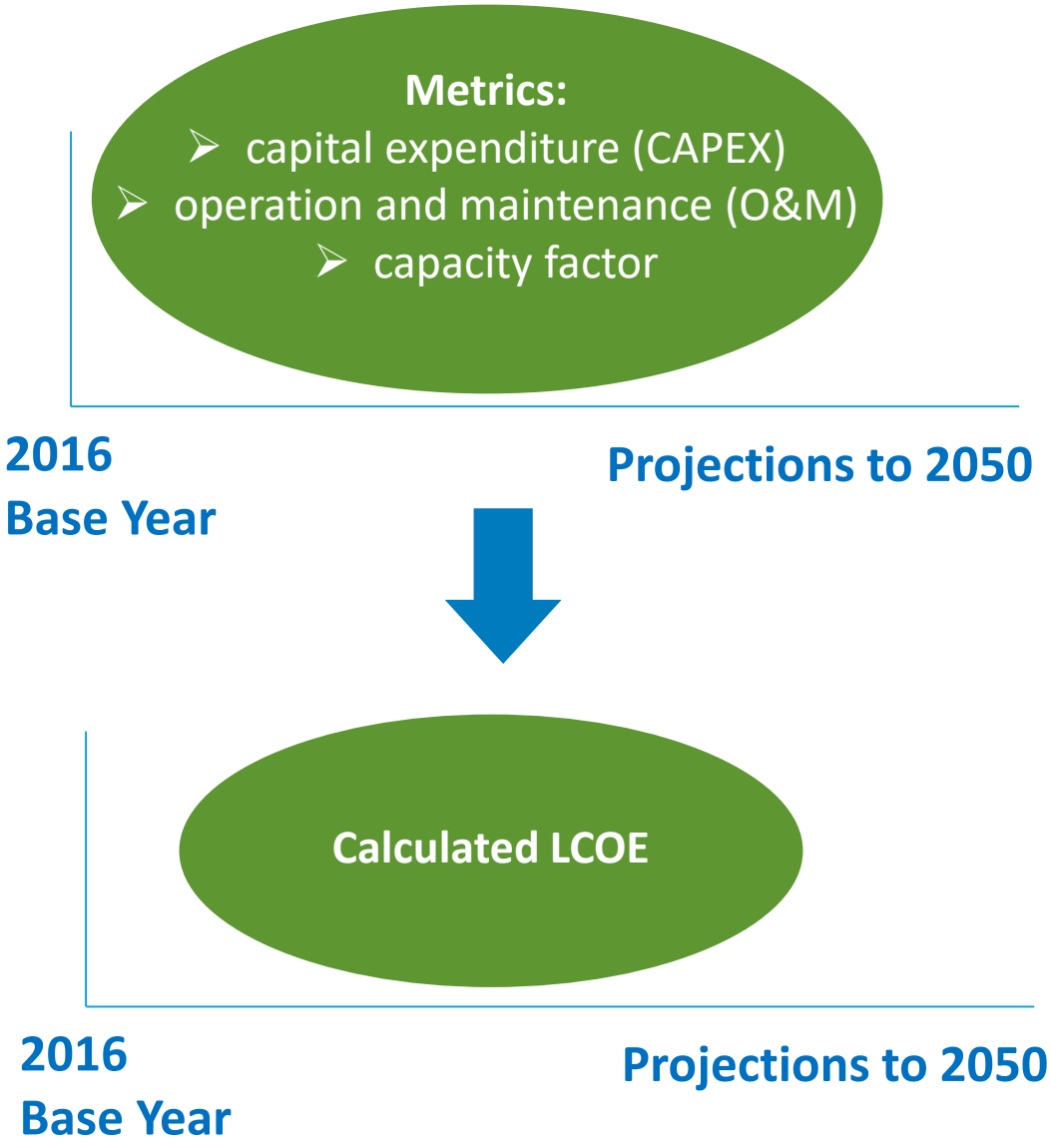
Cost and performance assumptions for renewable and conventional technologies



Standard Scenarios

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

The ATB provides cost and performance data.



Cost and performance data are provided for each

- Year
- Metric
- Resource
- Technology
- Technology cost scenario
- Financial case

… and are used to calculate LCOE for each financial assumptions scenario.

Technologies Covered

Renewable Energy Technologies
(Sourced from EERE/NREL)

Wind

- Land-Based
- Off-Shore

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

Conventional and Carbon Capture and Storage
(Sourced from EIA AEO 2018)

Natural Gas

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

Coal

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

Nuclear

- Gen 3

Biopower

- Dedicated
- Co-fired

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 are developed for CAPEX, capacity factor, and operation and maintenance (O&M)

3. Calculate LCOE

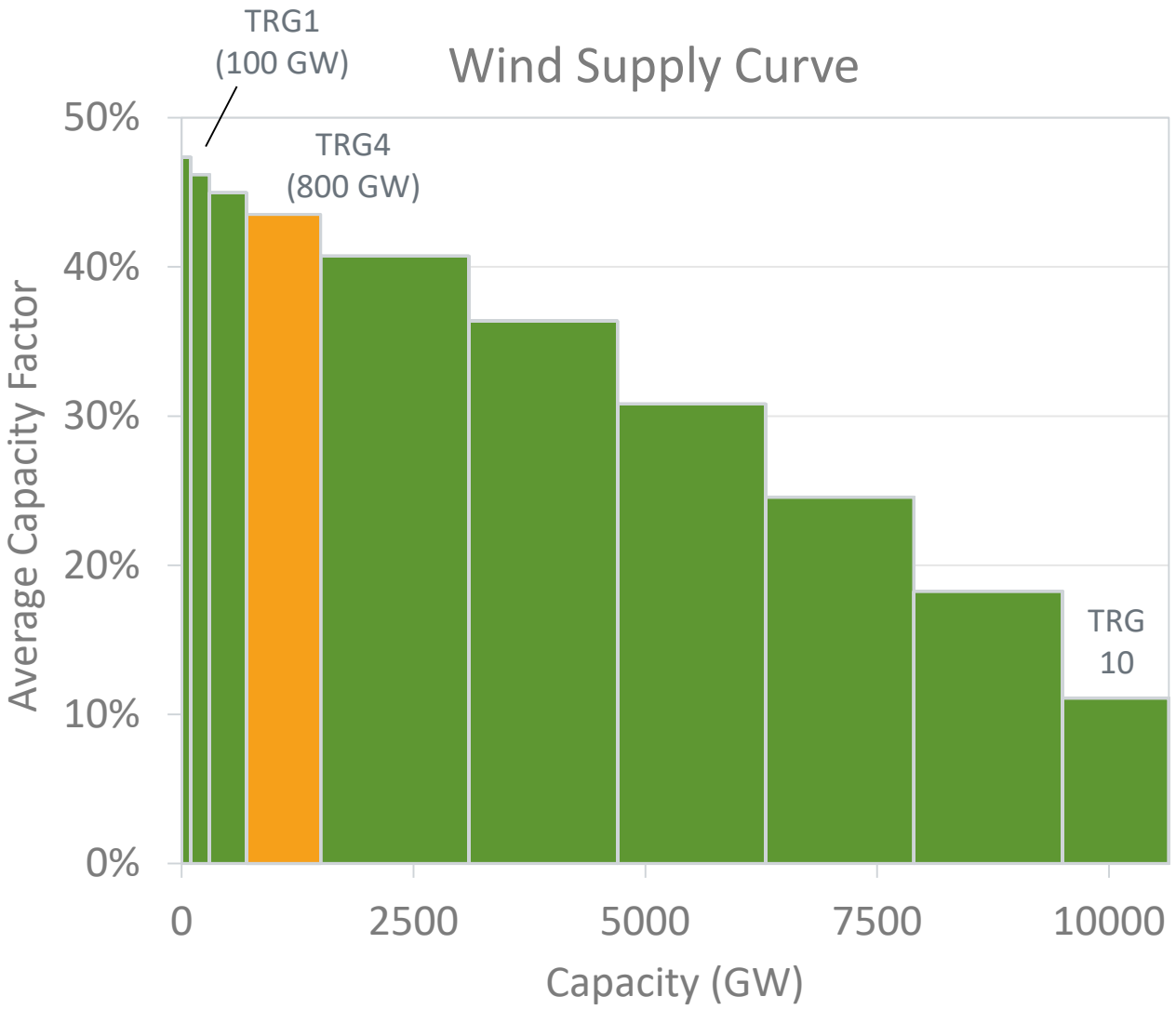
Use predetermined financial assumptions to calculate LCOE from CAPEX, capacity factor, and O&M

Step 1: Define Technologies/Resource Bin Categories

Technology	Bins	Distinguishing Characteristics
Land-based wind	10	Annual average wind speed
Offshore wind	15	Fixed and floating foundations, distance from shore, water depth, and annual average wind speed
Utility-scale, commercial, and residential PV	5 resource levels	Horizontal solar irradiance
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 percentage, and choice of capacity factor
Nuclear	1	Not applicable
Biopower	2	Dedicated or co-fired

[a] Representative bins for the ATB only. ReEDS implements a full site-specific supply curve.

Example of Technology/Resource Bins: Land-Based Wind



Resources binned by cost and quality into 10 techno-resource groups (TRGs)

TRG4 identified as most representative of future installations

Step 2: Base Year and Projections Synthesize Extensive Data

Base Year (2016): Informed by market reports and market data

Projections: Generally rely on published studies; qualitatively harmonized to three projection scenarios:

Constant Technology Cost	Mid Technology Cost	Low Technology Cost
• Current technology costs held constant • Represents limited/no technology improvement • No additional R&D	• Improvements characterized as "likely" or "not surprising" • Continued public and private R&D • Continued deployment and market growth	• Improvements at the "limit of surprise" • Not an absolute low bound • Increased public and private R&D, breakthroughs • Accelerated market growth

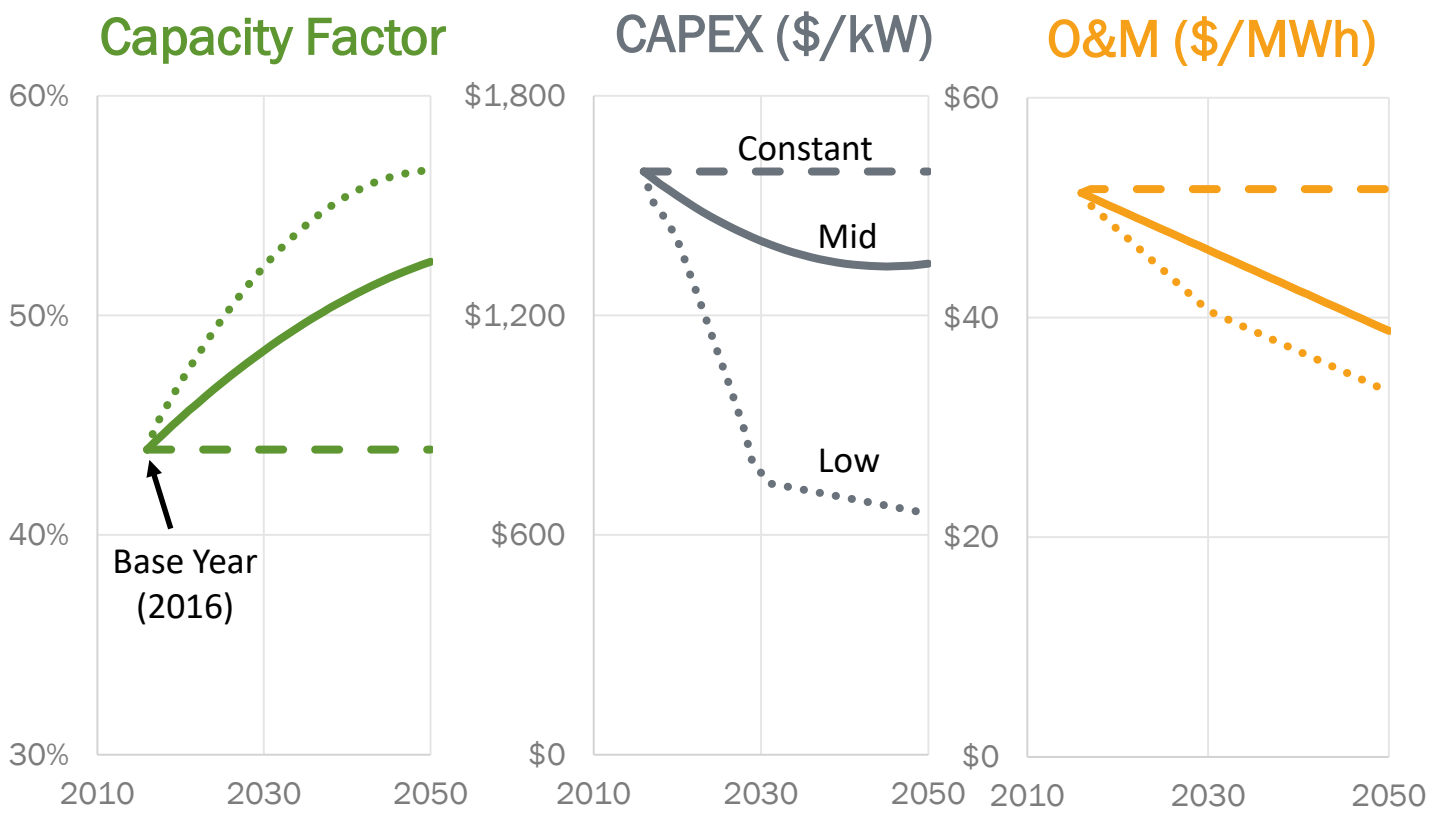
Sources of Base Year (2016)

Technology	Methods	Main Sources
Wind - Land-based - Offshore	Market data Bottom-up model	*2016 Wind Technologies Market Report* (LBNL 2017) *2016 Cost of Wind Energy Review* (NREL 2017) *Assessment of Economic Potential of Offshore Wind in the United States* (NREL 2017)
Solar Photovoltaics (PV) - Utility - Commercial and industrial - Residential	Market data Bottom-up model	*Utility-Scale Solar 2016* (LBNL 2017) *Tracking the Sun 10* (LBNL 2017) *U.S. Solar Photovoltaic System Cost Benchmark: Q1 2017* (NREL 2017)
CSP	Market data Unpublished data Bottom-up model	*Utility-Scale Solar 2016* (LBNL) *On the Path to SunShot* (DOE/NREL 2016) Survey of in-development projects (DOE unpublished)
Hydropower - New stream-reach - Non-powered Dams	Market data Bottom-up model	*Hydropower Baseline Cost Modeling* (ORNL 2015)
Geothermal - Binary and flash - EGS	Bottom-up model	Geothermal Energy Technology Evaluation Model (DOE 2016)
Fossil, Nuclear, and CCS	Engineering estimates	AEO2018 assumptions (EIA 2018)

Sources of Projections (to 2050)

Technology	Methods	Main Sources
Wind - Land-based - Offshore	Expert elicitation Bottom-up model Expert assessment	Expert elicitation survey on future wind energy costs (LBNL 2016) SMART Wind (NREL 2017)
Solar PV - Utility - Commercial and industrial - Residential	Literature survey Bottom-up model	Internal analysis (Feldman/NREL 2018) On the Path to SunShot (DOE/NREL 2016)
CSP	Market data Unpublished data Bottom-up model	Internal analysis (Kurup/NREL 2018) On the Path to SunShot (DOE/NREL 2016)
Hydropower - New stream - Non-powered Dams	Expert assessment Learning	Hydropower Vision (DOE 2016) NEMS (EIA 2017)
Geothermal - Binary and flash - EGS	Bottom-up model	Same as ATB 2017. Will be updated after Geothermal Vision Study is published.
Fossil, Nuclear, and CCS	Learning	AEO2018 outputs (EIA 2018)

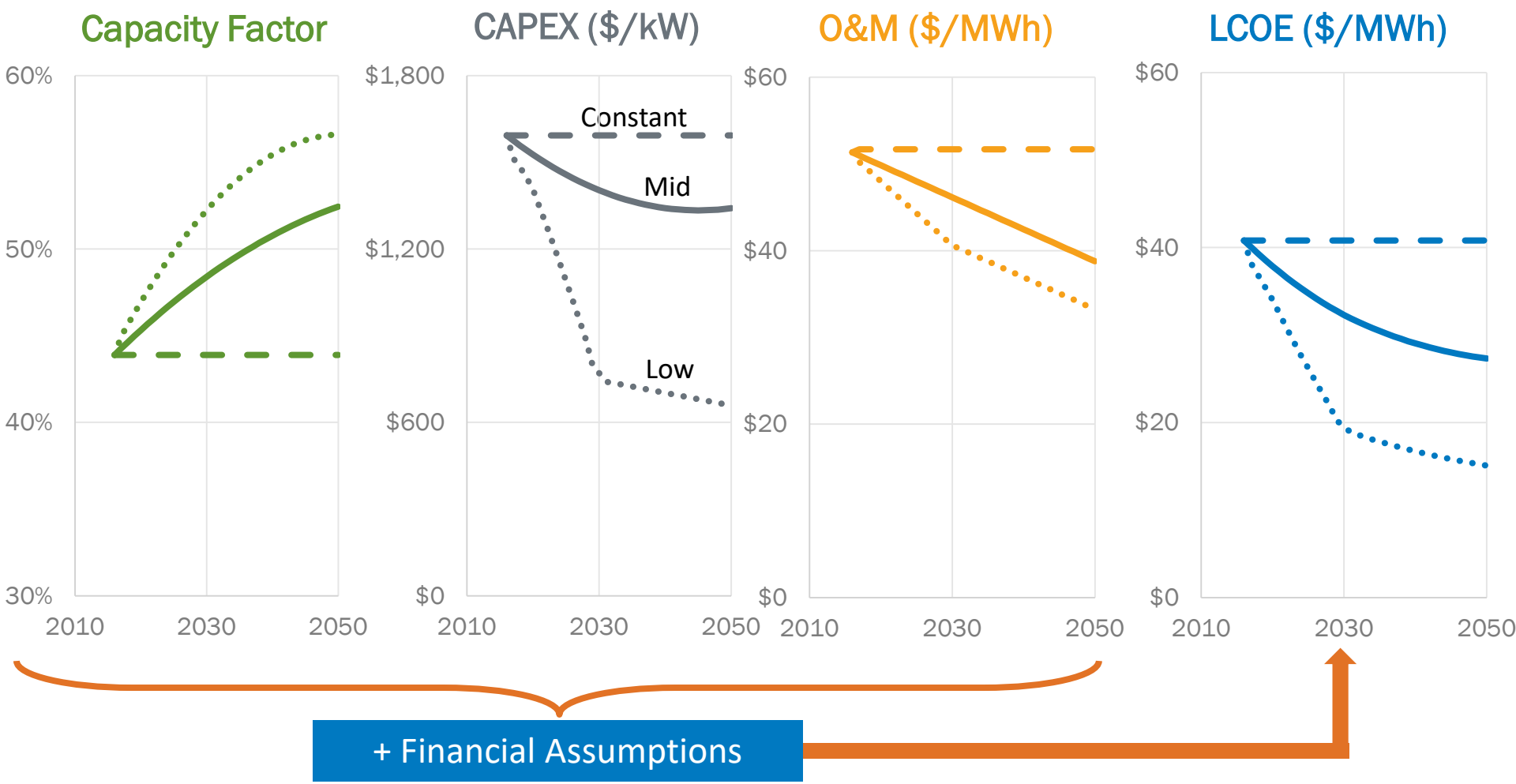
Example of Developing Future Scenarios: Land-Based Wind



For each TRG:

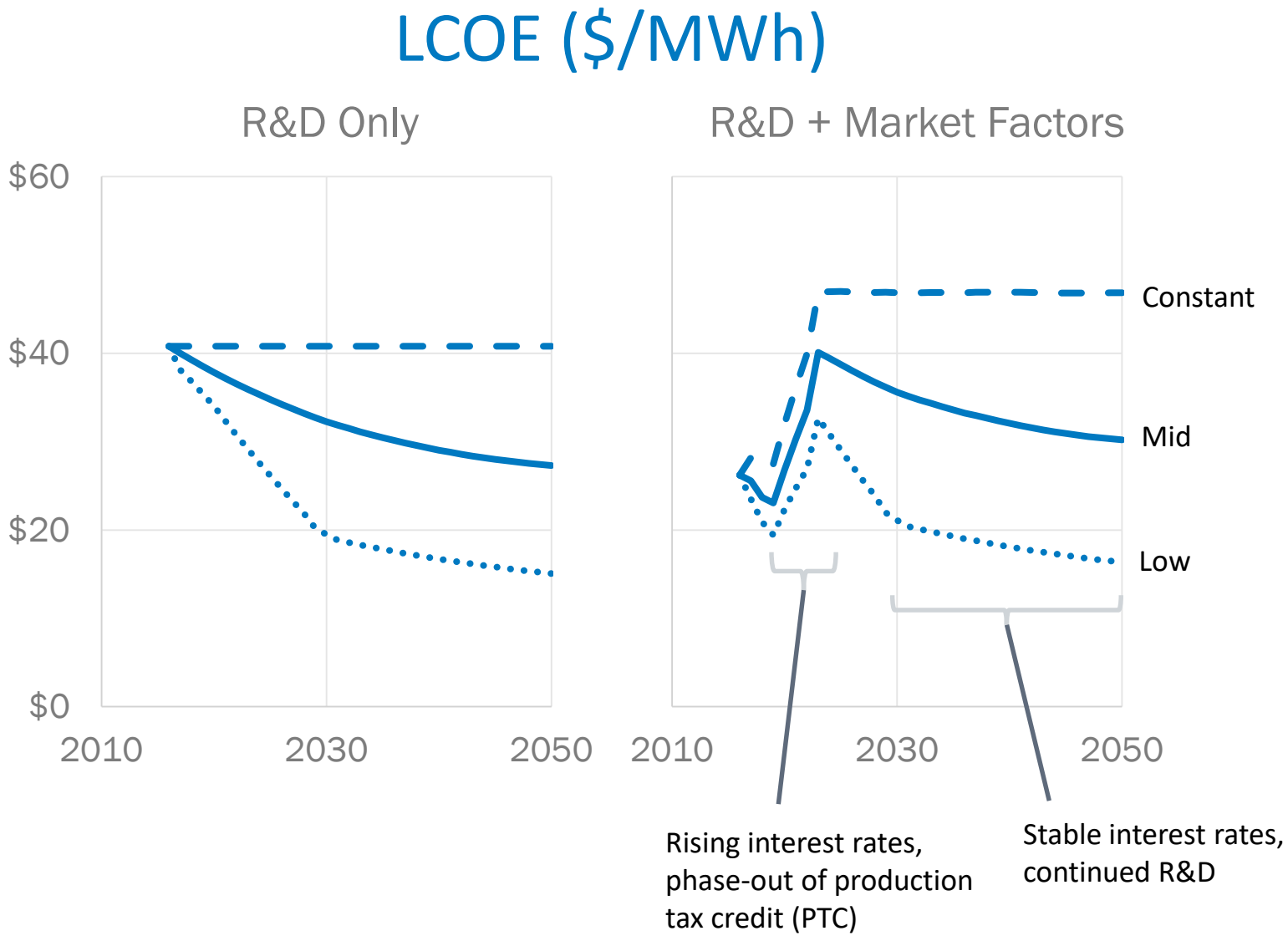
1. Report Base Year value for CAPEX, capacity factor, and O&M, generally relying on market data
2. Develop future scenarios for CAPEX, capacity factor, and O&M, generally relying on existing EERE/NREL work.

Step 3: Example of Calculating LCOE: Land-Based Wind TRG 4

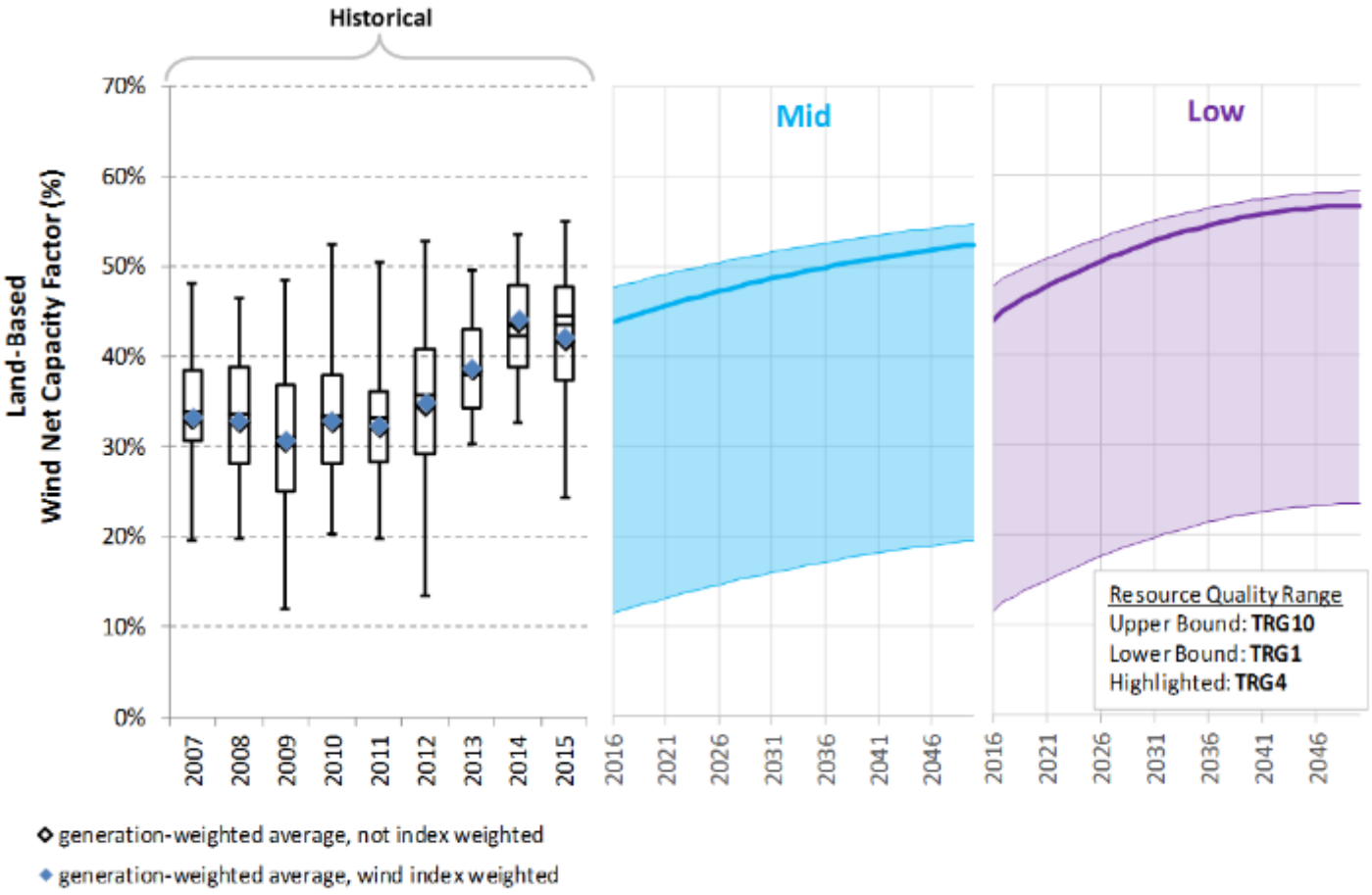


These are used to calculate LCOE scenarios using a given set of financial assumptions.

Example of Multiple LCOE Technology Cost Scenarios and Financial Assumptions Cases: Land-Based Wind TRG4

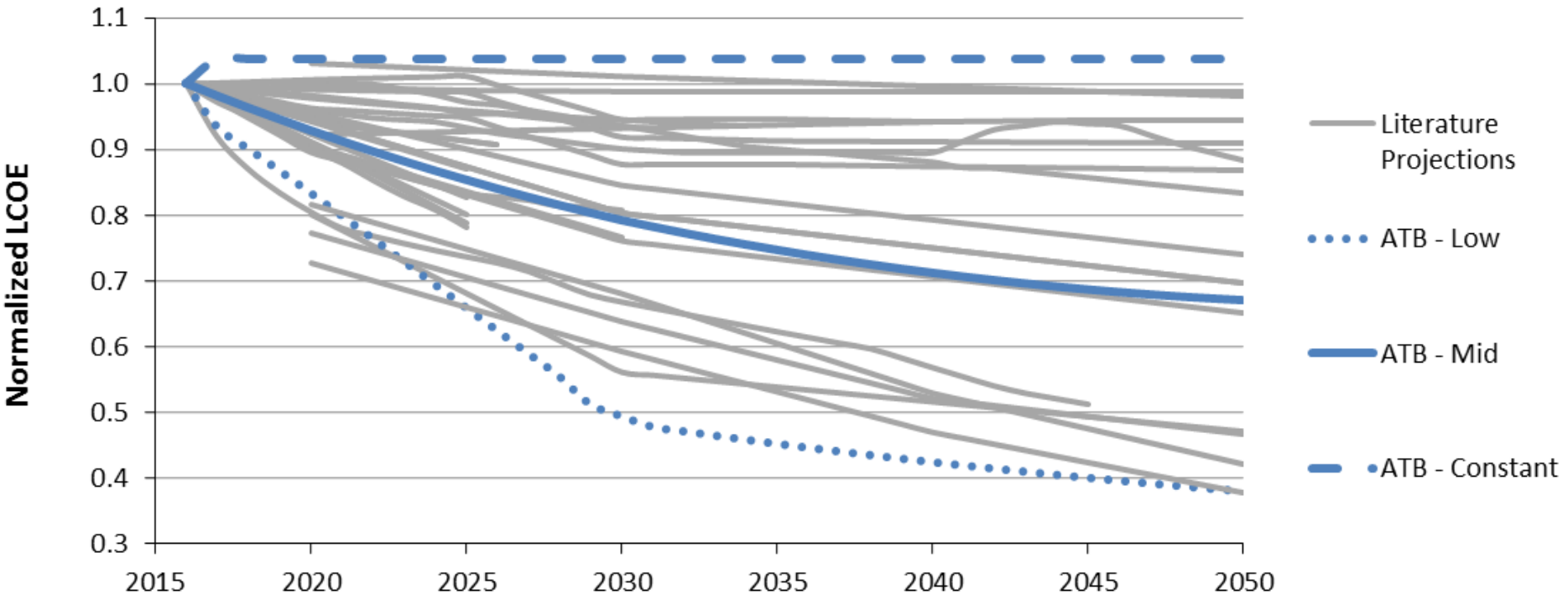


Projections Placed in Context of Past Trends …



Source: National Renewable Energy Laboratory Annual Technology Baseline (2018), http://atb.nrel.gov

… and Projections from Other Sources



Land-based wind ATB cost projections compared with published literature

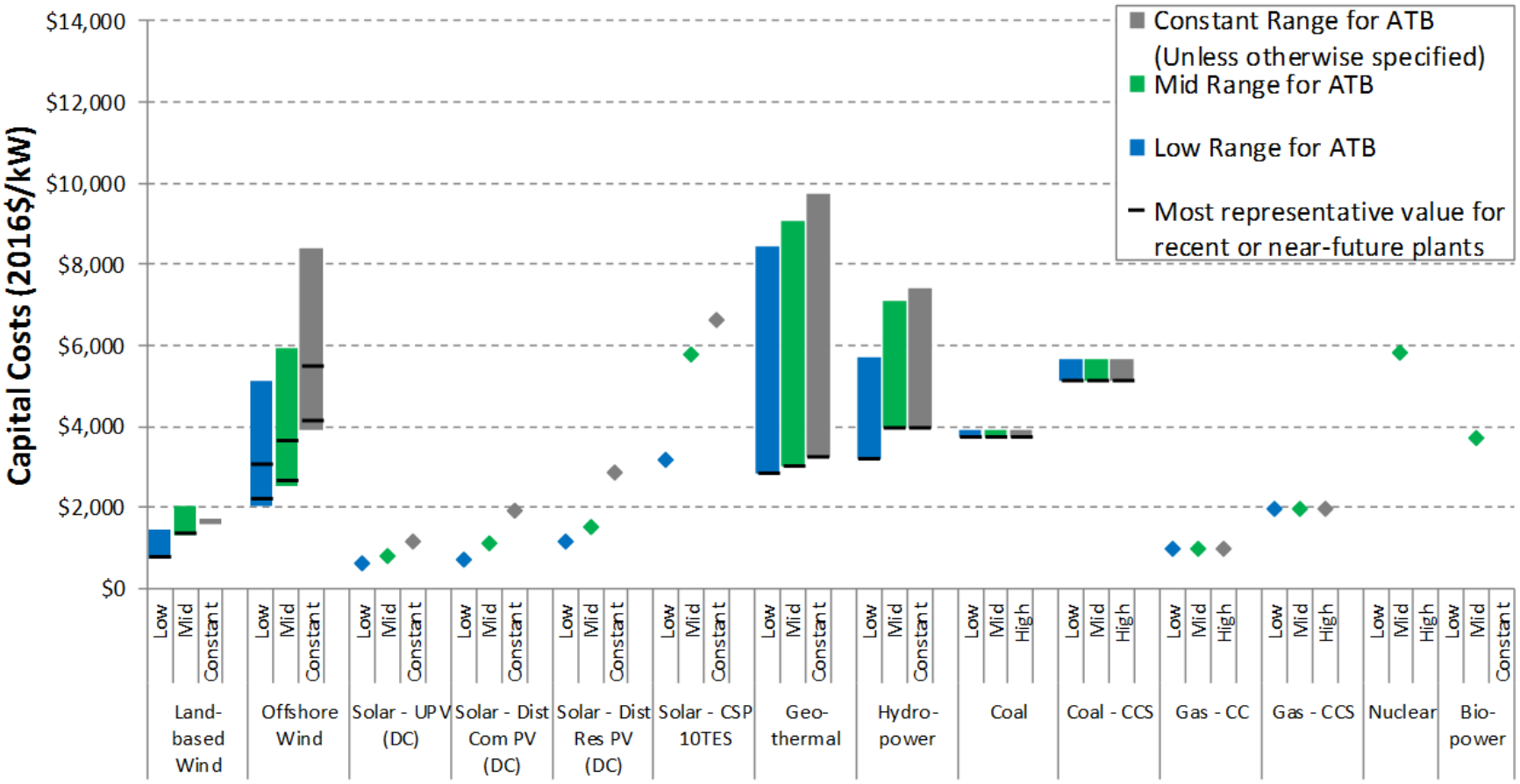
Source: National Renewable Energy Laboratory Annual Technology Baseline (2018), http://atb.nrel.gov

The 2018 ATB updates financial and technology assumptions.

LCOE Financial Assumptions	Added technology-specific financing assumptions
	Separated market effects on financing with an additional scenario
	Extended default capital recovery period to 30 years
Technology-Specific Updates	Wind: low case uses new SMART Wind report
	PV: More granularity in resource quality
	Geothermal: Geothermal Vision (when published)
	Storage: ReEDS 8-hr Li-ion battery costs added

Cost and Performance Summary

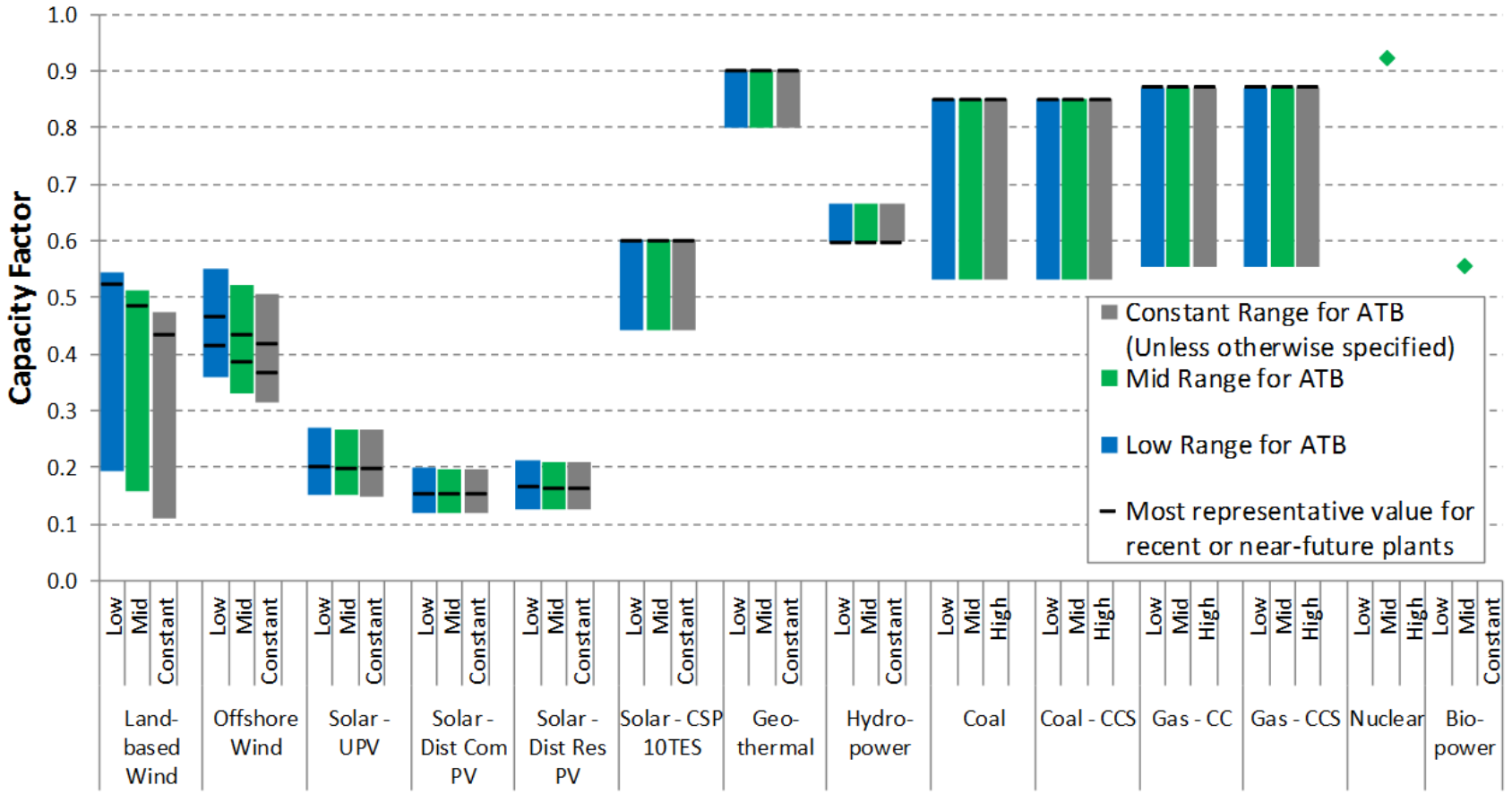
CAPEX Comparison, 2030



2018 ATB CAPEX range by technology for 2030

Source: National Renewable Energy Laboratory Annual Technology Baseline (2018), http://atb.nrel.gov

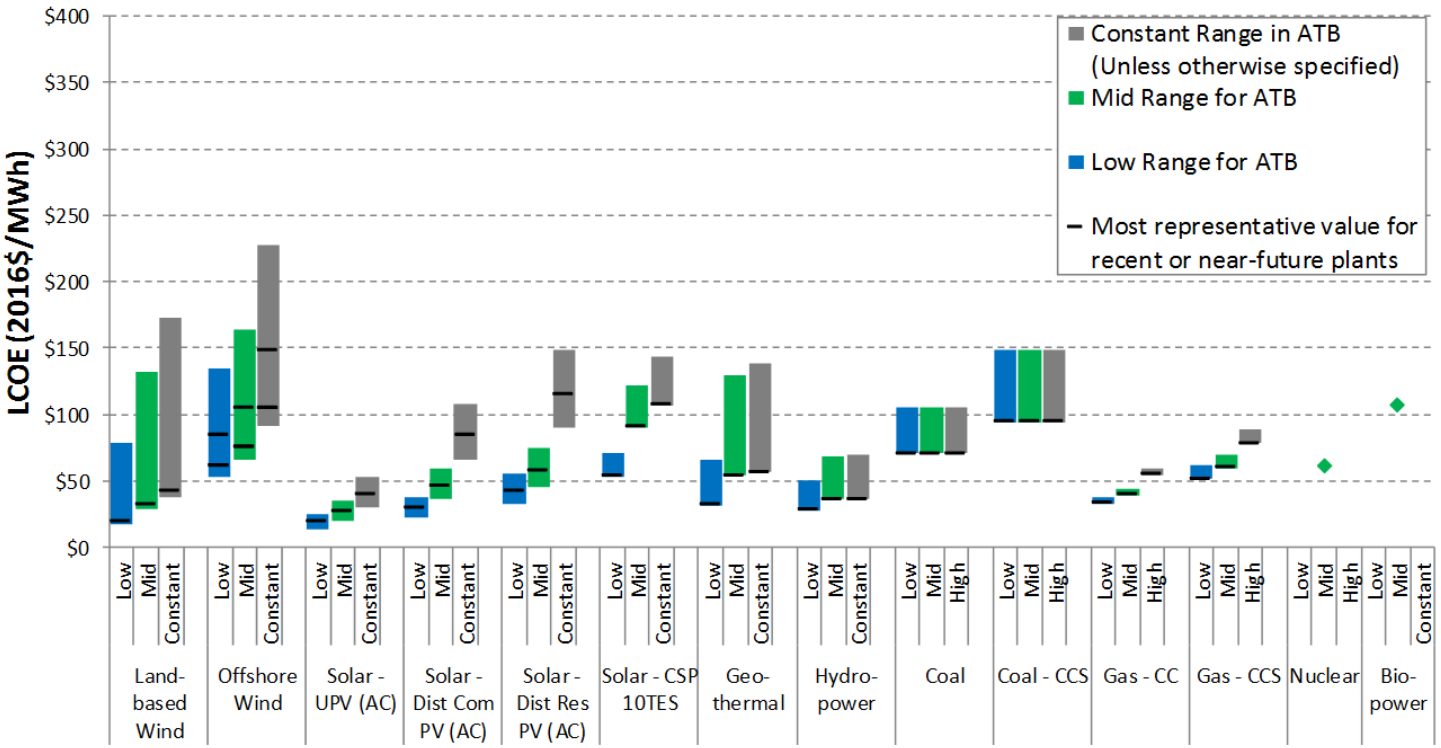
Capacity Factor Comparison, 2030



2018 ATB capacity factor range by technology for 2030

Source: National Renewable Energy Laboratory Annual Technology Baseline (2018), http://atb.nrel.gov

LCOE, 2030

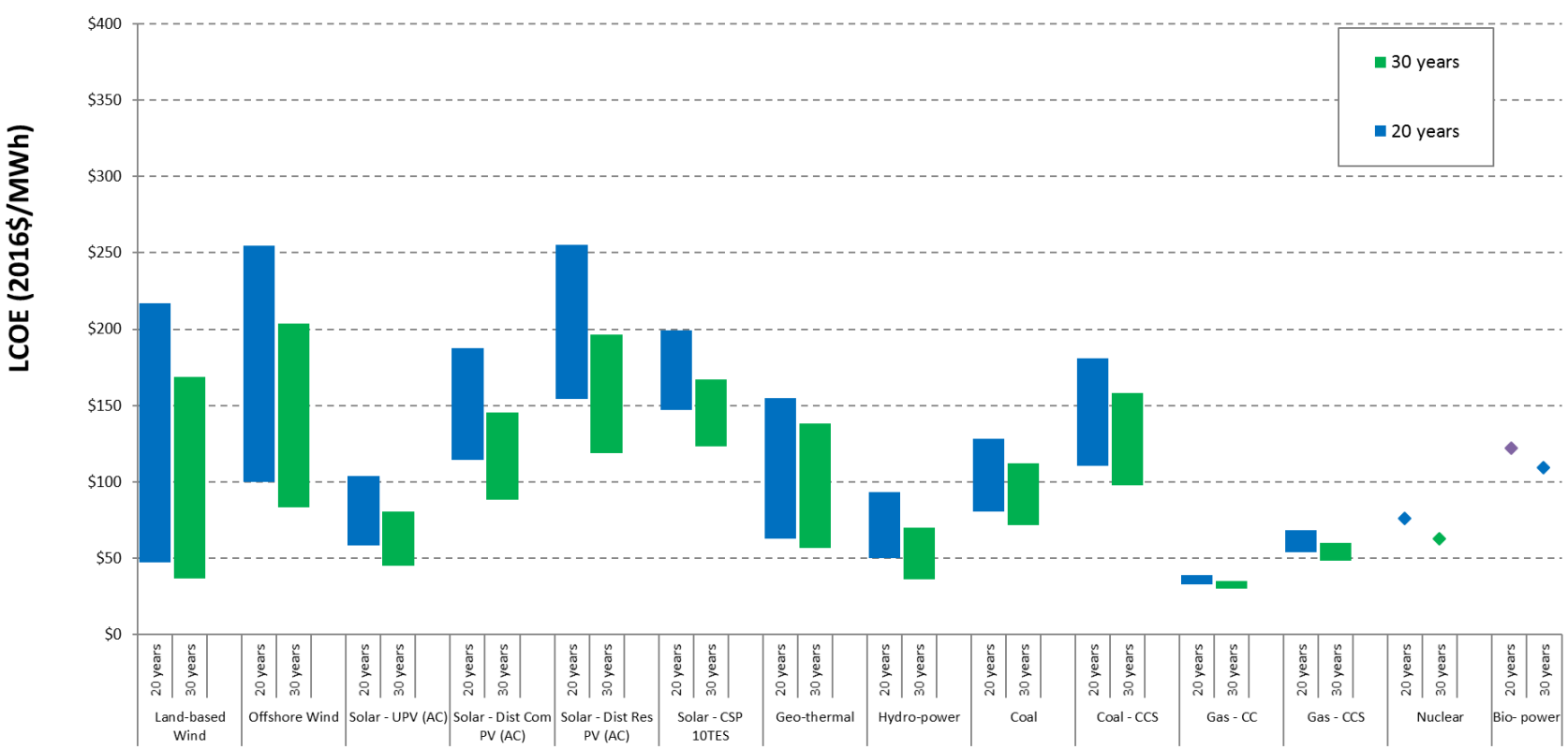


2018 ATB LCOE range by technology for 2030 based on R&D financial assumptions

Source: National Renewable Energy Laboratory Annual Technology Baseline (2018), http://atb.nrel.gov

- Cost and performance improvements for wind, solar, geothermal, and hydropower technologies result in lower magnitude LCOE and tighter range across resource.
- The LCOE calculation includes dynamic effects of R&D on technology cost, technology performance, and financial performance; with R&D financial assumptions, the calculation excludes economic dynamics such as background changes to inflation, interest, and return on equity and also excludes policies such as tax credits and tariffs

LCOE Sensitivity to Cost Recovery Period

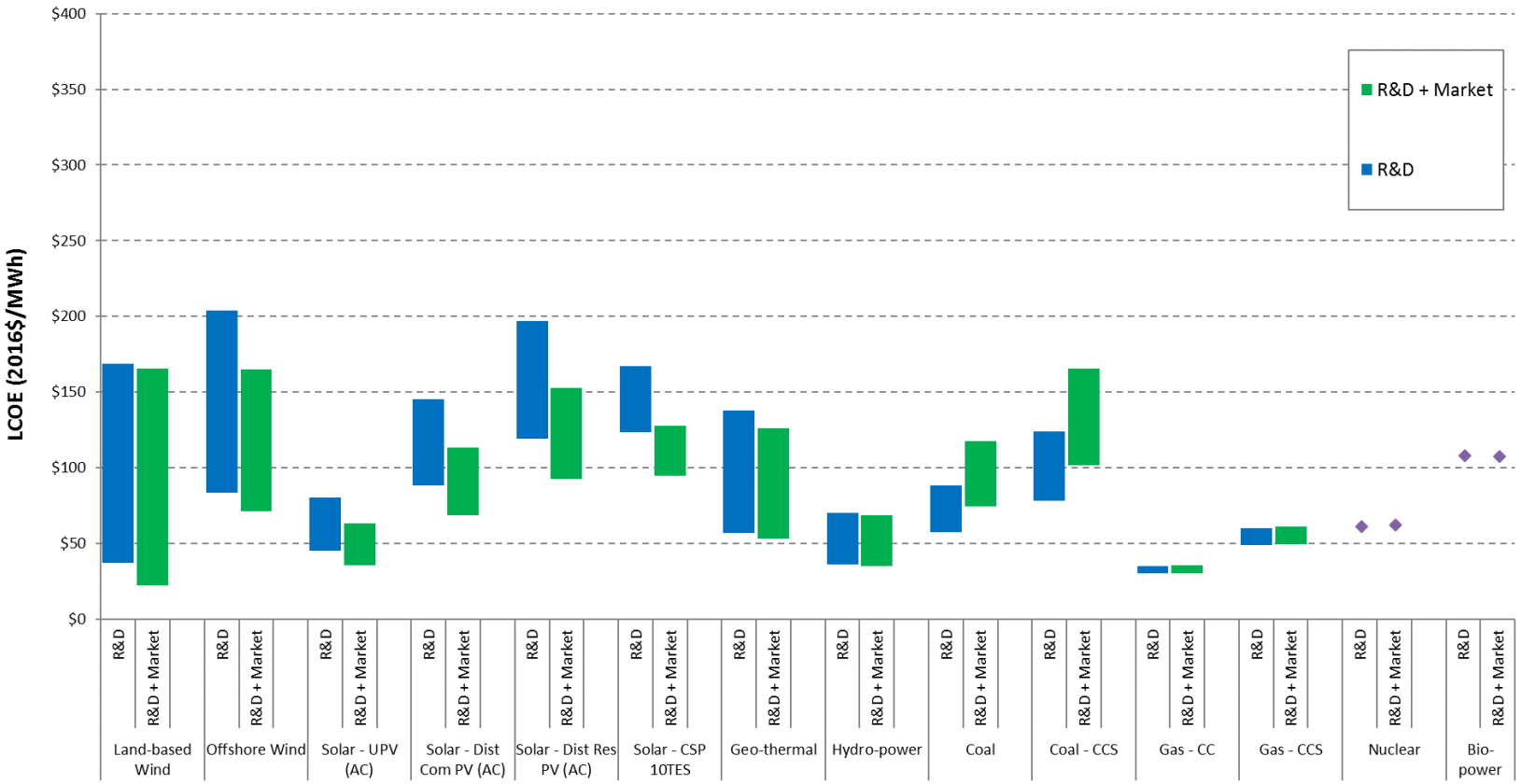


2018 ATB Base Year LCOE Sensitivity to Cost Recovery Period of Plant

Source: National Renewable Energy Laboratory Annual Technology Baseline (2018), http://atb.nrel.gov

- Cost recovery period is 30 years by default for all technologies.
- Cost recovery period of 20 years is shown for comparison.
- Spreadsheet users can input any cost recovery period.

LCOE Sensitivity to Financial Assumptions Case



Sensitivity of 2016 Base Year LCOE to project finance parameters

Source: National Renewable Energy Laboratory Annual Technology Baseline (2018), http://atb.nrel.gov

- R&D = R&D Only Financial Assumptions (constant background rates, no tax or tariff changes)
- R&D + Market = R&D Only + Market Financial Assumptions (dynamic background rates, taxes, and tariffs)
- ReEDS = ReEDS Financial Assumptions

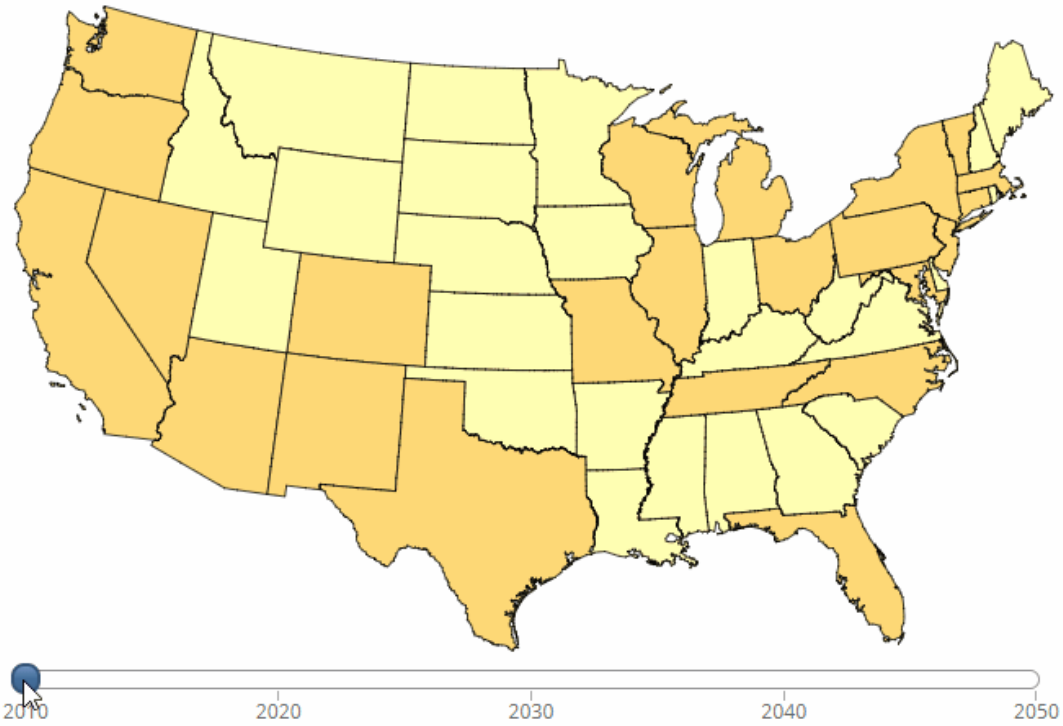
Standard Scenarios Preview

Standard Scenarios

- Covers more than 25 scenarios of the electricity sector
  - Low/high fuel prices, demand, retirements, technology costs
  - Various other futures such as low carbon scenarios, nuclear technology breakthrough, reduced transmission, and vehicle electrification
- Explores four areas of change in the electricity sector
  - Evolving system operations with increasing penetration of renewable energy
  - The potential for non-wind, non-PV renewable energy
  - The impact of increasing natural gas and renewable energy deployment on energy prices
  - What happens after the tax credits expire

Standard Scenarios Results Viewer

Link to Standard Scenarios



Publication Year

2017

Scenario 1:

Mid-Case Scenario

Scenario 2:

None

Capacity (2010):
Utility PV (GW)

Capacity | Utility PV

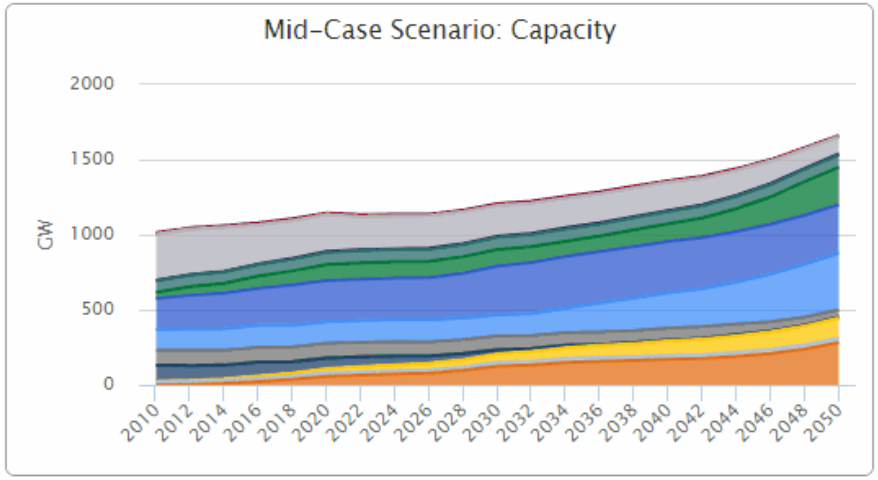
0	6.04 - 11.98
0.00 - 1.80	11.98 - 20.72
1.80 - 6.04	20.72 - 39.01

Compare Technologies | System Metrics

View and compare the contributions of each technology category to the total estimated generation or capacity.

Select All | Clear All

- Biopower
- Coal
- Hydro
- NG-CC
- Nuclear
- Oil-Gas-Steam
- Storage
- CSP
- Geothermal
- Land-based Wind
- NG-CT
- Offshore Wind
- Rooftop PV
- Utility PV



https://openei.org/apps/reeds/

Thank you!

The 2018 Annual Technology Baseline is available at atb.nrel.gov.

For all references, see https://atb.nrel.gov/electricity/2018/references.html.

www.nrel.gov

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NATIONAL RENEWABLE ENERGY LABORATORY

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