NREL
NATIONAL RENEWABLE ENERGY LABORATORY





2017 Annual Technology Baseline

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Outline

- Project Background and Methodology
  - Base Year Estimates
  - Future Year Projections
- Cost and Performance Summary
- Preview of 2017 Standard Scenarios

Purpose of the ATB

- Provide a transparent set of electricity generation technology cost and performance data for use in NREL analysis and make data available for others to use in energy analysis.
- The ATB represents a populated framework to identify technology-specific cost and performance parameters or other investment decision metrics across a range of resource characteristics, sites, or fuel price assumptions for electricity-generation technologies both at present and with projections through 2050 for these technologies:
  - Land-based and offshore wind plants
  - Utility-scale, commercial-scale and residential-scale PV plants
  - Concentrating solar plants
  - Geothermal plants
  - Hydropower plants
  - Natural-gas, coal, nuclear and biomass plants

The Annual Technology Baseline (ATB)

- Two products:
  - *ATB website*— includes details about the technologies and the methods used to create the projections
  - *ATB spreadsheet* — includes all the specific technology inputs for current and future costs and performance
- Associated product:
  - *Standard Scenarios Report* — suite of electricity sector scenarios using the ATB and other inputs that provide an outlook of how the sector might evolve over time under a range of possible conditions

Types of Uses of the ATB

- Long-term planning analysis for utilities and system operators (e.g., MISO, PJM, HECO)
- Input for academic studies (e.g., Stanford, University of Texas, University of Maryland)
- Policy analysis (e.g., Environmental Protection Agency, Council of Economic Advisors to the White House, various consulting groups)
- International analysis (e.g., Chilean Ministry of Energy, Canadian Institute for Integrated Energy Systems)
- Department of Energy analysis

ATB Format

- Each technology includes a summary, Base Year estimates, and projections through 2050
  - Overview of the technology and resource
  - CAPEX
  - CAPEX definition
  - O&M
  - Capacity factor
  - Description of methodology and comparison with other sources for future cost and performance projections
  - LCOE

Examples across technologies are presented in the following slides.

Summary of ATB Representative Plants

Technology	Plants	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	3 for each segment	Horizontal solar irradiance
Concentrating Solar Power	3	Direct normal solar irradiance
Geothermal	6	Hydrothermal, enhanced geothermal, binary or flash systems, reservoir temperature
Hydropower	8	Non-powered dams, new stream-reach development, head, and design capacity
Natural Gas	6	Combustion turbine, combined-cycle, carbon capture and storage (CCS), and choice of capacity factor
Coal	8	Pulverized coal, integrated gasification combined-cycle (IGCC), carbon capture and storage (CCS) percentage, and choice of capacity factor
Nuclear	1	Not applicable
Biopower	2	Dedicated or co-fired

Example of Wind TRG4 (8 m/s annual average wind speed)

LCOE calculated with current market conditions

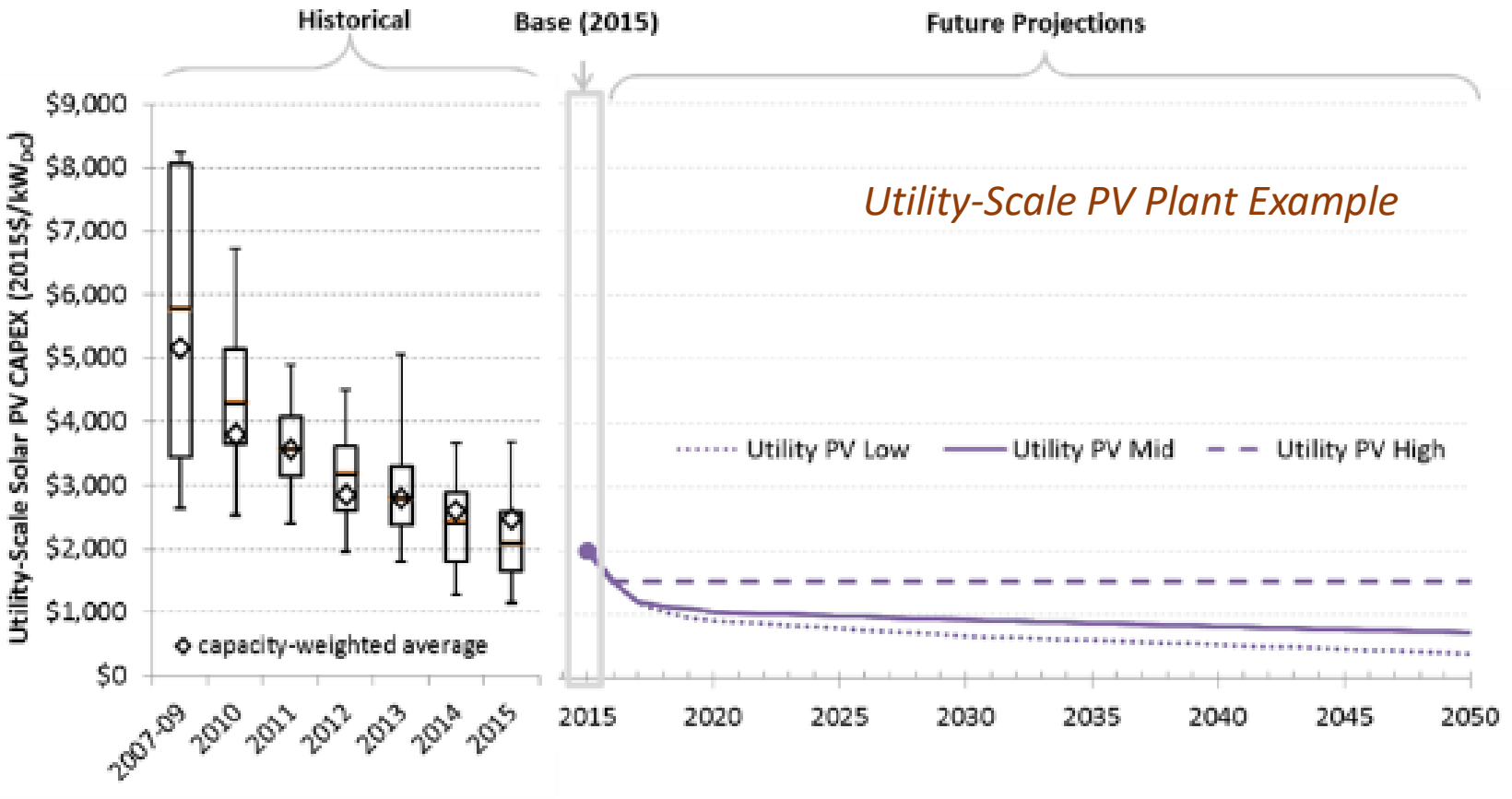
- The ATB includes representative plants for each renewable energy technology to illustrate the influence of resource on cost and performance.
- For each representative plant, estimates of CAPEX, O&M, capacity factor, and LCOE are developed for High/Mid/Low cost projections from the Base Year through 2050.
  - High = Base Year (or near-term estimates of projects under construction) equivalent through 2050 maintains current relative technology cost differences
  - Mid = technology advances through continued industry growth, public and private R&D investments, and market conditions relative to current levels that may be characterized as "likely"
  - Low = technology advances that may occur with breakthroughs, increased public and private R&D investments, and/or other market conditions that lead to cost and performance levels that may be characterized as the "limit of surprise," but not necessarily the absolute low bound.

Overview of Base Year (2015) Cost and Performance Methodology

Technology	Source
Land-based Wind Power Plants	Bottom-up modeling (Moné et al. 2017), compared to wind market data reports; methodology updated from *Wind Vision* (DOE 2015)
Offshore Wind Power Plants	Bottom-up modeling (Beiter et al. 2016), compared to wind market data reports
Utility, Residential, and Commercial PV Plants	Market data reports (2015), supplemented with bottom-up cost modeling from Fu et al. (2015) for 2016 estimate
Concentrating Solar Power Plants	Bottom-up cost modeling from Kurup and Turchi (2015), supplemented with industry input regarding projects under construction for operation in 2018
Geothermal Plants	Bottom-up cost modeling using GETEM
Hydropower Plants	Bottom-up cost modeling from *Hydropower Baseline Cost Modeling* (O'Connor et al. 2015) and *Hydropower Vision* (DOE 2016)
Conventional Plants	*Annual Energy Outlook* (EIA 2017) reported costs

CAPital EXpenditures (CAPEX)

Historical Trends, Current Estimates, and Future Projections

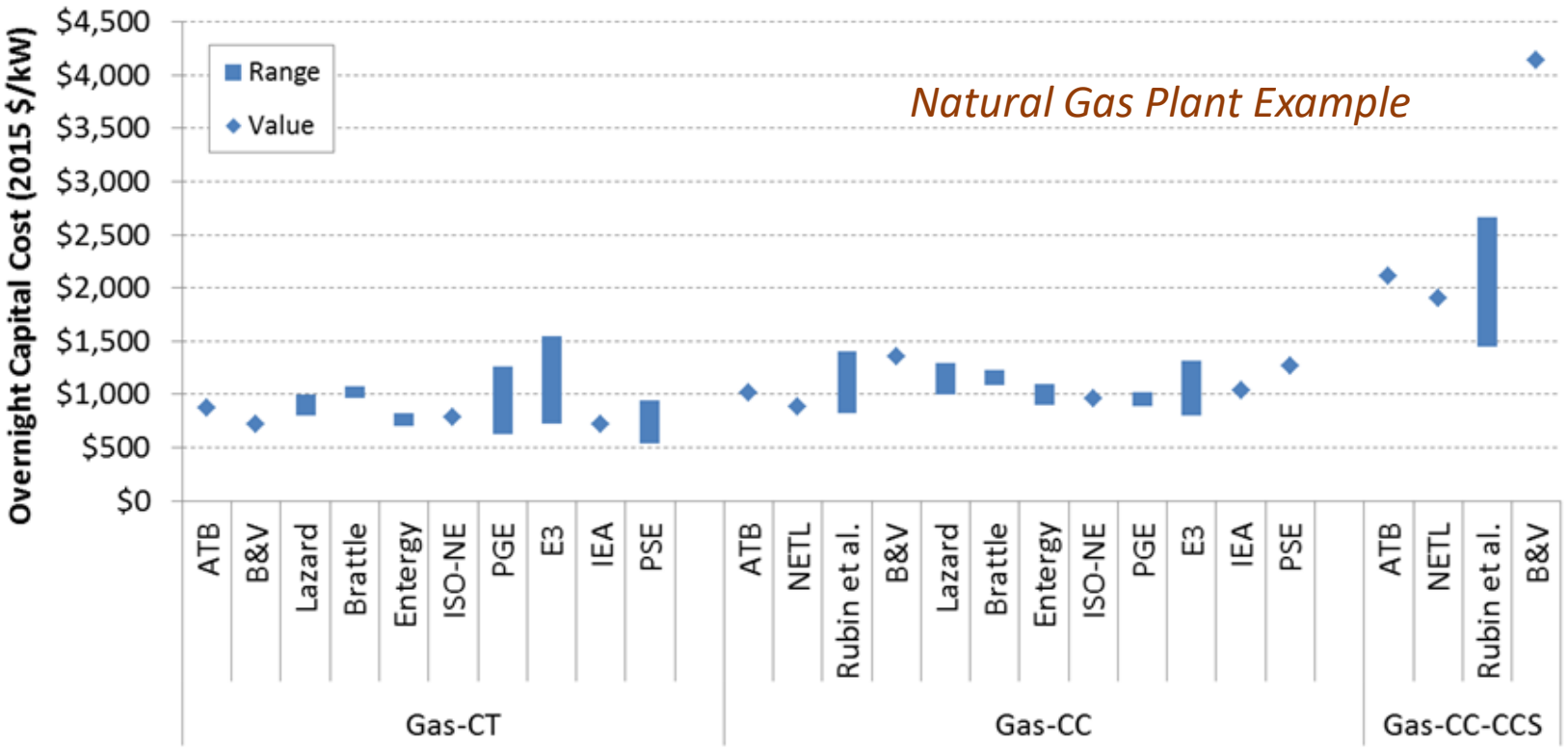


CAPEX (CAPital EXpenditures) historical trends, current estimates, and future projection for utility PV (DC)

Source: National Renewable Energy Laboratory Annual Technology Baseline (2017), http://atb.nrel.gov

Base Year estimate informed by historical record of U.S. project installations

CAPEX Comparison with Other Sources



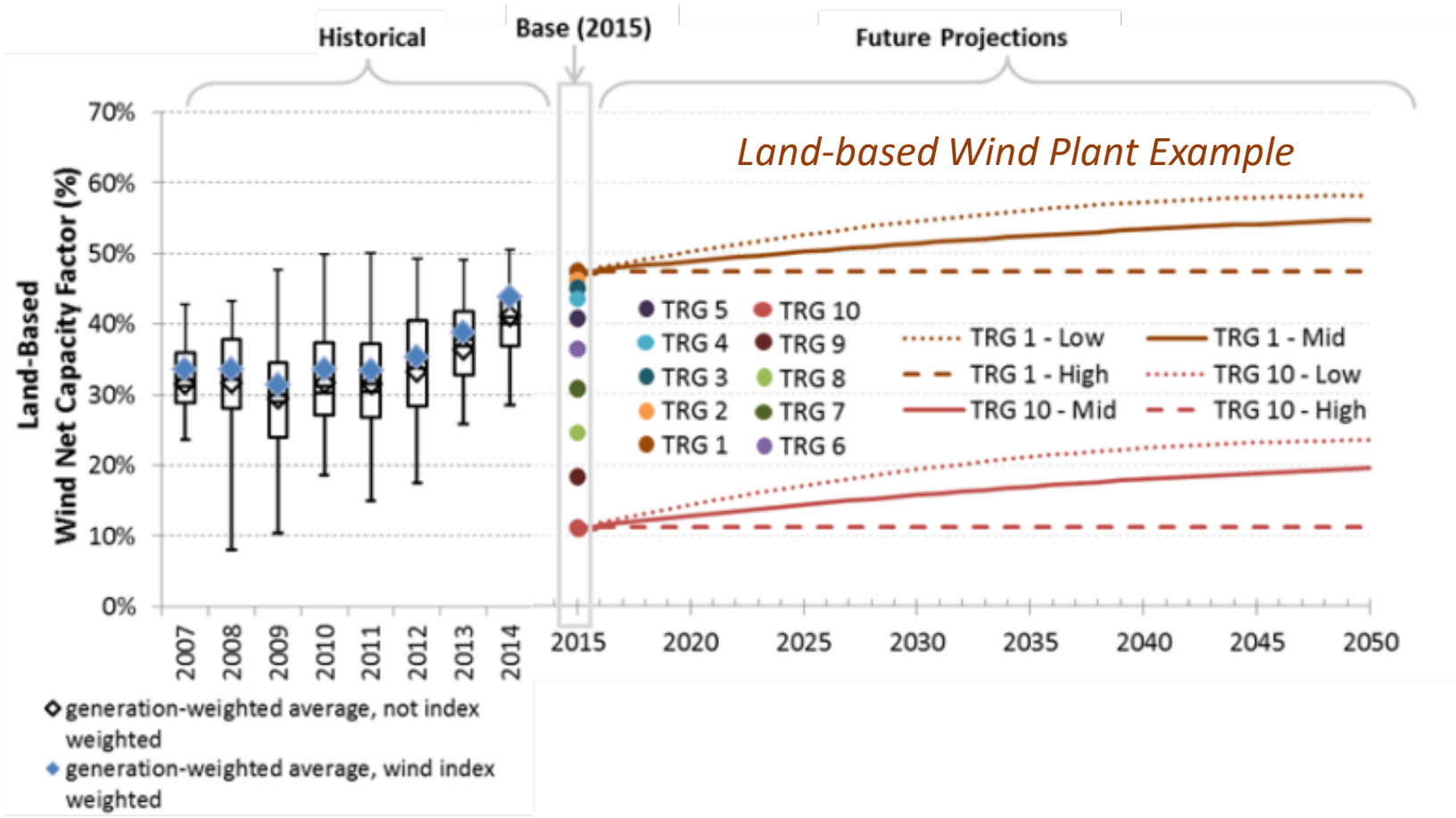
Natural Gas plant capital cost comparison by data source

Source: National Renewable Energy Laboratory Annual Technology Baseline (2017), http://atb.nrel.gov

Costs estimates from different publications vary due to differences in configuration (e.g., 2x1 vs. 1x1), turbine class, and methodology.

Capacity Factor

Expected Annual Average Energy Production Over Lifetime



Land-based wind net capacity factor

Source: National Renewable Energy Laboratory Annual Technology Baseline (2017), http://atb.nrel.gov

The ATB reflects possible range of renewable resources available in the United States and is informed by historical performance. Performance of existing operating plants may not correspond to the full array of hypothetical sites.

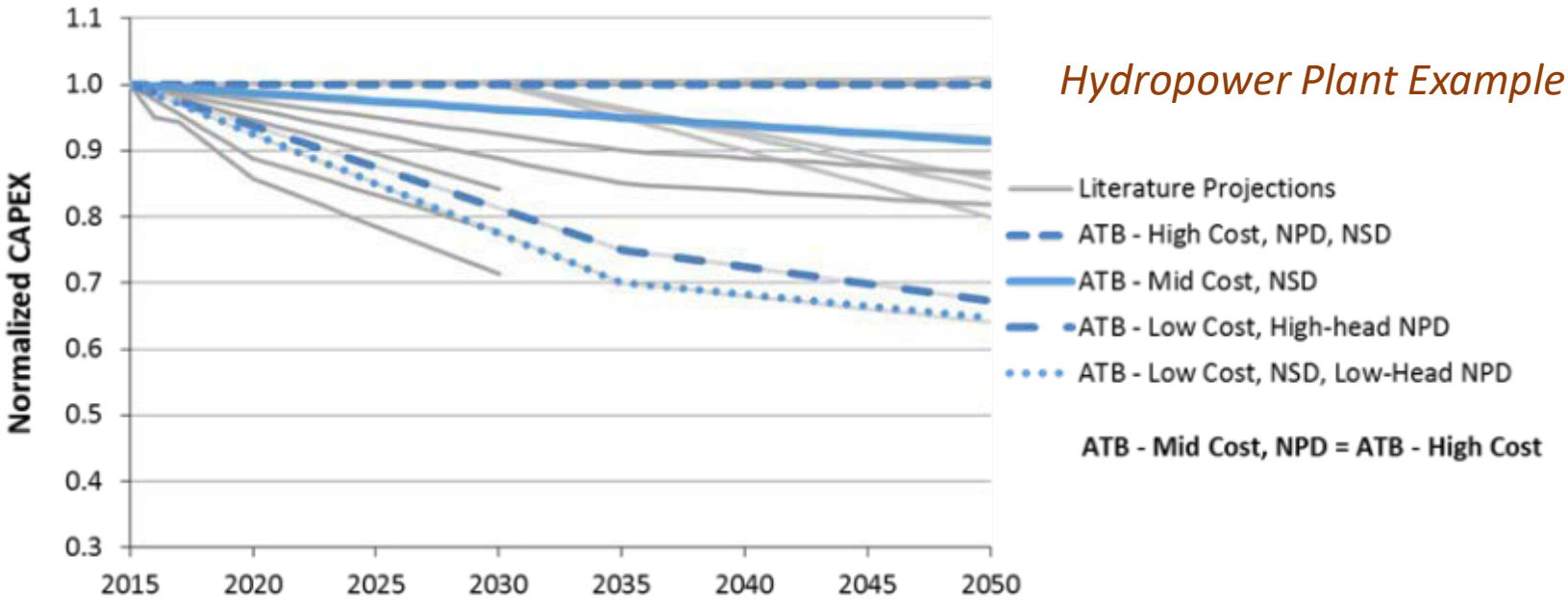
Overview of Future Year Cost and Performance Methodology

Technology	Methods	Source	ATB Mid & Low	Notes
Wind (land-based and offshore)	Expert elicitation	Wiser et. al. 2016	Mid: 50% probability scenario Low: 10% probability scenario	Scenarios reflect relative difference between Mid and Low associated with probability, include LCOE component projections (e.g., CAPEX and capacity factor)
Solar PV (utility and distributed)	Literature survey (CAPEX), single pathway (O&M)	Internal NREL analysis (Feldman)	Mid: Based on median of literature sample Low: Based on lower bound of literature sample	*Long term*: forecasts published in last three years *Short term*: forecasts published in last six months
CSP (10 hours thermal storage)	Single pathway, learning, literature survey	Internal NREL analysis (Kurup) and *On the Path to SunShot*	Mid: Based on median of literature sample Low: SunShot target achieved in 2035	Mid projection based on literature sample; Low projection informed by bottom-up analysis combined with learning rates
Hydropower (NPD, NSD)	Multiple pathway, expert input, learning	*Hydropower Vision (DOE 2016)*	Mid: *HV Reference* scenario Low: *HV Advanced Technology* scenario	Projections informed by industry expertise, identifiable potential future technology and process advancements, EIA minimum learning
Geothermal	Minimum learning	EIA NEMS	Mid: -5% CAPEX by 2035 Low: -10% CAPEX by 2035	Geothermal Vision study will result in detailed analysis for future ATB editions.

Future Cost and Performance Projection Methods

- *Expert Elicitation* — formal structured information gathering associated with probability level for multiple scenarios
- *Literature Survey* — assessment of statistics (e.g., median) associated with sample of published literature
- *Pathway Analysis* — use of engineering models, often with expert input about specific assumptions, to explore technology advance pathways associated with future outcomes
- *Expert Input* — information gathering to define and support assumptions for technology pathway analysis
- *Learning* — application of published learning rates and assumptions of future global or national capacity additions

Comparison of ATB Projections With Literature

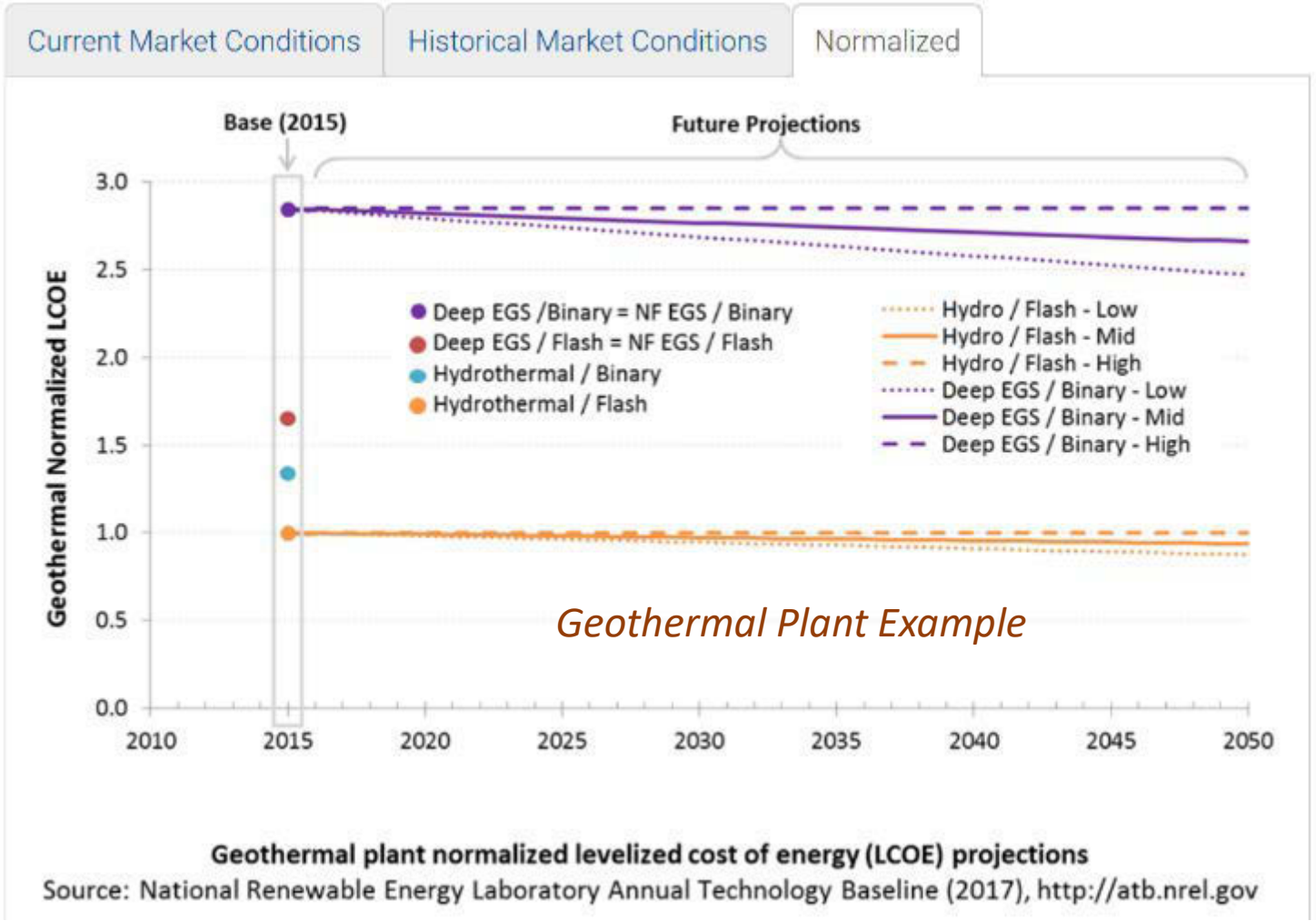


Hydropower ATB cost projections compared with published literature

Source: National Renewable Energy Laboratory Annual Technology Baseline (2017), http://atb.nrel.gov

ATB projections compared with other published literature for similar technologies to illustrate different perspectives of potential future technology advances.

LCOE Projections

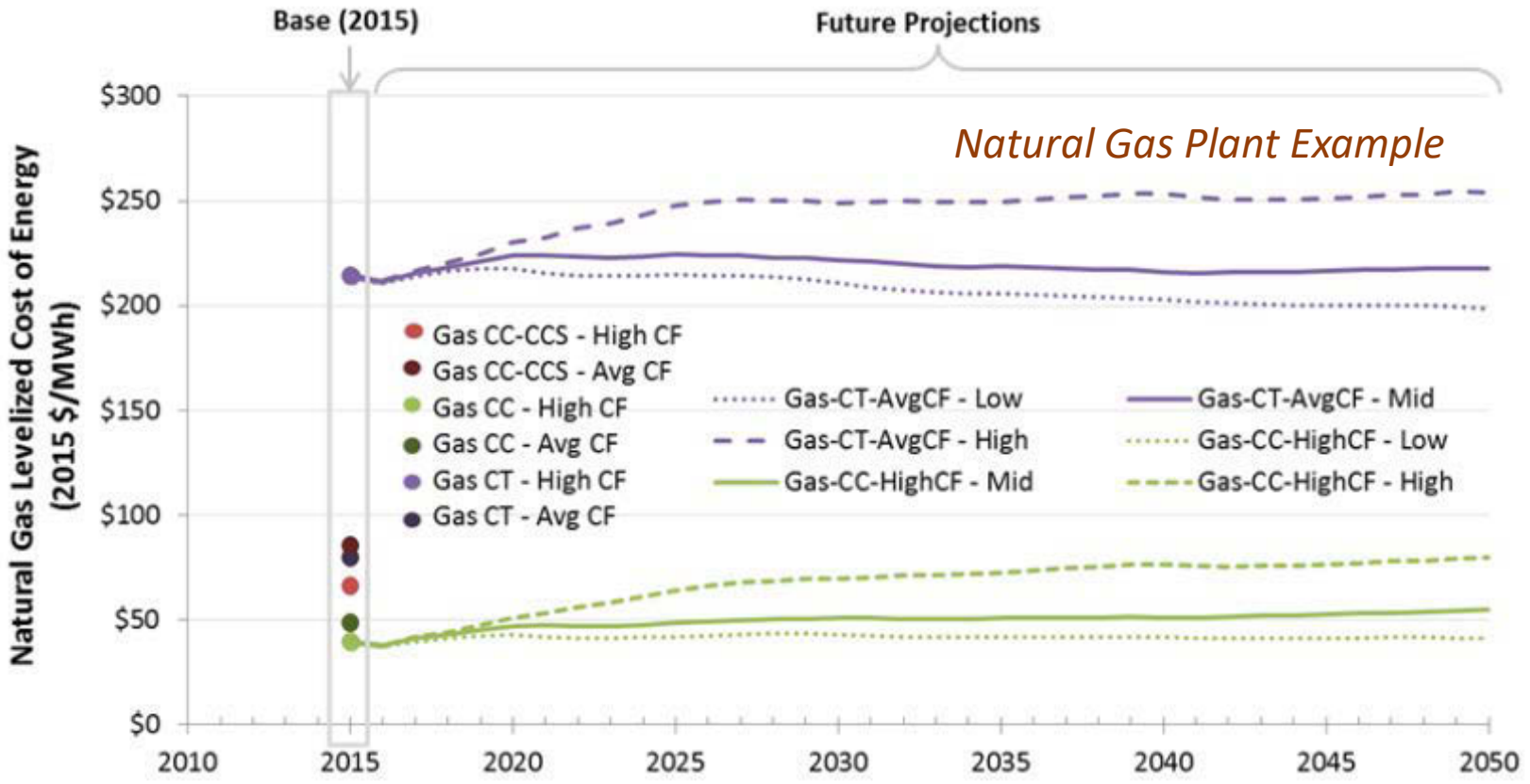


Geothermal plant normalized levelized cost of energy (LCOE) projections

Source: National Renewable Energy Laboratory Annual Technology Baseline (2017), http://atb.nrel.gov

ATB focuses on technology changes over time — CAPEX, O&M, and capacity factor. LCOE calculated using two different perspectives on macro-economic conditions and normalized to illustrate relative impact of technology changes.

Fuel-based Technology LCOE Projections



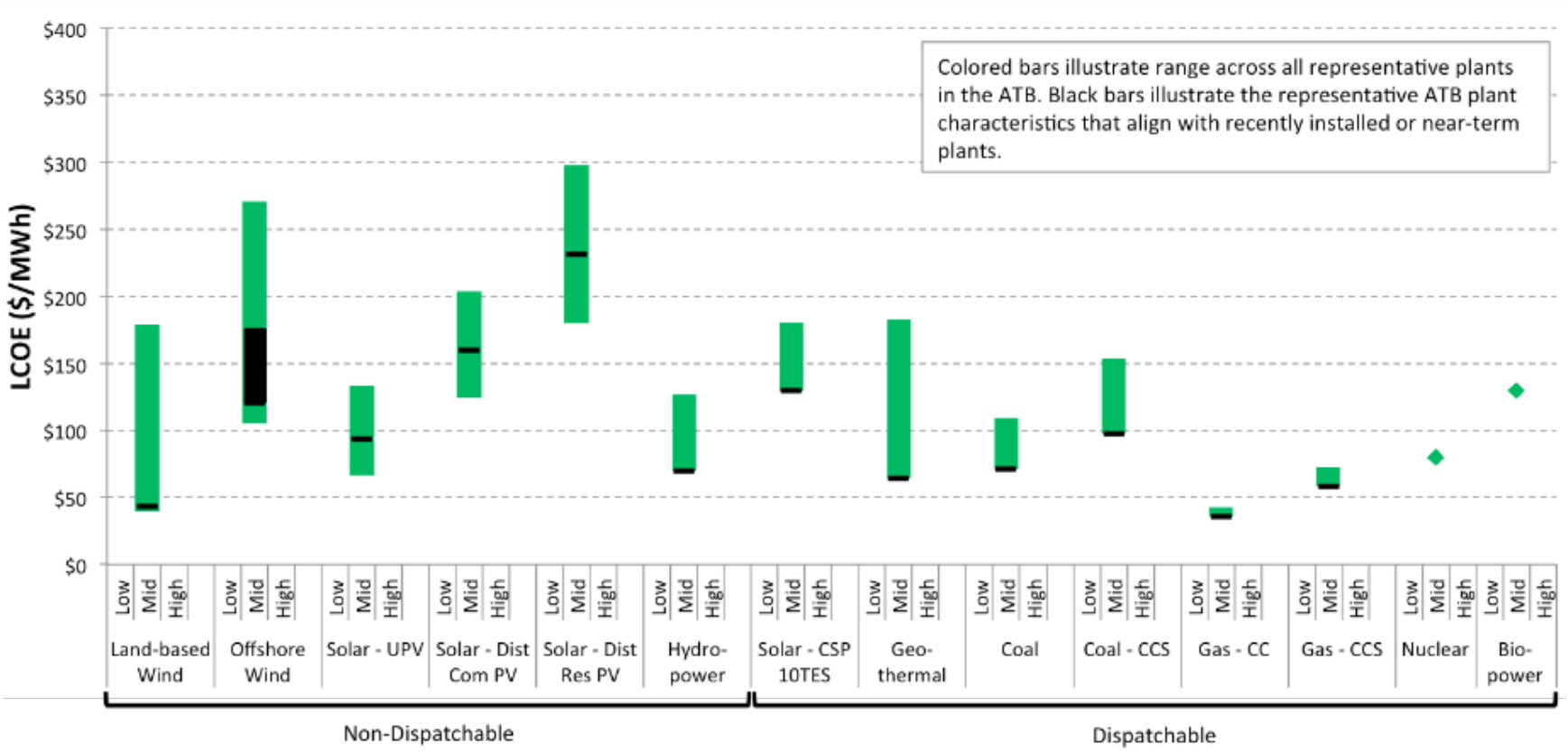
Natural gas plant LCOE projections based on long-term historical market conditions

Source: National Renewable Energy Laboratory Annual Technology Baseline (2017), http://atb.nrel.gov

The LCOE of natural gas plants are directly impacted by multiple natural gas fuel costs — high, medium, and low (similarly for coal and nuclear plants). The LCOE is also impacted by variations in the heat rate and O&M costs.

LCOE Values in 2015

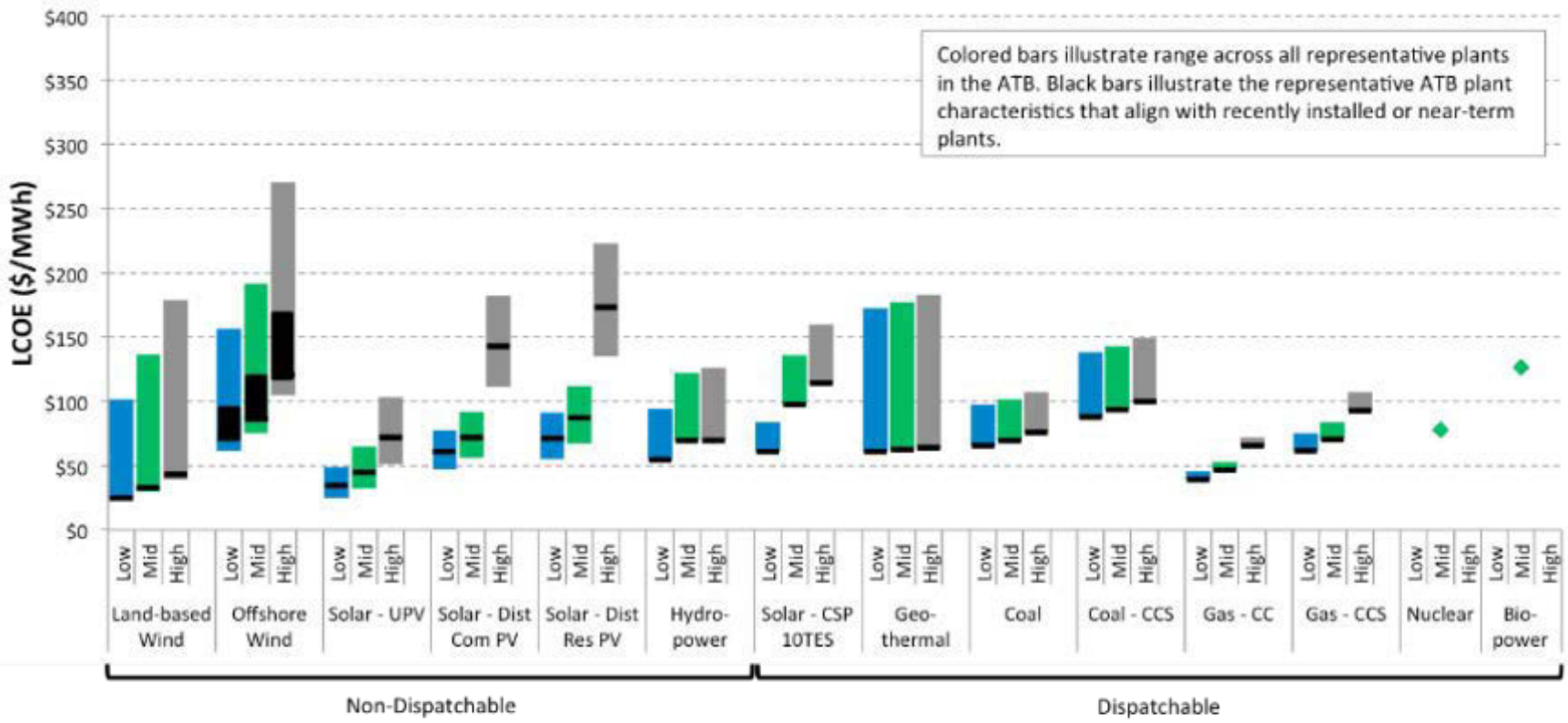
Ranges driven by underlying ranges in CAPEX and capacity factor



2017 ATB LCOE range by technology for 2015 based on current market conditions
Source: National Renewable Energy Laboratory Annual Technology Baseline (2017), http://atb.nrel.gov

The LCOE is included as a summary metric and is not the focus of this work.

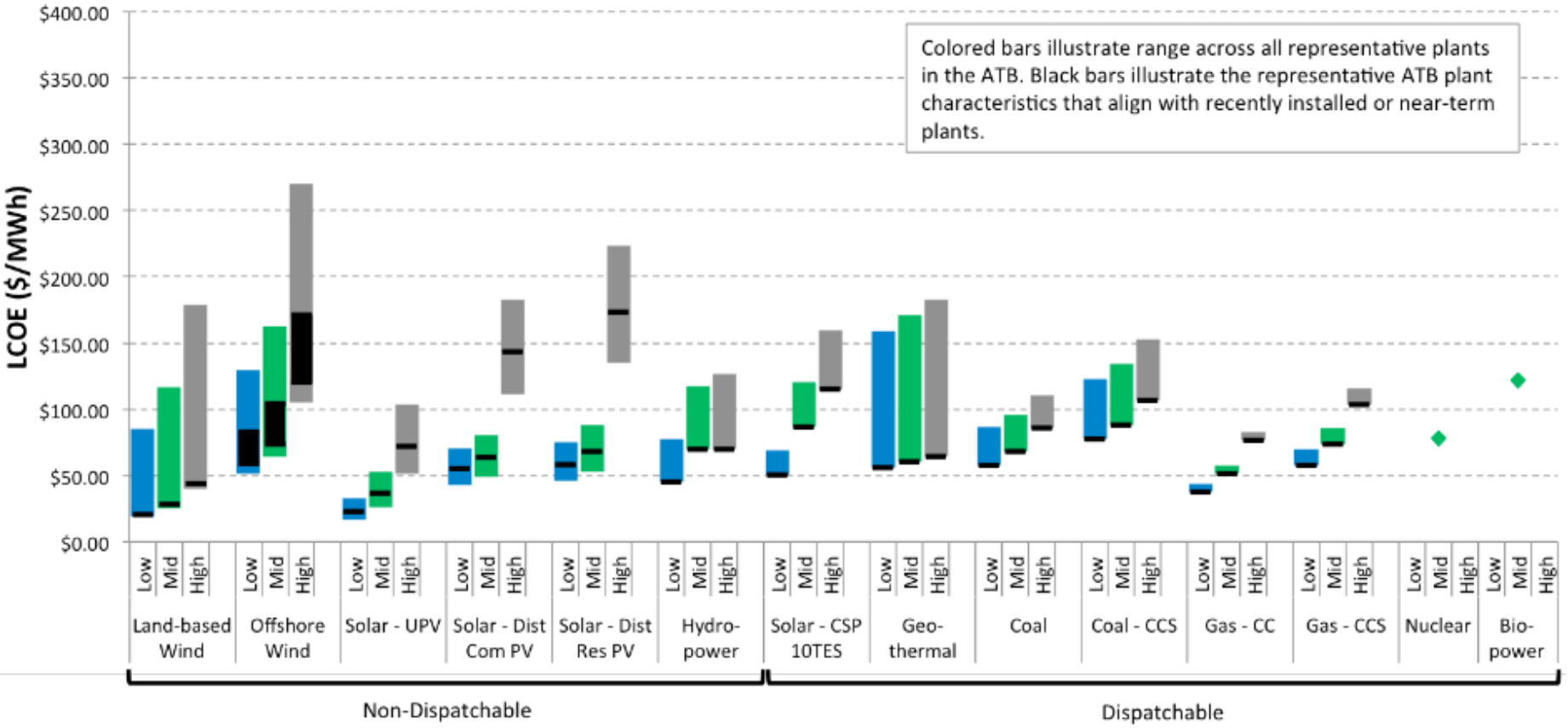
LCOE Projections in 2030



2017 ATB LCOE range by technology for 2030 based on current market conditions
Source: National Renewable Energy Laboratory Annual Technology Baseline (2017), 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.
- LCOE estimates do not include incentives (production tax credit, investment tax credit) and reflect cost of capital representative of current market conditions.

LCOE Projections in 2050

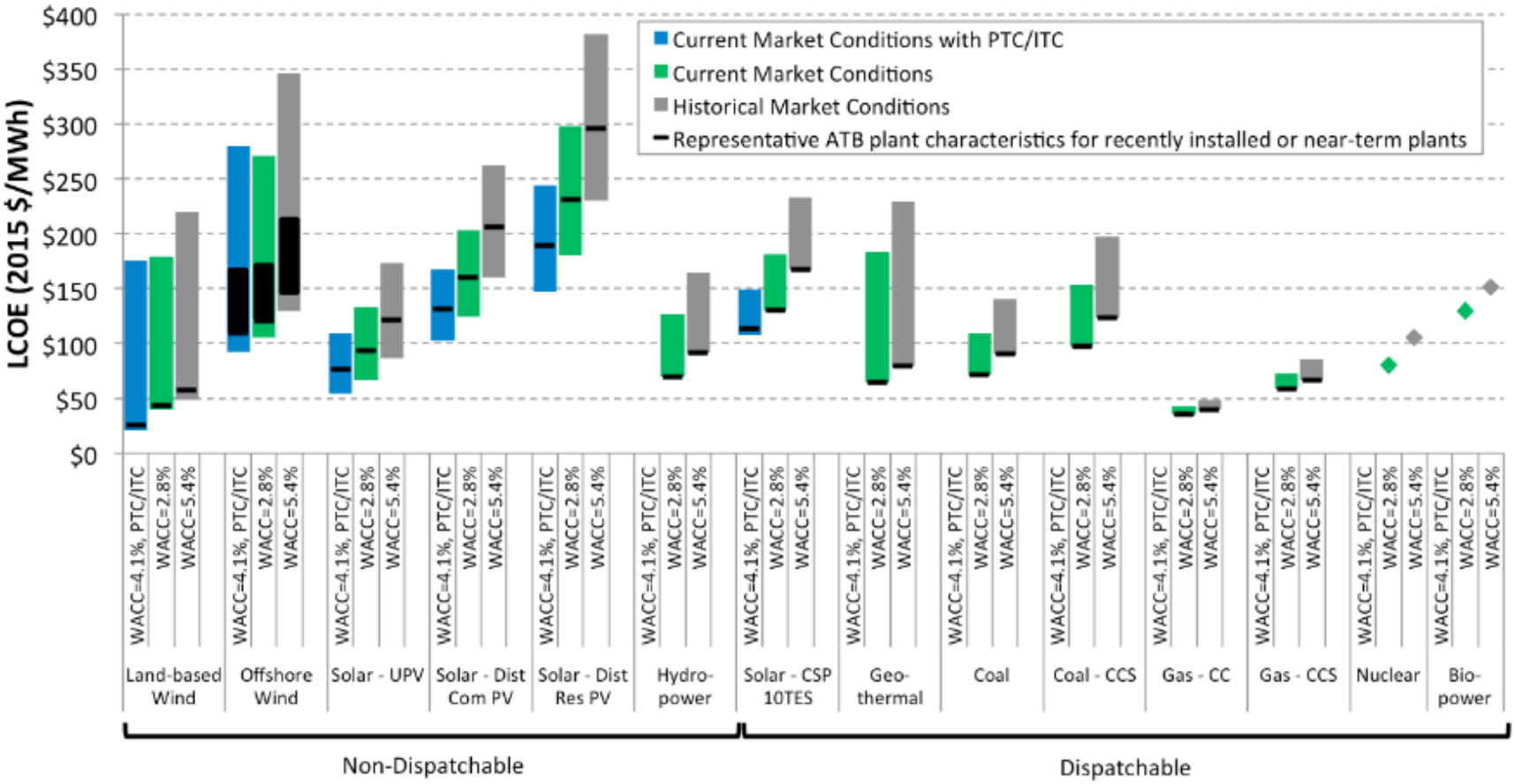


2017 ATB LCOE range by technology for 2050 based on current market conditions

Source: National Renewable Energy Laboratory Annual Technology Baseline (2017), 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.
- LCOE estimates do not include incentives (production tax credit, investment tax credit) and reflect cost of capital representative of Base Year.

Sensitivity of Base Year LCOE to Project Finance Parameters

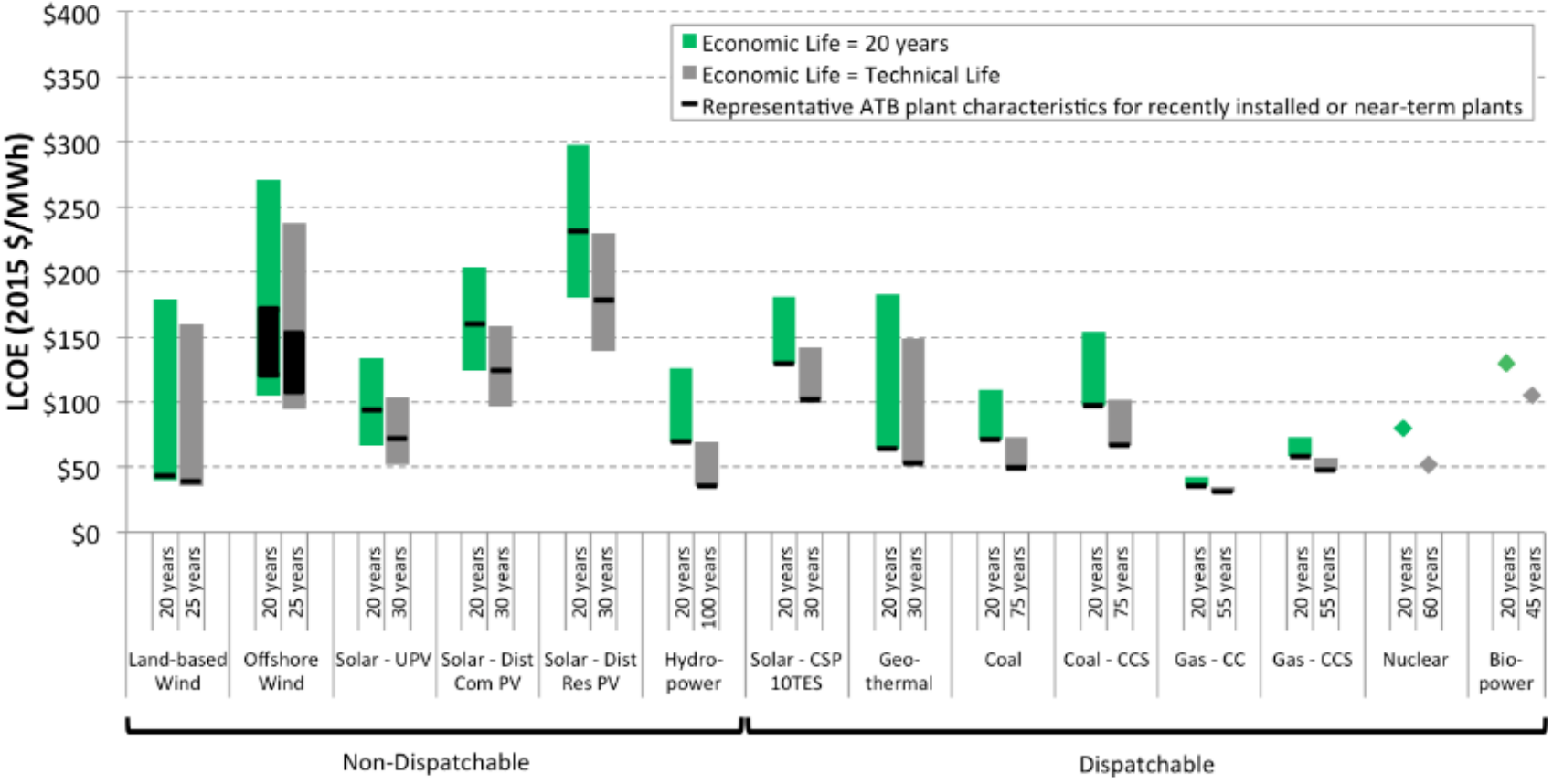


LCOE sensitivity to project finance parameters

Source: National Renewable Energy Laboratory Annual Technology Baseline (2017), http://atb.nrel.gov

- **Current Market Conditions**: This scenario reflects debt interest and return on equity rates to represent 2017 market conditions (AEO 2017)
- **Long-Term Historical Market Conditions**: Historically, debt interest and return on equity were represented with higher values. This scenario reflects debt interest and return on equity rates implemented in the ReEDS model and reflected in prior versions of the ATB and Standard Scenarios model results.

Sensitivity of Base Year LCOE to Economic Life



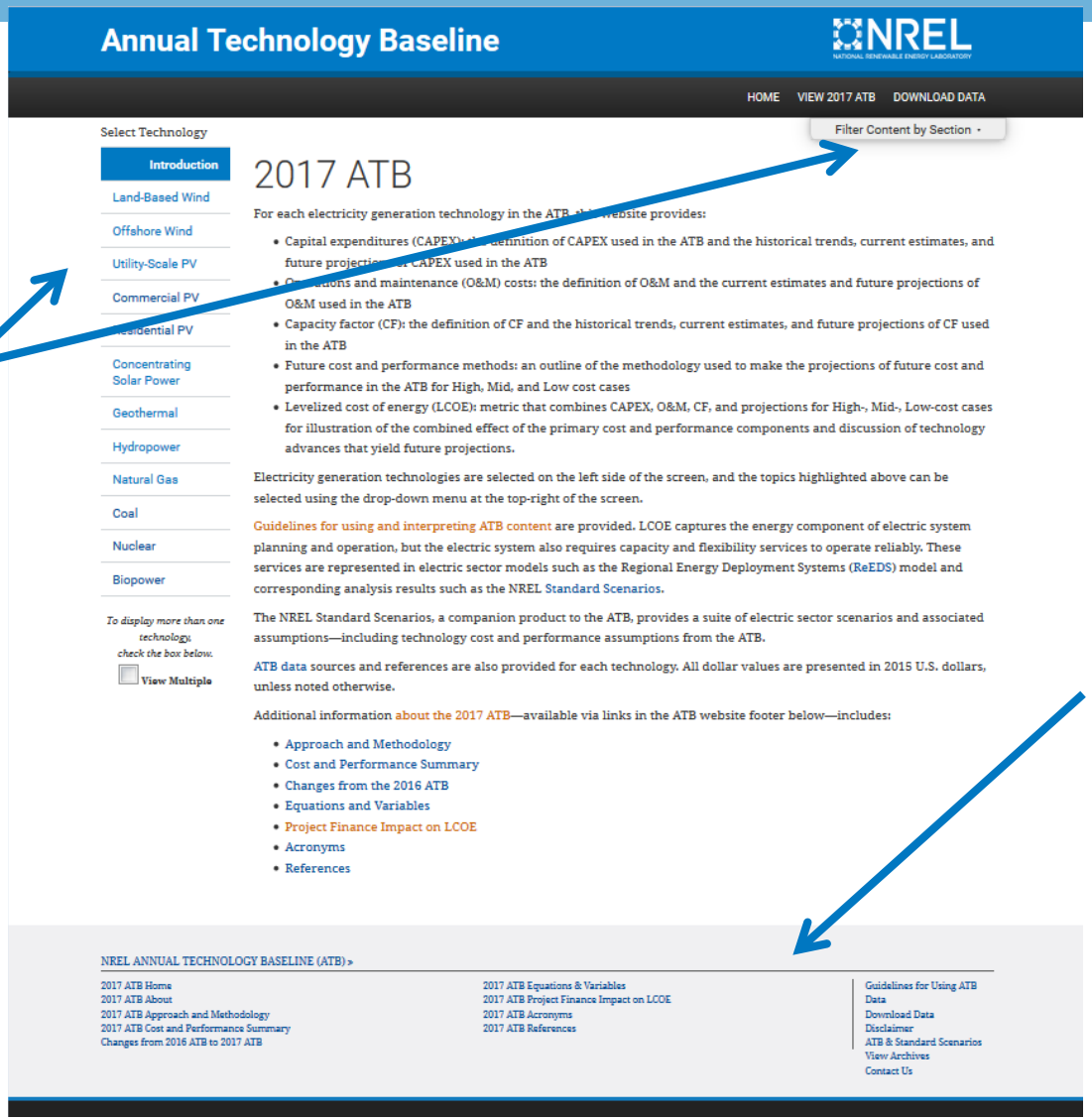
LCOE sensitivity to economic life

Source: National Renewable Energy Laboratory Annual Technology Baseline (2017), http://atb.nrel.gov

- Green: Economic life is 20 years for all technologies.
- Gray: Economic life is equal to technical life and varies by technology.

Website Improves Access to Information

User selects technology and content topic (e.g., CAPEX, O&M, Capacity Factor)



Cross-technology and general information

Website content mirrors prior edition PDF document but provides greater flexibility in presentation and ease of access by user.

Potential Improvements

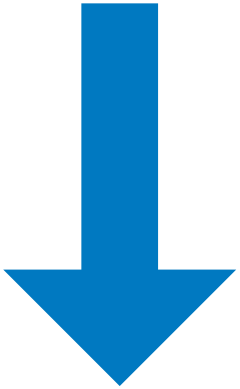
- Enhance geothermal representation with Geothermal Vision study insights
- Enhance cost and performance projections methodology with bottom-up modeling and technology advancement focus
- Add storage technologies

Standard Scenarios Preview

The ATB Data Are Inputs for Standard Scenarios

Annual Technology Baseline (ATB)

Cost and performance assumptions for renewable and conventional technologies



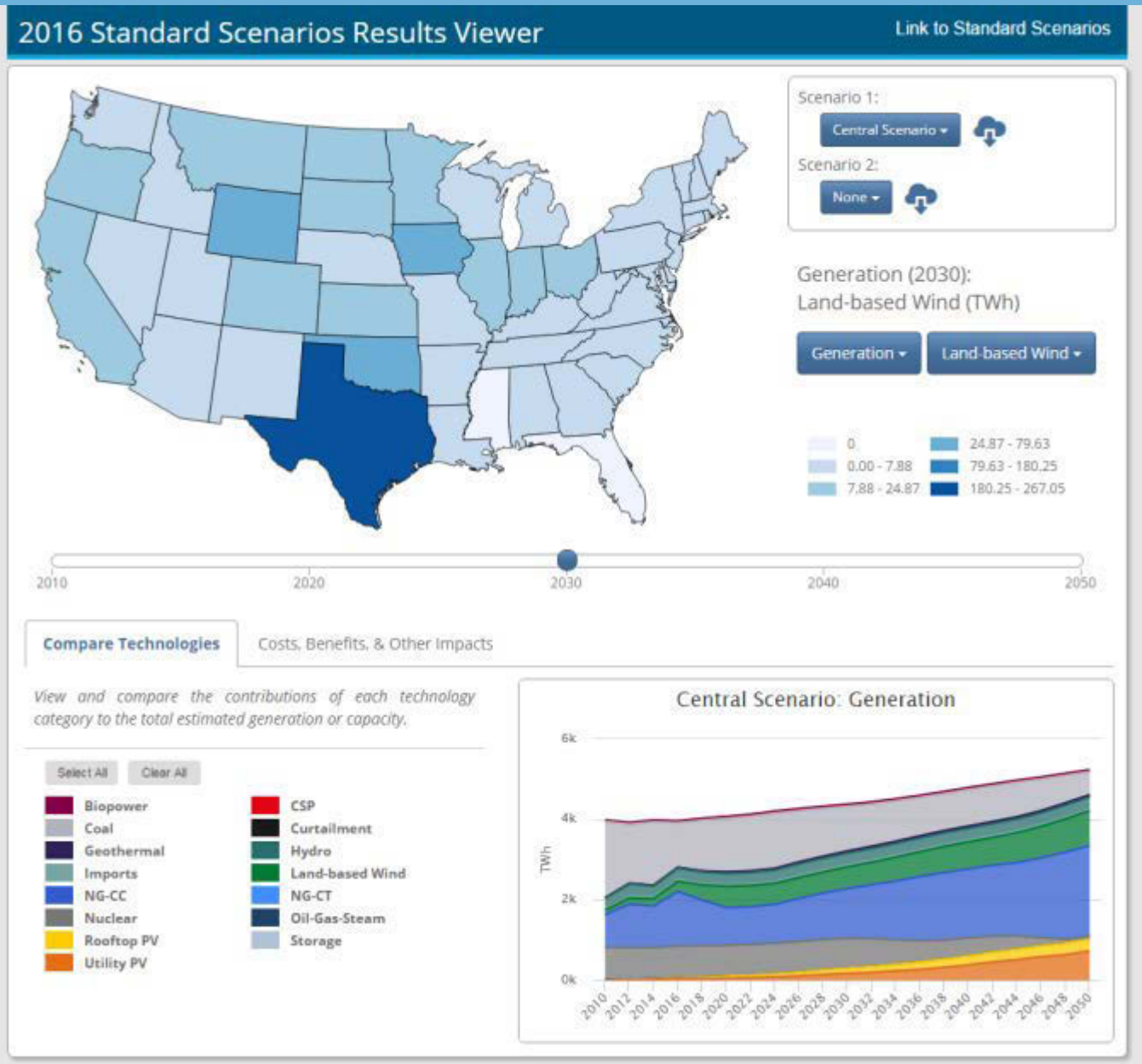
Standard Scenarios

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

Standard Scenarios

- 26 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
- Report explores four areas of change in the electricity sector
  - Natural Gas and RE continue to lead new capacity additions
  - Relative competiveness of Wind and PV drive mix of renewable energy
  - Storage has the potential to become a main-stream electric sector technology
  - Uncertainty in nuclear lifetimes leads to wide range of new capacity needs

Scenario Results to be Available Online



Thank you!

The 2017 Annual Technology Baseline is available at atb.nrel.gov.

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