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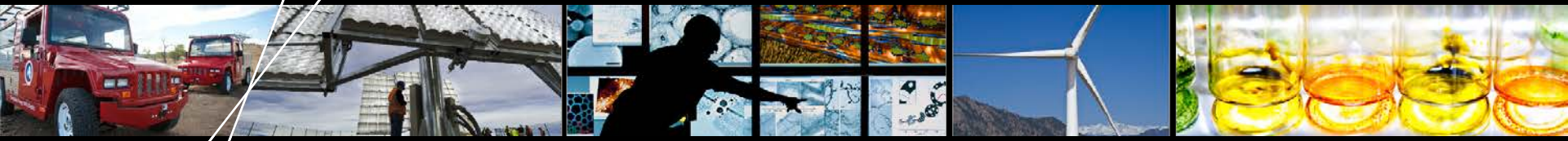
NATIONAL RENEWABLE ENERGY LABORATORY

2016 Annual Technology Baseline (ATB) – Webinar Presentation



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Outline

- Project Background
- ATB Methodology
- Summary of ATB Changes Since Last Year
- Preview of Standard Scenarios

Annual Technology Baseline (ATB)

- **Generation technology cost and performance: current data and future projections compiled into a single workbook**
  - Careful tracking of source data
  - Comparisons against historical data and other projections provided where feasible
  - Harmonization of methodologies where feasible
- **Updated and published annually to inform electricity sector analysis**

Annual Technology Baseline (ATB)

- **Two products:**
  - ATB spreadsheet – includes all the specific technology inputs for current and future costs and performance
  - ATB presentation – includes details about the technologies and the methods used to create the projections
- **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

ATB Technologies

- Land-based Wind Power Plants
- Offshore Wind Power Plants
- Utility-Scale Solar PV Power Plants
- Distributed Residential and Commercial-scale Solar PV
- Concentrating Solar Power Plants
- Geothermal Power Plants: Flash and Binary Organic Rankine Cycle
- Hydropower Plants: Upgrades to Existing Facilities, Powering Non-Powered Dams, and New Stream-reach Development
- Conventional Power Plants: Fossil, Bio, Nuclear

Annual Technology Baseline Objectives

- Develop consistent and normalized technology cost and performance assumptions
- Enable consistency in assumptions across analysis projects (and modeling)
- Facilitate the tracking and sourcing of input assumptions
- Reduce the lead time in conducting scenario analysis

Types of ATB Uses

- **Environmental Protection Agency**
  - Used in the final rule of the Clean Power Plan (CPP)
  - Used in climate/water modeling scenarios
- **NERC, Midwest ISO (MISO), PJM**
  - Adopted RE component for CPP-related analyses
- **Rhodium Group, Union of Concerned Scientists, Environmental Defense Fund, Resources for the Future, Sustainable Energy Economics, Global CCS Institute, Institute for Integrated Energy Systems (Canada), Comisión Nacional de Energía (Chile)**
  - Used for modeling, LCOE comparison, cost data
- **Hawaii Electric Company (HECO)**
  - Used to inform resource plan
- **Bureau of Land Management**
  - Solar Energy Zones modeling
- **Department of Energy**
  - Various electricity sector analysis

Overview of Current Costs in the ATB

Technology	Source
Land-based and Offshore Wind Power Plants	Wind Vision Report (2015), compared to wind market data reports
Utility, Residential, and Commercial PV Plants	Bottoms-up cost modeling from Feldman et al. (2015), compared to PV market data reports
Concentrating Solar Power Plants	Bottoms-up cost modeling from Kurup and Turchi (2015), compared to recent CSP plant (Crescent Dunes) costs
Geothermal Plants	Bottoms-up cost modeling using GETEM
Hydropower Plants	Hydropower Vision Report (2016), cost modeling from O'Connor et al. (2015)
Conventional Plants	Annual Energy Outlook reported costs

Overview of Future RE Cost Projections

Technology	Source	Rationale
Land-based and Offshore Wind Power Plants, Utility PV Plants, Residential and Commercial PV, Hydropower Plants	High, low, and median values of population from published studies that include cost projections for scenario modeling	Defining ATB High, Mid and Low cost cases as bounding scenarios to published literature provides a broad range of perspective
Concentrating Solar Power (CSP) Plants	High, low, and median values are taken from analysis of the published literature, primarily the SunShot Vision report and new technology pathway analysis in On the Path to SunShot reports.	Defining High, Mid and Low CSP cases in relation to detailed near-term analysis (2020) and relative to published literature provides a range of perspective
Geothermal Plants	Site-specific nature, relative maturity of technology, and lack of existing literature survey lead to assumption of no cost reduction (High, Mid) and application of learning similar to AEO 2015 (Low).	Geothermal Vision study which will likely result in industry developed cost reduction scenarios is underway.

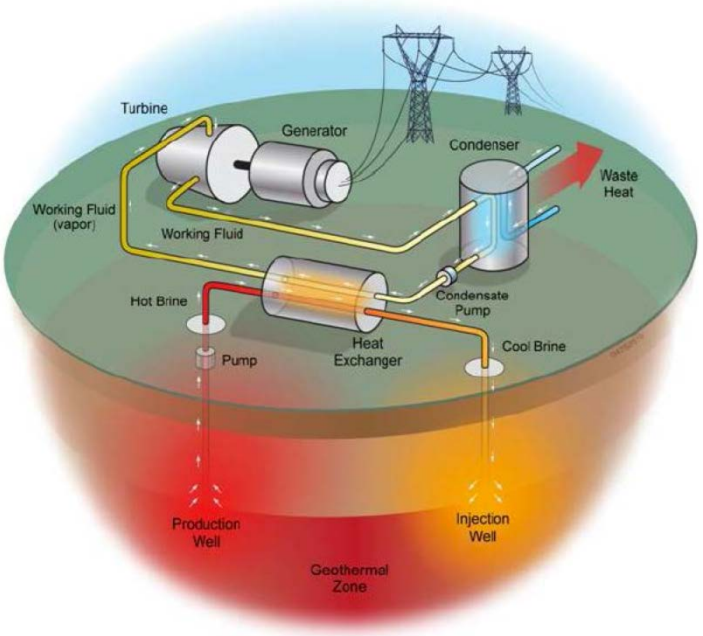
ATB Format

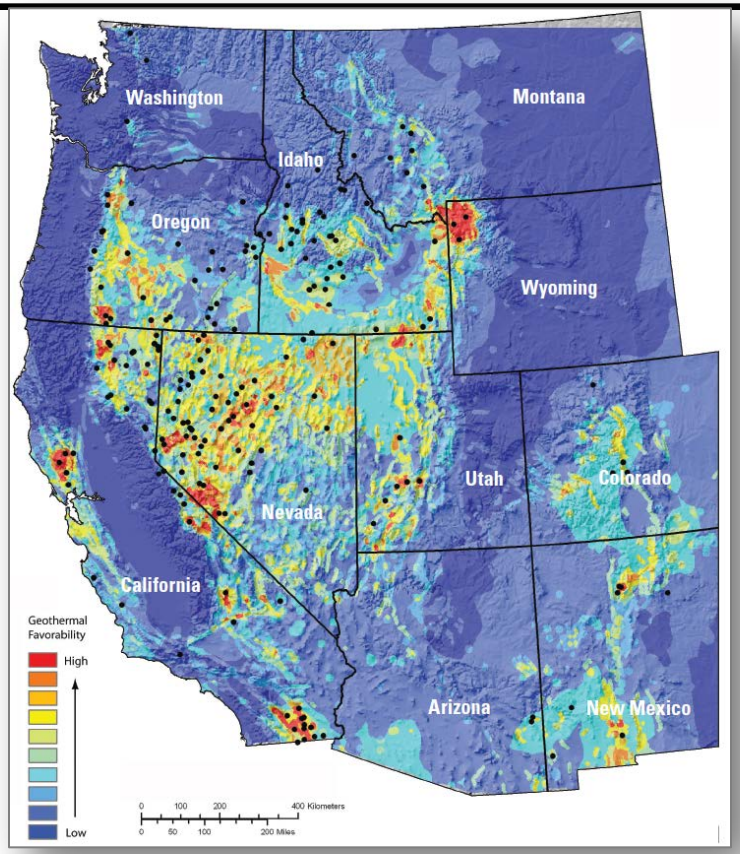
- **Each technology includes a summary**
  - Overview of the technology and resource
  - Capacity factor Base Year estimates and projection through 2050
  - CAPEX definition
  - CAPEX Base Year estimates and projection through 2050
  - O&M overview
  - Description of methodology and comparison with other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

Examples across technologies in following slides

Geothermal Technology Overview - Hydrothermal

[EXAMPLE SLIDE]





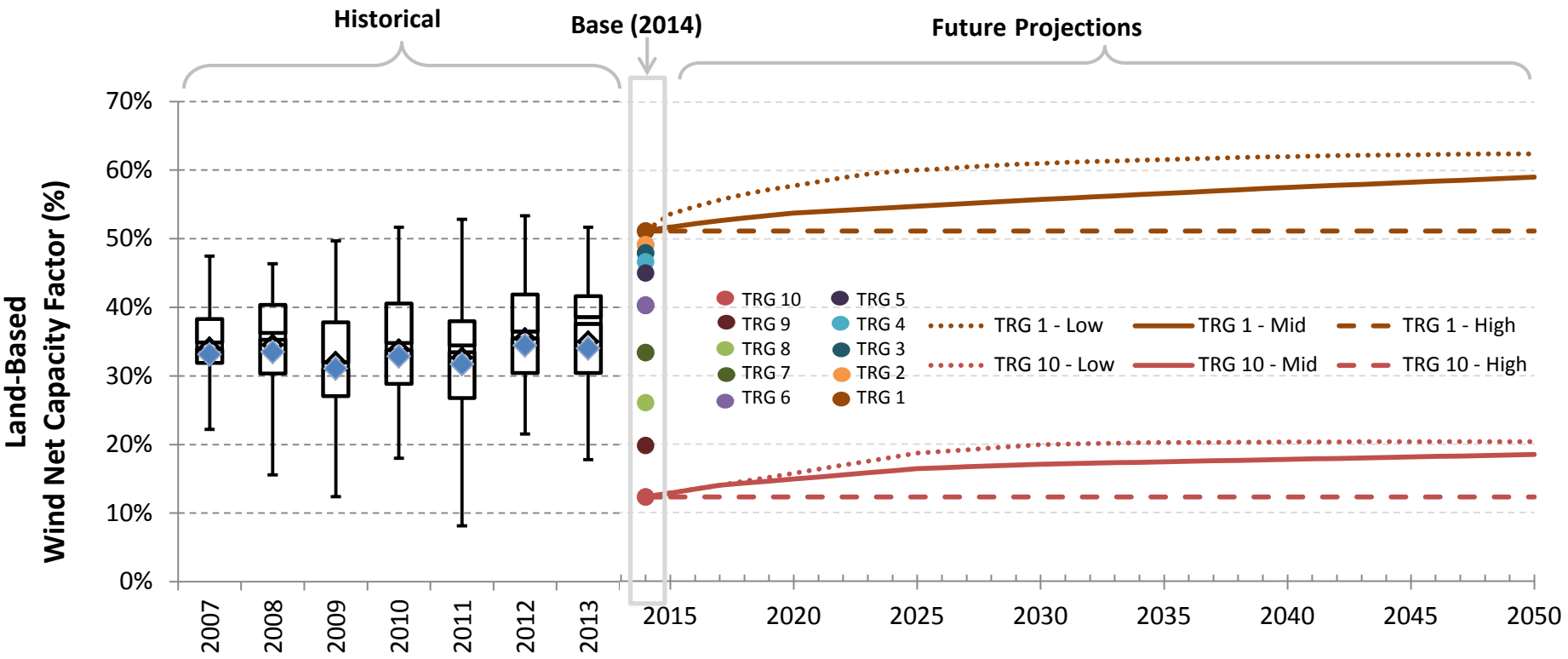
Source: Williams et al. (2008). USGS, "Assessment of Moderate- and High-Temperature Geothermal Resources of the United States," http://pubs.usgs.gov/2008/3082.

- **Hydrothermal Resource Potential**
  - Identified – 7,833 MW
  - Undiscovered – 37,537 MW
- **Development Costs – Calculated using "Geothermal Electricity Evaluation Model" (GETEM)**

[Additional detail and references in slide notes]

Land-based Wind Plant Capacity Factor: Expected Annual Average Energy Production Over Lifetime

[EXAMPLE SLIDE]



◇ generation-weighted average, not index weighted

◆ generation-weighted average, wind index weighted

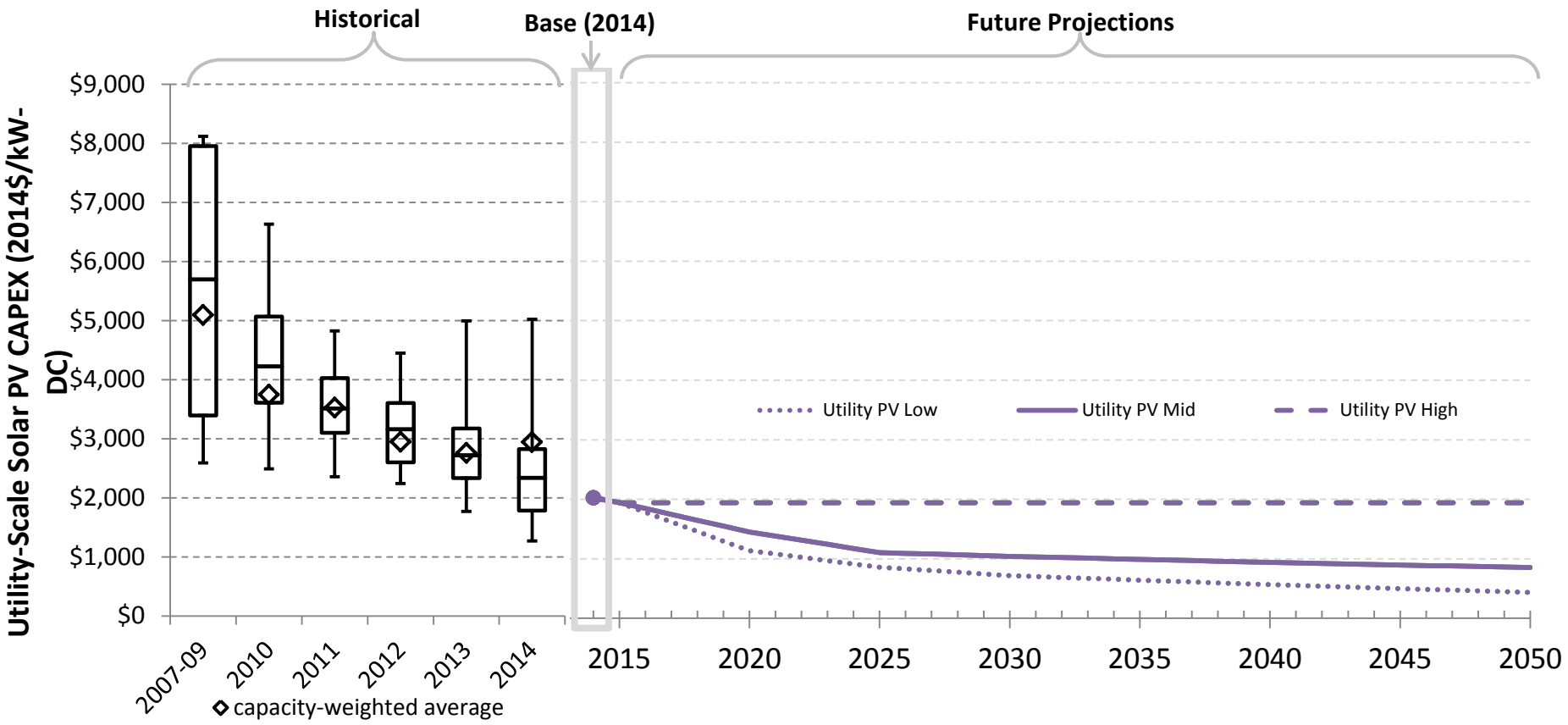
Historical data represents capacity factor for operation in 2014 for plants with Commercial Online Date specified by year.

Projection data represents expected annual CF for plants with Commercial Online Date specified by Year.

- **CF influenced by rotor swept area / generator capacity, hub height, hourly wind profile, expected downtime, energy losses within wind plant**
- **Majority of installed U.S. wind plants generally aligned with ATB estimates for performance in TRGs 5-7. High wind resource sites associated with TRGs 1 and 2 as well as very low wind resource sites associated with TRGs 8-10 are not as common in historic data, but the range of observed data encompasses ATB estimates.**

Utility PV:
CAPEX Historic Trends, Current Estimates, and Future Projections

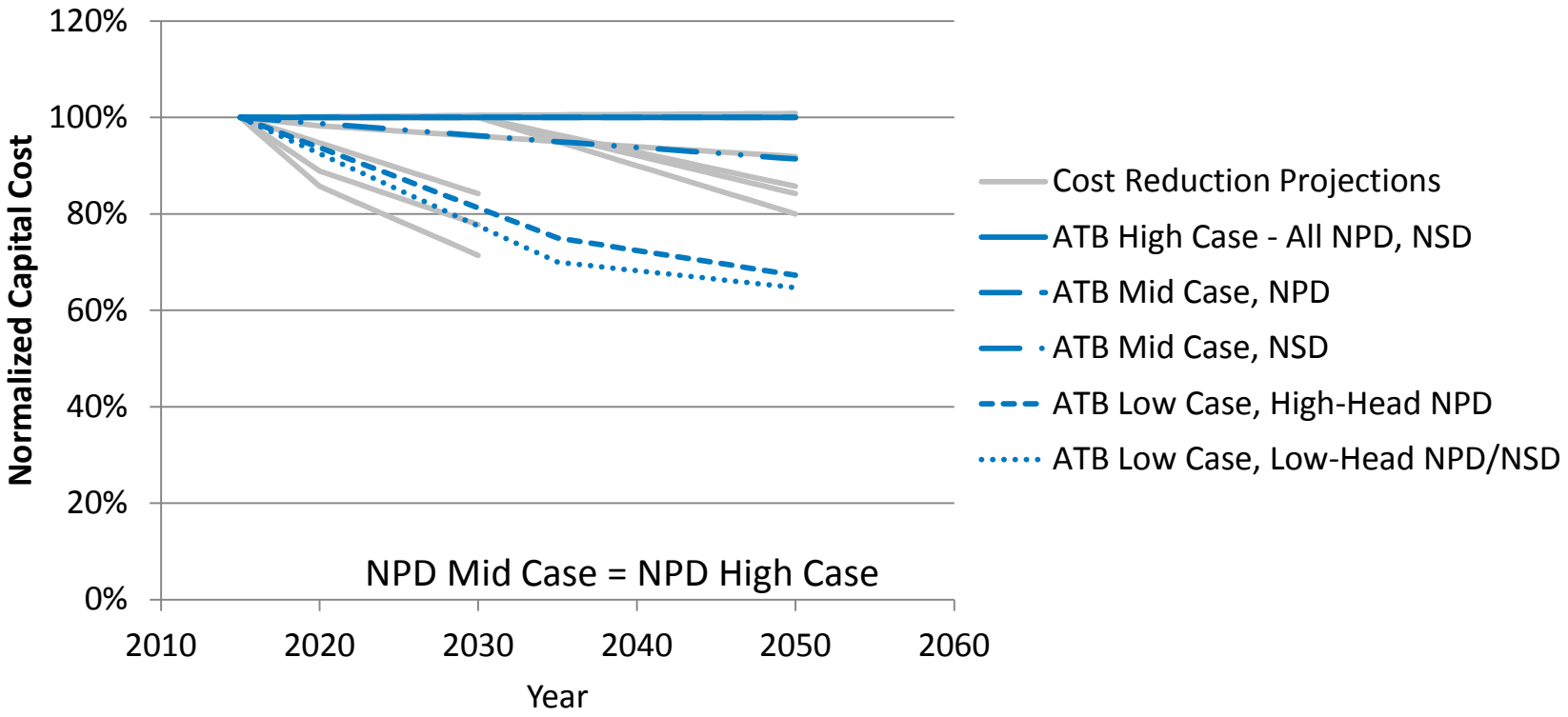
[EXAMPLE SLIDE]



- CAPEX estimates for 2015 reflect continued rapid decline supported by analysis of recent PPA pricing (Bolinger and Seel) for projects that will become operational in 2015 and beyond.
- CAPEX estimates should tend toward the low end of reported pricing because no regional impacts, time-lagged system prices, or spur line costs are included.
- Capacity weighted average system prices are higher than 80% of system prices in 2014 due to very large systems, with multi-year constructions schedules, installed.

[EXAMPLE SLIDE]

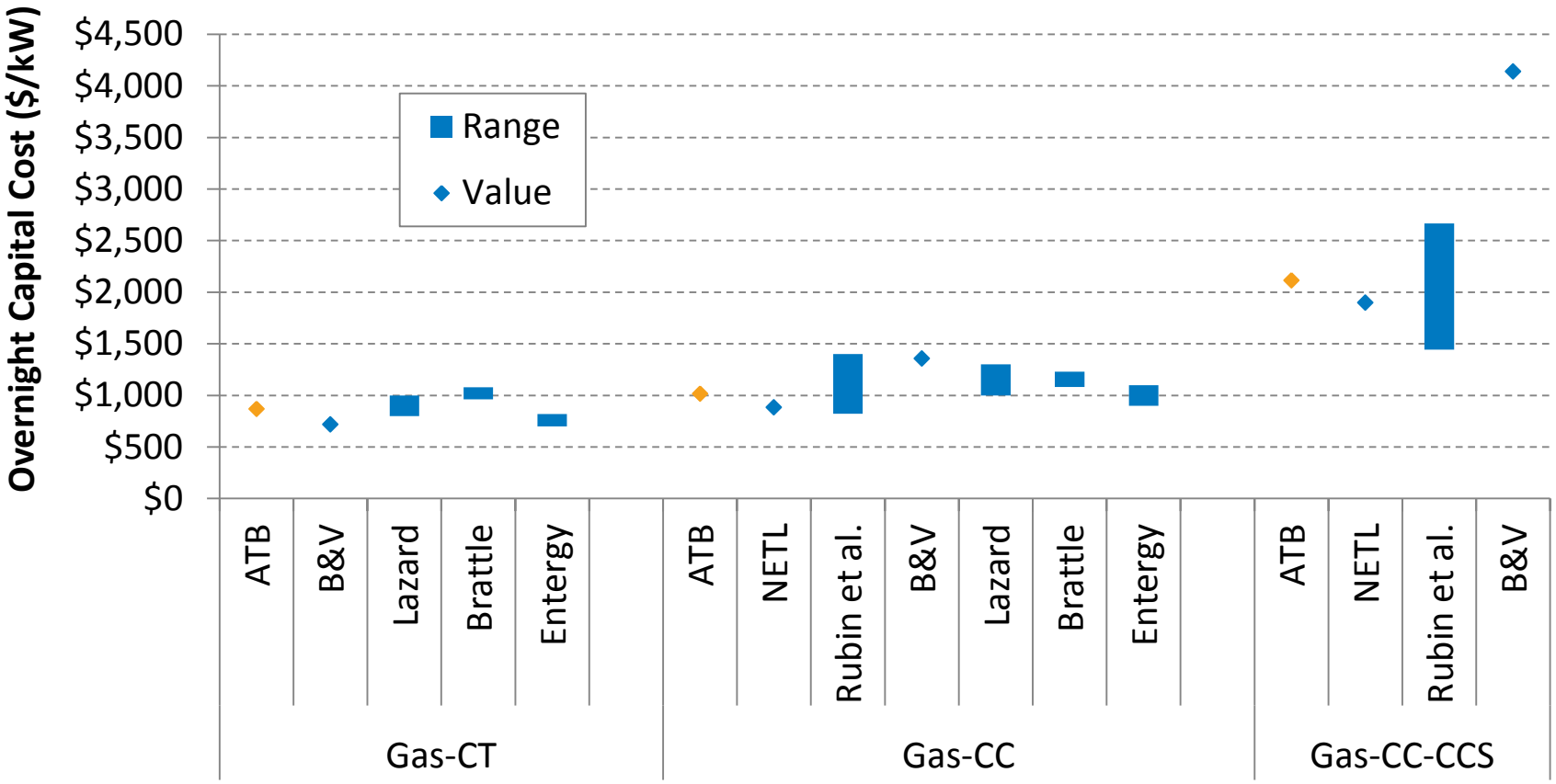
Hydropower Plant Cost and Performance Projections Methodology



- **Projections developed using bottom-up analysis of process and/or technology improvements to provide a range of future cost outcomes.**
  - Low Cost: gains achievable when pushing to the limits of potential new technologies such as modularity (in both civil structures and power train design), advanced manufacturing techniques, and materials.
  - Mid Cost: aggressive equipment standardization efforts, widespread implementation of value engineering and design/construction best practices using generally conventional technology, evolution of licensing processes.
  - High Cost: No change in CAPEX from 2015-2050

[EXAMPLE SLIDE]

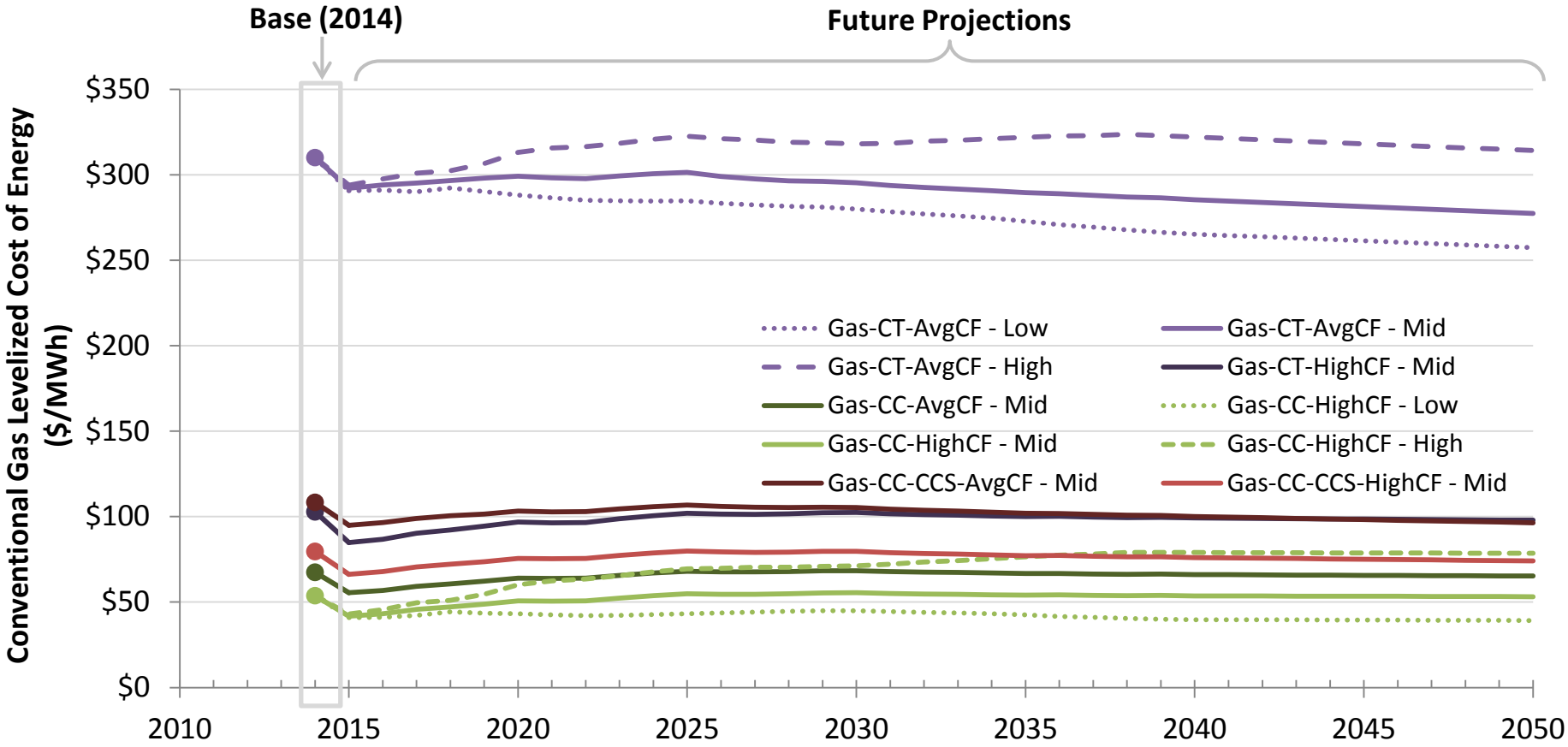
Comparison with Other Sources



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

[EXAMPLE SLIDE]

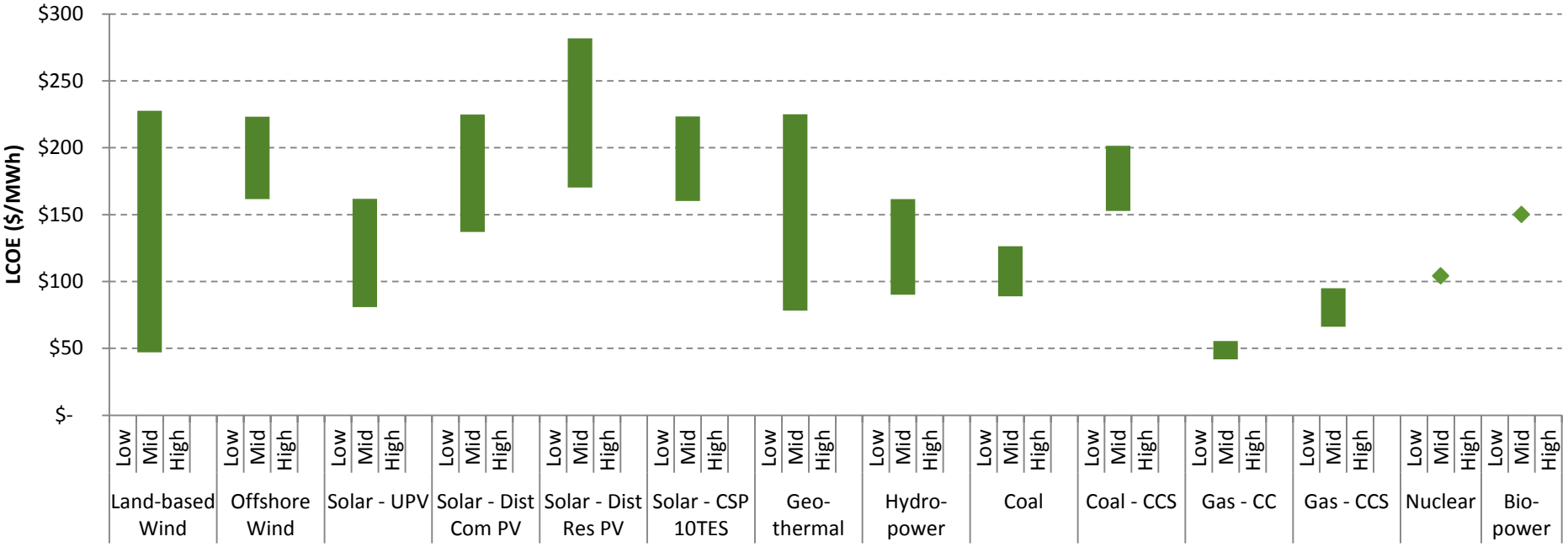
Natural Gas Cost and Performance Projections



- **The LCOE of natural gas plants are directly impacted by multiple natural gas fuel costs –high, medium, and low.**
- **The LCOE is also impacted by variations in the heat rate and O&M costs**

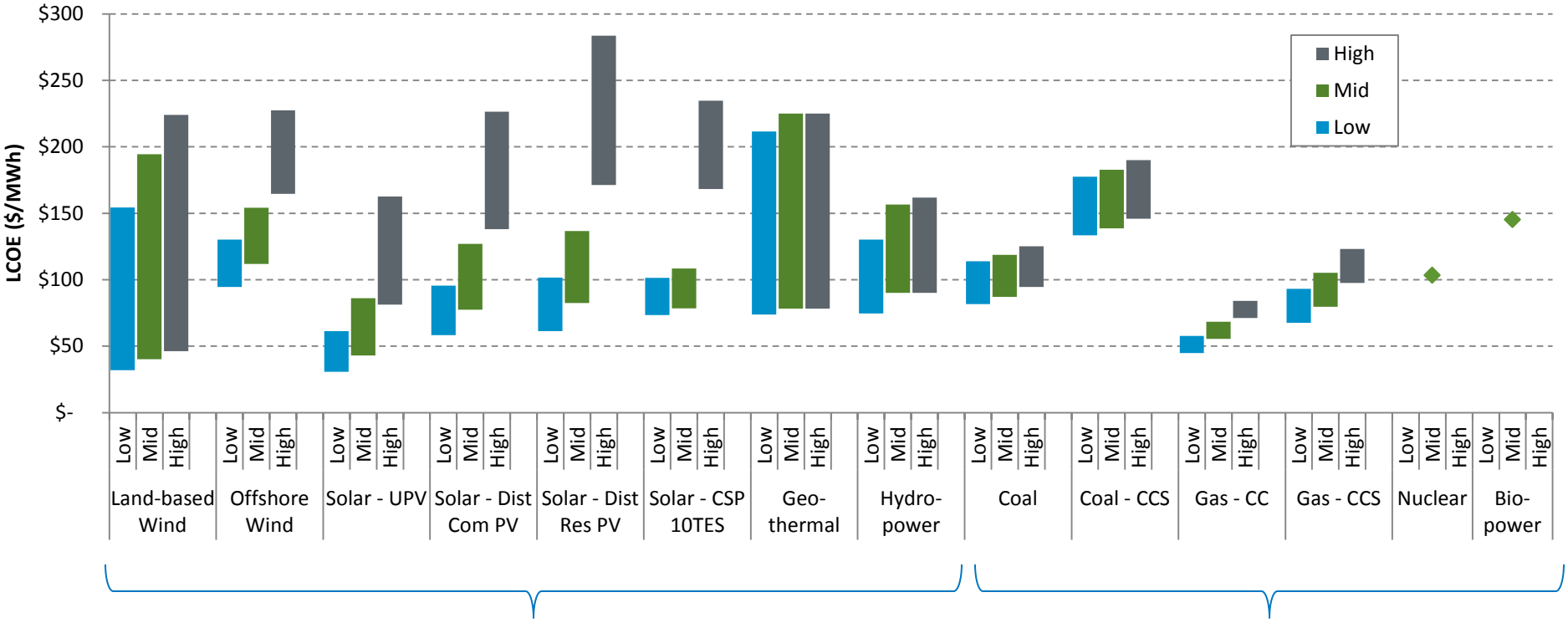
LCOE Values in 2015

- **Ranges driven by underlying ranges in CAPEX and capacity factor**



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

LCOE Projections in 2030



Cost and performance improvements for wind, solar, geothermal, and hydropower technologies result in lower magnitude LCOE and tighter range across resources.

Cost reductions for conventional technologies are associated with lower fuel costs.

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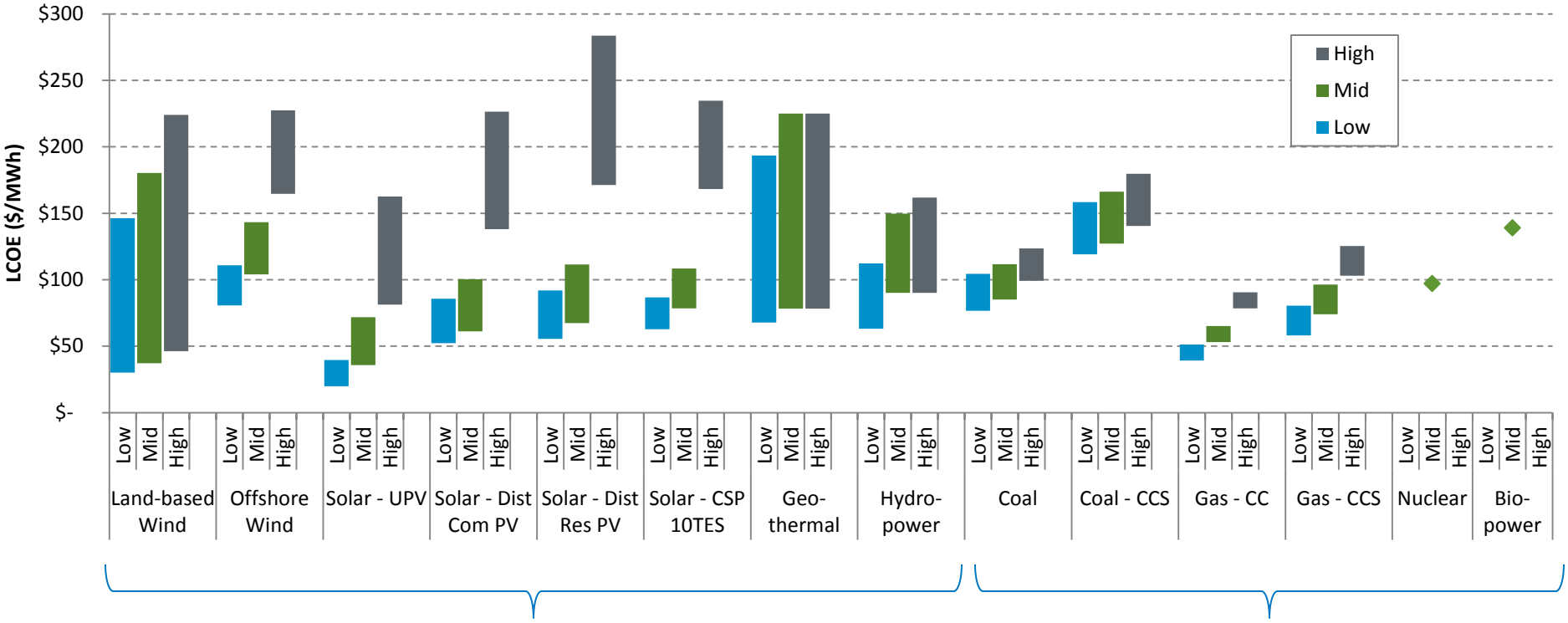
LCOE Projections in 2050



Cost and performance improvements for wind, solar, geothermal, and hydropower technologies result in lower magnitude LCOE and tighter range across resources.

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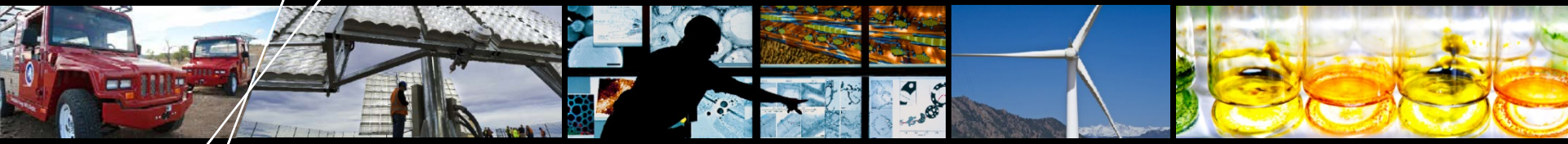


Changes from 2015 ATB to 2016 ATB

Basic Approach Remains the Same – Consistency Across Technologies Improved

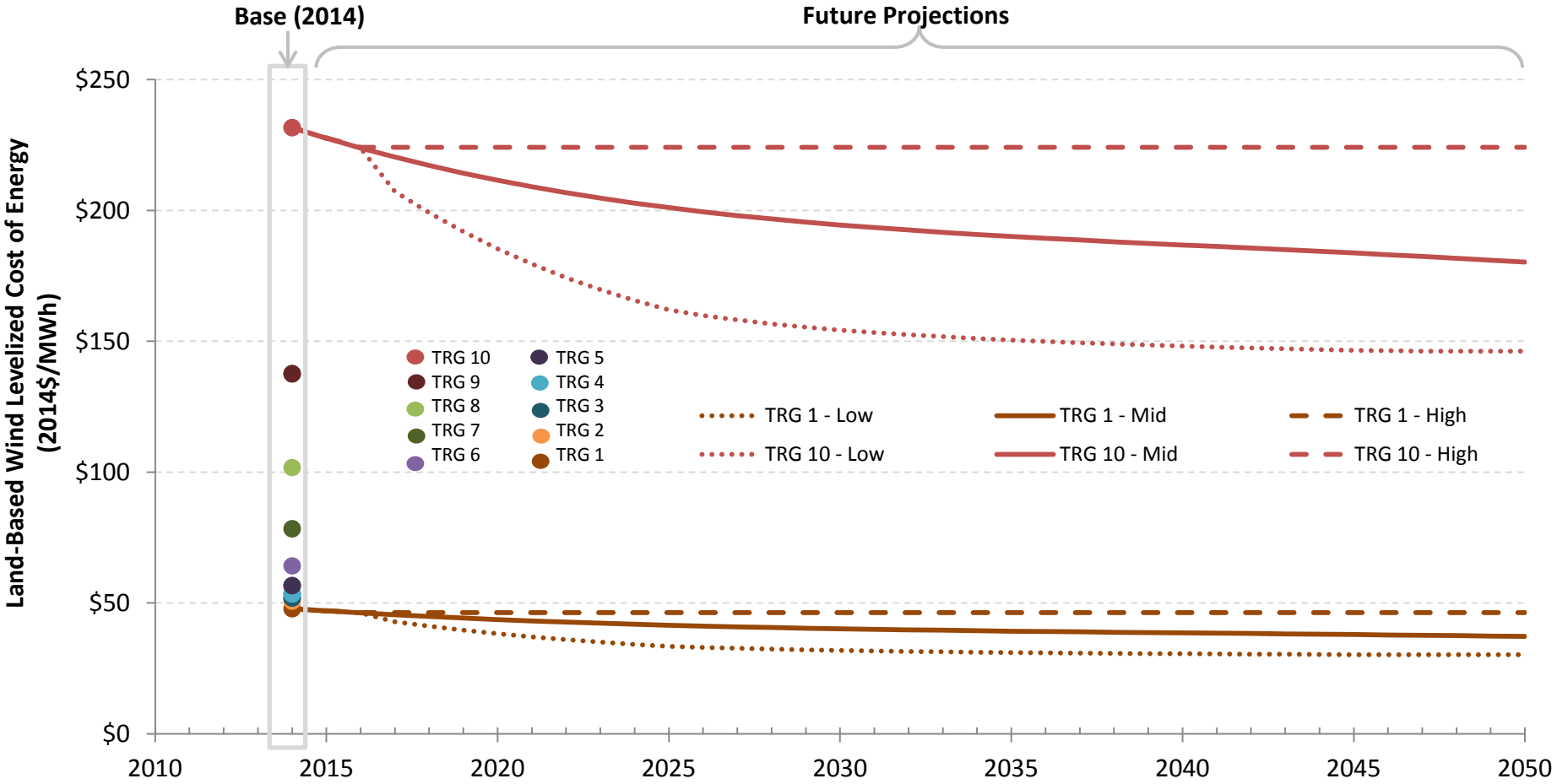
- **Base Year (current) cost and performance estimates from published, regularly updated sources or methods. If estimates are not based directly on market data, then they are compared with market observations as possible.**
- **Projections for future renewable energy cost and performance based on published literature such that:**
  - High = current cost
  - Mid = median value of literature or mid-level projection from published US-focus technology analysis (e.g., Hydropower Vision)
  - Low = low bound of literature or low-level projections from published US-focus technology analysis
  - Renewable energy exceptions include:
    - Geothermal: Vision study currently underway and will inform 2017 ATB
    - Solar CSP: Direct comparison not yet feasible due to differences in storage, field sizes, turbine technologies, etc.

Summary of Changes from 2015 ATB to 2016 ATB

- **Changes to all technologies**
  - Updated base year from 2013 to 2014
  - Updated dollar year from 2013$ to 2014$
  - Updated historical data to include data reported in 2014
  - Changed debt-to-equity ratio to 60/40 based on a literature review (see Mai et al., NREL/PR-6A20-65014, 2015)
  - Added comparison of ATB inputs and calculated LCOE against EIA and Lazard reported values

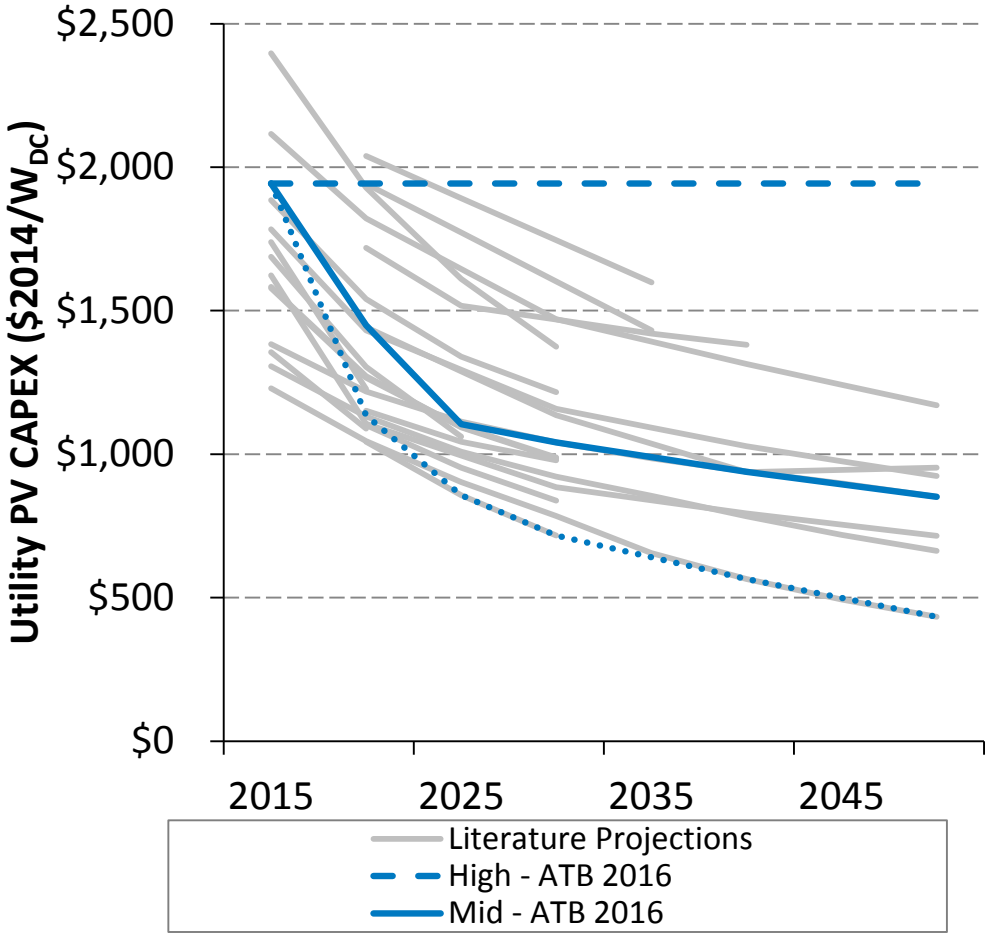
Land-based & Offshore Wind

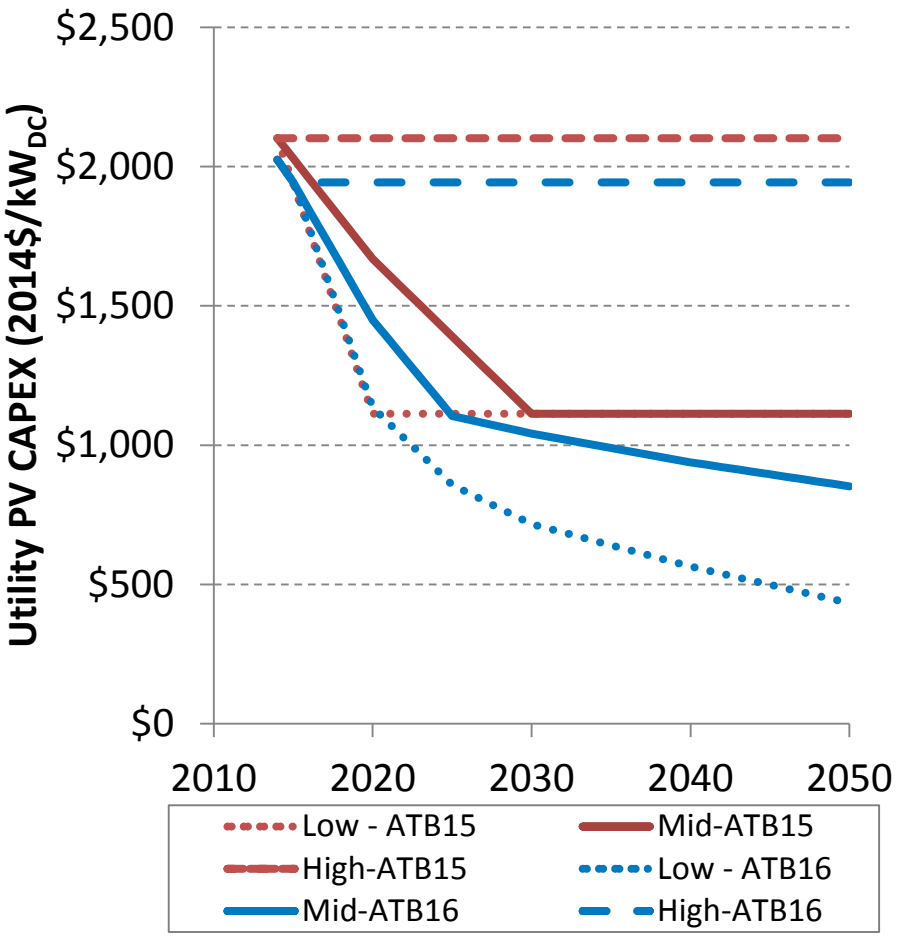
- **Base year and projections still based on Wind Vision, but TRGs expanded from 5 to 10**



Utility PV

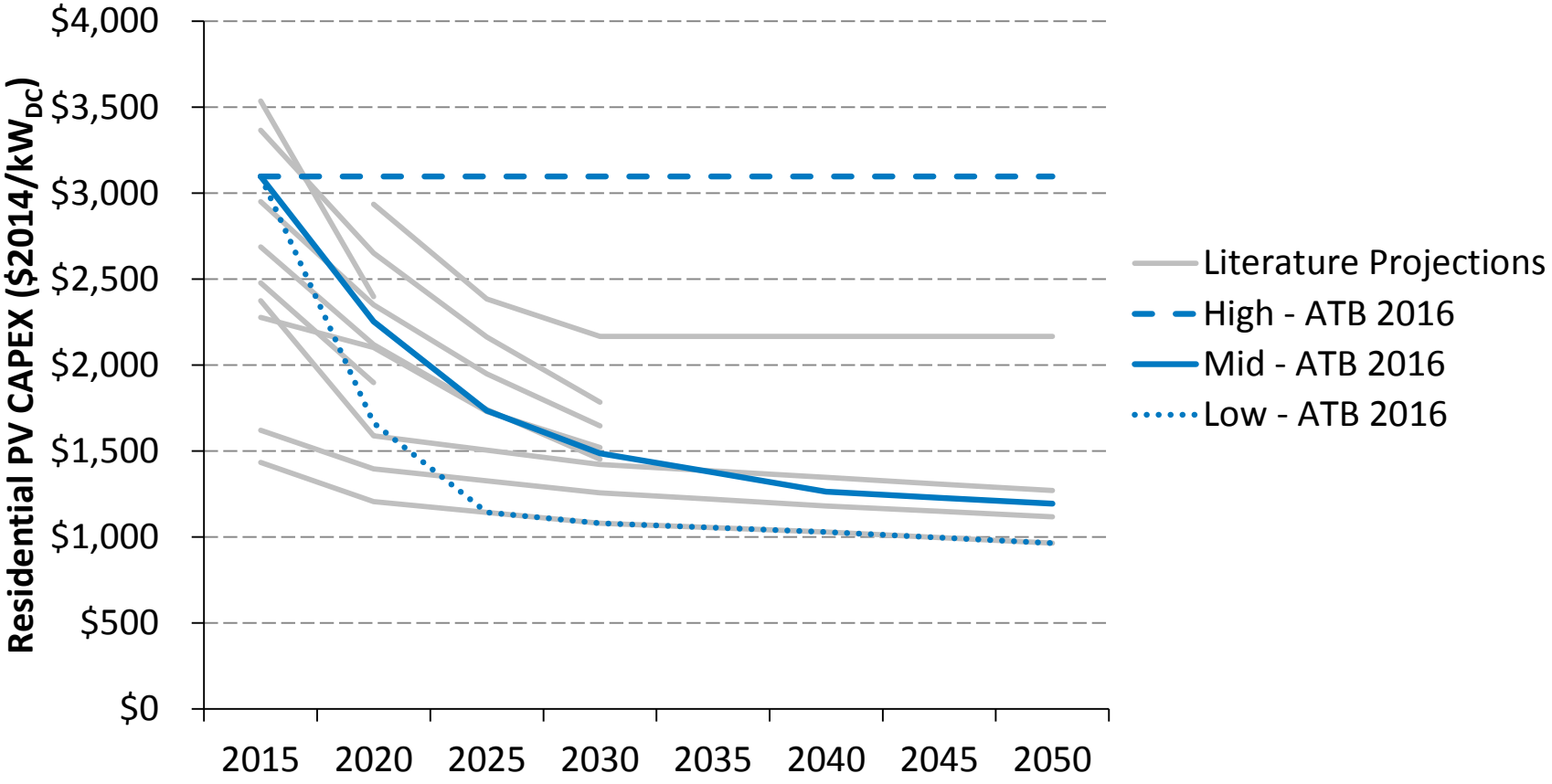
- **2014 & 2015 costs updated based on Feldman et al. NREL/PR-6A20-64898, 2015**
- **2016 ATB UPV projections are based on literature trajectories (Low = minimum; Mid = median) rather than SunShot Report trajectories used in ATB 2015**





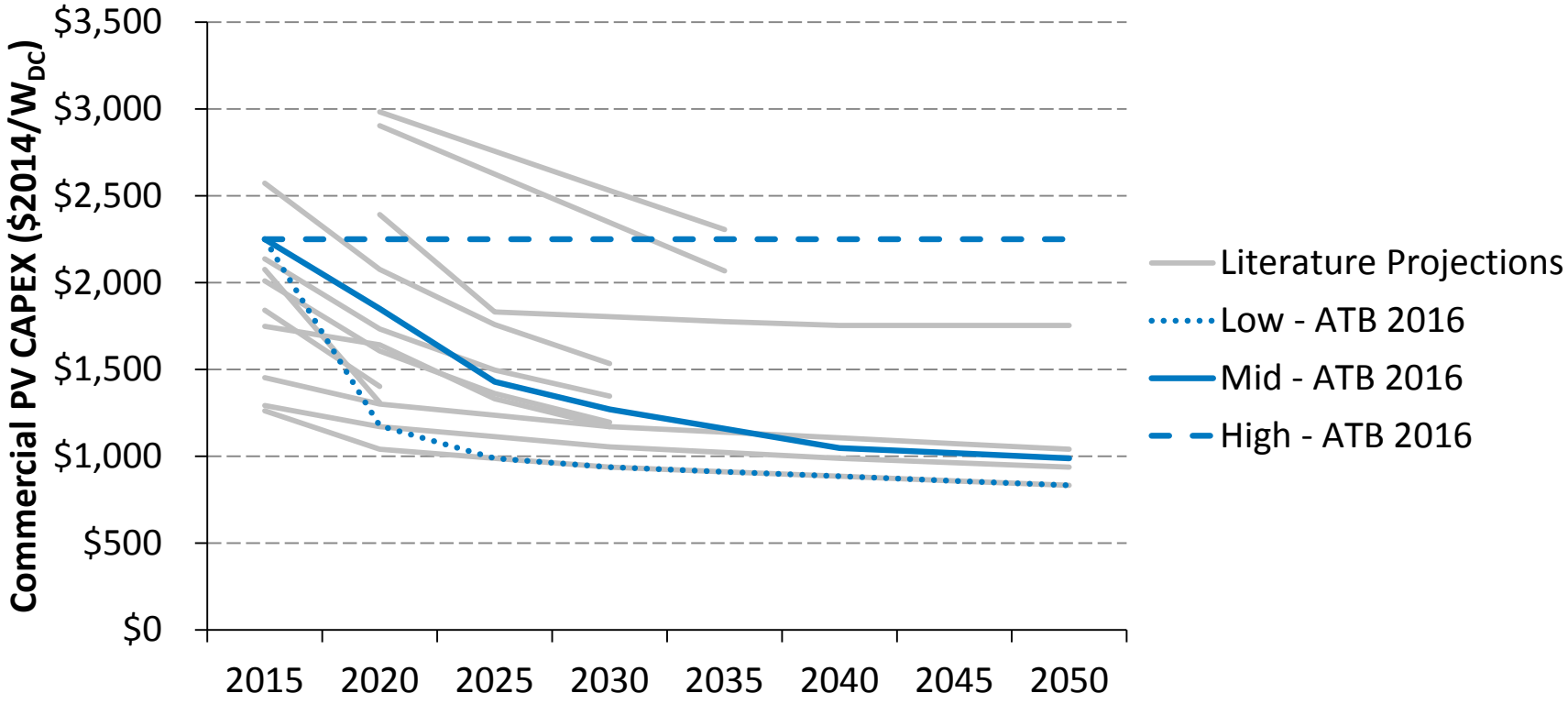
Residential PV

- **Residential PV projections are new in 2016**
- **Residential PV trajectories based on same methodology as UPV**



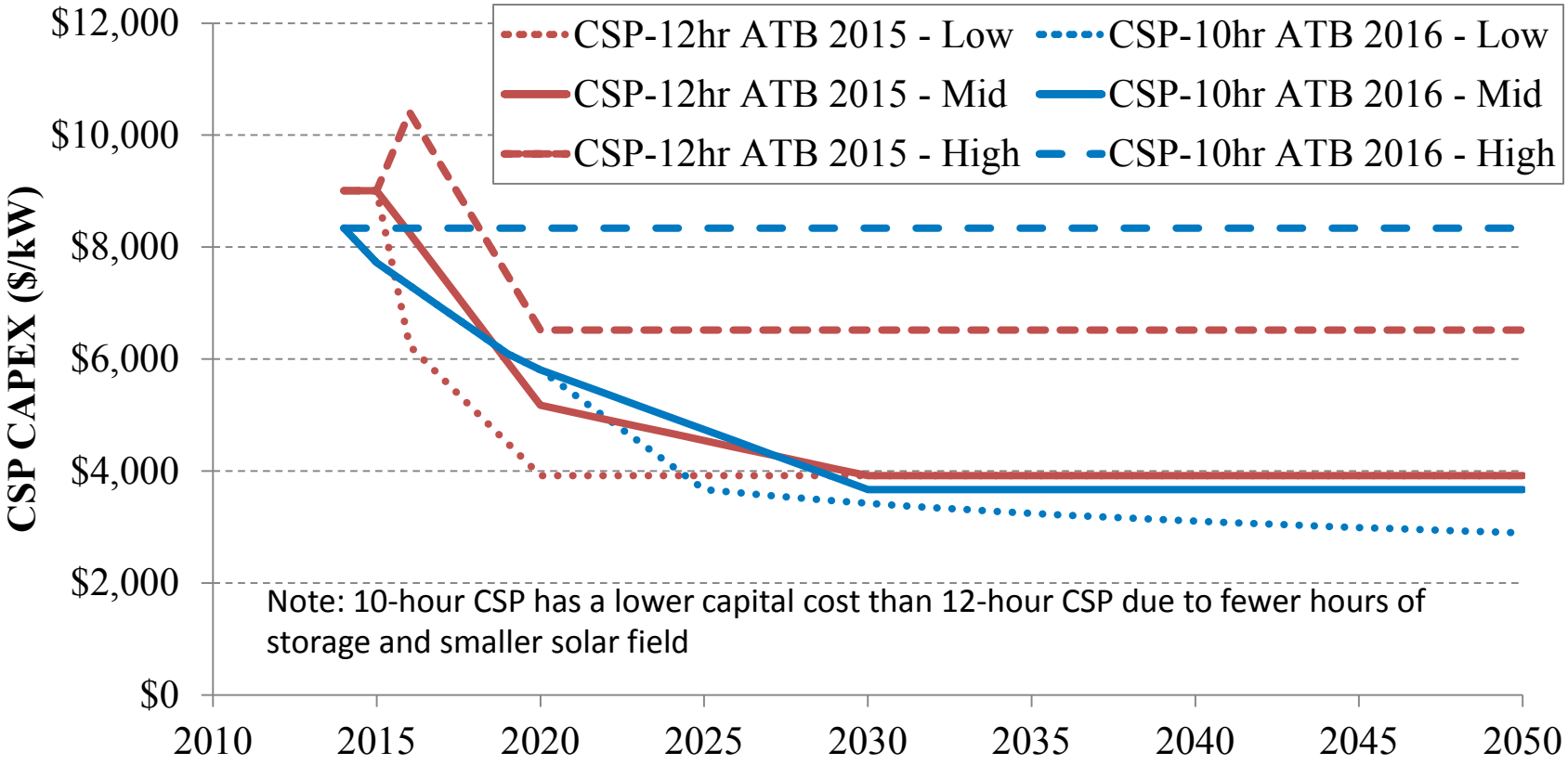
Commercial PV

- **Commercial PV projections are new in 2016**
- **Commercial PV trajectories based on same methodology as UPV**



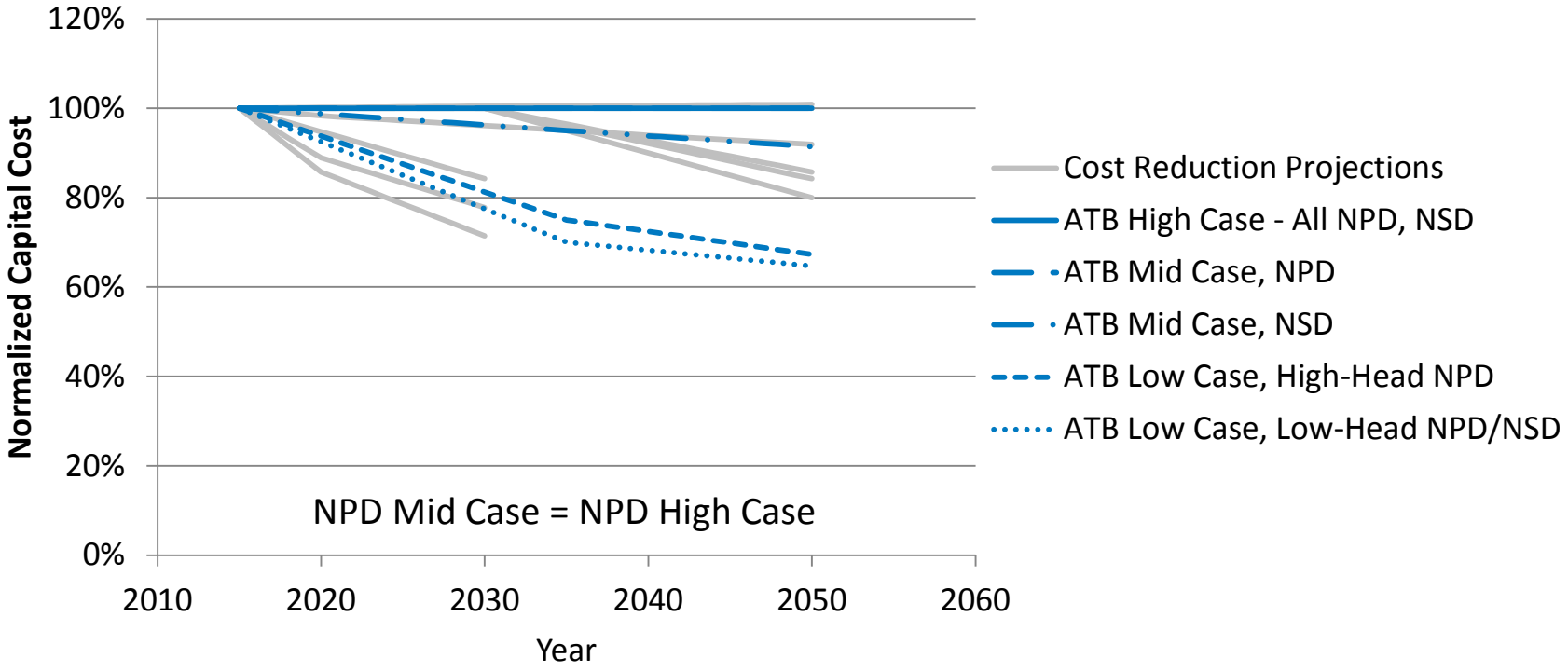
Concentrating Solar Power (CSP)

- **Default representation now uses 10 hours of storage and 2.4 solar multiple (2015 ATB used 12 and 6 hours with 2.5 and 2, respectively, for solar multiples)**
- **2020 point on mid and low cost scenarios is based on "On the Path to SunShot"**
- **Mid case still hits SunShot target in 2030**
- **Low case now hits SunShot target in 2025 instead of 2020, and includes learning post-2025**



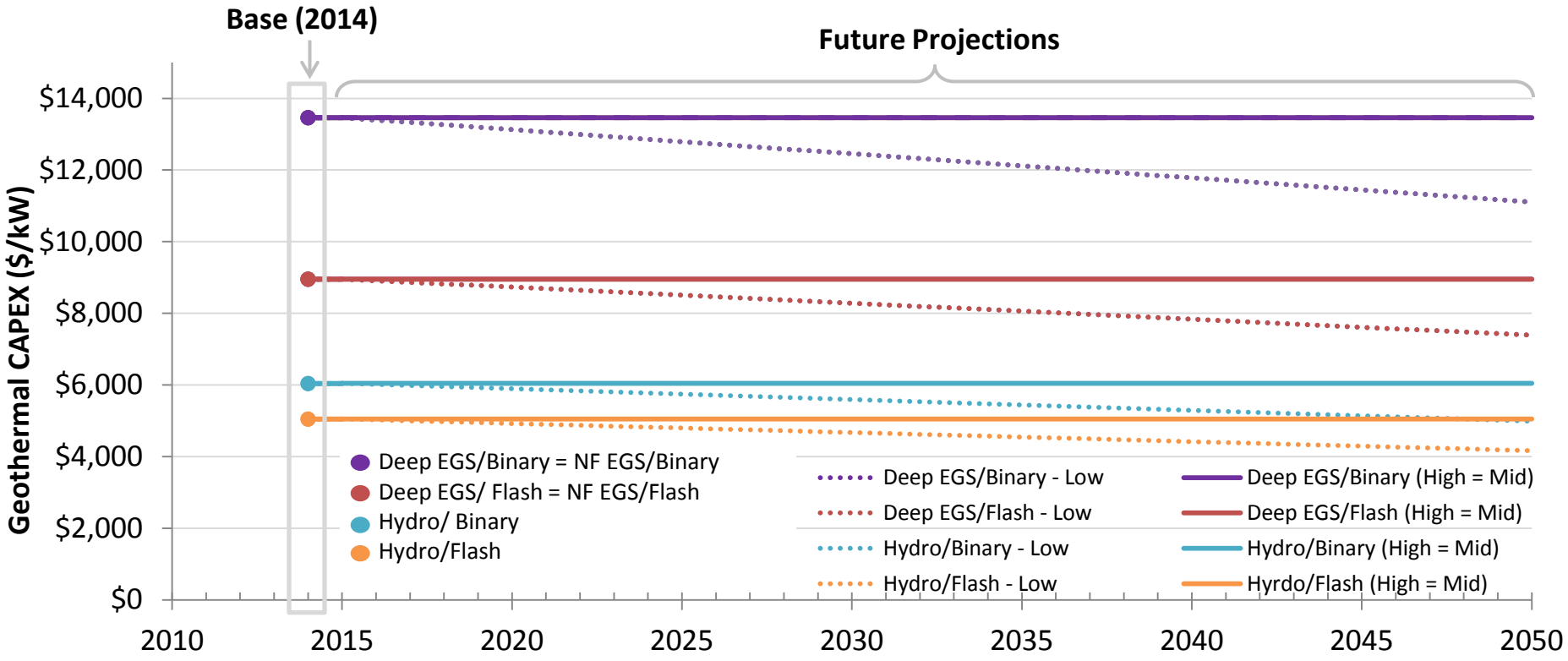
Hydropower

- **Projections based on industry input and comparison with published literature with focus on US resources (e.g., non-powered dams, new stream-reach development) from 2016 Hydropower Vision report.**
- **2015 ATB did not include hydropower projections**



Geothermal

- **AEO learning (10% cost reduction by 2035) applied for geothermal technologies to create a low cost trajectory**
- **2015 ATB did not include geothermal projections**



NF = Near-field; EGS = Enhanced Geothermal System

Conventional Technologies

- Updated conventional technologies to AEO 2016
- Updated natural gas and coal fuel costs to AEO 2016
- Added higher capacity factor coal and natural gas entries—coal and gas technologies now have a fleet wide capacity factor entry and a "maximum" capacity factor entry
- Included more information around current costs
- Extended capital cost reduction trajectories that ended in 2040 out to 2050

Summary of Changes from 2015 ATB to 2016 ATB

- **Land-based & Offshore Wind**
  - Base Year and Projections based on Wind Vision Report, unchanged from 2015 ATB.
  - Land-based TRGs expanded from 5 to 10
- **Solar PV**
  - Base Year: 2014 & 2015 costs updated based on Feldman et al. NREL/PR-6A20-64898, 2015
  - Projections: Updated UPV cost projection methodology to be literature-based (previous method was based on SunShot targets only)
  - Added commercial and residential PV Base Year and Projections using the same methodology as UPV
- **Solar CSP**
  - Base Year: Default representation is 10-hours of Thermal Energy Storage (2015 ATB had 6 and 12 hours)
  - Projections: High case uses current costs
  - Mid case assumes steady cost reduction and that CSP hits SunShot targets in 2030 (similar to 2015 ATB)
  - Low case projection assumes that CSP hits SunShot targets in 2025 based on new technology development assumptions from On the Path to SunShot; Low case includes learning rate for post-2025 cost reductions
- **Geothermal**
  - Base Year: Supply curves updated based on newer version of GETEM; added summary table to illustrate range across technology and resource
  - Cost projections are now included—The mid cost case keeps costs constant over time, the low cost case incorporates learning based on AEO 2015 (last year's ATB did not include geothermal projections)
- **Hydropower**
  - Base Year: Supply curves updated with published ORNL Hydropower Cost Report (same as Hydropower Vision); added summary table to illustrate range across technology and resource.
  - Cost projections now included—Projections are from 2016 Hydropower Vision report
- **Conventional**
  - Updated conventional technologies to AEO 2016
  - Updated natural gas and coal fuel costs to AEO 2016
  - Added higher capacity factor coal and natural gas entries—now coal and gas technologies have a fleet wide capacity factor entry and a "maximum" capacity factor entry
  - Included more information around current costs
  - Extended capital cost reduction trajectories from 2040-2050

Potential Improvements for 2017

- **Wiser et al. Wind Cost Report (expert elicitation)**
- **New Technologies**
  - Battery storage
  - Partial capture CCS plant
- **Regional Data**
  - Regional capital cost multipliers
  - Resource data
- **Improved format**

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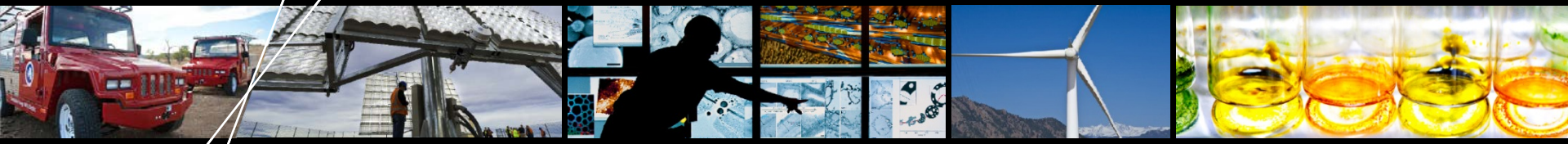
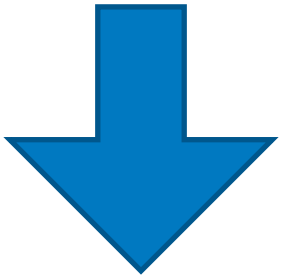


Standard Scenarios Preview

The ATB Data Are Inputs for Standard Scenarios

Annual Technology Baseline (ATB)

(Cost and performance assumptions for renewable and conventional technologies)



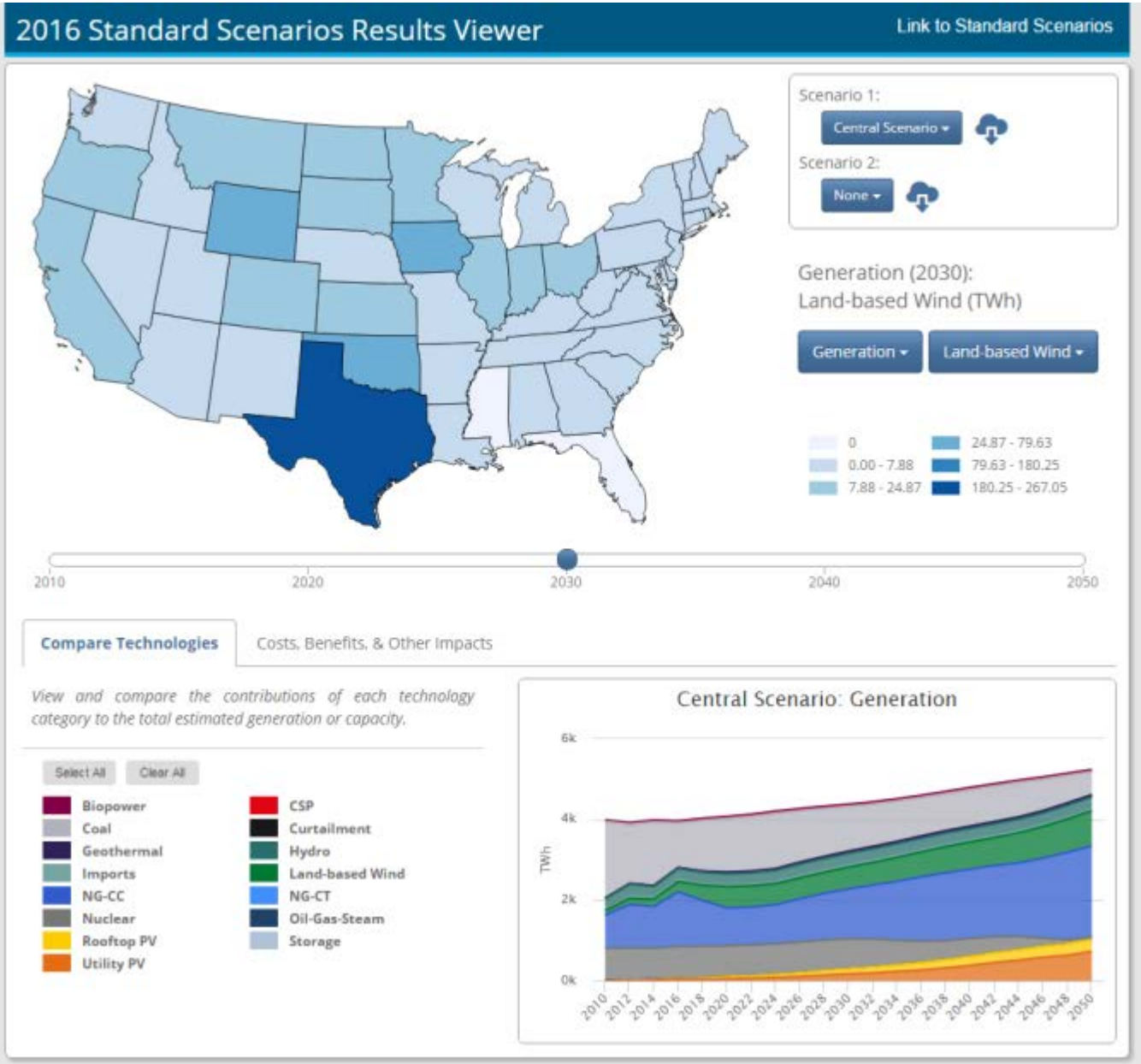
Standard Scenarios

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

Standard Scenarios

- **~20 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, vehicle electrification, etc.
- **Report explores four areas of change in the electricity sector**
  - Renewable Energy Cost Reduction & Deployment
  - Growth in Distributed Generation
  - Natural Gas Abundance
  - Power Sector Decarbonization

Scenario Results to Be Available Online



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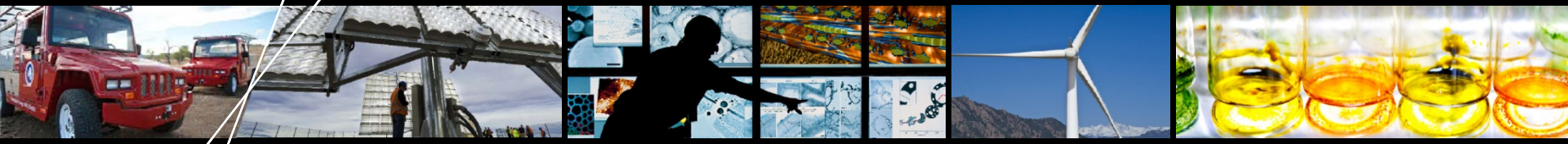

Questions or Comments?

The Annual Technology Baseline is available at

http://www.nrel.gov/analysis/data_tech_baseline.html

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