# SUMMARY OF 2020 DELIVERABLES

## Program 178 — Resource Planning for Electric Power Systems

This program briefing summarizes all Program 178 (P178) deliverables completed in 2020. The briefing includes deliverables completed by the two P178 project sets, PS178-A and PS178-B, as well as Technology Innovation[1] (TI) program deliverables produced in association with Program 178. Web links are included for each deliverable, which direct members to the download page for each publication on the EPRI website. The publications shown below are organized by project set. Each citation includes the title, research contact, publication date, and an abstract. Publications marked with an * are available to the public free of charge. Webcasts organized and hosted by PS178-A and PS178-B in 2019 are not included in this summary, but can be accessed by program members on the Program 178 cockpit on the EPRI Member Center.

Program 178 is part of the Energy Systems and Climate Analysis (ESCA) research group within the Integrated Grid and Energy Systems business sector (PDU-IGES). For more information on Program 178, contact Adam Diamant. For more information on ESCA research, visit the ESCA public website at http://esca.epri.com. To receive the ESCA group's quarterly newsletter with research updates, please email your request to eea@epri.com with "Join ESCA newsletter" in the subject line.

## CONTENTS



1. EPRI's Technology Innovation (TI) Program supports a portfolio of strategic research, early-stage technology development, and field demonstration projects aligned with energy sector evolution and managed by expert staff throughout EPRI's sectors.

- System Flexibility Investments and Energy Prices in Regional High Renewable Grids
- Incorporating DERs into Resource Planning: Exploring the Impacts of Electric Vehicle Adoption on Capacity Expansion Modeling
- Incorporating Distributed Energy Resources (DERs) into Resource Planning: Solar PV and Electric Vehicles – Annotated Literature Review
- Incorporating Energy Efficiency and Demand Response into Electric Company Power System Resource Planning
- 39th Annual Seminar on Fuels, Power Markets and Resource Planning
- Insights from Natural Gas Fuel Price Scenarios: A scenario-based analysis of the US electric sector through 2050

**TECHNOLOGY INNOVATION**

- Endogenous Learning for Projecting Future Capital Costs – Evaluation and Implications for Electric Power Generation Technologies

## PROJECT SET 178-A – TECHNOLOGY COST AND PERFORMANCE

PS178-A supports technology and resource planning, investment, retrofit and retirement decisions by providing comprehensive data, methodologies, and tools to improve understanding of the economic cost and engineering and environmental performance of conventional and advanced power generation, storage, and retrofit environmental control technologies to support new generation capacity screening and project development.

PS178-A also manages EPRI's world-renowned TAGWeb™ software that is widely used to support electric power resource planning and generation development activities in the United States and internationally. TAGWeb™ is a powerful internet-based software tool that provides technology cost and performance data and information on 19 different power generation and storage technologies. Each year, EPRI updates selected data and information contained in TAGWeb™ based on new data developed to complete each year's annual Technology Assessment Guide (TAG) studies.[2]

For more information, please contact Neil Kern.

### 2020 TAGWeb Software Technology Updates

*EPRI Software: https://tag.epri.com/*
*Project Contact: Neil Kern*
*Published December 2020*

#### *Abstract*

The TAGWeb™ (Technical Assessment Guide Web) is an integrated, web-based software tool that provides current cost and performance data, information and technology trends for electric power generation and storage technologies. The 2020 technology updates for TAGWeb™ included various technology models and configurations of aeroderivative combustion turbines, heavy frame combustion turbines, natural gas combined cycle with and without carbon capture, utility scale solar, commercial scale solar, residential scale solar, onshore wind, offshore wind, and energy storage.

Link: https://tag.epri.com/

### Lithium Ion Battery Storage Ongoing Cost Study and Estimating Tool

*EPRI Report 3002018500*
*Project Contact: Neil Kern*
*Published November 2020*

#### *Abstract*

The electric industry has been experiencing an exponential growth of battery energy storage deployments; however, there is industry wide inconsistency with determining appropriate values for operations and maintenance (O&M) planning. This study attempts to provide a bottom-up method of estimating O&M for battery energy storage systems with the ability to compare various maintenance strategies. This study outlines key areas of focus for energy storage systems as it pertains to O&M, various maintenance approaches, and what the benefits and trade-offs are for the different ap-

2. Learn more about EPRI's TAGWEB™ software here: https://www.epri.com/research/products/000000003002002230

proaches. These findings are summarized within the report and are meant to serve as a guide for decision making. The various strategies and estimated costs are used as the basis for a prototype tool developed as a part of this research, that provides users the ability to evaluate the different strategies based on their unique assumptions and how those assumptions impact the capacity, energy, and costs over the life of the battery. The overall goal is to deliver a clear and concise understanding of potential O&M strategies for battery energy storage systems and the impact on costs over an asset's life.

Link: https://www.epri.com/research/products/000000003002018500

## Understanding Firm Hybrid Resources: Creating Firm Electric Power from Wind and Solar with Storage

*EPRI Report 3002018415*
*Project Contact: Neil Kern*
*Published October 2020*

### *Abstract*

Firm Hybrid Resources (FHRs) combine variable renewable energy with firming provided by battery storage to offer an alternative to dispatchable fossil generation. This research compares the costs of FHR power, new gas combined cycle units, and combustion turbines for five U.S. states (Arizona, Colorado, North Carolina, New York, and Texas) across firm peaking, baseload, and 2016 output profiles for sample gas-fired units. While renewable energy is competitive with gas on an energy basis, the analysis finds that adding full firming to delivery (i.e., never having to draw on the grid to meet the contracted profile) can be costly due to the need to add extra generation and energy storage to counter the effects of renewable resource variability. Absent substantial FHR cost reductions and/or strong policy support, FHR power costs were found to be higher than for gas-fired alternatives across the delivery profiles and locations studied.

Link: https://www.epri.com/research/products/000000003002018415

## Breakdown of Energy Storage Cost Estimates: 2020 Update

*EPRI Report 3002017939*
*Project Contact: Neil Kern*
*Published April 2020*

### *Abstract*

As the energy storage industry continues to evolve, it is important for electric company utility planners to be aware of the battery energy storage system (BESS) landscape. For this study, the Electric Power Research Institute (EPRI) hired a third-party engineering procurement and construction contractor to solicit quotes from energy storage developers and then develop project construction estimates for five different energy storage technologies. EPRI has provided comments on the equipment and construction estimates that members can use to inform their decision making as they develop energy storage projects.

This report provides technology overviews, developer references, technology trade-offs, and case study examples of capital costs, operation and maintenance costs, and performance data for five different energy storage technologies at various levels of commercialization maturity. The energy storage technologies covered within this report are traditional flow, hybrid flow, lithium ion, zinc-air, and sodium-sulfur.

Lithium ion has the lowest capital expenses and operating expenses of the mature technologies and the highest roundtrip efficiency. There is still uncertainty surrounding ongoing OPEX costs due to limited experience with utility-scale systems. The costs presented in this study are based on examples that use assumptions to determine component replacement schedules. These assumptions can have a material impact on overall costs. As the industry gains experience, these estimates will be continually refined. Technologies such as zinc-air and sodium-sulfur may have lower estimated costs based on vendor quotations, but these technologies represent a much higher risk due to the limited number of utility-scale deployments and the small number of technology developers. Each project deployment needs to be analyzed independently as each BESS technology offers different performance trade-offs.

Link: https://www.epri.com/research/products/000000003002017939

## Natural Gas Technologies Cost and Performance Report

*EPRI Report 3002017458*
*Project Contact: Neil Kern*
*Published February 2020*

### *Abstract*

The purpose of this report is to serve as a background document for the 2019 TAGWeb™ natural gas technology cost and performance updates. The report provides an overview of the baseline bottom-up cost estimates and performance data. Additional cases were constructed by the Electric Power Research Institute, using baseline data for different technology configurations and locations based on previous studies, technical scaling factors, and regional adjustment data.

The report focuses on the cost, performance, and emissions from reciprocating internal combustion engine (RICE), combustion turbine (CT) simple-cycle, and CT combined-cycle technologies. The selection of technologies used in the report is intended to offer a range of plant sizes and types and includes RICE, aeroderivative CT, and frame CT technologies.

Link: https://www.epri.com/research/products/000000003002017458

## Technology Webcast Series

*EPRI Webcast Series*
*Project Contact: Neil Kern*
*Published April – October 2020*

### *Abstract*

The purpose of the Project Set 178A Technology Webcast Series is to bring in technology experts to present emerging technology topics and insights to electric company resource planners to inform and support their long-term planning activities. The 2020 portfolio of topics included hydrogen combustion turbines, bulk thermal energy storage, and advanced wind and solar technologies. During each of these webcasts EPRI experts discussed the status of technology development, benefits of the technologies, current research topics aiming to progress the technology, and market outlooks.

Link: https://www.epri.com/research/programs/069228/events/A006D361-1691-4E36-867C-65CBC8077401

https://www.epri.com/research/programs/069228/events/2DBD2498-0510-418C-B028-9AFC2EB6D305

https://www.epri.com/research/programs/069228/events/14A91AE9-2642-4ABB-A2AC-4C5C588F6094

# PROJECT SET 178-B – INTEGRATED ENERGY SYSTEM PLANNING AND MARKET ANALYSIS

PS178-B provides new analysis, tools, and methods to address current and future power system planning issues, including key structural and operational changes in the electric sector and approaches to more closely integrating electric generation, transmission and distribution planning. This project set also develops insights on evolving natural gas market dynamics and interactions with power markets, develops methods and tools to address uncertainty and risk in electric company resource planning, and targets research to address how companies can implement the Integrated Energy Network.

For more information, please contact Adam Diamant.

## 2020 REGEN Scenarios Analysis: Understanding Key Factors that May Impact Future Electricity Generation

*EPRI Report 3002018503*
*Project Contacts: John Taber and Srujana Goteti*
*Published December 2020*

### *Abstract*

For each of the past eight years, EPRI's research program on Integrated Energy System Planning, Fuels, and Market Analysis (Project Set 178-B) in conjunction with member electric companies has developed different scenarios of potential future technology, regulatory, and market conditions that may exist in the United States in the coming decades, and then analyzed how the United States electric sector might evolve under these scenarios. This report, and the accompanying slide presentation and Excel spreadsheet dataset, highlights the analysis conducted and results from our 2020 REGEN Scenarios Analysis Project. In 2020, we analyzed how the U.S. electric power generation mix may evolve from 2020 to 2050 under a 2020 Reference scenario and twelve different scenarios. These scenarios explored low carbon dioxide ($CO_2$) emissions targets, with a goal of achieving 0%, 5% or 10% $CO_2$ emissions by 2050 compared to 2020.

These scenarios also explored the potential impacts of key sensitivities including: (i) capital costs for new nuclear generation; (ii) capital costs for wind and solar photovoltaics (PV); and (iii) limitations on future construction of new inter-regional transmission infrastructure. The results focus on a deep dive into power system investment decisions in 2040.

Link: https://www.epri.com/research/products/000000003002018503

## Using an Hourly Simulation Tool to Compare the Value of System Flexibility Investments in Regional High-Renewable Power Systems

*EPRI Report 3002018587*
*Project Contacts: Adam Diamant*
*Published December 2020*

### *Abstract*

This annotated slide presentation explores the importance of considering power system "operational constraints" when conducting production cost modeling to explore the potential value of making new "flexibility investments," such as new natural gas combustion turbines, new inter-regional transmission lines or new battery energy storage systems. We used a power system "production cost" model (Power System Optimization) and an IEEE industry test power system topology (IEEE RTS 96 test system, updated by NREL for the GLMC), to model four different illustrative power system scenarios to explore the potential importance of incorporating operational constraints in production cost modeling. These scenarios include: (i) A Baseline which closely follows the original IEEE test system; (ii) A High Variable Renewable Energy (VRE) scenario that includes three times the amount of renewable generation as the Baseline; (iii) A Flexible Natural Gas scenario that explores system operations with twice the amount of flexible natural gas generation as the Baseline; and (iv) An Energy Storage scenario that includes the addition of 1 GW of battery energy storage to the Baseline system. The power system modeling done for this project strongly suggests that estimates of system operating cost, power prices, and dispatch patterns differ substantially depending on if operational constraints are explicitly considered in the production cost modeling of the scenarios.

Link: https://www.epri.com/research/products/000000003002018587

## System Flexibility Investments and Energy Prices in Regional High Renewable Grids

*EPRI Report 3002018501*
*Project Contacts: Nidhi Santen and John Bistline*
*Published March 2020*

### *Abstract*

This presentation explores the potential role of various system flexibility investments in regional electric power systems with high variable renewable energy deployment, and the impacts these investments can have on energy market prices. Using EPRI's United States Regional Economy, Greenhouse Gas, and Energy (US-REGEN) model, this research (1) examines the potential for a range of flexibility enhancing resources, such as natural gas turbines, energy storage, and transmission capacity investments, to support increased variability across a range of high-renewable regional grids; (2) explores the relative role and comparative value of these different system flexibility resources for different regions; and (3) analyzes potential implications of increased renewable deployment and system flexibility resource investments on regional bulk-system energy market prices.

Results show that (1) energy storage can be an important resource in high-renewable power systems, particularly in managing energy price volatility and preventing significant shifts in negative price hours; (2) new transmission capacity can support renewable deployment, but its marginal value decreases as regions further develop their own high-renewable grids; (3) natural gas combustion turbines continue to play an important role in supporting higher renewable grids, but their role might be more easily substituted for by other resources at very high penetration levels; and (4) overall, the level of variable renewable energy appears to be a larger determinant of changes in energy prices than the specific set of flexibility resources that may be available on the system.

Sensitivity analyses exploring these impacts under an alternate natural gas price suggest that results are relatively robust against future higher natural gas prices. Overall, this research develops a foundation for future research to further examine the value of system flexibility enhancing resources, including considering the additional grid services they may provide and additional asset-specific engineering and system-level operational constraints.

Link: https://www.epri.com/research/products/000000003002018501

## Incorporating DERs into Resource Planning: Exploring the Impacts of Electric Vehicle Adoption on Capacity Expansion Modeling

*EPRI Report 3002020059*
*Project Contacts: Adam Diamant*
*Published December 2020*

### *Abstract*

Electric company system planners face a variety of challenges in North America and internationally to stay abreast of the rapid, ongoing transformation of the electric power sector. One of the specific challenges they face is the need for improved forecasting that reflects better integration of customer-side behavior. The increasing penetration of distributed energy resources (DERs) and their rapid evolution has introduced a new challenge for planners to address in long-term planning models. This EPRI technical update is part of a larger, multi-year EPRI project to introduce and explore methods to incorporate DERs into long-term power system resource planning.

Development of robust and accurate load forecasts is the starting point of any electric power company's resource planning process. DERs can significantly alter load levels and profiles, so improved forecasting of DER adoption would make it possible for system planners to better account for the impact of DERs on the planned system resource mix. This implies that relying on robust methods to develop adoption levels for these distributed resources and integrating them into the long-term resource plans may lead to avoided or deferred investments, reducing total system resource costs. However, while DERs may help to mitigate some system infrastructure costs, they may also require additional mitigation measures to address their intermittency (e.g., in the case of solar PVs) and increased peak capacity requirements (e.g., in the case of unmanaged EV charging). Improved DER adoption forecasts and integration methods can help increase planners' confidence in DERs and inform ways to reduce system resource costs.

This EPRI technical update explores through quantitative modeling and analysis the potential impact of consumer adoption of electric vehicles (EVs) on capacity expansion modeling. The modeling conducted for this study shows that EV adoption can significantly impact system planning decisions within a typical planning time horizon, and that modeling results are highly dependent on specific system conditions, particularly generation mix and load shapes. Finally, the authors explored the potential impact of managed and unmanaged EV charging on capacity expansion and concluded managed EV charging can significantly reduce incremental capacity requirements. Although customer adoption of EVs is accelerating in many parts of the country, electric power system planners still have time to figure out the most appropriate ways to account for future EV adoption in their long-term resource plans. In addition, the results of this study may encourage electric companies to explore developing and implementing EV managed charging programs (active and passive) in the future.

Link: https://www.epri.com/research/products/000000003002020059

## Incorporating Distributed Energy Resources (DERs) into Resource Planning: Solar PV and Electric Vehicles – Annotated Literature Review

*EPRI Report 3002018502*
*Project Contact: Adam Diamant*
*Published September 2020*

### *Abstract*

Electric company system planners face a variety of challenges in North America and internationally to stay abreast and account for the rapid, ongoing transformation of the electric power sector. One of the specific challenges is the need for improved forecasting that reflects better integration of customer-side behavior. The increasing penetration of distributed energy resources (DERs) and their rapid evolution has introduced a new challenge for planners to address in long-term planning models. This EPRI technical update is part of a larger EPRI project to introduce and explore methods to incorporate DERs into long-term power system resource planning.

Development of robust and accurate load forecasts is the starting point of any electric power company's resource planning effort. DERs can significantly alter load levels and profiles, so improved forecasting of DER adoption would make it possible for system planners to better account for the impact of DERs on the planned system resource mix. This implies that relying on robust methods to develop adoption levels for these distributed resources and integrating them into the long-range resource plans may lead to avoided or deferred investments, reducing total system resource costs. However, while DERs may help to mitigate some system infrastructure costs, they may also require additional mitigation

measures to address their intermittency (e.g., in the case of solar PVs) and increased peak capacity requirements (e.g., in the case of unmanaged EV charging). Improved DER adoption forecasts and integration methods can help increase planners' confidence in DERs and inform ways to reduce system resource costs.

This EPRI Technical Update summarizes a comprehensive literature review designed to identify widely accepted methods used in the electric power sector to forecast adoption of rooftop solar photovoltaic resources (Rooftop PV) and electric vehicles (EV). The authors identified relevant literature on distributed solar PV and EV forecasting through consultation with EPRI subject matter experts, internet-based research, and a scan of the bibliographies of relevant reports. The studies identified in this literature review were developed by national labs, electric companies, industry research organizations, consultants, and academics. The authors reviewed 61 relevant studies, including studies focused on methods to develop solar PV and EV forecasts and published electric company Integrated Resource Plans (IRPs). The authors also identified IRPs from states with the highest levels of PV and EV penetrations to provide a more detailed look into implementations and identify prominent trends.

Link: https://www.epri.com/research/products/000000003002018502

## Incorporating Energy Efficiency and Demand Response into Electric Company Power System Resource Planning

*EPRI Tech Brief 3002019626*
*Project Contact: Adam Diamant*
*Published August 2020*

### *Abstract*

Electric companies, industry stakeholders, and regulators are placing increasing emphasis on accurately representing distributed energy resources (DER) in electric company long-term resource planning efforts. While there is substantial literature on the qualitative advantages and disadvantages of distributed energy resource modeling methods, there has been little research that quantitatively assesses implications across methods. This study quantitatively demonstrated the impact of a variety of approaches to representing energy efficiency (EE) and demand response (DR) in electric company resource planning modeling and analysis. Overall, a comparison of resource planning modeling simulations showed there are conditions under which certain approaches may be more appropriate than others for integrated resource planning. Resource planners can use the results and insights developed to assist them in deciding upon EE and DR modeling approaches for their own resource planning. Results also can be used by other industry stakeholders to analyze resource plans in a more informed way.

Link: https://www.epri.com/research/products/000000003002019626

## 39th Annual Seminar on Fuels, Power Markets and Resource Planning

*EPRI Workshop*
*Workshop Contact: Adam Diamant*
*November 2020*

### *Abstract*

On November 18–19, 2020, EPRI's Project Set 178-B hosted its annual seminar, which delivers and expands upon EPRI's research findings and explores topics of growing urgency to electric company generation, transmission, and distribution planners, fuel and asset managers and staff involved in market design, corporate strategy and risk management. The 2020 seminar offered three independent sessions spanning 2 days that focused on the following key topics:

- The role of natural gas in achieving deep decarbonization;
- Integrating energy system planning; and,
- Evolution of carbon pricing proposals in wholesale power markets.

Link: https://membercenter.epri.com/Programs/069228/pages/eventdetails.aspx?eventID=756BBBD7-B855-4F38-92A2-C7CE7B229218&eventScope=Cockpit&referer=EVENT_LIST

## Insights from Natural Gas Fuel Price Scenarios: A scenario-based analysis of the US electric sector through 2050

*EPRI Back Pocket Insight*
*Project Contact: John Taber*
*Published April 2020*

### *Abstract*

This Back Pocket Insight (BPI) summarizes key insights from one component of EPRI's 2019 REGEN Scenarios Analysis

Project that focused on exploring how the power generation fleet in the United States may evolve under different future natural gas (NG) price paths.

The 2019 REGEN Scenarios Analysis Project used EPRI's Unites States Regional Economy, Greenhouse Gas, and Energy (US-REGEN) model to examine the potential evolution of the U.S. power sector under 14 different scenarios that explored varying future NG prices, different policies to achieve near-zero or zero $CO_2$ emissions in the electric sector by mid-century, and different costs to deploy battery energy storage technologies. This overall analysis compares generation fleet evolution, electrification of various end-use technologies, regional electricity trade, policy compliance choices, technology costs, the potential role for energy storage, and other electric system impacts across the range of scenarios explored between 2020 and 2050.

Link: https://esca.epri.com/pdf/Back-Pocket-Insights/BPI_NG_REGEN_Insights.pdf

## TECHNOLOGY INNOVATION

### Endogenous Learning for Projecting Future Capital Costs – Evaluation and Implications for Electric Power Generation Technologies

*EPRI Report 3002019786*
*Project Contacts: Neil Kern*
*Published November 2020*


#### *Abstract*

As the electric power sector continues to transition in terms of the mix of power generation technologies supplying electricity, it is important to understand both the observed costs of those technologies and how they change over time. Having accurate technology cost information allows electric company planners and modelers to more effectively analyze potential future scenarios, which in turn impact investment decisions and ultimately how a company plans to meet their goals of delivering electricity to customers while achieving long term sustainability goals. This research demonstrates how endogenous learning models, when utilized and interpreted in consideration of key external factors (i.e., not directly related to innovation), can provide various stakeholders better insights to inform strategic decision making related to costs.

Utilizing ranges of learning rates rather than a single learning rate may be more informative. The evaluation of literature-recommended learning rates highlighted that a 5%–10%–15% learning rate range is informative for better understanding potential future costs for natural gas combustion turbines, 1%–5%–9% for natural gas combined cycle projects, 18%–20%–22% for solar PV projects, and 10%–12%–14% for onshore wind projects. Market dynamics; evolving technology characteristics; research, development and demonstration (RD&D), input costs; project financing; regulatory requirements; government intervention; and sustainability ambitions are highlighted as external factors that have and may continue to influence cost and price developments, and/or how changes in production costs translate into changes in market prices of select power generation technologies.


Link: https://www.epri.com/research/products/000000003002019786

**The Electric Power Research Institute, Inc.** (EPRI, www.epri.com) conducts research and development relating to the generation, delivery and use of electricity for the benefit of the public. An independent, nonprofit organization, EPRI brings together its scientists and engineers as well as experts from academia and industry to help address challenges in electricity, including reliability, efficiency, affordability, health, safety and the environment. EPRI also provides technology, policy and economic analyses to drive long-range research and development planning, and supports research in emerging technologies. EPRI members represent 90% of the electricity generated and delivered in the United States with international participation extending to nearly 40 countries. EPRI's principal offices and laboratories are located in Palo Alto, Calif.; Charlotte, N.C.; Knoxville, Tenn.; Dallas, Texas; Lenox, Mass.; and Washington, D.C.

Together . . . Shaping the Future of Electricity

3002020385 February 2021

**Electric Power Research Institute**
3420 Hillview Avenue, Palo Alto, California 94304-1338 • PO Box 10412, Palo Alto, California 94303-0813 USA • 800.313.3774
• 650.855.2121 • askepri@epri.com • www.epri.com