PNNL-28627

Pacific Northwest NATIONAL LABORATORY

Energy Storage in Integrated Resource Plans

Funded by the U.S. Department of Energy Office of Electricity

April 2019

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U.S. DEPARTMENT OF ENERGY

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Pacific Northwest National Laboratory
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Executive Summary

Staff at the Pacific Northwest National Laboratory (PNNL) performed a review of 21 recent integrated resource plans (IRPs) to determine how battery energy storage and pumped storage hydro (PSH) were treated by utilities and/or load serving entities[1] when planning resources for their future.

While specific procedures vary from one utility to another, an IRP is the process by which a utility projects future customer needs and identifies the resource mix that is most likely to meet those needs while minimizing cost and risk. IRPs are a key component of the regulatory process, shaping the utility's resource acquisition efforts and providing the "paper trail" that allows regulators to review the utility's process when evaluating the prudence of the final investment decision and determining whether the utility may recover those costs from ratepayers. Reviewing current IRPs provides insight into the grid needs that utilities are identifying, the degree to which planning processes are adapting to include the unique characteristics of energy storage, and potential levels of future industry investment in energy storage.

The emergence of scalable, flexible, and cost-competitive energy storage technologies is a recent phenomenon, and because traditional IRP models do not consider many of the services that energy storage can provide, the technology does not neatly fit into planning processes. For this report, we studied a broad cross-section of IRPs from utilities representing a diverse array of service territories, sizes, and ownership structures to assess the degree to which the industry is adapting planning processes to account for the unique benefits of energy storage. Where an IRP discussed energy storage, we first reviewed whether energy storage systems were treated as potential resources, or limited to research pilots or to technical appendices. The difference is significant: until technologies are widely adopted and commercially available with few risks, utilities will typically address regulator or stakeholder interest in the topic through a pilot or through a status report in an IRP. Treatment as a resource means that energy storage characteristics are evaluated as part of a portfolio of resources that could be dispatched to meet future load requirements, signifying a more serious review of energy storage potential and the potential for it to be selected as part of a cost-effective resource portfolio.

While some plans considered compressed air energy storage (CAES), batteries and PSH were the most widely analyzed forms of energy storage. This suggests that these resources serve a proxy function in the planning process, allowing utilities to identify the scale at which energy storage services may be beneficial. Where energy storage is selected as a resource, utilities may consider multiple storage technologies in the procurement process. Based on their prevalence in resource planning, this report focuses on battery and PSH resources.

Where an IRP included energy storage as a resource, additional review was conducted to identify the range of storage services included in the analysis and associated modeling tools. Because energy storage provides flexible services that are best analyzed with models that make dispatch decisions in sub-hourly time periods, this report explores to what degree utilities are employing modeling software with sub-hourly capabilities.

Key findings include the following:

- While no storage technology was universally analyzed in the IRPs, batteries were more likely to be analyzed than PSH. Of the 21 IRPs reviewed, 15 included batteries in their analysis, while 6 either

[1] IRPs are most frequently required by states with vertically integrated utilities. Some of the entities that prepared IRPs reviewed herein might more accurately be termed load serving entities, in one or more of the states in which they have service territory. For brevity, this report uses the terms utility or utilities when referring to the entities that prepared the IRPs reviewed herein.

did not discuss batteries or explicitly stated that they would not be analyzed. Only 10 of the plans studied PSH. Twelve plans also indicated future plans for a demonstration or pilot project to better understand battery storage.

- Of the 15 utilities that included battery storage as a resource option, 4 utilities selected batteries in their preferred portfolio and 2 plans selected batteries in an alternate portfolio. Key niches for which plans considered battery energy storage include system flexibility, peaking capacity, integrating renewables, and ancillary services, such as regulation and frequency response. Where battery storage was not analyzed or not selected, utilities cited cost as the primary reason.
- Of the 10 utilities that included PSH as a resource option, 2 utilities included PSH in their preferred portfolio and 1 utility selected it in an alternate portfolio. Both cases in which PSH was included in the preferred portfolio involved expansion of existing facilities. Where PSH was not analyzed or not selected, utilities cited environmental issues (e.g., lack of access to water or land, or the cost and length of environmental siting processes needed to gain such access) and cost.
- Cost estimates vary across utilities for all resource types, but the larger variation for battery storage suggests that utilities still have significant information gaps when it comes to batteries. Observed estimates for lithium-ion batteries covered a range of more than $1,900 per kilowatt (kW), and estimates for flow batteries covered a range of almost $3,000 per kW, while estimates for PSH covered a range of less than $800 per kW, and combustion turbine (CT) estimates covered a range of about $850 per kW.
- Utilities that analyzed more energy storage services in the IRP were more likely to select batteries in their preferred portfolio. While utilities generally acknowledged in their IRPs that energy storage can provide a wide range of services, most of the plans analyzed a minority of those services. None of the 10 utilities analyzing fewer than 3 services selected batteries in the preferred portfolio. Among the four utilities analyzing three or four services, one (25 percent) selected batteries in the preferred portfolio. Among the five utilities analyzing six or more services, three (60 percent) included a battery in the preferred portfolio.
- Where IRPs did analyze the benefits of energy storage, it is unclear how they did so. Many of the services that energy storage provides are physically and temporally granular, and traditional IRP models do not assess benefits at those levels. While some modeling software packages are beginning to offer those capabilities, it was not readily evident whether or to what degree utilities were using that functionality.

Looking ahead, the IRPs generally indicated needs for advancements in three areas before energy storage could be a competitive resource option. The first area is in storage costs; most plans stated expectations that battery prices would continue to decline and intentions to monitor those declines. The second area is in storage analytics; several IRPs expressed some frustration with the lack of tools or protocols for analyzing storage. The final area is in regulations, as some utilities operating within the footprint of a regional energy market identified the lack of market products to monetize the benefits of energy storage.

Based on this review, there are two apparent limiting factors on a utility’s ability to accurately include energy storage in resource planning: lack of reliable cost data and a lack of established industry practice. To address those limiting factors, the following additional research efforts are suggested:

- **Establish a mechanism for sharing current cost data and projected trends for energy storage technologies.** Properly valuing the benefits of energy storage is only one part of a proper analysis; weighing those benefits against accurate cost information is equally important in identifying cost-effective opportunities for energy storage. This study has identified a wide range in utility cost assumptions for energy storage, particularly for batteries. Establishing a mechanism for identifying and sharing data for all forms of commercially available energy storage would aid utilities and IRP stakeholders in converging assumptions that reflect both current prices and projected cost trends.

- **Refine existing planning support models and adapt energy storage assessment tools for investment planning.** Several IRPs reviewed in this study stated that computational and structural modeling limitations present an obstacle to including energy storage in IRPs. The U.S. Department of Energy (DOE), the national laboratories, and utility industry have extensive experience in quantifying and modeling the benefits of energy storage, and have developed several tools for doing so, but further adaptation for planning purposes may be warranted. Model developers should consider working with utilities to refine existing models to better meet IRP modeling needs.
- **Create a forum for sharing best practices in energy storage modeling.** The study revealed a gap in how utilities view energy storage; some are actively developing practices for modeling it, while many cited a lack of standard industry practices for energy storage as a barrier to including it in IRPs. This immediate work identifies anecdotal examples of a few utilities that are developing approaches to incorporate energy storage into the IRP process. Research to explore various practices developed by leading utilities and share them across the utility industry may contribute to standard industry practices, which some utilities indicated would improve storage modeling.

Acronyms and Abbreviations

ACC	Arizona Corporation Commission
ADMS	Advanced Distribution-Management System
APS	Arizona Public Service
BSET	Battery Storage Evaluation Tool
CAES	compressed air energy storage
CPUC	California Public Utilities Commission
CT	combustion turbine
DER	distributed energy resources
DOE	U.S. Department of Energy
DSM	demand-side management
Duke	Duke Energy Carolinas
EPRI	Electric Power Research Institute
FERC	Federal Energy Regulatory Commission
FPL	Florida Power & Light
GW	gigawatt
HB	House Bill
IOU	investor-owned utilities
IPL	Indianapolis Power & Light
IRP	integrated resource plan
ISO	independent system operator
ISOP	Integrated Systems and Operations Planning
IURC	Indiana Utility Regulatory Commission
kW	kilowatt
LIPA	Long Island Power Authority
MDPSC	Maryland Public Service Commission
MISO	Midcontinent Independent System Operator
MW	megawatt
MWh	megawatt-hour
NERC	North American Electric Reliability Corporation
NRECA	National Rural Electric Cooperative Association
NWA	non-wires alternative
NYPSC	New York Public Service Commission
PGE	Portland General Electric
PJM	PJM Interconnection LLC

PNNL	Pacific Northwest National Laboratory
PROMOD	production cost models
PSE	Puget Sound Energy
PSH	pumped storage hydropower
PUC	Public Utilities Commission
PUCO	Public Utilities Commission of Ohio
R&D	research and development
RFP	request for proposal
RTO	regional transmission organization
SB	Senate Bill
SCC	State Corporation Commission
T&D	transmission and distribution
TVA	Tennessee Valley Authority
UTC	Utilities and Transportation Commission
WUTC	Washington Utilities and Transportation Commission

Contents

Figures

Tables

1.0 Introduction

This report documents a review of 21 integrated resource plans (IRPs) performed by the Pacific Northwest National Laboratory (PNNL) for the U.S. Department of Energy (DOE). The review focused on how and to what extent each IRP included energy storage using batteries and pumped storage hydroelectric (PSH) projects (collectively, referred to as energy storage). Researchers chose to analyze IRPs because they are a foundational document in the utility planning and procurement process, and they provide insight into how the electric utility industry is adapting its processes to incorporate energy storage. Given the significant level of legislative and regulatory action on energy storage in recent years,[1] this report provides a timely indication of how utilities are beginning to respond to those actions. And finally, while an IRP is a snapshot of future needs that will change over time, this report is indicative of the level and timing of planned industry investments in energy storage.

The review asked three questions:

1. **If the IRP addresses energy storage, was it discussed in a technical appendix, identified for a pilot project, or treated as a resource for possible inclusion in the IRP resource portfolio?**

   As new technologies mature, they follow a general progression in the planning process. With a nascent technology, utilities will usually conduct a high-level study of the resource in a technical appendix to the IRP, identifying resource capabilities and development trends. This is a "wait-and-see" approach, where the utility can park developing technologies and monitor them as they mature. Depending on how slowly a resource proceeds toward commercial maturity, it may spend several planning cycles in a technical appendix. In addition to energy storage, small modular nuclear reactors, offshore wind, and tidal power are examples of technologies commonly studied in current technical appendices.

   As a technology continues to mature, subsequent IRPs may identify it as ready for a pilot or demonstration project, indicating that the technology has reached a level of commercial maturity, but requires further testing and validation by the utility before it can be included as a resource option. Once a utility is comfortable with the technology's capabilities, it will be included in the model as a resource option.

   This is a general outline of how new technologies work their way into the planning process; it is not a fixed process, and some utilities may blend steps (such as including energy storage as a resource option in the plan while simultaneously identifying a pilot project to advance the utility's understanding of the resource) or proceed right to the last step in the case of a rapidly maturing technology.

2. **If energy storage was included as a resource, what benefits were quantified in the resource model?**

   As will be discussed in greater detail in this report, traditional IRP models are not designed to consider many of the benefits that energy storage can provide. A traditional model is designed to identify the utility's resource needs in terms of energy (how much electricity will be needed to meet all customer needs through the whole year) and capacity (how much electricity will be needed at the point of highest customer demand). Conventional models also employ limited resolution in both

[1] PNNL tracks state-level policies related to energy storage in an interactive Energy Storage Policy Database, available at https://energystorage.pnnl.gov/regulatoryactivities.asp.

physical and temporal terms. Physically, the models are limited to analyzing the bulk power system, meaning that only large, transmission-connected resources are included. Temporally, the models identify energy and capacity needs on an hourly basis, meaning that sub-hourly benefits related to flexibility and grid support are not included.

For a flexible and scalable resource such as energy storage, these modeling conventions omit much of the potential value. Placing an energy storage resource in a traditional IRP model alongside other resource options results in a process that identifies all of the costs of energy storage, but few of the benefits.

Where a utility included energy storage as a resource option in its IRP, additional investigation was conducted to determine what energy storage services were analyzed. In other words, was the resource analysis limited to quantifying energy and/or capacity benefits, or were additional services included?

3. **How were the benefits quantified?**

   Given the relatively recent development of flexible and scalable energy storage resources, standardized approaches for incorporating the full range of energy storage values into the resource planning process have not yet developed. The national laboratories and utility industry have created various tools capable of analyzing energy storage from various perspectives (i.e., as a standalone resource, coupled with solar or another generator, behind the meter, or within an organized energy market), and private companies have developed modeling software capable of sub-hourly resource analysis, but these tools have not yet been widely incorporated into IRPs.

   Analyzing not just *what* services utilities are including in their analyses, but *how* the values of those services are calculated and incorporated into the planning process provides insight into how planning processes are adapting to include energy storage and other resources with similar flexibility characteristics.

The remainder of this report is organized as follows:

- Section 2.0 provides an overview of the IRP process, discusses its role in the overall regulatory process, and identifies the specific barriers that conventional practices create for energy storage.
- Section 3.0 presents the findings of how energy storage was treated in the 21 IRPs reviewed.
- Section 4.0 discusses the benefits of energy storage services included in the IRPs.
- Section 5.0 identifies the models employed by the utilities and their capabilities.
- Section 6.0 provides the publicly disclosed capital cost assumptions used by some of the utilities.
- Section 7.0 provides a summary and next steps.
- Section 8.0 presents the references that are cited in this report.
- Appendix A includes a list of the utilities and their IRPs.
- Appendix B includes the observed cost assumptions for energy storage resources.
- Appendix C reviews the legislative and regulatory actions that may impact future IRPs.
- Appendix D includes a bibliography of all resources reviewed.

2.0 The IRP Process

Conceptually, an IRP is a document prepared by a utility that projects electricity demand over a future period and identifies the optimal mix of resources for meeting that demand. In selecting the optimal mix of resources, the utility considers multiple potential futures and future resource portfolios, evaluating each in terms of both costs and risks to identify the portfolio of resources that is most likely to meet expected future needs at the lowest reasonable balance of costs and risks.

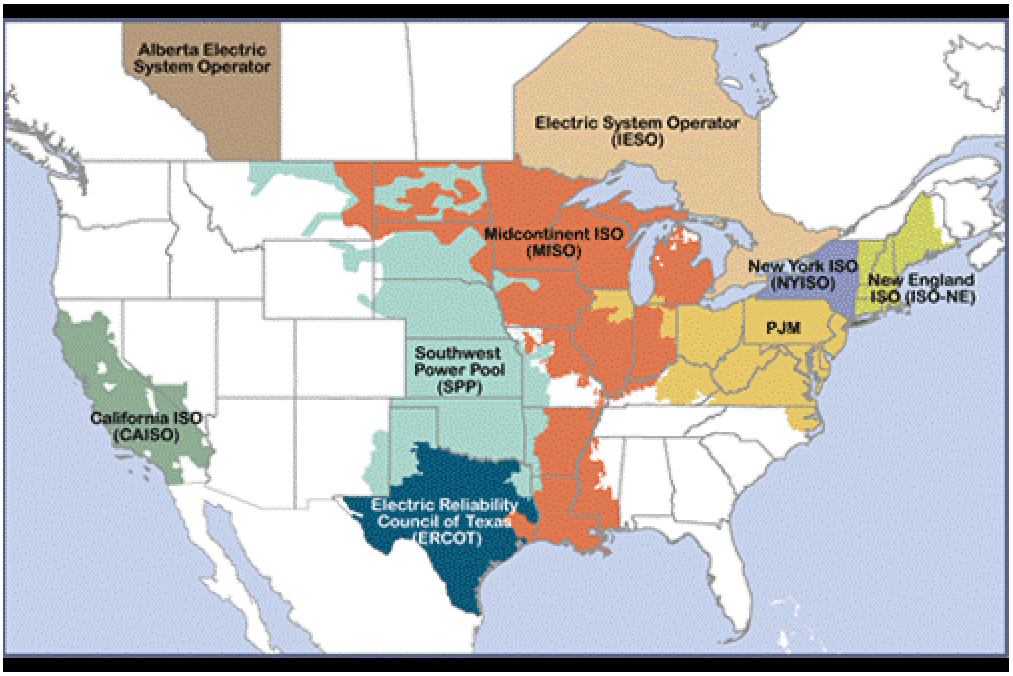
In practice, IRPs play a key role in the regulatory process, serving as a foundational document in multiple proceedings. The conclusions of the IRP shape subsequent resource procurement processes, informing how the utility structures its requests for proposal (RFPs) and potentially constraining the RFPs to only solicit proposals for technologies identified by the utility as preferred resources. In states with energy efficiency standards, IRPs serve as a planning tool to identify cost-effective efficiency programs and measures. But most importantly, IRPs provide documentation of the utility's planning and decision-making processes, and are used by regulators in determining whether the final investment decisions made by the utility were prudent and appropriate for including in customer rates.

As a result, IRPs tend to be creatures of state policy, with each state adopting its own statutes and administrative rules governing what is expected in the document based on state policies. States also take varying approaches to reviewing IRPs. Some states issue a formal decision to approve or reject the IRP after an adjudicated proceeding, while some states conduct a less formal review and either accept or reject the IRP, and other states treat IRPs as information-only filings that are not subject to any action. The approach depends on the desired outcome – some states use the IRP as a tool for issuing formal approval of the planned investments, while other states only approve investments after the fact, using the IRP as documentation of the utility's process. Timing requirements, such as the length of planning cycles (usually 2 or 3 years) and length of the planning horizon (usually 10 to 20 years), are set by states as well.

The IRP process was developed in the late 1970s, when the energy crisis and growing environmental movement in the United States pushed energy efficiency to the forefront of policymaking, leading regulators and utilities to integrate demand-side resource options alongside traditional supply-side resource options in the planning process (York and Narum 1996). Recent advances in energy storage and other distributed resources have renewed interest in the IRP process and driven a new round of planning adaptation, as multiple states have launched proceedings to update IRP policies to include requirements related to distribution system planning. Two states – Hawaii and Massachusetts – have already adopted substantive planning requirements directing utilities to submit grid modernization plans that include, among other things, processes for valuing distributed energy resources (DERs) and for analyzing non-wire alternatives to distribution system infrastructure investment (Cooke, Homer, and Schwartz 2018).

Growing needs for increased grid flexibility are also driving new IRP practices. Where the utility's job of balancing supply and demand was once a relatively straightforward process of matching predictable loads with dispatchable resources, changing technology is introducing unpredictability on both sides of the equation – non-dispatchable renewable resources on the supply side, and distributed generation and electric vehicles on the demand side. Managing that unpredictability has placed greater emphasis on identifying flexible resources that can quickly respond to changing grid needs, and states and utilities are adapting their processes to better identify and meet flexibility needs. In 2012, the Oregon Public Utilities Commission adopted new IRP guidelines that required utilities to identify flexible capacity needs and analyze how to best meet those needs (Oregon Public Utilities Commission 2012). Utilities in Washington, Hawaii, Arizona, and Colorado have also included flexibility planning in their IRP process in recent years (ESA 2018; Wilson and Biewald 2013).

IRPs are more common in vertically integrated states – those where a utility provides generation, transmission, and distribution services. In states that participate in regional markets operated by a Regional Transmission Operator (RTO) or Independent System Operator (ISO), on the other hand, transmission is performed by the market operator and distribution is performed by the utility, while responsibility for generation varies by region. For example, utilities in the California ISO, Midcontinent ISO, and Southwest Power Pool are either required or permitted to acquire their own generation resources. Figure 1 shows the footprint of RTOs and ISOs.



FERC

Figure 1. Map of RTO and ISO Entities

Driven by the proliferation of resource options and increasing environmental standards, some states within regional markets have taken a renewed interest in the IRP process in recent years. Citing the need for a cohesive planning approach to ensure that the state could achieve its aggressive environmental policies, the California Legislature reinstituted IRP requirements in 2015.[1] Michigan also adopted IRP requirements in 2016, emphasizing the need to identify additional opportunities for energy efficiency and demand response programs within the state.[2]

While details and procedures vary from one utility to another, Figure 2 shows a generic IRP process.

[1] California State Legislature, SB 350 (2015).
[2] Michigan State Legislature, SB 437 (2016).

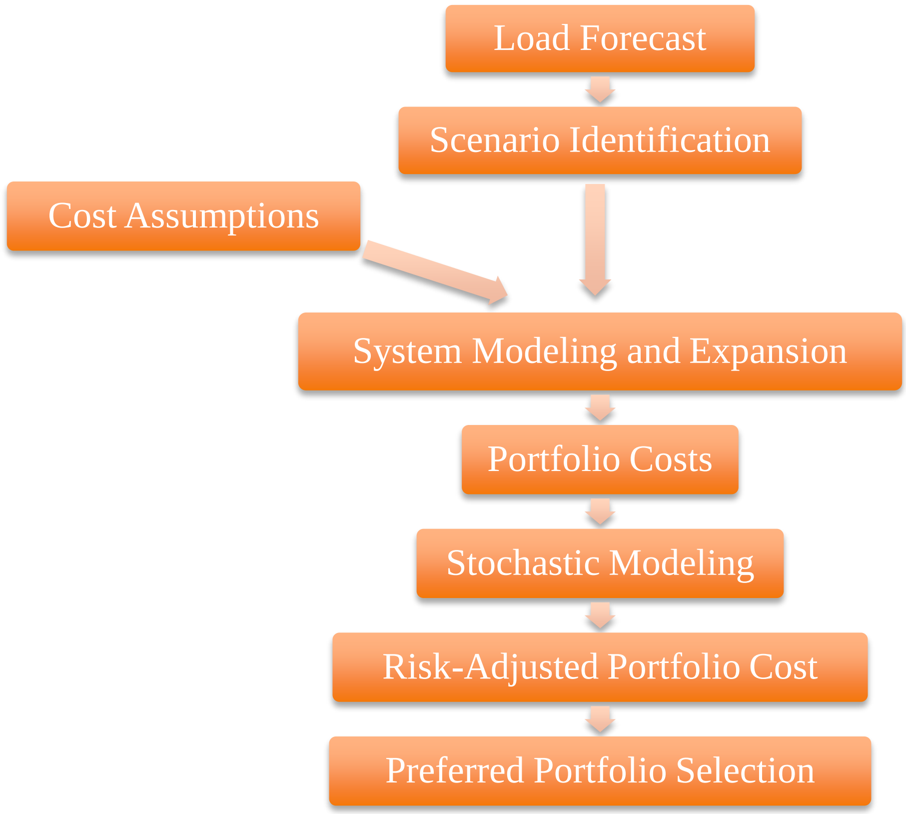


Figure 2. The Integrated Resource Planning Process

Using historical data to identify relationships between economic conditions and load, the utility projects electric demand over the planning period based on current forecasts for population growth, employment levels, electricity and competing fuel prices, and similar economic factors. Next, the utility identifies various scenarios representing alternate possible futures – such as a major technological breakthrough for a given technology or an environmental policy such as a carbon tax – that would change the costs and benefits of resource options.

For each scenario, the utility inputs its load forecast and assumptions about the cost and performance of resource options into modeling software, which identifies the optimal mix of existing resources and new investments to meet the projected needs based on the assumptions included in that scenario. For each scenario, the model will identify the type and timing of resource additions, retirements, or upgrades, as well as the total cost of the resource portfolio that it selected to meet demand over the planning period.

To further inform its analysis, the utility will then subject each portfolio to additional stochastic modeling to "stress test" how each portfolio would perform under a variety of uncertain circumstances, such as higher- or lower-than-expected load growth and higher- or lower-than expected fuel prices. This allows the utility to develop a risk-adjusted cost for each portfolio. It also enables a comparison of portfolios in terms of both cost and risk.

Based on that information, the utility will select a preferred portfolio – the resource mix that meets the most likely future conditions in the most efficient way, considering both costs and risks. Other portfolios are considered alternate portfolios – ones that the utility may pursue if the conditions assumed in those scenarios come to fruition. Finally, a utility develops an action plan to identify the near-term steps needed to develop the preferred portfolio.

2.1 IRP Practices Do Not Reveal Energy Storage Benefits

Preparing an IRP is a highly complex modeling exercise, so the industry has developed a number of simplifications designed to keep IRP models manageable and run times reasonable. Three of these practices – modeling in hourly increments, omitting ancillary services, and ignoring the distribution system – create a misalignment between traditional IRP models and flexible, scalable resources such as energy storage. Absent additional steps to account for flexible and locational values, traditional IRP models are unable to identify much of the potential value of energy storage.

Hourly Time-Step Modeling – Hourly modeling is done to limit the number of periods for which the IRP model must solve. In every increment, the model must develop a complex solution to meet the projected load, based on dozens of variables representing various generation units, market prices, weather, transmission constraints, and distributed resources. An hourly model covering a 20-year planning period must prepare 175,200 hourly solutions, and will generally take hours to run. That hourly resolution prevents the model from recognizing the value of flexible resources in responding to moment-to-moment changes in generation and load. However, increasing the resolution to 15-minute windows would quadruple the number of solutions to 700,800 and significantly increase run times for traditional models.

As system flexibility needs grow, utility practices and planning software developers are formulating new approaches to sub-hourly planning that provide increased granularity while maintaining reasonable model run times. As will be discussed in Section 5.0, some of the utilities involved in this study have begun employing modeling software that is capable of sub-hourly analysis.

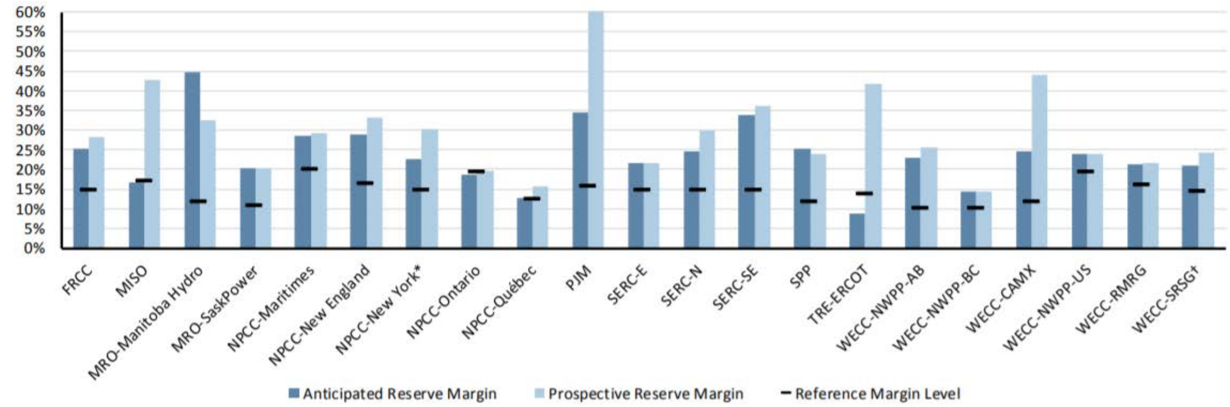
Ancillary Services – Omitting ancillary services from long-term adequacy planning creates a similar challenge for energy storage. Ancillary services are resource contributions required to keep the electric grid in balance and maintain reliability, and include such services as frequency response, regulation, and spinning reserve.[1] At present, an IRP model solves the load and generation balance in every time increment through a complex process involving dozens of variables like those listed above. Adding additional variables to solve for various ancillary service needs would significantly increase model complexity and run times.

Under conventional IRP practice, system planners create a proxy for ancillary services by oversizing the system – identifying the level of capacity needed to meet peak demand, and then adding additional resources beyond that level to ensure that excess capacity is available at all times to provide the ancillary services needed to maintain reliability. The North American Electric Reliability Corporation (NERC) requires utilities to ensure reliability by maintaining a sufficient reserve margin of generation to provide the necessary ancillary services at all times, though specific standards vary by region. In the Western Interconnection, for example, NERC requires utilities to maintain reserves equal to the larger of either the largest single generating unit on their system or 3 percent of load plus 3 percent of total generation.[2] In the Midcontinent Independent System Operator (MISO) and the PJM Interconnection LLC (PJM) systems, NERC requires grid operators to design the system with sufficient capacity such that, for a given planning year, the total probability of losing load due to insufficient generation during the peak hour of all days within the year is 0.1.[3]

NERC standards, however, serve only as a floor for reserve margins; individual grid operators and utilities can, and generally do, establish planning reserve margin requirements that are higher than those

[1] For more information about these and other mandatory electric grid reliability standards, see https://www.nerc.com/pa/Stand/Pages/ReliabilityStandards.aspx.
[2] NERC Standard BAL-002-WECC-2a.
[3] NERC Standard BAL-502-RF-03.

mandated by NERC. Each year, NERC forecasts expected reserve margin levels across various regions in North America; the results of the most recent study are presented in Figure 3, demonstrating that reserve margins vary widely among grid operators.



NERC[1]

Figure 3. North American Projected Reserve Margins

NERC's analysis identified a reference margin level for each region and then forecasted what the region's margin will be under the prospective case (i.e., the maximum level of reserves that may be achieved, subject to available transmission and completion of planned projects) and the anticipated case (i.e., the most likely level of reserves that will be available). While NERC found that three regions have an anticipated reserve margin below their reference level, most regions are well above it. On average, NERC's analysis shows that the anticipated reserve margins across the regions are 66 percent higher than reference margins, resulting in more than 70 gigawatts (GW) of capacity in excess of what would be needed to maintain reserve reference margins.

Due to its flexible nature, energy storage can potentially reduce reserve needs. Because it can quickly respond to grid needs and act as a load or generation, 1 megawatt (MW) of energy storage can provide a level of reliability that would otherwise require several megawatts of traditional generation resources. An early flywheel demonstration project supported by the DOE in Pennsylvania, for example, found that the fast-responding flywheel was able to provide 2.5 times as much regulation service to the grid as a conventional resource with the same nameplate capacity (Hazle Spindle 2016). While market design enabled the flywheel to monetize its flexibility benefits in that case, a traditional IRP model is not configured to optimize for ancillary services in a similar fashion, and so the IRP process cannot identify similar opportunities.

System Effects of Resource Location – IRP models are designed to balance generation resources and load at the system level, subject to existing transmission system constraints and new transmission necessary to connect new resources. The models do not optimize to improve performance of or reduce investment in the transmission and distribution systems by placing resources at specific locations. Doing so would require combining transmission and distribution system data, operations, and planning models; operational inputs for system reliability and service quality; and for most vertically integrated utilities, a level of resolution and insight into location-specific conditions that is not generally available. While such integration is complex, failure to recognize resource impacts at the transmission and distribution levels will also preclude the benefits that an energy storage device can provide by improving grid operations or deferring or displacing investments at those levels.

[1] NERC, 2018 Long-Term Reliability Assessment.

IRPs are not designed or intended to identify and quantify all of the benefits of energy storage resources. They are, however, the traditional gateway for establishing a utility's future needs, outlining near-term investments to meet those needs, and setting an expectation of rate recovery when those investments are made. As a highly versatile resource, energy storage provides a valuable lens into the challenges faced by next-generation technologies. Storage may have the potential to benefit utilities and ratepayers, but its ability to become a utility asset and deliver those benefits can be hampered by the tools and practices employed to justify investments.

In addition to the barriers identified above, in some cases, utilities conduct an initial screening of different technologies to determine which will be included as resource options. This first screening generally does not include the level of detailed modeling that is needed to fully identify the benefits of energy storage, meaning that storage may be removed from consideration before being modeled. Rather, the first screening looks at either high-level technical considerations or at a relatively uncomplicated assessment of the levelized cost per megawatt-hour (MWh). As an example of one such screening process, Duke Energy Carolinas (Duke) looks at the following attributes:

- "Technical feasibility and commercial availability in the marketplace
- Compliance with all Federal and State requirements
- Long-run reliability
- Reasonableness of the cost parameters" (Duke Energy Carolinas 2016).

As another example, Minnesota Power assesses what it refers to as a "levelized busbar cost," which takes into account capital costs, transmission, operations and maintenance and fuel costs (Minnesota Power 2015).

3.0 Inclusion of Storage

As stated in the introduction, the first question of this review asked whether battery energy storage and PSH were included in IRPs, and if so, whether energy storage was included in resource portfolios or whether it was limited to research and development (R&D) status. Table 1 summarizes the outcomes for battery storage and PSH in each of the 21 IRPs evaluated.

Table 1. Utility IRPs included in Analysis and Analysis Stages Identified for Storage Resources

	Battery Storage Analysis Stages					**PSH Analysis Stages**		
Utility	**Pilot or Research Phase**	**Selected, Main Portfolio**	**Selected, Alternative Portfolio**	**Batteries Screened**	**Not Analyzed**	**Selected for a Portfolio**	**PSH Screened**	**PSH Not Analyzed**
Arizona Public Service	√	√	√				√	
Black Hills			√					√
Burlington Electric Dept.	√			√				√
Dominion	√				√			√
Duke Energy, Carolinas	√	√*		√		√*		
El Paso Electric				√				√
Entergy				√				√
Florida Power & Light	√**				√			√
Georgia Power	√			√			√	
Indianapolis Power & Light	√	√	√					√
Kansas City Power & Light	√			√			√	
Kentucky Power Co.	√***			√				√
Long Island Power Authority		√						√
Minnesota Power				√			√	
Northwestern Energy	√			√			√	
NV Energy					√			√
Rocky Mountain Power	√		√				√	
Potomac Edison Company					√			√
Puget Sound Energy	√	√				√		
Tennessee Valley Authority					√		√	
Xcel Energy	√				√	√*		

*Batteries and/or PSH were included as resources in the portfolio studied, and were treated in a fashion akin to an existing resource. In both cases, the additions were not a new resource added as a result of the IRP reviewed herein.
**A 50-MW research project is underway, but the resource plan included no evidence of batteries being analyzed.
***Kentucky Power Company analyzed battery storage and found it non-cost effective, but added 10 MW to their main portfolio with the intention that they may be helpful in integrating renewable resources.

3.1 Technologies Reviewed

The authors acknowledge that other forms of storage exist and are under development, but elected to focus on battery storage and PSH for the purposes of this review. As technologically mature and utility-scale resources, they are the forms of energy storage that are most likely to be considered in an IRP. Other types of energy storage, such as thermal or mechanical technologies, may ultimately be selected through competitive bidding or policy directives, but batteries and PSH are the “proxy” energy storage resources that are most likely to be included in an IRP analysis and trigger the selection of storage in a resource portfolio.

While battery storage and PSH are the most likely storage resources to be included in an IRP, the technology trajectory and sector status of battery storage and PSH are very different. Pumped storage is the dominant form of electric energy storage in the United States, with 40 plants providing 22 GW of bulk energy storage. Most of the pumped storage fleet was constructed over 30 years ago and is owned by public and private utilities. Costs and performance characteristics of standard, fixed-speed pumped storage plants are established and stable, with long timeframes for development and commissioning (DOE 2014). According to DOE, there are additional development and technology upgrade opportunities that would allow PSH to be more responsive and provide ancillary services (DOE, no date). PSH can vary dramatically in size and offer significant flexibility for incorporating and balancing intermittent resources at scale.

Battery storage, on the other hand, is defined by rapid change, where characteristics, construction timeframes, and costs are continuously changing as more storage systems are deployed on the grid. At the same time, understanding is growing of long-term costs (e.g., decommissioning), cycling requirements, methods for optimized operations and system siting, and component lifespans. Battery storage utilizes diverse business models and currently scales to interconnect to the grid at transmission voltage, distribution voltage, or behind the meter on a customer’s premises. For these reasons, utilities differed on which technology to evaluate in IRPs and the treatment of these resources varied.

Although pumped storage hydropower is the dominant form of stationary electrical energy storage, its treatment within IRPs did not clearly indicate lessons for advanced storage analysis within a planning framework. Utilities with pumped storage resources already in their resource portfolio do not show specialized modeling or demonstration of benefits from energy storage that could apply to other storage resources. Even examples of preferred portfolio selection of pumped storage facility expansion appear to be conducted on a simple cost-benefit analysis for a single service, namely peak management, rather than an optimization of the storage resource within the portfolio to demonstrate adequate value.

In the IRPs reviewed herein, battery storage was studied more frequently than PSH. At least three factors structurally favor batteries:

- Siting flexibility – batteries can be installed where needed on the transmission and distribution system whereas siting of PSH is limited by the need for specific geology and availability of water,
- Lead time – battery build-time is generally assumed to be 1 year in IRPs while PSH build-time range from 5 years (e.g., see APS 2017) and as long as 15 years (PSE 2017), and
- Environmental concerns and/or permitting – for example, Duke’s 2016 IRP considered PSH but eliminated it from detailed portfolio analysis on technical grounds, citing environmental impact, permitting, and initial capital cost (Duke Energy Carolinas 2016).

3.2 Methodology for Selection of IRPs

For this review, 21 utilities were selected from across the country. The utilities were selected in a manner to ensure broad geographic coverage. The majority of utilities selected are investor-owned utilities (IOUs). While the selection process was not random, neither was there an effort to specifically target utilities perceived as being likely or unlikely to include energy storage. Several factors influenced the choice of IRPs that were reviewed. First was finding comparatively recent IRPs because utility-scale, cost-effective battery storage is a comparatively recent resource. Thus, for example, while searching for utilities in Oklahoma, South Dakota or North Dakota, the authors selected Black Hills Energy because they submitted their IRP for regulatory review in June of 2016, while another potential selection, Oklahoma Gas & Electric, prepared their IRP in 2014. Black Hills Energy is an example of another phenomenon of some note – namely, utilities with service territories in multiple states which submit the same IRP in multiple states, or which serve multiple states and are not required to submit IRPs in all states. The same utility was not reviewed for multiple jurisdictions. Similarly, the authors avoided reviewing multiple utilities that are members of the same utility holding companies.

Finally, some states were identified for review located in regions with RTOs or ISOs. However, states within RTO or ISO footprints tend to not require utilities to submit IRPs, and this required some flexibility in the selection process. For example, Maryland was selected for inclusion, but because regulated utilities have not been required to submit IRPs for several years, an IRP submitted to regulators in West Virginia by a utility with Maryland service territory was reviewed.

Figure 4 shows the states included in the service territories of the utilities whose IRPs were analyzed in this report. States included are shaded orange.

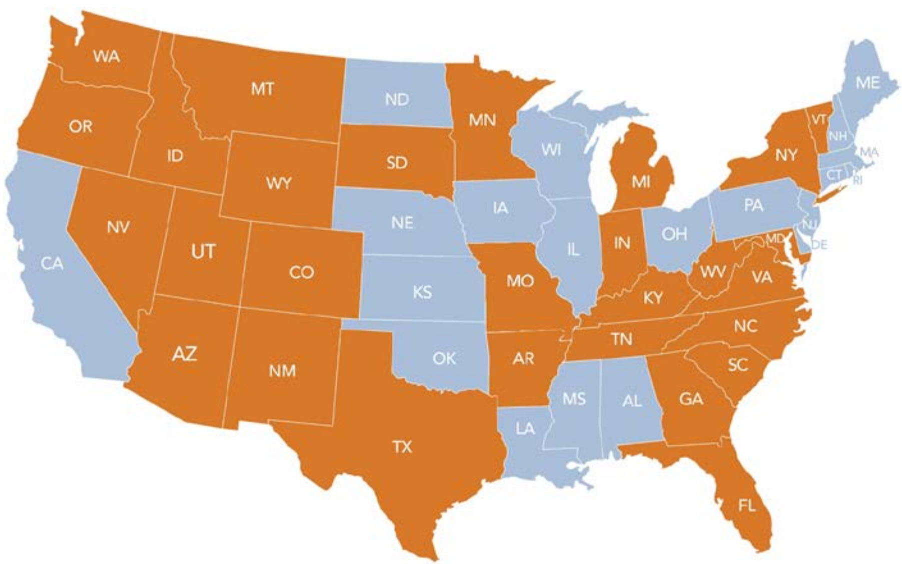


Figure 4. States Covered by Included Utilities

3.3 Inclusion of Battery Storage

Overall, 15 of the 21 utilities studied for this report included battery storage as a resource option in their IRP. The remaining six utilities either did not mention energy storage or explicitly mentioned that it would not be included. Of the 15 who included energy storage, 4 utilities selected it for their preferred portfolio, 4 utilities selected it in an alternate portfolio (2 of which had also selected storage in their preferred portfolio), and the remaining utilities did not select energy storage in any portfolio. A total of 12 utilities – some of which selected energy storage in a portfolio and some of which did not include it as a resource option – identified a plan to better understand the benefits of energy storage through a R&D effort. Figure 5 summarizes the battery storage outcomes in the IRPs studied.[1]

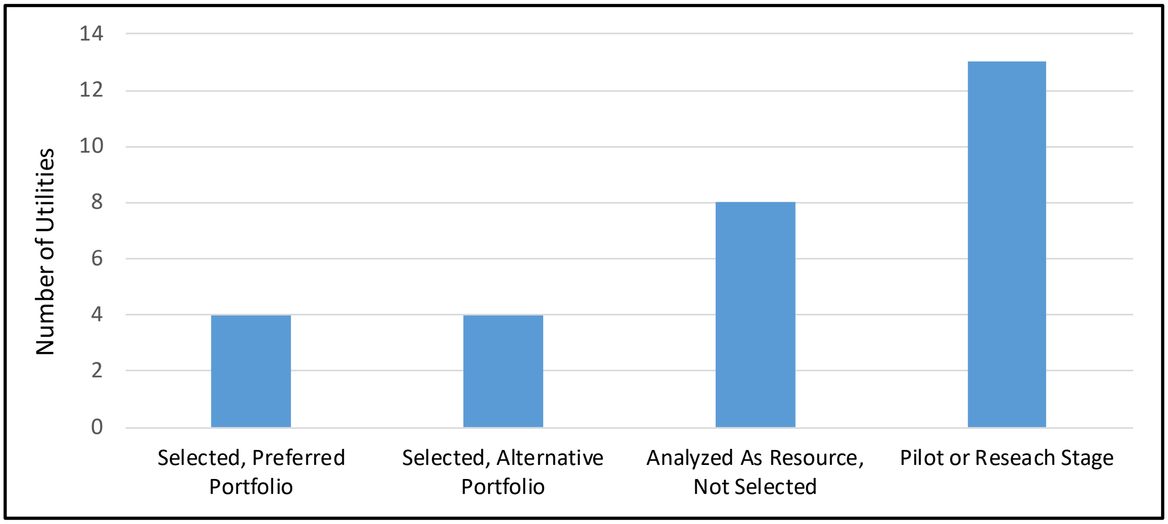


Figure 5. Status of Battery Storage in Integrated Resource Plans

The following four utilities selected batteries as part of their preferred portfolio:

- Puget Sound Energy (PSE) selected 75 MW for installation beginning in 2023;
- Arizona Public Service (APS) selected 507 MW for installation beginning in 2024;
- Indianapolis Power & Light (IPL) selected 500 MW for installation beginning in 2033; and
- Long Island Power Authority (LIPA) selected an unspecified amount of energy storage in its 2017 IRP; its governing board later approved 10 MW for installation (Harrington 2017).

A fifth utility, Kentucky Power Company, added a 10-MW battery system to the preferred portfolio after-the-fact for dealing with intermittent resources. Batteries were not selected in the portfolio screening process, but were later added because it was thought they would be helpful in integrating renewables (Kentucky Power Company 2016), so for purposes of this compilation, this was treated as a pilot project.

The four utilities that selected battery storage in an alternate portfolio generally did so in scenarios that included stricter emissions requirements or higher renewable resource mandates. These scenarios led to increased investment in renewable resources and energy storage to help integrate them. Two of the four utilities selected batteries in small quantities that are more consistent with pilot projects, rather than with resource needs. The four utilities selecting batteries in alternative cases were as follows:[2]

- Arizona Public Service selected 507 MW in 5 of 7 portfolios, and selected 1,107 MW in portfolios using greater levels of demand-side management (DSM) and renewables (APS 2017).

[1] The sum of the bars in Figure 5 is greater than 21 because some utilities fall into more than one category. Two utilities that selected storage in an alternative portfolio also selected it in their preferred portfolio, and several utilities that did not select storage in a portfolio indicated plans for a pilot project.

[2] This ignores alternative cases in which the IRP models were forced to select storage. For example, Rocky Mountain Power's 2017 IRP ran an alternative portfolio in which storage was forced into the model, and 80 MW were "selected."

- Black Hills (in their Colorado IRP filing) was required to analyze alternative cases including additional clean energy or energy efficient technologies, and selected 20 MW of batteries for installation in 2038/2039 (Black Hills 2016).
- IPL selected 600 MW of batteries for installation in 2030 in a portfolio that tests what happens if major fossil units' retirements are much earlier than other cases (IPL 2016).
- Rocky Mountain Power (PacifiCorp) selected small quantities (10 MW or less) of batteries in portfolios studying impacts of stricter regional emissions limits (Pacificorp 2017b).

Among utilities that did not select energy storage in a portfolio or did not include it as a resource option, cost was the most common reason cited. One utility expressed the desire to move cautiously with respect to including new resource options for reasons of maintaining reliability.

A common theme among utilities that declined to include battery storage as a resource option was a desire to explore the technology to inform potential inclusion in future IRPs. Six utilities did not analyze batteries, including those that did not mention battery storage or any variants[1] in their IRPs, and those that mentioned batteries but explicitly stated that batteries were not included in the analysis. [2] Three of those six utilities, however, did indicate that they would pursue at least one battery storage pilot project.

Figure 5 also shows that 13 utilities included battery energy storage in their R&D plans. Most already have projects underway which were identified in their IRPs. Projects range in size from under a MW (Dominion and Northwestern Energy), to Florida Power & Light's (FPL's) 53 MW, and up to the 150 MW "placeholders" identified in Duke's 2018 IRP. Table 2 summarizes the total of battery research projects in MW that were identifiable from the IRPs reviewed for this report. As noted in a footnote of Table 2, the authors are aware of other projects ongoing at some of the utilities reviewed for this report. In the interest of containing the scope of this report, the authors elected to not add to the results that were gleaned from sources other than the IRPs. One utility included among the 13 shown in Figure 5, Burlington Electric Department, indicated an intention to research battery energy storage, including researching storage in microgrids, but did not identify specific existing projects (Burlington Electric Department 2016).

Table 2. Battery Energy Storage Pilot or Research Projects Identified in IRPs

Utility	Pilot or Research Installations (MW)
Arizona Public Service	4.0
Dominion	0.8
Duke Energy, Carolinas*	38.9
Florida Power & Light	53.0
Georgia Power	1.3
Indianapolis Power & Light	20.0
Kansas City Power & Light	2.1
Kentucky Power Co.	10.0
Northwestern Energy	0.1

[1] Given the number of pages involved, it was infeasible to read every page of every IRP. Thus, IRPs were searched with Adobe Acrobat search tool, with searches looking for several variants of battery energy storage. Additionally, IRPs were skimmed thoroughly, particularly in cases where the search tool's effectiveness was in doubt.

[2] Note that the IRPs reviewed in this project were publicly available information downloaded off the internet. Many had significant amounts of information redacted as competitively sensitive information. It is possible that in one or more cases, analyses were performed but not documented in the publicly available data.

Utility	Pilot or Research Installations (MW)
Rocky Mountain Power	5.0
Puget Sound Energy**	2.0
Xcel Energy**	0.0
Total	**137.2**

*Duke's 2016 IRP listed numerous pilot or research projects; the total of which is shown in this table. Duke's 2018 IRP includes 140 MW of battery "placeholders," but as of this writing the authors are unaware of specific installations related to the placeholders.
**PSE's IRP identified one project. The authors are aware of others that would add 2.2 MW to the PSE total. Xcel also started two projects after the IRP was published, which would add 1.2 MW.

3.4 Inclusion of Combustion Turbines

Assuming simple cycle combustion turbines or reciprocating engines (collectively referred to herein as CTs) are the flexible resources most directly competing with battery storage in resource portfolios, the review examined the inclusion of CTs in the IRPs. Of the 21 IRPs reviewed, 19 utilities specifically identified CTs as a resource option. Of those, 7 utilities selected no CTs and 2 utilities selected 50 or fewer MW of CTs. Many of these utilities either need no new resources over their analysis period or were able to meet future resource needs relying on energy efficiency and renewable resources. Five utilities selected between 200 and 500 MW of CTs, including IPL, which also selected 500 MW of batteries. Only five utilities selected more than 500 MW of CTs. Of those, two utilities (APS and PSE) are among the utilities selecting batteries in their primary resource portfolio. Figure 6 summarizes the amount of CT resources selected by the utilities.

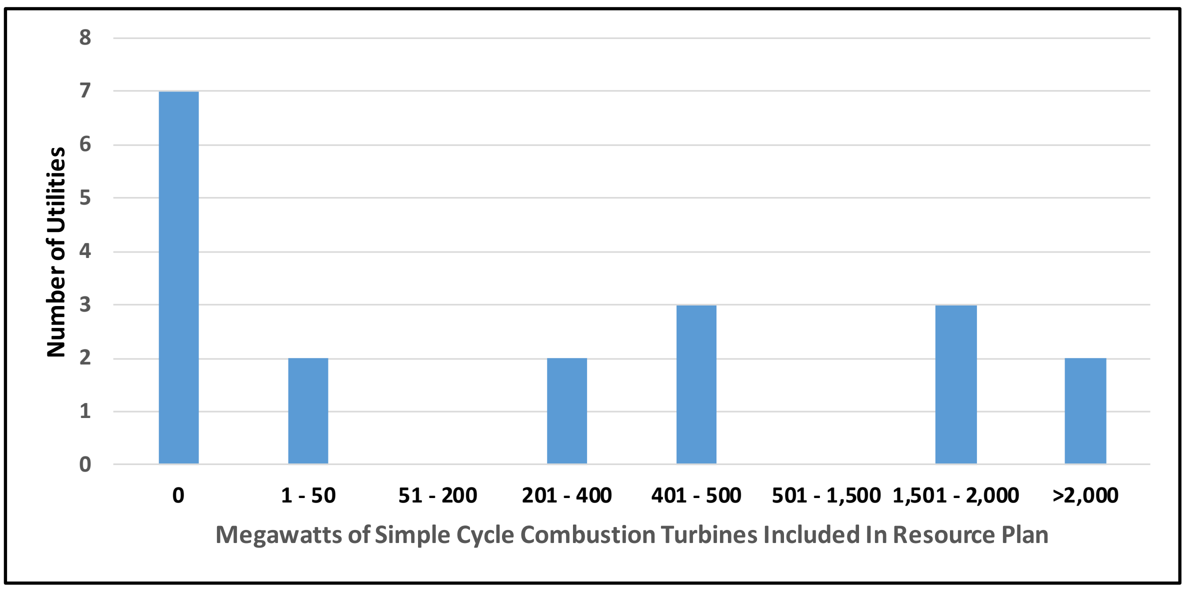


Figure 6. Distribution of Megawatts of Combustion Turbines Included in Resource Portfolios

Among utilities including batteries in their main portfolio, resource plans included a total of 1,092 MW of batteries and 1,975 MW of CTs.

3.5 Inclusion of Pumped Storage Hydropower

As it shows, two utilities included PSH in their preferred resource portfolio. In both cases, the utility was expanding an existing facility:

- Duke included an upgrade to its roughly 30-year old Bad Creek facility. Duke applied to the Federal Energy Regulatory Commission (FERC) in 2018 for approval to upgrade and refurbish the pump-turbines in the powerhouse as well as replace the existing runners and refurbish other equipment (FERC 2018a). In the process, Duke expected to increase the capacity of each of the four units by 46.4 MW, for a total upgrade of 186 MWs (Duke Energy Carolinas 2016).[1]
- Xcel Energy in Colorado also included an upgrade to its existing Cabin Creek facility. Cabin Creek was originally licensed in 1967, and needed refurbishments to continue operating. In 2015 the Colorado PUC approved a plan that included upgrades resulting in a 36-MW increase in capacity (Cotie 2015).

A third utility, Virginia Electric and Power Company (Dominion) is in the early stages of site selection studies related to a potential pumped storage facility that would be specifically linked to renewable energy resources. Under Virginia Senate Bill 1418, the Virginia General Assembly expressed their support for construction of "one or more pumped hydroelectric generation and storage facilities that utilize on-site or off-site renewable energy resources as all or a portion of their power source and such facilities and associated resources are located in the coalfield region of the Commonwealth" (Dominion 2017). Elsewhere Dominion also spoke of a need for more information or research on the subject of using PSH for integrating renewables. However, Dominion's IRP otherwise stated that PSH would not be considered for further analysis in the busbar curve analysis, meaning that PSH was screened as a potential resource, but eliminated on the basis of technical considerations and not available to be selected in resources portfolios (Dominion 2017). Figure 7 summarizes the role of PSH in the IRPs studied.

[1] The authors have noted differing estimates of the capacity to be provided by the upgrades. Duke's 2016 IRP was originally reviewed for this report. Duke has since issued a 2018 IRP which the authors recently noted, and reviewed. It should be understood that as time passes all of the utilities covered in this report would be expected to update their IRP, so a decision had to be made as to when to cut off analysis and cease to update text, tables, and figures. Many of the references to Duke herein refer to the 2016 IRP. In instances where the 2018 IRP materially impacts a conclusion or result, it has been reflected herein. In this specific instance, the 2018 IRP puts the PSH value at 65 MW per unit for a total of 260 MW (Duke Energy Carolinas 2018). FERC approved an upgrade from 1,065 to 1,400 MW (FERC 2018b).

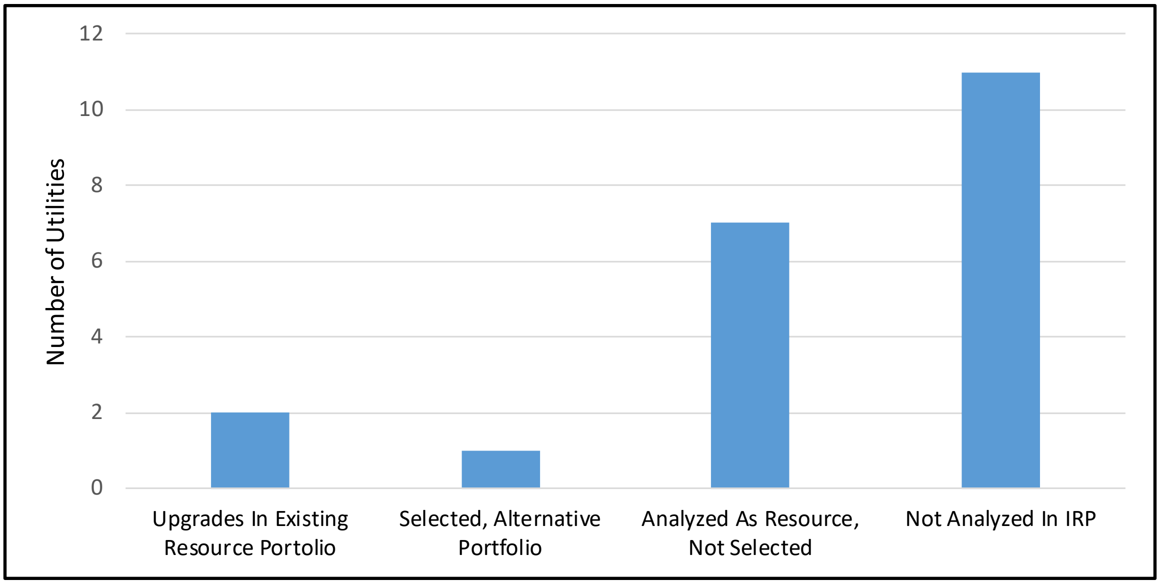


Figure 7. Status of PSH in IRPs

Seven utilities included PSH in their resource screening process, and eliminated it prior to portfolio analysis. The main reasons given for not selecting PSH was environmental (e.g., lack of access to water or land, or the cost and length of environmental siting processes needed to gain such access) and cost. The majority of utilities (11) either did not mention PSH in their IRP or stated they would not include it in the analysis.

4.0 Benefits of Battery Storage Quantified in IRPs

Energy storage is commonly linked to integration of intermittent renewable resources, either as a means for energy arbitrage (i.e., storing energy generated when prices are low for release during hours when prices are high) or for minimizing curtailment. However, as demonstrated in recent research and in the IRPs of some of the utilities that analyzed energy storage, the technology is capable of providing a broader range of grid services.

The *DOE/EPRI Electricity Storage Handbook in Collaboration with NRECA* (DOE/EPRI 2015), for example, identifies 18 discrete values that energy storage can provide to the grid or to customers. Driven by local grid needs, market rules, and utility structure, those values can vary significantly from one location to another, as shown in Figure 8 (Balducci et al. 2018).

Figure 8 demonstrates the need for each utility to individually identify and analyze the benefits of energy storage, as the value of individual benefits may vary widely across utilities. When dealing with more locational values such as relieving congestion or deferring investment in the transmission or distribution systems, values will likely vary widely even across the service territory of a single utility, depending on local constraints and needs.

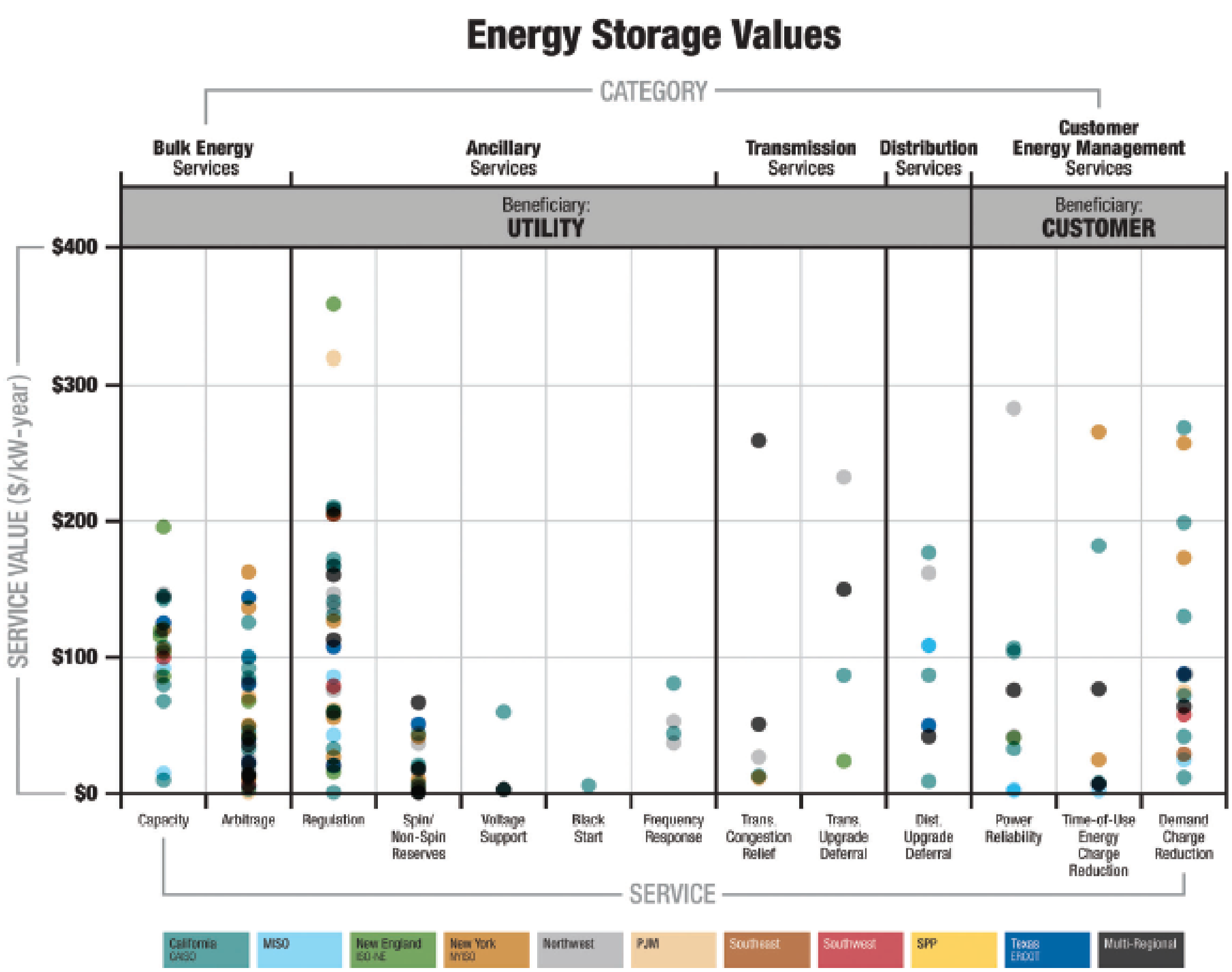


Figure 8. Energy Storage Values by Service Type and Location

The utility industry, however, has yet to develop a common taxonomy for analyzing the benefits of energy storage. In discussing the benefits of energy storage, many utilities included generic value for energy storage such as "flexibility" or "integrating renewables," which are not defined services and, in practice, would likely entail the provision of multiple defined services, such as load following, reserves, and regulation. How those services were defined and, more importantly, how they were quantified and reflected in resource valuation was not clear from filed plans.

Figure 9 lists the grid services and benefits of energy storage that utilities identified in their IRPs and the number of utilities that identified each benefit or service.

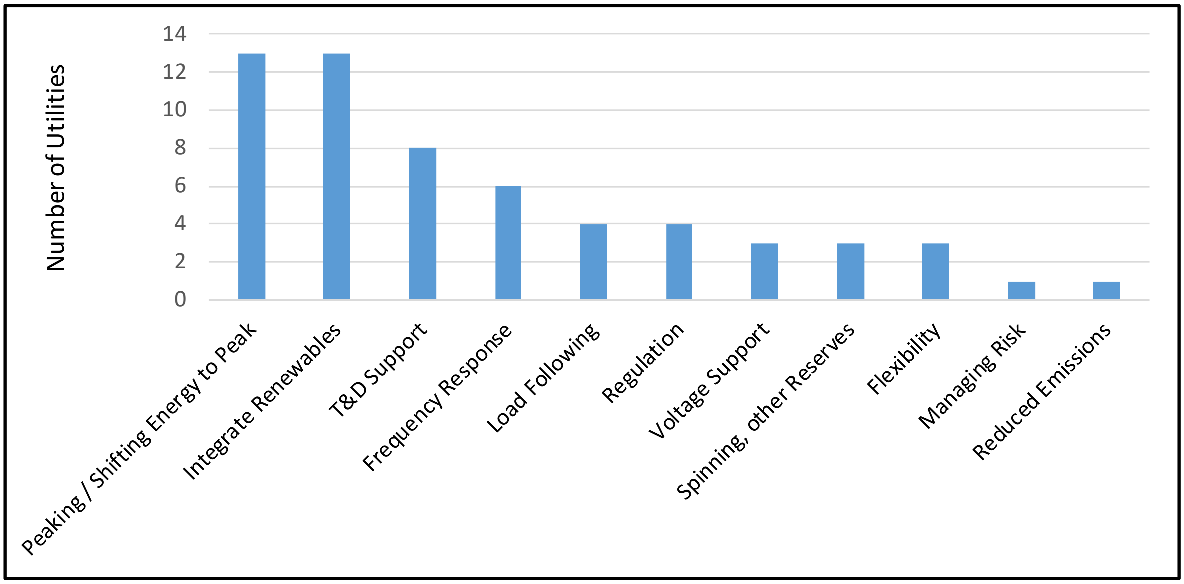


Figure 9. Benefits of Energy Storage Included in IRPs

The information in Figure 9 is based on the IRPs that analyzed batteries at least at the preliminary screening level. The information is derived from the list of services each IRP indicted that batteries can provide. For the most part, the list of services was often made clear. However, in most cases it was difficult to verify whether the services were all being analyzed, or simply listed. Also unclear in some cases was whether providing capacity in substations was intended as a means to defer substation upgrades or to provide improved service to customers in terms of power quality or voltage. Thus, transmission and distribution (T&D) services were lumped into one category (particularly since IRPs typically do not evaluate distribution systems). Discussions of T&D services tended to be found in the discussions of R&D projects and not in the portion of the IRP where the discussion was focused on placing a value on services, except to note the difficulty in assessing benefits where there may be trade-offs between T&D and generation services.

Figure 9 listed 11 services identified by utilities' IRPs. As can be seen from Figure 6, most of the utilities identified fewer than half of those 11 services. The most common number of services identified is two – typically some combination of capacity, integrating renewables, and T&D support. Figure 10 depicts the number of services identified by utilities' IRPs.

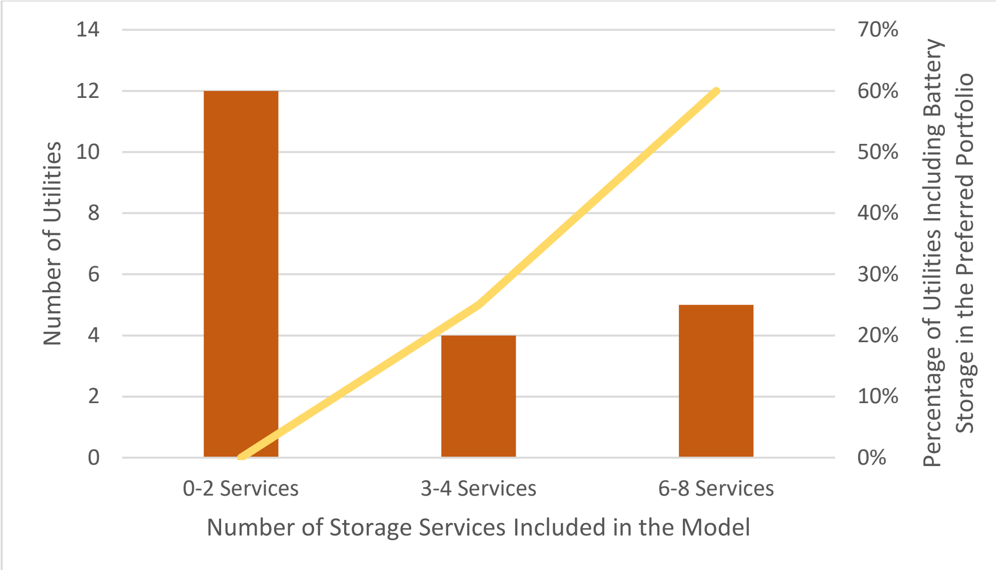


Figure 10. Distribution of Utilities by Number of Battery Storage Benefits Identified in IRP

Utilities that analyzed more energy storage services in the IRP were more likely to select batteries in their preferred portfolio. None of the 10 utilities analyzing fewer than 3 services selected batteries in the preferred portfolio. Among the five utilities analyzing three or four services, two (40 percent) selected batteries in the preferred portfolio. Among the six utilities analyzing six or more services, three (50 percent) included a battery in the preferred portfolio.

The three utilities that included the most battery capacity in their preferred portfolio (APS, PSE, and IPL) all included between six and eight energy storage services in their IRP. IPL primarily modeled batteries as peaking units, citing the lack of adequate modeling tools and the absence of supporting tariffs from the MISO to enable ancillary services valuation. IPL also discussed several other potential uses for batteries, including the utility's current use of an existing battery for frequency control and studying the use of batteries to replace black start units. APS and PSE modeled batteries as peaking units as well, but included batteries for other reasons. As PSE explained in its IRP, T&D benefits influenced the utility's selection of storage: "A small amount of utility-scale batteries appears cost effective at some point in the planning horizon in every scenario, given the assumed transmission and distribution benefits. By 2037, all scenarios have at least 50 MW, while a few have approximately 100 MW. It appears batteries are cost effective primarily because they can be sized to fit needs with slowly growing loads, in addition to being very flexible" (PSE 2017).

5.0 Models Used in IRPs

One of the goals of this research was to identify the type of modeling software utilized by utilities in their IRP processes, to understand the degree to which utilities are adopting software that moves beyond the limitations in conventional models. As explained in Section 2.0, conventional IRP models analyze system needs in broad terms, meaning that resource benefits associated with sub-hourly dispatch, provision of ancillary services, and local optimization of transmission and distribution systems are not captured. To account for the benefits of a flexible and scalable resource such as energy storage, models capable of analyzing resources with a high level of granularity – temporally (sub-hourly values) and spatially (locational values) – are needed (Balducci et al. 2018).

While this research provided some insight into what types of models utilities are using, it became apparent that additional, more in-depth research will be required to more fully answer the question of what models utilities are using and how they are using them. This section will communicate the lessons learned through this effort and make recommendations for future research in this area.

As was also discussed in Section 2.0, preparing an IRP is a highly complex exercise that consists of multiple, detailed steps. Because there are so many sub-tasks within the IRP process, many utilities employ multiple models to perform different tasks. For example, many utilities use a capacity expansion model to identify type and timing of resource additions for each portfolio, and then use a power cost model to run each portfolio through stochastic economic analysis. Additional models may be employed for other tasks, such as forecasting market prices or identifying potential levels of energy efficiency and other forms of demand-side management. Furthermore, as will be discussed below, some utilities began employing sub-hourly models for a limited subset of analyses in their most recent IRPs.

However, for the purposes of planning future resource investments, most utilities are using capacity expansion models and production cost models. The main differences between the two types of model are that production cost models tend toward hourly, chronological modeling of resource dispatch, while the capacity planning models tend to use non-chronological hourly modeling based on typical hour or typical week resolution. Production cost models also tend to show major transmission lines and nodes, while capacity expansion models tend to represent selected transmission lines (Fisher et al. 2016). This distinction is of some importance because several ancillary services provided by batteries might be best modeled on a sub-hourly basis (Balducci et al. 2018), and because industry literature pointing to the use of batteries for meeting intra-hour drops in wind or solar resources indicates that chronological modeling is preferable to typical hour or week sampling.

Several software packages have been developed in recent years that advertise sub-hourly modeling capabilities, some of which have been adopted by utilities studied in this report. Documents found on-line, reviews of the IRPs, and discussions with industry participants indicate that three models used by some of the utilities (PLEXOS, Aurora, and PowerSimm) can model on a sub-hourly basis. In addition, evidence found on-line indicates two other hourly production cost models (PROMOD and PROSYM) and one capacity planning model (Planning and Risk, which uses PROSYM) have some sub-hourly capabilities.

However, the research team was unable to operate the models to understand their capabilities, and a utility's usage of a model with sub-hourly capabilities does not necessarily mean that the utility used those capabilities. As a result, several areas of uncertainty remain regarding whether modeling capabilities that effectively characterize storage contributions are being used.

5.1 Emerging Models and Practices for Energy Storage

In general, utilities did not provide detailed explanations of how models were used to incorporate energy storage into the planning process. Generally, utilities limited the modeling discussion to a list of the modeling software packages used. A notable exception is PSE, which began using PLEXOS in its 2017 IRP, and provided a detailed explanation of how it used PLEXOS to capture sub-hourly benefits for energy storage and other flexible resources:

> To estimate the flexibility benefit of incremental resources, PLEXOS first runs the base case, which only contains PSE's current resource portfolio. Then, PLEXOS is run again with the addition of one new generic resource. The sub-hourly production cost result of the case with the base portfolio is then compared to the production cost of the case with the additional resource. Any cost reduction to the portfolio is assumed to be attributed to the new resources (PSE 2017).

PSE's approach demonstrates how additional, more granular models may be modularly added to the IRP process to quantify the benefits of flexible resources that are not captured in the conventional modeling process.

Portland General Electric (PGE) developed a similar approach in its 2016 IRP. While PGE was not one of the utilities studied in this report, the authors elected to include the utility's approach because other states and industry groups have cited it as a best practice (Washington UTC 2017; ESA 2018). PGE's methodology, which the utility called the "Net Cost" approach, employs an external model to capture all of the sub-hourly benefits of an energy storage system over its useful life, which would not be reflected in the IRP models. PGE then calculates the net present value of those benefits and subtracts them from the storage system's assumed costs, as shown in Figure 11 (Portland General Electric 2016).

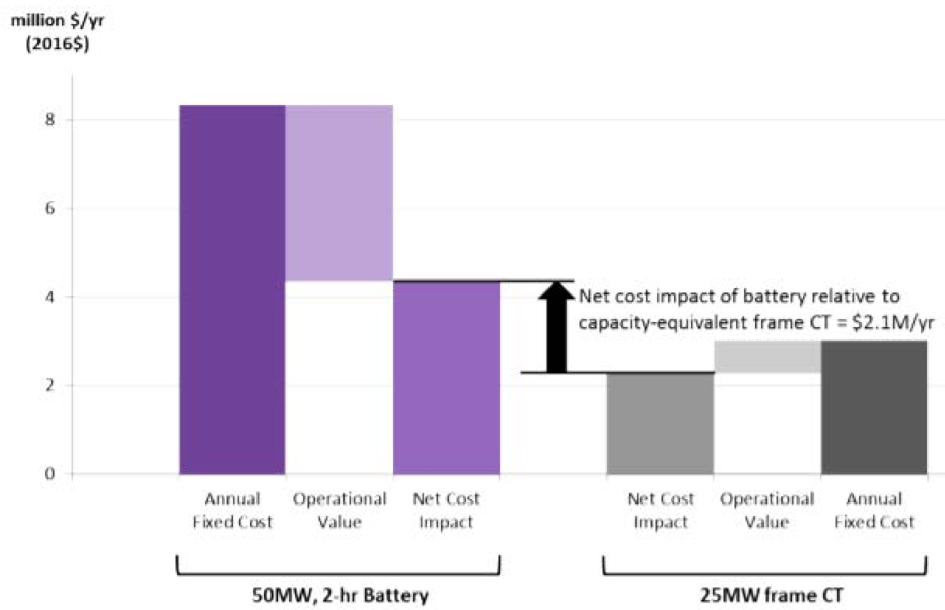


Figure 11. Portland General Electric's Net Cost Approach

The Net Cost methodology is somewhat limited in that it does not directly compare the benefits of energy storage alongside other resource options – as the IRP is supposed to do. However, it is an improvement over conventional approaches in that it captures granular benefits of energy storage that would otherwise be omitted from the planning process and is relatively easy to employ, as it can be added to the planning process without disruption and various entities offer models capable of doing such analysis at no cost.[1]

While several IRPs studied in this work indicated that utilities were developing procedures for modeling energy storage, Duke's 2018 IRP set forth a plan for developing those procedures, which the utility is calling the Integrated Systems and Operations Planning (ISOP) process.[2] Duke's 2018 IRP specifically acknowledges several grid services including frequency regulation, intermittent resource smoothing, and energy and capacity values, and T&D services including system deferrals, non-wires alternatives to traditional wires upgrades, and consumer value arising from transmission and distribution system reliability and power quality improvements. For future IRPs, the ISOP process is expected to result in planning models that can assist in quantifying benefits from all of the complimentary and competing benefits, tying together the IRP and T&D planning process more closely than in traditional IRPs. In the 2018 IRP, Duke included 150 MW of what they referred to as "battery storage placeholders," which are essentially pilot projects that were included in all of the resource portfolios Duke analyzed. These placeholders represent grid-connected batteries that Duke will deploy to gain real-world data and experience in identifying high-value applications in the transmission and/or distribution systems, which also can provide generation benefits (Duke Energy Carolinas 2018). The specific 150-MW target appears to have been developed exogenously as the authors found no description of how the target was developed in the IRP, and did find discussion on-line pointing to a rate case settlement in which Duke agreed to install 300 MW of battery storage in the Duke Energy Carolinas and Duke Progress service territories in North Carolina (Walton 2018; Spector 2018).

[1] For instance, PNNL has developed the Battery Storage Evaluation Tool (BSET), and the Electric Power Research Institute (EPRI) has developed StorageVET.

[2] The DEC IRP reviewed for this report was initially the 2016 IRP submitted in South Carolina. Because Duke subsequently submitted a 2018 IRP in North Carolina while this report was in production, it was also reviewed.

6.0 Capital Cost Estimates

The energy storage industry has undergone a period of dynamic development in recent years, marked by rapidly improving technologies and declining costs. In that environment, pinpointing a reasonably accurate estimate of storage system costs at a given point in time is a difficult exercise. However, as will be discussed in this section, identification of cost-effective energy storage opportunities is predicated on accurate cost assumptions.

To illustrate the difficulty of pinpointing a cost assumption, energy storage industry analysts found that from 2016–2017, which covers the planning period for most of the IRPs studied in this report, observed prices for lithium-ion battery systems fell by 24 percent; prices were further projected to continue declining at about 9 percent per year through 2023 (Wood Mackenzie & ESA 2019). As cost assumptions are inputs in the planning process, they tend to be formulated early in the planning process. If the assumptions for energy storage are based on observed prices at the time, they may be inaccurate by the time the plan is complete, and even more inaccurate by the time investment decisions are made. To improve the validity of cost assumptions for energy storage, reliable cost forecasts should be used.

Of the 21 plans reviewed, only eight publicly disclosed the utility's cost assumptions for new resources. A full list of observed cost assumptions for energy storage resources is in Appendix B. While this group represents an admittedly limited subset of the utilities, the cost assumptions that they disclosed support two observations. First, the lack of publicly disclosed cost assumptions limits the potential for public review of a key planning assumption and prevents resource providers from challenging those assumptions. If, for example, an energy storage provider could provide a project at a lower cost than that assumed by the utility, it would not have the necessary information to identify and challenge that assumption.

Second, the observed cost assumptions indicate that utilities in general are more certain of the costs for technologically mature resource like a combustion turbine or a pumped storage facility than they are for less mature resources like batteries, as shown in Figure 12.

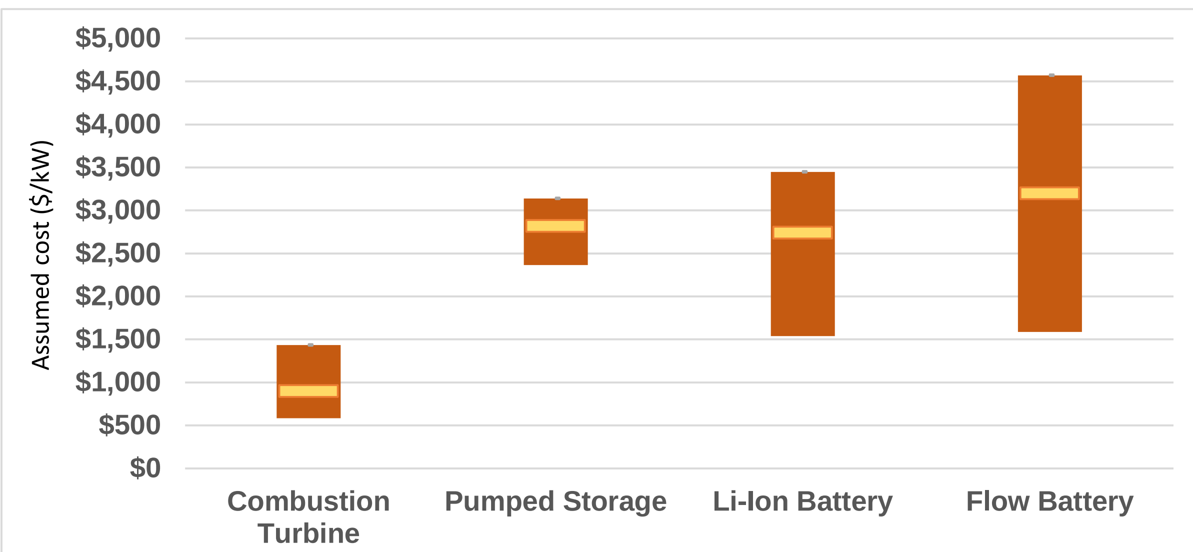


Figure 12. Range of Publicly Disclosed Resource Cost Assumptions

As Figure 12 shows, among utilities that disclosed their resource cost assumptions, the cost of gas-fired combustion turbines ranges from about $600 per kW to $1,400 per kW, and averages about $900 per kW. Though generally higher, cost assumptions for pumped storage resources exhibited a similar range, going from about $2,400 per kW to $3,100 per kW, and averaging about $2,800 per kW. When addressing battery-based energy storage, however, the range of cost assumptions exhibited a much wider spread. Assumptions for a four-hour lithium-ion battery, for example, ranged from about $1,500 per kW to about $3,400 per kW, with an average of about $2,700 per kW. Flow battery assumptions ranged from about $1,600 per kW to about $4,600 per kW, with an average about $3,200 per kW.

While uncertainty regarding new technologies may seem like an obvious finding, it is worth discussing for several reasons. First, as demonstrated in Figure 12, there is a near overlap between the high end of combustion turbine assumptions and the low end of battery assumptions, suggesting that there are likely some circumstances under which energy storage would be cost-competitive with a combustion turbine, even under conventional planning practices.

Secondly, while the total installed cost of a battery system will vary by specific project characteristics, such as point of interconnection, land ownership, and existing infrastructure, recent research suggests that a reasonable range of assumptions would be much smaller than the roughly $2,000 range exhibited for lithium ion batteries and the roughly $3,000 range exhibited for flow batteries (Lazard 2018).

Finally, accurate cost assumptions for energy storage are particularly important when it comes to energy storage. As presented in Section 4.0, utilities are adding the ability to value energy storage services in the IRP process to varying degrees. Absent such steps, an IRP is effectively capturing all of energy storage's costs, but only a small fraction of its benefits. As utilities adapt planning processes to include additional energy storage values, they are effectively reducing the net cost of storage, because all of the costs are already captured in the assumption. Utilizing accurate assumptions that capture energy storage cost declines – both observed and reasonably forecast – will allow for more prompt identification of cost-effective storage opportunities as value streams are layered in.

7.0 Summary and Next Steps

The purpose of this research was to identify the obstacles that energy storage technologies face within IRP processes and assess the degree to which the utility industry is including energy storage in IRPs. The findings suggest that the industry has taken significant steps to include energy storage in the planning process; 15 of the 21 utilities studied included battery storage as a resource option in their IRP, and 4 of those utilities selected battery storage as part of their preferred portfolio, while another 12 utilities indicated plans for a pilot storage project to better understand the technology. Where a utility's plan identified obstacles to battery storage, high capital costs and modeling challenges were frequently mentioned.

PSH faces a different set of barriers, as permitting timelines and geographic constraints were commonly cited by utilities that either did not include the technology or included it, but did not select it in the preferred portfolio. Of the 21 utilities, 10 studied PSH and 2 included it in resource plans, although in both cases the utility was expanding an existing PSH facility.

The review illuminates two remaining challenges that energy storage technologies are likely to continue facing in future IRPs: cost uncertainty and a lack of standard analytical tools and protocols. While cost assumptions for PSH were closely aligned, the wide range of cost assumptions for battery storage that were observed in the IRPs suggests general uncertainty about the costs of battery storage. As technologies continue to develop and new chemistries enter the market, this uncertainty is likely to continue. Recent research has identified current costs for several types of battery storage, but absent an effort to maintain current data in an accessible format, that information will soon be obsolete – particularly for developing chemistries.

The second challenge – lack of analytical tools and protocols – was a common refrain in the IRPs. While a small minority of utilities had selected planning tools to address energy storage and were developing protocols for using those tools, many utilities expressed frustration with the lack of tools and standard practices for modeling energy storage. There are tradeoffs when considering different energy storage technologies; batteries are scalable and flexible, but are limited in duration and technologically immature. PSH is technologically mature and capable of large scale and long duration, but has permitting and siting constraints. One of the key obstacles for energy storage technologies is that while the weaknesses are readily apparent, the strengths are not. Absent tools that can "balance the scale" by capturing the benefits of energy storage, models will be unable to identify when energy storage is a cost-effective option and what type would be most beneficial.

To ensure that utilities, regulators, and other IRP stakeholders have sufficient tools and information to fairly evaluate energy storage in future plans, the following additional research efforts are recommended for consideration by DOE and the national laboratories:

- **Establish a mechanism for sharing current cost data and projected trends for energy storage technologies**. Properly valuing the benefits of energy storage is only one part of a proper analysis; weighing those benefits against accurate cost information is equally important in identifying cost-effective opportunities for energy storage. This study has identified a wide range in utility cost assumptions for energy storage, particularly for batteries. Establishing a mechanism for identifying and sharing data for all forms of commercially available energy storage would aid utilities and IRP stakeholders in converging assumptions that reflect both current prices and projected cost trends.
- **Refine existing planning support models and adapt energy storage assessment tools for investment planning**. Several IRPs reviewed in this study stated that computational and structural modeling limitations present an obstacle to including energy storage in IRPs. The DOE, the national

laboratories, and utility industry have extensive experience in quantifying and modeling the benefits of energy storage, and have developed several tools for doing so, but further adaptation for planning purposes may be warranted. Model developers should consider working with utilities to refine existing models to better meet IRP modeling needs.

- **Create a forum for sharing best practices in energy storage modeling.** The study revealed a gap in how utilities view energy storage; some are actively developing practices for modeling it, while many cited a lack of standard industry practices for energy storage as a barrier to including it in IRPs. This immediate work identifies anecdotal examples of a few utilities that are developing approaches to incorporate energy storage into the IRP process. Research to explore various practices developed by leading utilities and share them across the utility industry may contribute to standard industry practices, which some utilities indicated would improve storage modeling.

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Appendix A

List of Utilities and Year of Integrated Resource Plan(s)

Appendix A

List of Utilities and Year of Integrated Resource Plan(s)

Table A.1. Utility and the Year of Its Integrated Resource Plan

Utility	Report State	Year(s)
Arizona Public Service Company	AZ	2017
Black Hills Energy	SD and CO	2016
Burlington Electric Department	VT	2016
Dominion (Virginia Electric and Power Company)	VA	2017 & 2018
Duke Energy, Carolinas	SC / NC	2016 & 2018
El Paso Electric	NM	2015
Entergy Arkansas	AR	2015
Florida Power & Light Company	FL	2017 & 2018
Georgia Power	GA	2016
Indianapolis Power & Light Company	IN	2016
Kansas City Power & Light Company	MO	2015 & 2018
Kentucky Power Company	KY	2016
Long Island Power Authority	NY	2017
Minnesota Power	MN	2015
Northwestern Energy	MT and SD	2016
Nevada Energy	NV	2016
PacifiCorp / Rocky Mountain Power	UT	2017** & 2018 update
Potomac Edison Company	WV	2016
Puget Sound Energy	WA	2017
Tennessee Valley Authority	TN	2015
Xcel Energy	CO	2016*

*IRP appears in reference list in two volumes, 2016a and 2016b.
**IRP appears in reference list in two volumes, 2017a and 2017b.

Appendix B

Observed Cost Assumptions for Energy Storage Resources

Appendix B

Observed Cost Assumptions for Energy Storage Resources

Table B.1. Cost Estimates for Battery Storage Systems from IRPs that Presented Cost Data

Utility	Capital Cost ($/kW)	Fixed O&M ($/kW)	Variable O&M ($/MWh)	Dollar Year
Arizona Public Service, 4 Hr. Li-Ion*	1,539	23.98	0.00	2016
Arizona Public Service, 4 Hr. Flow ±	1,589	31.78		2016
Arizona Public Service, 4 Hr. NaS**	1,740	34.80		2016
Arizona Public Service, 4 Hr. Lead Acid***	941	18.82		2016
Black Hills, NaS**	3,775			2012
Burlington Elec. Dept., 4 Hr. Li-Ion*	3,400	6.45		2017
Entergy, Lead Acid***	2,400	0.00	25.00	2015
Kentucky Power Co., 3 Hr. Li-Ion*	2,300	15.90	0.00	2016
Northwestern Energy, Li-Ion*	3,330	22.50	0.00	2016
Northwestern Energy, Flow±	4,570	30.00	43.00	2016
Northwestern Energy, NaS**	5,410	26.90	29.50	2016
PacifCorp, 1 Hr. Li-Ion*	1,319			2017
PacifCorp, 2 Hr. Li-Ion*	2,029			2017
PacifCorp, 4 Hr. Li-Ion*	3,449			2017
PacifCorp, 8 Hr. Li-Ion*	6,289			2017
PacifCorp, 1 Hr. Flow±	1,936			2017
PacifCorp, 2 Hr. Flow±*	2,731			2017
PacifCorp, 4 Hr. Flow±*	4,320			2017
PacifCorp, 8 Hr. Flow±*	7,499			2017
PacifiCorp, 8 Hr. NaS**	8,286			2017
Puget Sound, 2 Hr. Li-Ion*	1,514	23.68		2016
Puget Sound, 4 Hr. Li-Ion*	2,439	36.49		2016
Puget Sound, 4 Hr. Flow±	2,324	26.82		2016
Puget Sound, 6-Hr. Flow±	3,042	23.40		2016

*Lithium-ion batteries.
**Sodium-sulfur or NaS batteries.
***Lead acid batteries
±Flow batteries (vanadium redox)

Table B.2. Cost Estimates for Pumped Storage Hydro Systems from IRPs that Presented Cost Data

Utility	Capacity (MW)	Capital Cost ($/kW)	Fixed O&M ($/kW)	Variable O&M ($/MWh)	Dollar Year
Arizona Public Service	100	3,139	78.48	3.49	2016
Northwest Energy	–	2,920	15.3	0.10	2016
PacifCorp	383	3,468	21.1	0.00	2016
PacifCorp	711	2,861	16.86	0.00	2016
PacifCorp	1,200	3,601	15.58	0.00	2016
Tennessee Valley Authority	850	2,365*			2013

*Using U.S. Bureau of Economic Analysis Gross Domestic Product price deflators dated March 30, 2017, this translates to $2,465 in 2016$.

Appendix C

Legislative and Regulatory Actions Affecting Future Integrated Resource Plans

Appendix C

Legislative and Regulatory Actions Affecting Future Integrated Resource Plans

Looking forward, a number of factors are likely to impact how utilities – those within this study and the broader industry – will evaluate energy storage in future planning efforts. Numerous states have developed energy storage policies in recent years and, as identified in this report, several utilities are independently developing energy storage demonstration projects to inform future plans.

Whether a utility is seeking to identify best fits for energy storage to comply with a state mandate, implementing new policies for how storage should be treated in resource planning, or incorporating lessons learned from a demonstration project, there will be several drivers for utilities to improve storage modeling capabilities in future plans.

Table C.1 lists recent legislative and regulatory developments that could affect how energy storage is treated in future IRPs of the utilities in this study. Legislative actions generally set a mandate that requires utilities to invest in a certain level of energy storage or establish funding programs to assist them in doing so. In some cases, legislators direct regulators to conduct a more detailed analysis of energy storage technology or develop regulations specific to energy storage. The regulatory actions generally include rulemakings, in which regulators set new requirements for how energy storage should be treated in planning and other regulatory proceedings, or policy statements, in which regulators issue nonbinding guidance on how utilities should be treating energy storage. In some cases, regulatory actions arise from a decision in a rate case or other proceedings that resulted in a precedent on energy storage.

The actions listed on Table C.1 are mostly from 2016 and 2017, but a small number are from 2018. Although final actions may not have been timely to be directly reflected in the IRPs reviewed herein, given the length of regulatory proceedings, it is possible that utilities may have taken steps to improve their analysis of energy storage before final actions were taken.

Where Table C.1 includes no entries for a utility, it means that research (primarily web searches) did not reveal recent legislative or regulatory actions significantly affecting storage. Note that in some cases there was proposed legislation, and perhaps legislation that passed one house of the states’ legislatures, but no legislation passed and signed into law. Proposed legislation was not included in Table C.1.

Table C.1 includes one process that is was neither regulatory nor legislative, the Modernizing Minnesota Grid workshop shown next to Minnesota Power. The workshop process was hosted by a group within the University of Minnesota, and the attendees included representation of both regulatory and legislative branches within Minnesota.

Table C.1. Recent Legislative or Regulatory Actions

Utility	Type of Action	Description of Action
Arizona Public Service (AZ)	Regulatory	In 2016, the Arizona Corporation Commission (ACC) ordered and approved APS plans for a residential energy storage (battery) pilot.[1]
	Regulatory	In 2017, the ACC authorized APS to develop a $2 million incentive program to assist commercial customers in acquiring behind-the-meter storage to reduce load during peak periods.[2]
Black Hills (CO/SD)	Legislative	In 2018, the Colorado Legislature directed the Public Utilities Commission to establish, by Feb. 1, 2019, mechanisms for utilities to procure energy storage systems.[3]
	Legislative	In 2018, the Colorado Legislature established a right for electric consumers to install and interconnect energy storage systems, and directed the Public Utilities Commission to develop interconnection rules for customer-sited energy storage systems.[4]
Burlington Electric Dept. (VT)	Legislative	In 2017, the Vermont Legislature directed the Public Service Commission to prepare a report on deploying energy storage in the state and made energy storage projects eligible for funding through the Vermont Clean Energy Development Fund.[5]
Dominion (VA)	Legislative	In 2017, the Virginia legislature passed SB1258ER, an act to convert the Virginia Solar Energy Development Authority to the Virginia Solar Energy Development and Energy Storage Authority. The purpose of the authority is to support the development of solar energy and energy storage in the Commonwealth.[6] Also in 2017 the legislature passed HB 1760/SB 1418 which streamlines the regulatory approval process for pumped storage hydro projects and potentially favors conversions of abandoned coal mines into PSH facilities.[7]
	Legislative	In 2018, the Virginia Legislature passed HB 1558/SB 966, ‘Electric utility regulation; grid modernization; energy efficiency programs,’ which among other things directed the State Corporation Commission (SCC) to conduct pilot programs for the deployment of electric storage batteries with capacity limits up to 30 MW for Dominion (and 10 MW for Appalachian Power).[8]
Florida Power & Light (FL)	Regulatory	Approved Settlement Agreement in rate proceeding, including proposal for FPL to install up to 50 MW of battery storage.[9]
Long Island Power Authority (NY)	Legislative	Assembly bills A6571 of the 2017-2018 session and A08921 directed the New York Public Service Commission in consultation with other state agencies to establish and energy storage procurement target for 2030.[10] The entities subsequently established targets of 1,500 MW by 2025 and 3,000 MW by 2030.
		Governor Cuomo proposed to invest at least $200 million from the New York Green Bank for storage related investments, working toward a goal of 1,500 MWs by 2025.[11]
NV Energy (NV)	Legislative	Senate Bill (SB) 204 requires the Public Utilities Commission (PUC) of Nevada to investigate and establish biennial targets for certain utilities to procure energy storage systems.[12] The Nevada PUC opened a docket but has yet to establish targets.
	Legislative	SB 145 establishes an incentive program energy storage systems (and other DERs) – linked to the Solar Program.[13] The Nevada

		PUC opened a docket and, in May 2018, issued regulations incenting energy storage systems as part of the Solar Energy Incentive Program.[14]
PacifiCorp / Rocky Mountain Power (UT)	Legislative	SB 115 passed and signed into law allowing the state Public Service Commission to authorize a large-scale utility to establish innovated efficiency technology programs, including energy storage.[15]
Potomac Edison Company (MD)	Legislative	House Bill (HB) 773 requires the Power Plant Research Program to conduct a study of regulatory reforms and market incentives to increase the use of battery storage.[16]
	Legislative	Senate Bill 758 provides tax credits for residential and commercial battery storage.[17]
Puget Sound Energy (WA)	Legislative	The Washington Clean Energy Fund, established by the Washington Legislature, has approved funding for smart grid grants since 2013, including battery storage projects with Washington utilities.[18]
	Regulatory	The Washington Utilities and Transportation Commission (UTC) issued a policy statement indicating storage is a key technology for meeting the state's energy goals and that utilities should pursue advanced modeling in their IRPs to identify cost effective opportunities for storage development.[19]
Xcel Energy (CO / MN)	Regulatory	Received approval from Colorado Public Utilities Commission for cost recovery of capital costs of 2 energy storage projects.[20]

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Appendix D

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Appendix D

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