BEFORE THE PUBLIC UTILITY COMMISSION

OF OREGON

LC 77

In the Matter of PACIFICORP, dba PACIFIC POWER, 2021 Integrated Resource Plan.	**COMMENTS OF SWAN LAKE NORTH HYDRO, LLC AND FFP PROJECT 101, LLC**

The companies working to develop the Swan Lake and Goldendale pumped hydro storage projects (together, the "Projects")[1] appreciate the opportunity to provide comments on PacifiCorp's 2021 Draft Integrated Resource Plan (the "Draft IRP"), which was filed with the Oregon Public Utility Commission (the "Commission") in the above-referenced docket on September 1, 2021, and subsequently amended by an errata filing on September 15, 2021.[2] According to the procedural schedule adopted in this proceeding,[3] Staff and Intervenor's opening comments are due December 3, 2021. In accordance with that schedule, the Projects are hereby submitting these Comments.

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[1] The companies are Swan Lake North Hydro, LLC and FFP Project 101, LLC. FFP Project 101, LLC is developing the Goldendale Energy Storage Project, as noted in the Draft License Application submitted to the Federal Energy Regulatory Commission in Docket No. P-14861. While FFP Project 101, LLC is the entity developing Goldendale, and therefore is the intervenor in this proceeding, FFP Project 101, LLC may be referred to simply as "Goldendale" in this or subsequent filings with the Commission.

[2] Unless otherwise indicated, all references and citations to the Draft IRP in these Comments are to the Errata version filed on September 15, 2021.

[3] *See In the Matter of PacifiCorp, dba Pacific Power 2021 Integrated Resource Plan*, LC 77, Prehearing Conference Memorandum (issued Oct. 4, 2021), available at: https://edocs.puc.state.or.us/efdocs/HDC/lc77hdc16320.pdf.

I. SUMMARY OF COMMENTS

The Projects commend PacifiCorp's efforts to fairly consider pumped storage projects as part of the Draft IRP. While the Projects support many aspects of PacifiCorp's analysis of pumped storage projects in the Draft IRP, the Projects strongly recommend that PacifiCorp accelerate the procurement of pumped storage in the Draft IRP from the currently-assumed 2040 date in PacifiCorp's preferred portfolio.[4] Advancement of pumped storage is warranted for several reasons, including:

1. PacifiCorp's own analysis identifies these resources as amongst the lowest-cost resources available to meet clean energy goals;
2. Pumped storage provides a diversity of benefits to PacifiCorp that can maximize the efficiency and investment PacifiCorp plans to make in other, renewable generation resources, and whose 8-12 hour discharge capability will better align with PAC's winter peaking needs, particularly for its westside loads;
3. Advancing development of pumped storage is consistent with PacifiCorp's stated goals for this IRP;
4. Acquisition of pumped storage, at the same time PacifiCorp plans to build a large number of battery facilities in the coming decade, will serve as a hedge against various market factors that are likely to negatively impact batteries in the next decade; and
5. Market conditions, including compliance with recently-enacted clean energy bills in both Oregon and Washington and the long lead-time for constructing a pumped storage project, necessitate PacifiCorp taking earlier action to acquire these resources.

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[4] *See* Draft IRP at Fig. 1.3; *see also, id.* at p. 11 ("Through 2040, the 2021 IRP includes 4,781 MW of storage co-located with solar resources, 1,400 MW of standalone battery, and 500 MW of pumped hydro.").

The remainder of these comments address each of the above topics in further detail to demonstrate why advancing the procurement of pumped storage in the Draft IRP is not only warranted, but necessary, for PacifiCorp to achieve its clean energy goals. Finally, these Comments also highlight that several of PacifiCorp's modeling assumptions for pumped storage, and the Projects, are outdated and must be updated before issuance of the Final IRP.

II. THE PROJECTS' COMMENTS ON THE DRAFT IRP

As summarized above, the Projects strongly encourage PacifiCorp to accelerate the development of pumped storage resources from the currently-assumed 2040 in the Draft IRP based on several factors, further described below.

A. PacifiCorp's Analysis in the Draft IRP Suggests Pumped Storage Resources Are Lower-Cost Than Other Resources Included in the Preferred Portfolio.

PacifiCorp's own analysis of pumped storage resources in the Draft IRP demonstrates that these resources are amongst the lowest-cost, clean resources available. However, despite this conclusion, PacifiCorp's Preferred Portfolio selects higher-cost battery storage resources to meet PacifiCorp's energy and capacity needs through 2040. Thus, the Projects suggest that a more prudent, lower-cost approach—that considers a diversity of resource types, including pumped storage—would produce a lower overall cost, and a lower risk Preferred Portfolio, in accordance with the Commission's IRP Guidelines.[5] As a result, in order to comply with the Commission's IRP Guidelines, PacifiCorp should advance its consideration of pumped storage resources in the Preferred Portfolio, rather than waiting until 2040 to consider acquiring these resources.

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[5] *See In the Matter of Public Utility Commission of Oregon Investigation Into Integrated Resource Planning*, UM 1056, Order No. 07-002 at Guidelines at 1.c (Jan. 8, 2007), available at: https://apps.puc.state.or.us/orders/2007ords/07-002.pdf (stating that, "The primary goal must be the selection of a portfolio of resources with the best combination of expected costs and associated risks and uncertainties for the utility and its customers.") (emphasis added); *see also In the Matter of Public Utility Commission of Oregon Investigation Into Integrated Resource Planning,* UM 1056, Order No. 07-047 (Jan. 8, 2007), available at: https://apps.puc.state.or.us/orders/2007ords/07-047.pdf (together, the "IRP Guidelines").

As an example of how pumped storage resources represent a lower-cost, lower risk resource, the Projects note that Tables 7.1 (Supply-Side Resource Table) and 7.2 (Total Resource Cost for Supply-Side Resource Options) both indicate that the Projects are lower-cost options than most of the battery options PacifiCorp is modeling in the Draft IRP. These also appear to be part of the Preferred Portfolio. Specifically, Table 7.1 shows that the Projects have a base capital cost using $/kW) of $3,095 (for Swan Lake) and $2,833 (for Goldendale), whereas Li-Ion batteries (in a standalone configuration) are $3,167 for a 4 MWh discharge capacity and $4,622 for an 8 MWh discharge capacity.[6]

Similarly, Table 7.2 looks at total resource costs for the many different types of resources PacifiCorp is modeling in the Draft IRP. In doing so, Table 7.2 indicates that the total cost (inclusive of tax credits) for Swan Lake is $71.93/MW and $50.21 for Goldendale.[7] In contrast, most of the other types of storage resources included in Table 7.2—including standalone battery storage, solar + storage, or a combined wind, solar, and storage facility—have total costs (inclusive of tax credits) ranging from $59.37/MW (for a 200 MW solar facility in Milford, UT combined with a battery storage system with 4 hours discharge capability) to $158.75/MW (for a 200 MW solar facility in Yakima, WA, combined with a battery storage system with 4 hours discharge capability and a 200 MW wind facility).[8]

Despite the Projects clearly being amongst the lowest-cost available storage resources that PacifiCorp is considering in the Draft IRP, PacifiCorp's Preferred Portfolio includes, by the end of 2024, "697 MW of battery storage capacity—497 MW paired with solar and a 200 MW

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[6] *See* Draft IRP at Table 7.1, p. 172.

[7] *See id*. at Table 7.2, p. 182.

[8] *Id*. at p. 182.

standalone battery."[9] Furthermore, looking at PacifiCorp's Preferred Portfolio in the 2025 to 2030 timeframe, it appears the Preferred Portfolio includes hundreds (if not over a thousand) more MWs of solar + storage facilities, significant (hundreds more MWs) additional standalone battery facilities, and even some wind + storage,[10] all of which are included in the Preferred Portfolio more than a decade before inclusion of any pumped hydro facilities. However, as mentioned above, many of these storage resources have higher overall total costs as compared to the Projects.[11] As a result, PacifiCorp's Preferred Portfolio should be revised to advance the selection of pumped storage to ensure it meets the Commission's IRP Guidelines of identifying the "best combination of expected costs and associated risks and uncertainties"[12] for PacifiCorp's customers.

Furthermore, the Projects would also note that, the recent reconciliation bill that was passed by the U.S. House of Representatives includes a 30% Investment Tax Credit ("ITC") for standalone storage that would apply to pumped storage.[13] There is a high probability that the standalone storage ITC passed by the House is included in a Senate-revised reconciliation package. Once the reconciliation bill is approved by both chambers and enacted into law, the Projects will likely become eligible for a significant cost-savings associated with this ITC, making pumped storage even more cost-competitive than it currently is.

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[9] *Id*. at p. 292.

[10] *See* Fig. 9.31, p. 293.

[11] *See* Table 7.2, p. 182.

[12] IRP Guidelines at 1.c.

[13] *See Build Back Better Act – Rules Committee Print Section-by-Section*, Sec. 136102, p. 98, available at: https://rules.house.gov/sites/democrats.rules.house.gov/files/Section_by_Section_BBB.pdf (noting that the ITC would be expanded to include energy storage technology); *see also Better Back Better Legislation: Waterpower Qualifies for Advanced Energy Manufacturing Tax Credit*, National Hydropower Association, Nov. 22, 2021, available at: https://www.hydro.org/powerhouse/article/build-back-better-legislation-hydropower-qualifies-for-advanced-energy-manufacturing-tax-credit/.

As a result, not only does PacifiCorp's current analysis in the Draft IRP suggest that pumped storage should be selected before other resources PacifiCorp is selecting through the 2030 timeframe, other factors—such as tax credit eligibility—may make it even more imperative that PacifiCorp reevaluate its near-term treatment of pumped storage as part of the least-cost and least-risk portfolio of resources in this IRP.

As shown above, using the current inputs and assumptions in the Draft IRP, the Projects are already economic as compared to many other storage resources being modeled in PacifiCorp's Draft IRP (without any tax credit eligibility, unlike the other storage resources identified in Table 7.2). Nevertheless, the Projects would also note that many of the inputs and assumptions PacifiCorp is using relative to Swan Lake and Goldendale are outdated and incorrect. This issue is further explained in Section II.F below. However, the Projects note here, that once these assumptions and inputs are corrected, the Projects will likely become even more competitive (*i.e.*, even lower-cost) than they already are, and as a result, will become even lower-cost than those resources actually selected in the near-term portion (at least through 2030) of PacifiCorp's Preferred Portfolio.

B. Earlier Development of Pumped Storage Will Diversify PacifiCorp's Resource Mix, Thereby Maximizing the Value of PacifiCorp's Investments in Renewable Energy Projects.

The Draft IRP clearly demonstrates PacifiCorp's commitment to construction of significant renewable energy resources in the next 10-15 years. However, studies have shown the capacity benefits from renewable resources decrease significantly as additional resources of the same generation type or profile are added to utilities' systems (often referred to as "saturation").[14] For

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[14] *E.g., Resource Adequacy in the Pacific Northwest*, Energy+Environmental Economics at p. 70, March 2019, available at: https://www.ethree.com/wp-content/uploads/2019/03/E3_Resource_Adequacy_in_the_Pacific-Northwest_March_2019.pdf.

example, the figures below from a study by Energy+Environmental Economics ("E3") demonstrate that, absent a diversity of generation types, both wind and solar resources' capacity contributions decrease rapidly, as additional wind and solar resources are added to the system.[15]

Figure 22: Wind ELCC at Various Penetrations

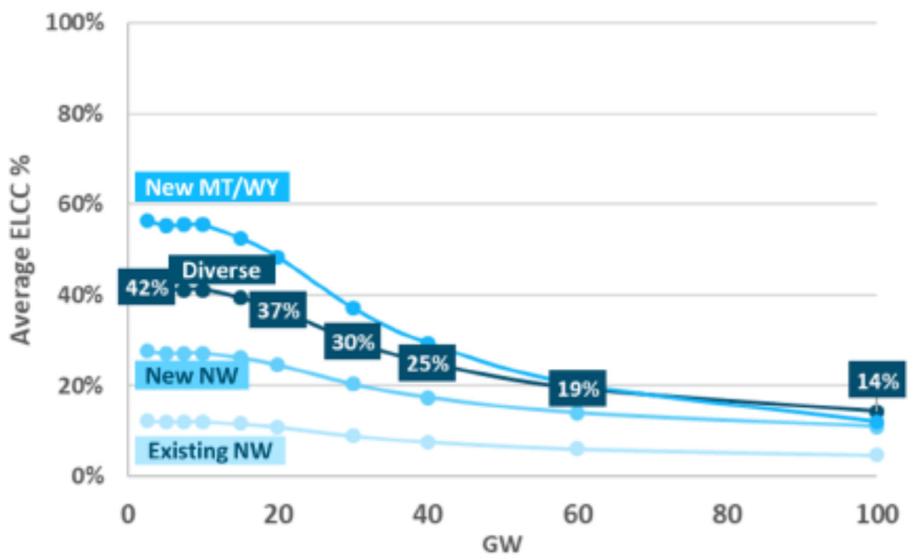
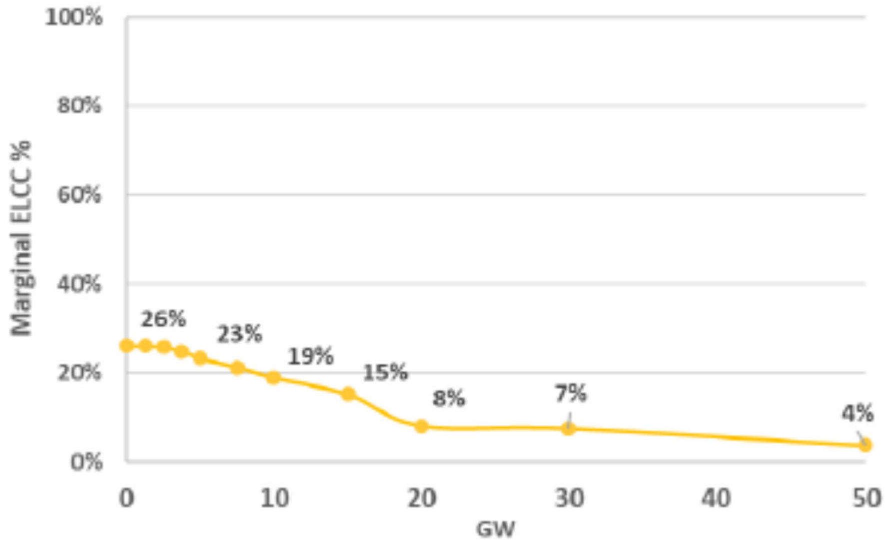


Figure 24: Solar ELCC at Various Penetrations



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[15] *Id*. at Fig. 22 and 24, pp. 55, 57.

The figures above clearly demonstrate diminishing capacity contributions, as resources become more saturated on the system.

The WECC Western Assessment of Resource Adequacy ("WARA") recommendations that are reflected in the Draft IRP also recognize the concerns around diminishing availability of resources due to saturation and extreme weather events. For example, the Draft IRP references the WARA and states that:

> **Recommendation 2:** Planning entities should consider not only how much additional capacity is needed to mitigate variability, but also the expected availability of the resource. Understanding the differences in resource type availability is crucial to performing resource adequacy studies.
>
> PacifiCorp also recognizes that widespread adoption of a targeted solution will cause risks to evolve, and solutions will need to evolve or change to target other conditions. To help retain flexibility for evolving needs, PacifiCorp increased the level of storage in its hybrid solar and storage resources to 100% of the solar nameplate with four-hour duration. <u>But even this results in diminishing returns for winter needs.</u>
>
> While four-hour storage provides significant flexibility, for instance to fill in gaps in typical renewable resource output, <u>uncertainty remains about expected renewable resource availability under extreme conditions</u>, which are relatively uncommon.[16]

To mitigate this problem of over-saturation and diminishing capacity contributions, and to therefore maximize the benefits to PacifiCorp's customers of its significant investments in renewable energy, PacifiCorp should further diversify its resource mix sooner than is currently projected in the Preferred Portfolio. Pumped storage is uniquely positioned to provide the type of diversity PacifiCorp needs to maximize the benefits of its investments in renewable energy because resources like the Projects are large, grid-scale, dispatchable, flexible, clean resources that can be operated in tandem with renewable energy resources to provide around-the-clock energy and capacity to a utility.

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[16] Draft IRP at p. 109 (emphasis added).

Similarly, the statements from the WARA recommendations above suggest that diversity is necessary to reliably serve customers through extreme weather events, which recent events have shown are becoming more common. Again, pumped storage resources are uniquely well-positioned to operate reliably through these types of events given their long discharge durations, flexible and dispatchable capacity, and ability to operate through extreme temperatures and weather events, unlike many other renewable and/or storage resources.

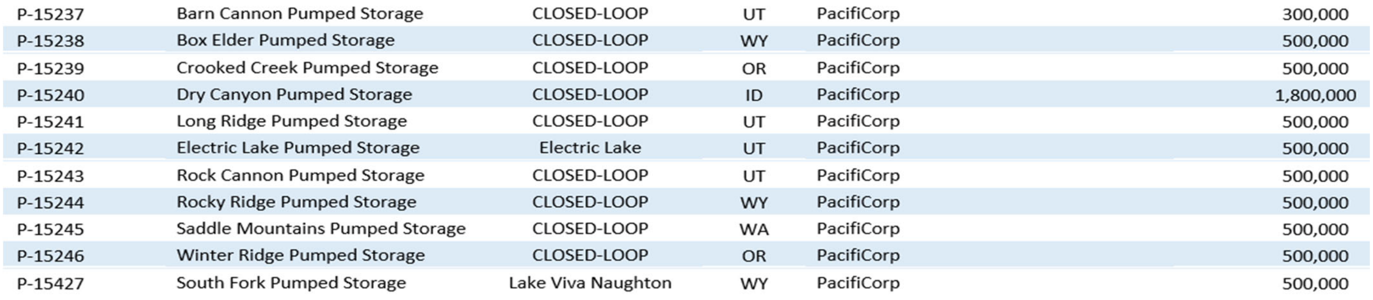
An additional benefit PacifiCorp would realize from earlier acquisition of pumped storage (in lieu of simply adding more batteries) would involve optimizing use of these resources' 8-12 hour discharge capability for raw capacity purposes. Such capability (in contrast to lithium-ion batteries' current four-hour discharge limitations) would better align with PacifiCorp's winter-peaking needs, especially for its southern Oregon and Yakima area loads. This more compatible winter peaking arrangement would also provide a partial hedge against any further delays in completion of the Boardman-to-Hemmingway and Gateway West transmission projects, which transmission projects would otherwise enable more energy and capacity transfers to serve these westside PacifiCorp loads.

Therefore, because diversity of resources is necessary for PacifiCorp to ensure it is maximizing the value of its upcoming investments in renewable resources, as well as to withstand the increasing number of extreme weather events, the Projects strongly recommend pumped storage procurement and consideration be advanced in the Preferred Portfolio. Doing so will align the development of pumped storage resources in the near-term (next 5-10 years) with PacifiCorp's intended and significant investments in renewable energy. Additionally, pumped storage would provide a significant source of generation diversity to PacifiCorp and its customers, given the lack of these resources currently operating on PacifiCorp's system.

C. Advancement of Pumped Storage is Consistent with PacifiCorp's Stated Goals for this IRP and the Company's Demonstrated Interest in Pumped Storage Projects.

According to the Draft IRP, PacifiCorp is focused on a "customer-centered vision" that embodies four "core themes," including: reliable power, resilient infrastructure, affordable prices, and clean energy.[17] Pumped storage clearly aligns with those four core themes because it would: (1) improve reliability through diversity benefits and providing dispatchable, flexible capacity; (2) provide additional resiliency by allowing PacifiCorp's system to better withstand extreme weather events; (3) provide PacifiCorp with affordable, dispatchable energy and capacity, particularly when compared to many of the resources currently in the Preferred Portfolio; and (4) provide PacifiCorp with clean energy on a scale few other resources are able to provide (nearly 400 MW for the Swan Lake project alone).

PacifiCorp also has a demonstrated interest in pumped storage, as evidenced by PacifiCorp's 6.6 GW of pumped storage preliminary permit applications that have been filed with the Federal Energy Regulatory Commission ("FERC"). For example, below is a table of the pumped storage resources for which PacifiCorp is actively seeking a license from the Federal Energy Regulatory Commission:[18]



Project Number	Project Name	Project Type	Location	Applicant	Project Size (MWh)
P-15237	Barn Cannon Pumped Storage	CLOSED-LOOP	UT	PacifiCorp	300,000
P-15238	Box Elder Pumped Storage	CLOSED-LOOP	WY	PacifiCorp	500,000
P-15239	Crooked Creek Pumped Storage	CLOSED-LOOP	OR	PacifiCorp	500,000
P-15240	Dry Canyon Pumped Storage	CLOSED-LOOP	ID	PacifiCorp	1,800,000
P-15241	Long Ridge Pumped Storage	CLOSED-LOOP	UT	PacifiCorp	500,000
P-15242	Electric Lake Pumped Storage	Electric Lake	UT	PacifiCorp	500,000
P-15243	Rock Cannon Pumped Storage	CLOSED-LOOP	UT	PacifiCorp	500,000
P-15244	Rocky Ridge Pumped Storage	CLOSED-LOOP	WY	PacifiCorp	500,000
P-15245	Saddle Mountains Pumped Storage	CLOSED-LOOP	WA	PacifiCorp	500,000
P-15246	Winter Ridge Pumped Storage	CLOSED-LOOP	OR	PacifiCorp	500,000
P-15427	South Fork Pumped Storage	Lake Viva Naughton	WY	PacifiCorp	500,000

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[17] Draft IRP at p. 2.

[18] PacifiCorp's projects listed in the table were found using FERC's eLibrary site, available at: https://elibrary.ferc.gov/eLibrary/search (enter the project number (e.g., P-15237) into the "Docket Number" field to find the status of each of PacifiCorp's pumped storage projects listed in the table). In total, these projects represent 6.6 GWh of potential pumped storage output.

However, despite this clear interest, pumped storage is not a significant part of PacifiCorp's Draft IRP until 2040 (or beyond), despite the numerous benefits these resources could provide to PacifiCorp in the near-term (5-10 years). Furthermore, because this 6.6 GW of potential pumped storage projects is not represented or discussed in the Draft IRP, there appears to be something of a disconnect between PacifiCorp's actions being taken to achieve a clean energy future and those that are presented in the Draft IRP. Furthermore, it is unclear to the Projects why PacifiCorp would seek to license nearly 6.6 GW of its own resources, which could take a decade or more to permit and construct, when there are other options available in the region (both Swan Lake and Goldendale) that are much further along in their development and could provide PacifiCorp the same benefits on a much shorter time-frame. And, given that the Projects are willing to consider various deal structures (ownership in whole or in part, PPA, seasonal products, etc.), PacifiCorp would not necessarily need to pursue its own pumped storage projects to obtain the operational control the company might desire in order to maximize the value of an investment in pumped storage.

Because the Projects are consistent with the Draft IRP's core goals and PacifiCorp's demonstrated interest in developing these types of projects, pumped storage should be advanced in the Preferred Portfolio to a nearer-term time-frame (5-10 years).

D. Over-Reliance on Batteries in the Next Decade, Rather than Simultaneously Pursuing Pumped Storage, Exposes PacifiCorp and its Customers to Unnecessary Market Risks.

The Projects are also concerned about the Draft IRP's over-reliance on batteries as a capacity resource, rather than a strategy of simultaneously pursuing both batteries and pumped storage resources. For example, the Draft IRP includes 6,181 MW of storage resources through

2040 (either standalone or combined with solar), but only 500 MW of pumped storage.[19] This significant over-reliance on batteries unnecessarily exposes PacifiCorp and its customers to various market factors, thereby increasing the risks associated with the Preferred Portfolio.

The Projects suggest that such over-reliance on batteries is misplaced, unfounded, and untested, unnecessarily exposing PacifiCorp's customers to higher-than-projected replacement costs and potential reliability concerns. As support for these concerns about the over-reliance on batteries, attached as Attachment A to these comments, is a series of three research papers by Navigant Consulting that highlights some of the complications, challenges, and pitfalls with relying too heavily on batteries, including the significant environmental degradation impacts and hidden costs of batteries.

Of particular note, the Projects would highlight that a key issue with proposing acquisition of Li-ion batteries for raw capacity needs is their likely performance for this new application. For example, a recent presentation by Energy GPS included the table reproduced below,[20] which considers how batteries in California are being utilized and suggests that batteries are well-suited for meeting ancillary services needs; however, they are largely unable to provide significant energy or capacity to utilities. As a result, batteries are not well-designed to meet utilities' capacity needs, which means that they are not well suited to provide the type of capacity PacifiCorp is modeling in its Draft IRP and Preferred Portfolio.

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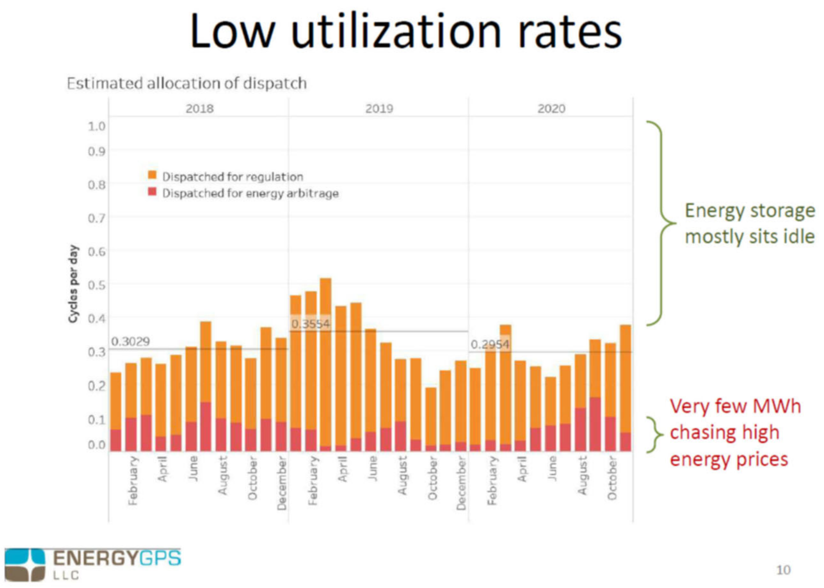
[19] Draft IRP at p. 11 ("Through 2040, the 2021 IRP includes 4,781 MW of storage co-located with solar resources, 1,400 MW of standalone battery, and 500 MW of pumped hydro.").

[20] Energy GPS, "The Next Technology – Batteries," Webinar, December 17, 2020.



Low utilization rates

Additionally, there is very little data on Li-ion battery performance for utility scale applications. Battery installations of over 50 MW have run for no more than 1-3 years in an operational grid/utility environment, meaning it is impossible to credibly judge whether a four-hour discharge duration used for capacity purposes is a suitable use for batteries. Currently planned Li-ion battery installations, especially in California, should provide the necessary operational data regarding whether batteries are suitable for this capacity purpose; however, it will probably not be sufficiently robust to validate (or rebuke) currently advertised Li-ion performance metrics until the post-2025 timeframe. The need for more data is especially important since, in an operational utility environment, these large battery installations will be fully charging and discharging several times per day over a multi-month per year period. Similar to a cell phone battery, the more it is used, the quicker its capacity degrades, meaning the currently-asserted and modeled assumptions regarding charge/discharge and useful life cannot be fully vetted until more information is available. Without existing evidence that supports PacifiCorp's anticipated reliance on batteries, the Projects suggest that PacifiCorp's massive battery acquisition campaign would over-expose PacifiCorp and its customers to significant replacement and upgrade costs more frequently than modeled,[21] thereby resulting in massively inflated battery acquisition and maintenance costs to the detriment of PacifiCorp's ratepayers.

Besides these potential performance issues with batteries, PacifiCorp should examine the serious problems CAISO is now experiencing in integrating Li-ion batteries into its grid to prevent additional outages in Summer 2021. Specifically, CAISO has been struggling to interconnect batteries and operate them. More pointedly, CAISO has found it cannot depend on their output to assist in meeting the summer net demand evening peaks, particularly when the sun sets. The battery owners want to retain the ability to provide high value/lucrative ancillary services throughout the day, in addition to supplying energy for the post-solar evening peak. CAISO is concerned that allowing such marketing flexibility will result in an insufficient state of charge to provide the necessary evening peak capacity to meet load. This debate has been going on for over two years with no resolution in sight. While this is a unique operational problem that should eventually be worked out, it provides an excellent example of the complex issues associated with integrating such a new technology with highly uncertain performance characteristics into the grid. Most experts believe that any eventual solution will cost a lot more, and result in suboptimal performance, as compare to what the California utilities and their regulators assumed when they initially acquired these resources. PacifiCorp will undoubtedly face the same state of charge/reliability problems if it acquires significant amounts of batteries to meet its peak capacity

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[21] Additionally, relying too heavily on batteries exposes PacifiCorp to the uncertain safety risks associated with batteries that have been shown to be the cause of fires and other safety risks. *See APS Details Cause of Battery Fire and Explosion, Proposes Safety Fixes*, Greentech Media, July 27, 2020, available at: https://www.greentechmedia.com/articles/read/aps-battery-fire-explosion-safety-lithium-mcmicken-fluence; *see also Vistra's 1.2 GWh Moss Landing Storage Facility Remains Offline After Overheating Incident,* UtilityDive, Sept. 7, 2021, available at: https://www.utilitydive.com/news/vistras-12-gwh-moss-landing-storage-facility-remains-offline-after-overhe/606178/ (highlighting problems with the largest battery storage system in the world and noting that, "Lithium-ion batteries carry the threat of thermal runaway, where a single overheating cell leads to a cascading temperature increase that results in a fire or explosion.).

needs. In contrast, pumped storage, given its longer discharge capability and inherent operational flexibility, will either avoid such problems entirely or greatly minimize their real-world cost and performance impacts inherent in batteries used to meet capacity needs.

Finally, over-reliance on batteries exposes PacifiCorp to significant supply chain risks associated with lithium. By way of example, the International Energy Agency estimates that just growth in demand for lithium as a result of Electric Vehicle adoption could result in an increase in demand for lithium of over 40 times by 2030.[22] Similarly, as a result of this demand, prices for lithium are expected to rise over the next decade.[23] Because most of the elements needed to produce a lithium-ion battery are located abroad (including lithium, cobalt, nickel, etc.), tight supplies, increasing demand, and uncertain access to these crucial elements of batteries exposes PacifiCorp to significant supply chain risks, given its over-reliance on batteries as a capacity resource. Instead, PacifiCorp should advance its consideration of pumped storage resources, which are not subject to these same market factors and are likely to negatively impact the value of battery storage assets in the future.

E. Compliance with Recently-Enacted Legislation and Various Other, Market Conditions Make Earlier Investment in Pumped Storage a Necessity.

The Projects also suggest that advancement of pumped storage in the Preferred Portfolio is necessary due to: (1) Oregon's recently-enacted 100% clean energy legislation, which the Draft IRP does not currently consider[24]; and (2) other, market factors that suggest PacifiCorp should take earlier action to develop pumped storage projects.

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[22] *Lithium Shortage May Stall Electric Car Revolution and Embed China's Lead: Report*, Forbes, Nov. 14, 2021, available at: https://www.forbes.com/sites/neilwinton/2021/11/14/lithium-shortage-may-stall-electric-car-revolution-and-embed-chinas-lead-report/?sh=175ae8e946ef.

[23] *Id.*

[24] Draft IRP at p. 64 ("PacifiCorp's 2023 IRP will include modeling to support House Bill 2021.").

While the Projects recognize that PacifiCorp has not yet modeled compliance with HB 2021 in this Draft IRP, there is little question that achieving that legislation's clean energy and emissions targets is going to require significant advancement and development of renewable energy in the coming decade. Therefore, coupled with all of the above reasons for moving up the development of pumped storage in the Preferred Portfolio, HB 2021 compliance is also likely to require PacifiCorp to consider large, clean capacity resources sooner than is currently projected in the Preferred Portfolio. As a result, it would be prudent for PacifiCorp to move up the inclusion of these resources into the near-term (5-10 years) time horizon, rather than waiting until 2040, as the Preferred Portfolio currently contemplates.

Similarly, as the Projects have repeatedly explained in various comments to the Commission,[25] pumped storage has significantly longer lead-times than most other resources due to the amount of time required to build the highly-technical, advanced turbines necessary for pumped storage projects. The current estimate from the manufacturer is up to five years to design the pump-turbine generators and place them into service. While the Projects have excellent relationships with their expected turbine manufacturers, and have received numerous assurances regarding timing for delivery of turbines, these parts are very complex, custom-designed for the site, and take much longer than most other resources to procure, particularly in comparison to wind or solar projects, which rely on more standardized, "off-the-shelf" equipment. Therefore, from the time a market signal is sent (*i.e.,* PacifiCorp signs a purchase agreement, selects a pumped storage project in a procurement process, etc.), a pumped storage resource can still take upwards of five years or more to build and construct.

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[25] Swan Lake previously provided an example project schedule to the Commission in Portland General Electric's IRP 2019 IRP docket. *See In the Matter of Portland General Electric Company, 2019 Integrated Resource Plan*, Opening Comments of Swan Lake North Hydro, LLC at Appendix A, LC 73 (filed Oct. 9, 2019), available at: https://edocs.puc.state.or.us/efdocs/HAC/lc73hac15838.pdf.

Thus, in order for a project developer to take the risk of putting down the significant capital necessary to begin the turbine acquisition process, developers need a market signal that suggests such capital is not unnecessarily being put at risk. As a result, it is imperative that PacifiCorp advance its consideration of pumped storage in the Preferred Portfolio so that the appropriate market signals can be sent in time for these resources to be online when they are actually needed to provide reliable, clean capacity and energy.

The Draft IRP projects that most of PacifiCorp's coal units will be retired no later than 2030.[26] As a result, PacifiCorp will need significant, dispatchable, clean capacity resources (like pumped storage) to be online by 2030 in order to provide dispatchable capacity to replace the retiring coal units. However, absent action by PacifiCorp to acquire a pumped storage resource in the next few years, there are few pumped storage projects in the region that could be online and available by 2030. As the Projects have shown throughout these Comments, waiting that long to actively pursue and consider pumped storage would be imprudent and does not align with PacifiCorp's own actions or stated goals for this IRP.

Similarly, changes in capacity markets—including increasing planning reserve margins and capacity shortfalls shown in nearly-every Western utility's IRP—are likely to make clean, dispatchable capacity resources like pumped storage extremely valuable.[27] Therefore, PacifiCorp's customers stand to receive significant benefits from early action in acquiring a clean, dispatchable capacity resource like pumped storage. Conversely, if PacifiCorp waits to act until 2040, it is unlikely capacity will be available from existing pumped storage resources that are

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[26] Draft IRP at p. 15 and Fig. 1.12.

[27] *E.g., Comments of Swan Lake North Hydro, LLC and the Goldendale Energy Storage Project on Portland General Electric Co.'s 2019 IRP Update*, LC 73 at pp. 3-9 (filed April 12, 2021), available at: https://apps.puc.state.or.us/edockets/edocs.asp?FileType=HAC&FileName=lc73hac161957.pdf&DocketID=21929&numSequence=155.

currently in development, meaning PacifiCorp will have to start from the beginning of the lengthy permitting and construction process, and incur all of the costs and risks associated therewith.

In addition to all of the reasons set forth above for why PacifiCorp should consider pumped storage sooner in its Preferred Portfolio, market factors around the long-lead time for pumped storage and changing capacity market dynamics also support PacifiCorp taking earlier action in order to make sure these resources are constructed and available in advance of a significant capacity need materializing.

F. Several of PacifiCorp's Modeling Inputs and Assumptions for the Projects Must be Updated Before Issuance of the Final IRP.

In reviewing the Draft IRP, the Projects also noticed that several of the inputs and assumptions for the Swan Lake and Goldendale projects, specifically, are outdated or incorrect and should be corrected before the Final IRP is issued. As shown above, the Projects, even with some of the outdated or incorrect assumptions, are already economic as compared to most other storage resources PacifiCorp is modeling in the Draft IRP. Nevertheless, once these assumptions and inputs are updated, the Projects are likely to perform even better and be even lower-cost than other resources. As a result, because updating this information is likely to materially alter PacifiCorp's analysis of the cost competitiveness of the Projects with respect to other, storage resources specifically, the Projects request that PacifiCorp re-run its IRP model in order to re-evaluate pumped storage in the Preferred Portfolio using accurate and up-to-date inputs and assumptions.

When reviewing Tables 7.1 and 7.2 of the Draft IRP, as well as Appendix F, there does not appear to be any consistent basis for determining design life amongst the various pumped storage projects. For example, in Table 7.1, some projects are shown with a 60-year design life, some are shown with 80, and one is shown with 50.[28] The Projects suggest PacifiCorp revise these numbers to use a uniform, 50-year design life approach, given that the FERC permits for these projects are for 50 years.

In addition to the above inputs and assumptions that need to be updated, the Projects have also identified a number of project-specific inputs and assumptions for both of Swan Lake and Goldendale that should be updated. One example of an inaccuracy for the Goldendale project is that PacifiCorp inconsistently treats it as a 1,200 MW resource or a 400 MW resource.[29] Other of the inaccuracies and assumptions that need to be updated are proprietary in nature (*e.g.*, pricing). As such, the Projects request a meeting with PacifiCorp's IRP staff to provide them with updated, accurate information and to correct any errors contained in the Draft IRP with respect to Swan Lake and Goldendale.

As noted above, once PacifiCorp updates the information being used in the Draft IRP for Swan Lake and Goldendale (particularly around pricing), the Projects request that PacifiCorp re-run its model (or, at least, a sensitivity to its model) to reflect this updated information. The Projects strongly believe that, while they are already competitive with any other storage resource in PacifiCorp's Draft IRP, once PacifiCorp updates the information for the Projects, they will become even more competitive with other storage resources and, as a result, will represent the least-cost, least-risk resources for PacifiCorp and its customers.

III. CONCLUSION

The Projects appreciate the opportunity to provide these Comments on the Draft IRP. For the reasons set forth in these Comments, the Projects request that PacifiCorp advance the

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[28] *Id*. at Table 7.1, p. 172.

[29] *E.g.,* Draft IRP at Tables 7.1 and 7.2 (listed as a 1,200 MW resource) vs. Appendix F (Generation Cashflows) at 1 (Table showing Goldendale as a 400 MW nominal output facility).

consideration of pumped storage in the Preferred Portfolio to coincide with PacifiCorp's anticipated significant development of renewable energy resources in the near-term (the next 5-10 years). Advancing pumped storage is warranted for the reasons described above, but is also necessary to ensure the Preferred Portfolio meets the Commission's IRP Guidelines of providing the "best combination of expected costs and associated risks and uncertainties for the utility and its customers."[30]

Please contact the undersigned with any questions or concerns.

Dated this 3rd day of December, 2021.

Respectfully submitted,

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[30] IRP Guidelines at 1.c.

ATTACHMENT A –

NAVIGANT WHITE PAPERS ON BATTERY STORAGE

NAVIGANT
RESEARCH

WHITE PAPER

What Is Driving Demand for Long Duration Energy Storage?

Commissioned by National Grid Ventures

Published 2Q 2019

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Section 1

INTRODUCTION

1.1 Defining Long Duration Energy Storage

A key feature of any energy storage system is its duration, which refers to the ratio between the system's maximum power output capacity in megawatts and its stored energy capacity in megawatt-hours. This metric indicates how long the system can discharge at full output capacity, and hence its relative value as a source of power. An energy storage system's duration also impacts its ability to provide grid services necessary to ensure reliability.

Navigant defines long duration energy storage as technologies capable of discharging at full power output for at least 5 hours. Currently available long duration storage technologies include pumped hydro storage, flow batteries, lithium ion (Li-ion) batteries, sodium sulfur batteries, power-to-gas, and compressed air energy storage (including liquid air storage).

Globally, installed energy storage capacity is approximately 156 GW, roughly 93% of which (144 GW) is pumped hydro storage. While the energy storage market has seen a significant increase in activity in the past 5 years, the majority of new energy storage projects offer relatively short duration output in the range of 1–4 hours. As such, there are limits to the grid services that these types of projects can provide, which will likely dampen demand for such projects in the long run as needs change.

Long duration energy storage systems play a key role in effectively integrating large amounts of renewable energy generation and ensuring that the overall operation of the grid is as efficient and reliable as possible.

1.2 Drivers of Demand for Long Duration Energy Storage

Integrating high percentages of renewable energy to a transmission grid has significant benefits in terms of reducing greenhouse gas emissions and helping to stabilize and lower energy costs, but it requires adapting the system to accommodate the characteristics of variable generation resources that may be located far from load. Long duration energy storage is uniquely suited to support this transition.

1.2.1 Grid Services

In addition to energy production, dispatchable fossil fuel generation has traditionally provided additional grid services that enhance reliability and stability. These grid services range from regulation service, which manages second-to-second imbalances in generation and load, to load following service, which meets daily ramps in demand.

While variable renewable energy resources like wind and solar are able to provide some grid services—especially shorter-term services like regulation—their intermittent nature limits their ability to fully replicate the longer duration system services like load following that fossil fuel generation provides. Although the grid impacts of adding renewable generation are relatively small at penetrations below 15%, above this level the loss of grid services from displaced fossil fuel generation creates a need for an alternate source.

Long duration energy storage can be used to shape and firm electricity from renewable sources so that it delivers a generation profile and grid services that are comparable to traditional fossil fuel generation during hours of peak demand.

An increasing number of jurisdictions (including California, Hawaii, and Washington) have set ambitious goals to reduce carbon emissions by sourcing 50% or even 100% of their electricity from renewable sources, creating a de facto demand for long duration energy storage facilities and the full suite of grid services they can provide.

1.2.2 Transmission Congestion

Transmission line congestion is an issue routinely faced by grid operators around the world, and can present particular challenges for renewable generation facilities, which are often located in areas far from load centers and served by inadequate regional transmission infrastructure. During periods of peak production, demand for transmission from remote renewable resources can exceed the capacity of the transmission grid to deliver that energy to load. At such times, the lack of transmission capacity will require utilities to curtail renewable generation, or turn to more expensive fossil generation resources located closer to load centers that can transmit energy over non-congested lines. In either case, the dollar and carbon cost of serving the load increases.

1.2.3 Renewable Energy Curtailment

Curtailment refers to the practice of stopping renewable energy production at times when supply exceeds demand, as well as when there is insufficient transmission capacity to deliver electricity to load centers, as discussed above. Curtailment is already occurring in markets with moderate penetrations of variable renewable energy, such as the central US, where abundant wind generation at night often exceeds demand, and midday in places such as Australia, California, and Hawaii, where solar photovoltaic generation outstrips consumption. Notably, in the month of April 2019, 190,070 MWh of electricity from California solar and wind farms was curtailed, breaking previous records. This curtailment trend is increasing substantially as California adds 1,500 MW–2,000 MW of solar (both rooftop and utility scale) to its grid every year.

> *In April 2019, California solar and wind farms curtailed 190,070 MWh of electricity, breaking previous records, according to the California Independent System Operator.*

Transmission congestion and variable renewable energy curtailment result in lower clean energy production and higher greenhouse gas emissions. By storing large amounts of energy for dispatch when transmission capacity is available, long duration energy storage offers an effective way to support high percentages of renewable generation and optimize the use of transmission assets, resulting in a more efficient electricity system.

1.2.4 The Limitations of Competing Storage Technologies

Additional drivers of demand for long duration energy storage are the limitations of existing battery technologies, and particularly those of Li-ion batteries, which include concerns about their relatively short lifespan and safety, as well as the availability of raw materials, security of the supply chain, and their environmental impact, topics that will be addressed in more detail in a subsequent white paper.

1.2.4.1 Lifespan

The lifespan of a battery is expressed in terms of the number of times it can be charged and discharged, which is referred to as a cycle. The cycle life of Li-ion batteries varies depending on the specific sub-chemistry used, and ranges from as low as 500 cycles for the least expensive Li-ion technologies to up to 10,000 for the most expensive, which translates into a 3–15-year lifespan depending on the application for which it is used. This is relatively short in the context of grid applications, so it is typical to extend a Li-ion battery’s life by replacing or augmenting its capacity when performance degrades. While these strategies can be effective, they also result in significantly higher operation and maintenance costs.

1.2.4.2 Safety

As with cycle life, different Li-ion chemistries vary in terms of safety profiles. More expensive and robust battery chemistries like lithium iron phosphate and lithium titanite oxide have strong safety records, while less expensive chemistries typically do not. Although significant advances have been made to improve the safety of large-scale stationary Li-ion batteries, instability and thermal runaway remain significant concerns in the industry. Numerous fires at large Li-ion battery energy storage facilities in 2018 and 2019 have highlighted these concerns and resulted in increasingly restrictive fire safety codes in jurisdictions around the world. The potential for safety incidents such as these serve to highlight the value of other long duration energy storage technologies that are inherently safer.

1.2.5 Resilience

Longer storage durations equate to the ability to provide backup power for a longer period, which is a major driver of interest in long duration storage. Furthermore, many long duration technologies such as pumped hydro storage, flow batteries, and compressed air do not have the same restrictions on cycle life as Li-ion and other batteries, thereby providing greater flexibility and resilience.

Section 2

THE ROLE OF LONG DURATION ENERGY STORAGE ON THE GRID

2.1 Reliable and Dispatchable Capacity

Long duration energy storage is essential to a grid that relies heavily on variable renewable generation, because it makes it possible to align supply with demand, and it can provide grid services historically offered by conventional fossil fuel power plants.

2.1.1 Matching Renewable Energy Supply with Demand

Unlike dispatchable fossil fuel facilities, renewable energy generation depends on resource availability, and periods of peak production may not align with periods of peak demand. The ability to store large amounts of renewable energy for release during periods of high demand may emerge as one of the most essential applications for long duration energy storage in the long term and is a particularly attractive benefit in areas that experience high levels of wind power curtailment at night, or solar curtailment during the day.

2.1.2 Reserves and Capacity

Reserves and capacity are services that help ensure the reliability of the grid by helping operators meet variations in electricity supply and demand. These grid services, which have traditionally been provided by conventional thermal generators, include spinning reserves, non-spinning reserve capacity, and load following.

Variable renewable energy resources like wind and solar can provide some grid services, but their non-dispatchable nature limits their ability to do so on a reliable basis. Similarly, shorter duration energy storage technologies are well suited for short duration ancillary services, but not for providing dispatchable capacity over periods longer than 5 hours. Reserve and capacity assets are often called upon for extended periods of time due to plant outages, extreme weather, and other issues.

As renewables gradually displace fossil fuel generation, the need for technologies that can economically provide a full suite of grid services will increase. Replacing most or all of a system’s fossil fuel baseload and peaking power plants with renewable energy will require pairing these resources with long duration, large-scale energy storage.

2.3 Transmission Optimization

As discussed in Section 1.2, large-scale renewable facilities are often located in remote areas with limited access to transmission lines. At times of peak production, these lines can become congested, forcing renewable generators to curtail their output, and resulting in the loss of clean energy as well as revenue losses for the generator and reduced energy security.

Long duration energy storage located at strategic points in the grid can be used to address this by saving renewable energy for release at times when transmission lines are less congested. Doing so improves the functionality of existing transmission infrastructure, making it possible to efficiently integrate new resources while postponing the need for costly transmission upgrades.

Section 3

CASE STUDIES

3.1 Pumped Hydro Storage in Europe

Long duration energy storage already serves as a critical resiliency resource for power systems with high percentages of renewable energy, notably on islands such as El Hierro in the Canary Islands and Kauai in Hawaii. However, long duration energy storage also plays a key role in the operation of much larger electricity grids.

Germany's power system is the largest in Europe and boasts more than 100 GW of wind and solar generation capacity. Under the Energiewende (energy transition) policy, the country aims to generate 35% of its electricity from renewables by 2020, rising to 80% by 2050. Achieving this will require new investments that may include additional transmission infrastructure, interconnections with neighboring countries, and energy storage.

While Germany has seen major growth in its battery energy storage market, most of this activity has been focused around short duration systems for grid stability services and residential customers integrating solar power. When it comes to effectively integrating over 100 GW of renewable generation, pumped hydro systems in Germany and neighboring countries are the long duration energy storage technology of choice.

These resources support the German energy transition by storing excess electric generation from variable renewable sources and dispatching it as needed to provide reliable capacity during periods of peak demand or reduced production. As the country moves toward increasingly higher percentages of renewables, new pumped hydro storage projects are being explored.

Germany's use of pumped hydro storage may provide a useful point of comparison for energy planners in the US. As an example, California has 30 GW of installed solar and wind, and the ability to leverage the long duration energy storage benefits of pumped hydro storage projects both in California and the Pacific Northwest.

3.2 Potential Capacity Shortages in the Western US

3.2.1 Pacific Northwest

In the US Pacific Northwest, a transition to a heavy reliance on renewable generation is underway and gaining momentum. Oregon has set ambitious carbon-reduction goals, and Washington recently passed legislation mandating that by 2030, 80% of electricity sold in the state must be carbon free.

Achieving these targets will require a major increase in variable renewable generation sources like solar and wind. According to the consulting and analytics firm E3, load growth and the replacement of retired fossil fuel power plants with renewable generation could result in an 8 GW capacity deficit in the US Pacific Northwest by 2030 unless new dispatchable capacity resources are developed.

Washington’s legislation will impact Puget Sound Energy, Avista, and PacifiCorp, all of which own shares of the Colstrip 3 and 4 coal plants. If the move to decarbonize Washington’s energy supply leads to the Colstrip facilities closing in 2025 rather than their current planned retirement in 2035, it will add another 1.5 GW to E3’s projected 8 GW capacity deficit in 2030. An additional impact of the legislation is that after 2030, these utilities will need to offset any carbon emissions associated with the use of gas-fired resources for commercial energy transactions.

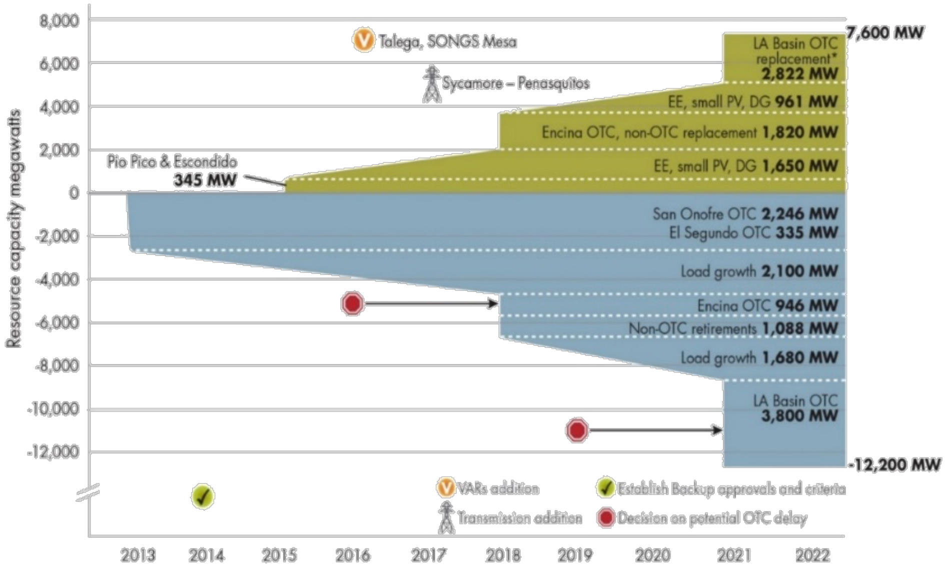
While the region has sufficient renewable energy resources to meet electricity demand, long duration energy storage technologies will have an important role in to play in providing the replacement capacity needed to ensure grid stability.

3.2.2 California

California has benefited from significant surplus capacity and energy from the Pacific Northwest for many years, but the magnitude of the anticipated capacity requirements described above will likely decrease capacity and energy available for export to California entities between 2020-2030.

California has set a target of getting 100% of its energy from carbon-free sources by 2045 (with at least 60% of supply from eligible renewable resources). Similar to the situation in the Pacific Northwest, as shown in Figure 3-1, as the state’s renewable energy capacity increases, fossil fuel power plants are being retired, resulting the loss of dispatchable capacity they provide. According to the California Independent System Operator (CAISO), up to 9.6 GW of natural gas-fired generation may be retired for economic reasons, and if even 4 GW (or less) of natural gas comes offline, the state could see load following shortfalls.

Figure 3-1. Electrical Capacity Retirement and Additions Forecasts, California Independent System Operator: 2013–2022



(Source: California Independent System Operator)

California already receives resource adequacy and capacity services from both standalone energy storage and renewable-plus-storage projects, with most storage projects having a 4-hour duration. In the long run, CAISO has predicted that as more thermal resources retire, reliability requirements may mean that demand for longer duration energy storage increases.

Long duration energy storage has a particularly important role to play in California, which faces a dual challenge of excess generation from solar during the day, and a steep increase or ramp in demand in the evening hours. Part of this increase in demand is caused by the charging of electric vehicles, the numbers of which are expected to grow dramatically over the next decade.

California has recently experienced winter 3-hour ramps of as much as 14,000 MWh. Long duration energy storage can store excess solar generated during the day and release it to meet the evening ramp.

Section 4

CONCLUSION

The transition to greater reliance on variable renewable generation is creating a need for expanded energy storage infrastructure in power grids around the world. It is important to recognize that different energy storage technologies offer features that make them best suited for different applications.

Short duration technologies are ideally suited for providing grid stability services and smoothing small fluctuations in renewable generation output. In contrast, long duration storage technologies like pumped hydro storage are uniquely able to stand in as a direct replacement for the bulk capacity reserves and other grid services provided by fossil fuel generators.

Grid operators managing systems as small as the island grids of El Hierro and the Hawaiian Islands, and as large as those of European countries have already recognized the value of longer duration energy storage as they make the transition to high levels of renewable energy.

To successfully follow suit, US grid operators charged with ensuring the reliability of their system under ambitious decarbonization goals will need to have both long and short duration energy technologies at their disposal.

Section 5

ACRONYM AND ABBREVIATION LIST

CAISO	California Independent System Operator
GW	Gigawatt
GWh	Gigawatt-hour
Li-ion	Lithium Ion
MW	Megawatt
MWh	Megawatt-hour
US	United States

Section 6

SCOPE OF STUDY

This white paper examines the market for long duration energy storage technologies on the power grid. Specific attention is paid to the drivers of long duration energy storage, the role for long duration energy storage on the grid, and case studies that illustrate the convergence of these issues. Navigant Research prepared this white paper to provide an independent analysis of the opportunities for long duration energy storage. This white paper does not consist of any endorsement of any specific technology, project, or company. Rather this paper provides readers with an understanding of the market for long duration storage and why it will be required for a future grid reliant on renewable energy generation.

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WHITE PAPER

Comparing the Costs of Long Duration Energy Storage Technologies

Commissioned by National Grid Ventures

Published 2Q 2019

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Section 1

INTRODUCTION

This white paper is the second in a three-part series exploring long duration energy storage technologies for the power grid. The first paper examined the factors driving the need for long duration energy storage and the role it plays on the grid. In this second paper, the installation and operating costs of the five competing long duration energy storage technologies are explored in greater detail. The third and final paper in the series will discuss other non-monetary factors that should be considered when evaluating energy storage technologies.

1.1 Utility-Scale Long Duration Energy Storage Technologies

The utility-scale energy storage market encompasses a range of technologies with differing operating characteristics, strengths, and weaknesses. Some technologies are best suited to provide short-duration grid stability services including frequency regulation and voltage support. Such technologies include flywheels, ultracapacitors, and certain lithium ion (Li-ion) chemistries. Other technologies like pumped hydro storage (PHS) or compressed air energy storage (CAES) systems are best designed for large-scale long duration bulk energy storage. The following sections introduce the five most prevalent technologies competing in the long duration energy storage market.

1.1.1 Pumped Hydro Storage

PHS has traditionally been the technology of choice for delivering long duration storage services. It is the most mature and the largest capacity storage technology available, and currently provides approximately 93 percent of global operational electricity storage capacity. PHS facilities pump water from one reservoir into another at a higher elevation, typically using lower priced off-peak or surplus renewable electricity. When energy is required, the water in the higher elevation reservoir is released and runs through hydraulic turbines that generate electricity. PHS plants typically have a round-trip efficiency of 75–80 percent.

> *A key feature of any energy storage system is its **discharge duration**, which refers to the ratio between the system's maximum power output capacity in megawatts and its stored energy capacity in megawatt-hours.*

PHS technology has evolved over the years. Variable speed pumps represent the latest generation of the technology and provide significant advantages. A variable speed pump turbine can be regulated to plus or minus 20 percent of capacity during a pumping cycle, which provides the ability to accurately follow changes in both load and the supply of fluctuating renewable generation. In addition, variable speed PHS facilities can be designed to transition rapidly between pumping and generating. This flexibility, combined with large storage capacity, means that PHS facilities offer grid operators capabilities that are critical to managing high penetrations of renewables and aligning variable renewable energy supply with shifts in load.

1.1.2 Compressed Air Energy Storage

CAES systems compress ambient air, store it under high pressure conditions, and then release it to power generator-tied turbines when electricity is needed. The largest barrier to CAES development arises from geographical restrictions because the systems require either natural underground caverns or underground tanks, which are rarely in convenient locations. CAES systems are advantageous for the purposes of large-scale storage because they typically range from 50 MW to 300 MW of power output and can be brought to full output in around 10 minutes. However, CAES systems have relatively low round-trip efficiencies, ranging from only 48 percent for older designs to as high as 75 percent for more modern systems. There are only two large-scale CAES plants in operation—one in the US state of Alabama and one in Germany, with durations of 26 and 4 hours, respectively.

1.1.3 Flow Batteries

Flow batteries are single-celled batteries that transform the electron flow from activated electrolyte into electric current. They achieve charge and discharge by pumping a liquid anolyte and catholyte across a membrane. While there are many different flow battery chemistries, the vanadium redox chemistry has emerged as the market's leading technology. The round-trip efficiency for flow batteries ranges from 65–85 percent.

***Round trip efficiency** refers to the difference between the amount of energy that is stored, and the amount of energy available for discharge. If a battery is charged with 100 kWh, but provides 75 kWh of energy when discharged, it has a round trip efficiency of 75 percent.*[1]

Flow batteries have several inherent advantages over other battery technologies. Their discharge duration is correlated to the volume of electrolytes stored, so storage can be increased simply by adding additional tanks of electrolyte, with limited marginal costs. The technology is also generally safer than Li-ion or molten salt batteries—the use of nonflammable electrolytes means that most flow battery systems do not present a fire safety hazard. However, the electrolytes used in most flow batteries are corrosive and may be an environmental hazard if spilled. Furthermore, flow batteries experience little to no depletion of active materials over time, giving them greater cycle life expectancies (10,000+ cycles) than other battery types.

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[1] Hennessy, Tim, "Calculating the True Cost of Energy Storage," *Renewable Energy World*, January 12, 2015.

1.1.4 Molten Salt Batteries

Molten salt batteries include sodium sulfur (NaS) and sodium-metal halide (NaMx) systems, both of which use a molten sodium anode and a solid beta-alumina electrolyte at high operating temperatures of about 300°C or more. Typical performance characteristics of NaS and NaMx batteries are relatively similar with regard to high energy density, long cycle life, and moderate-to-high round-trip efficiencies of 75–90 percent.

Molten salt batteries gained traction in the market early on, but the battery storage market has shifted heavily toward Li-ion technologies. This is because molten salt batteries' performance characteristics and high price point (which is driven by expensive beta-alumina membranes) make them better suited for long duration applications, while the energy storage industry has recently focused largely on short-duration applications.

1.1.5 Lithium Ion Batteries

Li-ion batteries use the flow of lithium ions between the cathode and anode of the battery to charge and discharge. Li-ion batteries have excelled as the primary chemistry of choice in consumer electronics for the last decade, and are now finding a limited role on the grid.

In general, Li-ion batteries have excellent energy and power densities and round-trip efficiency. However, as discussed in Section 2, their average duration of 4 hours limits their ability to support the integration of high percentages of renewable energy. A more thorough exploration of this issue is presented in the first white paper in this series, *What Is Driving Demand for Long Duration Energy Storage?*[2]

The relatively short cycle life of Li-ion batteries, which can range from 500 to 10,000 cycles depending on usage and the specific Li-ion chemistry that is used, translates into a 3–15-year lifespan. This makes Li-ion batteries an expensive choice for long-term grid applications.

In the context of energy storage systems, one sequence of charging and discharging is referred to as a ***cycle****. A system's* ***cycle life*** *refers to the number of times it can cycle or be charged and discharged before it degrades and becomes inoperable or unusable for a given application.*

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[2] Navigant Research and National Grid Ventures, *What Is Driving Demand for Long Duration Energy Storage?* SL Energy Storage, 2Q 2019, https://www.slenergystorage.com/resources.html.

Section 2

LONG DURATION ENERGY STORAGE TECHNOLOGIES: FACTORS TO CONSIDER WHEN EVALUATING COSTS

2.1 Comparing Apples to Oranges: Varying Characteristics and Costs

The five major long duration energy storage technologies discussed in this paper differ widely in terms of their operational benefits, cost structure, typical project scale, and development timelines. This section provides an overview of key points of comparison.

2.1.1 Discharge Duration

Discharge duration refers to the length of time an energy storage system can discharge at full output capacity. While all five major long duration energy storage technologies are capable of long duration discharge, they vary considerably in their range of duration. Table 2-1 lists the average discharge duration for each of these technologies.

Table 2-1. Average Discharge Duration Assumptions, Long Duration Energy Storage Technologies

Technology	Average Duration
CAES	3–24 hours
Flow Battery	2–12 hours
Lithium Ion Battery	0.5–8 hours
Molten Salt Battery	6–7 hours
Pumped Hydro Storage	6–24 hours

(Source: Navigant Research)

Although Li-ion battery projects can be designed to have a duration of up to 8 hours, most operational Li-ion batteries have durations of 4 hours or less. This places them at the low end of the duration range and limits their ability to offer a full suite of grid services. At the other end of the spectrum, PHS projects have average durations that range from 6 to 24 hours, with some plants designed to discharge at full power for longer than 24 hours. This duration enables them to replicate the grid and reliability services provided by conventional power plants.

2.1.2 Project Scale and Development Timelines

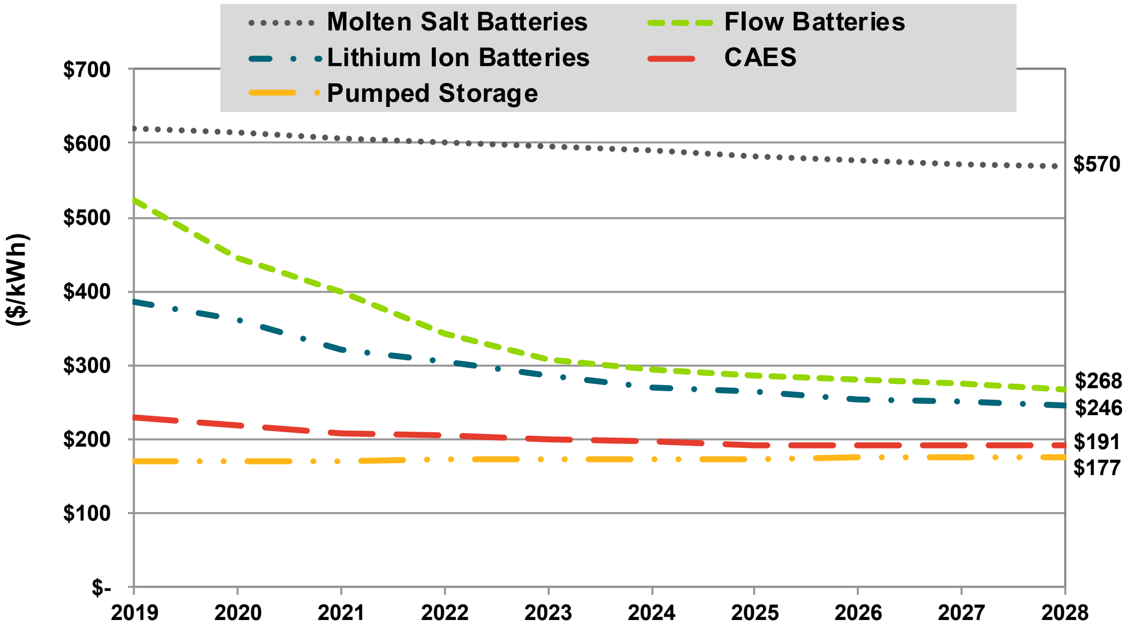
Long duration energy storage technologies can vary greatly in their scale and development timelines, with corresponding impacts on upfront costs. While battery projects can be deployed more quickly at a lower initial cost they are often smaller in scale, averaging 5–50 MW in capacity. In contrast, PHS and CAES facilities are typically large-scale plants that provide 100 MW of capacity or more, requiring significant upfront investment and longer lead times.

The scaling of duration and total project cost also varies considerably between technologies. For Li-ion battery projects, scaling to longer durations requires adding more battery packs, which represent the largest cost component of the project. Increasing duration results in an essentially linear increase in costs. By comparison, larger scale technologies such as PHS have different cost structures. Much of the cost to build a PHS project is fixed, coming from land development and construction. Scaling a PHS plant to longer durations requires only increasing the volume of the reservoirs being used, which has a relatively small impact on total system cost relatively to construction and development expenses.

2.1.3 Upfront Installed Costs versus Lifetime Costs

Long duration energy storage technologies have a wide range of installed costs, which are typically noted in dollars per kilowatt-hour of stored energy capacity. Navigant Research expects total upfront installed cost for each of the major technologies to range from $170.3/kWh for PHS to $619.7/kWh for molten salt batteries, as illustrated by Chart 2-1.

Chart 2-1. Average Utility-Scale Bulk Energy Storage System Installed Cost (CAPEX) by Battery Technology, World Markets: 2019-2028



(Source: Navigant Research)

The falling upfront costs of Li-ion batteries have made them attractive for some grid applications, but they have a short lifespan compared to conventional generation assets and PHS facilities, which are typically designed to last for several decades. The average lifespan of a Li-ion battery storage system ranges from 3–15 years depending on how it is used and how the specific Li-ion chemistry employed. While the inevitable degradation of Li-ion systems can be addressed by replacing depleted battery modules over time, this practice increases lifetime project costs considerably. These and other considerations are explored in Section 3.

Section 3

ACCURATELY COMPARING THE COST OF ENERGY STORAGE TECHNOLOGIES

3.1 Comparing Apples to Apples: Levelized Cost of Storage

When evaluating energy storage technology options, it is critical that grid operators and regulators consider key pieces of the energy storage cost puzzle beyond upfront cost. A levelized cost of storage (LCOS) calculation can be used to more accurately evaluate the lifetime costs of different technologies and yield cost per megawatt-hour figures that support fair and valid comparisons.

Lazard has conducted extensive evaluations of energy storage technologies and applications. The advisory firm has developed a method for calculating LCOS that is perhaps the most robust comparison of the true cost to own and operate different storage technologies.

Lazard's LCOS calculation factors in the upfront investment required for a given storage technology. The calculation also incorporates operating patterns (cycles per day/year) for a given application, depth of discharge, round-trip efficiency, annual operations and maintenance costs, equipment replacement costs, system charging costs, and the overall useful life to yield an estimate for the cost per megawatt-hour, thereby enabling an apples-to-apples comparison.

Figure 3-1 illustrates the stark contrast in the LCOS for PHS and Li-ion batteries over similar time periods based on PHS project evaluation conducted by the San Diego County Water Authority.[3] PHS projects are designed for up to 50 years of operation with limited equipment replacement, a lifespan that can be extended to 100 years with proper maintenance and component replacements. By comparison, Li-ion battery projects typically have much shorter lifespans, although it is possible to keep them operating for 20 or even 40 years with proper maintenance and battery replacement.

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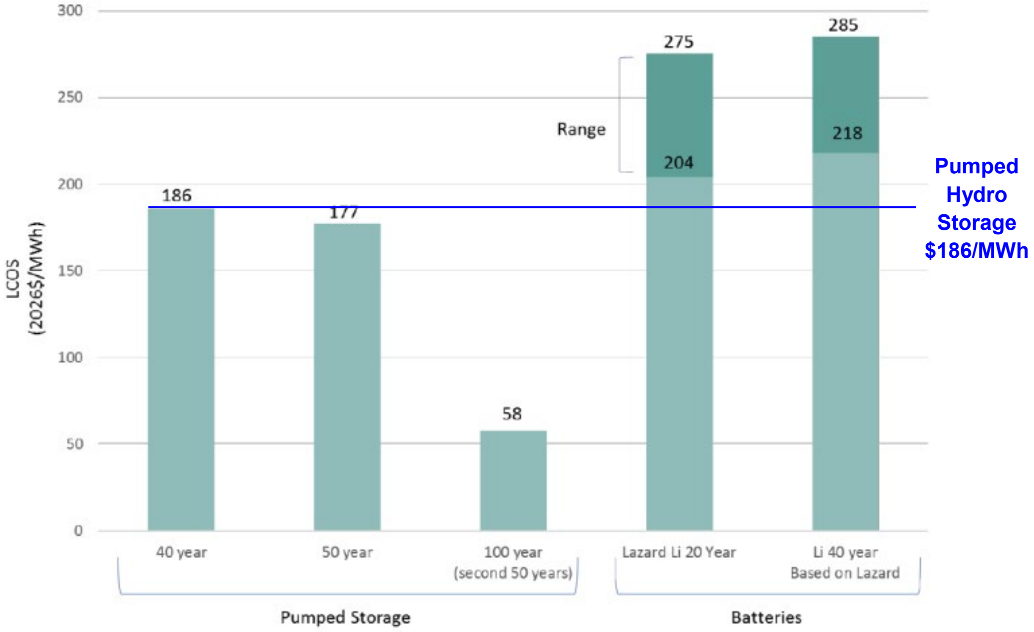
[3] Victor, David G, et al., *Pumped Energy Storage: Vital to California's Renewable Energy Future*. San Diego County Water Authority, 2019, *Pumped Energy Storage: Vital to California's Renewable Energy Future*, www.sdcwa.org/sites/default/files/White Paper - Pumped Energy Storage V.16.pdf.

As shown, these differences in operating life result in significantly higher levelized costs for Li-ion batteries. Using projected costs for facilities with a commercial operation date of January 1, 2026, over a 40-year operating life, PHS facilities have an LCOS of $186/MWh, compared to $285/MWh for Li-ion battery facilities for the same period.

Figure 3-1. Levelized Cost of Storage Comparison, Pumped Hydro Storage versus Li-ion Batteries



(Source: Lazard and San Diego County Water Authority)

Section 4

CONCLUSION

This report highlights several factors that can affect the true cost of different long duration energy storage technologies. In addition to the upfront costs to build a new project, the required operating costs and expected lifespan of each storage technology must also be considered.

While the falling upfront costs of Li-ion battery storage systems have attracted a lot of attention and increased the competitiveness of small to midsized battery projects, a more holistic view of total project costs shows that PHS and CAES deliver much better economics for ratepayers.

This white paper expands on the topic of long duration energy storage introduced in the first paper in this series. In addition to the financial considerations for each long duration technology presented in this report, there are many non-financial issues surrounding these technologies that must be considered when comparing technologies. These issues, including the safety, sustainability, and long-term reliability of battery energy storage technologies, will be explored in the third white paper in the series.

Section 5

ACRONYM AND ABBREVIATION LIST

CAES	Compressed Air Energy Storage
kWh	Kilowatt-hour
LCOS	Levelized Cost of Storage
Li-ion	Lithium Ion Battery
MW	Megawatt
MWh	Megawatt-hour
NaMx	Sodium-Metal Halide Battery
NaS	Sodium Sulfur Battery
PHS	Pumped Hydro Storage
US	United States

Section 6

SCOPE OF STUDY

This white paper examines the market for long duration energy storage technologies on the power grid. Specific attention is paid to the differences among technologies in terms of operational characteristics, lifetime, and project cost. Navigant Research prepared this white paper to provide an independent analysis of the opportunities for long duration energy storage. This white paper does not consist of any endorsement of any specific technology, project, or company. Rather, this paper provides readers with an understanding of technologies competing in the market for long duration storage and how they compare to one another.

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WHITE PAPER

Betting on Batteries?

Commissioned by National Grid Ventures

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Section 1

INTRODUCTION

1.1 Evaluating Energy Storage Options

This white paper is the third in a three-part series exploring long duration energy storage technologies. The first paper discussed why long duration energy storage is critical to the successful integration of large amounts of renewable energy, and how it will play a major role in the transition toward a more sustainable, reliable, and efficient electrical grid. The second paper explored the installation and operating costs of the five commercial long duration energy storage technologies. It notes that, with 144 GW installed worldwide, pumped hydro storage accounts for 93 percent of global energy storage capacity and is the most cost-effective option both today and in the long run. By comparison, lithium ion (Li-ion) battery storage has a relatively small market share, with 4.3 GW of installed capacity that accounts for 2.4% globally.

Li-ion batteries offer some advantages that make them the best choice of energy storage technology for certain applications, and ultimately, decarbonizing the electrical grid through the addition of large amounts of intermittent renewable energy sources will necessitate an “all of the above” approach to energy storage.

However, Li-ion batteries have several disadvantages related to safety, environmental, and supply chain that should be factored into evaluations of energy storage options. These concerns are the focus of this third and final paper in the series.

Decarbonizing the electrical grid through the addition of large amounts of intermittent renewable energy sources will necessitate an “all of the above” approach to energy storage.

1.2 The Global Market for Utility-Scale Energy Storage

The global market for utility-scale energy storage is expected to reach 155 GW in 2019, a figure that is predicted to increase to 271.5 GW by 2025. A small number of countries account for the majority of new utility-scale energy storage project capacity. In 2019, it is expected that the top 10 countries will account for 1,242 MW of new capacity, representing approximately 80 percent of the global market for the year. However, there is increasing geographic diversification in the market. Through 2028, the top 10 countries’ market share is projected to decline to approximately 72 percent.

1.2.1 Increasing Utility-Scale Market Share for Li-ion Batteries

Falling prices and flexible project designs have made Li-ion batteries the fastest growing energy storage technology. Annual new capacity additions are projected to ramp aggressively from 1,015 MW in 2019 to 15,682 MW in 2028, bringing total installed Li-ion battery capacity to a projected 80,908 MW and 69.5 percent of the estimated 116.5 GW global market by 2028. In terms of utility-scale capacity, Li-ion batteries are expected to account for 65 percent of new energy storage installations globally in 2019 and to exceed 17 GW by 2027.

Section 2

LI-ION BATTERY ENERGY STORAGE

2.1 Risks, Drawbacks, and Concerns

Concerns associated with the manufacture, use, and disposal of Li-ion batteries include safety, short lifespans, and lack of recycling capacity. These concerns also include global supply chain risks, potential price volatility, and significant environmental and social issues related to key raw materials. An examination of Li-ion battery energy storage should take these concerns into account and consider alternative energy storage technologies.

2.1.1 Safety

The primary safety concern with Li-ion batteries is the risk of fire due to thermal runaway, a situation in which the narrow range of safe operating temperatures is exceeded, initiating an unstoppable chain reaction. Li-ion batteries are designed to operate safely at temperatures between 15°C–45°C (59°F–113°F). At temperatures above 60°C (140°F), which can occur due to a short circuit or excessive current resulting from charging or discharging the battery too rapidly, the battery becomes unstable. Increased temperatures cause the release of additional energy, which raises temperatures even more. At temperatures above 100°C, the onset of thermal runaway becomes increasingly likely, and at temperatures above 144°C (291°F), it is almost inevitable.

Li-ion chemistries vary in terms of safety profiles, whereas more expensive and robust chemistries (like lithium iron phosphate and lithium titanate oxide) typically used in utility-scale applications are more stable than less expensive alternatives. Stability and thermal runaway remain significant concerns in the industry. Recent fires have impacted the stationary energy storage market and have prompted an increased focus on safety.

South Korea has led the world in battery energy storage capacity for 2 consecutive years and currently has nearly 25 percent of the world's Li-ion battery energy storage capacity. However, there were 23 reported fires in 2018, equating to tens of millions of dollars in losses. Of the approximately 1 GW of total installed capacity in South Korea, 40 MW (4 percent) of the installed capacity has been affected. As a result, 50 percent of South Korea's energy storage systems have been taken offline for inspection.

Many in the US attributed the South Korean Li-ion battery fires to poorly integrated systems. However, a 2019 fire at a Li-ion battery energy storage facility operated by Arizona Public Service (APS) has prompted a reevaluation of safety protocols for these systems in the US. Commissioner Sandra Kennedy issued a letter as part of the Arizona Corporation Commission's docket on the fire, in which she states that Li-ion batteries that use the types of chemistries involved in the APS fire "are not prudent and create unacceptable risks."[1]

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[1] Sandra D. Kennedy, "Arizona Corporation Commission Docket E-01345A-19-0076," (letter to the Commission, August 2, 2019), https://assets.documentcloud.org/documents/6240841/ACC-August-2-Kennedy-Letter-E000002248.pdf.

2.1.2 Short Lifespan

The exact cycle life of Li-ion batteries varies depending on the specific sub-chemistry used. Less expensive and less stable chemistries such as lithium cobalt oxide and lithium manganese oxide can have a relatively short cycle life in the range of 300–2,000 cycles, depending on manufacturer and usage. Alternatively, more robust chemistries such as lithium iron phosphate and lithium titanite oxide can last for 6,000–12,000 cycles. Depending on the specific services a system provides and the number of cycles per day, the calendar life for Li-ion batteries in grid storage applications may be as low as 3 years before capacity degradation occurs.

There are three approaches to addressing the relatively short cycle life of Li-ion batteries: replenishment of depleted materials, topping up the system by adding fresh modules to maintain the system's nameplate capacity, or fully replacing the system. While these methods can be effective in extending the life of a Li-ion battery project, they also result in expensive, recurring operations and maintenance costs.

> *A system's **cycle life** refers to the number of times it can cycle or be charged and discharged before it degrades and becomes inoperable or unusable for a given application.*

Of the five commercial long duration energy storage technologies, four have cycle lives that greatly exceed Li-ion batteries (pumped hydro, compressed air, flow batteries, and molten salt batteries). In the context of applications for the electrical grid, longevity is desirable from the standpoint of both reliability and ratepayer costs, and utilities are accustomed to deploying infrastructure assets that will last for decades.

Table 2-1. Average Cycle Life and Expected Lifespan of Long Duration Energy Storage Technologies

Technology	Cycle Life	Expected Lifespan
Pumped Hydro Storage	Technically Unlimited	50–100 years
Compressed Air Energy Storage	Technically Unlimited	20–40+ years
Flow Batteries	10,000+ cycles	20–25+ years
Molten Salt Batteries	4,500–10,000	15–20 years
Lithium Ion Batteries	500–10,000 cycles	3–15 years

(Source: Navigant Research)

2.1.3 Supply Chain Risks and Sustainability Concerns

The dramatic rise in portable electronics coupled with expected growth in the use of EVs and grid-connected battery storage systems has put increasing pressure on supply chains for the raw materials needed to produce Li-ion batteries. Lithium, cobalt, nickel, and graphite are all critical, with little flexibility for material substitution. In addition, limitations on supply diversity for some of these elements introduces risks to both individual firms and national interests. This section reviews supply chain concerns for lithium and cobalt in closer detail and examines sustainability concerns for four critical materials.

2.1.3.1 *Lithium Supply and Geopolitical Concerns*

There is little concern regarding lithium shortages. Lithium is an abundant mineral available from several concentrated sources; however, the industry's ability to increase battery-grade production to meet projected future demand is less certain.

Lithium is sold and used in two key forms: lithium carbonate, mainly produced from brines, and lithium hydroxide, which is largely produced from mined hard rock sources. Lithium hydroxide is the preferred form, because it offers longer battery life and larger capacity, two key factors in battery quality.

Only eight countries produce lithium, and of these, three—Chile, Australia, and China—account for over 85 percent of global production. In addition, four companies—Albemarle Corporation, FMC Corporation, Sociedad Química y Minera (SQM), and Talison Lithium—command 61 percent of the world's lithium mine output. While the global supply of both forms of lithium is sufficient to meet demand, the potential supply constraints combined with uncertainty about the rate of EV adoption make it difficult to forecast future long-term pricing, which has fluctuated in recent years.

2.1.3.2 *Chinese Control of Global Lithium Supplies*

Chinese companies have acquired substantial stakes in lithium mines around the world to secure the lithium resources needed to drive expansion. In late 2018, China-based Tianqi Lithium spent more than $4 billion to purchase a 23.8 percent stake in SQM, one of the world's largest and lowest-cost producers of lithium. Tianqi also owns 51 percent of a large Australian lithium mine. Combined with the nearly 20 percent of global lithium reserves held in-country, China now controls 40 percent of world supply.

Given the increasing strategic importance of lithium, China's control of nearly half the world's supply has caused some concern. In April 2019, France and Germany asked the European Commission to support a $1.9 billion battery cell consortium to challenge China's growth in the space. With the US–China trade war intensifying, several Chinese state media outlets have also begun floating the idea of banning exports of rare-earth elements to the US as a possible response to President Donald Trump's decision to increase tariffs on Chinese goods. As a result, American lawmakers are beginning to investigate options to reduce the nation's dependence on China for lithium imports and processing.

2.1.3.3 *Cobalt Supply and Geopolitical Concerns*

Less than 10 percent of cobalt occurs as a primary product. The remaining 90 percent, known as mine supply, is produced as a byproduct of copper and nickel mining, linking its availability to the supply and demand dynamics of its parent materials. Experts estimate that around 68 percent of global production is concentrated in the Democratic Republic of Congo (DRC), a figure some sources estimate could rise to 73 percent by 2023.[2]

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[2] Jason Deign, "Reliance on Congo Cobalt Grows Despite European Discoveries," *Greentech Media*, https://www.greentechmedia.com/articles/read/congo-cobalt-reliance-grows-despite-europe-discoveries#gs.to97yv, June 5, 2018.

2.1.3.3.2 *The "Blood Diamond of Batteries"*

This heavy dependence on the DRC has stark implications for sustainability given the well-documented human rights abuses of its mining industry, which have prompted some to call cobalt the "blood diamond of batteries." The DRC's copper belt accounts for almost half of the world's cobalt reserves at 3.75 million tons. While the majority is excavated at large-scale industrial mines, the DRC government reports that 20–30 percent of cobalt exports originate in artisanal mines, which are overwhelmingly unregulated and operate illegally. With an estimated 35,000 children employed in artisanal mines in the DRC, the ethical problem of child labor is a growing source of concern for all stakeholders. Poor working conditions in artisanal copper-cobalt mines also create serious health hazards for the estimated 255,000 laborers operating in the region. Over-exposure to cobalt can cause asthma, pneumonia, and heart and thyroid damage. The mines themselves tend to be little more than holes in the ground, with no suitable structural support to prevent collapse, and possess little or no protective equipment worn by the miners.

2.1.3.3.3 *Provenance and Traceability*

The issue of artisanal mining and child labor highlights one of the major challenges for cobalt consumers in the automotive, consumer electronics, and stationary storage sector, namely, the provenance and traceability of the material. Once mined, the mineral navigates a complex supply chain that can include the smelting of cobalt extracted from both artisanal and industrial mines, which is then exported overseas. China, which controls approximately 85 percent of global cobalt supply and produces some 60 percent of the world's refined cobalt, imports over 75 percent of its supply of the raw material from the DRC. The refined material is sold to battery manufacturers, which then sell their products to multinational brands. With no laws, widely acknowledged partnerships, or initiatives to support increased traceability for the metal, the lack of visibility down the supply chain leaves companies exposed to the ethical concerns tied to cobalt production. Systems that provide certainty about the origin of supplies and ensure they are not linked to child labor would likely result in a premium for certified materials, and also reduce the available supply for certain end-use sectors.

2.1.3.3.4 *Projected Price Volatility*

In addition to significant sustainability concerns, cobalt prices are expected to continue to increase due to production uncertainties. Cobalt refining is dominated by China, which accounts for approximately 60 percent of global production of refined cobalt. If midstream producers in other countries are to meet growing demand for cobalt from original equipment manufacturers, additional investment in refining capacity outside of China is needed. Given the projected increases in both EV adoption and the growth of portable electronics and stationary storage, cobalt demand is projected to increase fourfold between 2019 and 2028.

2.1.4 Environmental Impacts

Mining, processing, refining, and transporting four of the key materials required for Li-ion batteries—lithium, cobalt, nickel, and graphite—pose environmental risks. In addition, end-of-life concerns for spent Li-ion batteries are mounting as the use of Li-ion batteries for stationary energy storage expands.

2.1.4.1 Pollution

According to the US Environmental Protection Agency's recent life cycle analysis of Li-ion batteries, upstream materials extraction and processing and battery production pose significant potential for the eutrophication of bodies of water, ozone depletion, and ecological toxicity. For example, the production of soda used in processing lithium salts can lead to the creation of smog, which reduces visibility, causes eye and respiratory irritation, and harms vegetation. Aluminum production for the cooling system, cathodes, and other parts of the batteries is also highly energy intensive.

A 2016 *Washington Post* article on the impact of graphite mines and processing plants on China's air and water quality shed light on the global scale of environment degradation fueled by Li-ion battery production. China controls 70 percent of global graphite production capacity and experiences pollution from graphite mines and refineries that has resulted in stunted and damaged crops, high emissions of soot and particulate matter, and polluted water.

Similarly, nickel production is harsh on the environment. Processing the ore releases significant sulfur dioxide emissions, and like any ore mining activity, produces large amounts of slag. The Russian city of Norilsk is considered one of the most polluted places in the world, in large part because of nickel production. The Norlisk Nickel factory emits nearly 1.87 million tons of sulfur dioxide annually, and a river that runs through Norlisk famously turned bright red in 2016 after a flood washed mine waste into the river, a situation that was repeated in 2018.

The environmental impacts of China's extraction of mineral resources used in Li-ion batteries have also led to social unrest across Tibet. Since 2009, there have been more than 30 public protests against mining in response to the impact these activities have had on grasslands and rivers. In 2016, Ronda Lithium released toxic mine waste into a river in eastern Tibet, causing serious water pollution and the mass death of fish, resulting in local protests against the mining company. In 2013, lithium mine waste contaminated the same river, killing aquatic life and making local drinking water toxic.

2.1.4.2 GHG Footprint

As the use of Li-ion batteries for stationary storage becomes more prevalent, understanding the greenhouse gas (GHG) emissions burden of their production is increasingly important. A recent study conducted by the IVL Swedish Environmental Research Institute, on behalf of the Swedish Transport Administration and the Swedish Energy Agency, investigated the climate impact of Li-ion batteries from a life cycle perspective. The report concludes that for each kilowatt-hour of storage capacity in a Li-ion battery, emissions of 150 to 200 kg of CO_2 equivalent are generated.

Mining and refining were found to contribute to a relatively small portion (10–20 percent) of GHG emissions, independent of cell chemistry. The largest share (almost 50 percent) of GHG emissions result from battery manufacturing. This stems from the fact that the largest energy input in the production of Li-ion batteries is electricity. The IVL Swedish Environmental Research Institute study finds that energy efficiency and the electricity mix in the production stage present the best short-term opportunities to reduce the GHG emissions associated with Li-ion batteries.

These results were echoed by a recent study that estimated the GHG emissions from the production of Li-ion batteries in China and found that Li-ion batteries manufactured in China had GHG footprints that were double that of Li-ion batteries manufactured in the US due to the countries' respective electricity mixes.[3] Given that China is expected to control about two-thirds of global Li-ion battery manufacturing capacity by 2023, this elevated GHG emissions rate is significant.

2.1.4.3 Water Impacts

Water shortages and toxic spills from lithium mining in South America and Tibet further highlight the environmental concerns surrounding lithium extraction. One ton of lithium typically requires nearly 500,000 gallons of water to produce. As discussed in Section 2.1.3.1, lithium carbonate is produced from brines. Closed-basin brines, like those in South America's Lithium Triangle, are located primarily in arid regions where groundwater aquifers are rare and annual rainfall is limited. While the water pumped from the brines is undrinkable, the void left by these operations may be refilled by fresh groundwater. This can result in valuable water supplies in these locations being diverted away from local communities. In Chile's Salar de Atacama, for example, the lithium mining industry has used up to 65 percent of all available water in the region. Local communities in the region—many of them indigenous—are calling for the industry to be regulated.

2.1.4.4 Decommissioning and Disposal

As the market for stationary battery storage continues to grow, the question of how to deal with them at the end of their life cycle becomes more urgent. Li-ion batteries are classed as a dangerous good and are environmentally hazardous if disposed of incorrectly. The focus has primarily been on the disposal of hazardous materials used in Li-ion technology, rather on than extracting the materials for reuse. While cobalt has been historically recycled given its high value and use in alloys, recycling of Li-ion batteries is still in its infancy.

In the context of recycling automotive Li-ion batteries, a major factor that could temporarily delay the number of batteries sent for recycling is the potential to reuse them. It is anticipated that after primary usage in EVs, reuse in other applications such as stationary storage will become prominent. Repurposing EV batteries for use in stationary energy storage applications is already under commercialization and is viewed as a viable option. However, the lifespan of these reused Li-ion batteries will be even shorter than that of batteries purpose-built for grid usage, and this reuse delays fully dealing with the material recycling issues.

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[3] Hao Han, Mu Zhexuan, Jiang Shuhua, Liu Zongwei, et al, *GHG Emissions from the Production of Lithium-Ion Batteries for Electric Vehicles in China*, MDPI, http://www.mdpi.com/2071-1050/9/4/504/pdf, April 4, 2017.

Section 3

CONCLUSION

3.1 An “All of the Above” Approach

Energy storage is critical to the successful integration of large amounts of renewable energy and will play a major role in the decarbonization of the electricity grid. As the use of Li-ion batteries for renewable energy storage increases, it is important to recognize that while they are a suitable technology for certain applications, there are a wide range of concerns surrounding their manufacture, use, and disposal.

These concerns include safety, short lifespans, and lack of recycling capacity, as well as global supply chain risks, potential price volatility, and significant environmental and social issues related to key raw materials. Utility planners, regulators, and policymakers who seek to objectively evaluate the benefits and risks of Li-ion battery energy storage should take these concerns into account and give full consideration to alternative long duration energy storage technology options.

Pumped hydro storage is a well-established renewable energy storage technology that offers longevity, cost-effectiveness, energy security, and local economic development benefits. In addition, pumped hydro storage facilities have limited impact on the environment and decommissioning at the end of their 50- or 100-year lives is relatively straightforward.

Ultimately, the integration of large amounts of intermittent renewable energy sources will necessitate an “all of the above” approach to energy storage. Informed public policy and utility resource planning can help ensure that ratepayers receive the best value for their collective investment in energy storage infrastructure.

Section 4

ACRONYM AND ABBREVIATION LIST

DRC	Democratic Republic of Congo
EV	Electric Vehicle
GHG	Greenhouse Gas
kWh	Kilowatt-hour
Li-ion	Lithium Ion
MW	Megawatt
MWh	Megawatt-hour
SQM	Sociedad Química y Minera
US	United States

Section 5

SCOPE OF STUDY

This white paper examines the market for long duration energy storage technologies on the power grid. Specific attention is paid to the risks associated with battery energy storage, including environmental impact and supply chain concerns. Navigant Research prepared this white paper to provide an independent analysis of the opportunities for long duration energy storage. This white paper does not consist of any endorsement of any specific technology, project, or company. Rather this paper provides readers with an understanding of the market for long duration storage and why it will be required for a future grid reliant on renewable energy generation.

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