Long-Duration Energy Storage to Firm Windpower

By John Benson

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1. Introduction

It's not a screaming panic, but nevertheless, every ton of CO_2 and other greenhouse gasses (GHG) that we **do not** pump into the air now will be one less we need to deal with in the future. Also as more catastrophic effects of climate change emerge, we are likely to feel an urgency similar to a screaming panic.

So the subject of this post is important. The primary issue is, Large Battery Energy Storage Systems (BESS) based on Lithium-Ion (LiIon) technology like Tesla's Megapack[1] are ideal for a 4-hour run-time and thus mitigating most of the variability of photovoltaic (PV) generation. PV emits very little GHG, and when paired with LiIon BESS can cover most of the daily energy demand (at least where I live in Northern California), but not the much lower night-time demand after 9:00 PM.

Also, LiIon BESS's run-time is not effective for windpower. Although this can be remedied to a degree by segmenting a large LiIon BESS and stacking the segments, this greatly reduces their output. These issues were explored in the earlier post summarized and linked below.

Weekly to Seasonal Energy Storage: *Various electrochemical battery energy storage technologies will work to mitigate renewable variability, up to a point. Where that point is depends on the climate when the mitigation is needed, and the amount of mitigation (MWh) required in a given event. A large majority of large BESS procured by investor-owned utilities in California are lithium-ion batteries with a 4-hour run-time at their rated output.*

Without going into gory details about this, where I live (Northern California), these battery energy storage systems (BESS) work well to mitigate most of the daily variability that comes with photovoltaic arrays. However wind-power has variability that is much less predictable and sometimes has low-output durations of several days to over a week. Currently this does not cause a major problem because there is still enough gas-fired generation to offset the wind-variability, but as this is retired in the future years, it would be good to have more long-term storage options.

https://energycentral.com/c/gn/weekly-seasonal-energy-storage

Also, I already explored one candidate for the subject application in the paper earlier this year that is summarized and linked below.

A New Form of Energy: *Has anyone noticed that we use the same type of batteries to power smart-phones, laptops, electric vehicles, C&I facilities and Grids. These are all lithium-ion batteries. Yes there are a number of chemistries, ranging from expensive to very expensive. Lithium-ion batteries have a much higher energy density (watt-hours of energy per kg of mass) than other batteries. This is important in all portable electronics and vehicles, but what about facilities, and especially grids?*

[1] https://www.tesla.com/megapack

There are thousands of potential chemistries and configurations that can store and release electric power, and there must be hundreds of these that are substantially less expensive than lithium-ion batteries. Even if these have much lower energy density than LiIon batteries, they might be good candidates for grid energy storage.

Recently I came across such a candidate. This paper will be a review of their product. The name of the company is Form Energy, and thus the title of this paper.

https://energycentral.com/c/cp/new-form-energy

In 2020 I posted a paper on the then incumbents for long-term storage technologies. This is summarized and linked below.

Long-Term Storage: *This paper describes long-term storage technologies, some economic considerations, and recent developments.*

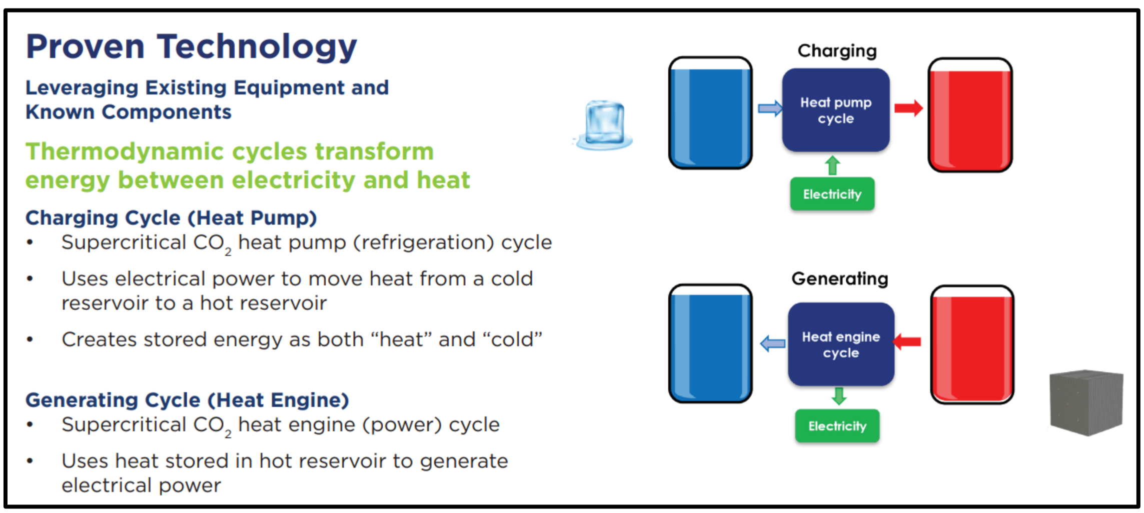
https://energycentral.com/c/cp/long-term-storage

In this paper we will look at other candidates for the role of mitigating windpower and other long-term power deficits. Also, as I was starting my final proofing of this paper, I came across another candidate application for long-term via our friends at the National Renewable Energy Lab (NREL). Since this paper was then below my average length, I added the paper describing this future application as the last Section.

2. Westinghouse / Echogen

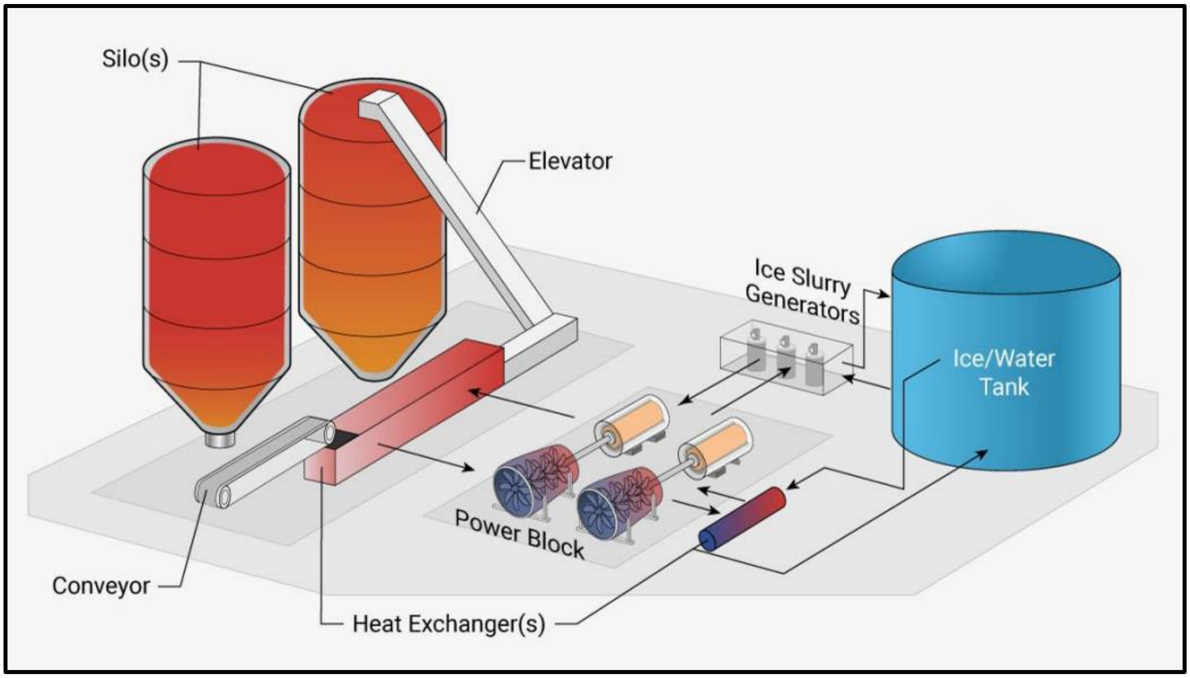
Westinghouse is a very old and large company that is currently mostly focused on Nuclear Technology. For that reason I immediately felt that this solution came from a partner, and quickly found out that it did (see section title). However, since is a very basic technology, I believe that Westinghouse probably has some unique components.

There is a graphic with descriptions for the Westinghouse version of this system below.[2]



The Echogen Version of this is below (next page). It should be noted that many of the incumbent technologies described in the above-referenced "Long-Term Storage" paper also use very basic technologies. One reason for this is that these solutions are much more cost-effective since they have long lifetimes with minimal maintenance.

[2] Westinghouse Pumped Thermal Energy Storage, Sep 2023, https://www.westinghousenuclear.com/Portals/0/energy-systems/WEC_Westinghouse_Energy_Storage.pdf?utm_source=Business_Wire&utm_medium=Press_Release&utm_campaign=Energy_Storage_9.22.23



Charging cycle:[3]

- Heat pump (refrigeration) cycle
- Uses electrical power to move heat from a cold reservoir to a hot reservoir
- Creates stored energy as both "heat" and "cold"

Generating cycle

- Heat engine (power) cycle
- Uses heat stored in hot reservoir to generate electrical power
- "Cold" energy improves performance of heat engine

2.1. Pilot

Westinghouse Electric Company announced today the Department of Energy has selected its project to deploy a 1.2 GWh utility-scale long-duration energy storage system in Healy, Alaska in support of planned wind power.[4]

The project represents the largest, planned single installation of long-duration energy storage in the United States and will demonstrate how the technology can firm intermittent renewable power at grid scale while also providing local and regional grid resiliency.

[3] Echogen Electro-Thermal Energy Storage (ETES), 2023, https://www.echogen.com/energy-storage/etes-system-overview/

[4] Westinghouse Electric Company, "Westinghouse Long Duration Energy Storage Solution Selected for Department of Energy Program in Alaska." Sep 22, 2023, https://info.westinghousenuclear.com/news/westinghouse-long-duration-energy-storage-solution-selected-for-department-of-energy-program-in-alaska

"Increasing access to affordable, reliable, and sustainable energy is one of my top goals as governor. Having an effective and affordable way to store energy has been the choke point for renewable energy technology. By providing long-duration energy storage, this project will help enable us to better utilize the renewable resources that are abundant in Alaska," said Alaska Governor Mike Dunleavy. "Congratulations to Golden Valley Electric Association and its partners for this significant step toward energy independence for the Railbelt."

"Westinghouse is dedicated to powering the future with clean energy solutions. Our long-duration energy storage system enables a higher penetration of renewables on the grid to achieve decarbonization goals without sacrificing overall stability," said Patrick Fragman, Westinghouse President and CEO. "We thank the DOE's Office of Clean Energy Demonstrations for this opportunity to showcase a ground-breaking technology."

"GVEA is pleased that Westinghouse's Long-Duration Energy Storage project has been selected by the DOE and we thank all project participants for their efforts," said John Burns, GVEA's President & CEO. "As a not-for-profit cooperative, GVEA's focus is on providing its members with low-cost and reliable power, while reducing emissions. We are excited about the potential of long duration energy storage and the role it can play in integrating renewable energy not only in Interior Alaska, but the rest of the Railbelt electric system which serves over 80% of Alaska's population."

Westinghouse has been advancing long-duration thermal energy storage technology for several years in collaboration with Echogen, the leading supplier of supercritical carbon dioxide (sCO_2) based technologies.

Pumped Thermal Energy Storage from Westinghouse solves many of the challenges associated with other long-duration energy storage applications, such as lithium-ion batteries, providing 10 or more hours of reliable energy storage with a simple, safe, cost-effective design in a compact footprint, delivering the lowest levelized cost of storage when paired with wind or solar. The system leverages readily available and inexpensive locally sourced materials, such as carbon steel, water and concrete, to enable rapid deployment anywhere around the globe.

Author's comments: When I worked for Landis & Gyr Systems in the 1980s (Landis & Gyr was later acquired by Siemens), we had several good customers in Alaska including Golden Valley Electric Association (GVEA) in Fairbanks, who had an LGS Energy Management System. I traveled to Alaska often to support these utilities.

Note that the Alaska Railbelt Utilities ("*Railbelt electric system*" in the above excerpt) are a group of five electric utilities that provide power to the Railbelt region of Alaska. The five utilities are Chugach Electric Association, Matanuska Electric Association, Golden Valley Electric Association, Homer Electric Association, and Seward electric system. The Railbelt region is a 600-mile stretch of land that includes the state's largest cities, including Anchorage, Fairbanks, and Juneau.[5]

[5] Note that I used Microsoft Bing generative AI to create this definition (with some edits by your author).

3. Other Candidates for Long-Term Energy Storage

I found a few other candidates (other than mentioned above and/or in earlier posts linked above) for long-term storage. These firms are described and referenced below.

3.1. Urban Electric Power

UEP's core technology revolutionizes the chemistry found in alkaline primary batteries and makes it rechargeable. This trusted battery chemistry is now reliably rechargeable, thanks to breakthrough technology advancements.[6]

Our battery utilizes earth-abundant zinc and manganese dioxide, which provide high energy density, low self-discharge, and are safe to operate and handle. The battery cells are modular, scaling from residential to commercial to utility applications.

3.2. Invinity Energy Systems

Vanadium flow batteries are a proven, decades-old storage technology. Invinity changed the game by crafting it into a factory-built product. Our safe, modular VFBs create storage solutions at any scale.[7]

Our energy storage has been deployed across the world. We have deployed 70 projects across 14 countries on five continents. Projects deployed or contracted with our customers store 75 MWh of energy. We have 73 patents that have been granted or are pending. We have invested 17 years developing our product and manufacturing.

3.3. Eos

Our latest generation Eos Z3 battery module sets new standards in simplicity, safety, durability, flexibility, and availability. Its ingenious design extracts the highest performance yet from our proven zinc hybrid cathode technology, solving the limitations that other stationery energy storage solutions ignore—and transforming how utility, industrial, and commercial customers store power.[8]

With more than 95 patents pending, published, or issued, our streamlined zinc-powered Eos Z3 battery module design features an aqueous electrolyte, bipolar electrodes, and a polymer casing.

Conductive plastic anodes and carbon-felt cathodes make up the Z3 electrodes. They're mechanically tough, corrosion resistant, and chemically stable, delivering for years with virtually no degradation. Plus, our bipolar structure simplifies internal battery connections to reduce internal resistance and improve round-trip efficiency.

Our innovative blend of water, halides, additives, and buffering agents make up our proprietary aqueous electrolyte. The formula both enhances zinc solubility and plating and eliminates the dendrite and densification issues that can lead to performance decay and safety hazards.

A rugged, injection-molded thermoplastic polymer exterior provides an optimized structure into which our electrodes are inserted—the Z3 design requires just 20 of them—minimizing materials, manufacturing, and maintenance. And all while eliminating the risk of any external leaking.

[6] Urban Electric Power homepage, https://urbanelectricpower.com/
[7] Invinity Energy Systems homepage, https://invinity.com/
[8] Eos Technology Page, https://www.eose.com/technology/

4. Moving Beyond Li-Ion – Winter Peaks

By the end of 2022 about 9 GW of energy storage had been added to the U.S. grid since 2010, adding to the roughly 23 GW of pumped storage hydropower (PSH) installed before that. Of the new storage capacity, more than 90% has a duration of 4-hr. or less, and in the last few years, Li-ion batteries have provided about 99% of new capacity.[9]

There is strong and growing interest in deploying energy storage with greater than 4 hours of capacity, which has been identified as potentially playing an important role in helping integrate larger amounts of renewable energy and achieving heavily decarbonized grids. Analysis in the Storage Futures Study[10] *identified economic opportunities for hundreds of gigawatts of 6–10 hour storage even without new policies targeted at reducing carbon emissions. When considering storage's role in decarbonization and enabling renewable energy, that potential could be even greater.*

Despite the large potential, there is still significant uncertainty regarding the role of longer-duration storage, and the possible technologies that can compete with Li-ion batteries in a shift toward longer durations.

Historically, 4-hour storage has been well-suited to providing capacity during summer peaks in many U.S. regions, which has led to several wholesale market regions adopting a "4-hour capacity rule." This rule allows storage with at least 4 hours of duration to receive full compensation in capacity markets or in other contracts for provision of firm capacity (with no additional capacity revenues for longer durations). This rule, along with limited additional energy arbitrage value for longer durations and the cost structure of Li-ion batteries, has created a disincentive for durations beyond 4 hours. Based in part on this rule, in 2021 and 2022, about 40% of storage capacity installed was exactly 4 hours of duration, and less than 6% had durations of greater than 4 hours.

The ability of 4-hour storage to meet peak demand during the summer is further enhanced with greater deployments of solar energy. However, the addition of solar, plus changing weather and electrification of building heating, may lead to a shift to net winter demand peaks, which are often longer than can be effectively served by 4-hour storage. Several regions of the United States (regions in the Southeast and Texas) have shifted to net winter peaks in recent years. As regions change rules for storage capacity credit, this could ultimately provide greater incentive for longer-duration storage in the coming years. Provision of additional services such as transmission congestion relief and resilience could also increase opportunities for longer-duration storage.

Several storage technology options have the potential to achieve lower per-unit of energy storage costs and longer service lifetimes. These characteristics could offset potentially higher power-related cost and lower efficiency to achieve life cycle cost parity at some duration. However, the new technologies must compete against the well-established Li-ion technology, with its expected cost reductions and potential ability to achieve longer durations. Cost parity for new technologies will likely depend on deployments at scale, and points to the potential role of policies to enable a diverse portfolio of cost-optimal storage technologies with longer durations to support the evolving grid.

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[9] Paul Denholm, Wesley Cole, and Nate Blair, National Renewable Energy Laboratory (NREL), "Moving Beyond 4-Hour Li-Ion Batteries: Challenges and Opportunities for Long(er)-Duration Energy Storage," September 2023, https://www.nrel.gov/docs/fy23osti/85878.pdf

[10] Your author summarized NREL's Storage Future Study in a five-part 2022 series. The following link is to Pt. 5 which has links to the other parts, https://energycentral.com/c/cp/energy-storage-futures-vol-5-role-and-impact-2050

Author's comments: The above introductory comments are from the Executive Summary of reference 9, but most of the rest of this section's content is from Section 3 of the referenced NREL Document.

Earlier sections of this document, and references in this document (mainly in the Intro) describe emerging technologies that can be used for long-term storage.

4.1. Shifting the Value Proposition

We describe two general changes that may shift the value proposition to storage with greater than 4 hours, illustrated conceptually in Figure 5. The changes are illustrated relative to the value proposition for storage in a current system with a 4-hour capacity rule described in Section 2 (orange line). The first potential shift (illustrated in the gray line) is a shift in the value of existing services toward longer duration... The second potential change (illustrated in the blue line) is the provision of new sources of value that favor longer durations. It is important to note that we are considering changes that will occur in the relatively near term, as opposed to changes that will occur associated with extremely large-scale deployment of renewables and deep decarbonization.

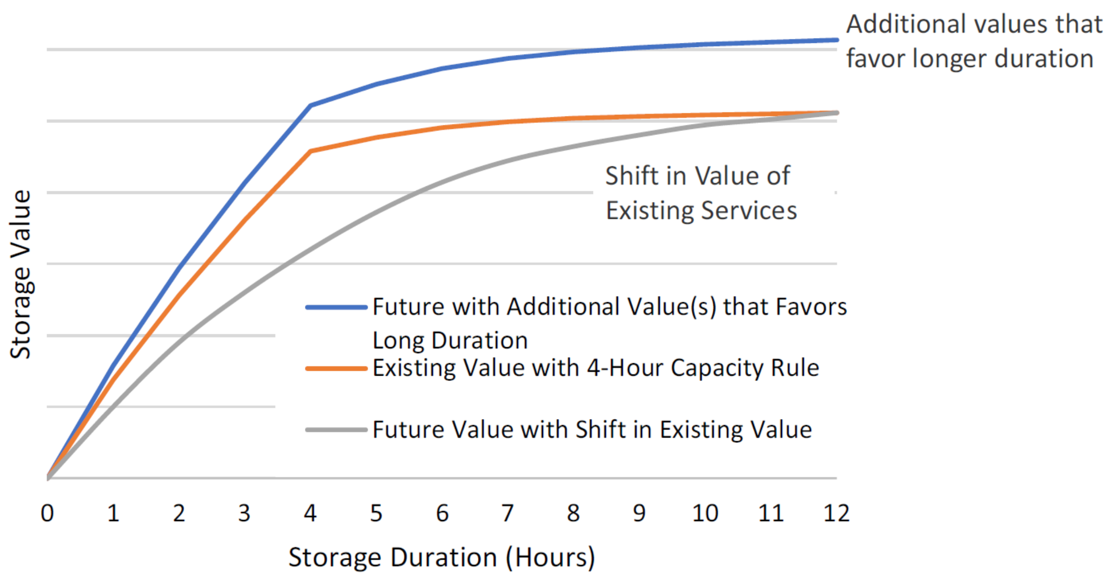

Figure 5. Two changes that could shift in the value proposition toward longer-duration energy storage include a shift in value of existing services (primarily a reduction in the value of shorter-duration storage) and provision of additional services that are suited for longer duration.

The 4-hour capacity rule is a simplification of a more complicated relationship between capacity value and duration, and it reflects near-term conditions (and only in some regions). Over time, rules will likely evolve to reflect changes in grid conditions that could shift the shape of the value curve and potentially incentivize longer-duration storage.

Author's comment: The primary thesis of this paper is: although Li-Ion battery energy storage systems (BESS) with a 4-hour duration is optimal for mitigating the current time-mismatch between Summer PV-production and peak demand, it is pretty useless for mitigating less predictable mismatches like wind-power production verses peak demand. Also, the primary early adapter market (California) further simplifies the PV mitigation dynamic by having very predictable Summer-weather.

As utility-scale BESS markets expand in other regions with more complex dynamics, and as climate change drives more weather complexity, long-duration storage will find more markets, which will drive the expansion of this product.

Even without sophisticated analysis, the basis for the 4-hour rule can be observed by examining the shapes of normal summer peak demand patterns that are typically well under 4 hours long in much of the United States. However, the shape and length of the peak demand period is changing due to an evolving grid mix, load, and weather patterns, with confounding factors that will both increase and decrease the value of 4-hour storage, ultimately impacting the value proposition for longer-duration storage…

As a result, the more near-term opportunity for longer-duration storage will occur due to a shift in demand peaks to winter. Resource adequacy metrics such as ELCC[11] identify the periods of greatest likelihood of a shortfall in meeting demand, and ELCC metrics are dominated by summer peaks in much of today's grid. However, a shift of (net) peak demand periods to the winter means ELCC will be more likely to be measured by winter performance.

Net winter peaks can result from the large supply of solar decreasing the summer peak, while making less significant contribution during the winter. Figure 10 compares the winter and summer peak profiles for ERCOT in 2022. The solid line shows the normal demand profile, where the summer peak (occurring July 20) was about 8% higher than the winter peak (December 23). However, the dashed lines show the net peak with solar, where significant solar production produced a net winter peak overall.

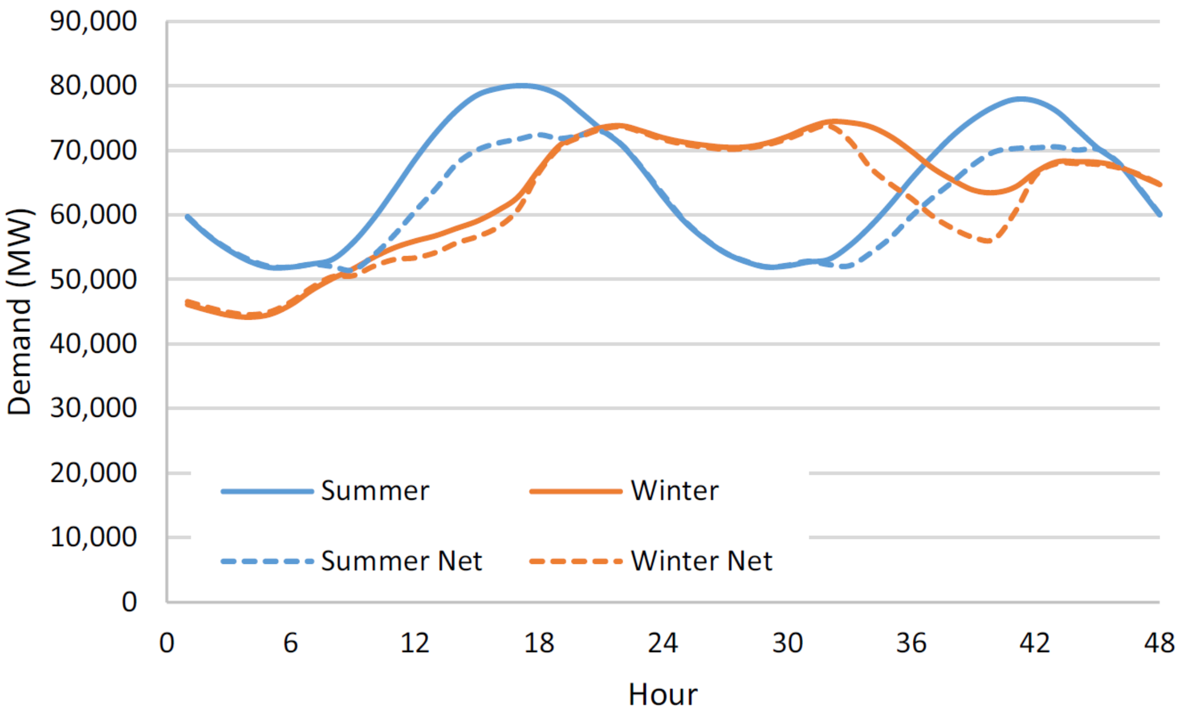

Figure 10. Comparison of winter and summer peak shapes in ERCOT in 2022 shows a transition to net winter peaks, with the impact of solar on summer peaks and winter peaks being flatter and longer.

[11] Effective load carrying capability

The shift to winter peaks (either net winter peaks due increased use of solar, or actual winter peaks due to increases in winter electric demand) is important because winter peaks tend to be longer than summer peaks, which reduces the ability of shorter-duration storage to have high capacity credit…

A few regions of the United States are already winter peaking, or are close to winter peaking even before the addition of solar. These are typically regions with fairly mild climates that rely on electric heating;

Author's comment: As climate change mitigation restrictions are imposed in the future much fuel-based winter heating will shift to electric heating, albeit more efficient heat-pump technology rather than electric-resistance heating. Also, for some users this shift may initially be to low-carbon versions of current fuels (like petroleum-based natural gas to biomethane, or petroleum-based fuel-oil to bio-based alternatives). However, the shift to clean fuels should only be a short-term patch during a transition to electric heat-pump plus increased efficiency. Low-cost renewable electricity plus improving efficiency in new loads should ultimately win the economic battle.

Locations that tend to have cold winters tend to rely on (historically) less costly fossil-fuels for heating. Electrification could lead to winter peaks, even without the impact of solar on summer peak demand reduction. Figure 14 illustrates results from a set of simulations that explores the possible change in load shape throughout the United States due to electrification. The example is from the NYISO region and shows how the summer peak in 2020 is significantly greater than the winter peak, but the 2032 scenarios show a significant growth in winter peak. This increase in winter peak, combined with the greater contribution of PV, would result in a shift to a net winter peak.

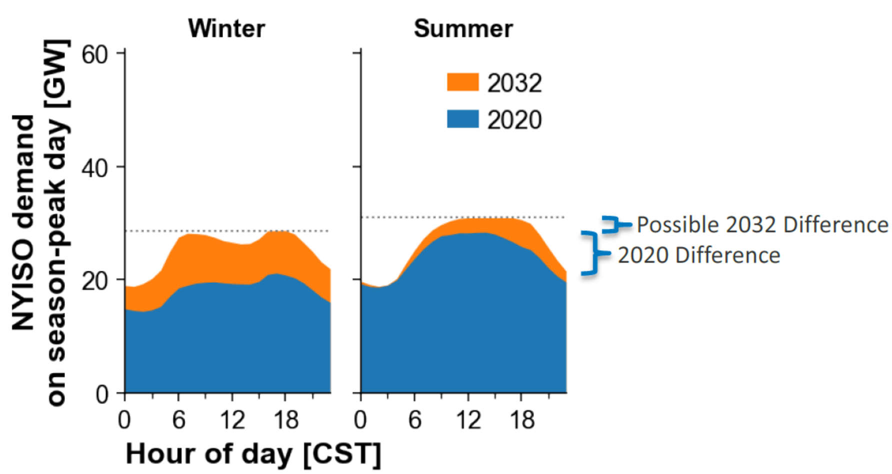

Figure 14. Example of the impact of electrification on the day with annual peak demand in NYISO, which could lead to a winter peak in the coming decade