Geothermal Energy as a Premium Power Source – Resilient Continuous Power

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Keywords

Geothermal energy, electric power, energy security, energy transition, electricity grid, clean energy, decarbonization, greenhouse gas reduction, electric grid reliability, resilience, energy transition, electric power technologies, renewable power, baseload power, Closed-Loop Geothermal, CLG, premium power, electricity generation

ABSTRACT

Energy security, supply reliability and resilience are becoming more valuable to business and organizations. Renewable geothermal baseload power offers a unique combination of energy security, reliability and resilience that make it more valuable per MWh than intermittent renewables, which require large land areas and battery backup. Other attributes of geothermal energy include versatility, because both heat and power can be supplied, dispatchability by the electricity grid operator, which intermittent wind and solar lack, load balancing, grid stability and black start capability, zero carbon emissions that can displace fossil GHG emissions, climate and weather independence that avoid outages and blackouts, low variable operating costs, much smaller land footprints, defendable on-site facilities utilizing underground geothermal heat reservoirs, and lower lifecycle costs than other generation technologies. Hence, the value premium for high availability, continuous geothermal power is substantially greater than generally realized. Geothermal energy's attributes offer the opportunity for the industry to charge a competitive premium price for its resilient continuous power.

1. Introduction

Despite the introduction of innovative technology in the geothermal industry, geothermal energy continues to decline as a percentage of the global energy portfolio. World geothermal capacity is only about 1% of total energy consumption and is projected to experience moderate growth of about 5% per year.[1] Meanwhile, much more rapid growth continues for both the wind and solar industries, while other renewable energy sources also make inroads into the global market, further depressing the market share of geothermal power. Note that geothermal is not even mentioned by name in this graph of global energy consumption by source.

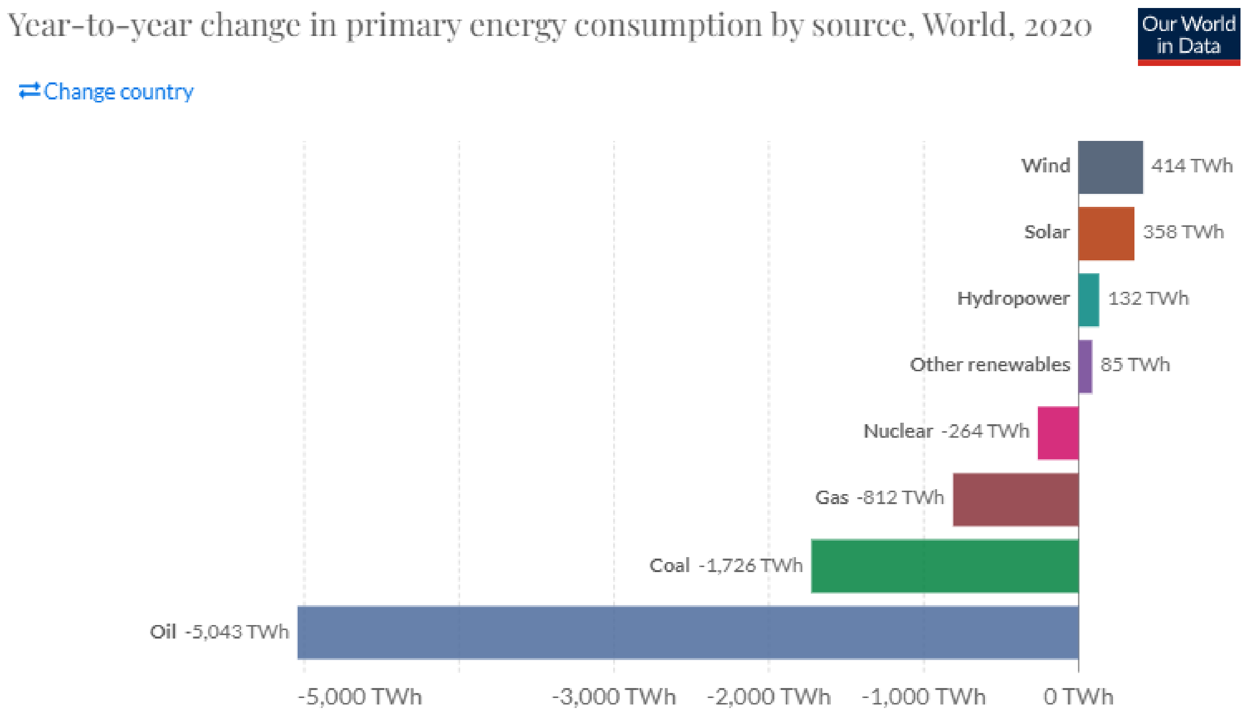

Figure 1 Source: "Our World in Data" BP Statistical Review of World Energy (2021) – Primary Energy Consumption by Source

Obviously, market fundamentals must dramatically improve for geothermal power to flourish. This paper argues that changing perceptions about the value of firm continuous baseload power generally, and energy assurance, reliability, and resilience specifically, make geothermal power more valuable relative to other renewables that lack many of geothermal's positive attributes. This value premium should enable geothermal energy producers to charge a competitive price reflecting geothermal power's added value, i.e., a premium price per MWh that will also spur investment in renewable geothermal projects and technology.

2. Market Challenges

To regain market relevance, the geothermal industry must attract sufficient investment to accelerate its capacity growth. That will not be easy. Despite significant improvements in underlying technology, such as drilling techniques, closed-loop geothermal (CLG) energy systems, and generating conversion efficiencies, these innovations by themselves are not yet sufficient to materially improve the investment sector's perception of geothermal as slow, risky, and "niche."

The geothermal industry has correctly asserted that it is the only large-scale power technology that provides clean AND continuous electric power. However, even in a world desperate for clean power, this argument has been insufficient to overcome the perception that the cost, risk and "time to revenue" issues will continue to constrain geothermal development.

Notwithstanding the challenges still facing geothermal power, the conventional wisdom fails to recognize that irreversible trends in the global energy market are combining to make geothermal power a premium energy product that will increasingly command a price premium relative to other renewable energy sources. This premium arises because geothermal power has a unique set of attributes that are individually and collectively increasing in market value. Consequently, a simple comparison of the conventional LCOE of geothermal power relative to solar and wind LCOE misses the crucial point that a MWh of geothermal is worth more than a MWh of other renewables. Wind and solar do not provide the same electricity services. Hence, simple comparisons of LCOE are misleading. System capacity mixes need more geothermal energy to complement solar and wind, in order to provide adequate resource reliability and resilience.

Why is that true? Most observers recognize that geothermal energy is the only major low-carbon renewable source capable of providing baseload power, maintaining grid stability and providing black start capability. But in very recent history baseload power has been regarded by some critics as inimical to the new "flexible" grid power model. In fact, some energy analysts went so far as to assert that "baseload is a dirty word." That idea was feasible when solar and wind were a small part of the energy portfolio, and the market futurists were enamored with visions of dynamic "on demand" power generation in a decentralized grid.

In other words, baseload power was considered a stolid relic of the old grid, dominated by coal and nuclear fuels, and unable to flexibly scale output as needed. This negative opinion prevailed because the prominent non-nuclear providers of baseload power – coal, oil, natural gas - were increasingly recognized as the drivers of climate change due to CO_2 and methane emissions. Nuclear power, also a baseload power, evoked images of Chernobyl, Fukushima and Three-Mile Island, three vastly different but serious nuclear events. Because of those perceptions, significant political pressure was applied to shut down baseload plants of all types and to instead invest in intermittent renewable power sources that were believed to be more compatible with the new renewable "green" paradigm that has, so far, ignored geothermal energy.

Now however, the negative results of the war on baseload power are roiling energy markets worldwide. When the mix of generating capacity has relied on too many non-dispatchable solar and wind resources in a system, particularly during hours when solar and wind generation dominates, wholesale market prices have plunged toward zero, rendering some baseload plants uneconomic to dispatch. In some markets solar and wind resources have increasingly been curtailed, and in noteworthy situations have not been able to prevent outages.

Unlike the previous situation where a diverse mix of dispatchable baseload, intermediate and peaking resources supplied adequate reserves across all hours, over-reliance on intermittent solar and wind during heat waves, diminished hydro availability due to drought, and cutoffs of fuel supplies have contributed to episodes of resource inadequacy, grid instability and systemwide or rolling blackouts. Germany's premature divestment of baseload power sources has resulted in very high prices and a dangerous dependence on Russian natural gas. Nations such as the UK have seen residential power prices more than double. The California grid instituted rolling outages in August 2020, when wind generation fell by 1,000 MW and solar power declined in the late afternoon due to cloud cover and, of course, the daily setting sun.[2] Texas came to a standstill in February of 2021 due to freezing weather making many natural gas plants inoperable and leaving some wind turbines idle. The multi-day Texas outages led to major property damage and loss of life and were caused by mismanagement, combined with freezing weather that shut down natural gas fired generation; the blackouts were not caused by renewable resources, although wind generation also diminished.

3. The Return to Baseload Power or the Move to Resilient Continuous Power

Consequently, there has been a growing realization of the importance and value of baseload power.[3] But that is not because customers are seeking nothing more than firm power. Instead, savvy customers are looking for more than just baseload energy; indeed, they are becoming quite specific about the additional qualities of the baseload power they desire. Specifically, these premium customers are seeking clean power that combines three inter-related attributes: security, reliability, and resilience. Dispatchable continuous power meets availability and reliability criteria. As a result, there is a rapidly growing opportunity to position geothermal power as a "premium power" source for multiple types of power customers, who place an increasingly high value on energy security coupled with reliability and resilience.

3.1 Local and National Energy Security

Energy security is measured by the degree of control a nation or region has over the supply of indigenous energy that it requires. While in past decades energy security was largely a function of coal, oil, and natural gas reserves, augmented by hydro and nuclear power, the impact of legislation and political action related to environmental concerns has led to a fundamental shift away from fossil fuels and nuclear toward "clean" energy sources such as wind and solar. Meanwhile, technical advancements, such as the Internet, robotics, and electric vehicles (EV) are irreversibly shifting energy consumption toward electric power. This trend means that national energy security will increasingly be defined as the ability to generate electric power without depending on fuel or transmission from other nations.

The 2022 Russian invasion of Ukraine abruptly refocused the world on the important political and economic reasons for not ceding control over major energy resources to belligerent foreign powers. In just a few weeks the shock of kinetic, large-scale warfare in Europe has made clear the danger of depending on authoritarian regimes to supply energy. These events have caused a reversal of the energy policies Europeans pursued for several decades, notably retiring traditional baseload power assets, such as coal and nuclear fueled generating plants, in favor of "cleaner" and more politically acceptable sources, such as natural gas. Europe is not alone in this problem as countries like Japan, Taiwan and Singapore have also become alarmed over their international energy dependence. Meanwhile, in response to geopolitical events, the United States has in 2022 found itself shopping for oil from current enemies, voluntarily depleting its strategic oil reserves to attempt to lower global oil prices and prescribing an increase in ethanol; all accompanied by foreseeable, but unintended consequences. These policy choices will have impacts that are not consistent with other economic and policy goals, perhaps delaying the global energy transition to reduce emissions of greenhouse gases (GHG).

Indeed, geothermal resources are potentially valuable components of future energy security. Its "fuel," i.e., the earth's heat, is ubiquitous, albeit at different depths. Heat production and power generation can occur at the same site. Consequently, on-site geothermal is always-on and can be dispatched, unlike oil and natural gas which may traverse thousands of miles and cross multiple national jurisdictions to go from the wellhead to the site of power generation. Moreover, geothermal heat and power systems can be tailored for multiple applications, including direct heating of buildings and residences, district heating, electricity production, "green" hydrogen production, the extraction of critical minerals, like lithium, from geothermal brines, water desalination, and other industrial, commercial processes.[4,5,6]

3.2. Reliability

The Energy Reliability Act of 2004, authored by the U.S. National Electric Reliability Council (NERC), defines reliability as a combination of sufficient resources to meet demand (aka resource adequacy, RA) and the ability to withstand disturbances (resilience and security). In its most simplistic format, Resource Adequacy can be calculated as the percentage of generating capacity above some measure of historic or forecast power usage, aka, the reserve margin. Security is a more complex topic but generally implies the ability to withstand a variety of external and reasonably foreseeable threats such as weather events, volcanic eruptions affecting global climate, terrorist attacks, cyber-attacks, and electromagnetic storms. The Electric Power Research Institute (EPRI) has prepared studies covering the impact of extreme events on Resource Adequacy and documented methods for estimating the value of service reliability and the costs of power outages.[7,8]

Together the Resource Adequacy and security of a given system determine the frequency and durations of outages or a power grid's "reliability." Before the advent of renewables, reliability was fairly easy to calculate using historical statistics and system-wide measures like Loss-of-Load-Probability (LOLP), and Loss-of-Load-Expectation (LOLE). Now, with the advent of significant wind and solar generation, both intermittency and the Effective Load Carrying Capability (ELCC) of additional generators must also be considered as primary factors in calculating grid reliability and judging the net economic benefits of capacity additions. This raises the question as to whether generators that are "available" (sun shining or wind blowing) only about 30% of the time should be called 30% "reliable" or whether more complete evaluations incorporating fault and event tree risk analyses combined with network power flow studies should encompass entire fuel cycles. In fact, there are diverse types of intermittencies - solar energy is intermittent but largely predicable for each time period of the year, while wind is both intermittent and less predictable.

The current reliability of the US grid has received increasing attention as the summer of 2022 approaches. Utility Dive reports “The central and Western United States will face elevated reliability risks this summer, as extreme temperatures, drought conditions and higher peak demands challenge grid operators, according to analysis published Wednesday by the North American Electric Reliability Corp… The unexpected tripping of solar generation is just one item on a list of reliability issues this summer, but as more solar is interconnected NERC officials say it could become a major threat.”

“The inverter tripping challenge is really one of the most risky issues we have to deal with as an industry in order to ensure we can reliably interconnect the nearly 500 GW of solar we see coming online in the next 10 years,” NERC Director of Reliability Assessment and Performance Analysis John Moura said Wednesday in a call with media.”[9,10]

While we must plan and invest more wisely in the future, customers usually don’t care whether power is unreliable due to mechanical failure, intermittency, or weather-related events; they are dependent on both the reliability of the grid and its resilience. Paradoxically, the grid demands greater reliability precisely at the same time as intermittent power supplies have become a much larger percentage of overall generating capacity.

3.3. Resilience

Reliability and resilience are easy to confuse because they are so closely related. Perhaps, it is useful to think of reliability as a system’s general ability to remain in service over an extended period, despite risks that can reasonably be expected to occur during that time. In one example reflecting reliability concerns, wind could only supply 7% of the UK’s electric energy during the first few weeks of September 2021, because winds were unseasonably and unpredictably low compared to the 18% supplied during the whole of August 2021. This contributed to an unusual run up in the wholesale price of natural gas, which was five times higher than at the same time in 2020.

Resilience, on the other hand, deals with lower probability but high impact events such as physical attacks, catastrophic sustained weather events, or targeted cyber-attacks. All may fall outside the boundaries of previous experience. Reliability is based on experience over time, while resilience is an inherent quality. The Texas “freeze” of February 2021, initiated by Winter Storm Uri, is a good example, as is the major earthquake and resulting tsunami that took out the Fukushima nuclear power plant. This event caused Japan to halt nuclear power expansion, at least temporarily, affecting the entire country's energy resilience and future energy supply strategy.

Indeed, our need for power resilience is rapidly increasing due to the interdependence of so many electrically powered systems. A failure in one system can easily cascade into the failure of multiple connected systems. The ransomware attack on the Colonial Pipeline system had knock-on effects. Likewise, the cutoff of Russian oil and natural gas will reverberate throughout our international energy systems, as well as requiring substantial societal and major geopolitical adjustments. As another example, artificial intelligence (AI) now controls the activity of many subsidiary systems, so any power failure of a critical AI system may, for reasons of safety, if nothing else, force the cascading shutdown of its subsidiary systems. Triple resiliency of such control systems is a must.

There are multiple ways to assess the resilience of a given electric power technology. The US Department of Energy Grid Modernization Lab Consortium developed the following metrics for measuring resilience:

Consequence Category	Resilience Metric
Direct	
Electrical Service	Cumulative customer-hours of outages
	Cumulative customer energy demand not served
	Average number (or percentage) of customers experiencing an outage during a specified time period
Critical Electrical Service	Cumulative critical customer-hours of outages
	Critical customer energy demand not served
	Average number (or percentage) of critical loads that experience an outage
Restoration	Time to recovery
	Cost of recovery
Monetary	Loss of utility revenue
	Cost of grid damages (e.g., repair or replace lines, transformers)
	Cost of recovery
	Avoided outage cost
Indirect	
Community Function	Critical services without power (e.g., hospitals, fire stations, police stations)
	Critical services without power for more than *N* hours (e.g., *N* > hours of backup fuel requirement)
Monetary	Loss of assets and perishables
	Business interruption costs
	Impact on Gross Municipal Product or Gross Regional Product
Other Critical Assets	Key production facilities without power
	Key military facilities without power

Table 1 Grid Modernization; Metrics Analysis (GMLS1.1) – Resilience", Volume 3, Grid Modernization Laboratory Consortium, April 2020[11]

The Electric Power Research Institute has also examined key issues surrounding resilience and global interests "in prioritizing investments to sustain quality of life and reduce the economic impacts of widespread and long-duration power outages."[12,13]

4. Premium Customers

In a sense, everyone is a premium energy customer. Everyone is at least inconvenienced, if not frustrated, by even a temporary power outage and would be willing to pay something more to prevent power outages. The price customers might be willing to pay is hard to determine, but the fact that residential customers continue in multiple places to pay double the former price demonstrates the low elasticity of demand for electric power. A June 2022 article in POWER discusses a number of the reliability, resilience and climate concerns currently driving commercial and industrial customers' needs to acquire premium power.[14]

Because businesses and organizations have more direct, severe, and calculable costs stemming from power outages than residential customers, they have even less tolerance for power outages. But the degree of pain is far from uniform; some customers are much more sensitive to power outages than others. For example, a major Texas manufacturing company privately stated that the Texas freeze idled 5,000 employees for more than a week and caused severe damage to equipment that took months to repair. Organizations whose mission might be compromised for being "offline" for only a few minutes are prime examples of premium power customers. For example, even a few minutes without power may be devastating to a military base or data center but not an immediate crisis for a grocery store. Similarly, a power outage at FEMA or an emergency response organization will have far greater ramifications than for an individual warehouse. To the extent that data centers, schedulers for supply chain and personal transportation, inventory control and power plants, credit card payments, bank transactions and other key services are disrupted, all of us are vulnerable.

5. Geothermal as the Supplier of Resilient Continuous Power

There is robust evidence that baseload geothermal energy has already become premium power in terms of its market value, if not in public perception. An insightful 2017 study by Orenstein and Thomsen showed that the value of firm geothermal power in the energy market increases relative to solar and wind, even as those sources comprise a greater share of the energy portfolio. This may occur, for example, as solar more frequently results in negative wholesale market prices during peak solar times and yet fails to meet peak consumption demand in late afternoons and evenings. According to this paper on a per MWh basis geothermal power in the western U.S. was already more valuable than solar power by 2017. More importantly, the authors argue that the value "premium" of geothermal relative to solar will grow to between $18 and $35 per MWh by 2027.[15] Note, however, that the predicted value premium is based solely on the energy market economics at that time. Other factors will make the geothermal energy premium even higher.[16]

The previously cited Princeton University study demonstrates the essential role played by baseload power plants. It points out that unless sufficient firm, dispatchable baseload power generation resources are added, the future electricity grid is likely to be riskier and less sustainable.[17] A 2020 analysis by Bartosz and Thomsen shows that even now geothermal power is more cost-competitive than solar and wind combined with storage.[18] An updated 2022 analysis further points out the disparity between added geothermal MWh and solar and wind MWh, which require backup and don't provide spinning reserves or black start capability. Thomsen describes "how geothermal now yields the highest economic value of any renewable resource in California and the surrounding region…based on recent historical and forecasted wholesale energy, capacity, and renewable energy credit (REC) market prices."[19] Because geothermal power technologies use the earth as their inexhaustible battery and have typical availabilities over 90% (while non-dispatchable solar and wind have usual availabilities below 35%), building more geothermal plants will not only help balance the grid and add resource diversity, but also provide more value per MWh delivered.

Moreover, when the entities that design, regulate and operate the electricity grid come to grips with the severity of problems created by favoring non-dispatchable, non-baseload, intermittent "variable" resources to the exclusion of resilient continuous resources, they will realize that today's wholesale market tariffs and payments must be redesigned and adjusted. In the face of growing climate risks and geopolitical disruptions, we must keep load-following and clean baseload power plants viable and profitable, leading to a more reliable and diverse mix of generating technologies. Various ways of monetizing the attributes of geothermal power have been described,[20] but as Distributed Energy Resources (DER), microgrids, Resilient Community Grids, and demand-side bidding enable electricity loads to be shaped across days, weeks and seasons, these developments will further enable baseload power resources that will increase the predictability, stability and affordability of electricity.

Additional research conducted by Acelerex, a Boston area SaaS and energy consulting firm, illustrates the compelling case for the value of geothermal relative to solar or wind. The Acelerex analysis concludes that when all market factors are considered in regions with sufficient solar insolation that might use batteries to provide continuous power around-the-clock when wind and solar are unavailable, the incremental value of a MWh of baseload geothermal is at least 5 times greater than an additional MWh of wind and solar. In the example shown in Figure 2 below, replacing 1 MW of resilient continuous geothermal output would require at least 5.5 MW of solar power and 15 MWh hour of energy storage. The average cost per MW capacity of solar power is currently about U.S. $1 million and the cost per MW of long-term battery storage is $2.6 million per MW.[21] Consequently, the capital investment of solar plus batteries is roughly $11.8 million per MW as compared to about $3 million for geothermal. On days without sun or in winter, there is greater need for storage and a proportionately greater cost difference.

This reason for this differential becomes more apparent when one considers that solar facilities generally have an availability of less than 30% vs. 90% or better for geothermal facilities. Moreover, 30% is an average, but this can vary substantially from day-to-day and season-to-season. Overall, geothermal delivers 90% availability, 24/7 365 days a year. The cost of the energy storage component is much more significant. According to a report published by the National Renewable Energy Laboratory citing multiple research studies, the 2020 overall current capital cost per kWh for 4-hour batteries ranges between $300 and $600.[22]

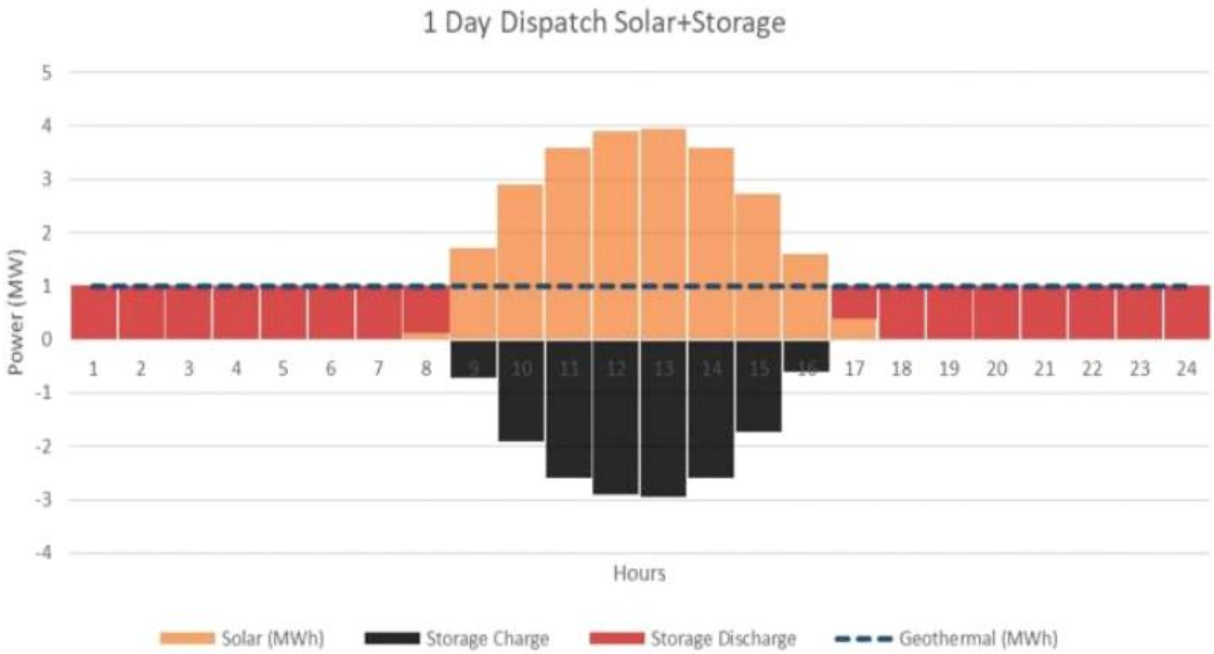

Figure 2 One Sunny Day Dispatch of Solar + Storage Needed to Equal 24 Hours of Resilient Continuous Geothermal Power (Acelerex analysis)

Figure 3 plots an expected Daily Capacity Factor duration curve over a year for a potential solar plant located in Bermuda. On peak insolation days the capacity factor would be about 30%. However, for 60 days per year the maximum capacity factor would be less than 16%. Clearly, other power plants would have to make up the difference. If instead, geothermal power was operated in this sunny climate, the daily and seasonal capacity factors would be about four times greater. If battery storage was charged by geothermal power, these batteries would be able to provide almost instantaneous flexibility, allowing both ramping up and down. Such reg-up and reg-down services are essential for grid frequency control. Moreover, because geothermal power is continuous, the batteries could be reliably charged every day, even when conditions might not always allow a solar plant to recharge the storage system. (Not to mention that geothermal power plants with its underground pipes and heat reservoir are considerably more resilient to weather events, like hurricanes.)

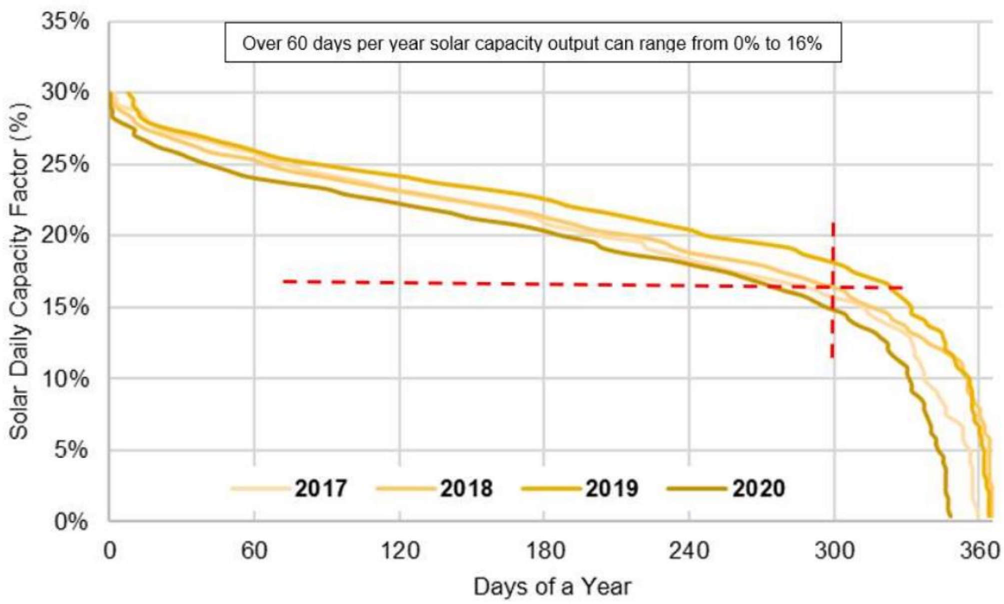

Figure 3 Daily capacity factor duration curve for Solar power generation in Bermuda (Number of Days Exceeded per Year) –Acelerex analysis

Projections of future electricity storage costs are shown in Figure 4. Of course, many causes can result in power outages that last longer than 4 hours, so the cost of backing up the grid without a proper mix of generation resources for even one or two days is very high.

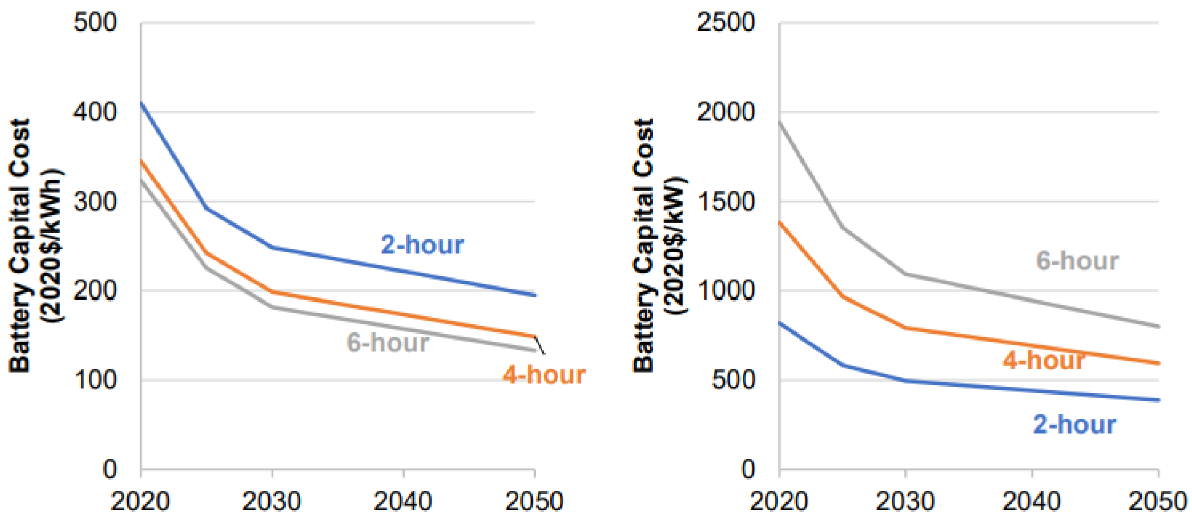

Figure 4. NREL, Battery Storage Capital Cost Projections for 2, 4, 6-hour Duration Discharge[23]

Up to this point the discussion has considered only the supply and generation stages of the energy market as sources of failure. This is shortsighted because nearly two-thirds of power outages occur in the distribution stage, and these are weather-related in most cases[24]. When power generation is co-located with power use, the risk is mainly in distribution of the fuel supply (e.g. coal, gas, uranium). Hydro and geothermal don't suffer from fuel delivery risk, although hydro resources are certainly seasonal, weather-related and highly affected by droughts. If power generation is not co-located with power use – the vast majority of cases - then electricity distribution is the most common cause of outages.

Geothermal energy has an innate advantage, because its generation and delivery processes can occur at the same location and are largely unaffected by extreme weather. The concept of "Geothermal Everywhere" is potentially feasible, if adequate RD&D funding is made available to develop geothermal heat and power technologies and to enable learning-by-doing to bring down costs. Today, however, due to the risk of power failures in the increasingly complex grid, some organizations are considering co-locating certain facilities to geothermal project sites, where energy security is assured. To ensure resilient continuous power, companies are also installing back-up microgrids or considering Resilient Community Grids,[25] so that they will have the local power generation and storage required to cover shortages from the main grid.

CONCLUSIONS

In the same way that the market has differentiated between "clean" and high emissions electric power, there are unmistakable signs that customers are imputing additional value to resilient, continuous, reliable, energy secure, and environmentally preferred power supplies. Although this power preference has been hastened and intensified in response to the rolling "black-outs" in California in 2020, the disastrous 2021 "freeze-out" in Texas, and disruptions in global energy markets caused by the unprovoked Russian invasion of the Ukraine, the underlying market forces driving the recognition of geothermal power as a premium form of energy will not only continue but will also become increasingly important. The renewable geothermal industry should calculate and publicize accurate information regarding this regional value differential between its Resilient Continuous Power product and competing supplies. Geothermal operators should competitively price projects based on the value provided, rather than relying upon simplistic comparisons of geothermal LCOE vs. wind and solar LCOE, either alone or as hybrid plants with battery storage. Comparisons must be developed and applied to value more of the essential energy attributes needed by the customer. Energy technology choices and the composition of combined energy systems must be made for energy systems and portfolios of resources that can provide the same services, including seasonal and around-the-clock reliability, energy security, grid stability and weather resilience. Today and in the foreseeable future, geothermal energy can best supply these essential attributes.

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