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OPPORTUNITIES AND CHALLENGES IN DEPLOYING INNOVATIVE BATTERY AND NON-BATTERY TECHNOLOGIES FOR ENERGY STORAGE

HEARING

BEFORE THE

COMMITTEE ON ENERGY AND NATURAL RESOURCES UNITED STATES SENATE

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CONTENTS

OPENING STATEMENTS

WITNESSES

ALPHABETICAL LISTING AND APPENDIX MATERIAL SUBMITTED

OPPORTUNITIES AND CHALLENGES IN DEPLOYING INNOVATIVE BATTERY AND NON-BATTERY TECHNOLOGIES FOR ENERGY STORAGE

THURSDAY, SEPTEMBER 22, 2022

U.S. SENATE,
COMMITTEE ON ENERGY AND NATURAL RESOURCES,
Washington, DC.

The Committee met, pursuant to notice, at 10:05 a.m. in Room SD–366, Dirksen Senate Office Building, Hon. Joe Manchin III, Chairman of the Committee, presiding.

OPENING STATEMENT OF HON. JOE MANCHIN III, U.S. SENATOR FROM WEST VIRGINIA

The CHAIRMAN. The Committee will come to order.

Before we get started, I want to take a moment to say thanks to Adam Berry who is staffing me today. Adam, stand up. I'm sorry to say that Adam is going to be leaving the Committee at the end of this week for a different mountain state. He is going home to the state of Colorado. Adam came to the Energy Committee as a research assistant in 2019. He was promoted to professional staff, handling energy efficiency, hydropower, and energy storage. Adam has done an unbelievable job. He was instrumental in advancing significant investments in these areas in the Bipartisan Infrastructure bill and the Inflation Reduction Act, and I thank him for his hard work. So Adam, job well done. Thank you.

[Applause.]

The CHAIRMAN. Today's hearing focuses on energy storage, one of the game-changing technologies that is increasingly critical in our effort to address climate change without sacrificing reliability of the electric grid. I want to welcome all the witnesses and thank them for being here today for this conversation. Today, we will discuss the opportunities and challenges in employing an innovative battery, and ways in which our recent investments in advancing this technology are paying off for Americans with new jobs to support the industry we are committed to growing here at home. Now, unlike many other energy technologies, energy storage can be provided by an increasingly diverse set of technologies, although pumped storage hydro and lithium-ion have dominated the field to date. When it comes to storage, there has rightly been a focus on the supply chain, particularly for lithium-ion batteries that power electric vehicles and phones in our pockets and many other modern technologies.

While we have benefited from the use of this important battery chemistry, the fact that China is responsible for 75 percent of global lithium-ion battery production, including 60 percent of the world's cathode production and 80 percent of the world's anode production, should give everyone pause. That is why I was proud to champion the Inflation Reduction Act, which incentivized the onshoring of the entire battery supply chain from the production and processing of raw materials to the battery pack assembly and everything in between. And we should also be focused on how we limit our use of these minerals in the first place, which is why I am thrilled West Virginia will be home to Sparkz's new cobalt-free lithium-ion battery manufacturing facility. This facility is bringing 350 jobs to Taylor County, a welcome investment for the community. And while lithium-ion batteries will certainly continue to play an important role in the storage conversation, they are not necessarily the best chemistry for every application.

As we have learned with the battery supply chain, it is unwise to put all of our eggs in one basket with one singular battery chemistry. We have so many options, from solid-state batteries to non-battery technologies like compressed air, molten salt, and gravity-based storage, and of course, we have metal-air batteries like Mr. Wiley's company Form Energy is working on. In fact, Form Energy is making 100-hour batteries with an innovative ion oxidation approach. Finally, a reason to like rust. So that is why we are here today, to hear from our witnesses about those innovative approaches to battery and non-battery storage that do not have as many domestic supply challenges.

Congress has super-charged investment in storage over the last few years, beginning with the Energy Act of 2020. I also want to note that one of our witnesses today, Spencer Nelson, was instrumental in putting that piece of legislation together as a member of Senator Murkowski's Energy Committee staff, and we are thrilled to have you back. The Energy Act provided $355 million in authorization for long-duration storage, demonstration, and pilot programs, many of which were championed by Senator King and Senator Heinrich and other members on this Committee that were later funded in full by the bipartisan Infrastructure Investment and Jobs Act. Along with funding for the Energy Act demonstration projects, the IIJ also included over $6 billion for research, development, demonstration, and deployment of battery processing, manufacturing, and recycling for both mobile and grid-scale storage applications. These bills, coupled with the Inflation Reduction Act, a new energy storage investment tax credit, a new battery production tax credit, and the addition of battery storage to the 25D residential tax credit, will help to commercialize innovative storage solutions and make them more accessible to the consumers. And we will ensure that these investments will be targeted to communities that need them most. The Inflation Reduction Act provides incentives for projects that locate in energy communities and included my 48C tax credit, which will invest $10 billion to retool, expand, and build new facilities that make or recycle energy-related products, including storage technologies in the United States. Additionally, $4 billion was set aside specifically for use in communities that have seen coal mines close and coal power plants shuttered over the past decade. This funding can help to continue traditional fossil states' roles as energy powerhouses long into the future.

With that, I want to thank, again, the witnesses for being with us today. I look forward to hearing from you all and the discussion we will have. I am going to turn to Ranking Member Barrasso for his opening remarks.

OPENING STATEMENT OF HON. JOHN BARRASSO, U.S. SENATOR FROM WYOMING

Senator BARRASSO. Well, thanks so much, Mr. Chairman. Thanks for holding this very important hearing today. We are grateful for the witnesses.

Energy storage is the ability, as we know, to retain energy when electricity production is high and then that energy can be used when electricity production is low. Wind and solar are weather-dependent technologies. If we are going to continue to add these technologies to the grid, energy storage is going to be critical for maintaining electric reliability. It is going to require more affordable and longer-duration storage technologies than we have right now. The only current long-duration, commercially available solution is pumped storage hydropower. Pumped storage involves pumping water to upper elevations when electricity production is high. The water is then released to produce hydropower when electricity production is low. Depending on the size of the reservoir, pumped storage can provide electricity for up to 16 hours. Today, pumped storage accounts for about 93 percent of all our utility-scale energy storage in this country. PacifiCorp, who is represented in our hearing today, has proposed 11 new pumped storage projects throughout the West.

There are also other technologies that show great potential for the near future. One of PacifCorp's subsidiaries plans to build TerraPower's first Natrium reactor in my home state of Wyoming. This is an advanced nuclear reactor that will produce enough electricity to power over a third of a million homes. It will include liquid salt tanks that will be able to store enough energy to produce additional electricity to power more than 150,000 homes for over five hours. Now, many utilities are investing in large arrays of lithium-ion batteries, similar to those used in today's electric vehicles. Others are investing in battery technologies with alternative materials. It is important to focus on the resources and efforts on deploying readily available, long-duration storage technologies. It is especially important that we invest in technologies that do not depend on supply chains controlled by our adversaries, like Russia and China. So I am pleased that TerraPower has committed to not use any Russian uranium to fuel its advanced reactor.

When it comes to lithium-ion batteries, we are heavily dependent on China. Lithium-ion batteries use large amounts of copper, nickel, lithium, manganese, graphite, and rare earth minerals and we rely on China for the overwhelming majority of all of these minerals. Focusing on developing pumped storage hydropower and thermal storage solutions, like the Natrium reactor, can help reduce this supply-chain risk. Broadening our priorities beyond lithium-ion batteries can also help address costs. According to the World Bank, pumped storage hydropower costs between $106 and

$200 per kilowatt-hour. This is significantly cheaper than lithium-ion batteries, which cost between $393 and $580 per kilowatt-hour. So 70 to 80 percent of the cost of lithium-ion batteries is directly tied to the raw materials. If we do not increase mining and processing here in the United States, the cost of these batteries is only going to increase as the demand increases. Since taking office, the Biden Administration has only made it more difficult to access American minerals. Last year, it canceled leases for a mine that contains 95 percent of our nation's nickel, 88 percent of our nation's cobalt, and 34 percent of our nation's copper. We cannot allow President Biden's hostility to mining to turn energy storage into another part of his made-in-China green energy policy.

So I want to thank all the witnesses for joining us today and look forward to your testimony.

Thank you, Mr. Chairman.

The CHAIRMAN. Thank you, Senator.

I would like to welcome our panel of witnesses. We have with us, Mr. Tim Hemstreet, Managing Director of Renewable Energy Development at PacifiCorp. We have next, Mr. Spencer Nelson, Managing Director of Research and New Initiatives at ClearPath. And finally, we have Mr. Ted Wiley, President and Chief Operating Officer of Form Energy.

Now, to hear from you all, we are going to start with Mr. Hemstreet for your opening statement.

STATEMENT OF TIM HEMSTREET, MANAGING DIRECTOR FOR RENEWABLE ENERGY DEVELOPMENT, PACIFICORP

Mr. HEMSTREET. Thank you, Mr. Chairman.

Chairman Manchin, Ranking Member Barrasso, and members of the Committee, I appreciate the opportunity to appear before you today. This hearing is important for the customers and communities throughout the West who drive our business. PacifiCorp is an electric utility that serves approximately 1.9 million customers in communities across Utah, Wyoming, and Idaho as Rocky Mountain Power, and Oregon, California, and Washington as Pacific Power. PacifiCorp owns more than 11,600 megawatts of hydropower, coal, gas, wind, solar, and geothermal resources with 40 percent of that capacity located in Wyoming. PacifiCorp is also the single largest owner and operator of transmission facilities in the West, and our system is expanding with construction of our Gateway South transmission project recently started in Wyoming. PacifiCorp can safely be described as an all-of-the-above energy company. We are a proud member of the Berkshire Hathaway energy family of businesses, but our customers, located predominately in rural areas of the West, know us as their local power company.

I have the responsibility to plan and develop renewable generation assets to serve our customers so that we can safely, reliably, and affordably meet their energy needs. PacifiCorp is seeing incredible growth in the amount of renewable generation we are bringing online. In 2020, PacifiCorp completed an expansion of its transmission system in eastern Wyoming, improving reliability and accessing cost-effective wind energy resources, doubling our own wind fleet in the process. We anticipate bringing an additional 12,000 megawatts of new renewable generation to serve our customers online over the next 20 years.

PacifiCorp is also looking at other generation resources to meet customer needs and has partnered in the development of TerraPower's Natrium advanced nuclear reactor proposed to be located at our retiring Naughton coal facility in Kemmerer, Wyoming. An important attribute of this technology is its molten salt energy storage capability. Because renewable wind and solar resources are not dispatchable, we also need to add substantial amounts of energy storage to ensure we can balance intermittent renewable generation with real-time customer energy needs. This calls for the addition of 5,500 megawatts of energy storage over the same 20-year period.

For the purposes of my testimony, I would like to focus on opportunities and challenges related to the deployment of pumped storage hydropower. PacifiCorp is adding solar and storage resources and we also anticipate adding a significant amount of stand-alone batteries in the coming years to meet short-duration energy storage needs. Pumped storage hydropower can play an important role that is unique by meeting the need for long-duration, proven, commercially available energy storage. Pumped storage hydropower can maintain grid reliability by providing spinning reserves and quickly ramping to balance energy supply and demand, allowing us to better integrate renewable resources cost-effectively. Pumped storage can also provide important ancillary services to the grid, including voltage and frequency support, inertia, and black start capabilities that enhance reliability and resiliency. By storing renewable energy during times of abundant supply, pumped storage can also help optimize the use of scarce transmission resources.

An important attribute of pumped storage is the ability of the technology to be deployed at scale with proposals for pumped storage projects before FERC that range up to thousands of megawatts in capacity. Additionally, hydropower projects have long asset lives. The average age of PacifiCorp's hydro units is 90 years. Finally, pumped storage projects can be developed with secure supply chains sourced domestically or with strategic partners. For these reasons, PacifiCorp is currently evaluating how we can incorporate pumped storage capabilities at our existing hydroelectric projects. We are also evaluating the feasibility of new pumped storage projects across our system, and in October of last year, we filed 11 preliminary permit applications with FERC in support of that effort. Four of these potential projects are located in Utah, three in Wyoming, two in Oregon, and one each in Idaho and Washington.

Despite the benefits that pumped storage hydropower provides, there are challenges to its development, including high up-front costs and long development timelines. Congress has taken a step in providing incentives to technology-neutral energy storage resources, and this will be helpful in solving some of the cost challenges faced by pumped storage. Development of a pumped storage project usually requires a license from FERC, and the licensing process for hydropower projects is highly complex and time consuming. A FERC licensing proceeding usually takes between seven to ten years to complete. Applicants must undertake extensive resource studies and coordinate with various federal and state agencies with different mandates to inform FERC's licensing decisions, resulting in a lengthy process that adds uncertainty to the development of these important projects. The need for improvements to the FERC licensing process is acknowledged by a diverse range of parties with varying interests in licensing decisions.

Recently, representatives of the hydropower industry, Native American tribes, and environmental stakeholders agreed upon consensus recommendations to Congress around a package of reforms to the Federal Power Act. Significantly, these reforms will provide for a three-year, start-to-finish licensing process for certain pumped storage projects. The Uncommon Dialogue licensing reforms are a step in the right direction, and additional steps could be taken to allow FERC to issue licenses in a more timely manner using existing agency authorities. It is important that Congress and federal agencies take steps to streamline the permit process for these projects. Failing to do so will make it more difficult for the private sector to commit the substantial resources needed to develop these projects so they can play a role in meeting our common goal of ensuring a safe and reliable energy system that fosters the economic growth of our communities.

Finally, pumped storage technology innovation is also an active area. Many opportunities for innovation are being pursued by the hydropower industry with respect to new and adaptations of existing pumped storage facilities, and increased application to pumped storage technology will surely spawn improvements in the future. I want to thank you again for the opportunity to participate in this hearing. PacifiCorp and Berkshire Hathaway Energy look forward to working with you further on these important issues. Thank you.

[The prepared statement of Mr. Hemstreet follows:]

Statement of Timothy J. Hemstreet
Managing Director of Renewable Energy Development for PacifiCorp

U.S. Senate Committee on Energy and Natural Resources

Full Committee Hearing on Opportunities and Challenges in Deploying Innovative Battery and Non-Battery Technologies for Energy Storage

September 22, 2022

Introduction

Chairman Manchin, Ranking Member Barrasso, and members of the Committee, I appreciate the opportunity to appear before you today as you consider energy storage technologies necessary for our evolving electric generation and transmission system, as well as challenges and opportunities related to their deployment. This hearing is important for the customers and communities throughout the West who drive our business.

My name is Tim Hemstreet, and I am the Managing Director for Renewable Energy Development for PacifiCorp, an electric utility that serves approximately 1.9 million customers in communities across Utah, Wyoming and Idaho through its Rocky Mountain Power division, and across Oregon, Washington and California through its Pacific Power division. PacifiCorp's generation and transmission assets are located in ten states in the Western U.S., and include over 11,600 megawatts of owned generation capacity from hydropower, coal, gas, wind, solar, geothermal and biomass resources, with 40 percent of that capacity located in Wyoming. PacifiCorp is the single largest owner and operator of high-voltage transmission facilities in the West, and our system is still expanding, with a recent groundbreaking in Medicine Bow, Wyoming for our Gateway South transmission project. PacifiCorp can safely be described as an "all of the above" energy company. We are a proud member of the Berkshire Hathaway Energy family of businesses, but our customers – located predominantly in rural areas of the West – know us as their local power company.

As the Managing Director of Renewable Energy Development, I have the responsibility to plan and develop renewable generation assets to serve our customers so that we can safely, reliably and affordably meet their energy needs. PacifiCorp is seeing incredible growth in the amount of renewable generation we are bringing online, in addition to demand-side management and energy efficiency measures, to ensure we can meet our customers' needs and continue to power the growth of our communities. We are deeply engaged in this effort: in 2020 PacifiCorp completed an expansion of its transmission capacity in eastern Wyoming to improve reliability and create access to the highly favorable wind energy generation available in that part of our system. This effort resulted in the doubling of PacifiCorp's owned wind fleet to more than 2,250 megawatts, or nearly twenty percent of its owned generating capacity, with further growth anticipated.

We anticipate bringing on an additional 12,000 megawatts of new renewable generation to serve our customers over a twenty-year planning horizon. These new generating resources are anticipated to be predominantly fueled by the wind and the sun.

However, wind and solar resources are not dispatchable, and we also need to add substantial amounts of energy storage to ensure we can balance intermittent renewable generation with real-time customer energy needs. Indeed, we have found that this need calls for the addition of 5,500 megawatts of energy storage over the next twenty years to ensure we can meet this constant balancing act where generation need meet customer demand at all times.

Other generation types may also play an important role in meeting this challenge, and PacifiCorp is partnering on the development of TerraPower's Natrium advanced nuclear reactor design that is proposed to be located at the site of one of PacifiCorp's retiring coal facilities in Wyoming. An important attribute of this technology is its energy storage component, which can allow the 345-megawatt reactor to increase facility output capacity to 500 megawatts for more than five and a half hours using energy stored in molten salt. Natrium's design enhances grid reliability and stability while continuing to produce reliable power for our customers.

The Importance of Pumped Storage to Support Long-Duration Storage Needs

PacifiCorp is currently adding energy storage coupled with solar generation, and we anticipate adding a significant amount of standalone battery resources in the coming years to meet short-duration storage needs. Pumped storage hydropower can play an additional role that is unique and important in meeting the growing need for long-duration, commercially available energy storage that will be necessary to continue to supply reliable energy in the future.

Hydropower has historically been a meaningful component of PacifiCorp's generation portfolio, and it continues to comprise approximately ten percent of its generation capacity. Pumped storage hydropower can provide spinning reserves and quickly ramp up to balance energy supply and demand to integrate renewable resources cost-effectively while maintaining system reliability. We are also very familiar with the ability of hydropower to generate emissions-free energy, while also providing important ancillary services, including voltage and frequency support, as well as inertia and black-start capabilities that enhance the reliability and resiliency of the grid.

Given the valuable attributes of hydropower, pumped storage hydropower can play a critical role in meeting the present need for energy storage. This is not surprising given pumped storage hydropower is already serving this function. The Department of Energy reported last year that ninety-three percent of the utility-scale energy storage capacity in the United States was provided by this tried-and-true technology.

Given this understanding of the value of pumped storage hydropower, PacifiCorp is currently evaluating how we can incorporate pumped storage capabilities at our existing hydroelectric projects. Enhancing existing facilities to provide additional energy storage and needed capacity can be cost-effective by increasing the utilization of existing infrastructure, while also reducing environmental impacts. PacifiCorp has also filed eleven preliminary permit applications with the Federal Energy Regulatory Commission (FERC) in October 2021 to allow it to evaluate the feasibility of new pumped storage hydropower developments at promising locations across our service territory. Four of these potential projects are located in Utah, three in Wyoming, two in Oregon and one each in Idaho and Washington. These preliminary permits will preserve the company's priority in the competitive FERC licensing process if feasibility studies indicate the projects may benefit our customers while minimizing impacts.

Another important attribute of pumped storage worthy of note is the ability of the technology to be deployed at scale, with proposals for pumped storage projects before FERC that range in scale up to thousands of megawatts in capacity. Additionally, hydropower projects have long asset lives – the average age of hydropower units in PacifiCorp's fleet is ninety years. Thus, we know that investments in this form of storage are durable and these projects can continue to provide benefits for decades after they are built. And these storage benefits do not degrade over time. Investments in pumped storage also relieves pressure on battery storage resources that may have a higher value when deployed in electric vehicles – an increasing area of load growth. Finally, pumped storage projects can be developed with secure supply chains sourced domestically or with strategic allies. This means pumped storage – given its durability and non-exotic sourcing and supply chains – can enhance our energy security.

Challenges and Opportunities for Pumped Storage Development

Despite the benefits of generation, load and grid support that pumped storage hydropower provides - there are challenges to its development. With long development timelines and high upfront costs, there has not been a large-scale pumped storage project brought online in the United States since the early 1990s.

Congress can help to address these issues by directing the U.S. Department of Energy to continue its efforts in evaluating how pumped storage can benefit the grid and maintain reliability to raise awareness about the value of pumped storage and other long-duration storage resources. Additional focus and assistance by national laboratories to model the value that pumped storage projects can provide to the grid can also be helpful to inform our modeling tools so they fully capture the value these projects provide.

Congress has already taken a step in providing incentives to technology-neutral storage resources, and this will be helpful in solving some of the economic challenges faced by pumped storage – and storage in general. Pumped storage projects, in particular, would also benefit by improved regulatory clarity that all components of these projects – dams, reservoirs, pumps, turbines, generators, water conveyances, generation interconnection and transmission tie lines – are included as property eligible for the newly enacted energy storage investment tax credit. This will provide needed certainty that will improve the ability of industry to raise capital and generate financing to support the development of these projects.

In most cases, development of a pumped storage project requires a license from FERC, and the licensing process for hydropower projects is highly complex and time consuming. A FERC licensing proceeding usually takes between seven to ten years to complete. Applicants must undertake extensive environmental studies in coordination with Federal and State agencies, and other stakeholders, to inform FERC's licensing process, including compliance with the National Environmental Policy Act, Clean Water Act, and the Endangered Species Act. These laws are, in turn, implemented by a number of Federal agencies, and some Federal laws, such as the Clean Water Act, are administered by States. The complex and lengthy licensing process, and the diffuse responsibility for licensing decisions and the terms and conditions that are ultimately incorporated into a license, adds uncertainty to the development of pumped storage projects.

The need for improvements to the FERC licensing process is acknowledged by a diverse number of parties with varying interests in licensing decisions. Recently, the representatives of the hydropower industry, Native American Tribes, and environmental stakeholders have agreed upon consensus recommendations to Congress around a package of reforms to the Federal Power Act. These recommendations have come out of a series of discussions among these stakeholders known as the Uncommon Dialogue. The reforms would improve the licensing process and result in more timely, less costly, and more scientifically defensible licensing decisions while also expanding the ability of Native American Tribes to represent their interests in licensing proceedings impacting Tribal lands. Significantly, these reforms would provide for a three-year licensing process for certain pumped storage projects. This is important to ensure pumped storage projects can be ready to meet the identified need for storage as our energy resource mix continues to evolve.

Enactment of the Uncommon Dialogue licensing reforms are a step in the right direction and will help address many challenges in the licensing process. Given the complexity of Federal laws, regulations, and policies that exist in the FERC process, additional steps could be taken to help applicants navigate the licensing process and enable FERC to issue licenses in a more timely manner, using existing agency authorities.

Given the long lead-time and costs associated with constructing pumped storage projects, it is important that Congress and Federal agencies take steps to streamline the permit process for these projects. Failing to do so will make it more difficult for the private sector to commit substantial resources to developing these projects in the near-term to meet our energy storage needs and meet our common goal of ensuring a safe and reliable energy system that fosters the economic growth of our communities.

I want to again thank you for the opportunity to participate in this hearing. PacifiCorp and Berkshire Hathaway Energy look forward to working with you further on these important issues.

The CHAIRMAN. Before we go to Mr. Nelson, I am going to turn it over to a former boss of yours. She wants to make sure you do it and do it right.

[Laughter.]

The CHAIRMAN. Senator Murkowski.

INTRODUCTORY STATEMENT OF HON. LISA MURKOWSKI, U.S. SENATOR FROM ALASKA

Senator MURKOWSKI. Thank you, Mr. Chairman, Ranking Member Barrasso, thank you. Thank you for the hearing this morning.

I know that we always try to have very strong and distinguished witnesses before our Committee, but when I looked at today's list, I knew I had to be here at the outset. And I am grateful to all of our witnesses, but I do want to just take a moment to welcome a former member of our Committee here. Spencer Nelson was with us for a period of time here on the Committee, but you may remember he was kind of the guy behind the scenes who did everything. He was my Swiss Army Knife when it came to the Energy Act that we were able to pass in 2020. We had a little bit of a skeletal crew at that time, but there was nothing that we put in front of Spencer or nothing that Spencer identified as "we need to get on this" that he did not pick up and handle and handle in a way that the next morning we were moving beyond that problem and on to the next.

So Spencer, it is good to have you back here in Dirksen 366. Know that we miss you. We miss your expertise, but congratulations on testifying before the Committee. This is the first time, but hopefully it is not going to be the last. Spencer is now the Managing Director for Research and New Initiatives at ClearPath. He is doing a great job over there, but you were an incredible asset to this Committee and we thank you for that.

Thank you, Mr. Chairman.

The CHAIRMAN. Thank you, Senator.

Now, Mr. Nelson.

STATEMENT OF SPENCER NELSON, MANAGING DIRECTOR, RESEARCH AND NEW INITIATIVES, CLEARPATH

Mr. NELSON. Thank you so much for that kind introduction, Senator. It was a true pleasure to work with this Committee and all the wonderful members and staff and it is, you know, something I will never forget, and we accomplished so much. And also, thank you to Chairman Manchin and Ranking Member Barrasso for the opportunity to testify today. Today I am going to cover four key topics. First, the valuable role of energy storage on the grid. Second, the limits of lithium-ion. Third, alternative energy storage technologies, and fourth, how to build on this Committee's wins over the past three years, of which there are many.

American grid operators face immense challenges as power use changes and emissions decline. The need for more electricity generation, along with new grid-scale energy storage solutions to maximize reliability, affordability, and clean energy has never been more urgent. Look, energy storage is not new to the grid. The first pumped hydro plants were built a century ago and have provided regular load shifting for baseload power generation ever since. Recently, lithium-ion batteries have been the primary new grid-scale storage. Lithium battery costs have fallen 90 percent since 2010 and are now 20 percent of total energy storage in the U.S. There are clear benefits from this growth. During the recent heat wave in California, batteries provided more than three gigawatts of power during peak demand, ultimately avoiding major blackouts.

But it is not all good news. While lithium-ion batteries are helpful for the grid, many rely on critical minerals that are not readily available in the U.S. The vast majority of manufacturing comes from China, which controls two-thirds of lithium pre-processing facilities, as well as 77 percent of manufacturing capacity worldwide. We need to find a way to onshore the entire battery supply chain, from critical minerals production all the way to battery manufacturing. Global demand for critical minerals in batteries is expected to skyrocket by up to 1,200 percent by 2030. Now, lithium-ion batteries are also tied to electric vehicles. So, as EV demand increases, so does the price of lithium. Prices for lithium have increased from $5,000 a ton to $70,000 a ton in just two years. So we ultimately need to innovate away from technologies that rely on critical minerals to begin with. For lithium-ion batteries, that means moving away from cathode designs that use nickel, currently controlled by Russia, and cobalt, which exploits child labor in the Congo.

Geopolitical and cost concerns are driving a transition to grid-scale lithium-iron-phosphate batteries that use fewer critical minerals, but unfortunately, this shift does not solve the broader problem of Chinese control of global lithium supply chains. As the share of renewable energy on the grid grows to as much as 40 percent by 2050 or more, reliability will increasingly depend on whether the wind is blowing or the sun is shining. And if the weather doesn't cooperate, long-duration storage is the best way to provide hours or days of energy capacity. Lithium-ion batteries are fundamentally impractical for this long-duration storage. They will help shift daily demand, but will not solve the seasonality problem that could occur with increased use of renewables. We should invest in non-lithium technologies that can provide 100 hours of storage or more.

Several categories of energy storage, like thermal, chemical, and mechanical, could provide affordable long-duration storage. For thermal energy storage, a great example is TerraPower's Natrium nuclear reactor being developed in Senator Barrasso's home State of Wyoming. That reactor will use molten salt storage to allow operation at full capacity while also ramping electricity output up and down. Other innovative solutions include flow batteries, hydrogen storage, and metal-air batteries, like those being developed by Form Energy. Batteries that use earth-abundant minerals can be long-duration and keep costs low. Additionally, mechanical, long-duration storage technologies, like pumped hydro, currently represent 80 percent of total energy storage on the grid and should be further expanded.

Finally, I would like to highlight the many bipartisan actions underway from the Department of Energy and this Committee to support energy storage. DOE has worked to reduce the cost of energy storage with the Trump Administration's Energy Storage Grand Challenge and its successor program, the Long-Duration Storage Shot. The current goal of Storage Shot would reduce the cost of long-duration storage 90 percent by 2035. Meanwhile, this Committee has catalyzed energy storage policy through landmark laws like the Energy Act of 2020, which included the bipartisan BEST Act that many of you worked on, that comprehensively reauthorized energy storage R&D with new demonstration programs that were later funded by the infrastructure law. At this point, DOE has not released funding opportunities for the storage demo programs, and the Committee should push for swift action. The Committee should also focus on identifying alternative sources of critical minerals and making it easier to develop them in the United States. We are not on track to meet our clean energy goals unless we make it easier to build cleaner, faster. Domestic processing and manufacturing facilities are a priority, and removing barriers to their development is a must.

Thank you for the opportunity to testify today. ClearPath is eager to assist the Committee in developing policies to support innovative energy storage technologies.

[The prepared statement of Mr. Nelson follows:]

Testimony of Spencer Nelson
Managing Director of Research & New Initiatives, ClearPath Inc.
U.S. Senate Energy and Natural Resources Committee
Opportunities and Challenges for Deploying Innovating Battery and Non-Battery Technologies for Energy Storage
Thursday, September 22, 2022

Good morning Chairman Manchin, Ranking Member Barrasso, and members of the Committee. My name is Spencer Nelson, and I am the Managing Director of Research & New Initiatives at ClearPath, a 501(c)(3) organization devoted to accelerating breakthrough innovations to reduce emissions in the energy and industrial sectors. To further that mission, ClearPath provides education and analysis to policymakers and collaborates with relevant partners to inform our independent research and policy development. An important point – ClearPath is supported by philanthropy, not industry.

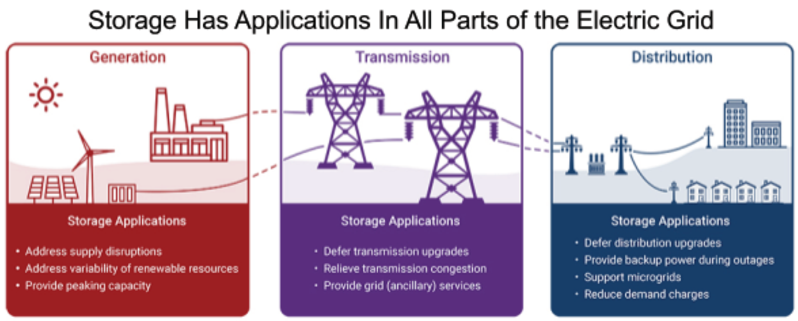
Thank you for the opportunity to be here. It is a privilege to testify before you today after working as Professional Staff for Senator Murkowski last Congress developing the Energy Act of 2020. I have great respect for the work of the members of this Committee and its staff across its entire jurisdiction. While the Energy Act made great progress to advance energy storage, the Committee's work in this area is far from over. There is great opportunity for supporting new energy storage technologies that bolster both baseload and renewable resources, and American innovation will play a key role. I will discuss four key topics today:

1. The valuable role of energy storage on the grid today;
2. The long-term limits of lithium and the importance of alternatives;
3. Advancing alternative energy storage technology solutions; and
4. Building on Federal Policy Wins in the Energy Act of 2020 and IIJA.

1. The Valuable Role of Energy Storage on the Grid Today

America's power grid is incredibly complex. It must balance hundreds of gigawatts of power demand with supply in real time over thousands of miles, with the potential for sudden disruptions due to weather, mechanical issues, or other unexpected disruptions like cyberattacks. The system relies on an intricate network of transmission and pipelines for the transportation of energy. As the American economy grows, the grid transitions to lower carbon resources, and consumer preferences change energy supply needs, our nation's grid operators face immense challenges. There are few places where this is more evident than the State of California, where a recent statewide grid emergency was declared to deal with record high energy demand due to blistering summer heat. The need for more firm, flexible electricity generation along with new grid-scale energy storage solutions to maximize reliable, affordable, and clean energy has never been more urgent.

Energy storage is not new to the electric grid. The energy storage technology with the greatest capacity in the United States today is pumped storage hydropower (PSH), in which water is pumped up or down a mountain when electricity demand is low and allowed to flow through a generator when demand is high. The first PSH plants were built a full century ago in the 1920s. PSH has historically been a tremendous asset by providing daily and weekly load shifting for baseload power generators like nuclear and coal power plants.

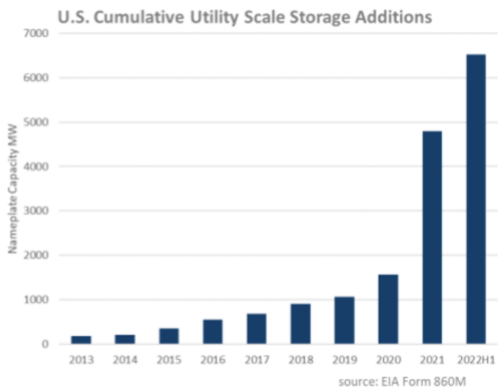


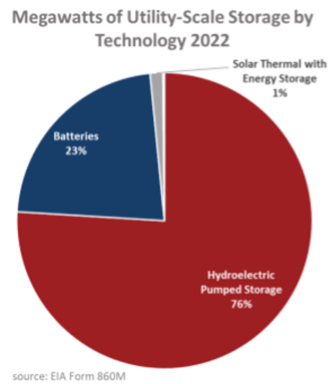
Innovative grid-scale technologies are opening up new roles for energy storage on the modern electric grid. Energy storage technologies now provide a wide variety of market services, including, but not limited to:

- Load shifting/peak shaving when demand is high;
- Reductions in the need for transmission capacity;
- Frequency regulation and other ancillary services for the grid;
- Operational flexibility for electric generators; and
- Reducing the need for overbuilding electric generating capacity.

While PSH remains the largest energy storage technology by capacity in the United States today, lithium-ion batteries are dominating new capacity additions. Boosted by the global development of electric vehicles, the cost of lithium-ion battery packs has fallen 90 percent since 2010, bringing down the cost of grid-scale batteries 75 percent along the way.[1] Lithium-ion batteries have grown tremendously; reaching nearly 7,000MW of generation capacity on the grid, a 920 percent increase since just 2017.[2] Looking ahead, there is 421GW of energy storage in the interconnection queue waiting to be added to the grid, nearly all of which is in the form of lithium-ion battery technology.[3] For context, this is equivalent to 40% of the total U.S. electric grid's capacity.

[1] https://arstechnica.com/science/2020/10/us-grid-battery-costs-dropped-70-over-3-years/
[2] July Generating 2022 860M
[3] https://emp.lbl.gov/generation-storage-and-hybrid-capacity . Important to note that due to issues in the interconnection market, likely only 25% of this capacity will ultimately be built.





The growth of grid-scale battery storage provides real benefits to the grid. During the 2022 California summer heat wave, batteries provided more than 3 GW of power during the hours of peak demand, which helped avoid blackouts.[4] Without the deployment of battery storage technology, outages would have been widespread, at tremendous cost to both California's economy and the state's residents.

Elsewhere, storage is being developed as a transmission asset. In places where additional transmission capacity is only needed for a few hours a day, adding storage assets to the grid can help avoid significant costs that would otherwise be borne by ratepayers.[5]

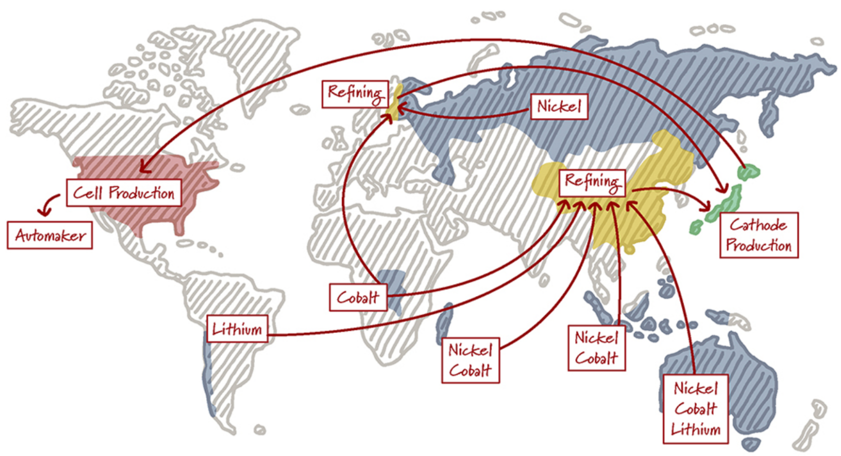
2. The Long-term Limits of Lithium and the Importance of Alternatives

While lithium-ion grid-scale batteries are useful and will likely have a role to play for the foreseeable future, there are several drawbacks to consider. First, the geopolitical implications of lithium-ion batteries are severe and tragic. The current most common form of lithium-ion batteries uses nickel-manganese-cobalt (NMC) cathodes, which rely heavily on a variety of critical minerals that are not readily available in the U.S. The current supply of these materials is concentrated in Australia, Chile, Democratic Republic of the Congo, and Russia, but the majority of processing and manufacturing comes from China. In 2021, China controlled two-thirds of lithium pre-processing facilities, as well as 77 percent of production capacity

[4] https://www.bloomberg.com/news/articles/2022-07-21/how-batteries-can-help-power-grids-withstand-heat-waves
[5] https://energystorage.org/storage-as-a-transmission-alternative-is-gaining-traction-in-many-rtos-isos/

worldwide.[6] Based on current trends, China will still hold 67 percent of global lithium ion cell capacity in 2030.[7]

Critical Minerals Production and Refining by Country



Global demand for critical minerals used in battery storage is expected to skyrocket – reaching between 180,000 and 300,000 tons by 2030, compared with 25,000 tons today.[8]

Another challenge with lithium-ion batteries tied to electric vehicles is that as the demand for EVs increases, so does the price of lithium. Prices for lithium carbonate have increased from $5,000 per ton in mid-2020 to $70,000 per ton in 2022 as demand has skyrocketed and supply has flatlined. This cost curve is unsustainable.

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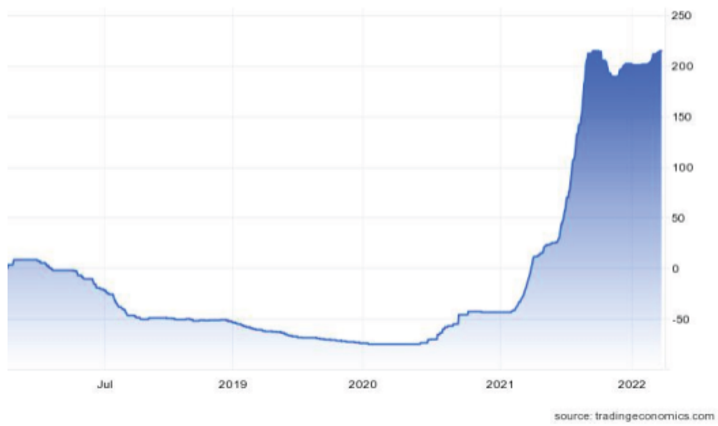
[6] https://www.wired.com/story/china-lithium-mining-production/

[7] https://www.benchmarkminerals.com/membership/global-battery-arms-race-200-gigafactories-china-leads-2/

[8] https://www.iea.org/data-and-statistics/charts/total-mineral-demand-from-battery-storage-additions-by-scenario-2020-2040

Percentage Increase in Lithium Carbonate Price Indexed to July 2017



Nickel and cobalt prices have also been highly volatile over the last year (due in part to the war in Ukraine), leading many in the stationary energy storage market to begin a transition towards lithium-iron-phosphate (LFP) chemistries, which utilize more earth-abundant minerals in return for lower round-trip efficiency.[9] This shift could offset some of the cost and geopolitical risks of non-lithium critical minerals, but does not solve the overall lithium challenge.[10]

As the share of variable, non-dispatchable energy from wind and solar on the electric grid grows, the reliability of the electric grid will increasingly depend on weather patterns like the sun shining or wind blowing. The Energy Information Administration (EIA) predicts that variable renewables could represent over 36 percent of total electricity generation in the United States by 2050, with much higher shares in some regions of the country.[11] If that is the case, sustained periods without sunlight or wind could occur in areas where solar and wind energy are a major source of energy and present a serious challenge for electric reliability.[12] In those instances, the options include either wheeling high volumes of electricity cross-country to make up for bad weather, greatly overbuilding solar and wind (by up to 4 times as much),[13] or having a seasonal long-duration storage option that could provide many hours or potentially days of energy capacity.

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[9] https://www.greentechmedia.com/articles/read/lfp-will-overtake-nmc-for-stationary-storage

[10] Notably, because LFP batteries are less reliant on critical minerals, they are less profitable to recycle and could pose additional challenges.

[11] For example, EIA's 2022 Annual Energy Outlook projects that over 80% of electricity generated in California in 2050 will be from renewable energy.

[12] https://pubs.rsc.org/en/content/articlelanding/2018/ee/c7ee03029k

[13] https://pv-magazine-usa.com/2020/05/14/overbuilding-solar-at-up-to-4-times-peak-load-yields-a-least-cost-all-renewables-grid/

The challenge is that lithium-ion batteries are fundamentally impractical for addressing the need of long-duration energy storage. In a lithium-ion battery system, the power and energy components are combined – meaning power and energy capacity scale at the same time. If you increase energy capacity, you increase power, and vice-versa. While this is a useful property for some applications, this presents a challenge for reducing the cost of long-duration applications for storage. The most common duration of lithium-ion systems currently deployed is four hours, and it is unlikely that systems will get much longer than eight hours anytime soon. Lithium batteries will continue to work for evening demand peaks and for frequency regulation – but will not solve the seasonality problem that could occur at higher levels of variable renewable energy. So what will?

3. Advancing Alternative Energy Storage Technology Solutions

Thankfully, there are alternatives to the narrow technology solution set currently being deployed on the American grid. Technological innovation can both reduce our reliance on foreign battery manufacturers and critical minerals and bolster our electricity grid with solutions that are cheaper and more reliable.

Finding Alternatives to Critical Minerals

In the near term, with the well-established interest in lithium-ion technologies, the U.S. needs to not only increase the direct production of lithium and other crucial materials, but also rapidly scale up its recycling in order to reduce our dependence on foreign sources. Currently, recycling rates for cobalt, copper, and nickel range from 30% to 60% while less than 1% of lithium is retrieved, underscoring the need to establish collection and market infrastructure in advance of projected demand.[14] Recycling of spent EV and storage batteries is expected to reduce the need for new, primary supplies of lithium, cobalt, nickel, and copper by approximately 10%.[15]

China controls more than two-thirds of global lithium processing facilities,[16] and unfortunately controls the vast majority of the battery recycling market as well. We need to find a way to onshore the entire critical minerals mining, processing, and supply chain manufacturing processes in the U.S. $6 Billion in recent funding from the bipartisan infrastructure law will go towards improving this.

While recycling can help, it is not an all-encompassing solution. Longer term, the best way to reduce America's reliance on foreign sources of critical minerals is to innovate away from technologies that rely on critical minerals that are supply constrained in the United States. For lithium-ion batteries, that means moving away from cathode designs that use minerals like nickel, which is currently controlled by russia, and away from cobalt, which often exploits child labor in the Democratic Republic of the Congo. As mentioned above, the transition to alternative

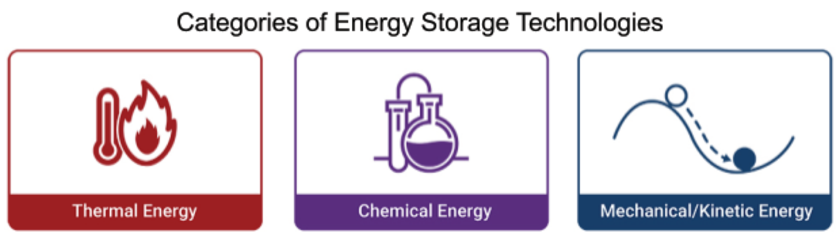
[14]https://iea.blob.core.windows.net/assets/ffd2a83b-8c30-4e9d-980a-52b6d9a86fdc/TheRoleofCriticalMineralsinCleanEnergyTransitions.pdf
[15]Ibid.
[16]https://www.wired.com/story/china-lithium-mining-production/#:~:text=China%20controls%20at%20least%20two,market%20for%20years%20to%20come.

technologies is already beginning in the grid-scale storage market as prices for nickel, cobalt, and other critical minerals skyrocket. The market is naturally selecting more earth-abundant technologies, and we should find a way to source more of those materials from domestic and allied producers.

It is important to note that even if the energy storage sector moves away from reliance on NMC cathodes, there will still be a vast need for lithium itself. Thus, there also needs to be a strong focus on developing domestic sources of lithium, including co-producing lithium from geothermal brines and expanding direct mining, in addition to recycling as much lithium from existing batteries as possible.

Alternative Long Duration Storage Technologies

Even if we managed to develop a supply chain composed solely of U.S. and allied nations for lithium-based batteries in the electric sector, those technologies still would not prove effective for long-duration applications. Since a 21st century grid requires storage options that can last upwards of 100 hours, the public and private sectors should aggressively invest in the demonstration and commercialization of non-lithium technologies.There are a variety of technologies under development — including thermal, chemical, and mechanical — that could both meet long-duration timelines and be cost competitive. Each technology must be assessed against several criteria, including supply security, performance, and price.[17]



By definition, a seasonable energy storage technology is a backstop that would rarely be required to fully discharge its rated capacity. These technologies would only be fully utilized during the worst of weather conditions or periods of intense stress on the grid. As a result, the energy cost of a long-duration technology must be incredibly low to reach significant deployment, likely below $20/kwh of energy capacity – far below today's energy storage costs.[18]

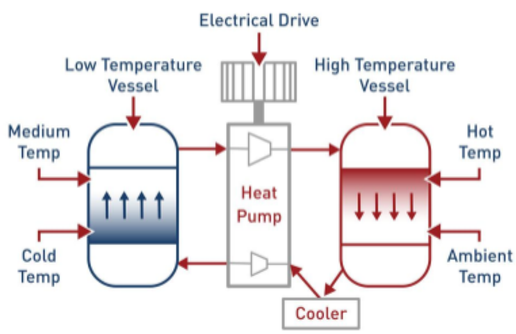
Thermal Energy Storage

Thermal energy storage takes excess heat energy and stores it in various materials, including rocks, cement, storage tanks, hydrogen, or in liquid air.

[17]https://www.atlanticcouncil.org/in-depth-research-reports/issue-brief/alternative-battery-chemistries-and-diversifying-clean-energy-supply-chains/
[18] https://doi.org/10.1016/j.joule.2021.08.002

These technologies transfer energy into a material that is capable of storing the energy for a longer time frame, capable of maximizing excess energy or arbitraging lower cost energy. There are a number of companies pioneering thermal energy storage in the United States, and the venture capital community has injected millions of private sector dollars into promising start-up companies like Malta and Antora. Another clever thermal energy storage example is TerraPower's Natrium nuclear reactor,[19] which would couple molten salt energy storage with a nuclear power plant. The nuclear plant would be able to run continuously by storing excess power as heat in the molten salt, and then use that heat to produce electricity as needed. The first commercial demonstration of TerraPower's novel technology is underway in Kemmerer, Wyoming as part of a public-private partnership via the signature Department of Energy's Advanced Reactor Demonstration Program (ARDP).

An Example of Thermal Energy Storage



There are additional exciting industry experiments focused on storing excess thermal energy in rocks; these substances store energy at very high or low temperatures, capturing the energy in both forms. Another concept is to develop flexible geothermal energy systems using geothermal reservoirs as heat storage so plants can remove heat stored from the reservoir when it is needed.[20]

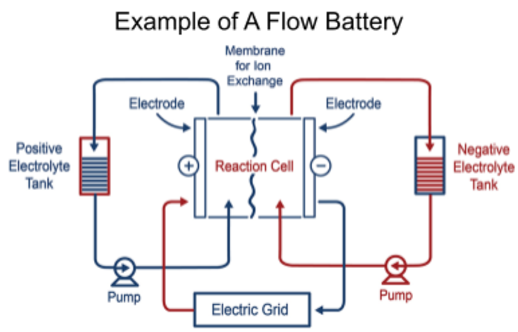
Chemical and Electrochemical Energy Storage

Long-duration chemical energy storage options include the production of liquid or gaseous fuels or battery technologies in which the energy and capacity portions of the battery are physically separated to allow longer duration storage.

Hydrogen is an energy storage technology that can be used for electricity generation through a fuel cell or direct combustion. Clean hydrogen can be produced either through electrolysis powered by low-carbon energy or through steam methane reformation of natural gas using carbon capture and storage technologies.

Beyond the production of chemical fuels, several varieties of batteries can be used for long-duration storage. One example is flow batteries, in which the electrodes are dissolved in electrolyte solutions stored in tanks – an anolyte tank containing an anode and a catholyte tank containing a cathode. These are pumped into cell stacks where the reversible reactions occur when the battery charges and discharges. Flow batteries can provide high efficiency, long

[19] https://www.terrapower.com/our-work/natriumpower/
[20] https://www.sciencedirect.com/science/article/abs/pii/S0306261922002537



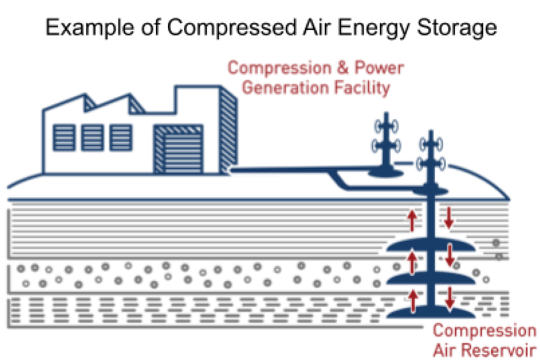
duration, and high safety levels, but some materials, such as vanadium, can be expensive.

There are also options to develop batteries that use sodium or iron as a cathode, with air serving as the anode. These “reversible rust” batteries, like those being developed by Form Energy, can be long duration and have very low materials costs, meaning they are cheaper as the energy-to-capacity ratio gets larger.

There is also growing international competition in the electrochemical long duration storage space. A recent report from the Boston Consulting Group found that U.S. companies began developing technologies earlier than most countries, but the U.S. now ranks 4th globally in patent volume for flow batteries and metal air batteries behind China, Japan, and South Korea.[21]

Mechanical and Kinetic Energy Storage

Many examples of effective mechanical and kinetic long-duration energy storage technologies exist. As previously discussed, the most classic of these is pumped storage hydropower, which currently represents 80 percent of total energy storage capacity in the U.S.



In many cases, pumped hydropower is used as a form of baseload electricity generation because it is reliable and inexpensive. However, over time it has become much more complex and can be used in various ways to help improve grid stability and act like a “peaker plant.”

In recent years, it has become much more difficult to site and permit new PSH facilities, despite their value to the grid. Some companies, such as Quidnet, are looking to develop

[21] https://thirdway.imgix.net/Potential-for-US-Competitiveness-in-Emerging-Clean-Technologies.pdf

alternative styles of pumped hydro by injecting water underground under pressure, which can later be released to generate electricity through a turbine as needed.

Another underground pressured energy storage option is Compressed Air Energy Storage or CAES. CAES stores energy in the form of compressed air in an underground reservoir for use at a later time. CAES systems release the pressurized air by heating it to expand it, turning a turbine, and generating electricity. CAES systems have several benefits, but ideally, they work best in balancing energy for greater integration of renewable energy, and ancillary services for the grid such as regulation, black-start, and grid stabilization.

Each of these solutions has a slightly different niche to fill, but all deserve a chance in the marketplace.

4. Building on Federal Policy Wins in the Energy Act of 2020 and IIJA

The Senate Energy Committee has historically been a leader in energy storage technology development. Some of the most recent actions include the bipartisan Better Energy Storage Technologies (BEST) Act, which comprehensively reauthorized energy storage R&D programs at the Department of Energy (DOE) and was cosponsored by many members of this committee.[22] It was enacted in the bipartisan Energy Act of 2020, alongside several other key energy storage provisions.

Those Energy Act of 2020 storage programs were later funded by the bipartisan infrastructure law, and are now being implemented by DOE.

DOE has been supportive of reducing the cost of grid-scale energy storage across a number of programs, most notably through the Trump Administration's Energy Storage Grand Challenge and its successor program, the Long-Duration Storage Shot.[23] Each of these programs aimed to greatly reduce the cost of advanced energy storage technologies. DOE's current goal is reducing the cost of long-duration storage by 90 percent by 2035, which would make long-duration options cost-competitive.[24]

DOE is also beginning to implement a variety of programs originally authorized by the bipartisan Energy Act that were later funded by the infrastructure law. These include demonstration programs for energy storage technologies, as well as programs for battery manufacturing and battery recycling. The battery manufacturing, recycling, and processing programs are in the process of accepting applications for funding.[25]

Going forward, it is crucial that this Committee play an active role in the oversight of these demonstrations to ensure they are implemented according to Congressional intent, support American manufacturers, and include a wide variety of technologies and end uses. While the

[22] https://www.collins.senate.gov/newsroom/collins-bill-advance-energy-storage-technology-signed-law
[23] https://www.energy.gov/energy-storage-grand-challenge/energy-storage-grand-challenge
[24] https://www.energy.gov/eere/long-duration-storage-shot
[25] ClearPath Infrastructure Tracker. https://clearpath.org/clearpath-infrastructure-tracker/

funding from the bipartisan infrastructure law for energy storage demonstrations authorized in the Energy Act was appropriated in November of 2021, it has been nearly a year and DOE has not yet released any funding to develop new technologies. This means that DOE now has only 4 years remaining to develop these programs.

This Committee should maintain a continued focus on identifying alternative sources of critical minerals and making it easier to develop critical minerals facilities in the United States. The Committee has already passed several bipartisan pieces of critical minerals legislation, but the funding for those programs needs to get out the door at DOE so alternative sources can be developed. Domestic lithium processing facilities are absolutely a priority, as China currently contains two-thirds of the world's capacity.

Removing barriers to resource and energy development is a must. At ClearPath, we have identified through work with the Aspen Institute that America is currently not on track to meet its clean energy goals unless we make it easier to build cleaner, faster.[26] Aspen's report identified several key principles for improving decarbonization project development. Additionally, there remain significant barriers for certain varieties of energy storage, such as pumped hydro, that need to be addressed individually.

Thank you again for the opportunity to testify today. ClearPath is eager to assist the Committee in developing policies to support innovative energy storage technologies. We applaud the Committee for taking on this critical topic that will increase electric reliability, lower costs, and reduce emissions.

[26] Aspen Institute, Energy and Environment Program. *Building Cleaner, Faster* *https://www.aspeninstitute.org/publications/building-cleaner-faster-report/*

The CHAIRMAN. Thank you.
Mr. Wiley.

STATEMENT OF TED WILEY, PRESIDENT AND CHIEF OPERATING OFFICER, FORM ENERGY

Mr. WILEY. Chairman Manchin, Ranking Member Barrasso, and distinguished members of the Committee, thank you for inviting me to testify on behalf of Form Energy at today's hearing to examine opportunities and challenges in deploying innovative battery technologies for energy storage. I am Ted Wiley. I am one of the co-founders, the President and Chief Operating Officer at Form Energy, and I am joined here today by my colleague, Nidhi Thaker, who heads our Policy and Regulatory Affairs. We are representing about 300 people across the country. Headquartered in Massachusetts, we have operations in California and Pennsylvania.

Today, many battery technologies on the market can only provide, at most, four to six hours of energy storage at full rated power. While this is adequate for some circumstances, recent severe weather events, ranging from heat waves to cold snaps to thousand-year rains, have hamstrung our electric grid. And as has been demonstrated over the last few years, we are increasingly reliant on vulnerable supply chains to meet our energy needs. To meet supply chain challenges and run the grid reliably and affordably, we need domestically manufactured energy storage technologies that are capable of cost-effectively storing electricity for multiple days during extended periods of extreme weather, grid outages, or low renewable generation. When we started Form Energy, we conducted a broad review of the available technologies and have reinvented and optimized the iron-air battery for the electric grid. Our breakthrough, low-cost, multi-day energy storage systems will be made in America and help ensure a reliable electric grid year-round.

As the Chairman and others on this Committee have highlighted, we cannot be overreliant on any single country to meet our energy needs. We need to strive for energy independence. The active components of our iron-air battery system are some of the safest, cheapest, and most abundant materials on the planet—low-cost iron, water, and air. In fact, every material in the battery is readily available here in the United States as well as at a global scale with opportunities for high recyclability at end of use. Our technology is based on research that was supported by the Department of Energy in the 1970's and is designed to drive down energy costs for American consumers. In fact, at scale, we will be able to store energy for less than a tenth the cost of lithium-ion battery technology.

The basic principle of operation in our battery is reversible rusting. You heard that right. While discharging, the battery breathes in oxygen from the air and converts iron metal to rust. When charging, electrical current converts that rust back into iron and the battery breathes out oxygen. This reversible rusting process allows our technology to deliver the 100-hour duration required to safely make solar and wind reliable year-round, anywhere in the country, with no risk of thermal runaway. When we started the company five years ago, me and my five co-founders had a vision to develop multi-day energy storage that would unlock the power of extremely low-cost renewable energy to transform the electric grid. Over the last five years, through rigorous R&D product engineering, we now have an iron-air battery product that is ready to scale.

We are grateful for the support and effort from this Committee, and in particular, Chairman Manchin, for making the Infrastructure Investment and Jobs Act, as well as the Inflation Reduction Act, a reality. These unprecedented investments by Congress position our country's clean energy innovation ecosystem for success and ensure that we can more effectively and efficiently leverage private-sector investment with smart, whole-of-government policies to support the energy transition reliably and affordably. Lithium-ion battery technology was invented in a lab in the early 80s and took decades to achieve gigawatt-scale production. With the support of these new laws, companies like Form Energy will be able to scale in years, not decades, which is the time frame needed to meet our country's energy goals: enhancing grid resilience and security, increasing grid reliability and safety, creating good-paying jobs and economically benefiting local communities, and ensuring that the inventions that secure our energy future are built right here in the United States. Right now, Form Energy is in the final stages of selecting a site for our first full-scale battery production factory, in America, east of the Mississippi River.

As we look to our future, when we are receiving hundreds of thousands of tons of iron every year by rail or by barge and turning it into electrodes for batteries, there are only a few places in the United States that make sense to build batteries like that because the infrastructure and the know-how is already there. Those are our historic coal and steel communities. Communities that sit on a river. Communities that have rail access. Communities that know how to make great things out of iron and have always been leaders in American energy production and innovation. We expect to announce the location of our first full-scale battery manufacturing facility in the coming months and look forward to being an integral part of that local community where we will create good-paying, permanent jobs that grow our team by hundreds, and will build cost-effective, safe batteries for the American clean energy future, and we look forward to keeping that factory humming for years to come.

Thank you again, Chairman Manchin, Ranking Member Barrasso, and distinguished members of the Committee for your time. I look forward to answering any questions that you might have.

[The prepared statement of Mr. Wiley follows:]

Testimony of Ted Wiley
President and Chief Operating Officer
Form Energy

U.S. Senate Committee on Energy and Natural Resources

Hearing on Opportunities and Challenges In Deploying Innovative Battery and Non-Battery Technologies for Energy Storage

Chairman Manchin, Ranking Member Barrasso, and distinguished members of the Committee, thank you for inviting me to testify on behalf of Form Energy at today's hearing to examine opportunities and challenges in deploying innovative battery technologies for energy storage.

My name is Ted Wiley. I am the Co-founder, President, and Chief Operating Officer of Form Energy, a long-duration energy storage company with more than 300 employees.

We are headquartered in Massachusetts – and also have operations in California and Pennsylvania.

Today, many battery technologies on the market can only provide, at most, four to six hours of energy storage at full rated power. While this is adequate for some circumstances, recent severe weather events – ranging from heat waves to cold snaps to thousand-year rains – have hamstrung our electric grid.

And, as has been demonstrated over the last few years – we are increasingly reliant on vulnerable supply chains to meet our energy needs.

To meet supply chain challenges and to run the grid reliably and affordably, we need new domestically-manufactured energy storage technologies capable of cost-effectively storing electricity for multiple days, during extended periods of extreme weather, grid outages, or low renewable generation.

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Our breakthrough, low-cost, multi-day energy storage systems will be made in America and help ensure a reliable electric grid year-round.

As the Chairman and others on this committee have highlighted, we cannot be over reliant on any single country to meet our energy needs. We need to strive for energy independence.

The active components of our iron-air battery system are some of the safest, cheapest, and most abundant materials on the planet — low-cost iron, water, and air. In fact, every material in our battery is readily available here in the U.S., as well as at the global scale, along with opportunities for high recyclability, as we think about end of life product management.

Our technology is based on research supported by the Department of Energy in the 1970s and is designed to drive down energy costs for American consumers. In fact, we will be able to store energy at less than 1/10th the cost of lithium-ion battery technology.

The basic principle of operation in our battery is reversible rusting.

While discharging, the battery breathes in oxygen from the air and converts iron metal to rust. While charging, the application of an electrical current converts the rust back to iron and the battery breathes out oxygen.

Through this process, our technology delivers 100-hour duration required to safely make solar and wind reliable, year round, anywhere in the country, with no risk of thermal runaway.

When we started the company five years ago, our vision was to develop a multi-day energy storage battery that would unlock the power of extremely low-cost renewable energy to transform the electric grid. Over the last five years, through rigorous R&D and product engineering, we now have an iron-air battery product ready to scale.

We are grateful for the support and effort from this Committee – and in particular Chairman Manchin – for making the Infrastructure Investment and Jobs Act – as well as the Inflation Reduction Act – a reality. These unprecedented investments by Congress position the American clean energy innovation ecosystem for success and ensure we can more effectively, and efficiently, leverage private sector investment with smart, whole-of-government policies, to support the energy transition reliably and affordably.

Lithium-ion battery technology was invented in a lab in the early 1980s and took decades to achieve gigawatt-scale production. With the support of these new laws, companies like Form Energy will be able to scale in the timeframe needed to meet our country's energy goals: enhancing grid resilience and security, increasing grid reliability and safety, creating good-paying jobs and economically benefiting local communities, and ensuring the inventions that secure our energy future are built right here in the United States.

Right now, Form Energy is in the final stages of a site selection process for our first full-scale battery production factory in America, east of the Mississippi River.

As we look to our future, when we are receiving hundreds of thousands of tons of iron by rail or barge and turning it into electrodes in batteries, there are only a few places in the United States that make sense to build these batteries because the infrastructure and know-how is already there. Those are our historic coal and steel communities – communities that sit on a river – communities that have rail access – communities that know how to make great things out of iron and have always been leaders in American energy production and innovation.

We expect to announce the location of our first full-scale battery manufacturing facility in the coming months and look forward to being an integral part of the local community, where we will grow our team by the hundreds to create good-paying, permanent jobs, build cost-effective, safe batteries for the American clean energy future, and keep the factory humming for years to come.

Thank you again, Chairman Manchin, Ranking Member Barrasso, and distinguished members of the Committee for your time. I look forward to answering any questions you may have.

The CHAIRMAN. Let me thank all three of you for your testimonies, it was quite enlightening. Really quick, I just have a couple things to evaluate.

The Inflation Reduction Act basically had a lot of incentives for production tax credits, incentive tax credits, things of that sort. I think, Mr. Wiley, you just touched on some of those, but Mr. Nelson, you can probably look at it from a standpoint of the whole industry, what is going and how it might invigorate and accelerate. And I would like for you, if you can, touch on that, those credits, if not for those credits would this come to fruition? Would it have been much slower coming, when you said decades versus years? And next of all, the permitting. We are in a permitting process right now—of evaluation. Do we need to change the permitting process in the United States of America to bring our energy to market quicker and more cost-effectively than what it is today? If you can give me just a little evaluation on that?

Mr. Hemstreet, you want to start on that, if you can, how it is affecting you?

Mr. HEMSTREET. Sure, thank you, Chairman.

Certainly, for pumped storage, the ITC and the IRA for technology-neutral storage is key. We have never had a storage ITC before. And so, for pumped storage, it is absolutely critical for allowing us to cost-effectively deploy those projects. So that is something the hydropower industry has long sought. It is very important for us to be able to finally put on and have incentives that allow us to build storage to back up all the renewables that we have been constructing for the past two decades. So from a perspective of pumped storage, yes, the ITC for storage is very critical.

What the challenge is now is that, given the acceleration in the renewable build that we see, we are now faced with a challenge in terms of getting these projects built as fast as, you know, the incentives. The incentives are now available to build them, but we really have a very difficult and challenging permitting pipeline to bring them, you know, into fruition in the time needed to——

The CHAIRMAN. So you have a ten-year window, but basically the way the permitting process works now, unless we accelerate that or revamp that, you are not going to come in that window?

Mr. HEMSTREET. Yes, I think, I mean, for licensing projects today, it takes seven to ten years. And so, if we are going to take that long to license a project and four years to construct a project, you know, that is a multi-decade, at times, process, and that, from my perspective, will not be soon enough when projects of this sort will be needed.

The CHAIRMAN. I got you.

Mr. Wiley—and then I am going to come back, Mr. Nelson, for you to give an evaluation of the whole market, as far as energy market.

Mr. WILEY. So on the topic of going faster, I think, absolutely. And I did say that lithium-ion took about 30 years to go from, you know, batteries in a lab in Arizona to, you know, in camcorders and eventually electric vehicles. We have been at it for five years and we think we can be at gigawatt scale in another five years. You know, that is going to shave 20 years off of the timeline. The mechanism there and the way that this happens is, you know, we have created certainty for a decade in the——

The CHAIRMAN. Do the tax credits give you the opportunity to do that, to accelerate that?

Mr. WILEY. That's right. The tax credits are critically important to catalyzing investor capital and giving us certainty that we can do what we need to in the market and they allow us to go to scale faster——

The CHAIRMAN. How about on permitting? Does permitting effect you all in your type of a business?

Mr. WILEY. I think on the topic of permitting, Form Energy supports Congressional action that would help clean energy companies across the country develop operations and scale in the United States. And we further support legislative action that ensures the benefits of the Infrastructure Law and the Inflation Reduction Act are fully implemented and leveraged. It is going to be important to do permitting reform.

The CHAIRMAN. Mr. Nelson, as the oversight there, what do you see in the whole arena?

Mr. NELSON. Yes, you know, from our perspective, the most important thing is that all policy is technically feasible, that it is economically realistic, and also that it is politically sustainable. Bipartisanship is really crucial for that. There has been a lot of really good bipartisan energy storage policy over the last few years, and you need something at each step of the chain, from basic R&D, applied R&D, demonstrations and market signals, and you are going to need pieces of all of that to get there. And it is really important, that bipartisanship piece, so that it stays politically durable and we are not spending a bunch of time fighting about, you know, repealing things along the way. Ultimately, no one policy is going to be enough. We are going to have to have all of these policies to be able to have a strong and reliable grid.

The CHAIRMAN. Okay.

Mr. Wiley, in your testimony, you always played a major role in providing this country with the energy it needs and what you are trying to do. We have the Sparkz zero-cobalt battery manufacturing facility coming into Bridgeport, as you know, and that is going to change a lot. The states like mine and Senator Barrasso's, being major energy states, have a certain attraction, because we have been in this business and you are giving some opportunities there and people are ready to go, like you said. So, siting, you know, it is a big thing, but as we transition in this country to the energy that we must have and the energy we would like to have, if those two could intersect then some of the people can do both, that is a transition where we leave nobody behind.

So as you are looking, and I understand in your testimony you said that you are looking in communities that have that opportunity, availability, and the experience. Are you finding those characteristics in energy, basically, in energy states that have been heavy lifters?

Mr. WILEY. That is exactly right, Senator Manchin. When we went out, we started with a nationwide search and we started with the footprint that we were looking for and the skill sets that we were looking for. And as I mentioned, we need hundreds of thousands of tons of iron to flow into a site and turn into batteries and the infrastructure that we need to do that is the same kind of infrastructure that has serviced things like steel plants and coal plants around the country. The workers that we need to take iron and transform it into a battery are the same kind of workers that have been building the infrastructure that made America for the last, you know, several decades. So we found that there is a really strong overlap where the rail and the river flow in together and the workers and the skill sets are already there in those energy communities. And we are really excited about what we found. We are about a month and a half away from making a major announcement on where we will put our factory.

The CHAIRMAN. We are all awaiting that decision.

Senator Barrasso.

Senator BARRASSO. Well, thanks so much, Mr. Chair.

Mr. Hemstreet, so PacifiCorp recently submitted nearly a dozen applications for preliminary permits to develop pumped storage hydropower. These applications are now pending before the FERC, the Federal Energy Regulatory Commission. These include three sites in my home State of Wyoming as well as sites in Idaho, Senator Risch's State, Senator Lee's home State of Utah, Oregon, Washington State. Why are you pursuing the development of pumped storage hydropower?

Mr. HEMSTREET. We see pumped storage hydropower as being very valuable from the perspective of maintaining grid reliability. We are very familiar with our hydropower fleet that provides us the ability to do that today and have flexible capacity, and that has been an important way that we have been able to integrate the renewable resources we brought online. So it is important for us, as we see more renewables coming online, that we do have resources that also are available and dependable when the wind isn't blowing or the sun isn't shining, and pumped storage can play that role, particularly in your state, Senator. We happen to make a lot of wind in eastern Wyoming, and are building a lot of new transmission, but yet, we are still transmission-constrained in that part of your state. And so, pumped storage, we think, can also play a role in making sure that the transmission we are building is optimized so that we are getting the most value out of the renewable resources we are putting there.

Senator BARRASSO. So you submitted these proposals nearly a year ago. Can you please speak to the timeline of the licensing process of FERC?

Mr. HEMSTREET. The licensing process for projects is typically on the order of seven to ten years. And so, for that reason——

Senator BARRASSO. Seven to ten years, and you are a year into the process?

Mr. HEMSTREET. Correct.

Senator BARRASSO. Okay.

Mr. HEMSTREET. And so, for that reason, it is really important that we do see some reform in the licensing process and we are very lucky that a lot of folks on all sides of these issues have done really important work to advance a set of reforms to the Federal Power Act that would let us do that in a consensus way. And that is really exciting.

Senator BARRASSO. And last year, PacifiCorp, along with its subsidiary Rocky Mountain Power and TerraPower announced they are going to build this first Natrium reactor in my home State of Wyoming. The advanced nuclear reactor is going to provide 345 megawatts of power. It is going to include a liquid salt-based energy storage system which is capable of increasing the reactor's output to 500 megawatts for over five hours. What kind of benefits will this storage system bring to the electric grid in Wyoming and to our neighboring states?

Mr. HEMSTREET. What it will do, Senator, it is a source of energy, pure energy, flat out, it has a very high-capacity factor. It is intended to run at 345 megawatts, 24/7. So that is going to produce needed energy for your state as well as neighboring states, and the ability of that molten salt energy storage to ramp and meet load means that it will be available when we are either not seeing renewable resources produce or when we are seeing customer demands increase. And so that is really important.

Senator BARRASSO. So how does this storage system compare to other energy storage technologies?

Mr. HEMSTREET. In one sense, what is attractive about this energy source is it is inherent in the design of that project. So rather than kind of a bolt-on afterthought, it is really just inherent in the way that entire plant is designed to make sure it can flexibly meet customer demands.

Senator BARRASSO. Next, I want to ask all three of you to comment. So this is today's Wall Street Journal—"California's Tesla Battery Fire"—editorial in today's Wall Street Journal. It explains that Tuesday, two days ago, a Tesla battery at a utility storage site caught fire. It triggered the shutdown of the state's scenic coastal highway in California and had warnings to local residents to shelter in place, told them not to use air purification systems, air conditioning and what other. It goes on to say that lithium-ion battery fires are notoriously hard to extinguish because they burn at extremely high temperatures and they produce dangerous fumes. So I would like each of you to discuss some of the public safety concerns associated with using lithium-ion batteries for energy storage.

Mr. HEMSTREET. I will start, Senator.

You know, I am really not familiar with, you know, the public safety aspects of that, but what I would say is that we know, as an all-of-the-above energy company, we want resource diversification, you know, in all the things that we do—we want wind, we want solar, we want geothermal. We will see batteries but we also think it is important to have diverse sources of storage and pumped storage hydropower can provide some of that diversity that we think we need.

Senator BARRASSO. Mr. Nelson.

Mr. NELSON. Yes, thank you for the question.

So ultimately, the flammable properties of lithium-ion batteries are due to the high power density, and you do not need to use those for grid-scale storage, necessarily. The reason we use them is because they are quite cheap because we have scaled them up for electric vehicles and for consumer electronics. I think it is really important that we begin to find ways to lower the cost of alternative sources, at least for grid-scale storage. That is helpful for large-scale deployment. It is also helpful for, you know, increasing grid reliability and reducing our reliance on other countries.

Senator BARRASSO. Thank you.

And Mr. Wiley.

Mr. WILEY. Yes, to further Mr. Nelson's comments, when we started the process of designing the battery chemistry that we are developing—iron-air—we looked closely at over 100 different chemistries, and one of the criteria was safety. In particular, not using any flammable materials and then developing a chemical reaction that doesn't have any pathway to thermal runaway, where the reaction itself is self-heating. So these batteries that we are developing are water based. They have a salt in the water, which is an alkaline salt, and there is no pathway to thermal runaway. And in fact, it is not flammable.

Senator BARRASSO. Thank you.

And Mr. Chairman, I would like to submit to the record, without objection, this California Tesla battery article from the Wall Street Journal.

The CHAIRMAN. Without objection.

[The editorial referred to follows:]

OPINIONREVIEW & OUTLOOK

California's Tesla Battery Fire

A reminder that solar and wind power aren't cost or risk free.

Editorial Board
9/22/22 6:38 pm ET

As if California doesn't have enough wildfire hazards, its drive to banish fossil fuels from the electric grid is creating another. On Tuesday a Tesla battery at a utility storage site in Monterey County caught fire, triggering the shutdown of the state's scenic coastal highway and shelter-in-place warnings for local residents.

California utilities have been installing large-scale batteries to back up renewables and provide power when the sun goes down. But now we're learning that batteries have their own reliability problems. It's not clear how utility PG&E's enormous 182.5 megawatt Tesla battery caught fire Tuesday, but the site had to be disconnected from the grid.

The PG&E facility is located adjacent to another 400 megawatt battery storage site, which has experienced two overheating incidents in the past year that forced part of the system to shut down. Lithium-ion battery fires are notoriously hard to extinguish because they burn at extremely high temperatures and produce dangerous fumes.

Hence Tuesday's warning by Monterey County officials asking residents to "Please shut your windows and turn off your ventilation systems." Fire drills may need to be modified for battery blazes that are becoming increasingly common and destructive.

Recall how a cargo ship transporting electric vehicles to the U.S. in February caught fire on the open seas. The 22-person crew had to be rescued, and hundreds of millions of dollars of merchandise was lost. A fire last July at a Tesla battery storage site in Australia required three days and a hazmat firefighting team to put out.

Australians were lucky that the fire didn't occur during their summer when it might have been even harder to control. Californians can likewise be grateful that Tuesday's battery fire didn't occur during the state's heat wave two weeks ago when the state power supply was tight. PG&E filed for bankruptcy in 2019 amid tens of billions of dollars in liabilities for wildfires linked to its equipment, and now it has a new risk to worry about.

The larger point is that there is no free lunch in producing energy. All sources have costs and carry risks. The difference is that while climate lobbyists and the media fret about oil spills, gas leaks and nuclear meltdowns, they ignore the very real costs and risks of renewables.

Appeared in the September 22, 2022, print edition as 'California's Tesla Battery Fire'.

Senator BARRASSO. Thank you, Mr. Chairman.

The CHAIRMAN. Thank you.

Senator Heinrich.

Senator HEINRICH. Thank you, Chairman.

It's a good thing gasoline is not flammable.

Senator BARRASSO. That would be bad. They had to close down the whole highway in California. It was awful. And tell people not to use their heating and cooling systems.

Senator HEINRICH. Let me talk to you about the IRA for a minute, for each of you, whoever wants to jump in. Talk to us for a couple minutes about the importance of setting tax policy incentives that are long-term and durable as opposed to year-by-year-by-year. How important was it that the incentives in the Inflation Reduction Act were decadal and send a consistent signal over time?

Mr. WILEY. So thank you, Senator Heinrich, for the question.

As a company that has spent the last five years in the R&D phase and is just at the base of the hill, looking up and thinking about scaling up manufacturing, we are going to go from 300 to 1,000 people working at the company over the next three years, and we are going to make major investments in a manufacturing plant, in a sales force to go take those batteries into the world. And having an incentive that is only going to last as long as it would take us to just get started on the manufacturing is not enough to catalyze the kind of investment we need to go do that. To go hire those 700 more people and to build, you know, 800,000 square feet of factory, and buy all of that iron and other materials to build the batteries. So having that ten-year incentive with a sunset is exactly the kind of scale we need to jump-start the effort and give our investors and our partners confidence that we are going to be there and that we are going to be able to deliver. Also, to give us confidence, internally, to commit ourselves with our full effort and faith to do this here in the United States.

Senator HEINRICH. Yes, I really look at the IRA, not just as a clean energy bill, but as industrial policy. And that is something we have pretended we did not need in the United States for a long time, but we desperately do need to be able to compete with our near-peer competitors around the world, like China.

For each of you, what advice would you have for Treasury as they begin to write rules to implement the 45X Battery Manufacturing Credit, 48C, the Advanced Manufacturing Credit, even 25D, the Residential Clean Energy Credit? What do you want to see in those, as Treasury makes those things real?

Mr. HEMSTREET. I will take that question from the perspective, at least, of pumped storage. I think what is going to be important is having certainty that all aspects of a pumped storage project, you know, the water empowerment, the water conveyance, the turbine, the generator, the pump, all of those aspects of getting a project online are considered part of that energy storage facility, and that will be important for what that tax credit means to us as it reduces the cost for our customers. And so, having that certainty that as we make investment decisions, we know what that customer impact is going to be with that tax credit. That is very important.

Senator HEINRICH. Yes.

Mr. NELSON. I would generally say that it is important to have strong private-sector engagement for the implementation of any law. We have seen, you know, prior implementation of tax credits. If they go poorly, then they can lead to rescissions or claw-backs of tax credits. So it is important to have strong private-sector engagement, generally.

Senator HEINRICH. Transparency and predictability.

Mr. NELSON. Transparency is very important.

Senator HEINRICH. Yes.

Mr. WILEY. And to add to what my colleagues have said, Senator Heinrich, we would like to see as broad of an interpretation as possible to fit as many technologies as possible into the bills or into the laws and allow them to scale. And in particular, we are looking for clear definitions of critical aspects of the credits. Clear definitions of, you know, for example, what an apprenticeship program is and, you know, clear definitions of what the domestic content standards mean.

Senator HEINRICH. I got you.

Mr. WILEY. And across the board, the more that those definitions are clear and implementable, the better. And frankly, the faster that we receive that clear guidance, we will have a better——

Senator HEINRICH. I am going to run out of time, but I want to ask you one more question about your partnership with Georgia Power. Talk a little bit about the scale of that and then also, just how you worked with Georgia Power and the software of the modeling tools that you used and how those differentiate from traditional tools, like capacity-expansion models that are not going to be as useful in the future.

Mr. WILEY. Georgia Power has a partnership with a large IT company, and they are looking to bring in new, 24/7 carbon-free electricity to power a data center, and they were looking out in the market for a solution and asking what kind of storage could help us do this? And we had been engaged with them for over four years in early discussions, and then as they came to us with the ask, we used our proprietary software, which is, as you mentioned, a capacity-expansion tool, that is a grid planning tool that was redesigned for a renewable energy future. So typical tools look at four representative days throughout the year. Our software looks at all of the hours of all the days of the year, 8,760 hours a year, to help think about what if the grid was powered by renewables. What kind of battery would you need to have 24 by 7 energy, when you need it, exactly when you need it, no matter what the power source is? The project itself will be about a 1,500 megawatt-hour battery that is going to do just that. It is going to show that a data center can use locally sourced, renewable energy to power it all the hours of the day, all of the days of the year.

The CHAIRMAN. Thank you, Senator.

Senator Cassidy.

Senator CASSIDY. Hey, thank you very much.

Mr. Hemstreet, the capital requirements to build this sort of hydro and to maintain it, as well as the kind of energy loss required to use some of your electrons to transport the water to the top—what does that do to your cost per kilowatt-hour of a wind farm, for example, if you add that cost, not just upon the turbine, but also that which has to inherently be attached to it in order to help with the intermittency?

Mr. HEMSTREET. Yes, I think, certainly the efficiency of these types of projects, as with any storage project, there are going to be losses, you know, on the inside, going up and going back down. So we see efficiency at about 81 percent, or 70 to 80 percent. So there is an energy loss, of course, in any form of storage. So that increases costs, of course because we are not able to capture every——

Senator CASSIDY. So, if you will, it increases the cost of energy by roughly 20 percent before you get to the capital requirements, correct?

Mr. HEMSTREET. Right. I mean, you are going to have to see that much of a spread in terms of the price on the whole.

Senator CASSIDY. And then, how much is the capital cost going to add to it, presuming that you have to pay for the capital cost with the price you charge for the electricity?

Mr. HEMSTREET. The cost of these projects is typically on the order of between $3,000 to $4,500 a KW today. So the high capital cost has been an impediment for pumped storage.

Senator CASSIDY. And so, again, when people speak about how cheap wind can be once installed, but if you amortize the expense and if you take the diminution and the energy efficiency, what does it do to the business model, absent a tax credit or whatever?

Mr. HEMSTREET. Well, we know that these types of resources are going to be important for meeting, reliably, in terms of the macroeconomics of, you know, all these resource decisions, you know, in totality, you know, it is not really something I am super familiar with.

Senator CASSIDY. Sounds great. I am going to move on, not to be rude, but just because I have limited time and maybe we will do a QFR to allow you to research it.

Mr. Nelson, hey, man, you are like the objective guy here. Is lithium going to crowd out what Mr. Wiley is talking about? I mean, like it's going to fill up the room and like, by the way, Mr. Wiley, I look forward to our announcement in Louisiana—spoiler alert—we've got the river, we've got the railroad, we've got use. We've been handling steel and iron for a long time. So I look forward to that ribbon-cutting, thank you very much, sir.

[Laughter.]

Senator CASSIDY. East of the Mississippi River, St. James Parish, perfect. I have a 200-acre site for you.

Mr. Nelson, is the kind of, you know—"oh my gosh, it's going to crowd out because everything is lithium"—going to encroach upon their ability to get market share?

Mr. NELSON. You know, there definitely is a history of technology lock-in we can see in a variety of different sectors. You can think about the QWERTY keyboard, for example. There is no particular reason why we use a QWERTY keyboard, it was the one that became the dominant technology. That certainly could happen with lithium-ion.

Senator CASSIDY. That is more of a standard than it is a product, though.

Mr. NELSON. No, there is no reason we have to use QWERTY keyboards.

Senator CASSIDY. I get that, but.

Mr. NELSON. Yes.

Senator CASSIDY. I don't want to waste time on that.

Mr. NELSON. Well, the same thing could happen with lithium-ion, which is why the Department of Energy's programs to support demonstrations of new technologies to give those a chance are so important. Investors are not going to be pouring a huge amount of money into big manufacturing projects unless they have relative certainty that the product is going to work at scale and you know, I would love Ted to also weigh in here, but that is why it is important for, you know, governments to engage in private-public partnerships to help get those technologies going so you can have that proof of concept and then the private sector can come in and scale technologies up.

Senator CASSIDY. Okay, then I will ask you this, but the others can be—and I have limited time, which is why I am not going to you on this, Mr. Wiley.

Let me ask about—I understand that there is an issue with storage related as well to the interconnection. Can you get the grid to kind of accept this battery influx when you may have limited capacity on your power lines? I am probably not explaining it well, but you are nodding your head as if you know what I am saying. Can you speak about that obstacle, if you will, to getting it into the grid?

Mr. NELSON. Yes, the interconnection queue, all new energy generation projects have to go through a process where they do an analysis to see what the impact will be. It is definitely a big challenge. It varies a lot on a regional basis. Right now, the average time for new generators to connect to the grid is 3.7 years. That has been increasing over time. In some places like California, the average time is eight years that you wait in the queue to know whether or not you can connect——

Senator CASSIDY. So California, which is attempting to go to all electric vehicles by 2035, therefore needs to expand and wants to get rid of fossil, so it needs this capacity, it takes eight years.

Mr. NELSON. On average, just waiting to know how much it is going to cost, yes.

Senator CASSIDY. And then how much longer to develop and deploy?

Mr. NELSON. Well, then it will take another two or three years after that for the construction and operation startup. And right now, there are 421 gigawatts of battery storage in the queue nationwide, but half of that is tied with renewables and we are probably only going to be able to build about 20 percent of that in the end, unless we work on the interconnection queue. FERC is working on this. There was a unanimous notice of proposed rulemaking they sent out a few weeks ago. So I am, you know, happy to see that there is bipartisan action on this, but it is absolutely a crucial, crucial problem. We are going to be putting out a paper on this. I will send it to your office.

Senator CASSIDY. To be clear, it is not just a queue, but it is also the transmission capacity, how they can absorb the generation from that which is occurring as well, and so, you not only have to permit this, you have to permit the increase in generation capacity.

Mr. NELSON. Yes, that is correct, sir.

Senator CASSIDY. So just to, you may not want to take this, if I may have 15 more seconds. It seems unrealistic that California is going to have both the storage and the transmission in order to go to an all-electric new car fleet in 2035, and you just give us timelines that would push, optimistically, those at the front of the queue into somewhere between 2032 and 2034. Do you think it is reasonable that California will have the capacity to address all their new electric vehicles by 2035?

Mr. NELSON. Is that one for me?

Senator CASSIDY. Yes.

Mr. NELSON. I think it will be a challenge, and permitting reform will be really essential for accelerating development of clean energy in California.

Senator CASSIDY. That's kind of a dodge, but I will give it to you.

Mr. NELSON. Well, it will be a huge challenge. They have a lot of state-specific regulatory requirements that slow down the development of new—CEQA, the California Environmental Quality Act, is a big issue. So right now, they are not on track to hit those goals.

Senator CASSIDY. Yes, that's——

Mr. NELSON. Which is partially why they are keeping Diablo Canyon online, things like that.

Senator CASSIDY. Thank you.

The CHAIRMAN. Senator Hirono.

Senator HIRONO. Thank you, Mr. Chairman. I thank the panelists for your testimony.

For Mr. Nelson, Hawaii not only faces some of the highest gas prices in the country, currently $5.27 cents per gallon, but our state also relies on oil for most of its electricity, and Hawaii has set an ambitious standard of 100 percent renewable power by 2045. We have reached nearly 40 percent renewable power, but families and businesses in Hawaii have had to watch their power bills go up with the global price of oil. Energy storage will be a critical part of our transition to renewable power. How can some of the energy storage technologies you discussed in your testimony help Hawaii meet its goal?

Mr. NELSON. Yes, thank you for that question, Senator Hirono.

I think long-duration energy storage is particularly important for Hawaii, especially considering its 100 percent renewable goal. You know, if you are trying to reach low emissions with a lot of renewables, you either need to greatly overbuild your renewable capacity to have enough extra generation when there is not enough sun, or you have enough storage capacity that you can then save up for those periods. Considering the land use constraints in Hawaii, I think long-duration will be really critical. I think some of the best would be some of the metal-air batteries or flow batteries that can take up a relatively small amount of land, but can provide long-duration storage.

Senator HIRONO. So that leads me to Mr. Wiley. Your testimony was really interesting and you are about to make a big announcement in siting a factory where you will produce these batteries. So does that mean that you have reached your goal of batteries with 100 hours of storage?

Mr. WILEY. We have, Senator. We have built over 3,000 batteries in our labs in Berkeley, California and Somerville, Massachusetts and the design is proven and we are ready to scale now to the manufacturing phase.

Senator HIRONO. The Hawaii Natural Energy Institute at the University of Hawaii conducts tests of batteries to assess the durability of batteries in a warm island climate. Would your batteries work in Hawaii?

Mr. WILEY. Absolutely, Senator.

Senator HIRONO. Have you tested your batteries at the Natural Institute?

Mr. WILEY. We haven't, but we are entering a phase where we need to identify third-party locations for testing and start that process.

Senator HIRONO. I hope that you do that, yes, I hope you come to Hawaii. I know you are being pitched all over the place in this Committee today.

Mr. Nelson, earlier this week, we saw the tremendous damage that Puerto Ricans are suffering from Hurricane Fiona, including an island-wide power outage for more than 3.2 million Americans. As an island state, Hawaii is also vulnerable to severe weather, and one solution on this challenge is the construction of microgrids, which can disconnect from the power grid when needed and then quickly restore power after storms. The Department of Energy's Energy Transition Initiative program is supporting Hawaiian Electric, which is the state's largest utility in evaluating which communities may benefit from establishing microgrids.

What role can advanced storage technologies play in building microgrids and otherwise increasing resilience to storms in places like Hawaii, Puerto Rico, and Alaska, that are separated from the mainland?

Mr. NELSON. Yes, thank you for the question, Senator Hirono. I worked on the Energy Transitions Initiative when I worked for Senator Murkowski. It is a critical program for Hawaii, Alaska, and also Maine. You know, I think microgrids can be an essential way to back up power, provide resilience in the case of extreme weather, allow systems to be islanded. I think it is really critical for infrastructure like firefighting and emergency response systems, to have islanding and microgrid capabilities. And on the topic of energy storage, it is particularly important for black start capabilities. So in the event of a blackout, it can get the grid going much faster, and that is probably one of its best applications.

Senator HIRONO. So since states like Hawaii, Alaska, and I think you mentioned Maine.

Mr. NELSON. Uh-huh.

Senator HIRONO. Are we moving fast enough in promoting microgrids or whatever we need to do to enable microgrids to be utilized in states like ours?

Mr. NELSON. Sure, well, in Alaska, almost all the communities by number are already isolated microgrids. I think for Hawaii and Maine, there is always a lot more you can do to implement the latest technology for grid energy.

Senator HIRONO. Such as?
Mr. NELSON. Hmm?
Senator HIRONO. Such as? What more things can we do?
Mr. NELSON. Yes, so, you can implement better demand management systems. Grid reliability behind the meter storage is also going to be really important. So making sure that those critical facilities do have independent battery systems as well as, potentially, diesel generators, and I think there is more that I can also provide through the record.
Senator HIRONO. Thank you.
Mr. NELSON. Yes.
Senator HIRONO. Thank you, Mr. Chairman.
The CHAIRMAN. Thank you.
Senator Murkowski.
Senator MURKOWSKI. Thank you, Mr. Chairman.
And I have several questions to just follow on to Senator Hirono. So thank you for that, particularly the emphasis on microgrids. And Spencer, I feel like you know the situation in Alaska all too well. You know that we are leading the country, probably the world in many ways, when it comes to microgrids. And so, we are looking at this whole aspect of storage and what that means for greater flexibility. We had some very severe storms this past weekend that impacted about a thousand miles of coastline. Communities were without power, fortunately, for a very brief period of time, which is good. But it speaks to this issue of resilience and why storage is so key within these islanded systems. You have to have—whether it is that restart, that cold start, your black start, or what you can do to help with surge and storms.
So this concept of how long we need the storage to be, and I appreciate what you are doing, Mr. Wiley, in pushing this out. One hundred hours—quite significant if you are in a storm that moves in and out, you know, maybe you only need that four hours. But a question to probably both of you here—how long is long enough, or does it just depend?
Mr. NELSON. Yes. Thank you for that question.
I saw the tragic photos from Newtok and Hooper Bay and it is really sad what has happened. I think it really depends on the situation of what your next best alternative is, right? So how long is it going to take to, typically, to be able to restore power when you are in such an isolated area, right? So what is your next best alternative?
Senator MURKOWSKI. So, in Newtok, our next best alternative is the diesel generator.
Mr. NELSON. Right.
Senator MURKOWSKI. And you are paying $11 a gallon——
Mr. NELSON. Yes.
Senator MURKOWSKI [continuing]. For your fuel, and the fuel tanker is still sitting outside of Nome because they cannot deliver, you don't have many options. So what do you do then?
Mr. NELSON. Right, yes, so in that case you would want a longer duration storage technology that could be much cheaper, or, honestly, at that point, you are going to want to have something like a microreactor, a nuclear microreactor, something that is much more reliable and dependable that is not going to be as weather-

dependent, but there are options, and you know, Ted can talk to this as well, that could be much longer. Of course, some of those technologies are going to be quite large. So the actual ability for you to build a very large, 100-hour system in Newtok, considering the semi-permafrost issues, I think that would be quite a challenge and I think it would be better to look at maybe some of the nuclear microreactor options for some of those isolated communities in the YK Delta.

Senator MURKOWSKI. It is a small scale——

Mr. NELSON. Yes, yes.

Senator MURKOWSKI [continuing]. That we deal with, as you know.

Mr. Wiley, I would like you to speak to, not only how long is long enough, but also you mentioned that your battery storage likes hot or warmer weather, well, we don't necessarily have that. We are interested in how it does in colder weather. There is some testing that has been going on as it relates to EV buses and how it holds charge in cold weather. So we are interested in the storage in a cold weather environment as well. So if you could hit on both of those?

Mr. WILEY. Okay, thank you for the question, Senator Murkowski.

The question of how long is long enough, that is one of the core questions that got our company started. I mean, that is probably our favorite question at Form Energy. And when we started asking it, as founders, five years ago, our initial reaction was that this is such a complicated question that you need software to answer it because it varies by location. We needed to understand how much renewable energy is there, of what type, what are the other grid assets that are available, to Spencer's point, so what is the mix? And then, we do a really complex simulation based on that, those local resources, and we looked all across the country. We looked in Alaska. We looked in Massachusetts. We looked in Arizona. We looked in California. We looked in Hawaii and said, how long is long enough by location? And the answer was that it depends, and 100 hours solves most of the opportunities for grid transition in most places. It solves the problem something like 98 percent of the time. One hundred hours covers these atypical weather events where you get a week without wind, like in Winter Storm Uri that came up and down the middle of the U.S.

The question about cold temperature—the very first customer we signed is Great River Energy in Minnesota, and the reason that they signed up with us, for our first project, is because of the polar vortex event that they experienced where temperatures dropped to negative 40, negative 50 degrees below zero. And so, in fact, we are designing the batteries for a Minnesota or Alaska winter at base line. That is the first design criteria that we used when we were developing batteries. So we would be happy to bring our batteries up to your great state.

Senator MURKOWSKI. Good. We look forward to that.

Mr. Chairman, Ranking Member Barrasso, I think it has been important as we are talking about the great application for storage and where this is going to take us, but what Spencer has outlined in response to Senator Cassidy's question, I think, was really, really key. I had no idea that this timeline that we are looking at—eight years, to not build it out, but just to get that cost determination as to how it is going to be integrated into the system and then another couple years there. So when we are thinking about how this all knits together in this great transition and all that we are doing, we have some reality checks in front of us. This whole issue of permitting and what that means, but this reality of the queue is very interesting. I would like to understand a little bit more of that.

And then, the other thing that Mr. Nelson highlighted in his testimony was critical minerals, something that the three of us—this entire Committee—has been working on and focused on, and our reality—we know that the stats out there don't lie. We are not producing enough, certainly in this country to meet the demand for lithium, to meet the demand for all of these other critical minerals that are going to be required for this holy grail that is going to be storage. And so, we are working hard to do more on critical minerals. We need to be doing more on permitting. We need to be moving faster, smarter, better because right now, things are not lining up with the goals that are being set out there and our ability to reach them, regardless of how fast we are moving.

So thank you for this hearing. I think it was really important.

The CHAIRMAN. Thank you, Senator.

Senator King.

Senator KING. Well, I want to congratulate you, Mr. Chairman, because I do not think you intended it this way, but this has been an hour-long infomercial for your permitting reform bill.

[Laughter.]

The CHAIRMAN. People on the front line, they are experiencing——

Senator KING. Well, and following up on Senator Murkowski's point, we cannot get there without permitting reform. It is just as simple as that. And those who are interested——

The CHAIRMAN. I think we all know that and we all are just——

Senator KING. Well, we know that, but I am not sure, but there are people, I mean, we have to understand that in order to get to a clean energy future, we have to rationalize and correct the deficiencies in the permitting or we will never get there because we are going to need to permit transmission. We are going to need to permit pumped storage projects. We are going to need to permit mining operations. And so, you cannot be for electric vehicles and be against lithium mining in the U.S. I mean, we just have to resolve that. And I think that is a very important point.

I could not believe it, the seven to ten years. What I say to people when they tell me that something is going to take years is that Eisenhower retook Europe in 11 months. Don't tell me it is going take ten years. That is ridiculous. And Mr. Chairman, I hope we are going to really make some serious inroads into that. Deadlines, meaningful deadlines, coordination of agency consideration, and conclusions within a reasonable period of time. Otherwise, we will never get there. We will simply not get to the clean energy future that we desire.

Mr. Wiley, I have never had a witness come who has a ready-made theme song for their company. One of the great rock and roll albums of all time is "Rust Never Sleeps", Neil Young and Crazy Horse, before you were born, perhaps, but——

[Laughter.]

The CHAIRMAN. Oh, boy.

Senator KING. You got it.

Senator BARRASSO. Better to burn out than to rust away——

Senator KING. There it is, yes.

[Laughter.]

Senator KING. Rust never sleeps.

I have to tell you, your testimony was so stunning it was almost too good to be true. You are talking about drastically lower cost, much safer, no foreign materials. What is the disadvantage of what you are proposing? Because if there aren't any, you are going to change the world.

Mr. WILEY. Thank you for the question, Senator King, and thank you for the advice on the song. I will look into it.

Senator KING. 1979, Neil Young.

Mr. WILEY. Every technology decision has tradeoffs and we are going to need more than just iron-air batteries to transform the grid. For us——

Senator KING. Does an iron-air battery have the 100-hour capacity you mentioned as the golden requirement?

Mr. WILEY. That is exactly right, Senator King. Iron-air batteries that we are developing are 100-hour batteries. And the tradeoff that we made, like the tradeoff that we bet the company on when we started was, a tenth of the cost for half the efficiency. And that really is at the core of it. We are looking at it and saying, you take less efficiency for radically lower cost.

Senator KING. Define efficiency as it applies in this case.

Mr. WILEY. For batteries, efficiency is how much energy you get out for how much energy you put in.

Senator KING. Okay, so you would have to charge it with more energy to get energy out than you would on a lithium-ion?

Mr. WILEY. That's right.

Senator KING. But the presumption here is that there is excess energy during peak times or that there could be if the sufficient resources were developed, whether it is wind, solar, or something else. Now what would be the efficiency of a lithium-ion?

Mr. WILEY. A lithium-ion battery is about 95 percent efficiency at the sell level and we will be about 50 percent efficient at the sell level—or at the plant level, just under it. And the modeling exercise that I described to Senator Murkowski really delivered that insight. If you can get to radically lower cost in a future that is highly renewable where we have overbuilt renewables in order to have it when we need it, there is a tremendous amount of energy that is arriving that needs to be shifted, and the right tradeoff to make, if you can make it, is trade capital cost for efficiency.

Senator KING. Well, I will certainly look forward to following the progress of this product because it is a very exciting one.

On the permitting reform, again, I think deadlines are important. And the other piece is domestic supply chain. I met yesterday with two heads of state from European countries. We have in front of us the all-time example of how dangerous it is to rely on other countries for critical supplies. I mean, Europe is facing a really huge challenge this winter because of their reliance on Russia. And you look back and you say, why, what were they thinking? I don't want to be in that position ten years from now saying, what were they thinking about getting critical minerals from China that power our country.

Mr. Nelson, am I right about that? I mean, it just seems to me this is a—we not only can see the problem, we can see the real impact of it right before our eyes this winter in Europe.

Mr. NELSON. Yes, I mean, the more that our future energy system relies on other countries, the less control we have over it. We have certainly seen that our increase in oil and gas production has put us in a very strong position in terms of global energy production because we are now a net producer of oil and gas, and that has been helpful. I think we can also be a net producer of energy storage technologies and all types of clean energy technologies as well.

Senator KING. Final question, though. Don't we have substantial lithium supplies in this country if we are willing to mine them?

Mr. NELSON. Yes, that is correct. There's a couple different ways. There are some lithium deposits in Nevada, which Senator Cortez Masto knows more about than I do. There are also really interesting opportunities to co-produce lithium with geothermal energy in the Salton Sea, which is something that was included in some of the work that you did on the Energy Act of 2020 as well. And there is a significant amount of lithium opportunity in Southern California.

Senator KING. Thank you.

Thank you, Mr. Chairman.

Senator BARRASSO [presiding]. Senator Daines.

Senator DAINES. Senator Barrasso, thank you.

I saw my good friend, Senator King, talking about what is happening in Europe as an example of what not to do in this energy crisis, which is, I think, a grave warning on two fronts. I agree with Senator King, it is on overreliance on adversaries for energy, but also, I would add to that, it was scaling back a diverse energy portfolio to exclusively rely on intermittent energy sources to ensure we begin with a balanced energy portfolio, as the Germans went off and shut down coal and nuclear. Germany, recently, just had to pass emergency legislation in early August. And I met with some of the members of the Bundestag on a couple of occasions, but they had to do that to keep its coal plants burning because they passed laws that didn't allow them to burn coal, just to keep the lights on, keep people warm this winter.

Europe may begin to ration energy because this green ideology has dominated their energy policy and the European economy is on the brink of a disaster as electricity prices have surged more than 300 percent. And I think this is the end result when an ideology, and policy that follows an ideology runs faster than on-the-ground reality. I met with another head of state of Europe here recently, who has a better energy portfolio and was questioning what was going on in places like Germany and around other places in Europe, and he said this to me—he said, Senator, a vision without an action plan is a hallucination. And sadly, now, many are going to be suffering this winter. Frankly, if the Biden Administration had its way, that would be the future of American energy. This is one of the key battles we face right now on policy going forward—to what do we do here to ensure that we have balanced energy. And I am not opposed to renewables. We have wonderful wind capacity in Montana, a lot of hydro, of course, and we have solar. So we are the Big Sky Country. But we should be expanding our energy portfolio with these renewables, not replacing baseload power until you can solve the storage problem and the intermittent nature of some of the renewables. That's why I think all-of-the-above is really, really important and has severe consequences if you get it wrong.

The Gordon Butte pumped storage project as a hydro project is a perfect example how Montana is leading in all-of-the-above solutions. Gordon Butte has a closed-loop hydropower system that will store and produce enough energy to help balance the increases in intermittent wind and solar energy coming online in Montana. And this project will be for generations in our state.

Mr. Nelson, how are closed-loop hydropower projects like Gordon Butte bolstering our energy storage capacities and enhancing existing grids?

Mr. NELSON. Thank you for that question, Senator Daines, and thanks for your leadership on the Senate Western Caucus.

You know, pumped storage hydro has a huge benefit, not just for renewables, but also for baseload resources. It can allow baseload resources to operate at a high capacity, even when demand is low, by instead charging up pumped storage systems. So they are an integral part of our energy system and have been for a long time.

Senator DAINES. I want to jump—thank you for that because that is a great example of baseload power with these hydropower systems. I want to talk about critical minerals for a moment. Clearly, it has been talked about a bit, but it ties right back to battery supply. The United States is import-dependent on China for 31 of the 50 minerals designated as critical by USGS. As we move forward with more renewable sources of energy, China, indeed, could become the OPEC of the future for renewable energy in terms of having a constraint, to constrain the supply chain and our ability to keep energy storage supply chains moving forward. Right now, countries that utilize slave labor have far lower environmental standards than the United States. Meanwhile, we have these radical environmental groups and the Ninth Circuit Court. The Ninth Circuit Court, who has litigation to tie up domestic mining of the materials needed for responsible, renewable energy development.

We have talked on this Committee, we had a mine in Montana, a copper mine—for 37 years been trying to permit it—37 years, going through multiple EISs and then they hold us up in the Ninth Circuit Court with the Endangered Species Act. These delays are a threat to national security. They hurt our economy. And they hold back the future of renewable energy technology.

Mr. Nelson, what steps need to be taken for the United States to begin to close that critical mineral gap with China? As Senator King mentioned, we have some critical mineral capacity here in America, but we just can't always get to it.

Mr. NELSON. Yes, thank you for that question.

You know, there are a number of different steps that we should be looking at. Of course, China mostly controls a lot of the processing and recycling facilities. They do not have a lot of direct production of many of the critical minerals. So one thing we can do is make sure that we are producing those here in the United States and having partnerships with allied countries like Canada and Australia to basically eliminate a lot of those initial sources that they control, and also making it easier to build those processing facilities here in the United States. So that means improving environmental permitting. It means improving exploration and leasing for production of various critical minerals. And it also means, you know, trying to innovate away from needing those to begin with. There are opportunities to develop new cathodes for batteries that use fewer critical minerals today, and there are companies that are working on that, and we should try to make that easier.

Senator DAINES. Mr. Chairman, I just have a closing comment here and then I will be done. I am over time, but for Mr. Hemstreet, I know PacifiCorp owns interest in Colstrip Units 3 and 4 and produces 1,480 megawatts of electricity for western states. It is critical that Colstrip continues operation long after 2025. We have seen what has happened in Germany. We need to be very, very careful with baseload power. I just would encourage you to work with Montanans to ensure that the continued operation and maintenance of Colstrip occurs. It is vital to the local community there, but importantly, the stability of the grid. I hope that politics does not get in the way of supporting hardworking Montanans with affordable, reliable energy. So thank you.

Mr. HEMSTREET. Thank you, Senator.

The CHAIRMAN [presiding]. Mr. Hemstreet made a really important point on how important it was for permitting reform because of what they are doing and the jobs they are bringing to Montana and all the work they have done out West in Wyoming and we appreciate that very much.

Senator DAINES. Thank you, Senator Manchin.

The CHAIRMAN. We have Senator Cortez Masto.

Senator CORTEZ MASTO. Thank you, Mr. Chairman. I so appreciate, gentlemen on the panel, the discussion today. And thank you for the shout-out for Nevada, because I do agree, we need to really source these critical minerals for the future around clean energy. But let me talk to you about, and let me just say, I do support an all-of-the-above approach to the question of storage supply. We have discussed in this Committee the lithium-ion battery needs and opportunities, hearing directly from Redwood Materials out of Nevada, and I can say there are others that are like Redwood, which is the American Battery Technology Company. They are both in Nevada and they are just two examples of why, really, Nevada is an innovation state. They are just what the U.S. critical mineral supply chain needs—American companies with the scientific expertise to accelerate both responsible mining of Nevada's unique critical mineral deposits as well as recycling spent batteries to ensure none of these minerals are wasted.

So I am going to open this up to the panel. Can each of you talk about where we see the intersection of both standard and emerging energy storage technologies working together? And I guess what I am looking for is examples where we can continue to develop the ion battery domestic resources as well as explore these innovative technologies and corporations so that they are not competitors. And maybe, Mr. Nelson, we can start with you.

Mr. NELSON. Yes, absolutely. Thanks for that question and thanks for your leadership on this Committee. I think, you know, much as we want a variety of different generation resources that provide different value—from renewables to dispatchable or nuclear, natural gas with carbon capture—all types of clean energy sources. There can also be a variety of different roles for energy storage technologies as well. Lithium-ion's high power density and quick discharge capacity means that it can be really good for quickly responding to sudden power fluctuation changes or voltage regulation. Meanwhile, other technologies that are longer duration are going to be more important for when there is a seasonality problem. So they really are quite complementary.

Senator CORTEZ MASTO. Thank you.

Mr. Wiley.

Mr. WILEY. Yes, I would just add to the point that Spencer made, and sort of tie back to a question that Senator King asked. He said, what is the tradeoff with iron-air batteries, in particular?

Our modeling, when we look at grids, almost always shows that when we are talking about batteries providing storage to increasing renewable grids, that a combination of iron-air and lithium-ion is most optimized. It provides the lowest cost system for users and the lowest rates to ratepayers. So our view is that it is going to take both. The lithium-ion is really driving the kind of stuff that happens inside the day—shifting energy from 3:00 in the afternoon when the sun is, you know, at the highest point until the evening, and then the long-duration storage provides things that happen over weeks or months or seasons.

Senator CORTEZ MASTO. Thank you.

Mr. Hemstreet.

Mr. HEMSTREET. I would echo the comments around resource diversity. We serve our customers with an integrated system across six states with generation in ten different states. Each of those areas has very unique transmission constraints. You have proximity to load and other issues that make different types of storage attractive in short duration and long-duration. Those opportunities will become apparent, I guess, as we move ahead in terms of what type of storage will be necessary to make sure we can maintain reliability for our customers.

Senator CORTEZ MASTO. Thank you.

And then, let me talk about workforce. I am curious—for the panel—again, what steps do we need to be taking in order to ensure that there is a capable workforce that is ready to deploy to energy storage technologies now and as they mature? Should we be thinking about this in Congress? What should we be doing to ensure that the workforce is ready and trained and moving forward in the direction that this new technology is taking us?

Mr. WILEY. Thank you for that question, Senator Cortez Masto.

That is a question that is top-of-mind for us right now as we think about selecting the site and building our first factory. I mentioned earlier that that factory is likely going to be at the location of a former steel plant or former coal plant that is, you know, located on a river with rail and in a community that has been building, you know, the stuff of that former plant for decades. Unfortunately, while there is a history of building the kinds of things we need, a lot of the people have left those communities, and so, I think one thing we are going to need is support in bringing the people back. The infrastructure is still there, but we need to retrain the workforce. We need workforce retraining programs that reach into our community colleges, reach into our high schools, and reach into the local college systems to help train the next generation of manufacturing workforce and engineers and designers that are going to help us scale this industry.

Senator CORTEZ MASTO. Or even reskilling the existing workforce, right?

Mr. WILEY. Absolutely. To the extent that the existing workforce is there, it would be tremendously valuable to reskill the existing workforce.

Senator CORTEZ MASTO. Sure. Okay.

Anyone else? I know my time is running out.

Mr. HEMSTREET. Sure. Certainly, in the utility industry we have seen, you know, an aging workforce, and that has been the challenge that we have been looking at, you know, for as long as I have been in the industry myself. And so, seeing that happen, we know we need to work with our communities foremost, labor unions, vocational schools, universities, and really expose young people to the opportunities that are available in the energy industry and the critical role that our energy system plays in serving our customers and powering our communities. So I think building that awareness and working closely with folks that are on the forefront of the next generation and showing them what opportunities are available will be important as we move ahead.

Senator CORTEZ MASTO. Thank you.

Thank you, Mr. Chairman.

The CHAIRMAN. Senator Hickenlooper. Oh, I'm sorry. Oh, he snuck in again.

[Laughter.]

The CHAIRMAN. Senator Hoeven.

Senator HICKENLOOPER. I yield to the——

Senator HOEVEN. I will defer to one of them while I am looking for my questions.

The CHAIRMAN. Okay.

Senator Hickenlooper.

Senator HICKENLOOPER. Thank you, Senator Hoeven.

So I will start with Mr. Nelson. And we have heard a number of facets of this permitting gridlock that I think you all have spoken to in one way or another. Do you know, has anyone actually tried to quantify what that cost comes out to be as we try to do the follow-through on the great transition? The costs of taking so long have to be enormous.

Mr. NELSON. Yes, I have seen some estimates. It is very difficult to estimate because, of course, if it doesn't happen then, you know, that could be a huge, huge cost for a project that just does not happen at all. I have also seen some estimates, for example, one for geothermal that finds that the fact that you have to go through NEPA up to six times to build a geothermal plant on public lands adds, you know, another 15 percent just from the financing costs, not to mention everything else. So it is quite high.

Senator HICKENLOOPER. It would be interesting to pull all those together as best we could.

Mr. Hemstreet, these various new technologies that help increase renewable energy and storage that you all are discussing, they are being integrated into the grid as we go through this great transition. This is such a critical part of the transition and yet, it is so complex, as I think all three of you have said. I think we need to ensure that while we are incorporating these changes, we keep in mind those three inherent, ultimate truths: that our energy system has to be inexpensive, reliable, and clean, which, given the complexity, is going to become increasingly hard. Is there anything DOE can do to assist utilities or grid operators or state regulators—can you supply computer modeling, for instance, to help take some of the complexity out and make sure we get the most bang for our buck?

Mr. HEMSTREET. You know, DOE has been very important and played a very important role in researching the importance of storage on the grid and providing a better awareness among policymakers and state regulators around the importance of storage and the benefits that that can provide to a reliable energy system. So we certainly support that work continuing. Advanced modeling of all storage technologies and the benefits they provide is really important because we do not often see the value of those attributes directly. And so, it is important that we build awareness of the value of those types of things so we can convey that to our stakeholders.

Senator HICKENLOOPER. Right. And I think that modeling, I am assuming—you could just nod or shake your heads, and maybe it wouldn't be in the record in that case, but—you all agree that this issue around permitting should be a national priority, is that——

Mr. HEMSTREET. Yes, I do.

Senator HICKENLOOPER. You could imagine you are sitting in the exit row on an airplane so you can answer with a voice, you know, in the exit row, when they ask if you are capable of getting out of the exit row, you cannot just nod your head. So do you all think that it is a national priority?

Mr. HEMSTREET. I do, Senator.

Mr. NELSON. Expedited permitting is important.

Mr. WILEY. Yes, I do as well, Senator.

Senator HICKENLOOPER. So as we do that modeling, I think for each of you, that to make sure that those concerns get inserted and maybe the costs—that the modeling can demonstrate what the cost is of adding to one or another aspect of this, obviously, as I said, is a very complex integration.

Dr. Wiley, there have been recent federal, state, and private-sector pushes to encourage all the research and development in storage and deployment, obviously, that you have been working on. There is always that valley of death, right, between the research and the commercialization, which it looks like you are just coming out of that valley and quite healthy. How could all of these efforts from federal, state, and private sectors be aligned to ensure that we don't lose the innovation and technology in that process of coming through the valley of death? Does that make sense?

Mr. WILEY. It does. And I wish I could say that we are coming out of it. I would say we are in it, and the fine work of this Committee and, you know, the U.S. Government, is helping us cross with the Inflation Reduction Act, with the Infrastructure bill, you know, and to abstract that a little bit, new technology for the energy industry takes usually decades and it needs help every step of the way, from fundamental science research to applied science research, taking breakthroughs and turning them into products. And then, we are at the next step in that process, which is scaling a product from something that scientists and engineers can build one or two of, in a lab, by hand, to something that trained technicians can build millions of in a factory.

Senator HICKENLOOPER. Right.

Mr. WILEY. And you know, in that case, we are competing against things that are already scaled up, that are already being made by the millions and already can make best use of the factory and labor. They have gone down the cost curve already. But we should not confuse what something costs at its beginning——

Senator HICKENLOOPER. Right.

Mr. WILEY [continuing]. With what it could cost in the end. Solar power panels, for example, were, you know, more than ten times what they cost today 10 years ago. They were 100 times what they cost today 20 years ago. And so, you know, if we looked 20 years ago and said, this is 100 times as expensive as a coal plant or a gas plant, we would have, you know, we would have closed the books and gone home. Now it is a fifth the cost of a coal plant or a gas plant to generate electricity from a solar panel. And so, I think we need to be looking to the future and saying, what is the potential of these technologies and then providing assistance every step of the way, especially to ones that advantage us as a country and help us, you know, be independent and be able to do what we need to do.

Senator HICKENLOOPER. Absolutely, and I agree completely that we need to find the ways to look at how we get to scale more quickly once we make that decision that this is something that needs support. And I look forward to seeing your progress as you go forward and begin scaling up your innovations.

Thank you. I yield back to the Chair.

The CHAIRMAN. That's so generous.

[Laughter.]

The CHAIRMAN. Senator Hoeven.

Senator HOEVEN. Thanks, Mr. Chair.

So one of the issues we have right now with the electric grid is not having enough baseload, which is why states like mine are working very hard to decarbonize coal. We have three projects right now going on to do that. Two are coal-fired electric plants. Another is actually a plant that converts coal to synthetic natural gas. So we are working on capturing the CO_2 and putting it down a hole with some of the tools that this Committee has put in place, some of the front-end funding for the equipment that has to go onto the plants to retrofit them, loan guarantees to help them, you know, finance the improvements and then 45Q because, well, it is technologically viable, we have to make it commercially viable.

But we are now at the point where with these tools and good state partnership with industry, our companies now are moving ahead and doing it so that we keep that long-term baseload. Without it, the grid is not stable. So I am going to start with Mr. Hemstreet and ask each of you, we are talking batteries today. Explain to me how the advances in batteries—what advances and in what time frame are going to actually, no kidding, help us stabilize this grid at a time when everybody wants more electricity? I mean, I get a kick out of, you know, everybody is talking about more electricity, whether it is for their cars or their computers or for data mining or anything else, but where is that 24/7, no kidding, electricity coming from? We are working on it. I just described. I want to hear how batteries, and in what time frame, and what way are going to get us to better grid stability.

Mr. HEMSTREET. Well, I will start with that. I think batteries, certainly, as you say, are going to be critical for allowing us to maintain the stability of the grid as we have higher and higher penetration of renewable resources. So, and actually, a critical component of this energy transition will be storage that makes us able to balance out intermittent renewables. In addition to that, you know, as I mentioned——

Senator HOEVEN. But that is general. I am asking what batteries, who is developing them, and in what timeline and what capacity?

Mr. HEMSTREET. Yes, I think, certainly, Mr. Wiley can help on the battery side. You know, I know we are just starting to deploy batteries as part of solar and storage projects and stand-alone batteries. Those are lithium-ion batteries, but we see, you know, we are open to all different types of technologies. And I am not particularly well-versed in exactly what type of batteries will be deployed over time or what will be the successful technology that wins the competitive race to serve our customers. But I do know that storage is going to be important, and long-duration storage, in particular.

Mr. NELSON. Yes, thank you for the question, Senator, and your leadership on carbon capture.

There is a lot of money that was appropriated through the Energy Act of 2020 as energy storage demonstration programs that could be going out today for energy storage demos, and the DOE has not yet put out funding opportunities for those. It is over $500 million. And I think that those demos would be coming on in maybe four or five years from now. So I think there is a huge opportunity there. There are a number of different companies that might be applying for that funding, like Form Energy. There is also Malta, which is developing molten salt storage, or Antora, which is also developing a thermal technology. There are also opportunities to use underground pumped hydro with a company called Quidnet. There are a variety of different companies that are developing these, and they are probably more on the scale of four to five years, which is why it is so important that we, you know, keep our dispatchable technologies online today and try to make those cleaner through, you know, carbon capture retrofits, like with Project Tundra, et cetera.

Mr. WILEY. Yes, thank you for the question, Senator Hoeven.

I had mentioned earlier, we are developing an iron-air battery, and an iron-air battery can use all domestic content. Today, we are 300 people in three locations across the country. In three years, we aim to have launched and scaled our first 500 megawatt, 5,000 megawatt-hours per-year, or excuse me, 50,000 megawatt-hours per-year production facility.

Senator HOEVEN. What time frame? I'm sorry.

Mr. WILEY. Three years.

Senator HOEVEN. To start building it?

Mr. WILEY. To be operational.

Senator HOEVEN. Operational.

Mr. WILEY. And producing 50,000 megawatt-hours per-year. And that would not have been possible without the Inflation Reduction Act to be able to catalyze the capital to make those investments and to proceed with that speed.

There are companies making the announcements for new battery factories all over the country right now, mostly for transportation, lithium-ion transportation. Today, there are about 60 gigawatt-hours, you know, of battery manufacturing in the United States. I believe that there is about a terawatt-hour, you know, just about 20 times what there is today, expected to be online by the end of the decade, primarily allocated to transportation.

The companies like us that are——

Senator HOEVEN. But, yes, that doesn't stabilize the grid. You are talking about transportation. I am talking about stabilizing the grid.

Mr. WILEY. That's right.

Senator HOEVEN. If I could, because I am, thank you, but Mr. Nelson, under pumped hydro, real quick. How does that work? You said underground pumped hydro.

Mr. NELSON. Oh, yes, so you can imagine that you can inject water underground and pressurize it and then you let it back out to, yes.

Senator HOEVEN. Oh, pressure, got it. Thank you.

Thank you, gentlemen, I appreciate it.

Thank you, Mr. Chair.

The CHAIRMAN. Thank you.

Senator Hyde-Smith.

Senator HYDE-SMITH. Thank you, Mr. Chairman, and thanks to the three of you for being here today.

My first question is for Mr. Nelson. It is no surprise that we, as a Congress, should be looking at a diverse portfolio when it comes to energy storage and how that storage affects our electricity grid, just as, which was mentioned previously, across-the-board technology advancements to increase storage reveal greater efficiency in many types of power systems assets. In Mississippi, action is being taken to develop a clean hydrogen hub incorporating renewable hydrogen production, long-duration geologic energy storage, and multiple industry end-users. Mr. Nelson, what are your views on the role of hydrogen in energy storage, and what benefits can we expect?

Mr. NELSON. Thank you for that question, Senator. Hydrogen is a really unique chemical in that it can be used for energy storage. It can also be used directly as an input. You can use it with fuel cells, for a variety of different things. Specifically, for the Mississippi project, it could be used for 100 percent electricity or when electricity is over-produced. It is, you know, it is really kind of a Swiss Army Knife molecule, and it can be stored for a very, very long period of time, and there are several projects underway to better store hydrogen for long-duration use.

Senator HYDE-SMITH. Okay, and no matter what substance these are given to, long-duration storage and other clean energy resources deployment simply will not happen unless electricity markets send the right signals for businesses to invest——

Mr. NELSON. Correct.

Senator HYDE-SMITH [continuing]. In these resources. So given that the electricity markets in this country vary by region, is any particular market structure or region more favorable to the rapid deployment of innovative energy technologies?

Mr. NELSON. Yes, so it depends on the type of technology, but I would say that in the short-term, until market structures are really available to send signals for long-duration capacity, probably some of the more regulated markets in the West and in the Southeast will be best able to deploy long-duration storage technologies because those utilities can make those investment decisions, but it is also going to vary based on the public utility commissions in those states.

Senator HYDE-SMITH. And we all know how the energy storage technology advancements could affect the deployment of utility-scale and distributed storage as well as what implications this could have on future power systems, infrastructure investments, and operations, but explain how energy storage advancements can enable us to maximize the value of existing infrastructure.

Mr. NELSON. Yes, thank you for that question.

So essentially, you know, when there is an imbalance in supply and demand, you either need to, you know, cut your supply or cut your demand, right? So what energy storage can do is, it can absorb extra supply when demand is low and then, it can supply that back when demand is high. So it can increase the utilization of any kind of asset on an equal footing, whether that is a baseload dispatchable power plant, or whether that is a more variable renewable energy source. So it is really helpful for maximizing the value of the grid.

Senator HYDE-SMITH. Okay. And let's talk about critical minerals, and if you could discuss what critical minerals are currently experiencing an evident shortage on a global scale, and how the availability of those minerals are necessary for investments when developing new energy storage and other clean energy technologies.

Mr. NELSON. Sure, thank you for that question.

At least for today's lithium-ion batteries, there are a number that are quite essential. Those include lithium, graphite, cobalt, nickel, and all of those are likely going to have a large increase in demand. The total demand increase for clean energy technologies between now and 2030 will be somewhere between 7 times and 12 times as much as the demand is today.

Senator HYDE-SMITH. And how do we address those demands?

Mr. NELSON. Yes, so we need to make it easier to build those facilities here, so, produce critical minerals in the United States. Also make it easier to build processing facilities, but also make sure that we are not overly reliant on those technologies unless they are absolutely necessary. Those types of batteries are really great for transportation or consumer electronics when you need a lot of power density. They are not as essential for the grid, and there are other great options, like pumped storage hydro or like, you know, metal-air batteries that can provide the duration of storage that is necessary at a low cost, even if it doesn't have the same power density.

Senator HYDE-SMITH. Thank you very much.

Thank you, Mr. Chairman. My time is expired.

The CHAIRMAN. Thank you, Senator, I appreciate it.

I just want to thank all of you again. I think you can tell from the questions you received and the concerns people have, we are going through a transition. We all know that, and we are going through a political transition of understanding we have to have energy that is going to be able to meet the needs of this country so we can be energy-independent and be able to help our allies around the world who are starving right now for energy. So it is going take Democrats and Republicans working as Americans, not retreating to their proverbial sides. I really believe all of your testimony has helped all of us understand the need we have, but I just appreciate it more than you know, and with that, members will have until the close of business tomorrow to submit additional questions for the record.

Again, thank you. Meeting adjourned.

[Whereupon, at 11:52 a.m., the hearing was adjourned.]

APPENDIX MATERIAL SUBMITTED

U.S. Senate Committee on Energy and Natural Resources
September 22, 2022 Hearing
Opportunities and Challenges in Deploying
Innovative Battery and Non-Battery Technologies for Energy Storage
Question for the Record Submitted to Mr. Spencer Nelson

Question from Senator Mazie K. Hirono

Question: What more could states like Hawaii, which is separated from the mainland, do to implement microgrids or other technologies to increase the resilience of the power system to extreme weather or other disasters?

Answer: Hawaii faces unique challenges for electric reliability, resilience, and resource adequacy due to the combination of its isolated grid network, limited land area, and 100% renewable energy target. Increasing the resilience of Hawaii's will require a three-part approach: improving the resilience of generation resources, the transmission system, and distribution networks. Storage, particularly long duration energy storage, can be a cross-cutting solution that simultaneously advances Hawaii's resilience, reliability, and policy goals.

Generation Solutions: A diverse mix of electricity generation resources will be the most resilient against changes in weather or extreme circumstances. For Hawaii, that means attempting to balance contributions from large-scale solar, rooftop solar, bioenergy, hydropower (including conventional and marine/hydrokinetic), geothermal, and wind energy. Over reliance on a single source of renewable energy could create risks for resource adequacy over a prolonged period of time. Crucially, some amount of backup generation, which may not be renewable, will need to be maintained for emergency situations.

Transmission & Distribution Solutions: a hardened transmission and development system (T&D) is one of the most crucial elements of grid resilience. Large scale transmission lines as well as overhead lines need to be hardened against high speed winds or falling trees, as well as wildfires. Other tactics such as undergrounding distribution wires improves T&D line resilience but is significantly more expensive. Therefore, underground wires may be cost-effective in more densely populated areas, such as Honolulu, but are unlikely to be deployed in more rural areas. Hawaiian Electric has proposed a grid resilience investment plan that would bolster a number of T&D systems across Hawaii.

Crosscutting Solutions: As discussed during the hearing, energy storage technologies can support both generation and T&D resilience if properly implemented. Grid-scale Lithium-ion energy storage can provide loadshifting from midday solar generation to cover evening peak demands, and longer duration technologies can be utilized to provide tens of hours of storage, or seasonal storage when renewable energy is unavailable. "Behind the meter" energy storage technologies can provide additional resilience benefits to homes or critical infrastructure facilities if there is a disruption on the grid. Behind-the-meter storage also pairs well with microgrids, allowing smaller grid systems to be islanded from the broader system if there is a power outage or downed transmission line.

October 12, 2022

The Honorable Joe Manchin III
Chairman
Committee on Energy and Natural Resources
304 Dirksen Senate Office Building
Washington, DC 20510

The Honorable John Barrasso
Ranking Member
Committee on Energy and Natural Resources
304 Dirksen Senate Office Building
Washington, DC 20510

Re. Statement for the Record of Ambri Inc. on the September 22, 2022, hearing on opportunities and challenges in deploying innovative battery and non-battery technologies for energy storage.

Chairman Manchin and Ranking Member Barrasso:

Ambri Inc. greatly appreciates the Committee's leadership on energy storage issues and for holding the hearing on September 22, 2022, focusing on opportunities and challenges in deploying innovative battery and non-battery technologies for energy storage. Ambri wishes to offer the following additional perspective as a statement for the record.

Background:

Massive growth in the renewable energy generation market is driving expected global energy storage market growth of 6x over the next several years. To optimize the transmission, distribution, and integration of generation assets, Ambri has developed a novel battery technology designed to meet the demand for large-scale, affordable energy storage.

Ambri batteries were born in the GroupSadoway lab at Massachusetts Institute of Technology (MIT). Ambri's Liquid Metal™ Battery technology utilizes commonly available, lower-cost materials compared to standard lithium-ion batteries and have comparable or superior performance in terms of response time, lifespan, energy capacity degradation, and footprint.

Ambri's battery chemistry utilizes a molten calcium alloy anode, a solid antimony cathode, and a molten salt electrolyte. At operating temperature, the anode and electrolyte melt, lending the term "Liquid Metal Battery." Ambri's battery technology avoids common degradation mechanisms that cause capacity fade compared to other battery chemistries – making them uniquely poised for long-duration energy storage markets. Ambri batteries are targeted at large scale energy storage markets, and are best suited for >10MWh, daily cycling applications.

Ambri's demand for antimony would utilize approximately 1% of world annual production plus recycling per GWh of Ambri batteries. Antimony is currently acquired in small quantities from a U.S. supplier that primarily sources from Mexico. The largest current global sources for antimony are in China, Russia, Tajikistan and Burma per the United States Geological Survey. Ambri is interested in antimony supply from domestic sources and to that end has signed an off-taker agreement with Perpetua Resources, the developer of the Stibnite Gold Project. Perpetua is in the process of restarting production from its gold-antimony project in the in the historic Stibnite Mining District in Idaho.

Earlier this year, Ambri announced the expansion of its manufacturing capacity after securing a new facility in Milford, Massachusetts. Ambri's new facility, measuring 140,000 square feet, will more than triple the size of Ambri's current manufacturing footprint and allow for a production capacity of 200,000 battery cells per year that will be installed into systems for customers starting in 2023. The new facility is expected to support up to 200 jobs and is estimated to be at full volume production in 2024.

In addition, Ambri is currently in the process of identifying the site for a full scal manufacturing facility to increase the production and deployment of its Liquid Metal™ Battery technology. The new facility will occupy a two million square foot area with an annual production capacity of 13.5GWh per year. Ambri has solicited interest from the following states: Alabama, Florida, Georgia, Nevada, North Carolina, South Carolina, Tennessee, Texas, Oklahoma, and Arizona. Ambri is currently viewing specific locations in four of the aforementioned states, and intends to select a site in the final quarter of 2022. Ambri seeks to begin construction in the first quarter of 2023 and begin production in in the third quarter of 2024. The facility will support approximately 2000 new permanent clean energy jobs. The facility will be used to manufacture the battery cells and assembling the battery system into a completed, ready to ship, final product.

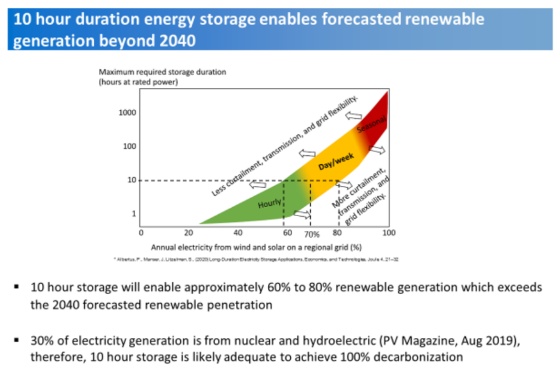
Ambri has also made several other recent announcements related to its progress towards commercialization. This includes the following:

- Earth & Wire, South Africa's independent renewable energy retail brand, placed an order for a 300 MW Ambri battery system to be combined with a 1,200 MWh wind- and solar-powered generation site in the Eastern Cape. To date, this is the largest battery energy storage system to be deployed in South Africa. Ambri will begin shipping batteries for this project in 2024 with installation completed in 2026.
- Xcel Energy, a leading energy provider focused on delivering a clean energy future, will use the world-class Solar Technology Acceleration Center (SolarTAC) to demonstrate Ambri's energy storage technology. Ambri's battery energy system will support Xcel Energy's renewable energy and economic development goals. The year-long energy storage project will be installed at SolarTAC in Aurora, Colorado, where advanced solar and distribution grid technologies have been tested in a real-world, grid-connected environment since 2011.
- Successfully commissioned a demonstration system for Microsoft, the largest cloud service provider. The system is part of a multi-phase program that enables Microsoft to reduce the need for diesel generation, allows for constant renewable power from any source, and provides access to ancillary services markets while providing back-up power for its datacenters.
- Received certification for UL 1973, the Standard for Batteries for Use in Stationary and Motive Auxiliary Power Applications, after successfully complying with the applicable requirements of the standard.

Recommendations:

Ambri wishes to offer the following recommendations to the Committee for consideration of activities related to battery storage:

- 10+ hour goals or targets for long-duration energy storage are misguided. Additional compressive metrics should be considered instead of the potentially misaligned challenge by identifying >10 hour duration energy storage as a critical development of the clean energy future.
    - Albertus, et al, while at ARPA-E,indicated that a ***maximum*** of 10 hour duration is needed to achieve 60% to 80% annual electricity from wind and solar as shown in the chart below:



    - The challenge is to fill the gap between today's 4 hour duration storage up to the 10 hour duration level. The critical issue is the financial attractiveness of an energy storage system performing daily energy shifting in an investable business case. As further explained by Albertus, et al, arbitraging energy from day to evening is the primary application and that requires a spark spread of $0.05 or greater plus a capacity contract of $50 - $75/kW-yr. Under those scenarios, an energy storage system of $150/kWh (all in price to developers) is required to achieve an investable project. There are very few energy storage systems that can achieve this important cost metric and Ambri batteries are one of them.

- Provide more pathways, in addition to the demonstration projects funded sec. 41001 of the Bipartisan Infrastructure Law (BIL), for the federal government to partner with energy storage companies on demonstration projects that power federal facilities and assets using long-duration energy storage. Ambri's batteries would serve as ideal energy storage systems for all types of federal facilities including DOD sites. Ambri battery systems occupy approximately the same space per MWh of energy as Li-ion battery systems yet operate with a longer lifespan, more safely and more quietly (no HVAC system). Ambri requests federal agencies (such as DOE/DOD) help Ambri serve the government's needs for distributed energy storage at its own properties.

Ambri thanks the Committee for providing the opportunity to provide a statement for the record.

With warm wishes,
Adam Briggs
Chief Commercial Officer
Ambri Inc.
53 Brigham Street, Unit 8, Marlborough, MA 01752

RENEWABLE THERMAL COLLABORATIVE

October 4, 2022

Blaine Collison, Executive Director
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The Honorable Joe Manchin
Chairman
Senate Committee on Energy
and Natural Resources
U.S. Senate
Washington, D.C., 20510

The Honorable John Barrasso
Ranking Member
Senate Committee on Energy
and Natural Resources
U.S. Senate
Washington, D.C., 20510

Delivery via e-mail

Chairman Manchin and Ranking Member Barrasso,

On behalf of the Renewable Thermal Collaborative (RTC), I ask that you submit this letter for the record for the Committee's September 22 hearing entitled "Opportunities and Challenges in Deploying Innovative Battery and Non-Battery Technologies for Energy Storage." The RTC applauds the Committee's attention to the critical role of energy storage in achieving decarbonization across critical sectors of our economy. While technologies such as lithium-ion batteries will be essential to decarbonize U.S. electricity amid a shift toward renewables, thermal energy storage will play a crucial role in decarbonizing industrial sectors amid this transition. It is therefore important to consider the role that thermal energy storage can play in enabling cost-effective industrial electrification and to support widespread deployment of this technology, including through tax incentives.

The urgency of addressing emissions from heating and cooling

The RTC serves as the leading coalition for organizations that are committed to scaling up renewable heating and cooling at their facilities and dramatically cutting carbon emissions.[1] RTC members are industrial and commercial thermal energy buyers with ambitious emissions reductions targets who recognize the urgent need to meet the growing demand for renewable heating and cooling in a manner that delivers sustainable, cost-competitive options at scale.[2] RTC members have ambitious emissions reduction targets and urgently require renewable solutions for their thermal energy emissions.

[1] The Renewable Thermal Collaborative was founded in 2017 and is facilitated by the Center for Climate and Energy Solutions, David Gardiner and Associates, and World Wildlife Fund.
[2] RTC members are U.S. and global manufacturers, municipalities, healthcare and university systems, and statewide offices.

RENEWABLE THERMAL COLLABORATIVE

Thermal energy is a key component of energy use in the U.S. and around the world, particularly in the industrial sector. Manufacturers and other industrial producers account for 30 percent of U.S. energy-related emissions and 24 percent of the country's overall direct emissions, nearly on par with electricity and just behind transportation.[3] The commercial and residential building sectors are responsible for 13 percent of U.S. emissions, with most of those emissions created in the use of energy for heating.[4]

Thermal energy storage as an opportunity to decarbonize industrial sectors and beyond

Just as technologies such as lithium-ion batteries are critical for balancing and decarbonizing an electricity grid that increasingly relies on intermittent, renewable sources of generation, thermal energy storage is critical for decarbonizing industrial sectors that will increasingly rely on renewable electricity and other renewable sources of energy. Standalone thermal energy storage can capture electricity from on-grid and off-grid renewables for highly efficient conversion into continuous heat that can be used immediately or stored for later use, even for long durations. These technologies often deploy insulated storage containers directly at the point of end use that contain commonly available solid materials such as rocks, metals, and ceramics that rapidly conduct heat.

Because these technologies, sometimes referred to as solid-state "Sensible Thermal Storage", can deliver even high temperature ranges (over 1,100 degrees Celsius) demanded by the most emissions-intensive industrial sectors, such as iron and steel, cement, refining, and chemicals, they are a potential drop-in decarbonization solution for process heat. They also show versatility in meeting the various end-use needs, from direct heat to steam and heat transfer fluids. Modularity is of critical importance in meeting the manufacturing and buildings sectors' different temperature and production process needs.

Benefits of thermal storage and the need for policy support

Thermal energy storage offers clear benefits in terms of costs and robust supply chains. Because they typically use commonly available materials (e.g. rocks, ceramics), these technologies are less reliant on foreign supply chains and can grow domestic manufacturing at relatively low cost as they reach scale. Secondly, like battery storage, thermal storage technologies are able to charge during hours of low-cost electricity generation, when renewable sources exceed grid demand and produce electricity that would otherwise be

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[3] Direct emissions are those that are produced at an industrial facility and do not include indirect emissions associated with electricity use. Direct emissions are produced by burning fuel for power or heat, through chemical reactions, and from leaks from industrial processes or equipment. "Industrial Decarbonization Roadmap", U.S. Department of Energy, September 2022, https://www.energy.gov/sites/default/files/2022-09/Industrial%20Decarbonization%20Roadmap.pdf

[4] "Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2020", Environmental Protection Agency, April 2022, https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks-1990-2020

RENEWABLE THERMAL COLLABORATIVE

curtailed. As renewable electricity capacity expands, so too does the potential for emissions reductions from thermal storage.

While thermal storage is well-suited to enable cost-effective industrial electrification, the technology is relevant for a variety of temperature ranges and applications, including district heating systems, buildings, mining, and agricultural processing. It is also relevant for electric utilities, since thermal energy can be converted back to electricity while also capturing waste heat for reuse.

Advancing thermal storage technologies requires additional policy support. This includes both continued funding for research, development, and demonstrations (RD&D) and tax incentives. The Inflation Reduction Act (IRA) takes a critical first step on the latter by adding energy storage to the Section 48 investment tax credit, including thermal storage. However, the legislative text narrowly defines thermal storage in the context of providing heating or cooling for a building through an HVAC system. In the future, it will be critical to expand this definition to a greater number of sectors and applications, especially manufacturing processes. The Bipartisan Infrastructure Law and existing DOE initiatives such as the Energy Storage Shot/Grand Challenge provide opportunities for RD&D, but it is important that these efforts include thermal storage alongside battery storage.

The RTC appreciates the Committee's attention to energy storage and welcomes the opportunity to provide additional information regarding thermal storage as an industrial and cross-sectoral decarbonization opportunity.

Sincerely,

Blaine Collison

Rondo Energy, Inc.
rondo.com

October 6, 2022

Senator Joe Manchin
Chairman, Senate Committee on Energy and Natural Resources
United States Senate
Washington, DC. 20510

Senator John Barrasso
Ranking Member, Senate Committee on Energy and Natural Resources
United States Senate
Washington, DC. 20510

Dear Chairman Manchin and Ranking Member Barrasso:

Re: Rondo Energy's Statement for the Record for the Full Committee Hearing on Opportunities and Challenges in Deploying Innovative Battery and Non-Battery Technologies for Energy Storage

Rondo Energy, Inc. (Rondo) appreciates this opportunity to submit a Statement for the Record regarding the opportunities and challenges for US energy storage. Rondo strongly supports the Senate Committee on Energy and Natural Resources in its ongoing efforts to solicit the latest information and deploy the lowest-cost, most effective technologies to achieve the nation's energy goals.

Rondo is an American company that has developed an innovative long duration energy storage technology to deliver zero-carbon heat to a wide range of industrial processes. The Rondo Heat Battery (RHB) captures intermittent electricity, stores energy as high temperature heat in bricks, and delivers continuous hot air or steam. The RHB stores heat energy at temperatures up to 1500°C–enabling use cases ranging from high-temperature steel, cement, and chemical manufacturing all the way to low-temperature food processing. The RHB meets the demanding needs of industry for safe, simple, low-cost energy and economically replaces fuel-fired furnaces and boilers—unlocking not only affordable, but also more predictable, energy prices for America's industries. When connected to the grid, the RHB can make use of otherwise curtailed solar and wind energy, cut the cost of clean energy, and strengthen grid stability and security.

Prominent long duration energy storage solutions hope to reach gigawatt scale in 5 years. Rondo expects to reach gigawatt scale in 2 years. Rondo's first commercial installations with large-scale thermal storage capacity are coming online in California within the next year—and a substantial portfolio of projects are currently in development. Rondo has the supply chain in place to deploy 3 GWh of storage per year, with zero reliance on critical materials.

Historically, it has been difficult to reduce American industries' exposure to volatile fossil fuel prices and curb their greenhouse gas emissions because of a lack of alternative high temperature heat solutions. The emergence of industrial battery storage, including the Rondo Heat Battery, provides an imminently feasible, cost-effective, and equitable way to decarbonize the industrial sector, in which 75% of the energy used is

Rondo Energy, Inc.
rondo.com

to produce heat. As the cost of renewables continues to drop, solutions like the RHB will offer an even more affordable source of heat for American industries and bolster their competitiveness on the world stage.

Heat battery technologies such as Rondo's can play a critical role in transitioning the American economy in ways that benefit everyone. Many of our most valuable jobs are with industries that rely on low-cost heat to drive their processes. Today those heat sources come from fossil fuels, and the handling and combustion of those fuels contribute to pollution and environmental problems in the communities those industries are located in. Rondo heat batteries deliver that process heat at low cost without any fuel use. So some of America's most critically energy-dependent industries can maintain and extend their competitiveness in a zero-carbon world; and some of America's most environmentally impacted communities can maintain and grow their local employment base while eliminating local pollution.

Heat batteries are also uniquely valuable in driving the transition to a zero-carbon economy because they intrinsically eliminate twice as much fuel combustion per unit of electricity as hydrogen systems. Converting electricity to hydrogen, compressing it, then combusting the hydrogen for heat incurs energy losses at each step, and lose half the total energy. All heat batteries convert electricity to heat, store the heat, and deliver it without those losses. So Rondo's heat batteries deliver twice as much fuel and CO_2 savings per unit of electric power as any hydrogen-for-heat system.

The intrinsic efficiency of heat batteries delivers a key benefit in America's transition to a zero-carbon economy. The rate-limiting step in decarbonizing American industry is how fast the wind and solar farms and the power transmission systems can be built. In the immediate term, rollout of heat battery systems can double the rate of industrial decarbonization.

Creating a new technology, however, is not without its challenges, and government support will be significant in enabling technologies like the Rondo Heat Battery to be successfully developed and manufactured in the US, deployed in their first commercial installations, and reach scale. Significant strides have been made in energy storage applications for our electricity grids and vehicles, but our industries have been largely neglected in the energy storage transition. Increased government support and attention on industrial power-to-heat energy storage solutions would not only help American industries reduce their emissions; our American industries would become more competitive and resilient too.

The Inflation Reduction Act established many important policies that will speed the transition to clean energy and provide deep benefits to the American economy. Rondo respectfully suggests that similar policies which enable and support early deployment of heat battery technologies can deliver even greater benefits at much lower taxpayer expense. We look forward to the opportunity to discuss these.