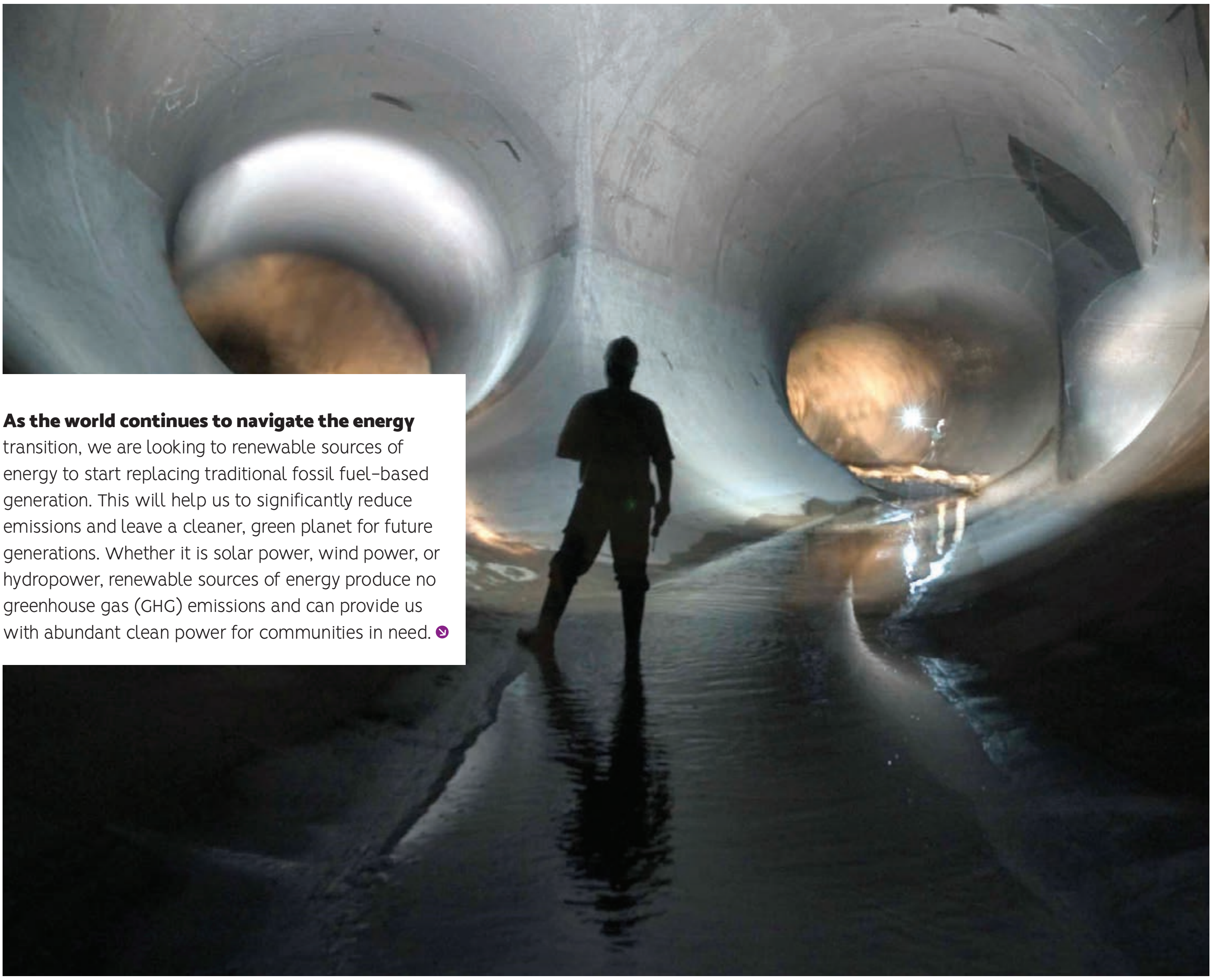
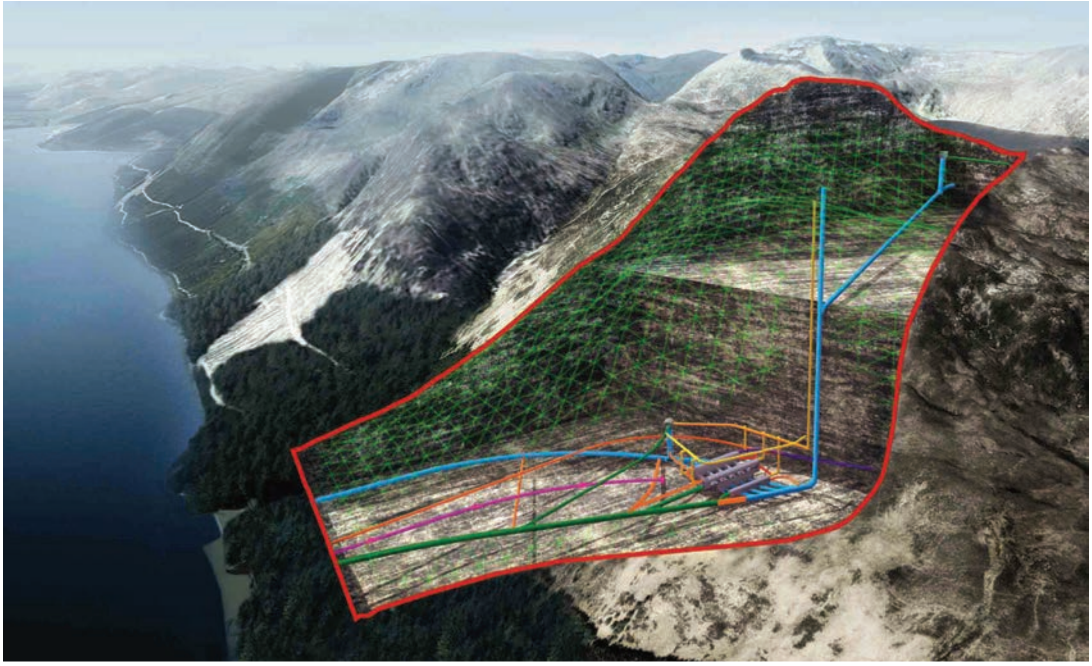
PUMPED STORAGE HYDROPOWER – HELPING TO DRIVE THE ENERGY TRANSITION

With the need to address the intermittent nature of renewable energy sources, pumped storage hydropower can help, says Stantec's **Greg Raines,** Vice President, and **Don Erpenbeck,** Vice President and Global Section Leader (Dams & Hydropower). Underground construction has a role to play in pursuing that path



As the world continues to navigate the energy transition, we are looking to renewable sources of energy to start replacing traditional fossil fuel-based generation. This will help us to significantly reduce emissions and leave a cleaner, green planet for future generations. Whether it is solar power, wind power, or hydropower, renewable sources of energy produce no greenhouse gas (GHG) emissions and can provide us with abundant clean power for communities in need.

Above: Inspecting Rocky Mt pumped storage tunnels ALL IMAGES COURTESY OF STANTEC

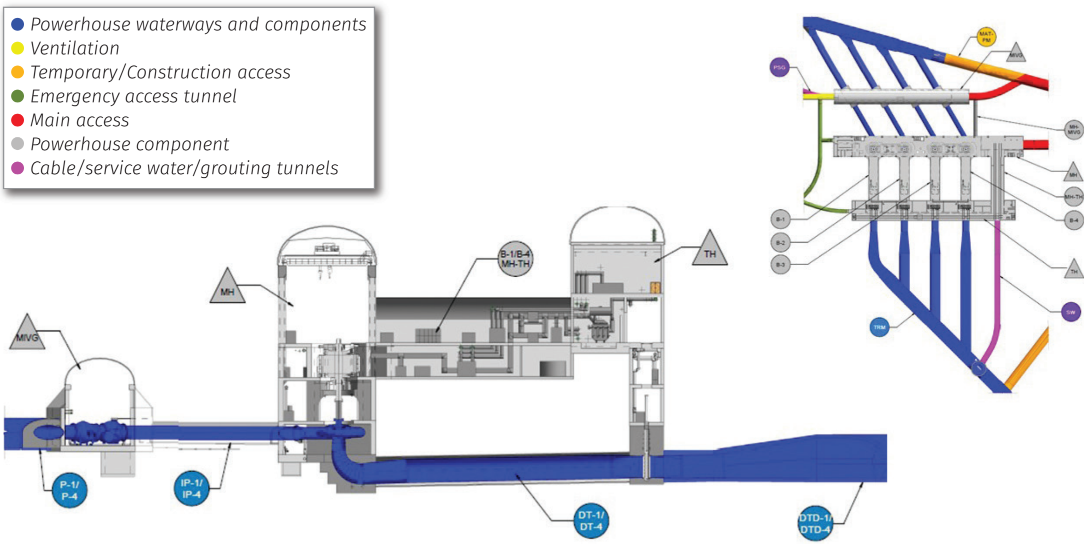


Right:
Schematic of tunnel network and caverns for Coire Glas pumped storage project in UK

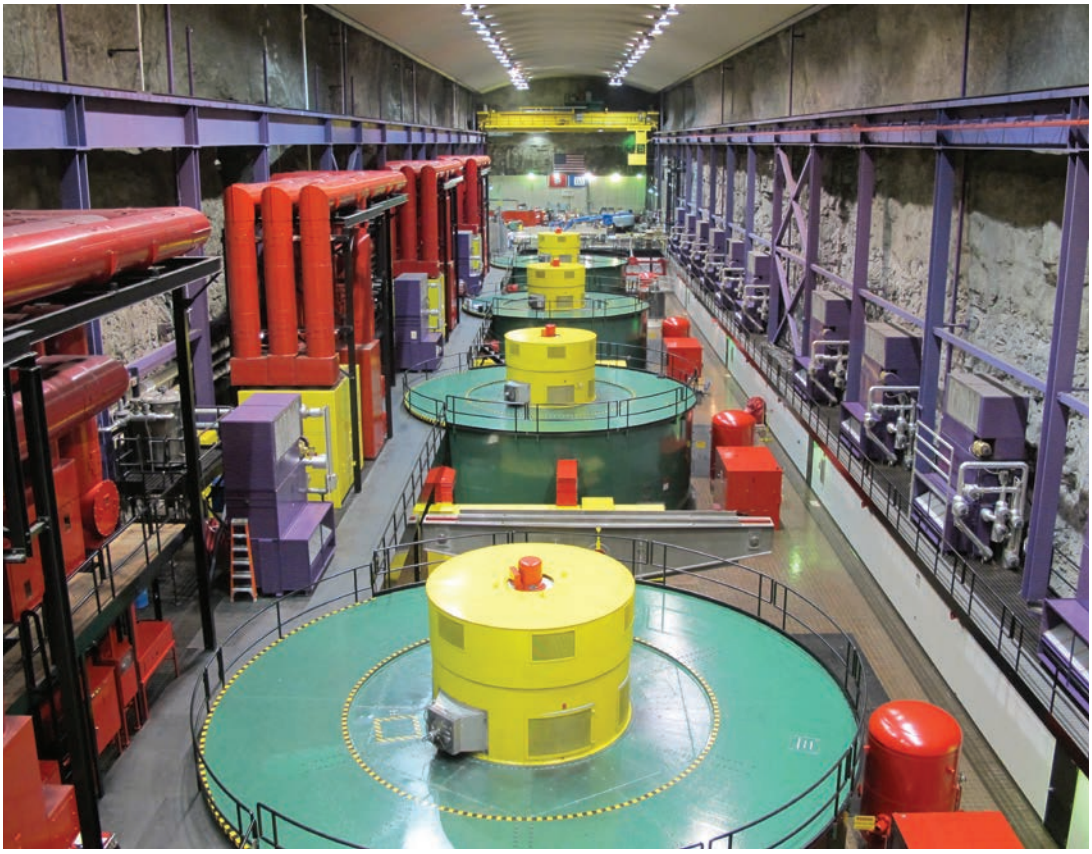
One of the primary challenges that the energy transition faces is the storage of electrical power. Why? Electricity in the grid must be in near-perfect balance of supply and demand with only a couple of seconds to adjust or voltage and frequency problems will occur. Because of the intermittent nature of power sources like solar or wind power, they cannot be turned off and on to match demand. After all, we can't generate these kinds of energy when the sun isn't shining or the wind isn't blowing. This has created a high demand for energy storage systems to store excess electricity to be used at times of peak, but also during the evening when sources like solar are coming offline while demand is still high.

When one thinks of energy storage, they likely think of a chemical battery. But there is another form of energy storage we have been relying on for years – some industry experts even refer to it as a 'water battery'. Water batteries, or pumped storage hydropower, currently store over 95% of the world's electricity. Traditionally, pumped storage had been used to take advantage of excess electricity produced by nuclear and fossil-fuel based plants in the middle of the night when most people are asleep. Now, it is being eyed as a sustainable solution for the energy transition, facilitating growth in renewables and providing grid-scale energy storage that supports a reliable grid.

So, let's look at what pumped storage is, how it works, the infrastructure needed for it, the barriers to widespread adoption, and how these kinds of projects can help drive the energy transition forward.



Right:
Typical layout arrangement of a 3-cavern design for a pumped storage project



Left:
Cavern with equipment inside Racoon Mountain pumped storage plant

WHAT IS PUMPED STORAGE?

Pumped storage hydropower is one of the oldest and most reliable forms of power storage. In fact, it's been around for more than a hundred years. The first pumped storage hydropower project was developed in Switzerland in 1907, and United States (US) started bringing projects online in the 1930's. Today, the International Hydropower Association (IHA) estimates that pumped storage hydropower projects can store up to 9000 gigawatt hours (GWh) of electricity worldwide.

So, how does pumped storage work?

Traditional hydroelectric projects use the pressure of water flowing downstream to spin turbines and generate electricity. These kinds of projects take advantage of water and use the potential energy of its vertical drop to generate renewable energy.

On the other hand, pumped storage projects add the ability to pump water back uphill to be reused time and time again to generate electricity. It is a closed system where water is pumped up, released down, and pumped up again, repeatedly. Obviously, this method would not work in a traditional river system. What pumped storage projects rely on is elevation.

Pumped storage projects utilize two reservoirs close together with a significant elevation difference. These two reservoirs are connected by tunnels that pass through a powerhouse. The powerhouse contains reversible pump-turbines that can generate electricity while in turbine mode and store energy while in pump mode. When there is excess electricity on the grid, water is pumped up for 'storage' in the upper reservoir. When electricity is needed, water is released back down, using the force of gravity to push water through the turbines to generate electricity. That water is then released back into the lower reservoir for later use. The powerhouses are typically an underground complex of caverns and waterways that are some of the largest in the world.

Pumped storage can give us the ability to better manage our grid. It has done so for generations, leveraging the excess energy from fossil fuel-based plants to pump water back up to the upper reservoir for use – energy that would have been lost regardless because we can't simply turn a coal plant on and off each night.

The benefits are clear, and we should be implementing more pumped storage projects around the world. So, let's look at what we need to do to drive more pumped storage projects forward to successful completion.

PUMPED STORAGE: KEY REQUIREMENTS

Pumped storage projects are complex to say the least. They require significant planning and collaboration across a wide range of disciplines. They require very specific site characteristics. And they require additional infrastructure like roads, tunnels, and shafts to make the project viable. Let's breakdown some of the key requirements for pumped storage projects:

Above: Pumped storage projects call for many and varied underground excavations from tunnels, shafts and adits to caverns

- **Finding the right geographic location:** To be economically viable, pumped storage projects need an elevation difference between the upper and lower reservoirs over a short distance. A common rule is that the water conduits should be no longer than 10 times the elevation difference. Suitable upper and lower reservoir sites are needed with it common to have one reservoir, typically the lower reservoir, already existing. Siting studies are required to identify potential candidate sites.
- **Designing the associated infrastructure:** Beyond the site facility, pumped storage projects require extensive associated infrastructure. These include access roads, bridges, tunnels, operations facilities, switch yard(s), and communications. These projects also require extensive transmission lines and electrical infrastructure to interconnect locations, adding to the complexity.
- **Complex tunnel system:** The underground components can become extremely complex with the powerhouse cavern, waterway tunnels and shafts, drainage galleries, manifolds, surge facilities, and access tunnels. With the powerhouse usually being on the critical path, access tunnels to the powerhouse need to have the quickest access. Other elements need construction access tunnels to not interfere with the powerhouse construction.
- **Integrated team:** Everything affects everything. A multidisciplinary team of experienced experts is required for pumped storage development. This demands careful integration as elements seem to be in a constant state of adjustment with each requiring interdisciplinary coordination. A well-developed integration plan must be executed to keep elements aligned. Design and construction tools such as BIM, Deswik, and Leapfrog can help facilitate integration.
- **And much more:** Licensing, permitting, and high voltage interconnection agreements are all needed in addition to the infrastructure. These are complex processes to be followed for approvals and can take years of upfront work to get a plant to the point of construction.

PUMPED STORAGE: UNDERGROUND COMPONENTS

While the reservoirs at pumped storage facilities are above ground and visible, a lot of the components for these projects are underground. Let's explore some of the key underground components that are needed for pumped storage projects.

- **Underground vs. pit style powerhouse:** Whether it is a one, two, or three cavern underground complex or a surface, pit, or shaft style powerhouse, an economic and environmentally acceptable powerhouse must be developed as the central component of the facility with the largest cost drivers. Extensive studies are required to resolve this most fundamental element. For performance issues, the pumps must be 25m to 50m deeper than the lower water level.

- **Tunnels and shafts:** Waterway, surge, access, ventilation, cable, drainage, and other types of tunnels and shafts are required to service all the requirements. The waterways form the backbone of the tunnels and shafts. They need to be able to handle the very high internal pressures along with high water velocities and surge pressures. For performance and economic reasons, the powerhouse should be close to the mid-point of the waterway tunnel system. This shortens the high-pressure tunnels but also makes the water in the tunnel more stable for quickly starting and stopping. These extreme challenges dictate many requirements from in-situ stress conditions, rock quality, consolidation grouting, excavation methods to limit rock damage, and robust lining with reinforced cast-in-place concrete and steel, with membranes used in some cases.
- **High voltage transformers and cables:** Placing transformers in underground facilities can be difficult but siting them on the surface can be more desirable to the operations. If placed underground, these components represent some of the largest and heaviest elements to install. So, the access tunnel needs to be designed so they can be carried in with a grade of typically less than 10%. This element drives a significant portion of the requirements to keep the access tunnel short for construction scheduling or the need for early construction access tunnels. The high voltage power must then be brought from the transformers to the surface in its own cable or shaft system.
- **Safety precautions:** Safety is paramount, from design to construction to operations. Fire and life safety during operations calls for extensive ventilation, isolation, and suppression systems. Ventilation systems can include dedicated shafts and tunnels with fans along with complex requirements for electrical power plants with high voltages. With the high-pressure water and caverns being below water levels, significant dewatering and sump systems are integrated into the complex.
- **Geotechnical:** Not only are we looking for good geotechnical conditions, but the investigation requirements are extensive with a geologic model needing to be developed with borings that can be very deep, time-consuming, and expensive to install. Several upfront stages are also needed. These can take years to complete from development through permitting execution and reporting. But it is also common to have an exploratory adit targeting the powerhouse where additional drilling and testing can be performed.

KEY CHALLENGES

As with any complex design, there are many challenges we face when developing pumped storage hydropower projects. From cost to siting to transmission infrastructure, engineers have a lot of problem-solving to do to ensure the successful implementation of these facilities, including:

- **Time and cost:** With the upfront licensing and permitting, infrastructure, design, and construction time, these projects typically take a minimum of seven to eight years to complete. With many roadblocks, that time can be greatly extended. When it comes to cost, these projects can cost billions of dollars. While justified, it is hard to develop in a capital improvement plan. The need is certainly there to augment renewables, but other technologies with lower up front capital costs, such as battery storage, can seem more attractive. The two types of power storage can overlap, but the long duration capacity of pumped storage projects far exceeds that of batteries, and the delay in financing may only delay the inevitable need for larger long duration storage. A typical pumped storage project has 8 to 12 hours of storage with some plants having over 20 hours at full power. Batteries tend to be better suited at less than 4 hours. Also, the life of pumped storage projects is over 100 years, regardless of how often it is discharged. A battery plant is substantially less than 15 years depending on how often it is discharged. The longer the storage duration and the longer the time horizon, the more favored pumped storage hydropower becomes.
- **Building enough to meet demand:** Many pumped storage facilities are needed to augment renewable energy. With capacity demands ever so close to capacity output, the potential for power shortages exists right now. Building enough pumped storage projects to meet demand is a formidable task, especially given the long lead time for full development to operations.
- **Procurement and scheduling:** Procurement includes finding a contractor to build and, in some cases, design the projects. Early lead item procurement, such as the pump-turbine generators designed and manufactured specifically for each application, are also needed. These projects can use complex delivery methods with EPC being the most common approach. Sometimes these methods can tie-up multiple entities for years during the procurement process, leading to longer schedules.
- **Finding the right site:** Pumped storage projects need elevation over short distances, access to water, sites for upper and lower reservoirs, appropriate geotechnical conditions, proximity to transmission facilities, and more. They also must be suitable for the public and government oversight agencies. The number of feasible sites becomes greatly limited, so much so that developers need to have multiple sites being developed as many factors can delay or eliminate a site.
- **Proximity to communities:** These projects need to be near existing transmission facilities and substations to avoid transmission problems as the cost and impacts for installation of new transmission lines can be significant. The transmission installation becomes its own project in addition to the power plant. Also, the closer they are to major load centers, such as a

city, the more beneficial they are to the quality of the power, allowing them to gain revenue for secondary services such as voltage and frequency regulation.

- **Industry capacity:** Hydropower development is a mature industry. But with limited hydropower installations over the last 50 years, particularly projects associated with pumped storage, the number of entities and skilled people to develop these projects is extremely limited. With the potential growth over the next 25 years, the capacity to deliver needs to grow even more so.

PROJECT EXAMPLES

There are hundreds of billions of dollars of pumped storage projects proposed worldwide, including in the US. However, only a handful are in or about to begin construction. Our teams at Stantec have vast experience when it comes to designing pumped storage projects. We have worked on projects all the around the world, from the US to the UK to Asia. It should come as no surprise, but not all pumped storage projects are the same. Some key examples of our project work include:

- **Coire Glas** in the UK, which is a new plant just beginning construction with an exploratory audit. The facility is a 1300-megawatt (MW) plant being constructed by SSE Renewables. It is the first such plant in 40 years to be built in the UK.
- In North America, **Eagle Mountain** is a 1300MW (26,000 MWh) scheme at a brownfield site outside of Palm Springs, California. It is ideally located on the high voltage corridor between Phoenix and Los Angeles. The site uses the mine pits from an old, abandoned iron mine as the reservoirs, connected by an underground power complex and waterway. The project has most of its permits and licenses. There is similar progress being made in Montana, Oregon, and Washington. With dozens of others in planning and early design, the time has come for more pumped storage in North America. After all, the last pumped storage project constructed in the US was very small and more than 15 years ago. The last utility grade project that compares in size was nearly 30 years ago.
- There are also examples around the world. The **Snowy 2.0** project in Australia is under construction but has been hit with some delays. It should be back in construction soon. Australia has several more projects in the hopper, with one potentially being the largest pumped storage project ever to be built. Israel also has developed three major facilities: Gilboa, Manarra, and Kochav. The 300MW Gilboaw was recently completed and is now in operation, Kokhav (344MW) is nearing completion while Manarra is just starting construction.

PROMOTING ENERGY RESILIENCY WITH PUMPED STORAGE HYDROPOWER

The energy transition won't happen overnight. It will take significant planning and investment in our electrical infrastructure. And as we start to bring more and more renewable energy online, we must find a way to reliably manage our grid. Like we said earlier, renewable forms of energy like solar power and wind power are great for society and the environment. But when the generation of solar wanes in the evening hours, or the generation of wind power wanes on calm days, we must find a way to sustainably store electricity for times of peak demand.

That's why we believe whole-heartedly in pumped storage hydropower projects. There is a reason these kinds of projects have been around for more than a century. Pumped storage is both reliable and sustainable, and it can reduce our need for fossil-fuel based generation. That's why it's a key to the energy transition, and why we're working around the world to develop these kinds of projects. ■