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68-86GW

Pumped hydro forecast for 2021-2030

10.4 hours

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$65-91bn

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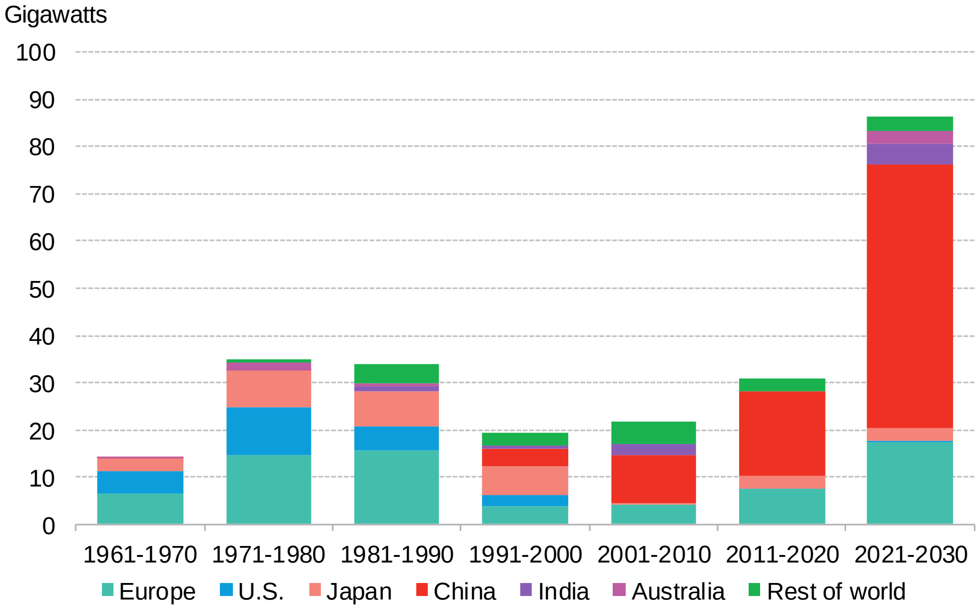
Cecilia L'Ecluse

Pumped Hydro: A Primer

Pumped hydro storage is a mature technology, used for bulk energy storage for more than a century. BNEF expects almost 90GW of new build this decade, triple the amount commissioned during the previous decade. This research note explores what drives the uptake of new pumped hydro projects and what their role can be in future grids.

- Pumped hydro construction today is dominated by China, where this technology is a key part of the energy strategy. Activity is beginning to increase in Europe and Australia.
- Historically, pumped hydro was developed to take advantage of energy arbitrage, by pumping at night and providing peak power during the day. This business model has been distorted by the increase in renewables in the electricity mix; instead, pumped storage now is built to integrate intermittent renewables generation, to provide flexibility to the grid and to offer long-term storage.
- Financing greenfield projects is challenging because of long development times, high upfront capital cost and a lack of financial incentives for long-term storage in deregulated electricity markets. Most pumped hydro projects rely on concessional financing, at least in part.
- Opportunities exist in refurbishment. Some 51GW of pumped hydro projects have been operating for more than 40 years. Refurbishment can extend their lifetimes to 80-100 years.
- With many countries now stating an ambition to reach net-zero emissions by mid-century, pumped storage fits the need for low-carbon, long-term storage.

Figure 1: Historical and forecast additions of pumped hydro projects, 1960-2030



Source: BloombergNEF. Note: 2021-2030 forecast includes projects under construction as well as projects that are in late state development (see figure 13).

1. Back to the forefront?

As of 2020, there are around 155GW of pumped storage capacity operational, making up 86% of global storage capacity

Today, pumped hydro makes 86% of installed in-front of the meter energy storage capacity on a GW basis worldwide. As of 2020, there are around 155GW of global pumped storage capacity operational (Figure 2). Europe (55GW), the U.S. (23GW), China (30.9GW) and Japan (27.6GW) make up 88% of this (Table 1).

The first pumped hydro project was developed in the 1890s in Limmat, Switzerland. Since the 1970s, additions have averaged some 20-35GW per decade, globally. Until the 1990s, pumped storage build was almost exclusively in Europe, the U.S. and Japan, to support base-load energy from fossil fuels and nuclear power by providing peaking capacity. There was a slump in the 1990s in new build in Europe and the U.S., at a time when many electricity markets liberalized – a process that tends not to provide an incentive for investment in new pumped hydro capacity. At the end of the Nineties, growth started in China, where pumped hydro is key to achieving its long-term power strategy. Now there is renewed attention globally (Figure 1), as governments try to figure out how their grids can support an increasing proportion of variable renewable generation. The announcement of net-zero emission pledges is likely to help drive future growth.

Table 1: Top 10 countries with operational pumped hydro capacity

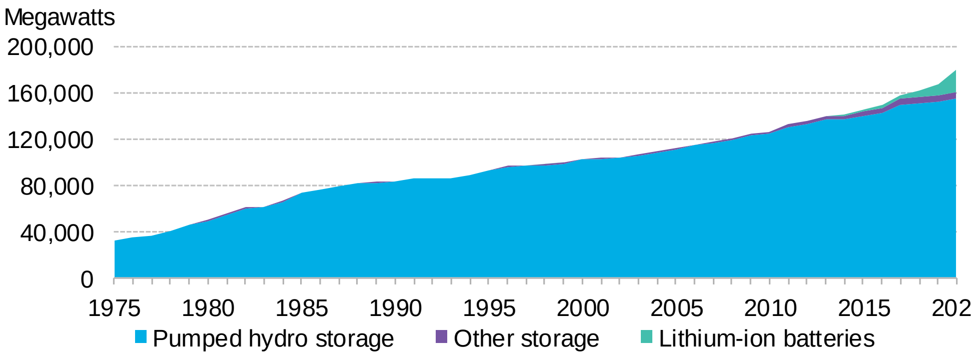
Country	Capacity
China	30.9GW
Japan	27.6GW
US	22.9GW
Italy	7.7GW
Germany	6.3GW
Spain	6.1GW
France	5.8GW
Austria	4.7GW
South Korea	4.7GW
India	4.1GW

Source: BloombergNEF, DOE global storage database

Pumped storage at glance

- Stores energy in the form of the gravitational potential energy of water, created by pumping from a lower reservoir into a higher reservoir. Energy is generated by running the water back down from the higher reservoir through a turbine.
- **Mature technology**, used as a form of **bulk energy storage** for more than a century.
- Historically, mainly used for **energy arbitrage** to meet **peak demand**, but now increasingly also for **ancillary services.**
- The capacity of new pumped storage plants is typically 500-1,000MW, but can be up to several GW.
- Storage durations are generally **much longer than for lithium-ion batteries**; the average duration for new pumped hydro plants is **10.4 hours.**
- Renewable, low-opex technology, with a very **long asset life** of up to 80 years.
- Efficiency of new plants is around 80%, **capex** is in the range **$0.6-2.1 million per MW.**

Figure 2: Cumulative operational global utility-scale storage capacity, 1975-2020



Source: BloombergNEF, DOE global storage database. Note: "other storage" includes electro-chemical, electro-mechanical and thermal storage. Li-ion battery capacity is based on BNEF data, pumped storage and "other storage" DOE data.

2. What pumped hydro can and cannot do

2.1. Bulk energy storage

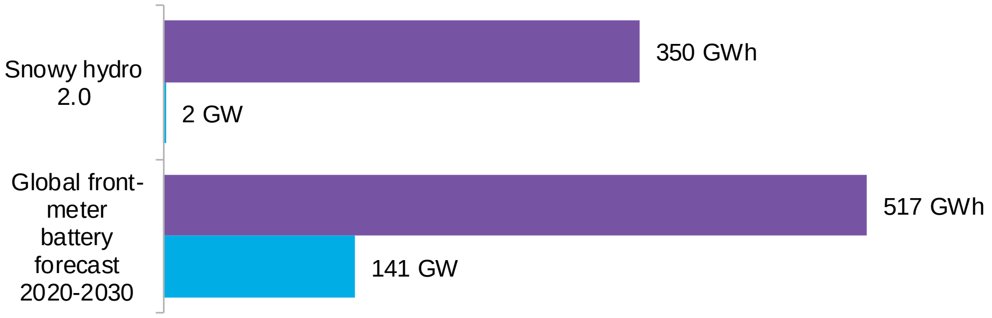
The size of the pumps and turbines determines the power output of a pumped hydro plant. The storage duration, however, is constrained by the amount of water that can be pumped, i.e. the size of the reservoirs. This means that power and energy are decoupled, which makes the technology well-suited for bulk energy storage. Pumped hydro projects with 10-20 hours of storage are common. By comparison, utility-scale battery projects typically provide up to four hours of storage today. As lithium-ion battery prices come down, project duration is increasing.

At the extreme, pumped hydro projects can have drastically longer storage duration than lithium-based systems. Snowy Hydro 2.0, a project under development in Australia, will have 2GW power output and 175 hours of storage when commissioned. This one project alone is the equivalent of 68% of our global front-meter battery forecast for the next decade on a GWh basis (Figure 3).

Snowy Hydro 2.0, a 2GW giant with 175 hours of storage

Snowy 2.0 is a government-owned pumped hydro project under construction in the state of New South Wales, Australia. The $1.9 million/MW ($10,900/MWh) scheme will make use of dams that are part of an existing hydro complex, with commissioning expected between 2025 and 2028. Paul Broad, CEO at Snowy Hydro, told BNEF that the operation of Snowy 2.0 will focus on both daily energy market operations, and providing bulk storage capacity in periods of low renewable energy production: “There are times when the sun stops shining and the wind is gone for several days in a row, which is when Snowy 2.0 can keep generating. But we also have firming contracts with solar and wind generators. This is a fully firmed hedged product that we sell in the market place and will be very competitive”.

Figure 3: Comparison of capacity and storage hours of large-scale batteries and pumped hydro



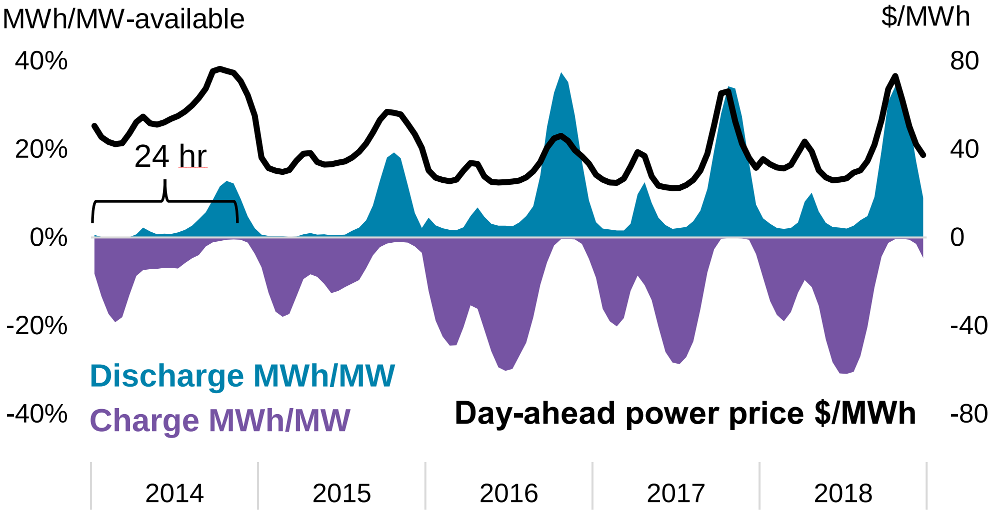
Source: BloombergNEF

2.2. Energy arbitrage

Pumped hydro plants built in the 1960-80s relied on energy arbitrage for their revenue. In Switzerland, for example, pumped hydro plants were built around a business model of pumping (storing energy) using cheap imported French nuclear energy at night, and generating during the daytime peak demand. However, in Europe, due to the increase in solar and wind generation in the electricity mix, the spread between day and night prices has decreased and become less volatile, especially in Germany and Switzerland.

In other markets, arbitrage opportunities are increasing again, for example in California. Helms Pumped Storage (1GW) is one of PG&E's most valuable assets, according to BNEF analysis. Its energy margins have risen substantially since 2016, due to increased arbitrage opportunities for storage facilities in PG&E in recent years. Daily power price spreads have widened since 2016 due to increased solar and hydro generation. Helms now charges in the middle of the day instead of late evenings, as increased solar generation has depressed midday power prices (Figure 4).[1]

Figure 4: Helm's generation and power price profiles – average day per year



Source: BloombergNEF

2.3. Ancillary services

Pumped hydro plants can provide a wide range of grid services. Systems can switch from standstill to generating in 60-90 seconds. With modern ternary units (see section 5 on technology) this can be even faster, for example the Kops II facility in Austria can reach its maximum output of 180MW in 20 seconds. Pumped hydro can provide the following services (definitions are provided in appendix A):

- Secondary and tertiary frequency response
- System inertia
- Blackstart, in case of black-outs
- Reactive power
- Voltage management

What pumped hydro projects cannot provide is primary frequency regulation. Pumped hydro is not fast enough to respond to rapidly changing power requirements.

For ancillary services, pumped hydro competes with lithium-ion batteries, many of which have been built in the last decade to provide frequency regulation. However, these are different technologies with different applications; for example, while lithium-ion batteries can provide

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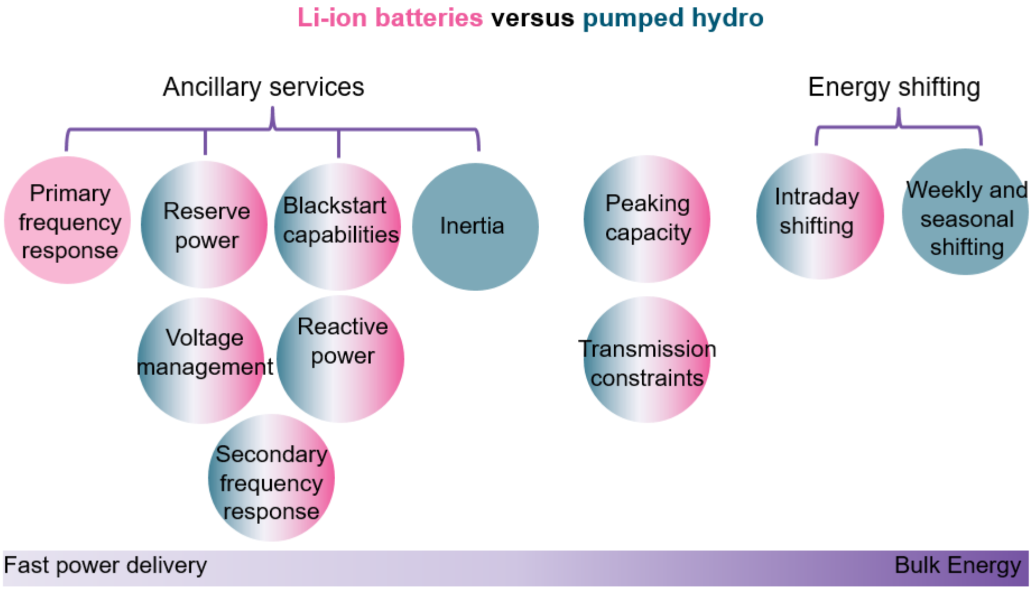
[1] *PG&E's Most Valuable Energy Storage Asset* (web | terminal)

primary frequency response, and pumped storage cannot, the latter can be used to shift energy over a number of weeks or even months. That is not feasible with batteries (because the efficiency of a lithium-based system drops if storing energy for more than a week).

Li-ion batteries and pumped hydro are not necessarily competitors. Both are needed, as they provide different services to the system.

While both technologies can provide other services, often one technology will be more suited to the task than the other, depending on whether fast power delivery or bulk energy is preferable for that kind of service (Figure 5). Mike McWilliams, head of energy at London-based economic forecasting company CEBR and an advisor on hydropower for the World Bank, told BNEF that people are beginning "to realize that batteries and pumped storage are not in competition, they are complementary: batteries are for rapid response and fast ramping, and active injection of power. Pumped hydro is a passive response in terms of system inertia. Batteries are good for stability, pumped hydro for security of supply. I am keen on having hybrid projects: pumped hydro with batteries. If you attach one-hour battery storage to pumped hydro, using the same switchyard, you have a very valuable grid stability tool."

Figure 5: Grid services provided by lithium-ion batteries and pumped hydro storage



Source: BloombergNEF

While pumped hydro can provide ancillary services, business cases cannot rely on this revenue stream alone. For the most valuable ancillary services (primary and secondary frequency response), pumped hydro is likely to be beaten by batteries. Moreover, as McWilliams said, financing on the back of ancillary services is not easy: "People tend to think that the grid paying for ancillary services is an ideal business model. But, for example in Ireland, there are 20 different revenue streams from grid services; some can be stacked and some cannot. If you are a developer trying to finance a pumped hydro project, doing it on the back of one tariff is hard enough, but with 15 different revenue streams it is a nightmare."

At the moment, services like inertia are not valued in most markets. This is beginning to change, and in 2020, the U.K. launched the first physical inertia service. In the future, more markets may start similar services to complement the synthetic inertia services provided by batteries.

Inertia versus synthetic inertia

Inertia is a property provided by spinning masses that are directly connected to the grid. The inertia that spinning masses provide means that if power input or demand drops, the severity of system frequency change is dampened. In place of grid-connected spinning masses, fast-responding energy storage systems such as lithium-ion batteries can provide synthetic inertia. This requires systems to react nearly instantaneously to counter any changes to frequency. While synthetic inertia is effective, it is an artificial response and must be carefully tuned to ensure it supports the grid in high-speed applications.

While synthetic inertia can be used to effectively replace inertia, some grid operators do distinguish between the two.

2.4. Integrating renewables

Pumped hydro can help integrating more renewables into the grid. For example, China used to have really high curtailment levels of renewable energy: in 2016, some 17.1% of wind generation and 9.8% of solar generation was curtailed. In 2019, curtailment was only 4% of wind and 2% of solar. The reason why curtailment levels came down was mostly a change in policy in 2017 (coal plants sometimes ran to meet quotas while wind was curtailed, before deregulation fixed this imbalance), but better interconnection and pumped hydro alleviating transmission constraints also helped.[2] Pumped storage plants are considered as part of the transmission system rather than generating assets, and are built to increase system flexibility and bring down curtailment levels for renewables. Pumped hydro is core in China's national plan, to integrate more renewables now; the country added 17.3GW new pumped hydro capacity during 2010-2020, and according to BNEF's forecast it will add another 56GW during 2021-2030.

In southern Australia, a "Battery of the Nation" development is proposed, to help integrate current and future renewable energy development.

Figure 6: Proposed interconnector between Victoria and Tasmania

Source: *Marinus link analysis report*

Hydro Tasmania's Battery of the Nation Initiative

Hydro Tasmania is the state-owned utility in Tasmania, owning approximately 2.5GW of conventional hydro capacity across 50 dams. The idea of the Battery of the Nation initiative is to use Tasmania's hydro resources and add several GW pumped storage "battery" that can firm up generation in Australia's southern states, as well as enable wind development to happen in Tasmania.

Tasmania and the southern shore of mainland Australia are separated by a sea, so the feasibility of this development depends on a good interconnection between Tasmania and the state of Victoria (Figure 6). Currently, the 500MW Basslink interconnector allows Hydro Tasmania to supply some of the peak load capacity on the Australian mainland. However, a bigger interconnection capacity is needed to make possible the Battery of the Nation project. The proposed Marinus link, consisting of two 750MW cables, would increase interconnection capacity to 2GW. The two cables are currently going through cost-benefit analysis. Once the interconnector is in place, new pumped hydro can support southern Australia's renewables expansion. Christopher Gwynne, program director at the Battery of Nation Initiative, explained how: "We modelled the future electricity market, and found that in the southern states with lots of wind and solar, pumped hydro sites with 12-24 hours of storage would have a high utilization in 10 years' time, when there is much more solar and wind and several coal plants will have retired. Pumped hydro sites with eight hours of storage or less would not be valuable as these

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[2] See *Solar and Wind Curtailment: A Waste of Energy?* (web | terminal)

may be directly competing with batteries in 10 years' time, but 12-plus hour pumped hydro will be valuable, as deep storage will then be very economical. We've already found three strong sites (1.7GW in total) that reach this requirement. Tasmania also has very good wind resources, so new pumped hydro will unlock new wind development as well."

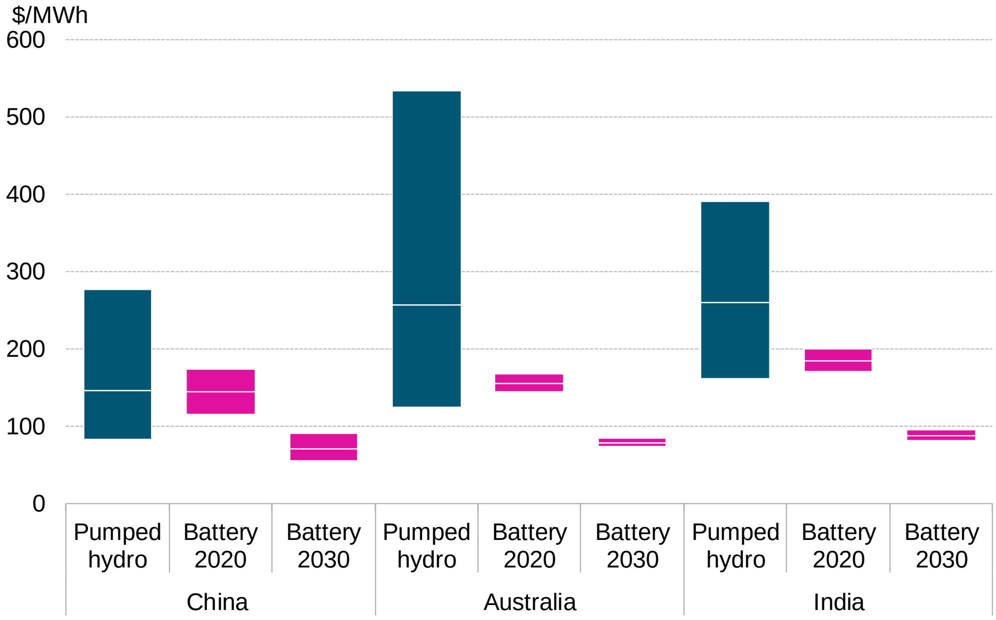
3. Capex and levelized cost of electricity

Pumped hydro sites are big infrastructure projects and no two projects are the same. Capex is always project-specific and depends on:

- The amount of **civil works** that are necessary. Civil works make up around 70% of the cost of pumped hydro projects and can include the construction of dams or excavation of reservoirs, the digging of tunnels, the digging of an underground powerhouse, surface works like road construction, etc. If some of these are already in place (e.g. the reservoirs), the project will cost less.
- The amount of **infrastructure** that is already onsite. Pumped hydro sites are usually connected to the high-voltage system. New transmission capacity can be a considerable cost. For example, the cost of the 250MW Kidston pumped hydro project (page 12) is estimated at A\$600 million (\$456 million at current exchange rates), with another A\$100 million dollars investment in transmission capacity.
- The type of **power unit** used (see section 5 on technology). Flexible, variable-speed turbines are more expensive than fixed-speed turbines.

For this reason, the levelized cost of electricity for pumped hydro ranges from \$82 to \$409/MWh (Figure 7):

Figure 7: Low, medium and high LCOE for pumped hydro and 4-hour utility-scale battery



Source: BloombergNEF

The capex of projects under construction (see full list in Excel attached to this note) range from $630,000 per MW (Tehri 1GW, India) to $2.1 million/MW (Tauernmoos 170MW, Austria). The average cost per MW for Chinese projects, at $794,000/MW, is considerably lower than the average cost per MW in other countries excluding China, at $1.5 million/MW. Table 2 shows capex for selected pumped hydro plants under construction, per megawatt.

Table 2: Capex of selected pumped hydro projects under construction

Project name	$/MW
Nant de Drance (Switzerland)	2.0 million
Snowy 2.0 (Australia)	1.9 million
Tauernmoos (Austria)	2.1 million
Abdelmoumen (Morocco)	0.9 million
Panlong (China)	0.9 million

Source: BloombergNEF

The cost per MWh had a very wide range, from as low as $11,000/MWh (Snowy 2.0) to $288,000/MWh (Tauernmoos). On a MWh basis, pumped hydro is now cheaper than lithium-ion battery storage, which costs around $300,000 /MWh for a four-hour system. By 2030, the cost of lithium-ion battery storage projects will have come down to around $167,000/MWh, roughly equal to a pumped hydro project.

On per MWh basis, the cost of pumped hydro ($11,000-288,000/MWh) is cheaper than that of li-ion batteries ($300,000/MWh). By 2030, the two technologies will be in the same cost range on a per-MWh basis.

4. Development opportunities and challenges

4.1. Greenfield

There are plenty of sites around the world that can be developed as greenfield pumped hydro. A study by Australian National University found 616,000 potential pumped hydro sites around the world, with a storage potential of 23 million GWh (Figure 8). This study was conducted using geographic information system (GIS) algorithms and did not take into account geological, environmental or heritage constraints, as well as the commercial viability of these sites. All of these are barriers to pumped hydro development (see 4.3.).

Figure 8: Potential greenfield sites for pumped hydro storage

Source: Australian National University

4.2. Brownfield and refurbishment

Expanding existing pumped hydro assets is cheaper and quicker than building greenfield sites, as existing dams, reservoirs, geological and environmental studies, and access roads, can be used. Pilar Gonzales, innovation manager at Iberdrola, the Spanish multinational utility that operates more than 3GW of pumped storage in Spain, told BNEF: "There is a lot of development going on in terms of improving flexibility and retrofitting existing plants by replacing the old turbines with reversible and/or variable-speed turbines. Moreover, Iberdrola analyzes existing dams to see if they could be used in the development of new pumped hydro sites. Spain alone has a potential of 10GW using existing dams. These potential projects have a much shorter development time, as you can just use existing reservoirs and connect them."

Iberdrola is also developing the 880MW Tamega pumped hydro project in Portugal.

878MW expansion of the La Muela pumped hydro site in Spain

In 2006, Iberdrola started the expansion of its 634MW La Muela I pumped hydro plant, which started operations in 1983. La Muela II was commissioned in 2013, at an investment cost of $537,000/MW, which is 68% below the average cost of greenfield pumped hydro plants in Europe. The expansion used the existing dams and reservoirs of the Cortes-La Muela hydro complex.

Refurbishing old pumped hydro plants is common practice, as the useful life of these assets can easily reach 80 years. In fact, most pumped hydro plants built since the 1950s are still in operation today. There are 51GW of pumped hydro projects that have been operating for more than 40 years now, and refurbishment can extend their lifetime to 80-100 years. Refurbishment can include replacing worn parts, but it can go further and modify or change the old turbines for newer, more efficient machines.

Refurbishment of the 360MW Ffestiniog pumped storage plant in Wales, U.K.

Ffestiniog has been in operation since 1963. In 2017, after 54 years in operation, Engie announced that it would refurbish the power station, to increase the flexibility of the power units and extend its lifetime by at least another 20 years. Voith Hydro won the contract to refurbish the first two power units, in total 180MW, for 40 million euros ($ 269,000/MW).

4.3. Challenges

Long development times

The development of a pumped storage project can easily take 8-10 years.

The **permitting process** for pumped hydro plants is **long and complex**. Constructing dams and reservoirs can have environmental impact, and this requires careful assessments by governments. Moreover, reservoirs are often located in hilly, inaccessible areas, for which extra licenses are necessary for the civil works. Taking into account the permitting process of around 3-5 years and a construction time of another 3-5 years, the development time of pumped storage projects can be 8-10 years.

Financing

Financing is tricky for pumped hydro projects for a number of reasons:

- The **high capital cost and long development times** are a major barrier in the way of attracting private finance. For most private investors, waiting 10 years for a return to come is too long.
- In some **deregulated electricity markets**, like the U.S. and Germany, there is **no financial incentive** for long-term storage and for building transmission. There is also no compensation for the flexibility services, like inertia and reactive power, that pumped hydro projects provide to the system. Long-term storage that supports renewables integration is critical to the system, but requires government planning (for example capacity payments) in order to attract financing.

Because of the long lead times and lack of financial incentives, it is hard to get private financers on board without some form of government backing. Most pumped hydro projects rely at least in part on concessional financing. The World Bank is heavily involved in financing these projects; since 2002, it has supported 42GW of conventional and pumped hydro projects. The European Investment Bank has also been active in Europe, for instance providing 650 million euros toward the construction of the Tâmega hydro complex in Portugal (see page 11).

Location

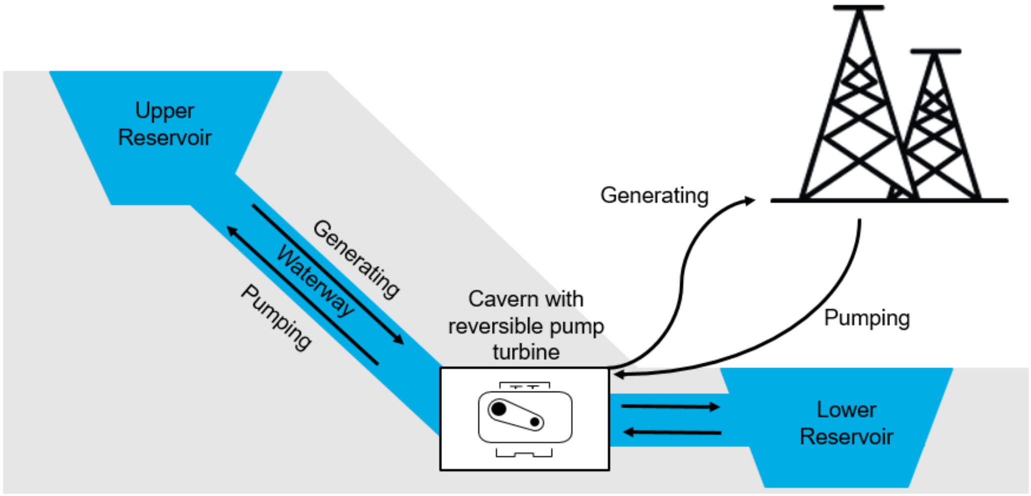
Pumped hydro projects are very location-specific: there needs to be water nearby, the geology has to be right as well as the elevation. These locations are not always close to load centers, where the storage is most necessary.

Climate change and the impact of droughts also needs to be considered, especially for open-loop projects.

5. Technology and innovation

Most pumped hydro plants have the same structure (Figure 9). Two water reservoirs are connected with a waterway. In an (underground) powerhouse, ternary machine sets or reversible pump-turbines have two modes: pump mode and generate mode. During pump mode, electricity from the grid drives a motor, and water is pumped from the lower reservoir into the upper reservoir. During generation mode, water flows from the upper reservoir into the lower reservoir and drives the turbine, which generates electricity.

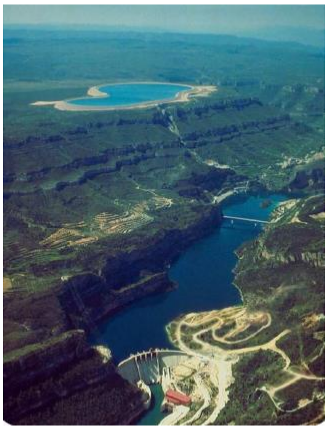
Figure 9: Basic configuration of a pumped hydro plant with a reversible pump turbine



Source: BloombergNEF

5.1. Open-loop versus closed-loop systems

Figure 10: Gouvães, open-loop pumped hydro



Source: Iberdrola

Reservoirs can either be open-loop or closed-loop. In open-loop systems, one of the reservoirs has a natural inflow. The storage complex is often a combination of a run-of-the-river hydro facility and pumped storage. Open-looped systems are better suited for seasonal bulk storage: they can provide storage for weeks or even months due to their large reservoirs

Gouvães, open-looped hydro, under construction in Portugal

The Tâmega hydroelectric complex, which Iberdrola is constructing along the Tâmega river in the north of Portugal, consists of three power plants, of which one pumped storage plant (Gouvães, Figure 10). Gouavães' lower reservoir uses natural inflow from the Tâmega river.

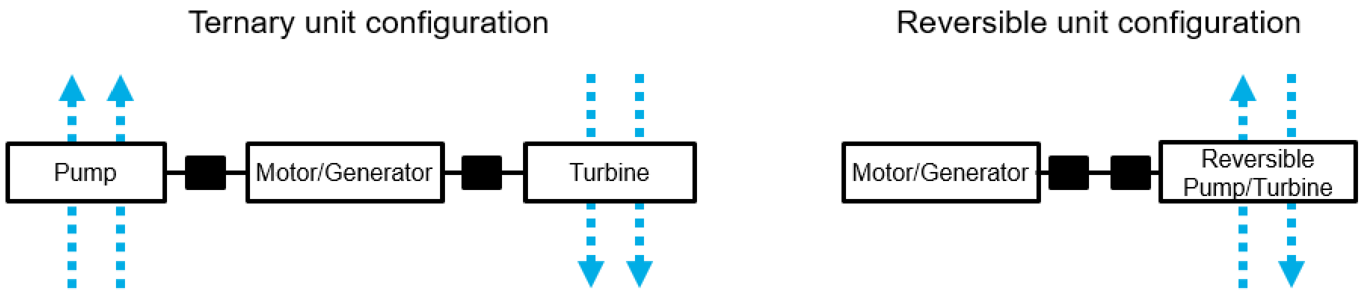
In a closed-loop system, both reservoirs are operated as a closed loop; i.e. there is no natural inflow or outflow in the upper reservoir and the maximum amount of water that can be circulated remains constant. In most cases, one or both reservoirs are artificial, which makes these systems more expensive. In moderate climates, rain and snow compensate for evaporation losses (If this is not the case, a water-refilling system is necessary). Closed-loop systems are easier to site: there are fewer environmental issues as they have no impact on rivers, and as they do not need to be located close to rivers, they can be located where they are needed to support the grid.

5.2. Pump and turbine configurations

The oldest or "classical" pumped storage configuration operates at a fixed speed and includes four machines: a pump with a motor and a turbine with a generator. This configuration is still used today when converting existing hydro plants into pumped storage by constructing a new lower reservoir and a separate pump station.

For the classical pumped storage configuration, the two models that are still dominant today emerged in the 1930s: ternary units and reversible pump turbines. **Ternary units** have a separate pump and turbine, connected to one motor/generator. This allows the pump and turbine to operate in parallel, which means that they can switch quickly between pumping and generation mode. In a next step, the pump and turbine can be combined into a **reversible pump/turbine** (Figure 11).

Figure 11: Ternary unit configuration vs reversible power unit configuration



Source: BloombergNEF,

Ternary units can change modes faster than reversible pump/turbines. For example, switching time from turbine to pumping for reversible pump/turbines is 420-470 seconds, while it is only 25-45 seconds for ternary units. Ternary units are also more suitable for load following. But reversible pump/turbines have lower investment and operational costs, and are easier to maintain. The majority of pumped hydro plants in use today have reversible pump-turbine units with fixed speed.

Table 3: Comparison of ternary and reversible power units

	Ternary units	Reversible pump turbine
Investment	🟥	🟩
Efficiency	🟩	🟥
Transition time between pump and turbine	🟩	🟥
Operation cost	🟥	🟩
Technical risks	🟥	🟩
Maintenance	🟥	🟩

Source: Voith Hydro[3]. Note: Red denotes a weak point, green denotes a strong point.

In the 1990s, **variable-speed turbines** were introduced in Japan. The main advantage of these is that they can adjust power consumption while pumping, which allows to offer frequency regulation services in both pumping and turbine mode. Moreover, as the speed adjusts, the reservoir volumes can be used in an optimized way. Variable-speed turbines are more expensive than fixed-speed ones, and the extra revenue from ancillary services and optimized operations does not always justify the extra cost.

5.3. Innovations in siting

Recently, pumped hydro developments have expanded beyond the use of rivers, dams and lakes as reservoirs. For example in Japan, the 30MW Okinawa Yanbaru seawater pumped storage plant was commissioned in 1999. The plant uses an excavated reservoir as its upper reservoir, and the sea as a lower reservoir. In Queensland, Australia, Genex is developing a pumped storage plant on an abandoned mining site.

Figure 12: Kidston pumped hydro reservoirs

Source: Genex Power

Case study: Using abandoned mine pits – Kidston pumped hydro

In Australia, clean energy and storage company Genex Power is developing a 250MW/2,000MWh pumped storage system that uses two abandoned mine pits, co-sited with a 50MW solar plant. Genex acquired the former gold mine site, including its infrastructure (two holes that can be used as reservoirs and a transmission line), from a private company, Barrick Gold Corporation. Simon Kidston, executive director at Genex Power, told BNEF that he reckons that the capital cost savings from using the existing infrastructure exceeds A$500 million.

The project is supported by the government of Queensland and received a A$610 million concessional loan from the Northern Australia Infrastructure Fund. Capex is estimated at A$600 million, plus A$100 million contribution to build a new transmission line. At the time of writing, the project has not reached financial close, but it had secured a long-term power purchase agreement with energy retailer Energy Australia (EA). Simon Kidston said: “EA will pay a fixed capacity payment to operate the plant. We, as asset owners just receive rental payments. So they can operate the plant how they want and use it for energy arbitrage as well as FCAS services (market ancillary services that are acquired by the Australian energy market operator).”

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[3] Voith Hydro in Thermal, Mechanical, and Hybrid Chemical Energy Storage Systems by Klaus Brun Timothy Allison Richard Dennis

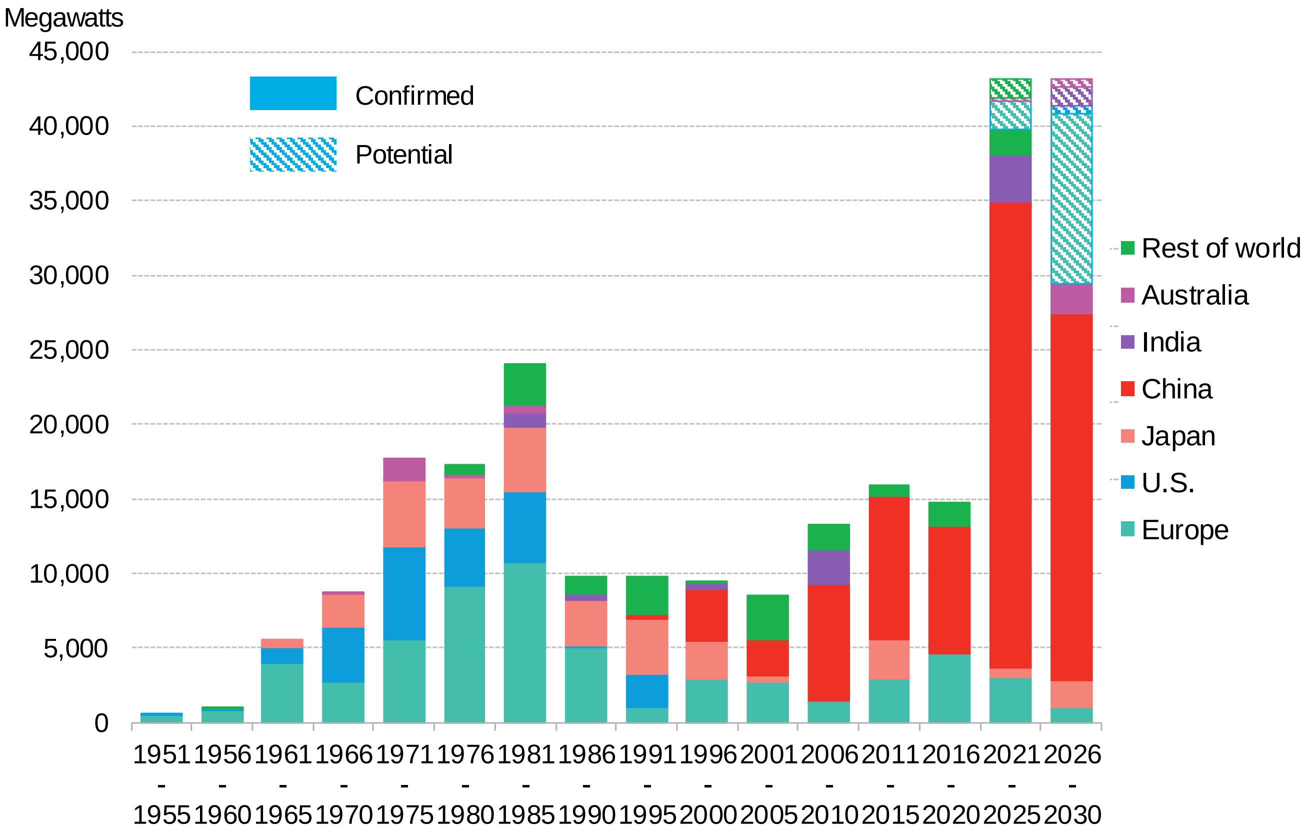
McWilliams, at CEBR, has proposed the concept of **location-agnostic pumped storage** (LAPS), based on a recent invention in the mining industry: “The main drawback for regular pumped storage is that you need a unique site. LAPS uses a vertical underground shaft of 1.4 kilometers deep, which connects a small underground reservoir at the bottom of the shaft with a reservoir on the surface. In the past, drilling a shaft 1.5km deep would take 2-3 years. But four years ago German company Harting developed a vertical driller shaft machine for the mining industry which can do it much faster. This technological advancement makes the concept of location-agnostic pumped storage feasible. Other than the new drilling equipment, the rest of the machinery is the same as that used in other pumped hydro projects.

“The main advantage compared to regular pumped storage is that you can develop this concept anywhere with reasonably good geology. Moreover, the surface footprint is much smaller than regular pumped storage and it is a closed-loop system, so permitting should be easier.” He said that this is still conceptual, but that a number of developers have expressed interest. His view is that a first project would most likely be developed in the Middle East, as countries there have access to financing and the electricity sector is not deregulated, so utilities could commission it. For more on LAPS, see *Pumped Hydro May Come Back to Eat Batteries’ Lunch* (web | terminal).

6. Outlook

Our outlook, based on data collection on individual projects, suggests that pumped hydro will make a strong comeback this decade, mainly driven by China, with activity in Europe also increasing (Figure 13). Some 69GW of pumped hydro projects are already under construction or financed, while another 17GW are in late stages of development or are highly likely to be commissioned under current country targets. Although the number of announcements of pumped hydro projects is high, generally only a small share will secure financing.

Figure 13: Pumped hydro historical additions and outlook



Source: BloombergNEF. Note: "potential" includes projects that are in late-state development (permits in place) but have not secured financing yet. For Europe it also includes capacity that will be built based on country targets.

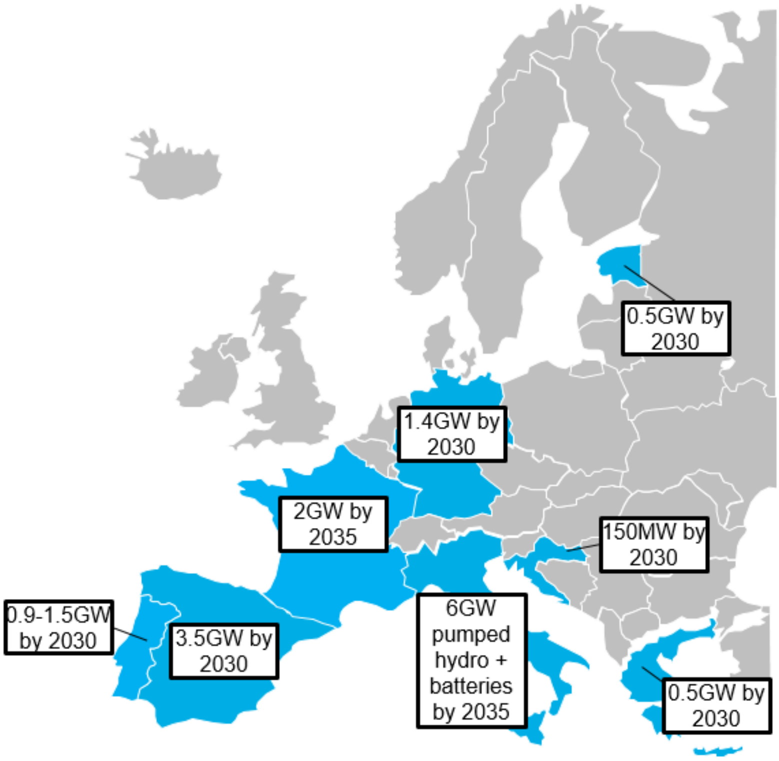
Pumped hydro is important in **China**'s power strategy. China's state-owned grid companies develop pumped hydro plants, as planned by the central government, and receive funding from provincial governments. The country's 13th five-year-plan (2016-2020) targeted 40GW by 2020, but by September 2020, installations had only hit 30.9GW. Based on BNEF's forecast, we expect cumulative pumped hydro capacity to reach 80-90GW by 2030.

In **Japan**, pumped hydro plants were previously developed to complement nuclear generation as a flexible source of storage and generation. Most pumped storage plants are owned by vertically integrated utilities. Since the Fukushima disaster, energy policy in Japan shifted away from nuclear towards renewables and the electricity market was further liberalized. There are currently 2.3GW under construction by Tokyo Electric Power Company – the remaining units of the Kazunogawa and Kannagawa pumped storage plants. It is unclear whether further plants will be developed in a more liberalized market.

In **Europe,** development during the last 10 years happened primarily in the Alps (Austria and Switzerland), and Iberia (Spain, Portugal). Although activity has picked up in recent years, it is not back to the high levels of the 1970s and 1980s, due to reduced arbitrage opportunities. Two Swiss pumped hydro plants under development were even suspended (Grimsel 3, 660MW, in 2013 and Lago Bianco, 1GW, in 2014), the developer stating that "it is not feasible to build due to the current market situation".

However, some European countries see pumped hydro storage as essential in order to make possible the inclusion of more renewables in their energy mixes. They included pumped hydro targets in their 2021-2030 Integrated National Energy and Climate Plans (NECPs), i.e. member states" plans on how they will meet their energy and climate targets (Figure 14). According to these targets, 12.5GW of new projects could be commissioned by 2030, on top of the current pipeline of 10GW. BloombergNEF sees particular opportunity in Iberia, which is not as well interconnected as the rest of Europe. Moreover, Europe's pumped hydro fleet is quite old (24GW of operating plants are more than 40 years old), so refurbishment of old plants will also increase.

Figure 14: Overview of new-build pumped hydro targets in Europe



Source: BloombergNEF, NECPs

The Australian government put pumped hydro at the core of energy security and reliability in 2016, following blackouts in the state of South Australia. Since then, federal and state governments have actively supported the development of new pumped hydro capacity. There are currently two main projects under development, Snowy Hydro 2.0 and Kidston. On December 15, 2020, Australia's Prime Minister Scott Morrison and Tasmanian government officials signed a deal to deliver the Marinus Link interconnector, which is a step forward for the Battery of the Nation initiative in Tasmania (see page 6). A fourth project, the 600MW Oven Mountain project in New South Wales, has been granted "critical state significant infrastructure" status by the government. It now needs to go through the environmental permitting process. More pumped hydro projects are likely to be developed over the coming years as state governments step up support. On November 9, 2020, the New South Wales state government released the Electricity Infrastructure Roadmap. It lays out the state's ambition to support new generators, long-duration storage projects and firming capacity. The government will set up an independent body, called the Consumer Trustee, which will sign long-term contracts with renewable generators, long-duration storage and firming assets. Further, to address the early development risks and long lead times of pumped hydro projects, the government has committed A$50 million in grants to assist developers undertaking feasibility studies. It aims to support up to 3GW of projects. The intention is to lower the barriers to entry for new capacity, allowing more competition amongst assets competing for long-duration storage or firming contracts. For more, see *New South Wales Roadmap to Rally Renewables Investors* (web | terminal).

Although lots of capacity was built **in the U.S.** in the past, no new project has been commissioned since 2012, when the 40MW Lake Hodges storage plant started operations in San Diego, and no plants are currently under construction. There are two reasons: it is very hard for pumped hydro projects to secure a permit (53GW of projects are in the environmental planning queue) and even if they do, it is hard to close financing. NextEra secured the rights to develop the 1,300MW Eagle Mountain pumped storage plant, at a disused mine, in 2016. All permits are in place, but at the time of writing, no financing has been closed. It is so expensive that it cannot be built without policy support.

However, changes are happening in California: on the October 16, 2020, eight community choice aggregators launched a ‘request for offers’ to procure 500MW long-duration storage (up to 16 hours), to come online before 2026. Several pumped hydro projects were among the 31 offers. At the time of writing, no results have been announced.

In **India**, mostly state-owned utilities develop pumped hydro projects, to help meet peak demand. The main project under construction right now is the 1GW Tehri pumped storage plant, with a scheduled commissioning date in December 2022. THDC India, a joint venture of the Indian government and the state government of Uttar Pradesh, is the project developer. Further, independent power producer Greenko secured financing on the 1.2GW Pinnapuram pumped storage project in Andhra Pradesh, which will work in tandem with 2GW of wind and 2GW of solar. Greenko has another 1.2GW pumped storage project under development.

Our pipeline for the **rest of world** from 2021-2030 includes projects in Indonesia, Israel, Morocco, Chile and the Philippines.

7. Getting to net zero – can pumped hydro fill the gap?

As more and more countries discuss net-zero targets, the question of how to decarbonize the last 5-10% of electricity generation arises. BNEF’s *New Energy Outlook* (web | terminal) indicates that gas peakers or coal are the most economic options to integrate large amount of renewable generation, but their use will get in the way of achieving net zero.

Our outlook projects that Germany will run on 68% wind and solar, and 83% renewables overall by 2040. Still, the country is seen having a 17% share of fossil fuel generation, three times the European average. This mainly reflects cheap lignite generation, which, despite contracting by 34%, still produces 56TWh per year in 2040. Germany is one of the countries that have pledged zero emissions by 2050. To decarbonize the last 17% of its electricity needs, pumped hydro could be used.

Figure 15: January week with low renewable output in 2040, Germany

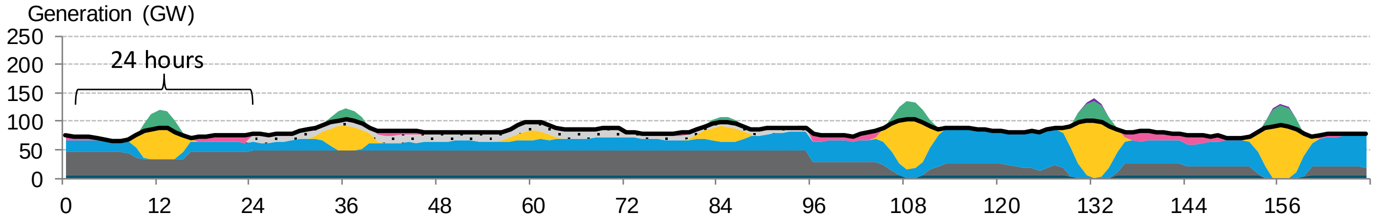


Figure 16: June week with median renewable output in 2040, Germany

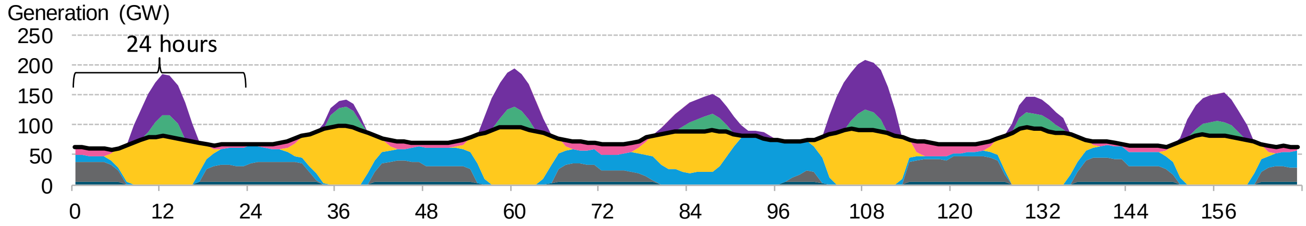
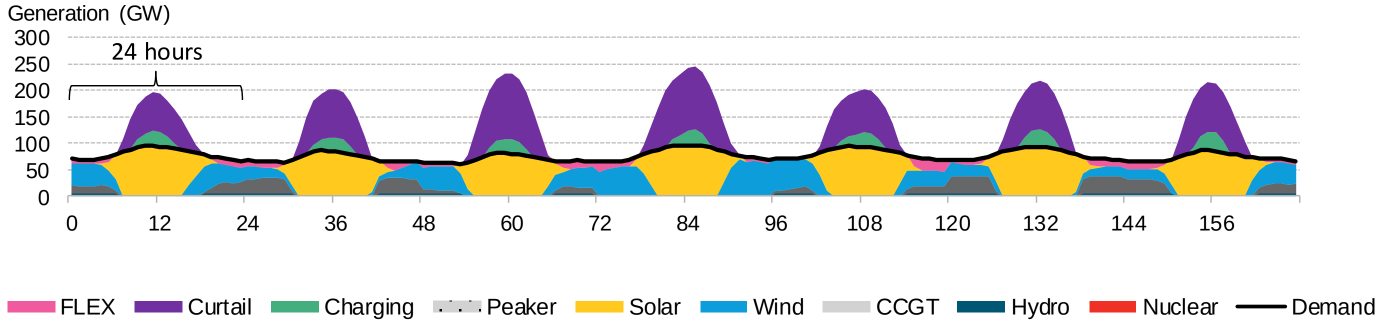


Figure 17: June with high renewable output in 2040, Germany



Source: BloombergNEF, Flexibility Solutions for High-Renewable Systems - Germany (web | terminal)

During periods of high renewable generation (Figure 17), clean short-duration storage could bridge the 4-10 hour gaps when coal generates. During periods with low renewable output however (Figure 15), lithium-ion batteries will quickly discharge their stored energy, and clean bulk storage will be necessary to fill in the gaps.

New Zealand is currently assessing whether pumped hydro can be the technology to bring its electricity mix to 100% renewables

Potential technologies that can provide clean, flexible and bulk capacity are pumped hydro storage, gas peakers using biogas, solar thermal, or hydrogen. It is also possible that by 2040 a unicorn technology will have emerged – for example Form Energy has developed a 150-hour storage technology using aqueous air batteries, which it claims to be 90% cheaper than lithium-ion batteries. On May 7, 2020, it signed a contract with Minnesota-based utility Great River Energy to jointly deploy a 1MW/150MWh pilot project.

Pumped storage fits the need for low-carbon, long-term storage, and it has also grid-stabilizing properties like reliable available capacity and fast balancing power, ancillary services, black-start capabilities and physical inertia. To reach net zero, grids need a mix of solutions, and whether pumped hydro is one of them will depend on government support to create markets for long-duration storage. Some countries like, New Zealand, are already assessing whether pumped hydro should be in the mix to reach a carbon-neutral grid. The cabinet approved funding for the "NZ Battery" project, which investigates possible energy storage options (including pumped hydro) to bring New Zealand to a carbon-neutral grid. If countries are serious about meeting their net-zero targets, we expect governments to provide more support for pumped hydro. Without government support, pumped hydro projects are unlikely to be built.

Appendices

Appendix A. Overview grid services

Include table with definitions from storage note and Lara's note

Table 4: Overview of grid services provided by energy storage systems

Grid service	Definition
Ancillary services	This is the provision or absorption of short bursts of power to maintain the balance of supply and demand and hence the frequency of the grid. They are often procured by the system operator, in the form of frequency regulation and reserves.
Frequency response	Frequency regulation is procured to correct minor deviations in operating frequency. These minor deviations are caused by imbalances in the demand and supply of electricity, which are expected during normal operation.
Reserve power	Generating facilities that act as spare capacity and can provide balancing services during peak demand periods.
Blackstart capabilities	The ability of a generator to start generating power from shutdown mode, without any outside electricity supply.
Voltage management	Voltage management ensures grid stability. Generators can provide voltage support through reactive power.
Reactive power	Generators that provide reactive power contribute to voltage management for the grid. In some markets, for example the U.K., generators can receive compensation for providing reactive power regulation.[4]
Inertia	A power system's ability to resist changes in frequency and keep it within the desired range. Synchronous generators provide inertia as they generally rotate at the same frequency as the grid. Asynchronous generators can also provide inertia, but it must be programmed to respond and is slightly delayed. Inertia can be shared across interconnected regions.
Peaking capacity	This is the provision of capacity to meet the system's peak.
Transmission constraints	Energy storage systems can be used as an alternative to traditional network reinforcement. It may meet a required incremental increase in transmission capacity, in place of a more expensive upgrade to the transmission line.
Energy shifting	Energy storage is charged at times of low electricity price and surplus supply, and discharged to meet demand.

Source: BloombergNEF

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[4] See *Paid to not Generate: U.K.'s Inertia Market* (web | terminal)

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