

The global renaissance of pumped storage

The global transition to clean energy aimed at decarbonizing the world's energy sector has seen rapid growth in intermittent renewable energy in recent years, combined with the gradual phasing out of an increasing volume of fossil fuel thermal power generation. With variable renewables set to account for an ever-increasing share of the world's electricity supply, the need for energy storage as a vital provider of flexibility for enhanced grid integration of solar and wind power is becoming increasingly evident. Storing energy from these intermittent sources during peak production hours, and drawing on this stored power when production has ebbed, have become essential elements of power system management, helping to ensure that electricity is available when and where it is needed and that it is not wasted through curtailment. In this article, *H&D* News Editor Martin Burdett presents global examples demonstrating the strong growth and contribution pumped storage is making to a low emissions future.

Of the rich range and still evolving array of grid-scale energy storage technology options, pumped storage hydropower and batteries currently stand out as the most likely to meet the needs of the low-carbon electricity grid of the future. The International Renewable Energy Agency (IRENA) estimates that 325 GW of new pumped storage alongside an estimated 150 GW of battery storage will be needed to meet its projected 2030 target for 45 per cent of power generation to come from renewable sources.

Many markets already have grid-scale energy storage in the form of pumped storage plants. With around 160 GW installed globally as of 2020, pumped-storage is by far the largest commercial grid-scale energy storage technology, accounting for 99 per cent of the storage market.

From the 1950s onwards, it became an integral component of a centralized generation model with large baseload coal and nuclear plants. Low-cost, night-time (off-peak) nuclear or coal generation was used for pumping, while the stored energy was then used to provide peak power during the day when it could replace expensive oil-fired generation. However, the increasing use of natural gas from the 1990s onwards saw the difference in price between off-peak and peak decrease, making energy storage less economically viable.

While a cost-effective and proven technology, its growth over the last 30 years has also been limited by its specific topographical requirements, lengthy development times, high capital costs and policy and regulatory constraints, which have not recognized and rewarded the critical ancillary services that it can provide to the grid, such as inertia, frequency and voltage support, back-up power and black start in emergency situations.

Times are changing, however, with governments, utilities and grid operators across the world acknowledging the need for the benefits that pumped storage will offer to future power systems. While new build remains limited to a few of markets for now, the scale of planned developments suggests a new era for the world's oldest energy storage technology.

Research carried out by the *International Journal on Hydropower & Dams* shows more than 44 GW of capacity under construction as of March 2022, of which close to 40 GW or more than 90 per cent is in the Asia-Pacific region. "We are seeing a renaissance in pumped storage, with significantly more activity in the market compared with the past one or two decades," Lars Meier, Head of Sales at Voith Hydro, told *H&D*. "The main trigger is intermittent renew-

ables and the resulting need for grid stability," he added.

A number of clear trends have been identified, including the increasing use of existing reservoirs or abandoned mining sites and proximity to transmission infrastructure as much as possible to reduce costs and environmental impacts. For similar reasons, many proposed projects are designed as closed-loop, off-stream schemes, which significantly reduces adverse impacts on natural river courses, and in turn facilitates permitting. Greenfield development, as well as modernization and repowering of existing schemes, are also seeing innovation in terms of design and technology. "A clear trend is the increasing use of variable speed solutions, which provides more flexibility and allows the owner-operator to offer a greater range of ancillary services," Meier said.

There is also a greater use of Early Contractor Involvement (ECI) to support optimization of the design, construction methodology, and the delivery programme, saving time and money. "A trend I see particularly with private developers in certain markets is the very early involvement of all relevant parties from civil companies, original equipment manufacturers, owners and owner's engineers, coming together to optimize the sites to make it cost effective," noted Meier. The ECI process has also presented an opportunity for developers and EPC contractors to tender preliminary and basic designs, which facilitates the rapid development of an advanced design, reducing time and minimizing project risk for the owner when compared with a traditional tender process.

China: the indisputable market leader

China is by far the largest contributor to global growth in pumped storage with 36 150 MW under construction and has been responsible for most of the global growth in pumped storage over recent years. As of March 2022, China has 38 large and medium-sized pumped-storage plants in operation, with a total capacity of 35.6 GW. Much more is planned given the country's potential for further growth with current capacity accounting for only 1.4 per cent of the country's total power capacity, far behind the average of 10 per cent in certain markets in Europe and the USA. In addition, China aims for renewable power to account for more than 50 per cent of its total electricity generation capacity by 2025, up from 42 per cent at present. China's pumped-storage capacity is expected to rise to 62 GW by the end of 2025 and to double to 120 GW by 2030, according to a medium- and long-term development plan for the country's pumped storage sector covering the period from

2021 to 2035 that was issued by China's National Energy Administration in September 2021.

At present, 27 projects are scheduled to be commissioned over the period 2022-2030, according to H&D research, of which 19 are being built by subsidiaries of the two major power grid companies: the State Grid Corporation of China (SGCC) and China Southern Power Grid (CSPG). To underline the expected scale of growth, China Southern Power Grid announced in October 2021 that it alone would install an estimated 21 GW of new pumped storage and start construction of a further 15 GW at a combined investment of approximately Yuan 200 billion (US\$ 94.3 billion) over the next decade to support the integration of 250 GW of renewable energy in the five southern provinces that it serves. Three projects are being built by one of the leading state power producers China Three Gorges Corporation totalling 4500 MW, including the 2100 MW Changlongshan project. Other notable ongoing projects include the 1 GW Henan Wuyue station in Henan Province, which will be the first pumped-storage power station to be built by the China National Nuclear Corporation.

Two main reasons explain the rate of growth of pumped storage in the country. In China, storage assets are considered as grid assets, and therefore are largely developed and managed by state-owned grid companies that benefit from clear business model as those costs are included in the grid operating expenses. Second, several regimes have been adopted over time to allow asset owners to cover projects' operating costs plus a rate of return on their capital costs, which are agreed with the regulator. The latest evolution is based on a two-part tariff scheme, which consists of a capacity payment and energy tariff. The capacity fee is regulated and settled for each project, together with the local power grid company. The capacity fee rewards the plant's availability and the support services that it provides to the grid (system reserve, frequency and voltage regulation, black start). The energy tariff compensates the variable operating costs such as pumping charges and generation losses. Compared with previous mechanisms that were solely based on capacity payment, this two-part tariff regime does not only provide fixed guaranteed revenues but also additional

Aerial view of the Kidston solar and pumped-storage project site.



payments depending on utilization, thus contributing to the optimization of those resources.

Strong growth in Australia

In Australia, two major schemes totalling 2250 MW are underway. Genex Power launched construction in June 2021 of the 250 MW (2 GWh) Kidston project (K2-Hydro), which will be the country's first green-field project in nearly 40 years, and one of the world's first co-located solar pumped-storage plants, while Snowy Hydro is currently expanding the pumped-storage capacity of the Snowy Mountains complex by 2000 MW.

The K2-Hydro project in the northeastern state of Queensland, which is being carried out by a joint venture of McConnell Dowell and John Holland, on behalf of Genex Power in a partnership with retailer EnergyAustralia, will serve as Genex's flagship project within the Kidston Renewable Energy Hub that will also comprise the operating 50 MW Stage 1 solar PV project, a multi-staged integrated solar project of up to 270 MW, which is under development, and the Kidston Stage 3 wind project with capacity of up to 150 MW. The closed-loop project, which will be equipped with two reversible pump-turbines supplied by Andritz Hydro, will provide 2000 MWh of storage capacity by repurposing two disused gold mine pits.

The A\$ 777 million (US\$ 573 million) project, including transmission infrastructure, is expected to begin operation in 2024. Genex Power reached financial close in May 2021 after securing A\$ 660 million (US\$ 487 million) in external financing comprising an A\$ 610 million (US\$ 458 million) long-term concessional debt facility from the Northern Australia Infrastructure Facility (NAIF) and an A\$ 47 million (US\$ 35 million) project grant from the Australian Renewable Energy Agency (ARENA). Genex expects to generate steady revenues, under an energy storage service agreement signed with EnergyAustralia for a term of up to 30 years, whereby, Genex will receive access payments from EnergyAustralia, which in turn will have the ability to draw upon K2-Hydro for additional power supply at critical periods, helping the retailer to mitigate its exposure to price spikes during peak demand periods.

A joint venture of Italy's Webuild and Australia's Clough are carrying out the civil and electro-mechanical works for the Snowy 2.0 project under an AU\$ 5.1 billion (US\$ 3.6 billion) contract awarded in 2019. Voith is supplying six 333 MW reversible pump-turbines, three of which are variable-speed, as well as motor generators, the auxiliary systems and automation. The Snowy 2.0 project is designed to add 2 GW of on-demand generation and 350 GWh of energy storage, providing 175 hours of continuous storage for the National Electricity Market.

The US \$4 billion project, which will make use of an existing upper dam (Tantangara) and existing lower dam (Talbingo) of the 4.1 GW complex, will involve the construction of about 27 km of underground tunnels to link the two reservoirs with a new underground power station. First power from Snowy 2.0 is expected in 2024. A feasibility study completed in 2017 confirmed Snowy 2.0's scale, strategic location and longevity as by far the cheapest and best option to decarbonize Australia's power market. Economic analysis by Marsden Jacobs Associates

showed that if Snowy 2.0 was not built, batteries and gas peaking plants would need to be installed at more than double the cost.

Numerous private projects are at various stages of development, supported by federal and state level funding, including the Australian Federal Government's Underwriting New Generation Investment (UNGI) programme, which was established to support firm generation capacity and increase competition as part of the Government's commitment to lowering electricity prices and increasing grid reliability. Funding for studies has also been made available to developers by ARENA. Leading projects are being developed in co-location with planned Renewable Energy Zones (REZs), which are proving popular with investors, as they benefit from strong network infrastructure that can accommodate large amounts of renewable capacity. Three projects in New South Wales, the 325 MW Central West, the 500 MW Dungowan and 600 MW Oven Mountain, as well as the 400 MW Big T project in Queensland are planned as integral components of planned REZs.

Government support for Indian pumped storage

India is a relative newcomer to pumped storage with its first project only commissioned in 1980. Currently eleven plants totalling 4804 MW are in operation, of which only seven in the pumping mode. However, pumped-storage capacity in India is set for significant growth, with the Indian Government keen to support the adoption of energy storage as an enabling technology for the country's ambitions to deploy 500 GW of renewable energy capacity by 2030. This would require the connection to the grid of about 29 GW or 108 GWh/year of energy storage, according to modelling by the Central Electricity Authority (CEA). A potential for 96 GW of pumped-storage potential has been identified by the CEA across India. As of 2022, three projects totalling 2700 MW are under construction: Tehri (1000 MW) in Uttarakhand by THDC, Kundah (500 MW) in Tamil Nadu by the state power utility Tangedco, and Pinnapuram (1200 MW) in Andhra Pradesh by IPP Greenko.

Construction of the Koyna Left Bank plant (80 MW) in Maharashtra has been delayed. Tehri will be the first such project developed by a central sector utility when commissioned in 2023. Kundah is also set for commissioning in 2023, according to GE Renewable Energy, which is supplying four 125 MW fixed speed turbines and generators under a contract awarded in 2020. In addition the 1 GW Turga project in Purulia in the eastern state of West Bengal has been approved by the CEA, with construction set to start in 2022 for commissioning in 2027. A joint venture of THDCIL and NPCIL has, meanwhile, been entrusted by the Government of Maharashtra with the development of the 700 MW Malshej Ghat scheme, for which an update of the detailed project report (DPR) has been completed and submitted to the state government authorities.

Several pumped-storage projects are being developed as part of integrated renewable energy parks, including two by Greenko: Pinnapuram (with the associated development of 400 MW of wind and 2000 MW of solar PV) and the 1260 MW Saundatti pumped storage project in the southwestern state of Karnataka, at an estimated overall cost of US\$ 2

billion. Andritz was contracted in October 2020 for the supply of four 240 MW units and two 120 MW reversible pump units for Pinnapuram. Commissioning of the first units is expected by 2023, it said, and once fully commissioned. A tender for the electro-mechanical supply for Saundatti was launched in February 2020. Greenko Energy Holdings closed finance in 2020 for Pinnapuram and Saundatti, with an equity injection of US\$ 824 million from affiliates of Singapore-based investment fund GIC and the Abu Dhabi Investment Authority (ADIA). Six other projects with a capacity of 4920 MW are being studied: Upper Indravati (Odisha, 600 MW), Upper Kolab (Odisha, 320 MW), Sharavathy (Karnataka, 2000 MW), Balimela (Odisha, 500 MW), Kodayar (Tamil Nadu, 500 MW) and Sillahalla Stage I (Tamil Nadu, 1000 MW).

A number of government statements and policy decisions in recent times underline the support of central government. In the Union Budget this February, the Finance Minister ruled that energy storage systems can be classified as infrastructure investments, making it easier to secure financing, while in January of this year, the Ministry of Power clarified energy storage's role, including its legal status, how it could be defined as a generator, or as part of the grid and what sort of ownership models could be applied. Ministers have also said that they are prepared to support the industry as long as that is necessary, including through holding government tenders for both standalone energy storage and hybrid renewable energy projects with storage at strategic locations. The new 'Energy Storage System' policy paper has, moreover, proposed to waive environment clearance for off-river schemes and the obligation to supply free power to host states. The transmission cost while selling or buying electricity from these storage systems may also be dropped, according to the 'Discussion Paper on Policy on Energy Storage Systems'. In 2019, hydropower was reclassified as renewable power and new policy rules were adopted to incentivize electricity supply during peak hours, better recognizing the value of flexible and dispatchable power solutions such as hydropower and pumped storage. India has, moreover, also amended its 'hybrid wind-solar with storage' policy, allowing pumped storage to participate in auctions together with wind and solar. In 2019 India launched the world's first GW renewables plus storage tender. Solar Energy Corporation of India (SECI) issued a tender for 1.2 GW of renewables, combined with 600 MW of storage capacity during six peak hours. Auctions including pumped storage will benefit from a 25 year PPA based on a two-part tariff (auctioned Peak Tariff and settled Off-Peak Tariff). There are another 3-4 GW of 'Round The Clock' green power tenders expected to be floated by SECI in the coming years.

Further developments across Asia

The first units of three major pumped-storage projects in Japan have been commissioned, with further units dependent on market developments. The first two 400 MW units of the Kyogoku plant being developed by Hokkaido Electric Power has already been commissioned with a further 1000 MW planned; TEPCO has already brought online 1200 MW out of a planned 1600 MW at Kazunogawa and 940 MW out of a total planned 2820 MW at Kannagawa. The final four 470

MW units of Kannagawa are scheduled to be commissioned by 2032. Kazunogawa is to be fully commissioned in 2024. In South Korea, Korea Hydro Nuclear Power Company is to construct three new stations totalling 1850 MW by 2031 under the Government's Eighth Basic Plan for Power Supply and Demand: Youngdong (500 MW), Hongcheon (600 MW) and Pocheon (750 MW).

Thailand's vertically integrated state utility, the Electricity Generating Authority of Thailand (EGAT), is studying two new 800 MW projects: Chulabhorn in Chaiyaphum Province and the Vajiralongkorn project in Kanchanaburi Province. For the former it has completed a feasibility study and is undertaking an environmental impact assessment. The Chulabhorn and Vajiralongkorn plants are currently scheduled to begin commercial operation in 2035 and 2037, respectively. In December 2019 it doubled the capacity at the 500 MW Lamtakong Jolabha Vadhana plant on the Lam Ta Khong in the northeastern province of Nakhon Ratchasima, with the entry into commercial operation of two new 250 MW units, which were supplied by Voith Hydro. In neighbouring Vietnam, state power producer and supplier Vietnam Electricity (EVN) is preparing the country's first pumped-storage scheme. The 1200 MW Bac Ai in the southern province of Ninh Thuan is planned to be developed in two phases at an estimated cost of around VND 21 100 billion (US\$ 910 million) with full commissioning scheduled for 2028. First phase work on the outtake for Bac Ai began in January 2020. Preparation of technical design and bidding documentation began in April 2021. Bac Ai will feature an upper reservoir capable of storing up to 9×10^6 m³ impounded by a 72 m-high dam on top of the Da Den Mountain. The Song Cai reservoir will act as the lower basin. Ten pumped-storage schemes totalling 8 GW have been studied, with 5.7 GW originally planned to be installed by 2030.

The World Bank is supporting the development of Indonesia's first pumped-storage hydropower plant between Jakarta and Bandung on the island of Java. In 2021 it approved a US\$ 380 million loan to Indonesia's Ministry of Energy and Mineral Resources for the construction of the 1040 MW Upper Cisokan plant, which remains a key part of the Java-Bali power system expansion plan. The US\$ 800 million project, co-financed by the Asian Infrastructure Investment Bank, is being developed by state utility, PLN. World Bank financing will also cover technical assistance and



The construction works for the 20 m raising of the Vieux Emosson dam.

capacity building for the preparation of the 900 MW Matenggeng project in the Cijolang river basin in West Java.

In the Philippines, nine private developers have to date been awarded service contracts by the Department of Energy for a total of 16 open-loop projects with an aggregate installed capacity of 6858 MW. The service contract provides exclusive rights to develop the resource and serves as the permit to carry out the requisite technical, economic, social and environmental studies. Fourteen of these projects totalling 6308 MW are proposed on the archipelago's main island of Luzon, with two on the second largest island of Visayas totalling 550 MW. Strategic Power Development Corporation is the leading developer, with a portfolio of six licensed projects totalling 2300 MW, while San Lorenzo Luiz Builders and Developers Group holds contracts for three projects totalling 650 MW. Three of the projects are slightly more advanced, with ongoing pre-construction activities: the 250 MW Alimit project in the Luzon province of Ifugao by SN Aboitiz Power (SNAP), a joint between SN Power of Norway and AboitizPower; the 600 MW Pantabangan project by First Gen Hydro Power Corporation (FGHPC) of the Lopez Group, and the 300 MW Aklan project in Visayas by Strategic Power Development Corporation. All the other projects are in a pre-development phase.

Austria leads the way in Europe

In Europe, no specific national support mechanisms have to date been introduced, although the EU is currently studying the introduction of a capacity mechanism. In spite of this, a number of mostly state utilities and grid operators are building or advancing with projects on the basis that the demand for flexible pumped storage will grow in correlation with the rise in variable renewables, as required to meet zero-carbon targets, and will be facilitated by the development of transmission grid capacity.

Austria is the continent's most active market for new pumped storage, with four projects totalling 865 MW currently under construction. Verbund is building the 480 MW Limberg III plant, as part of the Glockner-Kaprun power complex in the western state of Salzburg, and the 45 MW Reisseck II Plus project in the southern state of Carinthia. The €60 million (US\$ 66.8 million) Reisseck II Plus, which is an extension of the Reisseck II scheme that was commissioned in 2016, is scheduled to begin service at the end of 2023. Its turbine, motor generator and convertor are being supplied by GE. The €480 million (US\$ 528 million) Limberg III project, which will be equipped with two 240 MW variable-speed pump-turbines supplied by Voith and 270 MVA asynchronous motor generators by Andritz Hydro, is set to come online in 2025. Both projects are designed as closed-loop systems, using existing reservoirs with natural inflow.

OBB-Infrastruktur AG, the operator of the infrastructure of the state-owned Austrian rail network on behalf of the Austrian Federal Railways (Österreichische Bundesbahnen or OBB), is building a new 170 MW plant, which makes use of two existing reservoirs in the Stubach Valley in the state of Salzburg, to meet its increasing demand for traction power. The €300 million (US\$ 330 million) project is part of ÖBB's efforts to meet its supply needs with clean electricity. GE is supplying two variable speed pump-turbines and gen-

erators. After two decades of study, planning and permitting, construction work began in 2020 with commissioning scheduled for the end of 2025. TIWAG is constructing the 170 MW Kühltai 2 scheme in the Stubai Alps in the western state of Tyrol, which is expected to begin service by 2026. The €900 million (US\$ 991 million) project will link the existing Finstertal reservoir as the upper basin and a new lower reservoir through the construction of a 113 m-high rockfill dam.

Three further schemes are under development. TIWAG is carrying out an Environmental Impact Assessment for the 1015 MW Kaunertal project in Tyrol. The expansion of the existing Kaunertal plant, at a cost of around €2.5 billion (US\$ 2.75 billion), will benefit from the EU's 'Projects of Common Interests' public funding mechanism. Construction is scheduled to start in 2027 for commissioning by 2032. Energie AG Oberösterreich has received approval for the 170 MW, 1500 MWh/year, Ebensee scheme in the northern state of Upper Austria, and is carrying out detailed design and tender planning for the €235 million (US\$ 259 million) project. A final investment decision in 2023 would enable commissioning in 2027. The open-loop project with natural sub-basins would use the Traunsee as its lower reservoir and create an upper reservoir at Rumitzgraben offering a gross head of 491 m.

Verbund also completed the repowering of two pumped-storage plants in Austria in 2021. The repowering by Andritz Hydro of the Malta Oberstufe plant, which involved installation of new variable-speed pump turbines rated at 80 MW each, has seen capacity increased by 40 MW to 160 MW. The installed capacity in the turbine mode of Kaprun Oberstufe was increased by 48 MW to 160 MW while the capacity in pumping mode was augmented by 30 MW to 154 MW.

Portugal and Switzerland are in the final stages of commissioning new pumped-storage capacity. Two major projects are in the final stages of commissioning: the 880 MW Gouvães scheme in Portugal and the 900 MW Nant de Drance plant in Switzerland. A further five projects under construction.

Iberdrola, Spain's largest power producer, synchronized in January of this year the first unit at the 880 MW Gouvães plant, part of the 1158 MW Tâmega River hydropower complex in northern Portugal. All of the units are undergoing commissioning tests with Gouvães scheduled to be fully operational in mid-2022. Spain's Ferrovial Agroman, with local civil engineering group MSF Engenharia, undertook the civil works with the electro-mechanical equipment supplied by Andritz Hydro. The Tâmega complex is one of Europe's largest energy storage facilities, comprising three reservoirs (Gouvães, Daivões and Alto Tâmega) and three hydropower plants on the Tâmega, a tributary of the Douro. The project will involve an investment of more than €1.5 billion (US\$ 1.7 billion), of which Iberdrola secured €1.05 billion in debt financing comprising a €650 million (US\$ 700 million) loan from the European Investment Bank and a €400 million (US\$ 445 million) loan from Spain's Instituto de Crédito Oficial. Following a competitive tender held in 2008, Iberdrola signed a 70-year concession with the Government of Portugal in July 2014 for the construction and operation of Gouvães, the 160 MW Alto Tâmega dam and plant and the 118 MW Daivões storage facility.

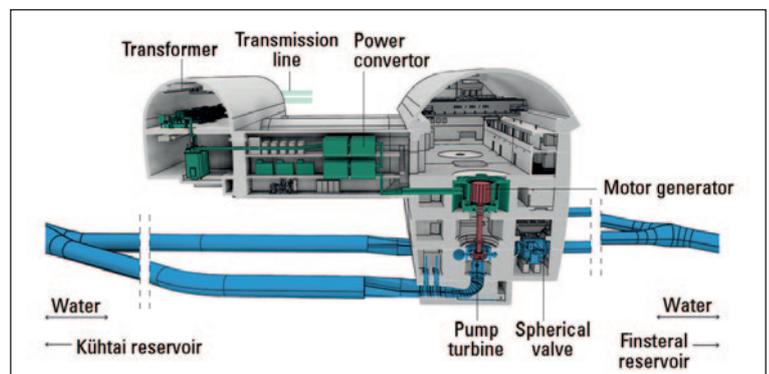
In Switzerland, the six 150 MW pump-turbines of the 900 MW Nant de Drance pumped-storage plant in the Valais municipality of Finhaut, are in the final test phase. The variable speed asynchronous units supplied by GE were synchronized in 2021 and are set to enter commercial operation by the middle of this year. The closed-loop plant, which exploits a head of more than 350 m between the existing Vieux-Emosson and Emosson dams, is being developed by Nant de Drance SA on behalf of shareholders Alpiq, the Swiss Federal Railways, Les Services Industriels de Bâle and FMV, at an estimated total cost of CHF 2.2 billion (US\$ 2.35 billion). The project involved the heightening of the Vieux Emosson double arch dam by 20 m to 76.5 m to double the upper reservoir's storage, and the construction of a new underground powerhouse. In the canton of Ticino, the 76 MW expansion of the 44 MW Ritom plant is underway. Voith was contracted in 2019 by Ritom, a joint venture between Swiss Rail (SBB) and the canton of Ticino, to replace the existing four Pelton turbines with two 60 MW Pelton turbines and a 60 MW storage pump. The new plant is to be commissioned in 2023.

The only other European country currently constructing new pumped-storage capacity is Spain where construction of the 200 MW, 3.5 GWh/year Salto de Chira scheme on the island of Gran Canaria in the Atlantic Ocean was launched by the national grid operator Red Electrica de España (REE) this February. REE expects to invest more than €400 million (US\$ 455 million) in the project, which will also include the construction of a seawater desalination plant and associated transmission infrastructure.

The project, which will use the existing Chira and Soria fresh water basins as the upper and lower reservoirs, is scheduled to begin service in 2027, when it is expected to meet around 36 per cent of the peak demand of the second most populous island of the Canary Islands. Salto de Chira will enable the island to increase renewable production by 37 per cent, and raise average annual coverage of electricity demand with renewables to at least 51 per cent from 20 per cent in 2021. As a result, its development will reduce annual CO₂ emissions by an extra 20 per cent and make savings in variable generation costs of an estimated €122 million per year by reducing fossil fuel imports.

Iberdrola, Spain's largest power producer, is redesigning the Middle Tajo River storage scheme and the associated enhancement of the Valparaiso mixed pumped-storage plant as part of a strategy to secure more flexibility from its hydropower fleet to support the clean energy transition. Indar-Ingeteam were contracted in June 2021 to modernize two units at the 132 MW

The planned Kühltai 2 power station.



Torrejón pumped-storage plant on the Tajo river, with the supply of two 45 MVA full power variable speed vertical motor generators, excitation systems with rotor monitoring and full power converters. Voith is modernizing five pump-turbines at the Torrejón and Valdecañas pumped-storage plants. For Torrejón, Voith will supply two 43 MW semi-axial pump turbines. As part of the modernization, the plant will be converted to full power variable-speed operation and in addition the head will be increased. Voith will also supply three Deriaz pump-turbines with a capacity of 83 MW each for Valdecañas. Commissioning of the two plants is scheduled for early 2025. The modernization work is being undertaken to enable pumping capability in Torrejón for a wide range of heads, restore pumping capability in Valdecañas, which ceased in the 1990s as a result of technical issues, and ensure a storage capacity of 280 GWh by connecting the scheme's reservoirs.

Development of new pumped-storage capacity in Germany has been and will continue to be constrained by the country's strict planning and environmental regulations. The sole project under construction is a hybrid wind and pumped-storage project, which is being completed by Max Bogl Wind AG in Baden-Württemberg. Voith Hydro is supplying the pump-turbines for the 18 MW Gaildorf project with a capacity of 16 MW in the pumping mode. Verbund, meanwhile, has applied to build the 300 MW Riedl pumped-storage project on the Danube river basin in Bavaria. An upper reservoir will be created between the districts of Gottsdorf and Riedl in Lower Bavaria and the Danube will be used as the lower reservoir, with an underground powerhouse to be built on the banks of the Danube and the inlet and outlet structures on the separating dam at the site of the Jochenstein powerplant. The project construction is likely to begin in 2023 and the project is expected to enter into operation in 2026.

North Macedonia is still seeking a private partner to build the long-standing 333 MW Cebren project under a Public Private Partnership (PPP) with the state power producer Elektrani Na Severna Makedonija (ESM). In March 2021, nine international bidders were prequalified for the design, financing, construction, operation and maintenance of the project, on the river Crna, including EDF, WeBuild, Gezhouba Group China and Power Construction Corporation of China. The winning bidder will create a project company with ESM and be granted a 60 year concession for the use of water for electricity generation, the exclusive right to build and operate Cebren and the Orlov Kamen dam, as well as operate the downstream 116 MW Tikves plant. The investment value is estimated at €570 million (US\$ 615 million), according to the tender launched in February 2020.

There is considerable interest in pumped storage in Greece, since its official commitment to close all lignite plants for power generation by 2028. RAE has issued permits for 14 projects with a combined capacity of 3037 MW though only the 680 MW Amphilocheia project by Terna Energy at an estimated cost of more than €500 million (US\$ 550 million) is expected online by 2030. The scheme was declared a project of common interest by the EU in 2013 and has received support from the EU's Connecting Europe Facility for its feasibility studies. Design and analysis for the project in Aetolia-Acarmania, in northwestern Greece, has been completed, but Terna, like other developers, is awaiting a new legal framework, now

expected by the middle of this year, for the operation of electricity storage to proceed to economic evaluation. Terna holds 1.5 GW of licensed pumped-storage capacity in Greece and has plans to also develop smaller facilities at Amari on the island of Crete, at Veria, and in the Peloponnese.

In the Baltic States, two projects are at advanced stages of development. Lithuania's state-controlled energy holding Ignitis Grupė approved in February 2021 the expansion of the 900 MW Kruonis plant with the addition of a 110 MW synchronous unit, at an estimated cost of up to €80 million (US\$ 88 million). It aims to have the new unit in operation by 2025, prior to Lithuania's synchronization with the Continental European network. Energiasalv is developing the world's first geotechnical pumped-storage plant in Paldiski, northwestern Estonia, using the Baltic Sea as an upper reservoir, and high strength crystalline bedrock at depths of 200 m for the lower reservoir and powerhouse. The Estonian 500 MW Pumped-Hydro Energy Storage project, with an initial storage capacity of 6 GWh over 12 hours, is planned to be commissioned in 2029 at an estimated cost of €650 million (US\$ 715 million).

In the UK, five projects totalling 4650 MW are at various stages of planning and permitting, while awaiting the introduction of an appropriate market investment framework. All of them are located in Scotland. The largest portfolio of projects belong to the ILI Group, a UK-based clean energy developer, which in January 2022 started the initial planning phase for the 1.5 GW/45 000 MWh Balliemore project at Loch Awe, Dalmally, in Argyll and Bute. It is the largest of three projects planned by ILI. Its 450 MW/2900 MWh Red John project at Loch Ness was awarded planning consent from the Scottish Government in June 2021, while ILI plans to submit a planning application for the 600 MW/14 500 MWh Corrievorkie project at Loch Erich in August 2022. The Scottish Government granted consent to SSE Renewables for the expanded 1500 MW/30 GWh Coire Glas scheme near Loch Lochy in Lochaber in the Scottish Highlands in October 2021. The Drax Group plans to submit a planning application in 2022 to more than double capacity at its 440 MW Cruachan facility in Argyll.

The absence of a framework for large-scale, long-duration storage and flexibility technologies means that private investment cannot currently be secured in new pumped-storage hydro projects, with no new plants built anywhere in the UK since 1984. The announcement from the Scottish Crown of new seabed leases for offshore wind and the UK Government's planned 40 GW to come on stream by 2030 means that energy storage projects become increasingly important, according to Mark Wilson, Chief Executive Officer of ILI Group. Wilson said the company is awaiting the outcome of the UK Government's Call for Evidence on long-duration storage, as having the necessary market mechanism in place will enable the current pipeline of pumped-storage capacity to be built. He said he believes a cap-and-floor mechanism as recommended in a recent report by KPMG "would get all these nationally significant infrastructure projects moving. Without such projects, the national renewable energy capacity would soon hit a 'Green Glass Ceiling' whereby adding more variable renewables actually threaten grid stability and security of supply in our grid network," he said. A report this

February by Aurora Energy Research shows that up to 24 GW of Long Duration Electricity Storage (LDES) could be needed to integrate wind power into a secure Net Zero electricity system.

Russia's invasion of Ukraine has ended any immediate plans for further pumped-storage development. The fourth unit at the Dnistrovskaya (Dniester) plant, on the river Dniester in the western oblast of Chernivtsi, with an installed capacity of 324 MW in generating mode and 421 MW in pumping mode, was commissioned in the summer of 2021. The first unit was launched in 2009, the second in 2013, and the third in 2015. The plant is designed to be equipped with seven identical units with total capacity of 2268 MW in the generating mode and 2947 MW in pumping mode. The remaining three units were scheduled to be completed by 2028. State hydropower producer UHE had also been pursuing plans to build the 1 GW Kanivskaya pumped-storage plant.

In Russia the construction of the Zagorskaya plant's second stage is underway, Zagorskaya PSPP-2, with a design capacity of 840 MW in the turbine mode and 1000 MW in the pumping mode. RusHydro expects to complete in 2022 the levelling of the site after subsidence. A final investment decision will be made based on the results of the site levelling. In addition, it is upgrading the Kubanskaya plant in Karachay-Cherkessia, the country's oldest pumped-storage plant. The modernization, which is scheduled to be completed in 2025, will boost capacity to 18.6 MW in the turbine mode from 15.9 MW and to 19.7 MW in the pumping mode from 14.4 MW. There are a number of further planned projects, but none is currently being developed owing to the lack of a mechanism to ensure a return on investment. The most developed project is Leningradskaya PSP in the St Petersburg region, with a design capacity of 1560 MW in the turbine mode and 1760 MW in the pumping mode.

Upgrading and repowering

Significant efforts are also going into the modernization and repowering of existing pumped storage, most notably in Europe, where sites for greenfield projects are relatively limited. Engie Electrabel is modernizing and expanding the 1080 MW Coe-Trois-Ponts plant in Belgium. Voith is replacing runners and distributors for the three units of the Coe I plant under a contract awarded in October 2021, which will increase installed capacity by 79 MW to 1159 MW when completed in early 2025.

Engie Electrabel is also increasing storage capacity by 450 MWh to 6450 MWh. In August 2021 it completed expansion works of the lower basin and began the expansion of the upper reservoir with the heightening of the dam by around 2 m. This work, to be completed by July 2023, will increase the storage volume of the upper basin by up to 600 000 m³.

Lithuania's Ignitis Grupė aims to complete the overhaul of the four units at the 900 MW Kruonis plant by 2025, prior to Lithuania's synchronization with the Continental European grid.

PGE Energia Odnawialna, the renewable energy arm of Poland's largest power producer, has tendered for the modernization of the 544 MW Porąbka-Żar plant in Silesia in southern Poland, and Bosnian Croat utility JP Elektroprivreda Hrvatske Zajednice Hercegovine (EPHZHB) is preparing plans for the modernization of the 420 MW Čapljina pumped-storage plant.

Litostroj Power was contracted in February 2021 by Verbund to produce four impellers for the 260 MW Rosshag plant in the Ziller Valley in Tyrol.

Private investment in pumped storage in Israel

Israel provides a rare example of private investment in pumped storage, to support its transition to clean energy with Independent Power Producers (IPPs) contracted to build and operate the facilities under 20-year Power Purchase Agreements with Israel Electric Corporation (IEC), the state-owned grid operator and dominant power producer, to cover the costs of investment, operation and maintenance, and a return on equity. Revenues are generated from basic availability payment, energy payment and performance payment. Extra revenues can be awarded for additional benefits provided to the IEC and are mainly based on the performance of the plant in terms of flexibility such as start-up time and transition times. The Israeli Electricity Authority has fixed a target of 800 MW of pumped hydro, accounting for five per cent of total installed capacity of 19.7 GW as of end-2021.

Following the commissioning in May 2020 of its first pumped-storage plant, the 300 MW Gilboa facility, Israel is advancing with its next two projects. Construction work is underway on the 344 MW Kochav Hayarden project near Beit She'an, which is scheduled to be commissioned in 2023. Hutchison Water, a subsidiary of Hong Kong-based CK Hutchison Holdings, in partnership with Noy Fund, an Israel-based energy and infrastructure investment company, is developing the project on a design-build-own-operate basis. A joint venture of Sinohydro and PowerChina Huadong Engineering is building the US\$ 600 million project under an EPC contract. GE is supplying all electro- and hydro-mechanical equipment and balance of plant and will operate the plant for a period of 20 years.

Manara will be Israel's third pumped-storage project, which is scheduled for commissioning in 2026. It was initially planned as a 340 MW project, but the lead developer Ellomay Capital was forced to downsize to 156 MW, after the government in 2019 limited development of pumped storage to 800 MW. The NIS 1.53 billion (US\$ 472 million) project, in the Upper Galilee region, is being built by Electra Infrastructure with Voith Hydro supplying the electro-mechanical equipment. O&M will be undertaken by a consortium of Voith Hydro, Verbund and the Israeli national water company, Mekorot. AFRY is providing owner's engineering services to the special purpose company, Ellomay Pumped Storage. Project finance totalling NIS 1.18 billion (US\$ 364 million) was secured from a consortium of Israeli banks and institutional investors, arranged and led by Mizrahi-Tefahot Bank, in February 2021. The two shareholders of the SPC - Ellomay Water Plants Holdings (75 per cent) and Sheva Mizrakot (25 per cent), undertook to provide aggregate equity financing of NIS 353 million (US\$ 109 million).

First pumped storage for the UAE

The Dubai Electricity and Water Authority (DEWA) is developing the first pumped-storage scheme in the Arabian Gulf. The 250 MW project at Hatta, the inland exclave of the Emirate of Dubai in the United Arab Emirates, is scheduled to be commissioned in 2024. The AED 1.92 billion (US\$ 520 million) project will diversify the energy mix and support the economic,

Pumped storage projects under construction as of March 2022											
Country	Region/River	Project name	Generation capacity	Pumping capacity	Storage capacity	Type	Head (m) (gross/net)	Name of developer	Turbine supplier	Est. cost	COD
			MW	MW	MWh/day	Closed-loop or Open-loop				US\$	
Australia	Queensland	Kidston	250	325	2000	CL, integrated	220	Genex Power/Energy Australia	Andritz Hydro	600m	2024
Australia	NSW	Snowy 2.0	2000	1860	350000	CL	600n/730g	Snowy Hydro	Voith Hydro	3700m	2025
Austria	Carinthia	Reisbeck II+	45	45		CL	60n	Verbund	GE Renewable Energy	68m	2023
Austria	Salzburg	Limberg III	480	480		CL	365n	Verbund	Voith Hydro	542m	2025
Austria	Salzburg	Tauernmoos	170	170	8500	OL	175-260, 220g	ÖBB Infrastruktur AG	GE Renewable Energy	336m	2025-2026
Austria	Tyrol, Oetzal Valley	Kühai 2	170	190		OL	120-250g	TIWAG AG	Voith Hydro	1024m	2026
China	Fujian	Zhouning	1200			OL		China Huadian Fuxin/Huadian Corporation	Harbin Electric Machinery	964m	2022
China	Chongqing	Panlong	1200			OL	462g	State Grid Xinyuan Company/SGCC	Dongfang Electric Company	1100m	2022
China	Shandong	Yimeng	900/1200			OL	375g	State Grid Xinyuan Company/SGCC	Dongfang Electric	1080m	2022
China	Heilongjiang, Mudan River	Huanggou	900/1200			OL	435g	SGCC			2023
China	Guangdong, Xianshui River	Meizhou I	1200					China Southern Power Grid Company		1100m	2023
China	Guangdong, Moyang River	Yangjiang I	1200					China Southern Power Grid Company	Harbin Electric Machinery	640m	2023
China	Zhuerduo River, Jilin,	Jilin Dunhua	900/1200			OL	694n	State Grid Xinyuan Company/SGCC	Dongfang Electric	1270m	2023
China	Zhejiang	Changlongshan	2100				710n	China Three Gorges Corporation	Dongfang Electric/Voith Hydro	1560m	2022-2023
China	Jiangsu	Jurong	1350			OL		State Grid Xinyuan Company/SGCC	Harbin Electric Machinery	1400m	2022-2024
China	Fujian	Yongtai	1200			OL	416n	Fujian Yongtai Mintou Pumped Storage Company	Dongfang Electric	970m	2023
China	Zhejiang	Tianhuangping II	700			OL	710n	China Three Gorges Corporation	Voith Hydro		2023
China	Huangya River, Henan	Henan Tianchi	1200	1260		OL	472-558, 510n	State Grid Xinyuan Company/SGCC	Voith Hydro	1040m	2023
China	Luanhe River, Hebei	Fengning 2	1800			OL	425n	State Grid Xinyuan Company/SGCC	Dongfang Electric/Andritz Hydro	1300m	2024
China	Yuehe River, Shaanxi province	ZhenAn	1400			OL	440n	Shaanxi ZhenAn Pumped Storage Company/SGCC	Andritz Hydro	1320m	2024
China	Shandong	Wendeng	1800			OL	471n	State Grid Xinyuan Company/SGCC	Harbin Electric Machinery	1340m	2022-2024
China	Zhejiang, Shimen River	Ninghai	1400			OL		State Grid Xinyuan Company/SGCC	Toshiba Hydro Power Systems	1160m	2024-2025

China	Xinjiang Uygur, Baiyang	Fukang	1200			OL	524-442	State Grid Xinyuan Company/SGCC		1200m	2024-2025
China	Fujian	Xiamen	1400			OL	545n	Fujian Xiamen Pumped Storage Company/SGCC	Voith Hydro	1250m	2025
China	Guangdong, Xianshui River	Meizhou II	1200			OL		China Southern Power Grid Company		260m	2025
China	Hubei River, Liaoning	Liaoning Qingyuan	1800	1500		OL	367-435	State Grid Liao Ning Qing Yuan PSP	Voith Hydro		2025
China	Shandong	Weifang	1200			OL		State Grid Xinyuan Company/SGCC		1170m	2025-2026
China	Hunan	Pingjiang	1400			CL	685	State Grid Xinyuan Company/SGCC		1390m	2025-2026
China	Zhejiang, Fangxi River	Jinyun	1800			OL	589n	State Grid Xinyuan Company/SGCC	Harbin Electric Machinery	1500	2025-2026
China	Henan	Henan Wuyue	1000			CL		China National Nuclear Corporation		1039m	2025-2026
China	Inner Mongolia	Zhinui	1200			OL		State Grid Xinyuan Company/SGCC			2025-2026
China	Zhejiang	Tiantai	1700			OL	725n	China Three Gorges Corporation		1530m	2026-2027
China		Yunxiao	1800			OL		China National Nuclear Corporation			2026-2027
China	Hubei, Luotian	Pingyanyuan	1400			OL	597n	China Three Gorges Corporation		1480m	2027-2028
Germany	Baden-Württemberg	Gaildorf	18	16			184	Max Bögl Wind AG	Voith Hydro		2023
India	Uttarakhand	Tehri	1000	1000		OL		NTPC/THDCIL	GE Renewable Energy	631m	2023
India	Maharashtra	Koyna Left Bank	80			OL		Water Resources Department of Maharashtra		50m	2025-2026
India	Tamil Nadu	Kundah	500			OL	236n	TANGEDCO	GE Renewable Energy	240m	2023
India	Andhra Pradesh	Pinnapuram	1200			CL	119.5	Greenko Energies Project	Andritz Hydro		2024
Israel	Beit She'an	Kokhav Hayarden	344		3100	CL	450n	Star Pumped Storage	GE Renewable Energy	700m	2023
Israel	Manara Cliffs	Manara	156				680n	Ellomay Pumped Storage	Voith Hydro	472m	2026
Japan	Honshu, Mimaiaiki River	Kanagawa	2820			OL	653	TEPCO	Hitachi/MHI/Toshiba		2032
Morocco	Taroudant, Issen River	Abdelmoumen	350			OL	555n	Office National de l'Electricité et de l'Eau Potable	Andritz Hydro	317m	2023
Portugal	Támega River	Gouvães	880	880		OL	657/645	Iberdrola	Andritz Hydro	1500m*	2022
Spain	Gran Canaria	Salto de Chira	200	220		CL		Red Electrica de España (REE)		455m	2027
Switzerland	Valais	Nant de Drance	900	900		CL	350g	Nant de Drance SA	GE Renewable Energy	2180m	2022
Switzerland	Ticino	Ritom	76	59	93840	OL, expansion	827g	Ritom SA	Voith Hydro	324m	2025
UAE	Hajar Mountains, Dubai	Hatta	250		1500	OL	150	DEWA	Andritz Hydro	391m	2024

The cost figures in US\$ millions based on March 2022 exchange rates are estimates and include in most cases all project costs including transmission infrastructure.

social and environmental development of Hatta, as well as help achieve the goals of Dubai Clean Energy 2050 to provide 75 per cent of Dubai's total power output from clean energy by 2050.

The project is being built by a consortium of Strabag Dubai LLC, Strabag AG, Andritz Hydro, and Ozkar, under a contract worth AED 1.437 billion (US\$ 391 million) which was awarded in August 2019. EDF assisted with the design of the project and is acting as owner's engineer. Straddling the Hajar Mountains bordering Oman, the scheme will make use of an existing reservoir impounded by the Sadd Hatta Al Awwal dam on the Wadi Zahra, which will act as the lower reservoir. The dam is located at el. 400 and impounds a reservoir with a storage capacity of 1716×10^6 gallons (7891×10^6 litres). An upper reservoir will be built in the Hajar Mountains at el. 700, with storage of up to 880×10^6 gallons (4000×10^6 litres). The facility will use solar energy produced from the future Mohammed bin Rashid Al Maktoum Solar Park to pump water to the upper reservoir during off-peak hours. The Mohammed bin Rashid Al Maktoum Solar Park, which will be the largest single-site solar park in the world with a planned capacity of 1 GW by 2020, and 5 GW by 2030, will comprise a range of photovoltaic and concentrated solar power technologies, in a total investment of AED 50 billion (US \$13.6 billion).

Turkey set to invest in pumped storage

Turkey remains one of Europe's leading markets for future hydropower development owing to a combination of abundant resources, a supportive government, and favourable policy framework but despite significant growth in wind and solar it has no operating pumped storage capacity. This is set to change. A consortium of China Gezhouba Group Corporation (CGCC), KAF Teknik and GE are planning Turkey's first pumped-storage plant at Eđirdir, in the western province of Isparta. The 1 GW project at Lake Eđirdir, requiring an investment of around US\$ 1.5 billion, was presented to the General Directorate of State Hydraulic Works (DSİ) in 2021 though no formal application has been made to date. The project, which is designed to help integrate growing variable renewables, would also complement Turkey's first nuclear powerplant at Akkuyu.

Plans for multiple projects continue in Iran

Three new schemes are at an advanced planning stage in western Iran. To date little variable renewable energy generation has been built, but the projects are designed initially to generate peak power, reduce the use and depreciation of the country's thermal powerplants and boost economic activity in the western regions bordering Iraq. The Seymareh, Azad and Rudbar Lorestan projects, which are being developed by the Iran Water & Power Resources Development Company, are all conceived to make use of existing reservoirs.

The Seymareh project will make use of a 180 m-high arch dam on the river Seimare in Ilam Province, which impounds a reservoir with a storage capacity of 3.2×10^9 m³. The 1 GW Rudbar Lorestan project on the river Rudbar, a tributary of the river Dez, in the province of Lorestan, has already been the subject of numerous studies and construction of access roads, and the diver-

sion tunnel were started in 2003. The 510 MW Azad plant in the province of Sanandaj, will use the existing Azad reservoir impounded by an embankment dam on the river Gura as the lower basin, and is designed with two single speed and one variable speed pump-turbines. The plant is to be connected to the dam via a 1600 m-long tunnel of which 110 m was built by 2010.

New projects underway in Africa

In Africa, just two pumped-storage projects are in an advanced stage of development. Morocco's state water and power utility, Office National de l'Electricité (ONE), is building the 350 MW Abdelmoumen plant, which at its scheduled commissioning in 2023 will be the country's second.

The US\$ 317 million scheme, on the river Issen, in the southern province of Taroudant, is being built by Vinci Construction of France in a joint venture with Andritz Hydro under a €284 million (US\$ 341 million) contract signed in 2018. ONE is also studying the potential for two further 300 MW pumped-storage facilities in the north of the country: El Menzel on the river Upper Sebou in the region of Fès-Meknès, and the Ifahsa scheme on the river Laou in the northwestern province of Chefchaouen. In March 2022, it selected a consortium of Portugal's Consultores de Engenharia e Ambiente (COBA) and local engineering group Conseil, Ingénierie et Développement (CID) to carry out studies for El Menzel. The preparatory studies including an Environmental and Social Impact Assessment (ESIA) are being financed by Germany's KfW, and the European Investment Bank. Morocco aims to increase the share of renewables from 42 per cent of national installed capacity in 2020 to 52 per cent by 2030, of which hydropower will account for 12 per cent.

Egypt is, meanwhile, developing the 2400 MW Attaqa Mountain pumped-storage plant, which will be the country's first. Located on the Attaqa Mountain at the northern end of the Red Sea mountain range, it is being developed by Sinohydro, on behalf of the Hydro Power Projects Executive Authority under the Ministry of Electricity and Renewable Energy, at an estimated cost of US\$ 2.7 billion. France's Artelia and Sweden's AF Consult were appointed as the owner's engineer in 2017.

Project pipeline building in the USA

The USA has the second largest pumped-storage capacity in operation in the world, with 43 plants totalling 21.9 GW and an estimated storage capacity of 553 GWh. New capacity has been limited over the past 30 years to mostly upgrades. However, interest is growing significantly. A total of 60 projects across 21 states with a total proposed capacity of 54.7 GW had received or applied for preliminary permits from the Federal Energy Regulatory Commission (FERC) as of February 2022. Many, however, will not go ahead given the stringent requirements for technical and economic viability, the fact that numerous projects face significant opposition on environmental grounds, and the fact that various developers are vying for projects in the same markets. Much of the new capacity will be built in the western USA, though geographic interest is spreading with projects being explored in Pennsylvania, Virginia, Oklahoma, Ohio and New York.

"What is driving most development activity and risk-taking at the early stage is the decarbonization shift," said Matthew Shapiro, CEO of rPlus Hydro, the coun-

try's leading pumped-storage developer. "There is no national policy yet, but on a state-by-state and utility-by-utility basis, there are significant shifts towards decarbonization with the retirement of coal-fired generation, changes to plans for new natural gas-fired capacity and renewable energy requirements that are being put in place, ranging from 50 per cent by 2030 up to 100 per cent by 2040 and 2050. We are not really waiting for a particular market mechanism, but rather looking at the reality of the situation, which is that we are going to need firm capacity sources to integrate all the wind and solar energy, and for us that points to pumped storage."

Several other factors are providing comfort to private developers, according to Shapiro. "The long lead time of these projects matches pretty well where things are going in terms of this shift to low-carbon generation," he said. "Pumped storage is also being included in the resource plans of more utilities, either the specific allocation of certain MWs or simply including the technology in the modelling. Some utilities themselves have started looking at sites and filing their own preliminary permits, which is a pretty good sign for future prospects," he added.

The business case in the USA will vary from market to market, but for Shapiro it is primarily a capacity play. "The emphasis will be on the availability of the storage and generation. In the event of non-utility ownership, this probably would mean what we would call a tolling agreement, which is a utility paying in fixed dollars per kW/year on a long-term contract for access to the capacity, plus any arbitrage between procuring the pumping energy at the lowest cost and the value of the peaking power, and value in the ancillary services market. However, we are not banking on the ancillary services market being a major stream of revenues, because there is only so much frequency regulation needed in a market. I think that in many cases the utilities may end up owning these assets and dispatching them by using those services as they would traditionally in a non-structured market," he concluded.

"The best value is the integration of renewables with pumped storage in a hybrid style arrangement," Rhett Hurless, Senior Vice President and COO of developer Absaroka Energy told *H&D*. "With this model, you can raise the capacity factor by 20-30 per cent," he noted. "With the retirement of coal units the grid needs inertia to ride through 'events', so with pumped-storage hydro we can fill that niche with spinning mass," he said when asked about the potential for providing ancillary services.

Three projects are currently fully licensed including the 400 MW/3400 MWh Gordon Butte project in the state of Montana, which as of March 2022 is ready for final design and construction. The developer Absaroka Energy is hopeful of achieving financial closure on the project, which will cost around US\$ 1 billion, this year with a view to commissioning the project by the end of 2027. Absaroka Energy received a major capital injection in 2019 from Copenhagen Infrastructure Partners (CIP), a Denmark-based energy infrastructure fund manager, which is also the owner of another licensed project, the 393 MW Swan Lake scheme in Oregon, as well as the 1.2 GW Goldendale project in Washington. A 50 year licence to build and operate Swan Lake was obtained in 2019 and a licence application was filed for Goldendale in June 2020. Swan Lake could go ahead

this year and be operational in 2026. The Goldendale project is scheduled to come online in 2028.

rPlus Hydro has a portfolio of ten projects with a combined capacity of 6550 MW for planned commissioning between 2029 and 2032. In February this year, it submitted a draft licence application for the 1000 MW White Pine closed loop pumped-storage project, in the western state of Nevada. The draft licence application starts a 90 day agency and public review process that will refine its proposal in preparation for the submission of the final licence application to FERC. rPlus Hydro also contracted Stantec in October 2021 to conduct a detailed feasibility study for the 900 MW Seminoe project in Wyoming, for which a draft licence application will be tendered later this year. The proposed project is currently scheduled to enter operation in 2029. Stantec is also conducting a feasibility study for Missouri River Energy Services for the 1800 MW Gregory County project in the midwestern state of South Dakota. In California, a consortium, comprising BHE Renewables, a wholly owned subsidiary of Berkshire Hathaway Energy Company, and Kiewit Development Company, was selected in January 2022 by the City of San Diego and the San Diego County Water Authority to begin negotiations to develop Phase 1 of the 500 MW San Vicente project. Commissioning for this closed loop, off-stream system is forecast for 2030.

One of the most innovative projects is a 20 MW pumped-storage plant that is being developed as part of an integrated renewable energy and irrigation complex in Hawaii by AES Clean Energy with the Kaua'i Island Utility Cooperative (KIUC). The project, on the Island of Kaua'i, also includes conventional hydropower, solar PV and battery storage; it is a key component in the state's decarbonization plans. The facility will pump water from the lower Mānā reservoir to the upper Pu'u 'Ōpae reservoir using production from the project's solar PV facility. AES is responsible for the construction and operation of the project under an agreement and a PPA signed with KIUC in 2020. ◇

Conclusions

In countries as diverse as China, India, Israel, Australia and Austria, pumped storage technology is being built to complement the growing penetration of wind and solar PV. With some 44 GW under construction and more than 70 GW currently at various stages of advanced planning, global pumped storage capacity could be doubled within the next decade. Development is not exclusive to established markets. The United Arab Emirates, Estonia, Indonesia, the Philippines and Vietnam are all developing their first such projects and the examples of the US, Australia and Israel show that pumped storage can be developed by private sector players without specific support mechanisms. Indeed clean energy targets are key drivers of investment in utility-scale generation and storage.

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