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News & Highlights

Weights-Based Gravity Energy Storage Looks to Scale Up

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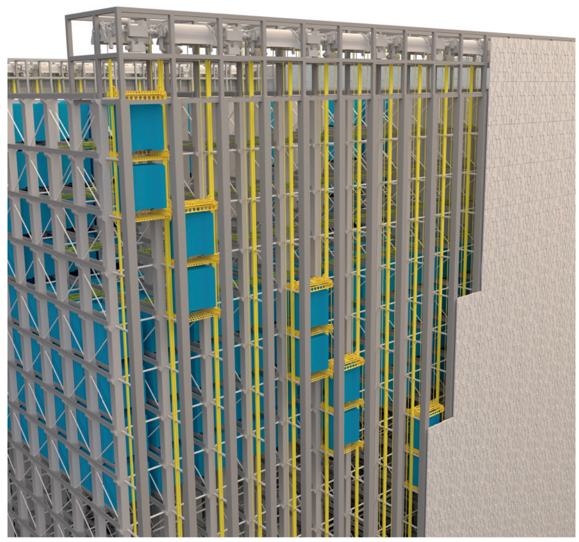
Innovative technology for gravity energy storage (GES), based on hoisting and lowering heavy weights to store and release energy in a highly sustainable manner, has now stepped onto the global stage. On 14 February 2022, Energy Vault Holdings, Inc., began trading on the New York Stock Exchange, after merging with a special purpose acquisition company, Novus Capital Corporation II; the transaction raised 235 million USD [1].

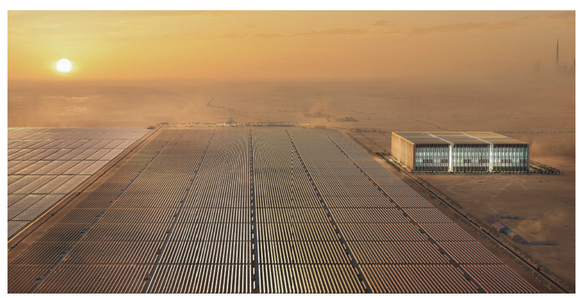
Energy Vault, with high-profile backers like actor and environmental activist Leonardo DiCaprio [2], aims to accelerate "the shift to a circular economy and a fully renewable world" through its Energy Vault Resiliency Centers (EVRC), boxlike buildings housing modular 10 MW·h "EVx" units that each contain about 1300 30-tonne weights in a 3D-gridlike track system (Fig. 1). When electricity production exceeds demand or the prices are low, electricity is consumed to lift these weights to the upper parts of the building, where they are stored on racks. When demand or price is high, the weights fall to generate electricity.

In October 2021, the company announced a deal with Washington, DC, USA-based DG Fuels, to provide 1.6 GW·h of energy storage across multiple projects, including one to "provide green electricity in conjunction with photovoltaic solar to firm and shape the renewable energy to match the demand load of (DG Fuels') green hydrogen production" [3]. The companies claim the partnership could result in revenues of half a billion USD [3]. Energy Vault, which has offices in West Lake Village, CA, USA, and Lugano, Switzerland, has inked additional deals with Melbourne, Victoria, Australia-based mining giant, Broken Hill Propriety Company, Ltd. (BHP), Sun Metals, a Queensland, Australia-based zinc refinery, and Saudi Aramco, a Dhahran, Saudi Arabia-based petroleum and natural gas company [4,5]. Earlier this year it also began building, with China Tianying, its first EVRC, a 100 MW·h facility in Rudong, Jiangsu Province, near Shanghai, said Robert Piconi, Energy Vault's chief executive officer. "We broke ground there in March," Piconi said. "And we have a few more facilities in other parts of the world coming right on its heels."

On a smaller stage, but also in 2021, the Edinburgh, UK–based GES company Gravitricity completed work on a grid-connected 250 kW demonstrator in Edinburgh that employs two 25-tonne weights suspended within a 15 m-high tower (Fig. 2). Gravitricity now plans to begin development of a full-scale GES plant in the Czech Republic, raising and lowering a single mass of 1000 tonnes in the shaft of an end-of-life coalmine to deliver up to 8 MW in power and 2 MW·h of energy storage [6]. "The project will be



(a)



(b)

Fig. 1. (a) An artist's illustration of Energy Vault's "EVx" GES modules, each of which can store 10 MW·h. A minimum of four of these modular units are built side by side to form what the company calls "EVRC," which can be up to 120 m tall; at these dimensions, 100 MW·h of storage would require about 9713 m^2 of land. About 1300 approximately 30-tonne masses (shown in blue) will be stored on racks within the structure of each EVx module. When "charging," these masses are lifted (lifts in yellow) and stored at higher elevations. When discharging, the process is reversed. (b) An artist's illustration of a solar power facility with an adjacent EVRC consisting here of nine EVx modular units in a square formation. The EVRC will "firm and shape" the output of the combined facility by storing gravitational potential energy when power generation is high and turning it back into electricity to release when the sun goes down. Credit: Energy Vault, with permission.

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situated in the Moravian–Silesian Region, where a number of coal mines are currently being decommissioned," said Gravitricity's Project Development Manager, Chris Yendell. "Following initial site visits in winter 2021/22, our next steps of development activity include further detailed feasibility studies and front-end engineering design." For the latter activity, Gravitricity won 1.15 million USD in funding from the United Kingdom government in February 2022 to investigate creating a purpose-built, multi-weight energy storage facility in northern England [7].

The concept of GES is not new. Pumped-storage hydroelectricity works by the same principle and is well established. Pumped hydro plants raise water from a lower reservoir to an upper reservoir when electricity supply exceeds demand and release the water back down through turbines to generate electricity when it is needed. The "round-trip" efficiency of this charge/discharge process can reach about 80%, similar to that of utility-scale batteries [8], an economically viable scheme given the swings in electricity need and prices at different times of the day. Piconi claims a round-trip efficiency of 75% in Energy Vault's first commercial demonstration unit—a crane-based system completed in July 2020 in Ticino, Switzerland (Fig. 3) [9]—and said he anticipates reaching 80% to 85% in the new EVx iteration of the company's technology.

About 96% of the world's estimated current power storage capacity is provided by pumped hydro, which in 2019 reached about 1.3 TW [10]. Historically, pumped hydro has married well with coal-fired and nuclear power systems, which operate more efficiently at a constant output that is not matched to the daily rise and fall of electricity demand [10]. Now, with climate change concerns driving the push to decarbonise and reduce fossil fuel consumption, a sharp turn to renewable energy—particularly wind and solar—is predicted in the coming decades [11,12]. But because these energy sources are by their nature variable, the demand for energy storage capacity is also predicted to increase substantially. Indeed, without a substantial increase in energy storage capacity, some experts warn that the development of renewables could be stymied [13].

The International Energy Association projects the need for energy storage will drive record growth in pumped hydro storage projects in this decade [14], though these projects are expensive and depend on specific geographical conditions. Chemical energy storage is another industry stepping up to meet the anticipated demand, with lithium-ion (Li-ion) batteries, including products such as Tesla Megapack utility-scale batteries, expected to play a significant role [15]. Bloomberg New Energy Finance (NEF) predicts global energy storage, excluding pumped hydro, to reach a capacity of 1 TW·h by 2030, more than twenty times that available in 2020 (Fig. 4) [16]. Much of this is expected to be supplied by Li-ion batteries, though novel, utility-scale "flow batteries" are also in development [17]. But Li-ion batteries are an imperfect storage solution, said Miles Franklin, Lead Engineer at Gravitricity: "Lithium-ion batteries are great for phones and electric vehicles, but not for static, grid-connected applications where high energy density is less important."

Advocates of weights-based GES claim it can provide not only the responsiveness of batteries but also many of the benefits of pumped hydro—without the downsides of enormous capital expenditure and need for specific geography. The principle is simple: energy stored = mass x lifted height x gravity. With gravity constant, the challenge becomes maximizing mass or height, and ideally both. Energy Vault's scheme commits to many 30-tonne masses dropping from a modest height of no more than 120 m. In contrast, by converting end-of-life mineshafts into energy storage facilities (Fig. 5), Gravitricity aims to drop single or dual masses of 1000 tonnes apiece—of steel fabrication with a high-density ballast—a very large distance, said Franklin: "Existing-shaft projects have obvious benefits, because the shaft is already in the ground, and we don't require the capital outlay to excavate a new one."

An important aspect of balancing demand and supply that GES facilities can facilitate is "peak shaving," which allows plant operators to buy electricity cheaply at times of low demand, store it as gravitational potential energy, and then release it for use at peak times when its cost is higher. Gravitricity's demonstrator tower showed that the setup can reach its full power output in less than a second, said Franklin. "The peak speed of the falling mass in our Edinburgh demonstrator was 0.62 mps [mps = meter per second]," he said. "The acceleration we achieved took it to full power fast." This level of responsiveness means that such GES plants could p-

Fig. 2. Gravitricity's grid-connected, 250 kW GES demonstrator uses two 25-tonne masses suspended within a 15 m tower. Credit: Gravitricity, with permission.

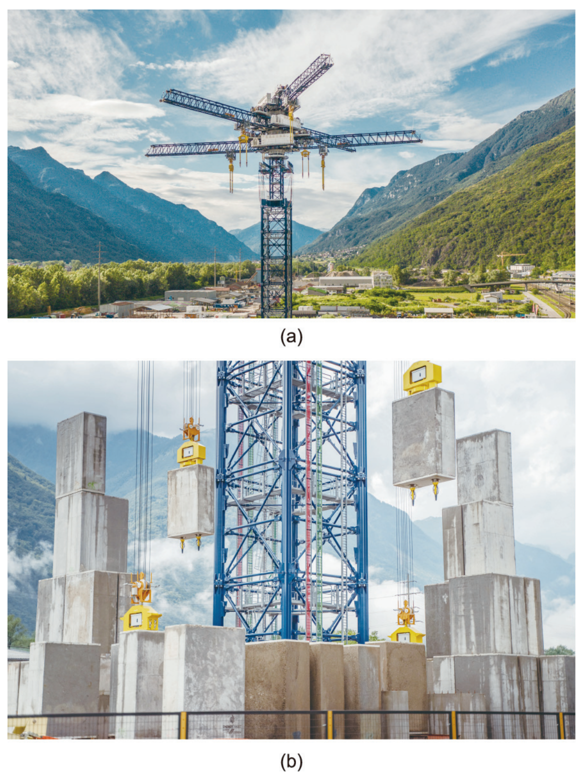

Fig. 3. Photographs of the top (a) and base (b) of a commercial demonstration of an earlier iteration of Energy Vault's technology involving a crane that lifted and lowered blocks weighing 35 tonnes apiece. The project was completed in Ticino, Switzerland, in 2020 and connected to the national grid. The company later decided to switch to the enclosed, modular format seen in Fig. 1. Credit: Energy Vault, with permission.

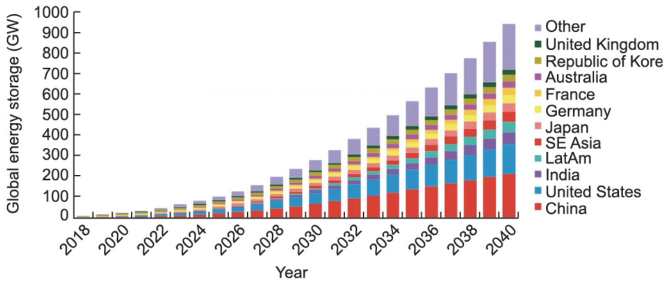

Fig. 4. Global cumulative storage deployments (excluding pumped hydropower), shown in GW, are expected to soar in the coming decades, driven in part by an anticipated drop in the cost of utility-scale Li-ion battery storage. Credit: BloombergNEF, with permission.

rovide short-term frequency balancing services for the wider electricity grid system, maintaining optimal conditions when demand exceeds generation or vice versa.

But the GES technology developed by Gravitricity and Energy Vault will not be sufficient to meet the expected enormous need for energy storage, according to Jim Fiske, chief technology officer of Gravity Power, a Santa Barbara, CA, USA-based GES startup. "The real need for gravity storage is not ancillary services like frequency balancing—it is bulk energy storage." Fiske's solution? "With hydraulics, you can lift a few million tonnes."

Gravity Power has designed a system in which the mass lowered and raised is a large piston, made of reinforced rock, which moves up and down inside a sealed, water-filled shaft about twice the height of the piston. The piston is raised by pumping water to the bottom of the shaft with the same technology used in pumped hydro. When electricity is needed, the piston sinks, pushing water through turbines to generate power (Fig. 6). "It is essentially pumped hydro—the powerhouse is identical to pumped hydro, and the hydraulics technology is extremely well developed," said Fiske. At full scale, Fiske envisions a piston 500 m tall and 50 m in diameter. "A big system might provide 400 MW for 8 or even 16 h," he said. The concept remains, however, on the drawing board while Gravity Power seeks commercial partners and investors.

Commenting on the Gravity Power scheme, Christoff Botha, a South African independent researcher and engineer who has reviewed a variety of GES designs [18], said: "With GES, people generally tend to say, 'That is a good idea'. Then you tell them how massive it needs to be, and suddenly people are saying 'That is too heavy. It is not going to work.' The Gravity Power model is appealing because it does not require cables, and water can support however much weight you want to put on it."

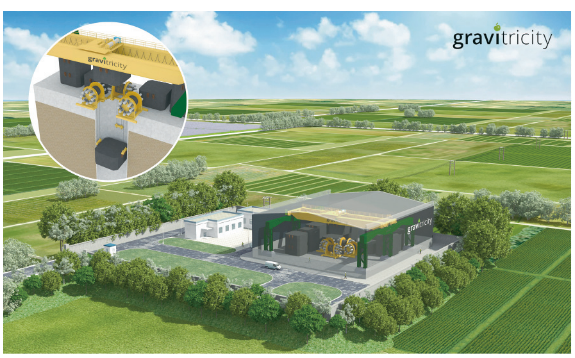

Fig. 5. An artist's illustration of a Gravitricity GES facility, built on top of an existing mineshaft or a purpose-excavated shaft. A single large mass, weighing about 1000 tonnes, is raised within the shaft to store energy, and lowered to generate electricity. Credit: Gravitricity, with permission.

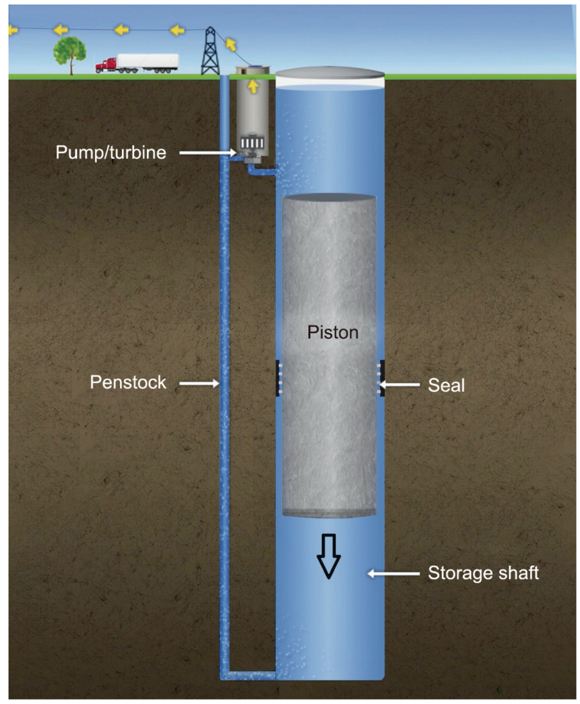

Fig. 6. The Gravity Power concept of GES involves technology similar to that used in pumped hydropower. A large piston made of reinforced rock, perhaps 500 m tall and 50 m in diameter, is held vertical in a sealed system surrounded by water (diagram not to scale). When storing energy, electricity is consumed pumping water into the bottom chamber, pushing the piston up. To discharge, the piston is allowed to fall, pushing water through a turbine to generate electricity. Credit: Gravity Power, with permission.

Regardless of GES type, advocates of the technology claim two key selling points, the first environmental: GES plants are in principle highly sustainable, do not emit greenhouse gases, and the masses do not degrade. On the other hand, however, it remains unclear how the carbon emissions from the manufacture of Energy Vault's large overground facilities and their many masses will impact the overall sustainability of the approach [19].

The second broadly claimed selling point is a low levelized cost of storage (LCOS) [20], the price per unit of energy stored/released that must be paid over the lifecycle of a GES plant to meet the cost of building and running it. The engineering simplicity of GES systems such as Gravitricity's, for example, means productivity for a very long time, with comparatively little maintenance required. "What is driving the LCOS numbers down is not that there is a low capital expenditure. In fact, the day-one cost is not expected to be lower than that for Li-ion batteries," said Franklin. "The key factor is that GES systems will have a lifetime similar to, if not greater than, existing grid infrastructure." By comparison, the charging and discharging of Li-ion batteries causes degradation that limits their lifetimes to around 10 to 15 years, or 3000 cycles [21], not to mention the downside of the environmental issues associated with mining and recycling of the elements needed for Li-ion batteries [22,23].

Despite its green credentials and potential long-term benefits, how the nascent GES industry will continue to develop is unclear. With the notable exception of Energy Vault, investments in GES remain comparatively small. "There are four or five other companies in addition to us, and none of them has proceeded past seed funding," said Piconi. "It's a very difficult problem to solve both sustainably and economically."

The dropping cost of Li-ion batteries and flow batteries [24], and their increasing adoption by the market also does not help. "There are lots of reasons why a particular type of energy storage technology is viable, and potentially valuable, only some of which are purely technical," said Thomas Morstyn, Lecturer in Power Electronics and Smart Grids at the University of Edinburgh, UK. "Only recently have some countries developed a clear, grid-based business model for battery energy storage. Do we need GES yet, or will we need it once there is a larger amount of renewable generation in play?"

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