HIDDEN POWERS

Switching to a completely renewable power grid presents today's engineers with a range of fascinating challenges. Tony Whitehead gets to grips with two developing solutions for capturing and storing energy from nature

As we look towards a future in which energy is generated almost entirely from renewable sources, an awkward question remains to be answered: what do you do when the wind isn't blowing and the sun isn't shining?

When renewables were only part of an energy supply mix that included fossil fuels, the solution was simple: simply turn up the gas to compensate until day dawned or the breeze got turbines moving again. But the closer we get to the world's declared target of net-zero carbon by 2050, the less this answer will do. We have to find ways to store energy for when nature is failing to provide.

Some technologies already ▷

exist, of course, perhaps the most effective being pumped hydro. At Ffestiniog in Wales, for example, spare power from times of low demand, particularly night-time, is used to pump water up to a reservoir in the hills. This can then be released to flow down through turbines to generate electricity in time to power the nation's kettles as the populace wakes in the morning.

Pumped hydro has been a useful moderator of electricity supply and demand in the UK since the 1960s, but more recently giant batteries have also begun to feature. Since 2017, what was then the world's largest battery, a 100 megawatt lithium-ion device made by Tesla, has been helping to even out power supply from a neighbouring wind farm in South Australia. An even bigger battery is planned to do the same for a solar power station in New South Wales.

But even between them, these methods of storing power do not entirely solve the problem. Pumped hydro relies heavily on there being suitable topography to create a high-level reservoir, and in many drier, flatter parts of the world this is simply not an option. And though batteries are becoming much more efficient, there are valid concerns about sourcing the rare-earth metals needed to make them and the environmental cost of their manufacture.

More solutions are needed, and one of them has just completed a demonstrator project at Ticino in southern Switzerland. Like pumped hydro, Energy Vault uses gravity to release stored energy, but instead of falling water, it uses falling blocks of concrete.

Energy Vault's commercial demonstration unit (CDU) is 80m high and features six crane-style jibs, each of which can lift or lower a "reservoir" of 35-tonne concrete blocks, measuring 4.2m by 2.8m by 1.4m. When there is a plentiful supply of power, the CDU lifts blocks and stacks them. Then when power is scarce, or demand is high, it lowers the blocks, the suspending cable driving dynamos to generate electricity.

The blocks are lowered at about 3m/second and each generates around 1MW as it falls, explains Davide Zampini, head of global research and development at Cemex, which developed and manufactured the specially designed blocks. "To see this thing working is amazing," he says. "The blocks go up and down surprisingly fast but then, like a high-speed lift, they slow at the last moment so they are stacked gently. The software controlling the shape of the stack, and so optimising the storage of potential energy, is also impressive – as is the level of control the cranes have. They are able to place blocks precisely, even in high winds."

The principle at work in Energy Vault is hardly new. A 14th-century clock in Salisbury cathedral, one of the world's oldest, is similarly powered by suspended weights falling (slowly this time) from a great height. Traditional cuckoo clocks work the same way.

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The ironic thing, Zampini notes, is that some of the most advanced technology in this project is in the blocks themselves. "Energy Vault wants to provide stored energy at a similar price to pumped hydro, so we have minimised the cost of the blocks by using an innovative, soil-based concrete."

The result is that almost 80% of each block is made from soil, and at Ticino, much of it came from the ground that was excavated to construct the foundations for the CDU's tower. This is achieved using soil-solidifying admixtures, which Cemex originally designed to create rural roads in developing countries quickly and cheaply. "But in fact, they have many uses, including cost-effective, soil-based concrete," says Zampini. "You can use a wide variety of soils because once you have analysed the content, you can adjust what else you put in the mix. The remaining 20% will comprise cement, the admixture, and perhaps a little sand or aggregate depending on what the soil is already giving us."

This mixture, dryer than

Left: The concept is scalable to a 100m-high tower using up to 8,000 blocks
Right: Each block has a 150mm layer of proprietary high-strength concrete on either end, to help them sit perfectly straight on top of the one below

most concrete mixes, is then compressed to form a very strong and durable block. "Conventional concrete is around 5 megapascals but this stuff is stronger – more like 10MPa. But it can be 20-30% cheaper than conventional concrete, especially important when blocks are produced in large numbers."

Several other advantages flow from the use of soil-based concrete. Because local soil can make up most of the mix, transport is minimised, and there is less need for the conventional resources of sand, aggregate and cement. The lower cement content and reduced transportation together lower the embodied carbon of each block. "And the polymers we use are biodegradable," adds Zampini. "So if for any reason you don't want your soil-based concrete any more, it can be crushed and returned to the ground as soil."

At Ticino, the CDU uses just 100 blocks, but Zampini says the concept is scalable to a 100m-high tower using up to 8,000 blocks. As these are stacked in concentric circular walls, they would create towers, with the blocks at the top storing a full 100m-drop's worth of potential energy.

Above: The crane stands 80m over a valley in Ticino, Switzerland. The concept is scalable to a 100m-high tower using up to 8,000 blocks

Of course, if you are going to be constantly building and unbuilding high towers out of giant concrete blocks, there are structural issues to consider, he points out. For this reason, it was essential that the blocks had both very precise dimensions and very square ends, so that each block sits perfectly straight on top of the one below. To ensure this, Cemex deployed more patent technology, casting on to the end of each block a layer of a proprietary concrete mix, Resilia HP.

"This is a very ductile, very strong material, eight times stronger than conventional concrete, and it can be cast with precision. You could have steel plates at each end of the blocks, but we have this instead. The 150mm-thick fibre reinforced plates are cast separately with connecting hooks, and then placed at each end of the moulds into which the soil-concrete mix is poured. The plates are strong enough to withstand the compression which is then applied to the mix."

As well as providing a lasting precision join between each block, the fibres add to their durability. "The soil concrete is strong, water-impermeable stuff – but this is much stronger still. The fibre mix increases both the tensile and flexural strength of the concrete and makes it extremely durable. It needs to be, as these blocks are continually being placed one on top of another and will be subject to wear and tear."

Once a block has been placed by the crane, it is locked into position by stops which slide automatically into place. Nevertheless, much of the tower's stability comes simply from the heavy blocks being accurately stacked. Would a 100m-high tower of such blocks really be safe?

"We have had the structures analysed by the University of California, Berkeley and they are more stable than you might think,"

Photos: Energy Vault

says Zampini. "As well as wind loading, they looked at how they might react to seismic events. The modelling shows that while the blocks would slide a little in relation to each other, this action absorbs a great deal of energy, helping to keep the tower stable."

Should the vision of an Energy Vault using thousands of blocks be realised, it would be a spectacular sight. In a desert it might provide a welcome point of interest, though a little creativity might be needed in more sensitive locations. Energy Vault points out that its falling blocks can be made in any colour – brown, say, or green – to help a tower blend into its surroundings. It may even be possible to use different coloured blocks like pixels to create pictures, or to display a company logo.

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"Once you start playing with this idea, the possibilities are endless," says Zampini. "With our admixture technology we could incorporate local waste streams like glass or plastic into the blocks as well as soil, so we would be contributing to the circular economy by using the mass of the waste to store green energy in concrete. A pleasing solution, I think."

Above: As the jib lowers the blocks, the suspending cable drives dynamos to generate electricity. The blocks drop at about 3m/second and each generates around 1MW as it falls

WAVE ENERGY CONVERTERS

Turning the tide

Everyone knows what a wind turbine looks like, and what a solar panel looks like. But what about a wave energy converter? How does it work? And what is it made of?

"In the renewable energy sector, wave energy is not as mature as, say, wind power," says Karoline Lende, an engineer in Arup's advanced digital engineering group. "The technology has not converged on one predominant design, nor is there yet agreement on the best materials to use for the designs that do exist."

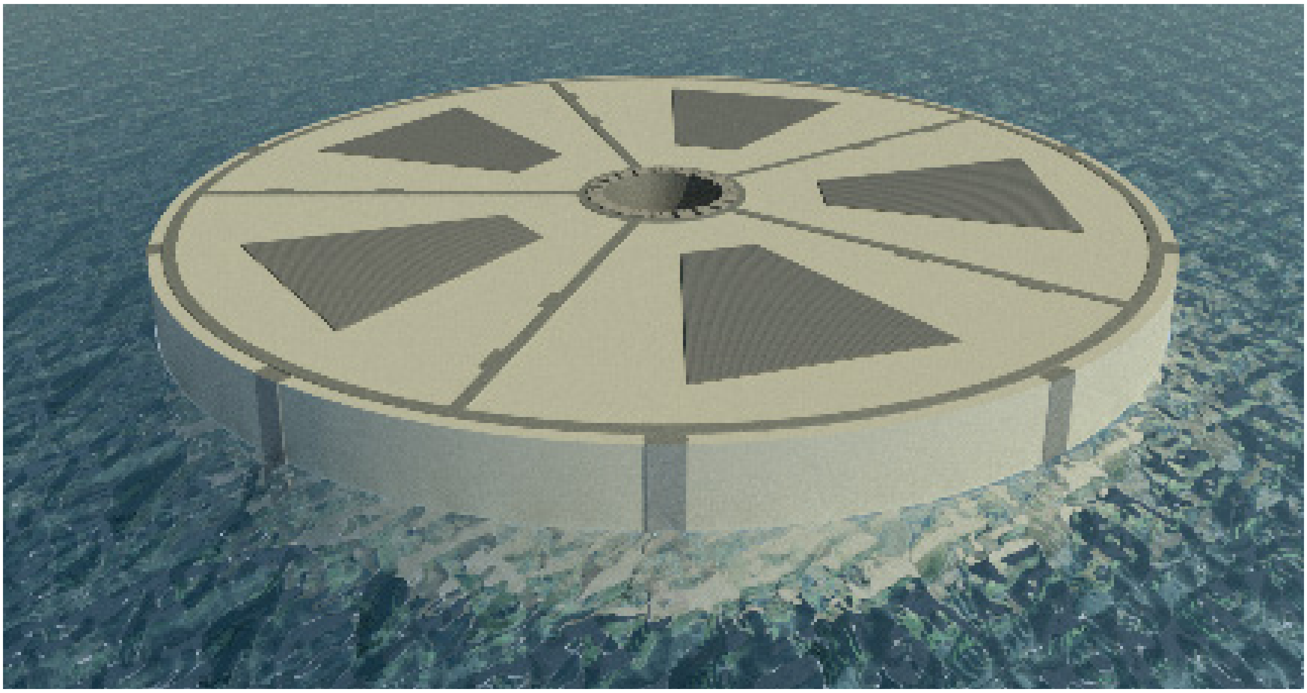
Lende has been working on a project sponsored by Wave Energy Scotland to test the suitability of concrete as a key material in wave energy converters (WEC). Arup looked at two designs: the Archimedes Wave Swing, developed by AWS Ocean Energy, and CETO from Australian firm, Carnegie Clean Energy. The Wave Swing features a large buoy, or floater, which moves up and down with the waves and effectively drives a large piston within a non-moving base tethered to the sea bed. A hydraulic motor converts this linear motion to rotary motion and this, in turn, drives a generator. CETO – named after the Greek goddess of sea monsters – is a 20m-diameter disc shape arranged to float beneath the surface where it can capture the orbital motion of waves and power hydraulic pumps which generate electricity onshore.

"Although these devices have different ways of capturing wave energy, they are both quite large, weighing hundreds of tonnes, and both operate below the surface of the waves," says Lende. "Both need a large moving component and a stationary component, and both need to have a certain mass and buoyancy to be efficient."

So what to make them from? The default material has tended to be steel – partly because it is relatively easy to fabricate experimental shapes and construct one-off prototypes. But because the buoyancy of the devices is key, they have often had to be weighed down with ballast to work properly.

Lende explains that even though the devices are located metres beneath the surface of the sea – a location that reduces wear from storms – they have to "want" to float if they are to capture wave movement. "But if they are too buoyant, they will exert too much pull on their tethers or the stationary part of the device. Hence the need for ballast."

Arup found that making the CETO buoy, and the Wave Swing's (stationary) silo, from concrete instead of steel, obviated the need for ballast and delivered a number of other advantages: "There is a well-developed precast concrete industry in Scotland which would be able to easily supply these components in the large numbers that might be required," says Lende. "We worked with contractor BAM to investigate the cost and practicality of creating these components from concrete and found that it could deliver savings of around 12%, assuming a 25-year device life. However, if you take advantage of the enhanced durability of concrete and



assume a 50-year device life, then we achieve a cost reduction of 20% compared to steel."

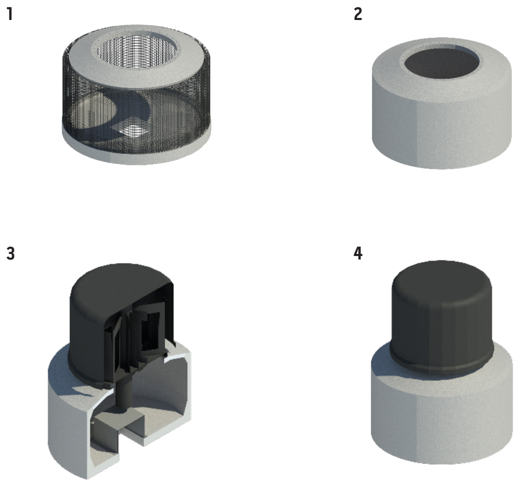
Much of the saving, she says, flows from reduced capex: "Especially when you make large numbers of either devices. But as concrete needs less maintenance than steel, there is also an opex saving that would apply to an all-concrete CETO device."

Arup has made its findings available to anyone interested in WEC design, along with a tool that helps designers calculate the buoyancy ratio of devices made from concrete.

"We also have information available on the embodied carbon values that designers can expect from concrete-based designs," says Lende. "Often there is little difference between concrete and steel, or concrete WECs can actually have lower embodied carbon than steel equivalents."

She adds that much of Arup's research in this area is applicable to other renewables technology, particularly "floating wind" – offshore turbines which, instead of having seabed foundations, stand on large hollow platforms made from concrete. Being hollow allows them to float, but being heavy and semi-submersed endows them with surprising stability. They can also be cheaper, involve less embodied carbon, and cause less disruption to local ecology than traditional foundations.

"These floating structures are much bigger than the WECs we have been looking at," says Lende. "But the benefits of local concrete supply chains, scalability, low maintenance and longer design lives all apply to floating wind platforms too. There's also scope for manufacturers of WECs and floating wind structures to share coastal manufacturing facilities such as concrete batching plant."



Top: CETO's precast concrete buoy is a 20m-diameter disc that floats beneath the surface, capturing the orbital motion of waves and powering hydraulic pumps
Above: The construction sequence for the Wave Swing's precast concrete silo

Both the Wave Swing and CETO are still prototypes, and have not been fully deployed at scale. But to have a mature and broad-based renewable energy sector, the immense power of the sea will need to be harnessed. And it's clear that it will take a material as durable, scalable and stable as precast concrete to catch those waves.