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Into thin air: Storage salvation for green energy

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If renewable energy is to succeed, we need to find a better way to store it. Liquid air batteries could be the answer

Editorial: "Time to nail the number one problem of green energy

Excess energy from the power station is used to power a giant fridge *(Image: Jez Coulson/Highview)*

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IT HAS been an unusually cool day in the flatlands of western Texas. As evening rises over the sprawling wind farm, the temperature continues to drop, and with it the wind. Far above, the blade of a towering turbine glides slowly to a halt. A few hours ago, these turbines were churning sufficient electricity into the grid to rival two nuclear power plants, enough to keep the lights on in 5 per cent of Texas. The state's power managers knew a drop was coming, but the speed has taken everyone by surprise.

The timing could not be worse. All across the state, people are coming home from work, flicking on lights, TVs and kettles. The power authority declares an emergency. Engineers request 30 megawatts of emergency power from Mexico. Supply to large industrial users is cut for more than an hour. It takes three hours before the system is finally stabilised.

This isn't a good day for renewable energy and it illustrates one reason why even modest targets consistently go unmet all around the world. In 2009, intermittent renewables accounted for a paltry 3.3 per cent of world energy generation. Wind, sun and wave are simply too fickle to be counted on. But that may be about to change - and salvation could literally come out of thin air.

It's not that we don't have enough energy sources. Indeed, every minute, enough solar radiation hits Earth to meet global energy needs for a year. Wind could also single-handedly take care of the entire world's demands, according to research published last year at Stanford University in California (*PNAS*, vol 109, p 15679). The reason it doesn't is down in part to the mismatch between when the energy can be obtained and when we can use it. Grid operators have to use back-up power stations, which forces up the cost of renewables. That's part of the reason why last year, renewable sources accounted for only 9.4 per cent of the electricity generated in the UK and 13 per cent of electricity in the US - well short of previous targets (see diagram).

It might seem obvious that the answer is to store the extra power when supply is high and demand is low and to tap it when the opposite is true. Indeed, the conventional power industry has done this for decades, particularly to salvage extra energy produced by nuclear power stations, which are too expensive to shut down when demand dips. One method is called pumped storage. At the Dinorwig power station in the UK, for example, water is pumped up into a reservoir on top of the Elidir Fawr mountain during periods of low demand. When energy demand spikes, the water is released down the mountain to drive turbines that feed the electricity grid. It's an extraordinary engineering achievement, housed in 16 kilometres of tunnels threaded through the mountain and capable of supplying 1300 megawatts in 12 seconds.

That power, speed and efficiency - about 80 per cent - is why pumped storage accounts for 99 per cent of the world's energy storage capacity. If every wind and solar farm had its own mountain reservoir, it might be possible to make wind energy a 24/7 resource.

Ambitious designs

In Ireland, a think tank called Spirit of Ireland is working on just such a project, a €3.6 billion undertaking that would use pumped storage to take full advantage of the country's copious supply of intermittent winds. "Wrong-time" energy from its large wind farms would drive seawater to a cliff-top reservoir.

But not every country can rely on pumped storage, which crucially depends on existing geographical features - or a willingness to shoulder the cost of building a mountain. So the success of renewable energy will depend on easier storage methods.

Developing these, however, has been far from straightforward. Batteries might seem the obvious choice, but scaling them up for grid storage has proved tricky. The Laurel mountain wind farm in West Virginia uses lithium batteries housed in shipping-container-sized structures to mop up unwanted electricity during low demand and send 32 megawatts back into the grid at high demand. They are highly efficient and have a small footprint. But they have drawbacks. Not only do they use exotic materials such as rare earth elements, but lithium battery storage is at least 10 times as expensive as pumped storage over the lifetime of a plant, according to a 2010 analysis by the Electric Power Research Institute in Palo Alto, California.

Some plants have turned to air, such as a natural gas plant operated by E.ON Kraftwerke in Huntorf, Germany. Instead of using excess electrical energy to drive water up a hill, they use it to compress and store air in salt caverns about 500 metres below ground. When they need the energy once more, they release the air to drive a turbine. The problem with this method is its efficiency, which rarely exceeds 50 per cent. Pressurising air causes it to heat up, which carries away a lot of the original energy. Then, to expand the compressed air, it must be heated a second time, using up even more energy.

The heat problem is being addressed in Germany, where a 90-megawatt demonstration plant is planned to be operational by 2019. But that won't solve the problem that compressed air storage relies on the presence of limestone caverns, aquifers or salt caves.

However, air may yet hold the key to energy storage - in liquid form. For the past two years, on a patch of land not much bigger than a basketball court in Slough, UK, a liquid air pilot storage plant has been quietly generating electricity using the excess energy from a neighbouring biomass plant. This tangle of gleaming white pipes and tanks has enough advantages over rival technologies to have been hailed as a critical part of our energy future. "This could save the UK billions," says Tim Fox, head of energy and environment at the Institution of Mechanical Engineers in London.

Air apparent

The plant combines existing technologies in a new way. The power station's excess energy is used to run a giant fridge that creates and stores liquid air. Wrong-time energy pulls ambient air out of the atmosphere and cools it to -196 °C, a temperature at which both oxygen and nitrogen are liquid. Once liquefied, 700 litres of air can be compressed into 1 litre and stored in a tank. When the local grid needs a top-up, some of the liquid is exposed to ambient temperature and the resulting expansion packs enough punch to drive a turbine. Best of all, because nitrogen boils at -195.8 °C, the process of returning it to ambient temperature requires very little energy.

According to Highview, the London-based company that operates the pilot plant, this technology will be capable of supplying tens or even hundreds of megawatts. A single 50-tonne tank - a standard piece of kit widely used in the chemical industry - could store enough liquid air to power around 15,000 homes for an hour, says Highview's Toby Peters. The mechanism is functionally equivalent to a battery that runs on air. Add more tanks, and liquid air plants can service more households for longer periods, perhaps even replacing the output of a medium-sized power station for several hours at a time.

Liquid air batteries could be deployed anywhere because they require neither a reservoir nor gravity. While the costs are still being determined, they are likely to be much cheaper than pumped storage, as no mountains need be excavated, and than lithium batteries, since the equipment required is already widely used. "All the components are available off the shelf," says

Yulong Ding, an engineer at the University of Leeds, UK, who has studied liquid air.

The only current drawback is efficiency. No process can store and release energy without wasting a little - even batteries lose 10 per cent to heat. But the process of liquefying air is even less efficient than compressing it: the energy you get back is an abysmal 25 per cent. The Slough pilot plant fares even worse. The demonstration project was not built with efficiency in mind, and it shows - efficiency is just 12 per cent. That said, simply scaling up the plant to commercial size and optimising it for efficiency will push that number to 50 per cent, Highview predicts, because larger turbines are more efficient than smaller ones. But Highview engineers also have a couple more tricks up their sleeves to further improve efficiency.

The first is to recycle the liquid air after it has been returned to ambient temperature by using it to heat up the liquid air that is just about to enter the turbine. This simple manoeuvre, the engineers say, will bump efficiency to 55 or 60 per cent.

A slightly more advanced trick makes use of thermodynamics. The bigger the temperature difference between the liquid air and the gas as it hits the turbine, the more explosive the expansion, and therefore the more energy goes into the grid. Highview engineers now pump the exhaust gases from the neighbouring biomass plant into the turbine to meet the liquefied air. In a commercial plant, this will cause the efficiency of the process to jump to 70 per cent, predicts Peters. These exhaust gases are considered low-grade heat because, at around 100 °C, they are not hot enough to be useful anywhere else.

Waste heat is easy to come by. The total heat wasted by industry, data centres and power plants in the UK is equivalent to that needed to heat every building in the country, says Fox. Simply locating liquid air plants adjacent to these facilities would "translate into extra electricity", he says.

Renewable future

But waste heat can play an even better trick, one that at first glance may appear implausible: bump the efficiency of the air batteries past 100 per cent. Using really hot exhaust - say, 150 °C or 200 °C - will transfer extra energy into the gasification process, says Ding, and salvaging some of the heat from the waste gases, which is normally lost to the atmosphere, can turn it into even more electricity.

There could be a lot of money in the commercialisation of air batteries. But all of this depends on a clear path toward renewable energy, and that requires more than just inventive engineering. An uncertain future for renewable energy can derail even promising projects. For example, Air Products, a large engineering firm based in Allentown, Pennsylvania, recently stopped worked on its liquid air energy storage system, citing the low price of natural gas. Without large amounts of renewable energy to store, their business model was moot.

However, the tide is turning. Governments are beginning to understand that the future of renewable energy hinges on robust, versatile energy storage. Get the right mix, and renewables could cost-effectively supply 99.9 per cent of the US electrical grid as early as 2030, according to a recent report from the University of Delaware in Newark.

Policymakers are paying attention. California, which generates more than 20 per cent of its electricity from renewables, is now ambitiously pursuing grid storage projects to meet its target of 33 per cent by 2020. "There's no doubt that energy storage will play an increasing role in the state's electricity grid as we add more and more clean energy to the system," says Laura Wisland of the Union of Concerned Scientists in Cambridge, Massachusetts. And in Texas, wind power shortages may soon be a thing of the past thanks to a recently passed law that clears the regulatory decks for grid storage.

New policies such as these should prompt a boom in energy storage. More than $100 billion is set to be invested in energy storage over the next decade and the race is on to capture that market. The winners will help solve the biggest environmental problem of our time.

Running on empty

Tired of putting petrol in your tank? In the future, your engine could run on thin air.

It may seem futuristic, but the air car dates back to 1903, when a British outfit called the

Liquid Air Car Company proposed the idea. Petrol vehicles are powered by the tiny explosions that occur every time a spark plug ignites a batch of fuel. But the rapid gasification that takes place when liquid nitrogen is exposed to heat can also produce enough force to move a piston (see main story). The theory was compelling, but the multi-stage engine required by the original design was too inefficient and costly to compete with the petrol car.

More than a century later, however, the idea is back, and this time it might work. British inventor Peter Dearman has produced a laboratory model of an engine that runs on liquid nitrogen, and his mechanism fixes the problem that stymied the Liquid Air Car by finding a way to heat the liquid air inside the engine.

An engine that runs on air would be a game-changer. It is cheap, safe and it only takes minutes to recharge the car, rivalling petrol's biggest selling point. Global engineering firm Ricardo has funded a demonstration engine that the team hopes to have running later this year.

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