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## **Beyond batteries: This technology could revolutionise energy**

Forget lithium battery fires: a safe, turbo-charged alternative way to store power could boost everything from smartphones to smart grids



Renaud Vigourt

**By Mark Harris**

AGAINST the backdrop of the Nevada desert a gigantic factory is taking shape. Look at the artist's impressions of the finished building and you could mistake it for a Martian colony, its ranks of solar panels stark against the reddish dirt. But this is the Gigafactory, a sprawling edifice covering around 600,000 square metres. Here, electric car company Tesla Motors plans to make a single component of its vehicles: the battery.

A good rechargeable car battery will set you back around \$10,000, for a product that is toxic, degrades substantially after a few years and must be carefully designed to avoid catastrophic overheating. The Gigafactory represents Tesla CEO Elon Musk's drive to make better batteries and so realise his dream of affordable electric cars.

Others are similarly exercised. Samsung's recent woes with exploding batteries in its Galaxy Note 7 smartphone caused it to recall all the devices and cease production. "It will cost us so much it makes my heart ache," said Koh Dong-Jin, president of Samsung's mobile business. Better, cheaper batteries are top of the wish list for almost any technology that's not powered by fossil fuels.

Yet as Musk and others are finding, it's proving a long, hard road. Might there be a better way? That's the claim of researchers championing a long-overlooked device to store and supply energy. They think it could actually stand more of a chance of delivering the power we need, how we need it – and so revolutionise the way we use energy. Is it time to look beyond batteries?



Renaud Vigourt

Rechargeable batteries store energy by performing a reversible chemical reaction in which ions are stored in and flow between positive and negative electrodes. The right materials, such as the lithium compounds common to both Tesla and Samsung's batteries, can store lots of energy, but are slow to charge and discharge, and heat up when they do. What exactly caused the Note 7 fault is not yet clear, but lithium ion batteries need tiny separators to keep components apart. If these are poorly designed or damaged they can fail, creating a short circuit that heats and damages other parts of the battery causing a runaway reaction. Such safety concerns, plus the sheer cost of lithium batteries, have long had chemists casting around for something better.

But chemistry isn't the only way to store electric charge. In devices known as capacitors, energy is physically stored in an electric field between metal electrodes. Capacitors are sprinters to the battery's long-distance runner, charging and discharging in a blink, and

doing this over and over again without their performance suffering. They are already used to power the flash on a camera.

But you can't run a car on a camera flash. A kilogram of petrol contains about 4000 Watt hours of useful energy, 30 times as much as the batteries in Tesla's current crop of vehicles. Traditional capacitors hold 1000 times less again, just 0.1 Watt hours per kg. If your car could drive 500 km on a tank of petrol, it would run little more than 16 metres using the same weight of capacitors.

It's unthinkable, then, that a traditional capacitor could ever compete with a battery. But many have had that exact thought – even Musk. “If I were to make a prediction, I'd think there's a good chance that it is not batteries but capacitors” that will deliver a breakthrough, he said in 2011. In that reading, it's just a case of guiding the continuing evolution of the capacitor.

## **Event: Reinventing Energy Summit – Meet the people shaping the future of energy**

That evolution stretches back to 1966, when Robert Rightmire at Standard Oil of Ohio was part of a team considering the future of fuel storage. He knew that the charge a capacitor could store depended on the surface area of its electrodes. So why not make these surfaces more spongy, the better to cram in charge? He produced a capacitor where the electrodes were coated with thin layers of carbon chemically punctured with millions of tiny holes. This so-called activated carbon is typically used for jobs like decaffeinating coffee, and has an internal area about 100,000 times larger than its outside surface. And it worked. Rightmire's “supercapacitors” stored 10 times as much energy as traditional capacitors.

### **Ditch the coconuts**

By the 1990s, small supercapacitors had become a commercial reality. They provided instant, short-lived back-up power to computers if the mains supply failed, so they could shut down safely. That's still a long way from powering a car. For a long time, not much changed. This was partly down to the curious source of that spongy carbon: coconuts.

“It's pure luck,” says Aaron Feaver, chief technical officer at EnerG2, an energy storage company based in Seattle. “The coconut didn't evolve to be an ultracapacitor electrode material, but it just happens to work pretty well.” Leftover husks are heated to 600 °C in an oxygen-free oven to get rid of all elements except carbon, a process known as pyrolysis. The carbon is then treated with chemicals to etch in the tiny pores.

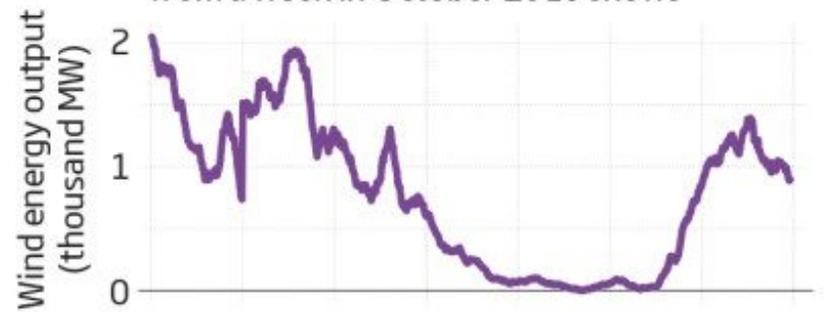
Coconuts were so cheap and convenient a source of carbon that no one thought much about other possibilities. At some point in the late 1990s, supercapacitors were rebranded “ultracapacitors”, but the principle remained the same.

# Supply and demand

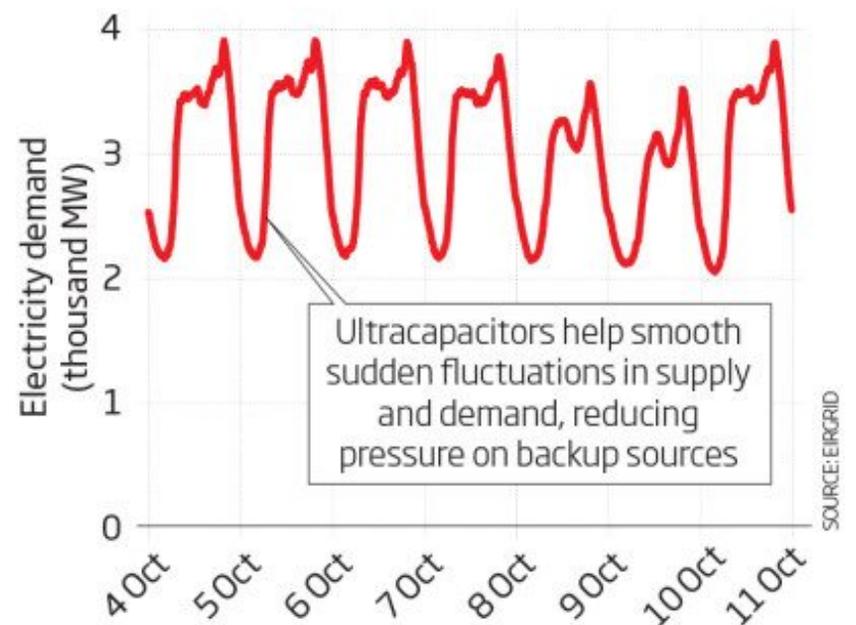
In Ireland, wind power now accounts for almost a quarter of energy supply



But it's highly intermittent, as this data from a week in October 2016 shows



Demand also fluctuates by the hour and day, requiring a large backup capacity in the form of batteries or fossil and nuclear sources



And they've continued to find new uses. Some wind turbine companies use them as an emergency alternative to batteries. Turbine blades need to be constantly adjusted to face the wind. If their electricity supply fails, the blades must quickly return to a neutral position to avoid strong gusts damaging or even destroying the turbine. That calls for a short power splurge – what ultracapacitors excel at. Plodding batteries are heavier and eventually need replacing. “Once you've put something into a turbine you're not going to want to go up and service it. You just want to forget it,” says Kim McGrath from Maxwell Technologies, an ultracapacitor manufacturer.

That special ability of ultracapacitors to provide a short zip of power is useful in other places too. In China, fleets of hybrid diesel buses are equipped with ultracapacitors that charge up swiftly from regenerative braking systems, and later accelerate the bus until the diesel engine can take over.

Meanwhile, material innovations suggest ways to store more juice in capacitors. In the mid-2000s Joel Schindall, John Kassakian and Riccardo Signorelli at the Massachusetts Institute of Technology began to explore whether other types of carbon might perform better than the coconut husks. It just so happened that a nearby lab housed Mildred Dresselhaus, known as the “queen of carbon science” for her work on exotic forms of the stuff. She helped the trio build a forest of tiny carbon nanotubes, cylinders of pure carbon 10,000 times smaller than a human hair, that could boast over 2000 square metres of area per gram.

Ultracapacitors using nanotubes have gone on to be a success, notably through FastCap Systems, a firm founded by John Cooley, also from MIT. FastCap have produced capacitors that will help power NASA missions to Venus and deep space. Its best model can hold 10 per cent of the charge of one of Tesla's batteries, about twice as much as the next best commercial product.

Such nanotube designs are expensive, and in general ultracapacitor capacity is still not enough to put the Gigafactory in jeopardy – but that might not be the point. “We do not ever expect ultracapacitors to be the primary energy storage device in an electric vehicle,” says Cooley. But if they can play the role of trusty sidekick, reducing the peak power load on tired batteries – the very thing that shortens their life – we could all benefit.

How so? While the idea of driving an electric car may or may not appeal to you, no one can ignore the problems facing electricity grids. We want energy supplies to be not just affordable, but reliable and green too. Ticking all those boxes is getting tougher, even for nations with highly developed economies. In October, for example, the UK fell out of the top 10 nations in the World Energy Council's Trilemma Index, an energy security ranking.

We have become serious about cheap green energy in recent years; renewables accounted for two-thirds of new generating capacity in the US last year, and over half worldwide, according to the United Nations. But on the one hand, demand for electricity varies widely and on the other, the supply of energy from renewables is intermittent. The wind doesn't always blow and the sun doesn't always shine (see “Supply and demand”).

This problem has been met with the concept of the smart grid, where networks of sensors and switches constantly monitor and adjust the flow of energy from all sorts of generators to consumers. But this inevitably means storing the electricity, and those sluggish batteries are once again where we trip up.

Using batteries as the sole storage medium isn't ideal for two reasons. First, constant charging and discharging shortens their life. Second, batteries can't release all their energy quickly, so grids need excess battery capacity to cope with short surges in demand over and above normal fluctuations. Adding ultracapacitors instead of supersizing the battery is a vast improvement. “The net effect is a reduction in the upfront expenditure and lower operating costs,” says McGrath. “And the technology has now gotten to the stage where it blows the market open for us.”

This year, Maxwell deployed two test ultracapacitor storage systems. One is in North Carolina, where the ultracapacitors are connected to a photovoltaic solar farm and a battery with a saltwater electrolyte. When the solar panels' output fluctuates due to passing clouds, the ultracapacitor goes to work. It can quickly supply nearly three times the power of the battery pack, but is exhausted in a couple of minutes. At that point, the battery, which holds about 40 times as much energy, steps in. The test is being carried out by Duke Energy, a utility company in the US with more than 7 million customers. It says the system is 10 to 15 per cent cheaper than a battery-only setup. “It should also slow down any degradation of the battery,” says Duke's Randy Wheelless.

Wind power is just as intermittent as the sun, and in the less balmy climes across the

Atlantic it is the go-to renewable power source. In Ireland, wind power accounts for almost a quarter of electricity generation, and the country wants that to be 40 per cent by 2020. It is here that the second test is taking place, in an experimental smart grid in Tallaght, near Dublin. Ultracapacitors connected to local government office buildings have proved able to compensate for changes in frequency of the electricity supply within a fraction of a second. Klaus Harder of FreqCon, a German firm that supplied the ultracapacitor-battery hybrid storage unit, says the ultracapacitors are so far living up to their promise.

FreqCon is planning to test a larger ultracapacitor-battery unit on the west coast of Ireland soon. But there is an ongoing challenge for the technology. Batteries may be imperfect, but they are still gradually improving. Ultracapacitors need to keep pace by increasing their capacity in tandem.

There is plenty of scope for that. Firms like EnerG2 say they will further improve the technology by using new sources of carbon to coat the electrodes. “Coconuts are cheap but they come with lots of natural contaminants and the activation process is toxic and expensive,” says Feaver. EnerG2 designs its own carbon based polymers, similar to the resins used for laminating plywood. It then pyrolyses and activates them using a simpler, greener process.

EnerG2’s carbon can also be tailored to different types of ultracapacitor. Those designed to quickly stop and start a car’s petrol engine to improve fuel efficiency need a quick burst of power, but for smoothing a domestic solar panel’s output, capacity might be more important than speed. Coconut carbon has pores whose size matches common electrolytes such as ammonium salts. But by adjusting its chemistry, says Feaver, EnerG2 can produce carbon with pores to match electrolytes designed for high power density, high energy density, or any combination of the two.

## **Practically invincible**

Some think there could be greater leaps ahead if we break our attachment to carbon. William Dichtel, a chemist at Northwestern University, Chicago, has developed polymer networks called covalent organic frameworks to work directly in ultracapacitors without needing pyrolysis. His team succeeded in producing a porous ultracapacitor material that approached the performance of a nanotube device but potentially at a fraction of the cost. “The caveat is that we’re chemists doing basic research, not Tesla trying to put this in a car in a profitable fashion,” says Dichtel.

There are concerns that exotic polymer-based ultracapacitors might not have the longevity of today’s carbon systems. True, these ultracapacitors are not invincible, says Feaver. “But when you compare them with batteries, they might as well be.” The battery in a cellphone or electric car is designed for 1000 charge-discharge cycles, whereas even Dichtel’s experimental ultracapacitor was stable for at least 10 times as many cycles.

Ultracapacitors have come so far from their humble beginnings that it is tempting to wonder if they might graduate beyond their sidekick role and oust batteries entirely. We’re far from that day, but perhaps it’s unwise to bet against it ever arriving. We know that Elon Musk toyed with a PhD studying ultracapacitors before quitting for his first Silicon Valley start-up. And Tesla Motors’ patents still make tantalising references to ultracapacitors. The

man once so enamoured with ultracapacitors hasn't entirely lost faith, then. Maybe they are still evolving behind the doors of that huge factory in Nevada.

*This article appeared in print under the headline "Help for heroes"*

## Article amended on 14 November 2016

*We have corrected the figures given in the graphs for wind-power generation in Ireland.*

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