ROBERTO CIGNA

How to keep the lights on without blowing the planet

Can we really get all our electricity from wind, sun and water by 2050, asks Peter Fairley

TO STAND any chance of halting runaway climate change, we need to squelch carbon emissions down to near zero by mid-century. That means getting off filthy fossil fuels – and fast. Few scientists would disagree with that, but there is precious little consensus on how to do it. Nuclear fission power is expensive and mired in controversy. Nuclear fusion, directly harnessing the kind of reactions that power the sun, remains a distant dream. Meanwhile, renewable energy is too unreliable to meet all our power demands.

Or is it? Clean energy technologies have come on leaps and bounds in the past decade or so. More recently, an impassioned debate has broken out among energy experts as to whether "100 per cent renewables" is now within our grasp and, if so, how we get there. "We can really mess this up," says Dan Kammen, an energy researcher at the University of California, Berkeley. "Just because we can make the shift doesn't mean we will." But the path we need to take – and the hurdles we face – are increasingly clear.

The renewables revolution has gathered momentum in recent years thanks to free-falling prices. And as clean becomes cheap, installation is surging. The world added 98 gigawatts (GW) of solar energy last year – more than any other energy source. Over half of that, 53 GW, was in China, which has long been the world's biggest consumer of dirty coal.

In California, the world's fifth-largest economy, renewables already provide over a third of electricity and will surpass 50 per cent well before 2030. Germany is aiming to get at least 80 per cent of its power renewably by 2050. Even oil and gas nations are setting ambitious renewables goals – the United Arab Emirates, for instance, plans to shift 44 per cent of its power to renewables by 2050.

That's great, but not enough. Tackling climate change requires more than just revamping the power grid. Converting services that currently run on fossil fuels, from transportation and heating to heavy industry, is also crucial. After increasing energy efficiency across the board, electrifying as many fuel-guzzlers as possible is the cheapest way to limit global warming to the target of 2°C above pre-industrial levels, according to the International Energy Agency.

That is a huge undertaking, and it is only just getting started (see "Electrifying!", page 28). Even if you just bring a few of the sectors that rely on burning fossil fuels onto the grid, the figures are daunting. Right now the world gets just a quarter of its electricity from renewables. In Europe, grid experts estimate that renewable generation must quadruple by 2050 (see "New generation", page 28).

Such a transition brings economic challenges. Renewables cost many times more to install than fossil generators, and workers will be dislocated as fossil industry jobs disappear. Low operating costs and reduced wholesale prices will also undercut the business case for flexible power sources, which means the way electricity is traded on the wholesale market will have to change. Ultimately, however, renewables deliver economically by slashing spending on fossil › fuel and avoiding environmental catastrophe, which hurts economic growth.

In 2015, Mark Jacobson of Stanford University took the bull by the horns, publishing a blueprint for shifting the US exclusively to wind, solar and hydro power by 2050 – not just for electricity, but for all of the country's energy needs. He and his colleagues calculated that it would require a 25-fold increase in renewable capacity over the next 35 years. They subsequently extended the award-winning roadmap to 139 countries, accounting for 99 per cent of global emissions.

Not everyone was convinced. Last summer, a group of researchers led by Christopher Clack, founder of a company called Vibrant Clean Energy, published a stinging riposte, arguing that Jacobson's plan rested on "implausible and inadequately supported assumptions". Jacobson sued Clack and the *Proceedings of the National Academy of Sciences*, which published the original paper and the rebuttal, for libel. He argued that the Clack pack's attack mischaracterised his modelling assumptions as errors, and that the journal had violated its own publishing rules. It didn't go down well. After taking flak for what many saw as an effort to stifle debate, Jacobson dropped the lawsuit in February.

What that spat and the whole 100-per-cent renewables argument really revolves around is one inescapable fact: the most abundant sources of renewable energy, namely wind and the sun, are capricious. The sun goes down, the wind drops, and seasons vary

24.5%

of global electricity production came from renewable sources in 2016

Source: Renewables 2017 Global Status Report, Renewable Energy Policy Network for the 21st Century

every year. The supply of renewable energy can plummet inconveniently just when local demand is peaking.

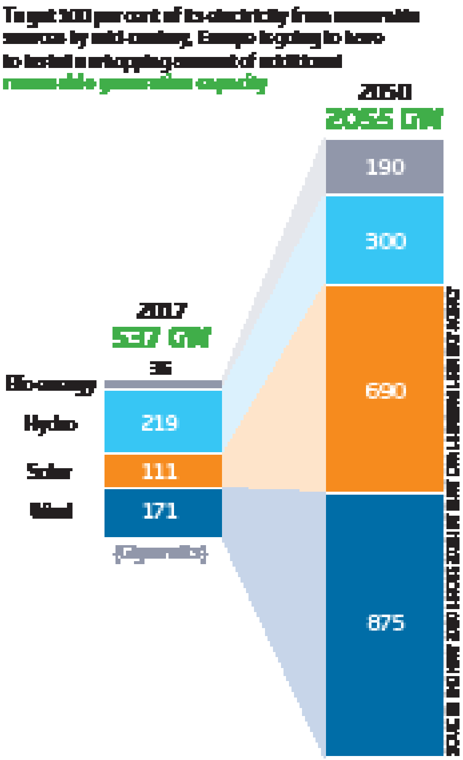
We can cope with that up to a point by tweaking today's grid. But the variability challenge really starts to bite when renewables exceed about 70 to 80 per cent, according to modelling by the Hawaiian Electric Company. Hawaii is the only US state that's already mandated to get to 100 per cent renewable power by mid-century (see "Success stories", page 30) – an ambition the company's vice president Colton Ching calls "big, hairy and audacious".

That's why Clack and some of his colleagues prefer not to rule out other low-carbon sources designed to produce power on demand: nuclear reactors and coal or gas generators that capture the CO_2 they produce. But both are punishingly expensive to build and operate and nuclear in particular enjoys precious little public support. "I was a nuclear-trained officer in the US Navy," says Doug Houseman, a smart grid expert who has consulted for more than 100 major energy companies. "I'm a big fan. But the political climate is such that the chances that we're going to be able to build sufficient nuclear [plants] are negligible."

For a growing number of energy companies, then, there is no option but to aggressively pursue 100 per cent renewables. "There is no future for anything that isn't renewable," says Ernesto Ciorra, the chief innovation officer at power and gas giant Enel. Everyone admits that it will be challenging. So how do we do it?

One way to deal with daily fluctuations in renewable energy supply is by finding clever ways to shift demand to take up surplus wind and solar when supply is running hot, and to defer consumption when it is not

New generation



ELECTRIFYING!

Getting 100 per cent of our electricity from renewable sources is a massive challenge (see main story), but it also creates an even larger carbon-cutting opportunity. The stuff we plug in today accounts for a measly one-fifth of global carbon emissions from energy. So if we're serious about deep decarbonisation, we need to plug a lot more into the grid.

Electrification looks relatively straightforward for cars. Electric motors move cars more efficiently than gas engines, and lithium batteries are becoming sufficiently cheap and durable. Sales of electric cars are already on an exponential upward curve, with China leading the way. Meanwhile, major economies such as France and the UK are doing their bit by banning petrol and diesel-fuelled cars from 2040.

Freight trucks, which produce over 7.5 per cent of US carbon emissions, are harder to plug in. Industrial processes that rely on burning gas are trickier still, since gas is a convenient way to deliver a lot of heat. But there's a solution: convert electricity to hydrogen gas and synthetic methane fuel.

For trucking in Europe, for example, subsidies a fraction the size of those that drove the ascent of wind and solar would make these "electrofuels" competitive with diesel by 2020, according to Jerry Murphy at University College Cork in Ireland. Heavy industry, including the steel plants that spew out 7 per cent of global carbon emissions, could run on hydrogen, too. In fact, Swedish steelmaker and energy company Vattenfall is designing the world's first steel plant powered by renewable hydrogen.

Electrification is a mammoth task. But recent progress in China, the world's biggest carbon polluter, is encouraging. Between 2000 and 2016, electricity's share of total energy there doubled from 11 to 22 per cent, and it will exceed 50 per cent by 2050, according to Shu Yinbiao, chairman of the State Grid Corporation of China.

(see “Managing expectations”, page 31). The other way to cope, of course, is simply to stockpile the surplus so we can use it when demand peaks.

Supercharged batteries such as the sprawling lithium-ion facility Tesla recently installed in Jamestown, Australia, are the most obvious option. Boasting a capacity of 100-megawatts, this is the world’s most powerful battery, for now at least. It can power up to 30,000 homes – albeit just for an hour.

In fairness, the Tesla battery was built as backup for South Australia, which has suffered a series of recent blackouts. Even so, its limitations go to show that although batteries could plausibly hold enough juice to cope with day-to-day peaks in demand, their cost makes them a prohibitively expensive answer to monthly and seasonal fluctuations, which are by far the biggest block in the road to 100 per cent renewables.

Pumped up

We don’t yet have devices capable of storing several months’ worth of renewable energy at a reasonable price, which is what we will need. But some well-tested solutions can take us a long way, and we have a raft of more innovative options that could be scaled up.

One trusty storage technology capable of doing a lot more is hydropower. Hydro reservoirs are giant reserves that store rain and meltwater, ready to be released through energy-generating turbines when demand peaks. Some hydropower plants can also use excess off-peak energy to pump water back uphill, where it recharges the reservoir, ready for another run through the power turbines. This pumped hydro technology accounts for the vast majority of global electricity storage and yet there is plenty of room to grow.

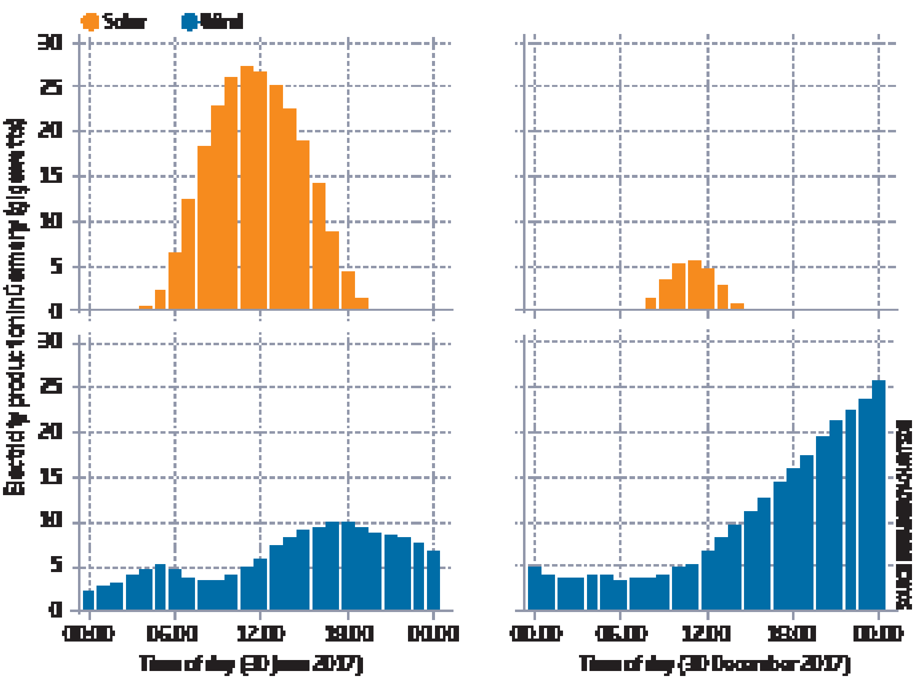
No wonder it’s back in fashion big time in some parts of the world. China more than doubled its pumped hydro capacity over the last decade and is in the process of more than doubling this again. Technology upgrades, meanwhile, are letting places that lack hilly geography or plentiful fresh water get in on the act. Australia, for instance, is evaluating a massive coastal plant to store power by raising seawater from Spencer Gulf to a reservoir 260-meters above sea level on the adjacent plateau.

But tapping hydropower for storage is complicated by other environmental concerns. Most of the water that drives the power-generating turbines must also sustain river ecosystems, irrigate crops and ›

ISTOCK / GETTY IMAGES PLUS

Intermittent power

Solar and wind are the most abundant sources of renewable electricity, but they are also the most variable, as 2017 data from Germany shows



PETRAS MALUKAS/AFP/GETTY IMAGES

SUCCESS STORIES

While more and more places are setting ambitious clean energy targets, some countries are already operating power grids with close to 100 per cent renewables. Typically, their success is down to geography. But other factors are at work too.

Costa Rica and Norway owe their successes to a rich supply of hydropower, the result of mountains and plentiful rain. Volcanic Iceland is doubly blessed with hydropower and geothermal energy. The real renewable growth leaders to watch, however, are the less geographically well-endowed countries that are nevertheless speeding forward. The cultural and political factors driving their energy transitions offer important lessons.

Denmark has boosted its wind power supply from under 5 per cent of electricity in 1990 to over 40 per cent today, and is heading for all-renewable power and heating by 2035. Much of the credit for their accelerated transition belongs to a strong "communitarian" ethic that encompasses environmental protection, says Benjamin Sovacool at the University of Sussex, UK. He says that a long-held consensus on climate change underpins stable long-term energy policy to address it.

Hawaii is the only US state with a mandate to reach 100 per cent renewables. The high cost of imported petroleum moved things along. But so has the fact that Hawaii, like Denmark, has a relatively small and cohesive population. "We tend to all know each other," says Colton Ching of the Hawaiian Electric Company. "That smallness allows us to make decisions, be nimble, and agree to things that would be much more difficult in a larger state." And maybe there is a lesson in that for larger and more diverse jurisdictions: work harder to forge consensus.

slake the thirst of cities. Then there's the need to flood tracts of land for reservoirs, often displacing settled communities.

Perhaps the most promising alternatives are rapidly improving techniques that convert surplus electricity into combustible hydrogen, methane or even synthetic diesel – fuels that, unlike electricity, lend themselves to bulk storage. Power to Gas (PtG), as it is known, begins by using electricity to split water into hydrogen and oxygen. The energetic hydrogen gas can then cleanly fuel cars and trucks or fire-up industrial boilers.

A limited amount of hydrogen can also be compressed and fed into gas pipeline networks and their large storage sites, ready for delivery when demand peaks. The hydrogen can even be reacted with CO_2 to produce renewable methane, which could replace fossilised natural gas altogether.

Unlimited storage

In a world brimming with depleted gas fields, the storage potential is essentially unlimited. Ireland's gas distributors already keep several weeks' supply on hand by injecting natural gas into the depleted Kinsale gas field off shore from Cork, says Jerry Murphy, a bioenergy researcher at University College Cork. There is no reason we can't take advantage of similar sites to store renewable gas.

PtG remains an emerging technology, and some experts dismiss it because hydrogen electrolysers – the devices that use electricity to split water – are less energy efficient and several times more expensive than batteries. Then again, others think this may be misreading the economics of long-term power storage. Battery costs explode as you multiply the amount of energy to be stored, says Ken Dragoon, who runs Flink Energy Consulting in Portland, Oregon. You have to buy twice as much battery capacity to store twice as much energy, whereas with electrolysers, doubling the gas produced from surplus power simply means operating the same equipment for twice as long. "At some point it becomes cheaper to use the electrolyser," says Dragoon. The amount of storage needed for a 100 per cent renewable energy system is way beyond that economic crossover.

These sorts of solutions could overcome short-term variations in renewables' generating capacity over hours or days, and even take some of the strain from inter-seasonal variability. The rest will require a different approach: rather than hoarding electricity locally, share it widely. After all, the wind is always blowing somewhere, and where it's not there may be sunshine. If you can zap enough wind and solar power from one place to another, you need less on reserve. That will require continental supergrids that move power more efficiently than we do today.

The technology exists: unlike conventional AC power lines, where electricity flows near the surface of a power line, high-voltage direct current (HVDC) transmission uses its full cross-section and thus encounters less resistance along the way. It can transmit big power without big losses over thousands of

High-voltage power lines, like these linking Poland and Lithuania, counter renewables' reliability problem

kilometres, and it can do so whenever we are ready. Continental supergrids can be built as soon as the power companies give the green light, says Rajendra Iyer, at General Electric's HVDC business unit. "The DC grid solutions are there. They can be deployed any time."

They already are in China, which has built a series of massive lines to supply its coastal megacities. This year, the State Grid Corporation of China expects to deploy its first 1,100,000-volt DC technology: a 3324-kilometre line capable of carrying 12 GW, roughly half of Spain's average consumption, that will put idled wind and solar farms in China's north-west back in operation. This "ultra-high voltage" tech also underpins its proposal to create a global supergrid that would make renewable energy relatively steady, cheap and bountiful. Imagine solar power from the Sahara available across Asia and Europe and you get an idea of China's ambition.

It sounds like a no-brainer. For inter-continental supergrids, however, the challenges are geopolitical and cultural. Nations must be willing to place their trust in imported energy – not so different from today's dependence on oil and gas produced in only a few parts of the world, but also not a minor complication at a time of increasing international tension. The discord that delayed the Nord Stream gas pipeline from Russia to Germany, and which now plagues its sequel, foreshadows the geopolitical hurdles facing supergrids.

The other barrier is public resistance. Opposition from communities that new DC power lines would traverse is one of the main reasons why Europe's transmission operators have, to date, stopped short of planning a continental supergrid.

Europe can probably get by without one. A technical study called the eHighways 2050 project, completed in 2015, suggests that Europe could shift to 100 per cent renewable power by expanding links between neighbouring countries rather than sending long lines across them. But foregoing a supergrid may raise energy costs, and even the smaller links Europe is planning face concerted local opposition. In 2013, Germany's grid regulator approved a trio of HVDC links to balance North Sea wind power against solar energy from southern Germany. Grid operators vowed they would be ready before the last nuclear power plants in the country shut down, planned for 2022. But under public pressure the German government dictated the power cables should run underground, delaying the project until at least 2025.

71 %

of energy experts surveyed in 2017 agreed that getting all of our electricity from renewables is realistic

Source: Renewables Global Futures Report, Renewable Energy Policy Network for the 21st Century

That sort of conflict, together with the technical and economic challenges for both super-charged storage and supergrids, makes the shift to 100 per cent renewable power seem daunting in the extreme.
Yet many scientists are more optimistic than ever. Jacobson remains bullish, and others see change in the wind too. "This is no longer just people like me who have been arguing for a renewable future for a long time, but also sceptics and more real-world focused engineers who thought it was a fiction," says Kammen, who was among the authors on the paper criticising Jacobson's blueprint.

The real question, they say, is not whether we can get to 100 per cent renewable energy, but whether we will do it in time. Moving fast means saying no to new fossil fuel generators, accelerating renewable installations, sustaining innovation to continue cutting storage and transmission costs and rethinking power markets.

As Jean-Baptiste Paquel, senior advisor for ENTSO-e, the Brussels-based consortium of European grid operators, says: "If you want to make this change and make it affordable, you need to push for all of these solutions." ■

MANAGING EXPECTATIONS

The inherent fickleness of weather-driven energy poses a big challenge for electricity grid operators, which must continuously balance supply and consumption. This will only get harder as more of our electricity comes from renewables. How will we manage steep drops in supply without today's go-to source of flexibility, the carbon-belching natural gas turbines that ramp up and down at will?

The cheapest bet is a strategy known as demand management – manipulating energy demand at certain times to keep the grid in balance. Operators such as the National Grid in the UK already incentivise businesses to trim their usage at times of peak demand or ramp it up when supply is surging. But the process is growing increasingly sophisticated. These days, smart meters and machine learning techniques are enabling grid operators to deftly tweak the growing number of residential devices linked to the web. In future, myriad appliances will be automatically activated when renewables are running hot and dialled-down when they are not.

The trick is to make demand management work for consumers, says Lindsay Anderson at Cornell University in Ithaca, New York. That means not only tweaking loads intelligently to avoid inconvenience, but also crafting rates that reward the use of renewable energy. "A lot of it can actually be invisible to the consumer while being a huge benefit to the grid," she says. "We have the technologies that we need. We just have to use them in creative ways."

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