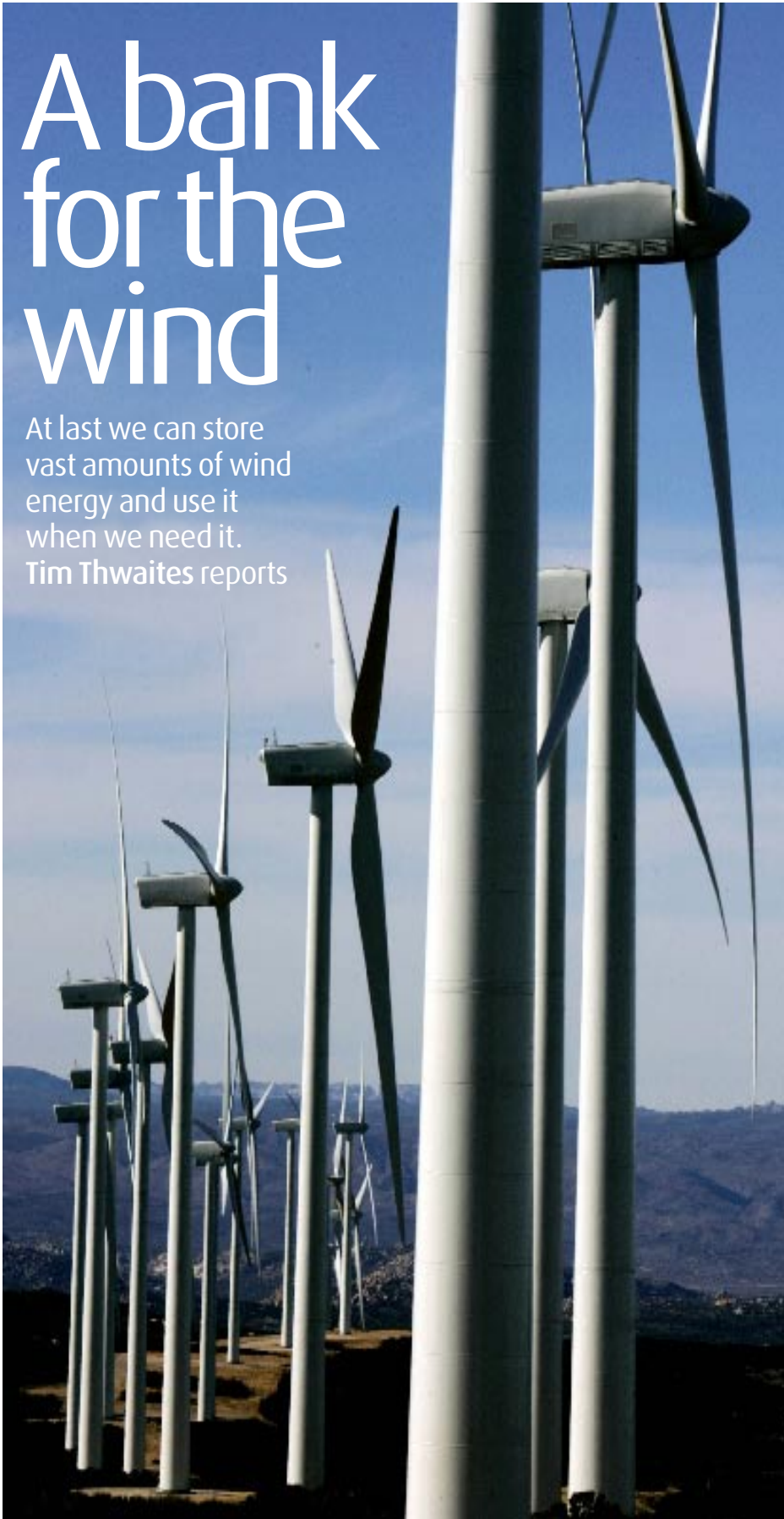




A bank for the wind

At last we can store vast amounts of wind energy and use it when we need it.
Tim Thwaites reports

Wind farms all too often face a mismatch between the supply of wind and the demand for power

SITTING at the western end of Bass Strait between the Australian mainland and Tasmania, King Island might not seem like a beacon to the future. Yet inside a large metal shed close to the island's west coast is an electricity storage system that promises to transform the role of wind energy.

King Island isn't connected to the mainland power grid, and apart from its own small wind farm it relied for a long time on diesel generators for its electricity. That changed in 2003 when the local utility company installed a mammoth rechargeable battery which ensures that as little wind energy as possible goes to waste. When the wind is strong, the wind farm's turbines generate more electricity than the islanders need. The battery is there to soak up the excess and pump it out again on days when the wind fades and the turbines' output falls. The battery installation has almost halved the quantity of fuel burnt by the diesel generators, saving not only money but also at least 2000 tonnes of carbon dioxide emissions each year.

So what's new? For years wind turbines and solar generators have been linked to back-up batteries that store energy in chemical form. In the lead-acid batteries most commonly used, the chemicals that store the energy remain inside the battery. The difference with the installation on King Island is that when wind power is plentiful the energy-rich chemicals are pumped out of the battery and into storage tanks, allowing fresh chemicals in to soak up more charge. To regenerate the electricity the flow is simply reversed.

Flow batteries like this have the advantage that their storage capacity can be expanded easily and cheaply by building larger tanks and adding more chemicals. The technology is already attracting interest from wind farmers, but flow batteries could also replace all sorts of conventional electricity storage systems – from the batteries in electric cars to large-scale hydroelectric pumped storage reservoirs.

Electricity is very different to commodities like coal or oil that can be stored up in summer ready to meet peak winter demand. With electricity, generating companies meet fluctuating demand by adjusting the supply, from day to day and minute to minute. Typically, they spread the load over large distribution grids and use a mix of huge, ▶

“Drivers could refill the tank with energised vanadium”

economical, “base-load” power stations supplemented by smaller, costlier generators that can be switched on and off at short notice.

Matching supply to demand is particularly problematical when it comes to renewable energy sources like the wind and the sun. The wind doesn’t always blow when needed, which means that electricity companies must keep conventional power stations standing by so that on calm days, or when electricity demand leaps, people will still be able to turn on the lights. These power sources can also be difficult to slot in and out of the generation mix. An effective way to store electricity on a large scale would give renewable power sources a welcome boost.

There is no shortage of ways to do this. Ideas range from storing energy underground using hot rocks or storing it as electrical charge in “super capacitors” to using off-peak capacity to pump water into reservoirs where it can drive generator turbines when demand peaks. Then there are various kinds of batteries. While each technology has its advantages, flow batteries seem to have the potential to satisfy the broadest variety of needs – from small power systems to large-scale grid storage – at a competitive price.

Flow batteries are more complex than conventional batteries. In a lead-acid battery, the electrical energy that charges it up is stored as chemical energy inside the battery. Flow batteries, in contrast, use two electrolyte solutions, each with a different “redox potential” – a measure of the electrolyte molecules’ affinity for electrons. What’s more, the electrolytes are stored in tanks outside the battery. When electricity is needed the two

electrolytes are pumped into separate halves of a reaction chamber, where they are kept apart by a thin membrane. The difference in the redox potential of the two electrolytes drives electric charges through the dividing membrane, generating a current that can be collected by electrodes. The flow of charge tends to even up the redox potentials of the two electrolytes, so a constant flow of electrolyte is needed to maintain the current. However, the electrolytes can be recharged. A current driven by an outside source will reverse the electrochemical reaction and regenerate the electrolytes, which can be pumped back into the tanks.

No more leaks

The installation at King Island has its origins in the 1980s when Maria Skyllas-Kazacos, a young Australian chemical engineer, started a research programme on flow batteries at the University of New South Wales in Sydney. This focused on one of the big weaknesses of these devices. The membranes separating the two electrolytes allowed molecules of electrolyte to leak across. As a result, each solution became increasingly contaminated with the other, reducing the battery’s output.

Skyllas-Kazacos’s solution to this problem was to use the same chemical element for both electrolytes. She could still provide the required difference in redox potential by ensuring that the element was in different “oxidation states” in the two solutions – in other words its atoms carried different electrical charges. The element she eventually decided on was the metal vanadium, which

can exist in four different charge states – from $V(II)$, in which each vanadium atom has two positive charges, to $V(V)$, with five. Dissolving vanadium pentoxide in dilute sulphuric acid creates a sulphate solution containing almost equal numbers of $V(III)$ and $V(IV)$ ions.

When Skyllas-Kazacos added the solution to the two chambers of her flow battery and connected an outside power supply to the electrodes, she found that the vanadium at the positive electrode changed into the $V(V)$ form while at the negative electrode it all converted to the $V(II)$ form. With the external battery disconnected, electrons flowed spontaneously from the $V(II)$ ions to the $V(V)$ ions and the flow battery generated a current (see Graphic). Best of all, it didn’t matter too much if a few vanadium ions on one side of the membrane leaked across to the other: this slightly discharged the battery, but after a recharge the electrolyte on each side was as good as new.

After more than a decade of development, Skyllas-Kazacos’s technology was licensed to a Melbourne-based company called Pinnacle VRB, which installed the vanadium flow battery on King Island. With 70,000 litres of vanadium sulphate solution stored in large metal tanks, the battery can deliver 400 kilowatts for 2 hours at a stretch. It has increased the average proportion of wind-derived electricity in the island’s grid from about 12 per cent to more than 40 per cent.

It hasn’t all been plain sailing, though. For example, engineers have had to solve a perennial problem with flow batteries – how to prevent leaks that allow energy to literally dribble away – as well as working out how to construct long-lasting membranes.

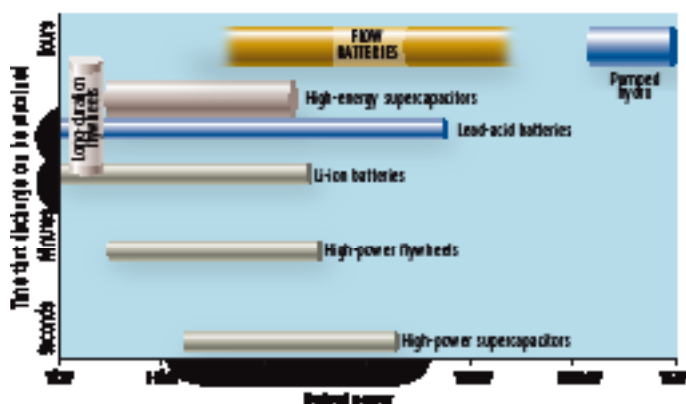
With the installation at King Island up and running, it shows the advantages of vanadium flow batteries over conventional electricity storage. Their working lifetime is limited only by that of the membrane and other hardware, and is expected to be several times the two to three-year lifespan of a lead-acid battery. Like lead-acid batteries, they deliver up to 80 per cent of the electricity used to charge them, but they also maintain this efficiency for years.

One of the key advantages of flow batteries is their scalability. To increase peak power output you add more battery cells, but the amount of energy they will store – and therefore the time they will operate on a full charge – can be expanded almost indefinitely by building bigger tanks and filling them with chemicals. The result is that the batteries can be used in a wide range of roles, from 1-kilowatt-hour units (like a large automotive battery, say), to power-station scales of hundreds of megawatt-hours.

Small vanadium flow batteries are already operating in Japan, where they are used for applications such as back-up power at

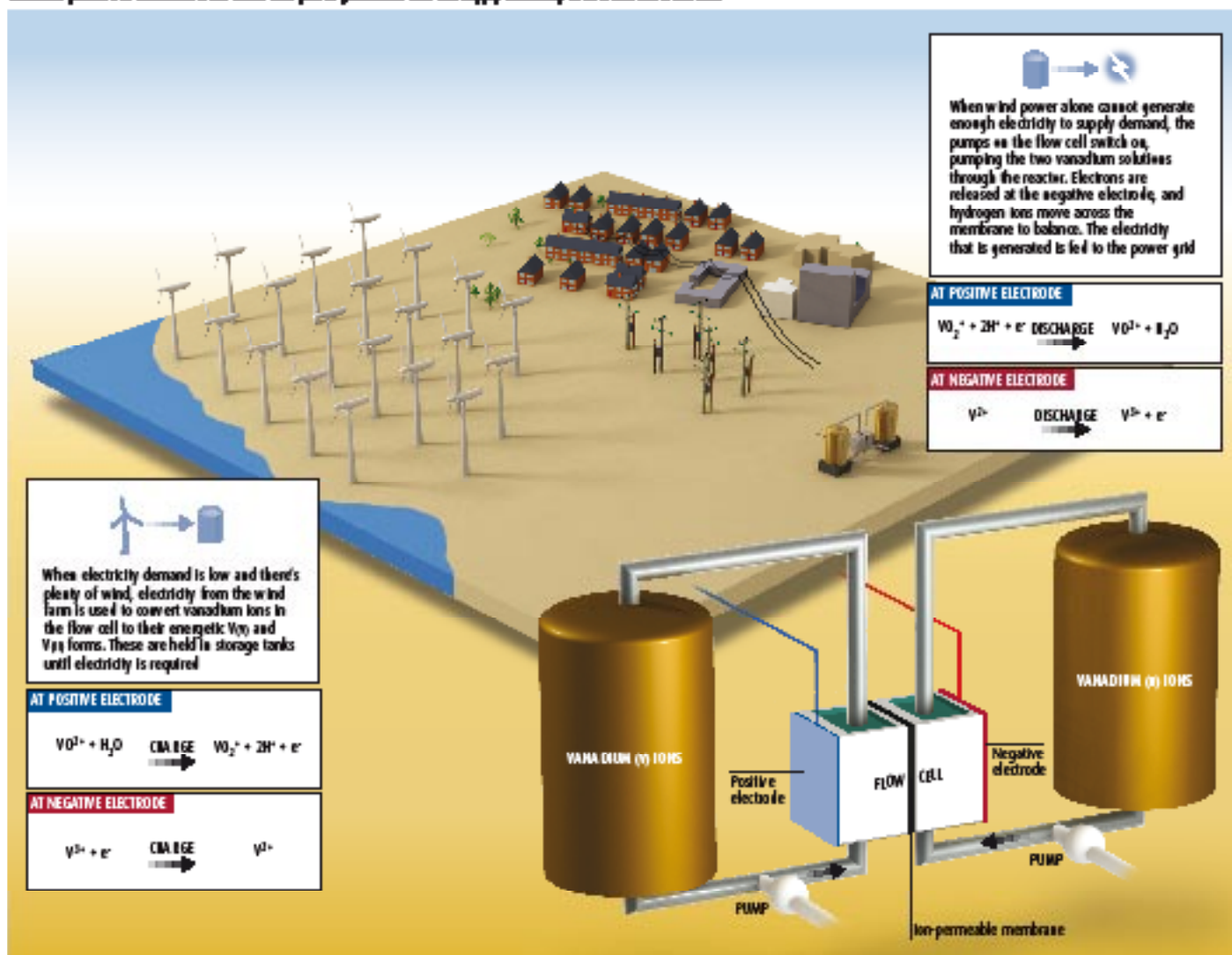
POWER TO THE PEOPLE

Flow batteries are just one technology that can store electricity, but they could be among the cheapest and most versatile for large-scale storage



CATCHING THE WIND

Large rechargeable batteries called vanadium flow batteries can store energy from the wind and release it later as electricity. Potentially cheaper and more efficient than other storage technology, these batteries promise to transform wind farms into power generators that can supply electricity even when the wind dies



industrial plants. In the US, a 2-megawatt-hour battery installed in Castle Valley in south-east Utah has allowed the local power company PacifiCorp to meet increasing peak power demands without needing to increase the capacity of the ageing 300-kilometre distribution line that feeds the area.

The vanadium-based technology developed at the University of New South Wales is now being put to use by VRB Power Systems, based in Vancouver, Canada. Last year the company signed a \$6.3 million contract to construct a 12-megawatt-hour vanadium battery at the Sorne Hill wind farm in Donegal, Ireland. The idea is to offer a guaranteed supply of wind-generated electricity, and improve the economics of the wind farm by selling stored electricity to the grid at peak times when prices are highest.

The company has commissioned a new production line with the capacity to turn out

2500 5-kilowatt batteries each year. The first dozen of these new batteries are currently under evaluation by customers including the National Research Council Canada and one of North America's biggest cellphone companies.

This is an important stage of development. At present, as with any new technology lacking economies of scale, flow battery systems are more expensive than competing products, but that could change once the new production line is running.

Basic research is continuing too. Vanadium sulphate solutions cannot be made very concentrated so the energy stored in a given volume of vanadium flow batteries is about half that of lead-acid batteries. This rules them out for applications where compactness and low weight are at premium – electric cars being a prime example. So Skyllas-Kazacos and her team want to replace vanadium sulphate with vanadium bromide, which is

more than twice as soluble. She expects that research to be completed by 2008.

VRB Power Systems has already tested its units in electric golf carts. Just as with existing electric vehicles, a car equipped with a flow battery could be charged by plugging it into an electric socket. Enticingly, though, flow batteries might one day allow drivers to refill the tank with energised electrolyte. The spent solution can be recycled.

Whether or not we will one day top up our cars with vanadium, King Island has proved that flow batteries already have a practical role to play, keeping wind-generated electricity humming through the wires even when the breeze drops. You might not even notice it's there – but that's probably the biggest compliment you could pay it. ●

Tim Thwaites is a science journalist based in Melbourne, Australia