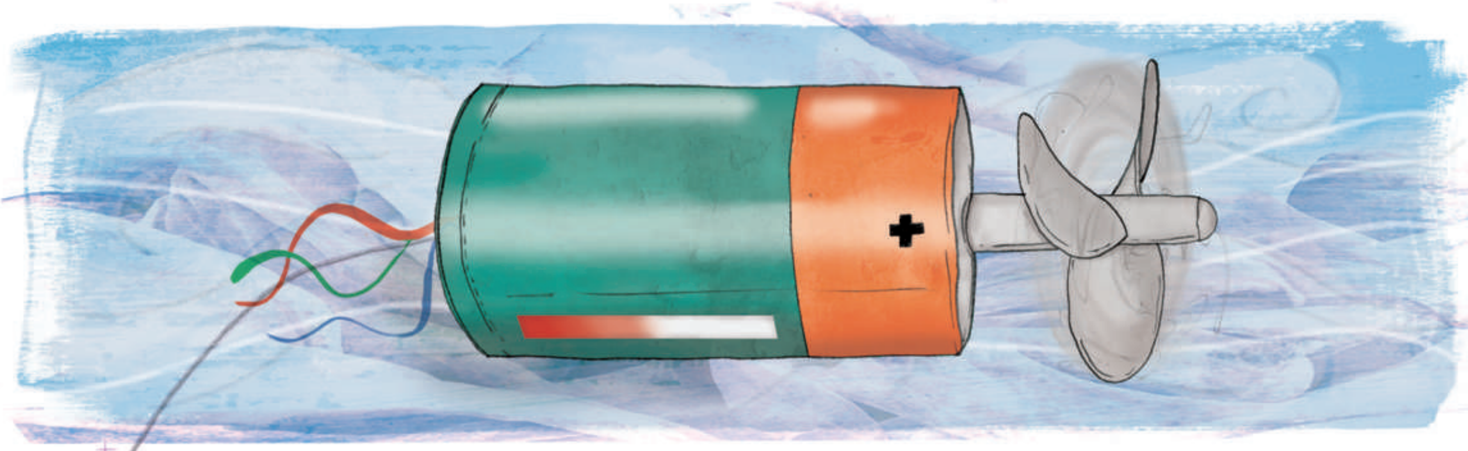


ILLUSTRATION: J. TAYLOR

HIGH HOPES

A vast supply of energy is racing around the planet far above the surface. **Erik Vance** meets the engineers trying to bring the power of high-altitude wind down to earth.

A ride on a kite boat might just kill you from fright — if it doesn't crush you first. The vessel is essentially an 8-metre catamaran dragged behind a kite the size of a movie screen — a lot of horse-power for such a small craft. That concern grips me as I skitter across the surface of San Francisco Bay at 40 kilometres per hour. Sudden tugs from the kite jerk the boat from side to side and sometimes nearly out of the water.

But we stay upright, thanks to the skill of the boat's inventor, Don Montague. The 46-year-old pioneer of kite surfing deftly keeps the 200-kilogram craft from flipping up with each gust and crushing its passengers beneath it.

Montague has no intention of selling this floating hazard on the open market — he created it to break speed records and amuse himself. Today he has brought me out to demonstrate the raw power in the skies, just waiting to be tapped. Montague is part of the high-altitude wind movement, promoting an idea on the very fringes of energy development: tethered airborne devices that collect energy from the wind far above the surface. The designs of the aircraft vary widely, as does the height at which they would fly, but all seek to exploit the fact that the farther one goes from the ground, the stronger and steadier the available wind.

For at least a century, engineers have dreamed of pulling electricity from high in the atmosphere. However, only recently have lightweight materials and computer guidance systems emerged that make the idea feasible. In the past five years, what was once seen as a crackpot scheme has entered the early stages of a research-and-development race that is attracting tens of millions of dollars from major private backers such as Google.

Leading the way is a tiny, dedicated community of Californian inventors and kite surfers. As yet, they have generated little electricity and failed to win over mainstream wind experts. But several start-up companies — among them Makani Power, the one Montague has co-founded — plan to put prototypes into the air within the next 18 months.

This moment is overdue for Ken Caldeira, a climate researcher at Stanford University, California, who has long promoted generating power from high-altitude wind. He says wind in some locations contains at least ten times the energy of sunlight, when measured by surface area, but that conventional surface-mounted wind turbines collect only a fraction of that because friction with the ground brakes winds at the surface.

Caldeira's favourite area of study is the powerful high-altitude air currents called jet streams, which taken together contain 100 times as much energy as humans use today. They are "the highest concentration of renewable energy in large quantities," he says. "Sooner or later we will be extracting energy out of high-altitude winds."

There's another advantage to harvesting the wind at altitude. Breezes at the surface blow intermittently, so even in windy sites turbines typically collect only 30–40% of the energy that would be available if they ran continuously. High-altitude devices could push that number towards 80%, thanks to the steadier flow aloft and the possibility of moving higher and lower in the atmosphere to find the best wind.

Recently, Caldeira and Cristina Archer of California State University in Chico published the first comprehensive analysis[1] of global data on wind above 500 metres. They found that the most energetic winds are found in the jet streams, 10,000 metres up, above some of the spots that require large amounts of power, such as Japan and the eastern United States. However, at that height the resource is difficult to predict and even harder to reach.

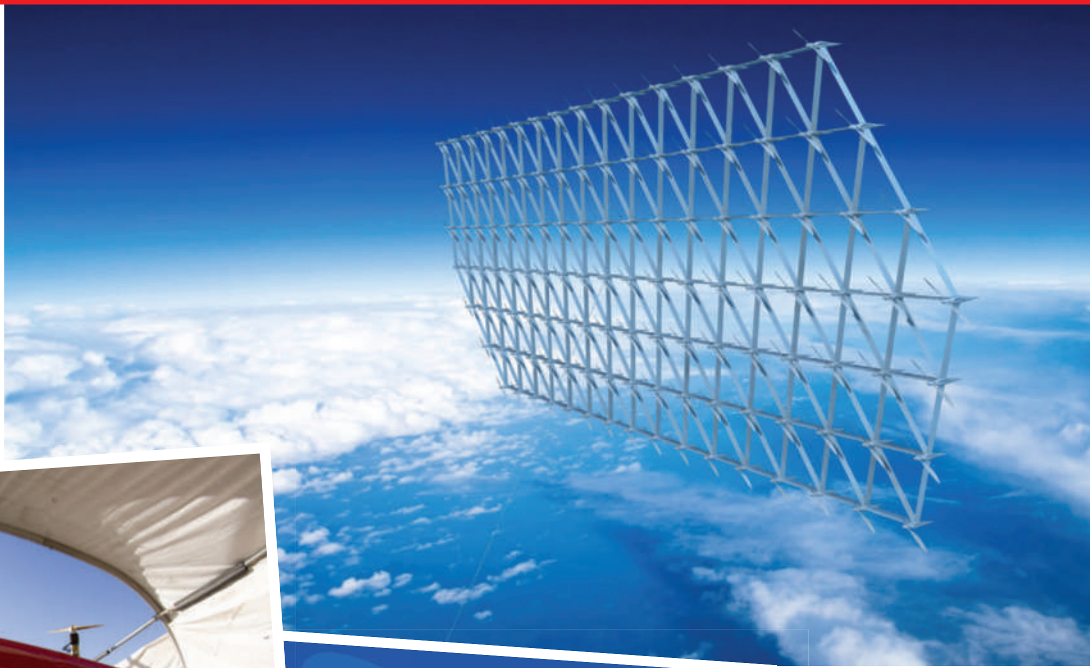
Most engineers are not planning to go so high. The power of wind grows as the cube of its speed, so even the moderate increase in wind strength a few hundred metres above the surface produces large power gains.

Trade secrets

Leonard Shepard, president of Sky Windpower near Irvine, California, makes that point clear by listing the current wind speeds above Red Bluff, a small town in the northern part of the state that has detailed weather measurements. At ground level, a light breeze is blowing at under 10 kilometres per hour. At 900 metres, the speed reaches 50 kilometres per hour. But conventional wind turbines only stand about 130 metres or so above the ground. So a wind collector flying 900 metres above the town could theoretically gather 125 times as much energy as a turbine on the ground.

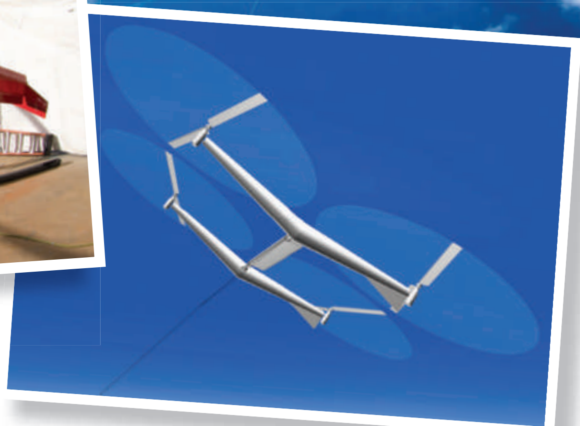
Sky Windpower is developing an unmanned helicopter design with four horizontal rotors that would hover at altitude. Shepard says he plans to send a prototype with four 2-metre rotors aloft this year to collect electricity at a few hundred metres. Once it gets up to a

Different ways to tap the winds aloft: JoeBen Bevirt's vision of a turbine array flying 10,000 metres above Earth's surface (right); Makani Power's prototype wing demonstrates its hovering abilities (below); the Sky Windpower concept (below, right); Makani engineers test the design of their carbon-fibre wing (bottom, right).



JOBY ENERGY INC.

A. DUNLAP/MAKANI POWER



B. SHEPARD

certain height, the wind will spin the rotors and keep it up, but he declines to give many more details than that. A penchant for secrecy is common in the high-altitude wind world: until they have a working prototype, companies are careful not to reveal too much about their designs.

Kite dudes

Corporate secrecy mixes with surf culture at the offices of Makani Power, located on a desolate former naval air base in Alameda, California. In 2006, Montague teamed up with two avid kite surfers, inventor Saul Griffith and Griffith's former student Corwin Hardham, to mix kite know-how with engineering to harness the wind's energy.

The office is in a flight control tower and feels like a 1990s Internet start-up company. Near the entrance hang a dozen high-end bicycles, and windsurfing gear lies about in the workshop. The tower's control room, now the company lounge, has microbrews on tap. And hardly anyone seems to wear shoes.

Despite the Lost-Boys-in-Neverland atmosphere, Makani's design is not fantasy. It starts with a pilotless glider that resembles a giant boomerang made of lightweight carbon fibre. The glider is tethered to the ground by cords at each side, like the kite over Montague's boat. By pulling the cords a controller can send the glider sailing back and forth in a wide loop while four rotors on the leading edge spin to generate energy. Hardham — who is co-chief executive with Montague — says the kite would ideally fly at 200–1,000 metres. Although wind at this relatively low altitude is slowed by friction with the ground, the back-and-forth movement significantly boosts the speed of the air passing through the rotors, says Hardham. A 30-metre, 1-tonne carbon-fibre glider flying in a moderate 32-kilometre-per-hour wind could produce 750 kilowatts — about as much as a small industrial turbine, but with a fraction of the materials, he says.

"It's surprising how good the opportunity is," Hardham says. "If we can make this work I think it's the best renewable conversion technology there is."

But he quickly tempers this, saying that there is still a lot to be done. For one thing, the power needs to be transferred from the kite to the ground. Both Makani and Sky Windpower are hesitant to go into detail about the tethers they would use, but they would probably be some kind of nylon fibre cord with an electrical cable at its core.

Hardham and others say that the tether is less a concern than automation. The biggest challenge, it seems, is controlling the device as it takes off, lands and flies in unpredictable weather. Their longest test run so far was a 30-hour flight for a 3-metre wing at a breezy site on the island of Maui, Hawaii. As the device gets larger, controlling it becomes easier, but the consequences of a crash grow more expensive.

Californians do not have a monopoly on high-flying energy efforts. The Dutch astronaut Wubbo Ockels, who once collaborated with Montague, has developed a concept called Laddermill, which would fly multiple kites at various heights, all tethered to one turbine on the ground. As the kites rise, the turbine spins and generates power. The kites are then brought down again and the process repeats. And in Italy, another windsurfing enthusiast and engineer named Massimo Ippolito started a company called Kite Gen in 2007 to produce power by using several kites to turn a giant ring-shaped structure on the ground. Both companies have managed to create prototypes of single kites and have generated up to 10 kilowatts of electricity. Another company, Magenn, based in Kanata, Ontario, Canada, plans in the next year or two to release a spinning dirigible capable of generating 100 kilowatts that may cost around US$500,000.

Even a decade ago, designs such as these

B. PFEIFFER/MAKANI POWER

would have been impossible. However, with lighter materials and advances in pilotless flight, high-altitude wind is starting to attract money. Kite Gen was promised €50 million ($71 million) by the Italian government, although that funding has fallen through because of the financial crisis. Magenn, which is backed by private investors, says it has a capital base in the region of $10 million. Makani is partially funded by the Internet giant Google as a part of its philanthropic wing, Google.org. Google put $15 million into the company in 2007 — one-third of Google's total budget for renewable-energy research. And the company recently injected another dose of funds into Makani. Geoff Sharples of Google's RE<C initiative, which seeks to develop renewable-energy sources that will be cheaper than coal, declines to reveal the exact amount but says it was of the same order as the original investment. It's the only wind project that the company supports.

A. DUNLAP/MAKANI POWER

Lit by a spotlight, Makani's prototype kite completes a computer-controlled, 30-hour test flight in the skies over Maui, Hawaii.

Sharples knows the wind world well, having previously served as an executive with Clipper Windpower, a major turbine manufacturer based in Carpinteria, California. The conventional earthbound approach is limited, he thinks, by the availability of conveniently located windy land. Although there is a viable alternative — erecting turbines offshore — Google is investing in high-altitude wind because the energy payoff could be so much bigger.

But companies such as Makani have a long way to go. Wind-industry insiders say a new technology needs to be capable of producing at least 1 megawatt — roughly enough to supply 1,000 homes — to get the attention of energy utility companies. To date, no high-altitude wind company has generated anything close to this. In June, the US National Research Council issued a report on renewable energy that briefly mentioned high-altitude wind power as a possibility more than 25 years in the future[2].

For now, most people in the wind-power industry are apparently ignoring high-altitude efforts. "I don't think anyone has given it a serious, objective study who wasn't already committed to the technology," says Robert Thresher, an engineer at the National Renewable Energy Laboratory in Golden, Colorado, which writes certification guidelines for wind technology. Wind experts at the lab are not enthusiastic about high-energy wind and say they wish inventors would focus their talents on conventional turbines. Thresher says he sees much more potential in offshore turbines than flying ones.

Such naysaying has not stopped another Californian inventor from sinking millions of his own dollars into the concept. Deep in the heavily wooded Santa Cruz Mountains, JoeBen Bevirt is chasing the ultimate wind prize — the strong, steady jet streams that scream along at 200 kilometres per hour, 10,000 metres up. Projects that seek to tap this resource draw the most scepticism from conventional wind engineers.

Bevirt has created a number of consumer and industrial products, such as robots for gene sequencing, mobile-phone headsets and a small camera tripod that can grip a branch or pole. In 2007, he sold his robotics company for $50 million.

"I should be retired right now. I should be kite surfing on the beach," Bevirt says. "But I am so passionate about this that I am working 18 or 20 hours a day, driving as hard as I have ever driven in my life."

"I should be retired right now. But I am so passionate about this that I am working 18 or 20 hours a day."
— JoeBen Bevirt

He has come up with a concept that crosses Sky Windpower's helicopter rotors with Makani's sleek wings, the offspring being a diamond-shaped double-wing frame with rotors at each corner. By itself, it looks somewhat like the Wright Brothers' Flyer with an extra pair of rotors. Because of the strength of the jet streams, he expects each 11-metre rotor to produce a staggering 250–500 kilowatts. However, the design is modular, with many possible configurations: a system may have 4, 32 or even 96 rotors.

The system would lift off like a helicopter, with electricity from the ground used to turn its horizontal rotors to generate lift. Once it reached a desired height, the device would pitch forwards so that the wall of rotors would point into the wind and the frame act as glider wings, keeping the network aloft. Turned now by the wind, the rotors would generate electricity.

The design is far from foolproof. As with Makani's wing, take-off and landing require complicated control algorithms. Any tether reaching to 10,000 metres will need to be extremely light. And because a crash could kill people on the ground, the device could fly only over an uninhabited zone at least half the size of London.

Despite these challenges, Bevirt has the confidence of someone who has successfully brought products to market. He has founded a company, Joby Energy in Santa Cruz, to develop his concept. So far, he says he has invested $2 million in the project and plans to keep funding it as long as is necessary.

"I am very selective about the things that I pour my energy into. The fact that I am pouring my energy into this and that I am also willing to pour a lot of money into it lends credibility to the fact that it's not a crackpot scheme," he says.

Coming soon?

Like their energy source, the prospects of success for Bevirt and other high-altitude wind aficionados are up in the air. Makani has generated little more than 10 kilowatts, although it plans to run a bigger prototype this year. Sky Windpower also aims to test an experimental version of its concept this year. The first company to bring a design to market will probably be Canada's Magenn, although the size and drag of its blimp-like units may preclude them from generating enough energy to compete with big industrial turbines.

As a newcomer who started work only in 2008, Bevirt has yet to produce any energy, but he plans to start this summer and get a product to market around 2011. He says he doesn't mind that many engineers write off high-altitude wind power. The proof will come soon enough, he says.

While giving a tour of his workshop, Bevirt demonstrates a 1-metre scale model of his device. During the first test, it buzzes over my head like a wobbly bird. Later, as a mortified employee looks on, the device flips over and snaps in two during take-off.

Bevirt just smiles. "Oh well," he says. "Sometimes that happens too." ■

Erik Vance is a freelance science writer in Berkeley, California.

1. Archer, C. L. & Caldeira, K. *Energies* **2,** 307–319 (2009).
2. America's Energy Future Panel on Electricity from Renewable Resources *Electricity From Renewable Resources: Status, Prospects, and Impediments* 53 (National Academies Press, 2009).