If our leaders just put their minds to it, a giant transmission web for renewable power could pull the plug on dirty fossil fuels for ever. **David Strahan** reports

Green grid

THOMAS EDISON might have relished the irony. Just as his most famous legacy, the incandescent light bulb, heads for extinction, his other great passion, direct electric current, is set to boom. The bulb that has dominated lighting for more than a century is now a pariah in the era of climate change and banned in many countries. Meanwhile, direct current – defeated by alternating current in the race to capture the electricity market in the 1890s – could help us hold back global warming.

As electricity demand soars, and utility companies rush to install renewable-energy generators, it has become obvious that existing electricity transmission systems can't cope. Engineers in Europe and the US know they need to improve their grids, and huge new investment has been announced. Yet simply adding extra capacity using the same old systems may not be the best solution. Instead, putting a new twist on an old technology could transform the way we get electricity.

Although DC lost out to AC in the early days of electrification, high-voltage direct current (HVDC) has long had a niche role – transmitting large amounts of power over long distances because it is more efficient than conventional AC lines. Now it is also set to become a key link for the growing number of renewable-energy generators, particularly offshore wind farms. This is leading many in the energy industry to take a fresh look at DC.

Some engineers are thinking big. Their calculations suggest that continent-wide HVDC "supergrids" could help smooth out the variable levels of power created by many far-flung renewable generators to make a fully dependable supply. Supporters say this will eventually mean that coal, gas and nuclear power could be ditched, with renewables replacing them within a couple of decades.

Elements of such a supergrid will soon begin to materialise in Europe, and a proposed €1.2 billion ($1.5 billion) subsidy could help develop these links across the region. Meanwhile, in the US, President Obama's $150 billion energy plan includes a target of 25 per cent renewable electricity by 2025, implying massive investment in high-voltage lines, many of which are likely to be HVDC. At the same time, tests on new superconducting HVDC cables suggest that a grid incorporating this technology could act as a mammoth energy store, helping buffer consumers and utilities against the vagaries of the weather (see "Supercooled grid", page 44).

> "One of the advantages of the supergrid is that renewables can be sited where wind and sunlight are best for generating electricity"

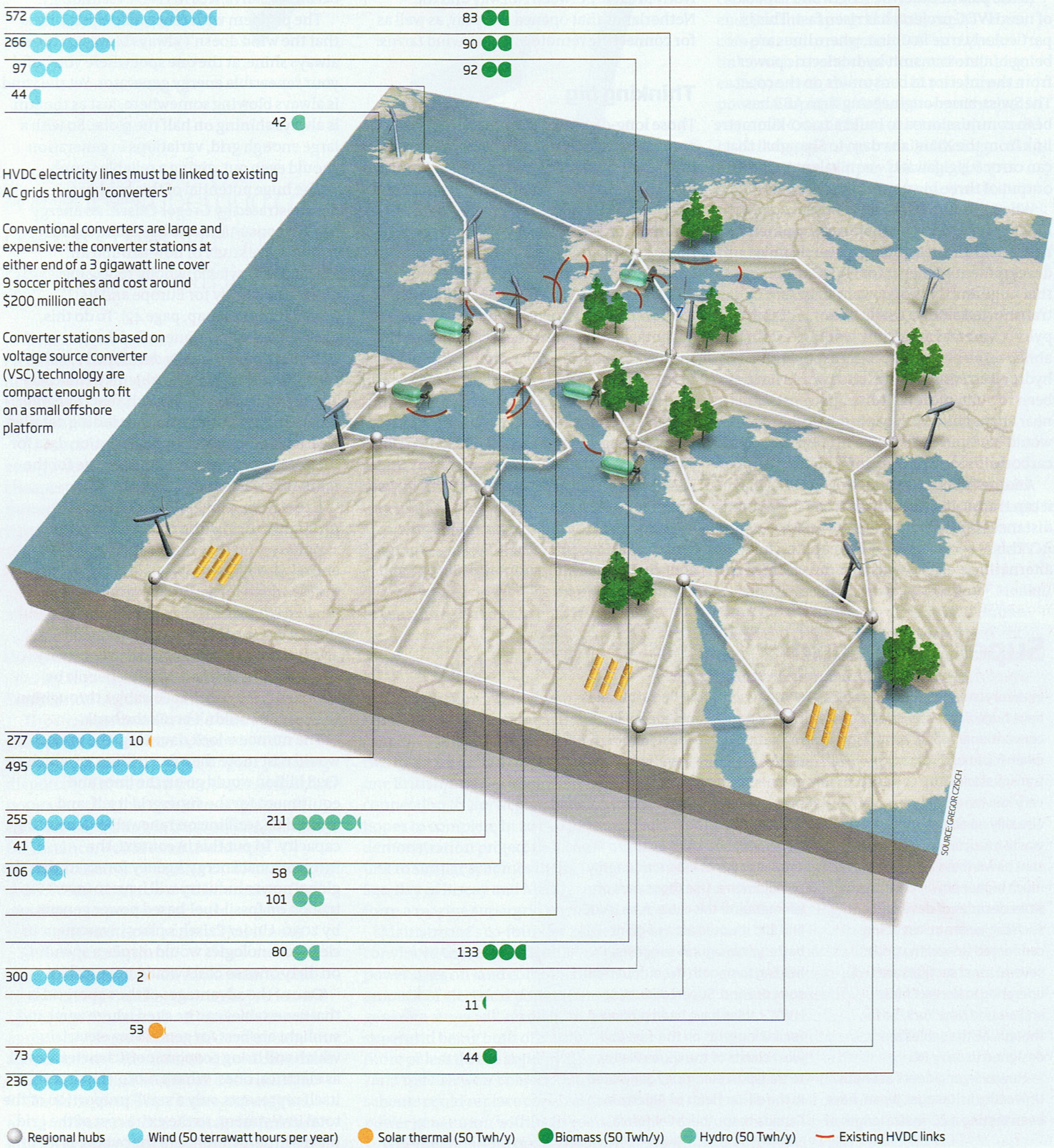
"Whichever way you look at it, there is no doubt that HVDC's time has come," says Graeme Bathurst, technical director of the British-based grid consultancy TNEI.

Edison lost his "battle of the currents" with Nikola Tesla and Westinghouse Electric because at the time AC was a more practical proposition. Put simply, efficient long-distance transmission required high voltages while the public needed safer, lower voltages. That required transformers, which existed for AC networks, but not for DC.

Despite this victory, DC is far more efficient: at the same voltage, it suffers much lower transmission losses than AC. This is because in a DC line the direction of the current is constant, whereas in an AC line it reverses 100 or 120 times a second. This induces small currents in the transmission line insulation, and this energy is then lost as heat. Because of this, HVDC has long enjoyed a niche role transporting large amounts of power efficiently over unusually long ›

Running on renewables

There are over 100 high voltage direct current (HVDC) lines globally. Adding new HVDC links to existing ones could create a grid capable of delivering a wholly renewable electricity supply. German engineer Gregor Czisch has calculated the number and scale of renewable generators that would make this possible in Europe



distances. One of the earliest big projects was a 600-megawatt link built in 1965 in New Zealand to connect the North and South Islands, which was later upgraded to 1200 megawatts.

In the past decade, the length and capacity of new HVDC projects has risen fast. This is particularly true in China, where lines are being built to transmit hydroelectric power from the interior to consumers on the coast. The Swiss-based engineering firm ABB has been commissioned to build a 2000-kilometre link from the Xianjiaba dam to Shanghai that can carry 6.4 gigawatts – equivalent to the output of three big power stations.

When the current starts to flow in 2011, ABB says it will deliver major environmental benefits. Gunnar Asplund, research and development manager for HVDC at ABB, says that huge amounts of power can be transmitted along a single line of HVDC pylons, whereas an AC link would need three abreast. The alternative to transporting hydroelectricity long-distance would have been to build more coal-fired power stations near Shanghai, which Asplund estimates would have put an extra 40 million tonnes of carbon dioxide into the atmosphere each year.

Another major advantage of HVDC is that it can transmit electricity over much greater distances underground and underwater than AC. This is because AC produces powerful alternating electric fields that cause large additional energy losses if the line is buried or submerged. For DC this "capacitance" effect is negligible. That makes HVDC essential for subsea interconnectors like the 600-kilometre NorNed cable between Norway and the Netherlands that opened last year, as well as for connecting remote offshore wind farms.

Thinking big

Those long-distance links are nothing compared with the plans of Desertec, an organisation founded by the Club of Rome – a Swiss-based sustainability think tank – and the National Energy Research Center in Amman, Jordan. Since 2003, Desertec has been arguing for remote electricity generation based largely on concentrating solar power (CSP) in North Africa and the Middle East. CSP is relatively expensive, but has one big advantage: some of the heat captured during the day can be stored in molten salts and used to generate electricity overnight. Desertec says this technology alone could supply 17 per cent of Europe's power by 2050, imported via 20 to 40 long-distance HVDC lines. Other supporters of the concept, however, say that HVDC could deliver even more – a wholly renewable electricity supply.

The basis of that supply is probably the most ambitious plan for HVDC: the supergrid concept now gaining support in Europe and North America. The idea itself is not new – it was first proposed by the architect and designer Buckminster Fuller in the 1950s – but only now is it becoming a practical possibility because of advances in HVDC technology.

The problem with renewable electricity is that the wind doesn't always blow, nor the sun always shine, at the one spot where you build your renewable energy generator. Yet the wind is always blowing somewhere, just as the sun is always shining on half the globe. So with a large enough grid, variations in generation should even out, giving a reliable supply.

The huge potential of this has been demonstrated by Gregor Czisch, an energy system consultant who has made the first quantitative study of how to build an economically viable, wholly renewable electricity supply for Europe and its neighbours (see map, page 43). To do this, Czisch used a technique called linear optimisation, originally developed to solve complicated logistical problems in industry and commerce. It took Czisch years to gather the necessary information, including detailed weather and electricity consumption data for the whole area and investment costs for the main renewable technologies.

Czisch then plugged this data into a program to devise the cheapest electricity supply system that could satisfy demand entirely from renewables. He allowed it to decide which forms of generation should be sited where, as well as plan the routes and capacity of the HVDC lines. The results were astonishing. Not only could the electricity demand of more than a billion people be supplied solely from renewables throughout the year, it wouldn't break the bank.

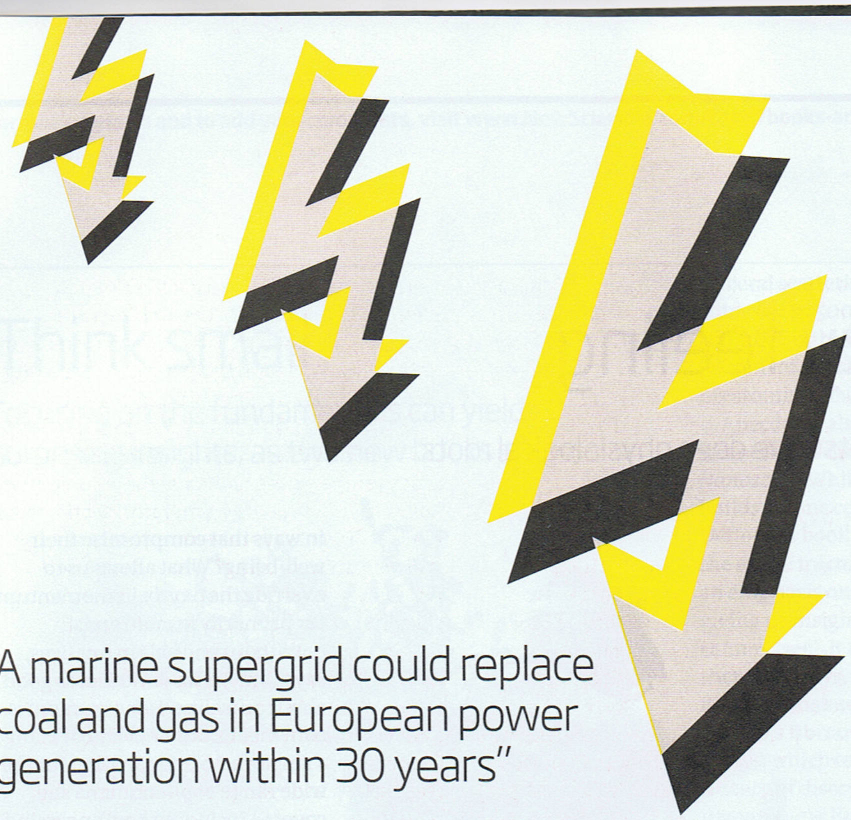
The numbers look daunting: the project would cost more than €1.5 trillion, of which €128 billion would go on the lines and equipment for the supergrid itself, and around €1.4 trillion on renewable-generating capacity. To put this in context, the International Energy Agency forecasts that the global power industry will have to invest $13.6 trillion on fossil-fuel-based power generation by 2030. Under Czisch's plan, investment in clean technologies would displace spending on dirty ones so costs would not escalate.

One of the advantages of the supergrid is that renewables can be sited where wind and sunlight are best for generating electricity, which will bring economic efficiencies as well as electrical ones. What's more, the supergrid itself represents only a small proportion of the total investment, so the extra cost of the grid makes little difference to the overall price of

Supercooled grid

In theory, superconducting cables have huge advantages over conventional copper conductors when it comes to electricity transmission. Once cooled to very low temperatures, they have virtually no electrical resistance, waste much less of the power sent down them and can bear much higher power densities. After decades of development, such cables are at last being connected to working grids: several short sections are operating in Korea, China and around New York. So far, though, all the cables are designed to carry AC.

However, engineers at Chubu University in Kasugai, Japan, have been testing a 20-metre length of HVDC superconducting cable and they believe it could eventually revolutionise electricity distribution. The team, led by engineer Satarou Yamaguchi, have come up with a new cable design that can be cooled more effectively and store up to 4 megajoules of magnetic energy per kilometre. Use thousands of kilometres of this cable as an HVDC line and it would act as a giant battery, Yamaguchi suggests, helping to smooth the output from solar or wind. Superconducting HVDC cables have been proposed for linking grids on the east and west coasts of the US, as well as to transport electricity generated in the oil-tar fields of Alberta in Canada to southern California.



> "A marine supergrid could replace coal and gas in European power generation within 30 years"

electricity. Czisch calculates the system could deliver electricity for less than 4.7 euro cents per kilowatt-hour – roughly the price of German wholesale electricity in 2005.

In Czisch's main study, the bulk of the energy would come from onshore wind, the cheapest form of renewable generation, with powerful summer winds in Morocco and Egypt complementing winter gales around the North Sea. Most of the rest would come from existing hydropower in the Nordic countries and the Alps, which would be turned on only when the other sources failed to match demand. In an alternative scenario, Czisch found that European demand could be satisfied entirely from renewables without imports from Africa, but at a slightly higher cost.

The supergrid would need tens of thousands of kilometres of new HVDC lines, which could provoke lengthy planning disputes in Europe. On the other hand, Czisch points out that this would be only a small addition to existing infrastructure: Germany, for instance, would need to add only 8000 kilometres of new HVDC to its existing grid of more than 100,000 kilometres. "For less than a 10 per cent increase we get a totally renewable electricity supply. This is not a problem; it's a bargain."

Yet public opposition could push up the costs. An HVDC link between the French and Spanish grids across the Pyrenees was only approved last year when the developers agreed to bury the cable. Predicted costs have now risen fourfold, to about €500 million.

The European HVDC supergrid may be an ambitious vision, but potential links are already on their way. Sweden, Germany and Denmark are considering a three-way interconnector at a site called Kriegers Flak in the Baltic Sea, where the three countries plan to build offshore wind farms. Since the wind farms will be close together, and each must be joined to its respective country, connecting them with a short HVDC link could be a cheap way to allow cross-border electricity trading. Meanwhile, the European Commission has appointed a coordinator to encourage countries in northern Europe to collaborate over offshore wind, and is mapping the winds of the North Sea to help plan HVDC links.

Subsea grid

British company Mainstream Renewable Power plans to create what it calls a "supernode" in the North Sea, consisting of two interconnected offshore wind farms – one British, one German – with a back-up connection to Norwegian hydro, which it hopes to complete in 2015. This would be a demonstration project that could expand and link to similar schemes in the Baltic Sea, Irish Sea, Bay of Biscay and Mediterranean Sea to form a marine supergrid encircling Europe.

Mainstream's co-founder Eddie O'Connor is convinced that the difficulties of putting new power lines on land combined with the large amount of electrical power that wind can generate at sea will result in most of the supergrid being built offshore. "We could more or less do the supergrid by sea," he says, "and the fish won't object." He reckons his scheme could replace coal and gas in European power generation within 30 years.

Whether offshore or on, the supergrid will depend on HVDC, but opinions differ about how quickly HVDC can deliver the full benefits of the grid. Almost all existing HVDC links are "point to point", consisting of a single line or cable with one AC converter station at each end. But the supergrid would need a more complicated arrangement of "multipoint" links, with several converter stations along each line, each able to feed in and draw out power. A sophisticated control system is also required. Czisch insists that his project could be built using only proven technology, citing an EU-sponsored study published in 2000 which concluded that a proposed multipoint network to connect Russia, Lithuania, Poland and Germany was "technically feasible". On this basis, and with the support of several retired HVDC experts, Czisch claims there are no meaningful obstacles left.

Others are more cautious. "There is a difference between what is technically possible and equipment being commercially available," says Bathurst. "The R&D lead times are measured in years."

Asplund says that to get the full benefit of the supergrid, it will need to be a "meshed" network that could cope with the failure of a line by diverting power automatically to its destination via other lines. That would require further technological developments, such as better DC circuit breakers, but he expects those breakthroughs to come soon.

Time is short, however, warns Peter Menke, from the transmission division at German-based electronics and electrical engineering company Siemens. It can take years to secure planning permission for new lines, he says. "The need to increase grid capacity in Europe is so great that we should start to build the HVDC backbone right now."

With so much riding on HVDC, remaining technical problems will be cracked soon, Bathurst believes. "The real issue now is not can we do it – yes we can – but do we want to?"

Taking the British national grid as an example, there is reason to think the supergrid could be with us surprisingly quickly: starting in 1925, it took only a decade to build the British grid, cutting electricity costs by a quarter. If the politics can be squared, it looks like Edison may soon be enjoying posthumous revenge. ■

David Strahan is the author of *The Last Oil Shock: A survival guide to the imminent extinction of petroleum man* (www.lastoilshock.com). To discover how vulnerable our electricity grids are to solar storms, grab a copy of next week's *New Scientist*, on sale from 19 March