

An abstract graphic in the top right corner of the page, consisting of a network of green dots connected by thin lines, resembling a molecular structure or a data network. The dots are arranged in a roughly circular pattern, with some lines extending outwards. The overall color is a light green.

NEW
SCIENTIST
GAMECHANGERS

ENERGY

Peter Fairley

NEW SCIENTIST GAMECHANGERS

Introduction

THE future is a moving target. Technology, society and politics are all continually changing - and all dependent on each other. This confusion of intertwined factors makes any attempt to predict what will happen next enormously complex and error-prone.

That's true even when the underlying trends are relatively easily grasped. For example, we've grown used to the idea that the performance of computer processors will increase exponentially - as famously predicted by Intel founder Gordon Moore, and turned into a self-fulfilling prophecy by the semiconductor industry. But not many people could have predicted how comprehensively the rise of computers, and then smartphones, would transform our world.

It's more difficult still when change is abrupt or disruptive. The invention of practical quantum computers, for example, would transform our ability to tackle problems that currently require enormous (or infeasible) processing power. The consequences would be far-reaching. For example, such devices could render conventional encryption useless - thus demolishing the foundations of modern trade and communications. And while they might disrupt business as usual, they would also support the development of applications we can't even conceive of today.

So when we at *New Scientist* decided to take a look at how some of the key drivers of business - energy, money and people - might change over the next five to 10 years, we decided to invite provocations, rather than make predictions. We've asked three writers with deep understanding of these areas to tell us how they think the future could unfold, and how it might confound our initial expectations.

The author of our first GameChangers report is Peter Fairley, a journalist who has been immersed for decades in the energy sector - covering every aspect, from technology to policy to climate change. His review of the landscape has led him to suggest that we're already well into a largely unheralded energy revolution - and that there's much more to come.

Only time will tell if the analysis here hits the nail on the head - or sails wide off the mark. Let us know what you think at labs@newscientist.com

Sally Adee,
Editor, *GameChangers*



GAME CHANGERS ENERGY

Peter Fairley

LET'S rewind to 2010. Fossil fuels were fast losing their appeal for policymakers as awareness of their environmental impact grew. The trouble was that replacing them with cleaner options would involve sweeping changes to the way the world generates and uses power. So how long would it take, assuming it even got going?

If you'd looked to studies from the world's most respected energy pundits - from the International Energy Agency (IEA), the US Energy Information Administration, even ExxonMobil - you'd have got it wrong. But a high-profile environmental organisation got it right: Greenpeace.

That year, Greenpeace published a report entitled *Energy [R]evolution: A sustainable world energy outlook*. The scenario it painted might have seemed a tree-hugging fantasy at the time, coming as it did in the wake of the failed Copenhagen climate summit. The report alluded to political and economic upheavals that seemed implausible - and in fact several have yet to come to pass. There is no sign yet, for example, of the steep drop in nuclear energy it projected.

But Greenpeace's forecast of the growth in wind power has proved right on target, while that for photovoltaic solar power (solar PV) actually substantially underestimated growth.

Did Greenpeace just get lucky? Perhaps, but it was also more willing to defy the prevailing wisdom than anyone else. That wisdom was - and, for some, still is - that "decarbonisation" will take place only when the world runs out of oil, natural gas and coal. Since we still have plenty of these in reserve, decarbonisation is no more than a far-off ideal.

But the experience of the past five years suggests that an energy revolution has quietly got under way. This report presents evidence suggesting that the feedback loops that have kept fossil fuels strong, and renewables weak, are being overturned. Looking ahead, those trends are set to accelerate, as a result of unprecedented changes in how we produce and consume energy.

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THE FALL OF KING COAL

- In 2015, coal use declined in both China and the US
- Rock-bottom coal prices have not stimulated demand from other countries
- The IEA expects global coal consumption in 2020 to be at 2013 levels

Coal fired the engines of China's rapid industrialisation. Between 1990 and 2013, the country's coal consumption quadrupled, and from 2007 onwards, its carbon emissions overtook those of the US. So it was a surprise when, last December, preliminary data on Chinese consumption suggested that global coal demand had stalled. China used about 2.9 per cent less coal in 2014 than the year before, and it appears to have cut back even more in 2015 according to the IEA, putting it on track for its first two consecutive annual declines since 1982.

Why has China's rampant appetite for coal hit a wall? In part, it was down to its slowing economy, and the shift in growth away from manufacturing towards less energy-intensive service industries. Coal also looks less dependable than it once did. The country's congested railroads cannot distribute it fast enough to meet demand, with blackouts common in the summer.

Add to that China's terrible problems with pollution, which its leaders worry could fuel social unrest. Chinese internet portal Tencent recorded more than 150 million downloads of *Under the Dome*, a documentary on the pollution pouring out of China's poorly regulated coal-fired power plants and diesel trucks, within just three days before censors squelched domestic access to the film. So coal is falling from favour with both China's politicians and its people.

At the same time, China is building an increasingly diverse energy portfolio. Although new coal-fired power plants are still going up, China is building more hydropower stations, nuclear reactors, and solar and wind farms than any other country. A tripling in output from wind farms, concentrated in the north of the country, meant that coal's share of the country's power generation slipped from 78 to 75 per cent between 2010 and 2013. By 2020, it will have slid to around 60 per cent.

What China does, the rest of the world seems to mirror. Coal's share of US electricity generation dropped from 39 per cent in 2014 to 34 per cent in



GOING NOWHERE

Decarbonisation is driving the shift in the world's energy supplies, but some low-carbon options will remain sidelined in the next five years. Policy and technology advances may help them break through after 2020 – or they could be destined for the energy scrap heap.

NUCLEAR

Nuclear's share of global electricity generation peaked in 1996 at 17.6 per cent; in 2020 it will probably be around 12 per cent. A few countries bent on diversifying their energy supplies are building new reactors, such as China. But most aren't, and existing nuclear users such as the US and UK are retiring reactors faster than they can be replaced.

What ails nuclear energy is its cost. Reactors give a steady supply of low-carbon energy, but their construction costs are high and rising. In 2015, the Nuclear Energy Agency estimated that equipment costs had risen 20 per cent since 2010, largely due to upgrades mandated after the 2011 Fukushima Daiichi disaster in Japan. Asset managers Lazard projects that reactors starting construction today will deliver power costing \$92 to \$132 per megawatt-hour over the course of their operating life. Even the low end of this range is well above the cost of solar and wind power.

BIOFUELS

After booming over the last decade, motor fuels produced from crops are stalling. Analysis suggests that their carbon footprint is only marginally better than that of petroleum-based fuels, prompting regulators to dial back)

THE FALL OF KING COAL

2015, its lowest level since records began in 1949. In the UK, coal delivered 24 per cent of power output last year, its lowest level since 1951. Few expect coal to recover: most of the decline is down to the rise of cheap natural gas, but wind and solar are also on the up.

With the two biggest economies cooling on coal, prices have declined by up to 70 per cent. That would once have prompted other countries to double down, but not this time. This is a worldwide shift as countries decide, for their own idiosyncratic reasons, to avoid coal. The IEA projects the size of the global coal market in 2020 to be 5.8 billion tonnes - almost its 2013 level. ■



incentives, particularly for biofuels produced from food crops. The European Union recently revised a target calling for biofuels to provide 10 per cent of fuels by 2020, capping crop-based biofuels at 7 per cent.

Such moves are an opportunity for advanced biofuels such as cellulosic ethanol, produced from fibrous agricultural waste, trees, or grasses. But these fuels are pricey: the IEA says they are competitive only when oil prices exceed \$100 per barrel. It projects that biofuels will stall at about 4 per cent of motor fuels through 2020 - though they are likely to have an important long-term role in the aviation industry.

CARBON CAPTURE AND STORAGE

The substantial cost of climate change mitigation can be halved, according to the Intergovernmental Panel on Climate Change, if you can capture CO₂ from coal, natural gas and biomass-fired power plants and store it underground.

So why are carbon capture and storage (CCS) schemes falling by the wayside? The UK, for example, recently pulled the plug on a £1 billion plan to capture CO₂ from coal-fired generators and sequester it in depleted North Sea gas fields.

The reason is that CCS itself is costly and energy-intensive. In 2014, Canadian utility SaskPower retrofitted a coal-fired plant with a \$1 billion CCS system. That reduced electricity output by about 20 per cent - potentially making the plant uneconomic. CCS may yet have its day, but the technology needs a breakthrough. ■

MONEY TALKS

- Investors are starting to consider “carbon risk” when looking at fossil fuel industries
- Funds controlling more than \$3tn plan to move away from the sector
- The “fossil fuel monolith” is cracking under this unprecedented pressure

It's not just coal. Oil has suffered too, its price crashing as hydraulic fracturing and other innovative drilling techniques have increased US oil and gas production even as rising fuel efficiency, particularly in the automotive sector, have flattened global demand. The price of crude halved two years in a row, dipping below \$27 a barrel this January.

These low prices are pummelling investment. The IEA reports that global investment in oil and gas production declined by 20 per cent in 2015 and will decline nearly as much this year: if borne out, it would be the sector's first consecutive annual drops since the 1980s. It projects that if oil prices stay below \$50 a barrel, US producers will pump out 2.5 million fewer barrels per day in 2020. Canada's tar-sands bitumen developers are in full retreat, cancelling billions of dollars in planned infrastructure. (Middle Eastern producers, whose oil is cheapest, are likely to keep on pumping and gaining market share.)

Now, investors are taking a harder look at how climate change policy will affect future demand for fossil fuels, as the coal industry's rout creates startling examples of what analysts call “carbon risk.” Consider the trials of Peabody Energy, the world's largest private sector coal firm, whose shares last year lost 93 per cent of their value. In early January, another big firm, Arch Coal, declared bankruptcy. Institutions managing over \$3 trillion in assets have pledged to pull support for coal, bitumen and the like, including Allianz, Europe's largest insurer, and California's huge public employee pension funds.

The oil and gas sector is next in line: investment bank Morgan Stanley warned that, thanks to last year's Paris agreement, opportunities to “profitably invest” in oil and gas exploration could be waning by 2020.

The fossil fuel sector as a whole is on the brink of a public opinion pivot akin to the one experienced by the tobacco industry a decade ago - and its ability to put on a united front in the face of challenges is disintegrating.



ELECTRIFYING TRANSPORT

Planes, trains and automobiles burning fossil fuels contribute one-seventh of global greenhouse gas emissions. The hope is that those emissions can be slashed by replacing today's fleets with electric equivalents drawing power from an increasingly decarbonised grid.

After long years in the wilderness, plug-in vehicles are finally catching on, beginning with passenger cars. In the West, cars like the Nissan Leaf and Tesla S have broken the mould for everyday and deluxe battery-powered cars, respectively. In China, analysts predict the government will foster the installation of about 12,000 public charging stations. By the end of 2015, China had only 778 charging stations, according to the Society of Automotive Engineers of China.

Electric vehicle charging is an attractive market for the generating industry, especially with demand from homes and businesses flat or dropping as efficiency improvements kick in. And modulating the cost of charging a vehicle according to wider demand also offers a promising way to keep power supply and demand in balance as grids increasingly rely on fluctuating wind and solar power.

Of course the range of today's electric cars is limited by the need to plug them in periodically. Trains face no such problem provided operators are willing to electrify routes. NASA is now testing multi-propeller aircraft designs that could someday lead to all-electric aircraft, but there will not be a plug-in 747 any time soon. For today's planes, biofuels are a better solution. ■

MONEY TALKS

“You’re seeing a fracturing of the fossil fuel monolith,” says Susan Reid, vice-president for energy and climate at Ceres, a Boston-based non-profit focused on sustainable investing. Oil and gas firms are engaged in public relations cat-fights with coal; multinationals have split ranks over climate change. The house is divided.

Emboldened politicians are seizing the opportunity to challenge the industry. US President Barack Obama recently rejected the Keystone XL pipeline, which would have pumped diluted tar-sands bitumen to the Gulf coast. Even natural gas is facing scrutiny, despite its producers’ claims that it is environmentally friendlier than oil. Governments are demanding action to reduce leakage of methane, a far more potent greenhouse gas than carbon dioxide, during its extraction; new US rules limiting its release are expected to take full effect in 2020. ■



TAX AND SPEND

- Fossil fuels' hidden costs to health and the environment are coming under scrutiny
- Massive fossil fuel subsidies are also under threat
- Carbon taxes and markets are likely to expand globally

Investors and politicians alike are responding to the increasingly obvious need for action on climate change - by making explicit fossil fuel costs that have long been obscured, keeping them artificially cheap (see "Counting the real cost", right). This is in turn leading to major scrutiny of long-standing fossil fuel subsidies to both the mining industries and consumers of their product.

Conservative estimates put the subsidies at roughly \$500 billion a year worldwide - over four times as much as global subsidies for renewable energy. A recent analysis from the International Monetary Fund, which factored in a wider range of supports, such as state subsidies of healthcare costs linked with pollution from burning fossil fuels, arrived at a figure more than 10 times that: \$5.4 trillion. That's a lot of money that politicians can spend elsewhere, and some are doing so: Germany is on track to end coal subsidies by 2018, for example, while other countries cutting back broadly include Indonesia, Malaysia and Thailand.

There is still plenty of resistance. The US Congress has ignored President Obama's annual calls to eliminate \$4 billion in oil and gas sector tax incentives. Fossil energy suppliers will "hang on to every last subsidy", says Ceres's Reid. However, she adds that the logic behind cutting subsidies is "unassailable", noting that even the CEO of Enel - one of the world's biggest electric utilities, based in Rome, Italy - recently called for their elimination.

Indeed, Reid expects the pendulum to swing all the way from fuel subsidies to carbon pricing. By 2020, she says, a "critical mass" of the world's leading economies will be putting a price on carbon, forcing fossil fuel producers to internalise some of their products' healthcare and ecosystem costs. The Canadian province of British Columbia charges a CAN\$30 (US\$21) fee per tonne of carbon in fuels, for example; neighbouring Alberta plans to impose a similar carbon tax by 2018.

Others are developing carbon markets rather than taxes: "cap-and-trade"



COUNTING THE REAL COST

Global subsidies for fossil fuels dwarf those for renewables, especially when we include health and environmental costs which governments and the public have to bear

SUBSIDIES FOR RENEWABLES:
\$101 BILLION

SUBSIDIES FOR FOSSIL FUELS:

Direct support in the form of tax cuts, loan guarantees etc

\$548 BILLION

SOURCE: OECD

Fuel production and use

\$775 BILLION

SOURCE: ODI

"Hidden" underwriting eg of healthcare costs related to air pollution, plus underestimates of environmental costs

\$4.2 TRILLION

SOURCE: INTERNATIONAL MONETARY FUND

TAX AND SPEND

schemes that make industries acquire tradable carbon credits in order to legally pump CO₂ into the atmosphere. China has piloted seven such markets in major centres such as Shanghai, Tianjin and Shenzhen since 2013 and plans to have a national market in place by 2018. Industries can take a similar approach: the global aviation industry, for example, is set to operate such a market by 2020.

This transition will not be easy. Europe's groundbreaking carbon market experienced serious teething problems with member states issuing too many credits, thus undercutting the price of emissions. Next-generation markets, such as one shared by California and Quebec, include features aimed at making them more effective: for example, a floor below which the price of carbon credits cannot fall maintains pressure on polluters. ■



POWER UP

- Economies of scale are now on the side of renewables
- China has become the world's biggest maker of solar panels

All this is only half the story. The past half-decade has been as good for renewables as it has been bad for fossil fuels. Between 2009 and 2014, the cost of photovoltaic (PV) panels dropped 80 per cent and the price of wind turbines by nearly a third, according to the International Renewable Energy Agency in Abu Dhabi.

Peter Asmus, a principal research analyst with energy consultancy Navigant Research, predicts that solar power will reach parity with grid prices - becoming as cheap as gas or coal - by 2020 in most markets with decent sunlight, having already done so in several countries including Mexico and Germany (see "Competing on price", right). "That's a game changer," he says.

How has this happened? It's not because of transformative technologies. Although there have been steady incremental improvements in efficiency (with the very best panels now exceeding 20 per cent), over the past 50 years, the power output we can achieve with a given size of silicon panel has only about doubled. The fall in cost is the result of scale production and advances in manufacturing, as well as reductions in the cost of non-panel items such as financing, installation and grid connection.

Costs will continue to drop: technology is expected to provide efficiency boosts after 2020 as manufacturers bring out tandem cells that feature crystalline silicon cells coated with a layer of thin-film PV, allowing them to capture a wider swathe of the solar spectrum.

China, in particular, has been at the centre of this global boom. In 2010, Beijing began doling out \$42 billion of subsidised loans to the country's solar manufacturers. Aided by this infusion of cash, within two years, Chinese factories' share of global solar panel manufacturing had risen from 45 to 56 per cent, and in 2013 it reached 70 per cent. The cost of each watt of power dropped from \$2.79 to \$1.59.

Such advances increase optimism and funding for next-generation



COMPETING ON PRICE

As of 2015, 30 countries and parts of another nine had achieved "grid parity" - their small-scale solar energy costs less than grid electricity



SOURCE: DEUTSCHE BANK

POWER UP

renewables, and it's not just solar. Offshore wind farms are installing ever-larger turbines that capture exponentially more energy: the first US offshore farm, in Rhode Island, will include 180-metre-tall beasts that can each generate enough power for about 2800 homes. Even taller next-generation turbines will be erected over the next four years in the North Sea and the Irish Sea, each powering about 7500 households.

New wind and solar power farms are competing head-on with coal and gas-fired projects. As a result, they are projected to account for almost two-thirds of the growth in global power capacity anticipated through 2020, a trend that is set to accelerate. In January, the US Congress voted to extend tax credits for wind and solar power. As a result of this vote, Navigant Research predicts there will be 50 per cent more solar installations in the US by 2020, and projects a comparable jolt for wind power.

Other renewables in the wings are poised to catch the next wave. For example, geothermal energy developers are testing out advanced drilling techniques, developed in the oil and gas sector, to tap deep hotspots at lower cost.

Other aspects of the economy are echoing these changes. In the US, for example, the Bureau of Labor Statistics finds that solar and wind farms will provide some of the growth industries of the next decade. ■



PLUGGING THE GAP

- *Wind and solar power output is inherently contingent on the weather*
 - *The intermittent nature of renewable power can be overcome by using batteries to store energy*
 - *Trading power requires new infrastructure, regulations and business models*
-

Renewables have a well-publicised Achilles' heel: wind turbines and solar panels are inherently dependent on the weather, so cannot be relied on to provide full power as and when required. How do you balance supply and demand at all times without falling back on fossil fuels? One option is nuclear energy, but its high cost and perceived risks have deterred many countries from investing in it (see "Going nowhere", page 3).

Another is to build giant batteries into the grid. Peter Asmus at Navigant Research points to the transformation under way in California, where the grid is adapting to one of the world's fastest energy transitions. Renewable power, including that generated by hundreds of thousands of rooftop solar systems, has doubled to over 20 per cent of the state's electricity over the past decade; it could reach 33 per cent by 2020. By then, solar and wind power will regularly exceed demand in the middle of the day, but solar output will plummet later on, just as demand is peaking.

Californian regulators have told utilities to start mastering the use of batteries to manage solar power surges, mandating that they install enough battery capacity to store and release 1.3 GW of power. Grid storage is also growing rapidly in Germany and Japan thanks to government subsidies.

But grid storage isn't just about batteries. The most widely used method of storing power is pumped storage, which uses some of the excess energy to pump water up a hill and then, when demand is high, lets it flow down a hill again to drive a turbine. It's an excellent idea, but it only works if you have a reservoir and a hill. So myriad research efforts are trying to develop next-generation grid storage technologies. Renewable-generated power can be stored as compressed air pumped into underground salt caverns. The heat from concentrated solar plants can be stored in molten salt. A surprising number of things can be turned into a battery - from ice to flywheels to liquid air.

Most of these ideas are still in development, and we'll need a lot more



PLUGGING THE GAP

storage to make a fully renewable grid. Or do we? Perhaps not, according to a recent paper in *Nature Climate Change*. Modelling a hypothetical power grid, the authors found it could run purely on renewables, provided many far-flung regions could be connected so as to move energy from where it's being produced to where it's needed. The California Independent System Operator, which coordinates the state's grid, is already negotiating deals with neighbouring utilities to facilitate spontaneous swaps of excess renewable energy.

New York State is also radically redesigning how it plans and operates its power grid. And in Europe, grid operators are turning energy sharing into a science, creating algorithms that automatically evaluate grid conditions and maximise power flows across borders.

Such flexibility requires upgraded infrastructure. Moving power with higher precision and lower losses between regions, for example, requires direct-current transmission lines. High-voltage DC power links, mostly via subsea cables, increasingly swap wind power generated in the North Sea region for solar power surpluses in southern Europe, for example. DC cables are also enabling hydropower reservoirs in Scandinavia to serve as power buffers for the European grid.

"The technology is now there. It's really the regulations and business models that are trying to catch up," says Asmus. By 2020, he predicts, the rules of the next-generation power grid will be coming into clear focus. ■



BALANCING ACTS

- *Power utilities will soon be able to actively manage demand, as well as supply*
- *Smart devices will turn end users into active, rather than passive, consumers*
- *Upgrading energy efficiency is an overlooked but effective way to reduce demand*

It's not just about power lines. There are also advances at the lowest level of the grid's architecture: homes and businesses. Until recently, they simply sucked up power as and when they wanted it. Now advances in power electronics and internet connectivity make it possible to choreograph the energy consumption of myriad distributed devices, from rooftop solar panels to individual household appliances.

This will give grid operators the ability to manipulate not just supply but also demand for power. Historically, they adjusted power generation up and down to match whatever homes and business consumed. By 2020, load will in many cases be throttled to match whatever renewable power sources are offering - and in ways that consumers won't resent (or even notice) as they naturally do emergency brownouts and power cuts.

How? One example is smart thermostats, such as Google's Nest, which allow utilities to turn off residential air conditioners when they are not needed and the grid is under strain, or turn them on when there is excess power available. Electric vehicles provide another mechanism (see "Electrifying transport", page 5); California-based start-up Electric Motor Werks will soon be adjusting charging rates for 1000 residential electric-vehicle points in real time.

Another easily overlooked factor that will lessen demand and the need for fossil fuel baseload plants is energy efficiency. The IEA's core projections often discounted this, leading to total energy demand being overstated. Yet improvements in energy efficiency are already the cheapest "source" of energy, according to projections by asset management firm Lazard.

Increasingly ambitious efficiency standards are giving consumers better choices. And utilities are learning how to drive energy-saving behaviour through, for example, rankings on monthly bills that tell consumers how their usage compares with their neighbours' - exploiting our susceptibility to keeping up with the Joneses.



BALANCING ACTS

These measures can keep the grid humming smoothly without adding extra hardware. Lazard's latest survey of electricity generation options, released in November, put the average cost of energy-saving investments at no more than \$50 per megawatt-hour. That compares with \$50 to \$70 per megawatt-hour to produce power at a utility-scale solar farm, and \$65 to \$150 per megawatt-hour for a coal-fired power plant. ■



THE OFF-GRID BILLION

- *Developing countries can benefit from advances in renewables and smart grids*
- *India is on track to become a leader in renewable energy*
- *Microgrids will deliver electricity to tens of millions by 2020*

While advances in technology are allowing major industrial economies to clean up their act, their greatest impact could be in countries not yet locked into traditional energy infrastructure.

The standout example in 2020 is likely to be India. Since the election of Prime Minister Narendra Modi in 2014, it has gone from a renewable energy laggard to a powerhouse. Modi pledged to grow India's solar power capacity 30-fold by 2022, and he is delivering. Thanks to cost reductions and policy reforms, Indian PV installations doubled last year and are likely to double again in 2016, rocketing the country from 11th in the global solar rankings to second or third place, says Tobias Engelmeier, founder of Bridge to India, a solar-market consultancy based in New Delhi and Munich, Germany.

In November 2015, Missouri-based solar developer SunEdison secured rights to build a solar generating plant in Andhra Pradesh which would produce power at below-average cost for India. Engelmeier expects 40 to 50 gigawatts of solar capacity to be installed by 2020, overtaking the nuclear power capacity that India has been trying to install since the 1950s.

Utility-scale plants will help many of India's people, but not the fifth of its population who are not on the grid. Some 1.1 billion people in Africa, South Asia and Latin America have no grid access; at current rates of electrification, millions will still be waiting in 2030.

Enter the microgrid, which makes it possible to supply electricity to rural communities that may be hundreds of kilometres from a power line. Microgrids are local, self-contained electrical grids used, for example, by the military to power remote bases, or to keep them running when weather knocks them off the grid. These are traditionally powered by diesel generators, but microgrids with solar panels, batteries and digital technology could herald a new era of clean, local energy.



SMART MICROGRIDS

There's nothing fundamentally new about microgrids, powering a neighbourhood or other small community using their own mini generator. Where they can push the envelope is by marrying renewables with modern communications technologies, such as cellular networks.

Take the 25 microgrids installed by Nairobi-based SteamaCo in off-grid Kenyan and Tanzanian villages since 2013. Each derives power from a solar array, which also powers electronic control boxes that use text messaging to swap data and instructions with SteamaCo's headquarters. In this way, the system can meter each customer's electricity usage and bill them through M-Pesa, Kenya's mobile phone-based payments system.

It is a back-to-the-future story in a sense, since SteamaCo's hub-and-spoke architecture resembles the first European and North American grids that Thomas Edison and other power pioneers built in the late 19th century.


Many microgrids players are seeking to sign up cellular operators as key clients. The Rockefeller Foundation committed \$75 million last year to supporting microgrid companies applying this model in India. It sees long-term contracts to power cellular towers as a "bankable" foundation for PV arrays that also serve)

THE OFF-GRID BILLION

Goldman Sachs, working with the non-profit Climate Group, expects that remote microgrids will serve nearly a million households in India by 2018, up from less than 100,000 last year. They project even more impact from “nanogrids”, generating just 10 to 200 watts for a single home or business; at least five million of these will be installed in India between 2014 and 2018, they predict. Such solutions could leapfrog the need for traditional grids much as cellular telephone networks leapfrogged wired ones.

There is no reason that the same technology cannot be brought to bear for the world’s other off-grid inhabitants. Since 2013, 25 microgrids have been installed by Nairobi-based SteamaCo in off-grid villages in Kenya and Tanzania (see “Smart microgrids”, page 15). By 2020, the technology should be hitting its stride: fully developed and easily deployed where needed. Microgrids not only help electrify the world, but do so without burning a gram of fossil fuel.

Nor will microgrids be limited to the developing world. Ageing and unreliable infrastructure is driving similar projects in regions that have long been connected to national grids. For example, with ever more powerful storms leaving the town of Nassau, New York, facing constant blackouts, local government is considering a switch to microgrids by 2020. ■



village residents and small businesses. The foundation’s goal is to electrify 1000 villages in India by 2018.

Microgrid veteran Andy Schoeter, founder of Laos-based Sunlabob Renewable Energy, argues that microgrids make the most sense for truly remote areas of the developing world, such as the 10 percent of Laos’s population that live in mountainous areas that will still be without a grid connection in 2020. But he cautions that progress will be hard-won and will require considerable public investment. Schoeter, whose firm operates in 30 countries in Asia, Africa and the Pacific Islands, says India’s success with microgrids reflects its relatively well-developed infrastructure and its clusters of villages. ■

CONCLUSION

By 2020, renewable energy sources such as wind and solar will be cheap and easy to manage. Technological advances, environmental concerns and political backing will drive their adoption around the world. The IEA foresees renewable energy growing by 40 per cent between 2014 and 2020 - adding 598 gigawatts, which is twice as much Japan's entire generating capacity.

Renewable energy is entering a virtuous circle, with rising investment and greater deployment bringing down costs. There is no better evidence of that than the Paris Agreement clinched in December - the product of a far more successful summit than the fiasco in Copenhagen which preceded Greenpeace's *Energy [R]evolution* scenario. The Paris talks succeeded because renewables now make economic sense, not just because delegates' hearts were in the right place.

Fossil fuels, in contrast, appear locked in a downward spiral, in which financial and political misfortune feed off each other. Subsidies that support fossil fuels, despite their environmental toll, are being replaced with carbon pricing schemes that weigh these fuels down. Investors are more closely scrutinising the risks inherent in stocks and bonds underpinned by reserves of coal, oil and natural gas that may never be tapped.

As IEA executive director Fatih Birol put it on the eve of the Paris climate talks: "There should be no energy company in the world who would believe that climate policies will not affect their businesses. If any company believes that climate policies are [just] the issue of the NGOs and think tanks, they are making a grave mistake."

If the last five years saw rapid change, the next five hold even more radical changes in store. What does Greenpeace, more willing to think radically than the energy establishment in 2010, think now? Worldwide, it sees a third more wind turbine capacity and 84 per cent more solar power in 2020 than the IEA.

Some will be shocked by the increasing pace at which fossil fuels and renewables are experiencing contrasting fortunes. But anyone who has been paying attention over the past five years won't be surprised. ■

