Innovation in Energy

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Revolution needed to power the future

Breakthroughs in key technologies will be needed to balance future energy demand with global ambitions to curb emissions, says *Ed Crooks*

Installing for time: workers position a wind turbine on the Champs-Élysées before the Paris climate talks aimed at curbing global warming — Patrick Kovarik/AFP/Getty Images

Early in the Paris climate talks last month, Todd Stern, the US special envoy for climate change, set out for a group of reporters the administration's view on how the problem should be tackled.

"We have a lot of technology that is available right now on the shelf," he said. "It's being used, and can be used more, to drive emissions down now. But to get where we need to get, we need more."

The need for more innovation in energy was one of the strongest points of agreement at the Paris talks. Some have suggested that the most important news to come out of the conference was not the final accord, signed with great fanfare by the governments of 195 countries, but the commitments made by governments and wealthy individuals to research and develop technologies that can help the climate.

Energy innovation is a concept that has become almost universally popular — among all from the most traditional of oil companies to the most radical of environmental groups.

For all the rising enthusiasm, though, investing in innovation remains a hazardous and uncertain business in energy, as in other industries. There are many potentially significant technologies out there, a few of them described in this report. Some of them may have a huge impact on the world's greenhouse gas emissions, many more are likely to fizzle out and fail.

The Paris accord committed its signatories to holding the rise in global temperatures since pre-industrial times to "well below" 2 degrees centigrade, while "pursuing efforts" to keep that increase to 1.5 degrees. To meet that objective, they also agreed that global greenhouse gas emissions should reach a peak "as soon as possible" and then start falling rapidly.

If we were allowed only to use today's technology, those objectives could in theory still be achieved.

Mark Jacobson of Stanford University and Mark Delucchi of the University of California Davis have published papers arguing that it would be possible to derive all the world's energy, for all uses, from only wind, solar and hydro power, by 2050.

Their analysis used only existing technologies that had already been deployed, at least in pilot projects, by 2010. But that would mean a huge transition and would require vast investment. Mr Jacobson and Mr Delucchi suggested the world would need 3.8m new large wind turbines, for example.

The cost would be higher than fossil fuels, at least at first, and there could also be deepening conflicts between tackling climate change and other policy objectives, such as improving access to energy for the billions of people who

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Inside

Electric vehicles VW stakes claim for peace, love and understanding, writes *Andy Sharman*

Hippy classic aims to switch happy campers to cooler fuel

Feeling groovy: the latest VW concept vehicle
John Locher/AP

When Herbert Diess, head of the Volkswagen passenger car brand, gave his keynote speech at this month's Consumer Electronics Show in Las Vegas, he offered two messages.

The first was to say sorry for the emissions test-rigging scandal that affects 11m cars worldwide. The second was to say how the world's second-biggest carmaker was moving on from a crisis which has severely damaged its reputation and prompted legal action from US authorities.

Mr Diess showed off Budd-E: a camper van concept that suggests peace, love, happiness and, above all, electric power. The vehicle builds on VW's heritage as manufacturer of the cult caravanette, which became a symbol of alternative living in the 1960s.

The new car, though only a concept, is technically capable of 233 miles on a single charge and able to repower to 80 per cent of its battery capacity in half an hour. "We are now creating a different and better company," said Mr Diess. "A new Volkswagen."

For all the negative effects of the diesel emissions scandal that last year engulfed Europe's largest carmaker, analysts have suggested that the positive outcome could be a deeper commitment from companies, suppliers and customers to alternative fuels.

The VW concept at the CES followed a pledge in September from the Wolfsburg-based company to develop a range of 20 electric and plug-in hybrid vehicles by 2020 — including a Porsche capable of 500km per charge.

Yet, for all the optimism expressed by the flashy concepts and verbal commitments, the present reality remains bleak for battery-powered vehicles. Electrified cars ranging from mild hybrids, where an electric motor assists an internal combustion engine, to pure electrics and hydrogen fuel-cell vehicles accounted for just 3 per cent of global sales in 2015, according to LMC Automotive. Battery costs remain high and the supporting infrastructure patchy.

Growth in the UK and Europe looks relatively impressive. About 73,000 alternative-fuel vehicles were sold in the UK in 2015, up about a third on the year before.

But with unusually low fuel prices, electric cars had a harder time in the US, where sales of plug-in vehicles declined 17 per cent in 2015 versus the year before, according to Autodata, a research group. That was despite seemingly insatiable consumer appetite for new cars that pushed overall sales in the country to record levels.

Nonetheless, tough fuel economy targets mean carmakers have no choice but to embrace electrification and make sure electric models start to gain commercial traction.

In Europe, carmakers must meet an average target of 95g of carbon dioxide per kilometre across their fleets by 2021, down from 130g last year. In the US, rules introduced in 2012 demand that manufacturers nearly double average fuel economy — to 54.5 miles per gallon — by 2025.

Consumer acceptance will depend on companies solving the problems linked to electric vehicles. They are seen as expensive and limited in range and even in breach of the basic promise of the motor car — "the freedom to go where you want and when you want", as Mr Diess put it.

General Motors used the CES to introduce the production version of the 2017 Chevrolet Bolt, which is capable of 200 miles on a single charge and expected to cost $30,000 — after government incentives — which is lower than the average new car price in the US, notes vehicle price guide Kelley Blue Book.

> Opinion [focusing on] electric cars as oddball spaceships or makeshift milk floats is changing

"The Bolt EV is truly the first EV that cracks the code of long range at an affordable price," said Mary Barra, chief executive and chairman of GM.

At the heart of the EV dilemma lie battery costs. If batteries were cheaper, carmakers would be able to add more cells for better range, reducing reliance on charging networks. High battery costs mean few companies make money from electric cars.

But here at least there is more positive news for the development of the market. Despite a recent rise in the price of lithium, the raw material used in the batteries that power most electric cars, battery costs have come down 70 per cent over the past five years to about $375 per kWh, says research by brokerage CLSA. That is set to fall by at least 20 per cent a year to reach just over $200 by 2018.

That would put battery costs close to the point at which analysts think plug-in vehicles will be able to go mainstream. This will also be accompanied by constantly increasing energy density, rising by about 10 per cent a year, says Matt Breidert, senior portfolio manager at Ecofin, the fund manager that specialises in alternative energy.

"The reason this matters is that, rather than pushing the total cost of the incoming EV model down each year, we are likely going to simply keep prices relatively constant and dramatically increase the range of each year's model," he says. Range limitations have hampered the uptake of early electric models.

The arrival of vehicles such as the Tesla Model S, which launched in 2012 and blends sleek looks with critically acclaimed performance, also means public opinion about electric cars as oddball spaceships or makeshift milk floats is changing. "More and more people are getting used to seeing them and generally accept that the technology now works," says Mr Breidert. "I think if the next generation of EV models are indeed better on range and functionality, we will see a faster adoption rate."

Experts set out their vision for small-scale fission

Nuclear power

More modest facilities allow greater flexibility and savings, reports *Kiran Stacey*

A nuclear power station that can be placed on the back of a truck — or even a barge — could be the future of atomic power around the world.

While many big countries are building a new generation of nuclear power stations as a way of providing reliable power while also hitting carbon reduction targets, such facilities have proved expensive to build, often requiring significant government subsidies to ensure they are completed.

As a result, some in the nuclear industry are pinning their hopes on new technologies, which involve building small nuclear power plants in modules in a factory and transporting them to the sites where they will run.

"Small modular reactors will open up nuclear power to places and situations that have never traditionally invested in nuclear power," says David Hess, of the World Nuclear Association.

The idea of nuclear power on a small scale is not new. India and Pakistan have nuclear units with a capacity of 300MW — a tenth of the size of the £18bn facility planned for Hinkley Point in south-west England.

Over the last few decades, building smaller stations went out of fashion as governments and companies looked for economies of scale. This has changed recently, as companies have developed the technology to be able to build large parts of power plants in a factory and transport them to different sites. Such a process allows both flexibility and cost savings.

Tom Mundy, an executive vice-president at NuScale, one of the companies developing small modular reactors (SMRs) comments: "We wanted to make sure our steam-generating unit could be transported by a special truck, on the railways, or the waterways." NuScale's main module, which contains both the reactor core and the water heating system, is roughly 22m long by 4m wide.

Mr Mundy adds that the economics for SMRs only work if operators order a whole fleet of smaller plants, helping drive down the overall cost per unit. "We are not talking about economies of scale here but economies of multiples," he says.

Another change that has driven the technology has been the privatisation of energy markets around the world. While governments has had big enough balance sheets to be able to finance larger nuclear projects, companies are less likely to unless they get some form of state support.

The UK government has guaranteed EDF, the French energy company, £92.50 per megawatt hour of the electricity it will eventually produce at Hinkley Point. The current wholesale price is about half of that, leading to accusations that the taxpayer is being overcharged.

Dieter Helm, a professor of energy at Oxford university, says: "The big pressurised reactor approach has come to the end of the road. In developed countries, there is no appetite to develop these."

Clusters of smaller reactors help not only because they cost less overall, but because they can start producing electricity quickly before further units are added to expand overall capacity. This means that investors see returns earlier.

For developed economies which already have large amounts of baseload power, but struggle with the intermittent generation that comes with renewable sources, smaller reactors could provide a solution. "Reactors can be turned up or down, on or off, to help meet load requirements," says Mr Mundy.

Different countries are at different stages with the technology. The US and the UK are pushing ahead, with both governments putting money into research. China is developing a type of reactor that can be placed underground, which will help allay concerns about large nuclear plants being a security risk.

Some believe that Japan could become a significant market in the aftermath of the Fukushima disaster in 2011. Mitsubishi is developing a design that might begin being licensed in the 2020s but industry executives say this will be mainly for export, with Japanese energy policy, at present, focusing more on the clean-up after Fukushima than on new nuclear technologies.

Even if companies and governments decide to press ahead as quickly as possible, none of the new technologies under development is likely to be ready and licensed until the mid-2020s.

> 'The big pressurised-reactor approach has come to the end of the road'
> Professor Dieter Helm

Before then, companies need to prove that small reactors can be economic — despite the increased costs of extra grid connections, staffing and licensing costs — and safe. Several projects, such as a Russian plan to build a floating small reactor, have been delayed for either technical or financial reasons.

Companies might still need state money to build the first units. As Dame Sue Ion, a fellow of the UK's Royal Academy of Engineers, and a prominent supporter of nuclear power, comments: "There are lots of advantages to small reactors. But could they require as much state funding as Hinkley Point? That will depend on what it costs to get the first one away and proven."

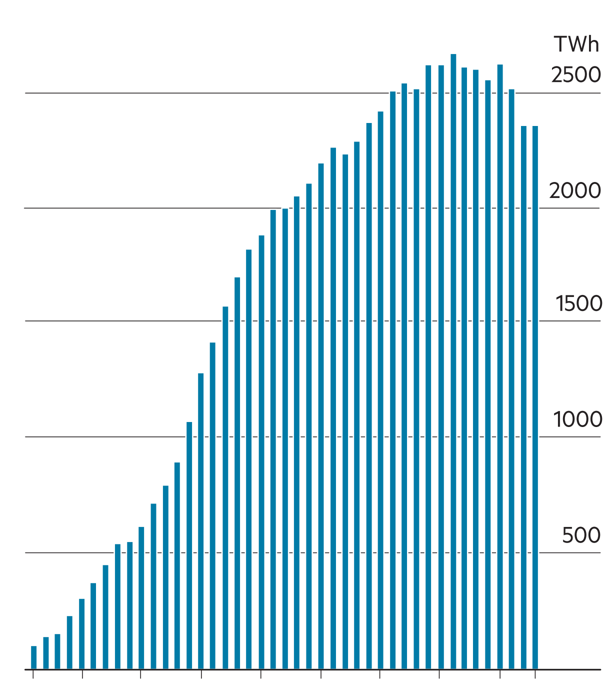
Worldwide nuclear electricity production

The first commercial nuclear power stations started operation in the 1950s

There are about 440 commercial nuclear power reactors operable in 31 countries, with over 380,000 MW of total capacity. About 65 more reactors are under construction

They provide over 11% of the world's electricity as continuous, reliable base-load power, without carbon dioxide emissions

56 countries operate a total of about 240 research reactors and a further 180 nuclear reactors power some 140 ships and submarines



FT graphic Source: World Nuclear Association

Hope springs eternal for fusion breakthrough

Research

The hunt for an alternative to nuclear fission continues, reports *Clive Cookson*

Undeterred by taunts that fusion always seems to lie 50 years in the future as a commercial energy source, a growing programme of research is aimed at taming the nuclear reaction that powers the sun and the H-bomb. It releases energy by combining light elements, in contrast to the atom-splitting fission process that drives current nuclear power stations.

Fusion research falls into three different camps. One is the traditional "big science" approach — exemplified by ITER, a project to build an experimental fusion reactor at Cadarache in France.

Second is a wave of start-ups whose ambition is to deliver power more quickly and less expensively than the big public projects. These companies are using the same hot fusion approach, forcing atomic nuclei together at extreme temperatures and pressures.

Lurking out in left field is a third way — utterly different in that it claims to release fusion energy in much more moderate conditions, close to room temperature. This approach, a successor to the "cold fusion" experiments carried out by Stanley Pons and Martin Fleischmann in 1989 and now usually called "low energy nuclear reaction" or LENR, is ignored by the scientific mainstream but making progress according to devotees in labs around the world.

All three techniques offer the long-term promise of virtually limitless carbon-free energy with much less radioactive waste than nuclear fission.

Hot fusion projects use various techniques to sustain the reaction. Leading the way is "magnetic confinement". Here a powerful magnetic field keeps the reactants, a plasma of hydrogen isotopes heated to 100m degrees centigrade, inside the reactor. If they touch the vessel's walls, the reaction stops.

The most popular magnetic reactor is the doughnut-shaped tokamak, invented in the 1950s Soviet Union. Its largest manifestation will be ITER, a partnership between the EU, China, Japan, South Korea, US, Russia and India, which is building a tokamak 10 metres high surrounded by superconducting magnets. When ITER was set up in 2006, it was expected it should have started up this year. Now completion is expected in 2025 and the estimated cost has soared above $20bn.

The ITER cryostat, designed to house super-conducting magnets and deliver a super-cool fusion environment

An alternative configuration for magnetic confinement is the stellarator, which has a more sinuous twisted shape. The world's most ambitious stellarator, the €370m Wendelstein 7-X in Germany, starts up this year.

Radically different is "inertial confinement". More than 150 ultra-powerful lasers focus their energy simultaneously on a pellet of hydrogen fuel, triggering fusion. Two publicly funded facilities are taking this approach: the National Ignition Facility in California and Laser Mégajoule in France.

The new wave of privately funded fusion companies in Europe and North America is using both inertial and magnetic confinement. Among them is First Light Fusion, an Oxford university spinout that raised £22.7m last August.

Another UK fusion start-up Tokamak Energy is aiming for commercial energy from magnetic confinement, based on a miniature version of the technology used at ITER. "Compact fusion power is no longer a pipe dream," says David Kingham, Tokamak chief executive. "We are aiming for that 'Wright Brothers' moment of take-off for fusion energy within 10 years."

If so there will be considerable competition from well-funded North American companies focusing on magnetic confinement. Leading fusion start-ups there include General Fusion in Canada and Tri Alpha Energy and Helion Energy in the US. At least one large company, Lockheed Martin, is also active in the field.

While there is considerable interaction between scientists working on hot fusion, cold fusion research takes place in a world of its own. Many mainstream scientists will not touch LENR which they see as tainted by the cold fusion fiasco of 1989, when Profs Fleischmann and Pons claimed to have achieved fusion on a lab bench — an experiment that others could not reproduce. However, after more than 25 years of experimentation, several research groups have built up evidence that real nuclear reactions lay behind the pair's results. The problem according to Professor Huw Price, a philosopher of science at Cambridge university, is that cold fusion became a "reputation trap" which most researchers avoid because they know the scientific world will not take their work seriously.

Carbon capture at risk of running out of steam

Emission control

Hopes are fading for the widespread adoption of CO2 sequestration to help ameliorate the use of fossil fuels, writes *Mike Scott*

For many years, carbon capture and storage (CCS) — trapping carbon emissions as they are emitted by power stations and industrial installations and storing them underground — has been hailed as vital to helping decarbonise the economics of energy.

The circumstances are stark, says Luke Warren, chief executive of the Carbon Capture and Storage Association: "If you remove CCS from the mix, the cost of meeting the target of limiting average temperature to two degrees centigrade rises by 138 per cent."

Nonetheless, progress in establishing the credentials of the process has been slow. According to Greenpeace, the environmental pressure group: "Despite years of vociferous backing from the International Energy Agency, the Intergovernmental Panel on Climate Change and a host of major world leaders, CCS continues to move forward at only a snail's pace".

The world's first commercial-scale plant was opened in 2014 at the Boundary Dam coal-fired power plant in Saskatchewan, Canada, and two more plants are due to be commissioned this year, one in Mississippi and the other in Texas.

Shell's Quest scheme in the Canadian province of Alberta, launched in November 2015, is the world's first CCS project to reduce emissions from the processing and burning of oil sands.

While there are 22 projects operating or under construction worldwide, capacity is tiny compared with what is needed to meet a target of curbing global warming levels to a 2 degree centigrade target, let alone the 1.5 degree aspiration agreed at Paris climate talks.

Part of the problem is that power generators and industrial emitters say they cannot afford to create CCS facilities without government help.

"Companies cannot make the huge investments needed with no prospect of a return. We need a framework where we can develop hundreds of plants over time," Mr Warren says. "There are a lot of costs around the development of infrastructure such as pipelines and storage facilities that mean the costs of early projects will be quite high, but as other projects are linked in to that infrastructure costs will fall quite quickly."

> 'Some put it across as a magic bullet that means you don't need to do other stuff'

Ben Caldecott, director of the Stranded Assets Programme at the University of Oxford's Smith School of Enterprise, says: "Policymakers are not willing to write a blank cheque for this."

A case in point was the UK government's decision late in 2015 to withdraw funding for a £1bn CCS technology competition. The US had also decided earlier in the year to stop funding the FutureGen project aimed a demonstrating the feasibility of capturing emissions from coal-fired stations. Many CCS initiatives were launched before the financial crisis and have become casualties of governments' need to retrench.

Boundary Dam coal-fired power plant in Canada

Benjamin Sporton, chief executive of the World Coal Association, is optimistic that the industry is set to take off. "Boundary Dam has provided important learning about how to cut the costs of CCS, with developers saying they could build a second plant for 30 per cent less than the first one," he says.

"Coal will play an important role in the world's energy mix for years to come, so if we are going to meet our climate targets, CCS is essential," he adds.

Yet others argue that focusing on CCS for power generation is the wrong approach.

"Many CCS advocates put it across as a magic bullet that means you don't need to do the other stuff like energy efficiency and clean technology. That's very far from the truth," says Anthony Hobley of the Carbon Tracker Initiative, which highlights the potential for stranded assets in the fossil fuels sector.

CCS for large-scale power generation does not make sense, adds Mr Caldecott. "There are multiple risks including competition from new technologies such as renewables and energy storage. There are also performance penalties in relation to efficiency and water use, while there is also political opposition, especially for onshore storage [of CO2]," he says.

The technology really comes into play for emissions in industries such as steelmaking where there is no alternative way of cutting emissions, argues Mr Hobley. "In energy, there are clear alternatives to coal but for some industrial processes it's very hard to see how they can cut emissions without CCS."

Focusing on industrial applications in the first instance also makes CCS more manageable, says Aniruddha Sharma, chief executive of Carbon Clean Solutions, a company that makes chemicals that he says can cut the cost of carbon capture facilities by 30 per cent.

"In the UK, we can build a CCS facility for the chemical industry that can capture 60,000 tons of carbon a year for £20m-£23m. In India, we can do it for £10m-£12m. That's a scale that companies can work with. Talk of billion dollar utility-scale facilities just scares people," he says.

The other problem for CCS compared with other low-carbon technologies is the end-market — a renewable energy project creates electricity that can be sold but there is a limited market for captured CO2. It is notable the three plants that will be operational by the end of the year are all using the captured gas to help improve productivity in nearby oil wells in a process known as enhanced oil recovery (EOR). "The projects that have got off the ground have been those where they have a use for the CO2," says Mr Sporton.

However, apart from EOR and some demand for carbonating beverages, there is currently limited call for CO2.

Unless that changes, or governments are more prepared to step in to support the industry, progress is likely to remain slow.

Revolution needed to power the future

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still have inadequate supplies.

There are various examples of evidence that the menu of energy options available today is unsatisfactory: the slow penetration of electric vehicles into car markets worldwide; the repeated false dawns for advanced biofuels; the high — although falling — cost of battery storage for electricity; the dearth of carbon capture projects that are making any progress; the public resistance to onshore wind turbines.

Gernot Wagner, lead senior economist at the Environmental Defense Fund, a US campaign group, says that new technologies will be essential if the world is to bring greenhouse gas emissions under control.

"Is it theoretically possible we could do it, based on the technology that we have today and that we know how to deploy at scale? Yes, it is. Is it going to happen? No," he says.

Of the two energy innovation plans launched in Paris, one was backed by the governments of the Group of 20 leading economies and the other by a group of billionaires including Bill Gates, founder of Microsoft, Mukesh Ambani, chairman of the Reliance group, and Amazon founder Jeff Bezos.

That initiative was particularly noteworthy because it was led by the private sector, which will have to lead the way in developing the key innovations that are needed. As President Barack Obama put it at the launch of the project: "The ambitious targets that we've set for ourselves can be reached in large part by the efforts of our scientists, our businesses, our workers, our investors." Alex Trembath of the Breakthrough Institute, a think-tank that makes the case for increased investment in energy innovation, draws an analogy with the most successful technological advance in the industry over the past two decades: the US shale gas and oil revolution.

Barack Obama: a fan of green energy

Before the shale industry emerged as a commercial proposition in the mid-2000s, there were decades of co-operation between private and public sectors, working on understanding the rocks and examining possible techniques that could unlock them.

Mr Trembath says that in a similar way, partnerships between government and the industry could also help the advance of "clean" energy technologies, including renewables and nuclear power.

There is, however, one crucial difference between gas and renewables. With gas, producers can be confident that if they can deliver it to the right place, they can sell it.

Renewable energy is still subsidised in much of the world, meaning that if the policy regime changes, the pay-offs for innovation can change, too. It creates an additional element of political risk in any investment appraisal. Mr Wagner argues that innovation cannot be a substitute for other policies to tackle climate change, in particular a tax or other price imposed on carbon, to incentivise everyone to emit less of it.

"It's often presented as a choice between one and the other, but it's a false choice," he says. "It's not either/or: it's a price on carbon and induced innovation that we need."

The biggest problem with pinning hopes for the climate on energy innovation is that, like other forms of technological progress, it is highly unpredictable. Twenty years ago, most people thought it would be impossible to produce gas from shale at commercially viable rates. Today, shale accounts for more than half of all US gas production.

In 1976, US government officials set out plans for nuclear fusion power that suggested the first working demonstration reactors could be starting up in 2005-10 at the latest.

The latest experimental reactor, ITER in France, is scheduled to start its first fusion reactions in 2027. When the first demonstration plants might be built is anybody's guess.

In the mid-2000s, companies were making claims that cellulosic ethanol, produced from agricultural waste rather than foodstuffs, would soon be commercially available. A decade later, there are a few commercial-scale plants, but overall growth has been much slower than the US Government expected or hoped.

If we are relying on innovation to reduce the risk of catastrophic climate change, that is not a very comforting conclusion. Mr Trembath accepts that, but argues that with global greenhouse emissions still on a rising trend — albeit with a probable dip last year — other attempts to address the threat since the 1997 Kyoto protocol have been largely unsuccessful.

"I don't think anyone should reassure themselves and say we should be confident we're going to limit warming to 2 degrees," he says. "But investing in clean energy innovation, as uncertain as it is, is basically the best that we've got — because I haven't seen any other strategies working so far."

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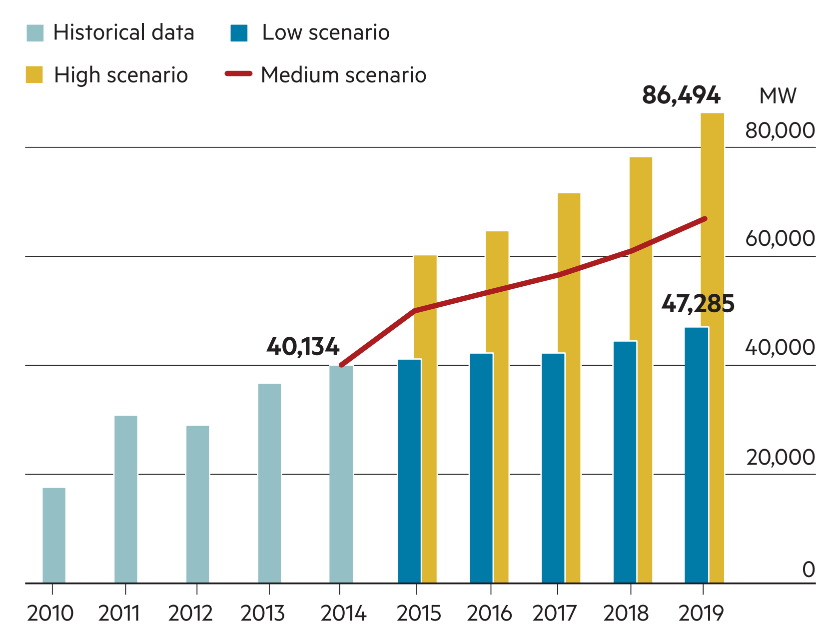
Photovoltaic progress: a view of the Beirut River Solar Snake, a 30m wide installation of PV panels over a river bed in the Lebanese capital — Joseph Eid/AFP/Getty Images

Swanson's Law provides green ray of sunshine

Solar power Falling costs compared with those of fossil fuels are boosting appeal, reports *Ed Crooks*

Global solar PV annual market scenarios
Until 2019



FT graphic Source: Solar Power Europe

Not every brilliant innovation leads to the launch of a flashy new product. In reality, most important innovation is done by taking existing ideas, adapting and refining them to make them commercially viable.

Solar power is a perfect example. The scientific intuition behind it — the photovoltaic effect — has been known since Edmond Becquerel discovered it in 1839. Silicon solar cells have been in use since Bell Laboratories developed them in the 1950s. Thin film solar cells made from chemicals layered on sheets of glass or other materials were developed in the 1970s.

Today PV solar power is becoming a competitive technology, capable of displacing fossil fuel in some markets even without any government subsidy.

The reason for this advance is not that there are new types of solar panel available. It is that the costs of the existing technologies, both silicon cells and thin film, have fallen because of improvements in the efficiency of the panels and of the manufacturing process.

The global average cost of solar panels dropped by about 70 per cent from $9.70 per watt in 1980 to $3.03 per watt a quarter-century later in 2005, according to Paula Mints of SPV Market Research. It dropped a further 75 per cent over the ten years to 2015, falling to just 75 cents per watt, and the decline is continuing.

Over the period, there have been many attempts to do something radically different in solar power. Solyndra, a California-based solar manufacturing company that collapsed in 2011 after having been lent more than $500m by the US government, has become a byword for the risks of public sector support for politically favoured energy technologies. Solyndra's panels were made using sets of glass tubes rather than the standard flat sheets. The company claimed various advantages including lower installation costs that would offset the greater complexity of its product, but those claims turned out to be overstated.

> In ten years' time, it could be competitive even in cold and grey northern Europe

General Electric thought that with its vast resources and technical capabilities it too could be successful in solar power, and in 2011 planned to enter the market with advanced thin film technology. As panel prices fell, however, GE decided that it could not compete and in 2013 it cancelled its proposed factory in Colorado. It is still carrying out research on solar power, in an alliance with Arizona-based First Solar, but it is no longer looking at becoming a manufacturer.

Part of the explanation for why solar panel prices have fallen so sharply over the past decade is the boom in production in China, which has lower wage costs than the leading producers in Europe, Japan and the US. That boom contributed to massive overcapacity in the world market, putting further downward pressure on prices.

There has also been a steady downward progress in the cost of solar power along a path that is sometimes described as "Swanson's Law", after Richard Swanson, the founder of US company SunPower. As Mr Swanson says, it is a standard learning curve familiar from other industries: each time the total volume of solar panels that has been produced doubles, their cost drops by 20 per cent.

The latest manifestation of that is the increasing automation of manufacturing processes in the industry.

SolarCity, the US residential solar company chaired by Elon Musk, in 2014 bought a PV specialist and manufacturer called Silevo and announced a plan to build a large new factory in Buffalo, New York. One of the reasons that plan is viable, the company has said, is the automation of production.

Increased automation is a feature of new investment in solar manufacturing worldwide. As global excess capacity for module production shrinks, some manufacturers have been announcing plans to build new factories in countries including Malaysia, Thailand and India. Automation is one of the principal means by which they are aiming to hold costs down.

The other important trend driving solar costs is the efficiency of the panels. For a given panel cost, converting more solar energy into electricity means cheaper power. First Solar, for example, has achieved big improvements in the efficiency of its thin film panels.

In the first quarter of 2011, the average efficiency of the panels it produced was 11.7 per cent, representing the proportion of the solar energy hitting the panel that it puts out as electric energy. Last year, it reported that it had developed a model with 18.6 per cent efficiency, a record for cadmium telluride thin film modules.

Solar power is most economic in countries that have a lot of sunshine. But industry executives predict that in ten years' time it could be competitive without subsidy even in cold and grey northern Europe, through continued improvements in the existing technologies. Given the record of the past decade, it would seem rash to bet against it.

Researchers seek artificial route to harnessing solar

Photosynthesis Academics point to a commercial future for nascent energy source, says *Mike Scott*

The world is now used to the idea of generating energy from sunlight — the installed capacity of photovoltaic solar panels passed 200 gigawatts in 2015 — but PV is only part of the story when it comes to harnessing the sun's power.

"Many people mix up energy and electricity. Only about one-sixth of energy comes from electricity, the rest is in the form of fuels," says Professor Leif Hammarström, chair of the Solar Energy Platform Sweden. "Renewable electricity needs to be complemented with renewable fuels."

For many people this means biofuels but the more obscure field of artificial photosynthesis received a high-profile boost at the recent Paris climate talks when Microsoft co-founder Bill Gates praised its potential at the launch of his Breakthrough Energy Coalition. "If it works, it would be magical," he told reporters at the conference.

"We're accustomed now to the idea that we can create electricity from sunlight but there's a problem with that — electricity still can't be stored," says Professor Harry Atwater, director of the Joint Center for Artificial Photosynthesis, a collaboration between five research institutes in California. "Artificial photosynthesis enables the direct conversion of sunlight into chemical fuels, which means storable solar fuel."

Natural photosynthesis is the process by which plants take CO_2, one of the key greenhouse gases causing climate change, from the atmosphere and create the precursors of starch and sugar, with the addition of water, Prof Atwater explains. Humankind already takes advantage of this process to produce low-carbon fuels in the form of biofuels, but, says Prof Atwater: "Natural photosynthesis is not optimised for efficiency, it's optimised for the sustainability of plants. We have a biofuel infrastructure but its efficiency is capped by the efficiency of natural photosynthesis, which only converts about 1 per cent of the sunlight into fuel."

He adds: "If we turned all of the available arable land in the US over to biofuels production, we still wouldn't produce enough fuel to run the American vehicle fleet. We can't go carbon-free using traditional biofuels."

In the pursuit of developing artificial conversion of sunshine into chemical power, researchers have been able to build and operate integrated solar fuel generators that split water to produce combustible hydrogen with an overall efficiency of 10 per cent. By adding CO_2 to the mix, it is also possible to make hydrocarbons that can be made into fuels, chemicals or plastics, although this demands chemically more complex techniques.

As the field develops, decisions will need to be made on whether to focus on producing hydrogen or hydrocarbons such as methanol.

"The scientific maturity of splitting water [to produce hydrogen] is greater and some people think we should focus on hydrogen but that would require building a hydrogen infrastructure that does not yet exist," says Prof Atwater.

Advocate: Bill Gates praises potential

"One of the attractive things about making methanol is that there is already a 95 per cent efficient process to turn methanol into gasoline, so if we have a carbon-free source of methanol we can create low-carbon gasoline pretty easily."

The other benefit of producing hydrocarbons is that CO_2 captured from power stations and industrial facilities could be used as a feedstock, creating a new market for gases and thus making carbon capture and storage more viable.

"If we wanted to preserve the current fuel infrastructure, we would probably want to make hydrocarbon fuels," Prof Atwater adds. "JCAP has just changed its focus from hydrogen production to directly making hydrocarbons."

Both Profs Atwater and Hammarström are quick to point out that the technology remains in its infancy, even though research has been going on since the 1970s. "At the moment, we don't have an artificial photosynthesis industry," Prof Hammarström says. "Current devices are expensive and don't last long enough but we have shown that it works — it is no longer just an idea."

"It's been really exciting to see the tremendous growth in the field in the last five years, in countries ranging from the US to Korea, Japan and China," he adds.

The field is starting to attract some of the world's biggest companies — Shell and Total are members of the Solar Fuels Institute based at Northwestern University in Chicago.

Siemens researchers are working with universities in Switzerland and Germany on developing catalysts that will help to produce hydrocarbons.

> 'We have shown that it works — it is no longer just an idea'

The first commercial products made using artificial photosynthesis are likely to be speciality chemicals rather than fuel as these are more expensive and so the technology is more likely to be competitive. "I think we are in the same place we were in 1985 with PV. Solar panels were more than $100 a watt. Now they are $0.50 a watt. There is a real opportunity here," says Prof Atwater.

US vehicle fleet needs to plug in to shale gas glut

OPINION

Yossie Hollander

The fracking revolution is still largely misunderstood by the oil and gas industry. It helped the US attain a measure of independence from imported oil but even today we import about 6.5m barrels a day, equivalent to one-third of US consumption.

However, the current low price of oil is making many shale operations unprofitable, causing massive lay-offs and threatening to bankrupt many companies in the oil patch. US oil production is declining again.

Here is where oil and gas companies get it wrong. The fracking revolution is not about oil; it is about natural gas and natural gas liquids such as ethane and propane.

Most fracking wells produce more hydrocarbons, in the form of natural gas and natural gas liquids, than oil.

That is one of the main reasons the price of these energy sources has collapsed. In many cases, the wells have been shut down, or the excess of these gas and liquids are flared, or burnt off, into the air.

The solution is to use them in the transportation sector, specifically to turn natural gas into alcohol fuels to run millions of vehicles that are already on the road. This will increase the revenue from each fracking well and the industry will become profitable at oil-price levels under $50 a barrel.

The US is awash with natural gas. Last year, the average Henry Hub price per million British Thermal Units — the standard industry benchmark for gas contracts — was $2.61. This was equivalent to about a third of the of cost of oil calculated by the calorific measure over the same period.

However, in the most important shale-oil regions the price is even as low as $1.

The price of natural gas liquids is much lower still and is often measured in cents. Sometimes it turns negative.

Much of this resource continues to be unexploited. In 2014, drillers flared 288.7bn cu ft of gas, compared with 91.2bn in 2000. That amounts to more than $10bn worth of natural gas simply wasted.

Of course, cheap natural gas has become a favoured fuel for power generation as coal-fired plants are slowly phased out. But the transition is costly and time-consuming. Even if natural gas reached 100 per cent adoption (something that is not likely to happen in the next two decades) it would only replace $28bn of coal-related costs a year.

The largest opportunity is to replace $135bn worth of imported oil a year, or more than $300bn of oil used overall, largely in the transportation sector.

Natural gas has been used as a vehicle fuel for years, in compressed form known as CNG. It is mostly used in larger vehicles such as refuse trucks and city buses. The fuel is an ideal replacement for the diesel market and should grow in the coming years.

But it is not a solution for the gasoline or petrol markets. Passenger vehicles that run on CNG cost thousands of dollars more than their gasoline-powered counterparts. Conversions of the current fleet are similarly expensive.

Even so, there are 250m gasoline cars, trucks and SUVs on US roads today that could potentially run on alcohol fuels like ethanol and methanol.

Pump up the volume: the use of E85 fuel needs to be expanded on station forecourts

Most ethanol in the US is derived from corn. However, ethanol could also be produced from natural gas at prices much lower than gasoline. Methanol, for example, is already made from natural gas.

As part of taking economic advantage of low commodity prices, the conversion of gas could be done close to the wellhead and, once converted to liquid, there would be no need to expand pipeline infrastructure to transport it.

The most convenient aspect of fuel derived from the conversion of natural gas to alcohol is that it can be used immediately in more than 19m flex-fuel vehicles already on the road.

These are factory-built to use any combination of gasoline or ethanol blends up to E85, the specification for a fuel blend containing 85 per cent of denatured ethanol fuel and 15 per cent gasoline.

Additionally, tens of millions of other gasoline-only vehicles could potentially be modified to run on alcohol fuels simply through software changes to the on-board computers.

There is no need to wait decades for a new fleet of high-tech vehicles, or massive taxpayer investment, to bring alcohol fuels based on natural gas to market.

The current US fleet is ready to consume cheaper fuels, as shown by the many E85 stations in the country that earn higher revenue and margins on their ethanol-based E85 fuel sales than gasoline.

All that is needed to make this a reality is the will, and the vision, to diversify our transportation fuels market.

The result would be an entirely new revenue source for oil and gas companies, increased employment, a reliable, cheaper price for consumers and a stronger and safer US economy that keeps more of its fuel expenditures at home.

The opportunity is right beneath our feet.

Yossie Hollander is co-founder of the Fuel Freedom Foundation and founder of Our Energy Policy Foundation, a non-partisan group that promotes fuel choice in the transport sector