Engineering the Future

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The world struggles to keep up

The rate of innovation outstrips our ability to make sense of it all, writes *Peter Marsh*

Illustration: Hitandrun Media

Among the many champions of their own specific area of science and technology, at least Jennifer Holmgren, chief executive of Lanzatech, has something to shout about.

The Illinois-based company is developing a chemical treatment capable of turning the carbon-rich waste gases of many industries into valuable chemicals and fuels.

Ms Holmgren estimates that if all the waste gases of the global steel business alone were treated using her company's process, the world would instantly find a way to create a fifth of the annual fuel requirement of the global aircraft fleet.

The Lanzatech technology "challenges our perceptions of waste and will have a game-changing impact on the way we think about commodity sourcing and supply", Ms Holmgren says.

The ideas under development at Lanzatech are just one instance of the range of technology-based concepts that look capable of transforming people's lives over the next 30 years. The statistics behind the trends are impressive.

This year, according to projections by Battelle, the US science and technology development group, the world will spend about $1.6tn on research and development in a range of engineering-related disciplines from robotics to social media.

The numbers of people working in technology-related research now stands at more than 7m, with growing numbers in countries such as China, India and Brazil that have only in the past 15 years started to register in the top league of technology.

Many of the world's most exciting companies have engineering innovation at their heart. They include not just the obvious names such as Google and Apple in the US, but less well known concerns such as Coloplast, a Danish leader in wound and surgical care, Essilor, a French company that is the world leader in making personalised spectacle lenses and Keyence of Japan, a specialist in industrial equipment.

Then there are fairly small businesses – set up in recent years to explore novel areas of science and technology – that have barely registered in the corporate universe but offer great promise. Examples include DNA2.0 and Genome Compiler, two US-based pioneers in synthetic biology, and Roli and Sugru in the UK, which are exploiting ideas in electronics-based musical instruments and synthetic chemicals, respectively.

How can we work out the impact of this great mass of technology development?

On the one hand, there is a school of thought that denigrates today's level of innovation as rather marginal by comparison to some of the big changes of the past. This is based on the idea that the product breakthroughs of the early 21st century – summed up in the popular imagination by people putting photos on Facebook or using the internet to control domestic appliances – look feeble when put alongside the invention of the steam engine or the advent of electricity generation.

But equally vehement are those experts arguing that the wealth of activity, often involving collaboration of researchers in many parts of the

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Manufacturers lament lack of engineers

UK skills shortage

Companies are turning to other countries to fill the gap, says *Henry Foy*

Andrew Churchill just can't get the staff.

The managing director at JJ Churchill, a British gas turbine blade manufacturer, has spent the past three months trying to hire 26 employees.

But, as £800,000 worth of new machinery sits idle in his production plant, waiting for engineers to start operating it, he has so far only managed to find 13, at a substantial cost in time and money.

"The skills shortage is the biggest growth constraint for manufacturing in the UK, for sure," says Mr Churchill. "If you cannot get the skilled people to build the products in the first place, all the other worries are irrelevant."

It is a lament heard loud and clear across the UK's manufacturing industry. Employers report that a chronic shortage of skilled graduates and school leavers is the biggest impediment to growth, and risks derailing the government's ambitions to rebalance the economy towards manufacturing and away from finance.

"If we are looking for an aerospace engineer, for instance, we will be extremely unlikely to find one," says Mr Churchill, who employs fewer than 140 people. "We will search, and search, and search, and find nothing."

In a recent report, the Institution of Engineering and Technology (IET) wrote that a lack of people with engineering and science knowledge is "a potentially severe constraint" on the growth of manufacturing output in Britain.

The IET, a global engineering trade body, warns that smaller companies unable to afford to train employees internally may suffer if the deficit is not addressed. The shrinking pool of engineering talent will be mopped up by rising demand from larger, better capitalised manufacturers.

EEF, the UK's manufacturers' association, believes four out of five British manufacturers are struggling with recruitment, with two out of three citing a lack of technical skills.

However, it is not only smaller manufacturers that are struggling. Dyson, one of the UK's most prominent manufacturers, fears it will not be able to fill its 3,000 vacancies over the next decade. "I have no idea where these engineers are going to come from," founder James Dyson wrote in the Financial Times.

He said his company had trebled its headcount of UK engineers in the past three years, but has "hit a wall" in terms of finding fresh talent.

"Skills shortages in the advanced manufacturing and engineering industries are at crisis levels," says Jo Lopes, head of technical excellence at Jaguar Land Rover, the UK's second-largest carmaker.

JLR is luckier than most. Its brand clout and position at the top of the automotive food chain mean it typically gets to choose the best graduates available.

But the company still struggles to fill crucial roles. JLR had 26,000 applicants for 340 graduate positions last year. While 75 per cent of the jobs were in engineering, only 19 per cent of applicants wanted to be engineers. And only a small minority of those had the right skills.

JLR fills the gap with employees from outside the UK, and works with secondary schools to encourage young children to become interested in a career in engineering.

> 'If we are looking for an aerospace engineer, we will be extremely unlikely to find one'

Because of the shortfall at its UK factories, JLR has been forced to send work overseas to better equipped and better staffed suppliers.

Mr Lopes says: "Significant progress is yet to be made in addressing the issues that have been around for a number of years."

Executives say that the government is only just waking up to the shortage, and warn that Britain risks losing its core manufacturing base and smaller supply chain companies unless the disconnect between demand and supply is corrected.

Last month, the UK government launched 'Your Life', the latest initiative to promote so-called Stem subjects (science, technology, engineering and mathematics) among young people.

Only about 32,000 16-year-olds study physics in the UK, according to government data, a steep fall from the 150,000 that study the subject at earlier ages, before they must specialise.

"We have got some systemic problems on the teaching side," says Mr Churchill. "I think the government is beginning to understand what the problem is, and that has come from successes in our rival countries, such as Germany." He adds that JJ Churchill spends about 30 per cent of a new employee's first year salary filling each role.

The coalition government, which has made increasing manufacturing's share of GDP a primary economic objective, has earmarked £400m to promote science and engineering courses at UK universities, and has built a dedicated training facility for apprenticeship schemes.

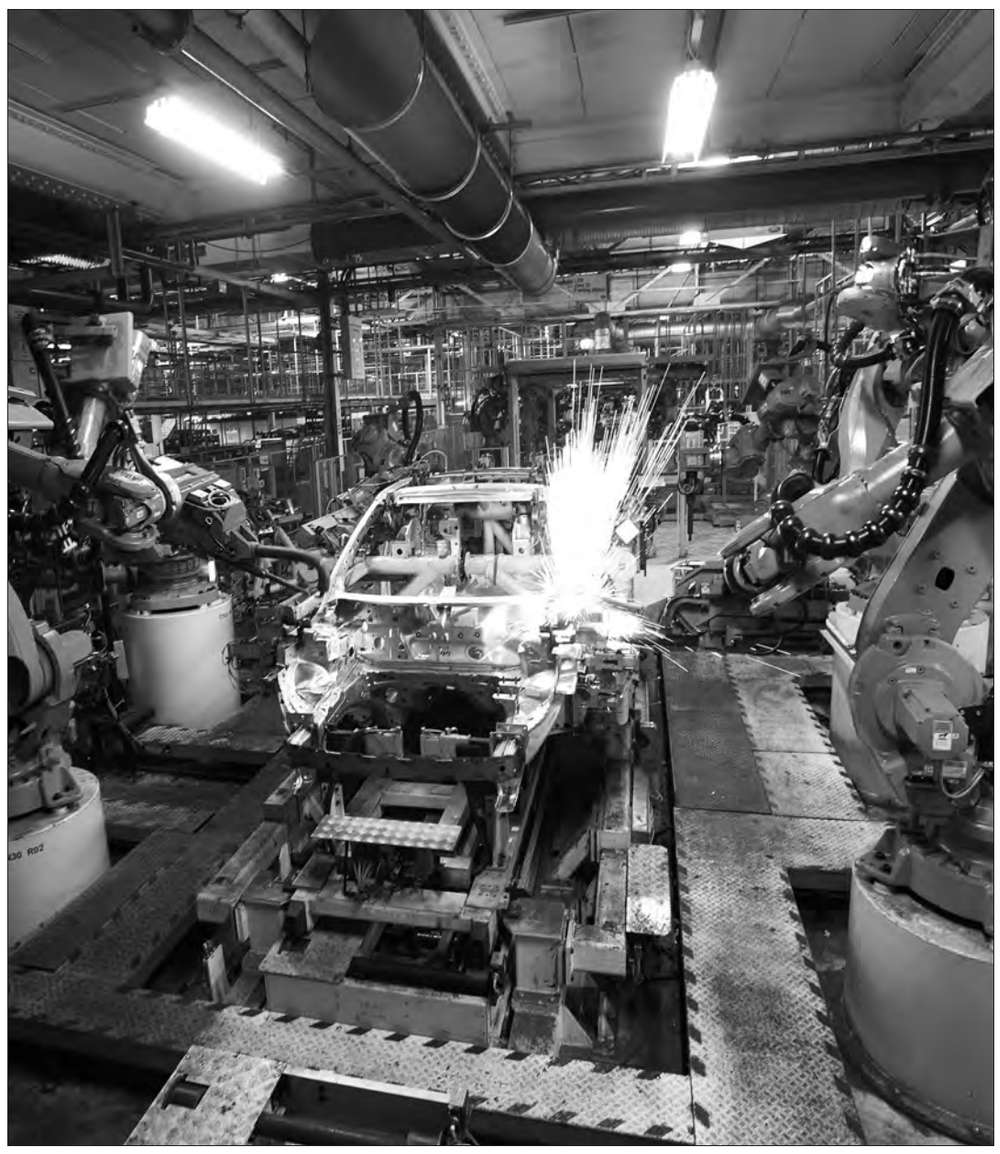
It is also working closely with large employers such as Airbus and BMW to develop strategies for increasing the number and efficiency of engineering apprenticeships, which numbered 140,000 last year.

But, despite the extra attention, employers in the sector still think that young students are not being educated enough about the opportunities in manufacturing, and are instead steered towards industries such as finance and services.

"It is a perennial problem. The basic skills are still lacking," says Margaret Wood, chairwoman of ICW, a specialist glass manufacturer. People are turning away from the practical applications. I set this business up 22 years ago, and I still put my overalls on."

Consumers and regulators drive flexible production

Automotive Companies need to produce tailor-made vehicles at mass-market prices in order to stay competitive, reports *Henry Foy*



Future proofing: using aluminium has created the need for a new suite of robots at Jaguar Land Rover
Bloomberg

At Toyota's factory in Burnaston in the English Midlands, two models, each in two versions, with 10 choices of engine and 120 configurations roll down the same production line, through the same assembly stations.

Not that you would know that each car is different.

Autonomous delivery trolleys make sure the right components are brought to each assembly station seconds before they are fastened, screwed or placed into the right vehicle. Intelligent drills ensure the right torque is applied to the right bolts.

There are no red doors being closed on blue cars. The various cars roll smoothly along and off the line as if they were identical.

The business of building cars has never been so complex. Ever-advancing engine, communication and entertainment technology, pressure from consumers to provide myriad bespoke design options, combined with subtle differences in global standards mean factories need to cater to hundreds of thousands of permutations for every model.

And with the advance of revolutionary concepts such as electric cars, which require complete redesigns of vehicle dynamics, and the widespread use of new materials, such as aluminium and carbon fibre, factories are being forced to become smarter than ever, or be left behind.

"You are seeing big changes in the industry, and all the [manufacturers] are driving it," says Ray Schappert, global director of product management at PPG, a supplier to almost all the world's car factories. "We need to be a step ahead of them, because when they want it, we need to have it on the shelf."

Regulation and environmental concerns are the root cause of the bulk of the disruption.

New means of powering cars, such as electric motors, hydrogen fuel cells or hybrid engines that combine combustion with batteries have made carmakers tweak their factories to integrate new assembly stations into their production lines.

And more fundamentally, new materials that make cars lighter, and thus more efficient, are forcing carmakers to redesign their plants and the basic techniques they use to build vehicles.

British carmaker Jaguar Land Rover's most advanced models are made from aluminium, not steel, meaning that the panels are riveted together, not welded, calling for a whole new suite of robots.

Ford, which is also going to make its best-selling F-150 truck out of aluminium, has been forced to shut two factories for a total of 13 weeks in order to refit them to adapt to the new metal, and the changed assembly processes.

"There is a serious level of complexity, and these new technologies that are being introduced are moving people out of their comfort zone," says Mr Schappert. "Joining aluminium panels together, for example, is not as easy as joining steel together. They need to think a bit differently."

But some carmakers are also making things more complex for themselves, trusting new flexible and reactive production lines to deliver tailor-made vehicles at mass-market prices.

General Motors says there is a "virtually unlimited" number of permutations customers can choose for their small Opel Adam city car, which starts from £12,000 in the UK.

Do you fancy paisley-patterned wing mirrors on your pink car? Maybe a yellow steering-wheel and white seats? Select online and the carmaker will build it for you on a production line that can tweak every aspect of the vehicles.

But given the increased complexity, and the resulting increased danger of potential mistakes and recall crises, the most modern car factories track the movement and use of every single part, down to single screws.

Employees register at assembly stations that scan each individual vehicle, and record the catalogue number of every component that is added, so that quality controllers can pinpoint any error down to the drill that was used.

And it is not just the content of the cars that is forcing the automotive industry to rethink the way it manufactures them.

In an average car factory, the paint shop accounts for at least half the energy consumption, because of the huge amount of heat needed to dry the layers of paint in what are essentially ovens.

At BMW's factory in Oxford, England, where the company builds the Mini, a world-first procedure that involves four layers of paint instead of five means the carmaker has reduced its paint shop energy consumption by more than 25 per cent.

PPG has developed paint products that reduce water consumption by car factories, and also can be used on multiple metals, allowing carmakers to run various cars through the same paint shop.

EU should spur invention, not mediocrity

Opinion
JAMES DYSON

A label is a quick informative point of navigation: the good from the bad, the old from the new, the organic from the not-quite-so-organic and the cheap from the pricey.

The EU loves labels. And I suppose, inevitably, I am about to be labelled "eurosceptic", because I am deeply troubled by its forthcoming energy labelling for vacuum cleaners, a grading system which is unfair, unrealistic and – bluntly – unfathomable.

The eurocrats hope its label will guide people towards the most energy-efficient and best performing vacuum cleaners for sucking up dust, debris and Doritos from the floors of Parisian apartments, Ibizan villas and Bradford terraces.

The mission is laudable: 25 per cent of Europe's energy consumption is by households. TVs, washing machines, fridges, coffee machines . . . The list goes on. Vacuum cleaners too.

But an environmental label isn't worth the paper it's printed on unless the machine to which it sticks is efficiently engineered: better performance, fewer materials and less energy.

Otherwise, people simply carry on using energy-hungry machines and mistrust anything claiming to be energy efficient.

EU labelling systems are unscrupulously manipulated: loopholes found and regulation diluted. They become a box ticking exercise that benefits nobody.

Carmakers are known to test fuel efficiency with tape sealed door joints, disconnected batteries and disabled air conditioning – hardly representative of the proverbial journey from A to B, but all 'fair game' according to the EU's rules.

The vacuum cleaner energy label is headed the same way – thanks to a cluster of traditional continental manufacturers unprepared or ill-equipped to innovate.

The EU regulators' 'fair game' in this instance is a dust-free laboratory environment and a box-fresh, brand new vacuum cleaner with nothing to clean for testing against the label's criteria.

The new label rewards manufacturers of outmoded bagged vacuums because, apparently, bags aren't an environmental cost in the eyes of the regulators.

Maybe there are houses in Stuttgart where puffed up and puffed out dusty old vacuum bags are neatly stacked in kitchen cupboards (you know, just in case)? Or perhaps they are repurposed to level uneven Bierkeller tables in Gütersloh?

Clearly, according to the EU, any purpose other than discarding them for landfill. Why reward waste, let alone poor performance in the home?

You'd be forgiven for forgetting the performance problem with vacuum bags, because it's been more than 20 years since the invention of bagless, cyclonic machines.

Vacuum bags are porous. As air is drawn into the machine, dust and dirt fill the bag. Yet all the air has to pass through the bag.

It's a fundamentally flawed design because the bag's pores quickly clog with the dust it is trying to capture, restricting the air so the machine rapidly loses suction.

As it decreases, energy usage increases. And that's precisely what you want a vacuum for – its suction.

Vacuum bags linger in landfill or are burnt – especially the newer plastic ones. The machines in which they wheeze and gasp are prematurely consigned to the scrap heap too. Bags harm the environment and are expensive.

Instead the EU kowtows to industrial heavyweights. Industry and government should work together, but regulation is best when it allows invention to flourish.

The EU must throw down the gauntlet to engineers rather than accommodate the status quo. I'm thinking less contravention of cucumber curvature regulations or the packaging of olive oil bottles, and more the kind of legislation that rewards and inspires those who innovate.

Sometimes industry will drag its feet – in which case politicians will need to be bold and show determination. But engineers must fight their corner too.

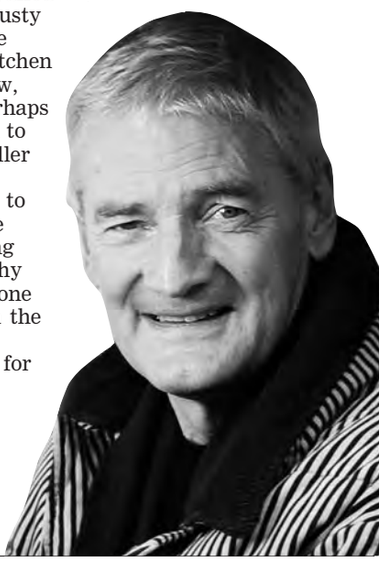
Turning the lights out on incandescent lightbulbs has been a bumpy ride, but the EU decisively backed new technologies. It has opened up a race for engineers to develop ever more efficient Compact Fluorescent Lamps and LED lighting and has spurred a wave of R&D that might not otherwise have happened.

Badges, labels and brands: it's all about conformity and majority rule. Conformity does not spur inventiveness.

Inventiveness – and therefore progress – is stifled when systematic.

Brussels, by all means set challenges and parameters, but please do not create sustainability legislation that rewards sustained mediocrity and waste.

Dyson is taking the EU to judicial review at the European courts over the legislation, which becomes compulsory from September



Clean sweep: EU must not allow labelling system to be 'gamed'

The world struggles to keep up with the pace of change

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world working across multiple scientific disciplines, is leading to a huge number of important advances.

"Those who claim there are few options for important innovations strike me as suffering from a failure of imagination," says Benjamin Jones, a professor at the Kellogg School of Management at the US's Northwestern University.

Richard Lipsey, emeritus professor of economics at Simon Fraser University in Canada, and an authority on technology trends, is also bullish.

He points to a list of current changes. "We are now seeing artificial limbs that respond to brain impulses as if they were part of people's own bodies; the continuing transformation of personal interactions, revolutions and politics through social media.

"Then, there is the fact that we are probably the last generation of people who will die with only the genetic characteristics that they inherited from their parents [and] the end of the two-century-long age of fossil fuels, as they are replaced by solar, geothermal and wind power.

"We have the promise of a nanotechnology revolution that will transform virtually everything that we use; and the ability to learn through scanning technology more about how the brain functions than could have ever have been dreamt of by Sigmund Freud.

"What is feeble about this?"

Shane Greenstein, a management and strategy expert at the Kellogg management school, points to the incremental nature of many technology shifts both today and in the past, in areas from aircraft to mobile phones.

It follows that to have a chance of coming up with a big breakthrough in a product or process, technology developers – in whatever field – have to be capable of building on the great wealth of innovations that have already happened.

This fact is true not just in the areas of technology that often hit the headlines – such as the new manufacturing field of 3D printing or efforts in the energy industry to find novel carbon-free fuels – but in supposedly more mature fields such as steelmaking.

Greg Ludkovsky, head of R&D at ArcelorMittal, the world's biggest steelmaker, says the step-by-step nature of change in his sector is still capable of having a big impact.

He reports "unparalleled improvements" in engineers' ability to create new forms of steel, or improve ways of making it. These include making the substance lighter and stronger and so of greater use in customer businesses from cranes to cookers.

"At the moment, we [at ArcelorMittal] are developing some 100 products for the automotive industry alone," says Mr Ludkovsky.

For all this weight of activity, measuring what is going on in either social or economic terms – and also working out which countries are ahead of others – is fraught with difficulty.

David Rejeski, of the Woodrow Wilson International Center, a US think-tank, says: "The essence of [technology] disruption is how difficult it is to perceive, let alone measure."

When economists and statisticians resort to customary measurement methods, such as counting patents or R&D spending, or looking at productivity data, these techniques normally provide only a partial picture, according to Prof Josh Lerner, head of the entrepreneurial management unit at Harvard Business School.

> $1.6tn
> **Global spending in 2014 on engineering-related R&D**

He points out that patents and research spending count only the "inputs" to the innovation process rather than what most people are interested in: "outputs" or actual results.

Meanwhile, most studies of productivity rely on measurement of how prices of goods and services affected by information technology have changed over time, an area strewn with statistical minefields.

The sheer pervasiveness and complexity of technology make it hard to unravel the effects of single or even multiple lines of technical development, according to Kenneth Carlaw, an economist at University of British Columbia in Canada.

Prof Carlaw uses an example from the automotive industry to make his point.

"What is the marginal contribution of a car tyre? The whole car cannot move without the inflated tyre. Now consider the same scenario without a driver, or with no steering-wheel, or fuel. Each of these marginal contributions plays a part in providing the overall transportation service.

"But each contribution may not be measurable, because it is tied to all the other technologies that are important."

It appears that – for all the level of technology change and interest in the power of engineering to create radical shifts in how the world works – the ability of humans to make sense of it all may not be increasing at the same rate as innovation activity overall.

Now you can print your own robot

Trends Advanced technologies are entering the mainstream, writes *Tanya Powley*

From using 3D printing in reconstructive facial surgery to employing robots to look after the elderly, a new wave of advanced technologies has entered the mainstream.

3D printing, or additive manufacturing, may have been around since the 1980s, but it is only in recent years that advances in the technology have helped it play a bigger role in both industry and consumer markets.

The global products and services market for 3D printing, which is used to make everything from plastic figurines to complex parts for jet engines, rose 34.9 per cent to $3.07bn in 2013, according to a report by Wohlers Associates, a 3D printing consultancy.

This was its highest growth in 17 years, adding to expectations that the technology could unleash a new industrial revolution.

"The industry is experiencing change that we have not seen in 20-plus years of tracking it," says Tim Caffrey, senior consultant at Wohlers. "What's most exciting is that we have barely scratched the surface of what's possible."

Medical businesses are using the technology to design highly personalised products, such as hearing aids and dental implants.

In March, surgeons at Morriston Hospital in Swansea used pioneering surgery, with a series of 3D printed parts, to reconstruct the face of man who had been in a serious motorbike accident.

While manufacturers have long used 3D printing to make plastic prototypes and products for testing, several of the world's biggest companies are leading the way in moving the technology from design shop to factory floor.

New techniques, involving the use of lasers to melt metal powders, are enabling manufacturers to build complex shapes from metals such as titanium or aluminium.

Boeing currently prints 200 parts for 10 aircraft platforms, while GE is using 3D printing machines to make fuel nozzles for jet engines. Those fuel nozzles used to consist of 18 parts but now comprise a single piece, making it up to 25 per cent lighter. By 2020, it expects to have made 100,000 3D printed fuel nozzles.

Support services: robotics is moving from industry to everyday life

If 3D printing is having something of a moment, then robotics is enjoying a bigger one.

Robots may have so far failed to take over the world – a vision put about by science fiction writers – but technology developments are now resulting in big advances.

For the past 50 years, robots have been a mainstay in manufacturing sectors such as automotive, where big caged-off machines are used to perform dangerous and dirty jobs such as welding and heavy lifting.

But, as smarter technology takes hold – with developments in machine vision, mobility and artificial intelligence – robots are starting to come out of the safety cage and work side-by-side with humans. This is opening up new robotic markets.

Robots are being used in healthcare to undertake delicate surgery, as well as to drive hospital trolleys used to transport medicines, samples for the lab, meals, laundry, heavy loads and hazardous waste.

A report by McKinsey Global Institute, the consultancy's research arm, has estimated that the application of advanced robotics across healthcare, manufacturing and services could generate a potential economic boost of $1.7tn to $4.5tn a year by 2025, including more than $800bn to $2.6tn in value from healthcare uses.

"The big explosive market for robotics is in services," says Robert Richardson, director of the Leeds EPSRC National Facility for Innovative Robotic Systems.

"Robotics is finally moving from industry into everyday life and that's a big challenge," he adds.

Governments around the world are committing more money to robotics. The EU is disbursing some €1bn, while the UK government has made robotics and autonomous systems part of its eight great technologies initiative.

"It's a lot clearer that there is support for robotics than it was even five years ago," says Rich Walker, managing director of Shadow Robots, a UK-based robotics research company.

But while the potential of both 3D printing and robotics is huge, they are unlikely to cause a massive disruption to industry or everyday life in the immediate future.

3D printing is still being held back by the costs involved – both the machines themselves and the metal and other materials they use remain expensive.

Another problem is machine capability, which limits the use of the technology for mass production.

Meanwhile, advanced robotics also comes with safety concerns. Regulators are still catching up with what are the legal liabilities of robots being let out of their safety cages, which could see regulations being introduced that slow down their development.

The threat these technologies pose to jobs could also hamper progress.

According to McKinsey, policies discouraging adoption of advanced robots – by protecting manual jobs or levying taxes on robots – could limit their economic impact.

Majors may be too big to succeed

Pharmaceuticals

Poor returns have led many drug companies to conclude that 'small is beautiful', reports *Andrew Jack*

As Pfizer eyed a £70bn takeover of AstraZeneca this spring, the prospective deal highlighted an awkward truth for the chief executives of both pharmaceutical groups: neither had a healthy stock of experimental drugs in their own pipelines.

While recent months witnessed a "biotech bubble", with surging valuations for fledgling drug developers on public markets – notably in the US – the broader picture of innovation for new medicines remains disappointing.

Overall, there has been a slight increase in the number of products approved by US and European regulators in the past few years, but the underlying trend is broadly unchanged.

That may partly be because tougher standards have increased the rate of refusals; but the number of applications for drug authorisations has remained all but flat, despite the billions of dollars spent on research.

For a long time, larger drug companies have sought to boost productivity by bringing greater scale to discovery. That has allowed them to invest in costly techniques such as high-throughput screening of new compounds. Many have also sought to buy companies with better pipelines to compensate for expiring patents on the products in their own portfolios. Yet investors have been pushing back against companies' attempts to spend their way out of trouble and continue to invest in "bricks and mortar".

"How do you combine innovation and rapid product development when bringing together two of the largest pharma entities on the globe?" asks Steve Brozak, president of WBB Securities. "It's an oxymoron, like 'military intelligence'."

Jo Walton, pharmaceutical analyst with Credit Suisse, also highlights the poor returns on all the money spent by industry in recent years. When she plots R&D spending against estimated peak sales for drugs that will be launched in coming years, Pfizer ranks among the lowest in the industry. AstraZeneca is not far ahead.

A recent study by SSR, a US-based research firm, shows a similar pattern. The message? Small is beautiful.

Mid-sized quoted biotech companies have generally provided far better returns than their larger peers. Of course, many even smaller – and unquoted – biotech companies fail too.

But smaller scale is an approach that the larger pharmaceutical companies have all sought to emulate as they seek to improve their rates of innovation. Most have restructured round more modest biotech-sized units, giving greater freedom and accountability to scientists.

Francesco de Rubertis, a partner with Index Ventures, a venture capital company, says: "One of the key differentiators between winning companies and lagging ones is the nature of people in decision-making positions. The empowerment of people close to the action, enabling decisions to be taken by those with their ears to the ground, is better."

Bernard Munos, a consultant to industry, praises larger companies such as GlaxoSmithKline and Johnson & Johnson for just such a shift to a more entrepreneurial, small-scale culture, which he says is beginning to pay off with higher numbers of new drug filings.

> To secure the future of drug development, the industry needs to address the issue of affordability

"Some have been successful at producing more and better innovation," he says. "But the industry has not addressed the third requirement to secure the future of drug development: affordability. You need to take a major chunk of cost out of the system."

He argues that as healthcare systems resist the rising costs of new drugs, further disruption – probably driven by companies outside the pharmaceutical industry – is required.

He points in particular to the role of data companies and the use of biosensors to collect far more information on patients as essential factors to improved understanding and more efficient drug development.

Academia and business join forces to improve innovation

Commercialisation

Europe wants to build viable companies from lab discoveries, says *Tanya Powley*

"We need to get away from the stereotype that Britain is full of clever boffins who aren't very good at business," says Vince Cable, the UK's business secretary.

Britain is one of several countries around the world that are pouring government funding into science in an attempt to bridge the so-called "valley of death" – the perilous terrain where scientific breakthroughs are turned into commercial successes.

In 2011, the UK government launched its Catapult network, an elite group of technology and innovation centres modelled on the long-established Fraunhofer Society, a German applied research organisation.

Catapult centres aim to form partnerships with universities and companies to develop research to the point where it can be turned into commercially successful projects.

The government plans to create nine of them over five years with £1.4bn of public and private investment.

So far, it has established seven, with the final two – focused on energy systems and precision medicine – to open next year. The current hubs employ 1,400 scientists and engineers.

In the March budget, chancellor George Osborne committed an additional £220m of funding for science, declaring: "If Britain is not leading the world in science, technology, and engineering, then we are condemning our country to fall behind [other industrialised economies]."

While it is still early days for the UK network, some of the seven hubs have made more progress than others.

The High Value Manufacturing Catapult – which has seven constituents – has already worked with more than 1,000 companies on 850 projects. It employs 1,100 of the 1,400 people working across the UK's Catapult network.

One constituent, the Manufacturing Technology Centre (MTC) in Ansty, near Coventry, plans to launch an industrial design programme next year that will help commercialise research. It plans to pick some of the best ideas from industrial design graduates in the region and help them launch a company in which the MTC will take a small share.

"One in 10 will become a SME, but one in 100 could become the next James Dyson," says Clive Hickman, chief executive of MTC, who previously headed engineering in India at Tata Motors. The scheme will launch in June 2015 with about 20 graduates on the programme. The UK hopes one day to replicate the success of the Fraunhofer Society, which was founded in 1949 and employs more than 22,000 people in 66 institutes. These include some across the world, including the US, Portugal, UK and Italy.

One of Fraunhofer's best-known innovations is probably the MP3 digital music format, developed in the 1980s and given currency by Apple's iPod.

But, despite being home to one of the biggest applied research organisations, Europe has also long had difficulties commercialising university research.

Bert D'Hooghe, policy adviser at the European Round Table of Industrialists, a leading manufacturing lobby group, says the continent needs to invest more in research and development, as well as creating the right framework for innovation activities.

> 'Public procurement [is often used] as a strategic tool to create demand for innovations'

Overall EU R&D spending has remained at about 2 per cent of GDP in the past decade, a long way off the 3 per cent target the EU wants to achieve by 2020.

Mr D'Hooghe points out that one issue has been that EU research has not always been close to the market.

"Other regions of the world for example use public procurement as a strategic tool to create demand for their innovations," he says.

The European Commission is hoping to improve co-operation between academia and business through its Horizon 2020 research and innovation strategy. This aims to inject €70bn into European technology-driven industries over the next seven years.

Policy makers and businesses agree that there is a need to improve the infrastructure of innovation, from nurturing new ideas to financing high-tech start-ups.

Rich Walker, managing director of Shadow Robots, a UK-based robotics research company, says that a big concern for him in the UK is that the "final mile" of funding is not in place for commercialising research.

"Instead, large US companies are buying up early-stage companies, which, of course, means the loss of both the business and the intellectual property assets of the business to the UK," he says.

Governments are trying to address this issue. In April, London mayor Boris Johnson launched MedCity, a body that aims to help London and the southeast compete with US biotech hubs such as Boston and San Francisco.

The aim of MedCity is to bring together universities, businesses and scientists from London, Oxford and Cambridge to promote a so-called "golden triangle", making it easier to connect academics and entrepreneurs with investors.

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Technology for the common man

Award recipients The European Patent Office honours inventors of all persuasions, writes *Brian Bollen*

Professor Christofer "Chris" Toumazou, the first British winner of a prize in this contest since 2008, began his career developing energy-efficient microchips for mobile phones.

At the age of 33, he became the youngest professor ever to teach at Imperial College London, where he focused on ways of combining electrical engineering and microchip technology with biomedicine. He did all this after leaving school at 16 with no qualifications. On the way, he picked up undergraduate and postgraduate degrees in electrical engineering at Oxford Polytechnic, now Oxford Brookes University.

Professor Toumazou's latest invention – a USB stick that decodes a patient's DNA within minutes – puts the ability to unravel the complexities of the human genome at people's fingertips. His decision to delve into the world of genetic disorders came about because his son Marcus has a rare hereditary form of kidney disease.

European Patent Office spokesman Oswald Schröder describes the professor – who won the European Inventor Award 2014: Research category – as someone who thinks outside the box. He is interested in quick results to a practical end.

He wants to make technology available to laymen not to tell them details of their DNA that they will not understand, but to tell them whether, like Angelina Jolie, they run a higher risk of developing breast cancer. He also has a natural instinct for business, adds Mr Schröder.

Professor Toumazou's invention employs small silicon microchips that can identify genetic mutations that determine a person's predisposition to certain hereditary diseases. These portable, low-power devices can analyse data on the spot rather than in a lab. They reflect a shift in emphasis from treating illnesses to preventing and diagnosing them in a targeted manner.

The tests take the form of a so-called lab on a chip – organic semiconductors and sensors that use very small amounts of chemicals to conduct the tests. The chip can be inserted into a USB stick and provide results that are viewable on a computer within 20 minutes.

Mr Schröder describes Professor Toumazou as a "brilliant guy, and a man who wants to interest young people in science and the amazing careers that they could have, in a way that many schools do not.

> A lab on a chip that can conduct tests on the spot

His other research includes cochlear implants for born-deaf children, an artificial pancreas for type 1 diabetics, wireless heart monitors for personalised ambulatory health monitoring pre- and post-operatively, and inventing an intelligent neural stimulator as a drug alternative for obesity.

Professor Toumazou is a Fellow of the Royal Academy of Engineering, a Fellow of the Royal Society and a Fellow of the Academy of Medical Sciences.

Innovative individuals: Christofer 'Chris' Toumazou (left) and Artur Fischer have for years grappled with complex problems. To see how the prize winners were chosen, visit www.ft.com/reports

Artur Fischer, who was born on New Year's eve 1919, is described by admirers as the Edison of his day. One of the world's most prolific inventors, he has more than 1,100 applications for patents and utility models (also known as petty patents), in Germany alone and countless more round the world. These have brought him numerous awards, including the honorary title of "engineer" from the University of Stuttgart. And now the European Inventor Award 2014: Life Time Achievement.

Most of his inventions can be traced back to personal experiences: the photographer who refused to take a picture because of the fire hazard resulting from a magnesium flashlight; the toy construction set he wanted as a child.

Mr Fischer received his first patent in 1949, for the synchronised photo flash. A long list of inventions and patents followed, from cup holders and CD boxes to storage trays and ventilation nozzles.

> The small plastic wall plug transformed construction

His natural flair for business is demonstrated by the way in which he commercialised the toy construction kit he developed as a gift for the children of his clients, says European Patent Office spokesman Oswald Schröder.

The Fischertechnik kit for children was launched in 1964 and became a bestseller. These building-block sets give children a basic understanding of technology and help them develop hand-eye co-ordination, fine motor skills, spatial awareness, logical thinking, and creativity. Because of their precision, engineers used some of Fischertechnik's early products to simulate industrial robotics and build models of computer-controlled production plants.

But it is the small plastic plug that Mr Fischer invented in 1958 that has been produced and copied in every corner of the world, revolutionising the construction industry and bringing him the title king of the wall plug. This wall plug, or screw anchor, allows screws to be fastened in materials that wouldn't usually support heavier objects.

The invention transformed construction and do-it-yourself markets and replaced all previous types of wall plugs. Rivalled only by screws and nails, it is one of the most frequently used building supplies in the world. An estimated 14m wall plugs and anchors are produced every day.

This was only the starting point. Mr Fischer influenced more novel solutions to construction problems, including steel anchors, drill units, chemical fixings and adhesives.

Fischerwerke, the company founded in 1948 by Mr Fischer, a former prisoner of war, now has several divisions, including Fischer Automotive Systems and Fischer Consulting.

"Mr Fischer is an amazing personality, not just as an inventor known for the sheer number of patents but also as a great entrepreneur," says Mr Schröder.

Courtroom victories lead nowhere

Smartphone patents

Lawsuits have cost millions but Apple and Samsung are no closer to a resolution, says *Tim Bradshaw*

When Apple and Samsung returned to the courtroom in April to fight it out over smartphone patents, the stakes seemed higher than ever.

Apple was seeking more than $2bn in damages from its South Korean rival – twice what it was awarded by a jury in the same courtroom in 2012.

But 18 months after that blockbuster verdict, Apple is still no closer to getting its hands on that compensation, as appeals drag on.

And this time, the jury in San Jose, California, was not so sympathetic to Apple's cause. While Samsung was found to have infringed three patents covering the iPhone's operating system, iOS, Apple was awarded just $120m.

"It's a fraction of what Apple sought and probably wasn't substantially more than Apple spent on lawyers," says Mark McKenna, law professor at the University of Notre Dame. "It's hard to imagine that Apple sees this as a real victory."

Richard Windsor, tech analyst with Radio Free Mobile, says the trial "once again exposes the critical flaw of the patent system in its current form . . .

"The legal cycle is much longer than the device life cycle, meaning that by the time an infringement finding can be won, the device is already obsolete and no longer shipping."

Apple has sought an injunction against US sales of Samsung phones that are "not more than colorably different" from the ageing Galaxy S3 and Note 2 devices cited in court, but Samsung has proven capable of designing around infringing features to avoid a block on sales.

In the meantime, smartphone sales have continued to soar. More than 1bn were sold last year, according to researchers at IDC, the market intelligence firm. Samsung's 31 per cent market share was more than double Apple's in the crucial fourth quarter.

Mark Lemley, a professor at Stanford Law School, says: "We can continue fighting this out piece by piece forever, but it doesn't seem to be having any real effect on the marketplace." He has represented tech clients, including Google, as a partner at the San Francisco firm Durie Tangri.

While the tech giants have been slugging it out between themselves, Prof Lemley says that a common enemy has grown stronger: the litigious "non-practising entities" that hoard intellectual property without using it to create products – better known as "patent trolls".

Apple was sued 59 times in 2013 by trolls, according to Prof Lemley, bringing the total number of open lawsuits against it to more than 200.

In June, Interdigital, a mobile technology patent company, struck a licensing agreement with Samsung worth hundreds of millions of dollars and is pressing Apple for a similar deal.

This approach may have, in part, motivated a settlement between Apple and Google in mid-May.

The two remain arch-rivals in the smartphone wars, responsible for the two dominant mobile operating systems, iOS and Android.

They dismissed all outstanding litigation between them and agreed to "work together in some areas of patent reform".

One person familiar with the agreement says this unlikely alliance is aimed at lobbying governments for greater protection from trolls. Nonetheless, progress in reforming the US patent system remains slow.

However, the lack of a cross-licensing agreement between the two companies, which would indemnify both from future litigation over smartphone patent infringement, was unusual, says Prof Lemley. "It does not look like most of the ways you settle patent litigation."

One tactic may be that the agreement leaves Apple free to pursue Samsung, whose mobile devices use Android.

After the last trial focused on Android software, any broader agreement between Apple and Google might have allowed Samsung to argue that any infringement found in its smartphones was covered by that deal too.

Apple's litigation against Samsung was begun under its late co-founder Steve Jobs, who described it as part of a "holy war" against Android, which he saw as slavishly copying the iPhone.

> 'By the time an infringement finding can be won, the device is already obsolete'

However, competition between the two mobile platforms has remained fierce, with each leapfrogging the other with the introduction of additional features every year.

Refinements to smartphones' hardware may have slowed, but software continues to improve at a rapid clip.

Commentators see some of Apple's latest enhancements in iOS 8 – such as an improved keyboard, cloud services integration and changes in the way apps can communicate with each other – as playing catch-up with Android, while Samsung and Google are still striving to match the iPhone's security, stability, and overall simplicity.

Steve Milunovich, an analyst at UBS, says: "Although the Wall Street view is that smartphones are a mature market, there is plenty of innovation left as regards their use."

"When technologies are new, integration is crucial to user acceptance . . . The iPhone increasingly acts as a digital hub."

Art offers manufacturing fresh perspectives

Creative forces

Tackling problems from a different perspective produces smarter outcomes, finds *Rose Jacobs*

Amy Bernhardt does not exactly fit the mould of America's famed 19th century industrialists: she's an artist and designer with a painterly style; an occasional night-school student; a woman.

Yet the Rhode Island School of Design (RISD) graduate is preparing to revive the once-mighty, now diminished textile industry in the northeastern US by opening a manufacturing facility in Rhode Island.

The operation, funded by a philanthropic grant, will focus on digitally printed textiles and, in particular, on printing technologies that use less energy and water than those employed by the fashion industry.

Why hasn't the fashion industry beaten Ms Bernhardt to the punch? Because, says Rosanne Somerson, RISD's president, the ability to step back from a process and rethink it entirely often requires an artist's mind. "Artists and designers don't just solve problems, they reframe questions," she says.

Art school presidents are not alone in believing that a stronger relationship between art and manufacturing can help post-industrial economies re-embrace, and benefit from, a culture of making.

RISD receives numerous requests every year from companies hoping to team up with students to tackle a particular problem. Recent applicants include Samsung, Facebook, ESPN, a sports broadcaster, and Steinway, the piano maker.

Separately, advanced-manufacturers such as Intel are forging relationships between engineers within the company and artists outside it. And politicians and policy makers are increasingly open to the idea that art education ought to be part of a renewed focus in schools on science, technology, engineering and maths (Stem).

None of this is entirely new: the relationship between art and advanced manufacturing stretches back to Leonardo di Vinci and further.

But Pat Sweet, an engineer with Bombardier who blogs about the profession, believes the link has grown slack, with manufacturers prioritising control and efficiency over dynamism.

That is dangerous, he says, given the level of uncertainty in today's economy. "Uncertainty is born of the expectation that things will change and the level of complexity. The more creative you are, the more likely you'll be able to deal with change."

Ms Somerson agrees: "There are countries and companies with expertise in manufacturing but if they don't put innovation at their heart, they're just responding to a need; and when the need goes away, they're finished".

Hence the recent blossoming of partnerships between industry and art. Intel joined up with Vice Magazine in 2009 to launch a joint media platform, The Creators Project. It was originally meant simply to showcase the work of artists using technology innovatively, says Rebecca Brown, director of media at Intel. But then the company's research division, Intel Labs, got involved, and engineers now tap artists for ideas and advice – seeking out fibre artists, for example, when developing smart-technology T-shirts, or photographers when exploring the structures of bridges. Whether this represents a value-for-money proposition, Ms Brown will only say: "Intel is incredibly focused on results and return, and five years for Intel [the time the programme's been running] is incredibly long."

> 'Artists and designers don't just solve problems, they reframe questions'

The conversation is happening in Europe, too. EEF, the UK's manufacturing association, recently organised a conference in which industry got a chance to learn more about 3D printing and rapid prototyping from a team at the Royal College of Art.

But Phil Brownsword, an engineer and EEF's south-west regional director, thinks this sort of collaboration and a more general embrace of creativity needs to happen earlier in an engineer's career, too. He says of his education: "At no point was I evaluated on how creative I was."

Research suggests that a lack of creativity in education could imperil innovation. A paper published in August 2013 in the Economic Development Quarterly showed that exposure to art and music as a child increased a person's chance of owning a patent. It also suggested the correlation between early exposure to art and an interest in science or engineering is strong. Graduates of Michigan State University's honours college who majored in Stem subjects were "more likely to have extensive arts and crafts skills than the average American", the researchers found.

RISD has tried to foster dual interests by teaming up with nearby Brown University to let students obtain cross-disciplinary degrees. Further afield, it is leading a push called "Stem to Steam" to advocate the integration of art into kindergarten and graduate-school education around the world, and to encourage manufacturers to hire artists and designers.

Pat Sweet says smart manufacturers will not need much encouragement. "Being an artist is about moving people and when engineering is done really well it's not just about filling specifications – it's about making something that will change people's lives."

'Miracle material' prompts huge global spending on research

Graphene

No one wants to be left behind in the race to develop this form of carbon, says *Tanya Powley*

It only emerged from a physics lab in Manchester in 2004, but graphene has already been lauded as the first "miracle material" of the 21st century.

Graphene is a sheet of carbon, one atom thick, which is stronger than steel and conducts heat and electricity efficiently. It promises a range of applications including superfast computers, foldable mobile phones and superstrong aircraft wings.

The race to find ways to commercialise it is on. Governments and companies around the world are pouring money into research to secure their participation in the graphene revolution.

More than 11,000 patents and patent applications have been filed globally.

If one looks at these figures at face value, Asian companies and organisations appear to be winning the race, taking out nearly two-thirds of the patents made to date. Samsung of South Korea leads the corporate pack, with 594 published graphene patent applications, according to Cambridge IP, a UK-based technology strategy company.

Samsung is reluctant to discuss its graphene research and development, but in April the company announced that it had discovered a "breakthrough" method to speed the commercialisation of graphene.

"The new method . . . synthesises large-area graphene into a single crystal on a semiconductor, maintaining its electric and mechanical properties," says Samsung. This could lead to the material being used in commercial devices sooner than expected, but it remains to be seen whether Samsung's breakthrough will give it the lead in graphene-based electronics.

Even companies that are pouring money into graphene research are aware that the wonder material may not live up to its promises.

IBM of the US is one of the five biggest holders of graphene patents, with 276 to date, but one of its leading scientists says graphene needs to go beyond the "euphoria" stage.

Supratik Guha, global director for the physical sciences at IBM, says: "I'm not sliding off my chair with excitement, but it's an interesting material.

"We have world-class results, but it needs to prove itself in terms of differentiating applications."

Mr Guha is more sceptical than some scientists over the ability of graphene to replace silicon as the go-to material for electronics. Graphene lacks something called a "band gap", which other semiconductors such as silicon have that allow it to be switched on and off.

"Somebody needs to come up with a way of figuring out how to open up such a band gap in graphene before we would be interested or excited about it ever being even a candidate to replace silicon," says Mr Guha.

Scientists have warned that it could take another 10 to 20 years before full-scale commercialisation of graphene takes place.

In the meantime, governments are committing more funds to research.

> More than 11,000 graphene patents and patent applications have been filed globally

Both the UK government and the European Union are determined to protect the continent's stake in a material devised in Britain, following concerns about being outpaced by US and Asian competitors.

Some of this concern stems from patent analysis.

The UK has filed just 101 graphene patents to date, while Europe has 772. By comparison, the US has made 1,913 patent applications, says Cambridge IP.

In his March budget, George Osborne pledged further investment, describing graphene as a "great British discovery" and sardonically advocated breaking the habit of a lifetime and develop it commercially in Britain.

The government has invested in a £61m National Graphene Institute, due to open next year in Manchester, with the aim of being "the world's leading centre of graphene research".

This will work with industry and investors to help accelerate commercialisation.

A bigger investment will come from the EU, which last year launched a 10-year €1bn graphene research programme through its Horizon 2020 scheme.