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RURAL BROADBAND

HIGH-TECH LIFEBOATS

INTELLIGENT PROSTHETICS

NEW SHETLAND GAS PLANT

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EDITORIAL

STANDARDS ENABLE MARKET ACCESS

Dr Scott Steedman

Preparing for Brexit means finding solutions to many issues, not least in engineering, that will arise from severing the UK's close links with the EU's institutions and processes. Brexit could mean many things, so it is important to provide an interpretation of what it could mean that helps to secure the best possible outcome for the UK from the EU negotiations.

At a policy level, the Royal Academy of Engineering, on behalf of Engineering the Future, an alliance of the 38 professional engineering organisations, is coordinating advice on Brexit for government, including the question of standards. The Construction and Infrastructure Brexit Group, led by Sir John Armitt CBE FREng, is also preparing detailed statements on codes and standards alongside other issues such as skills, research, procurement and investment.

In my role at BSI (British Standards Institution), responsible for the UK's national standards body, we are concerned over what Brexit will mean for the UK's use of the industry standards system that underpins the single market. Over the past few decades, the UK has become a global leader in the creation and adoption of international and European standards. These standards are often drafted by UK industry experts and certainly influenced through UK involvement. Today, more than 95% of the industry standards that are adopted as British Standards are international or European. Adoption of international standards and the withdrawal of conflicting national standards has created a simple and efficient market structure across the UK, where engineering companies need only look to one single standard on any given issue.

With the right codes and standards, engineering companies can request or supply products or services that meet pre-agreed requirements, for example, in terms of a technical specification, a business process or simply guidance. In engineering, it is increasingly common to rely on consensus-based international standards, which simplifies compliance, enables reciprocal market access and accelerates the use of new technologies and processes.

Economic research carried out by the Centre for Economics and Business Research in 2015, *The Economic Contribution of Standards to the UK Economy*, showed that the most productive sectors (aerospace and automotive) are those that make best use of standards. As the UK seeks new trading relationships around the world, there is a great opportunity for the UK engineering sector to shape its own agenda through the use of codes and standards that drive activity towards British technologies and business practice.

The single market in Europe employs this model. Over time, the industry-led European standards system has reduced the number of voluntary standards that industry might need to use in business across the 33 individual member countries from around 160,000 to just 19,000. It is the most sophisticated market structure in the world. The system is managed by its members, separately from the EU, and is supported by tens of thousands of industry and societal experts.

Most European standards are developed by industry for its own purposes. However, the EU also uses the European standards system to support a range of regulatory requirements by inviting industry experts, through the national members, to propose or develop voluntary standards on particular topics,. The engineering sector depends on these standards for the delivery of its products and services across the domestic, European and international markets.

Post Brexit, UK industry will continue to use these internationally recognised European standards for business. One of the simplest means of securing market access across Europe for the UK is through agreement on non-tariff barriers, particularly standards. In this case, it is likely that engineering experts in the UK will continue to participate in the European standards system, where they can influence the standards their industries need to use – a win-win for engineering.

The commitment by UK experts to the development and implementation of international and European standards has brought huge advantage to the UK's economy, building a platform for investment, trade and innovation. The UK is seen as a thought leader in shaping the specifications, codes and guidance on engineering practices and new technologies used throughout Europe and around the world. In the Brexit negotiations, defining the role of standards will be central to achieving a positive outcome for the engineering sector.

Dr Scott Steedman CBE FREng
Editor-in-Chief

IN BRIEF

AFRICA PRIZE FOR ENGINEERING INNOVATION

Arthur Zang, an innovator from Cameroon, has won the second Africa Prize for Engineering Innovation for his heart-monitoring device, the Cardio-Pad. The invention could change the way that Africans access treatment for heart disease, a critical illness across sub-Saharan Africa.

The Cardio-Pad is a small tablet device that allows any healthcare professional to perform heart diagnostics at any location. These diagnostics, sent to a cardiologist via a mobile phone network, can be interpreted in less than 20 minutes and enable the cardiologist to discover, monitor or rule out a heart condition. As cardiologists are often located in big cities, the device will reduce the number of expensive trips that people living in rural areas will have to take.

Zang's innovation earned him a prize of £25,000, and three other finalists each received £10,000 to support their businesses in the fields of health technology and access to energy.

Eddie Aijuka from Uganda created Kamata, an electricity-theft-prevention device that attaches to a household power supply and alerts authorities and cuts it off when the power is tampered with. Felix Kimaru and the Totohealth team from Kenya invented a web-based network that supplies mothers and pregnant women with life-saving information and advice. Matt Wainwright and the Standard Microgrid team from South Africa devised an electricity utility-in-a-box that speeds up rural electrification and reduces energy costs.

The Royal Academy of Engineering launched the Africa Prize for Engineering Innovation in 2014 with the aim of stimulating, celebrating and rewarding innovation and entrepreneurship in sub-Saharan Africa. It encourages talented engineers to use their skills to develop solutions to local challenges, highlighting the importance of engineering in improving quality of life and economic development. Twelve shortlisted Africa Prize entrants from nine countries in sub-Saharan Africa received business training and mentoring, during which they learned to develop business plans and market their innovations.

At the awards ceremony in Dar es Salaam, Tanzania, the four finalists pitched their innovations to the judges and audience, who then voted on the most promising engineering innovation. The judging panel was led by Malcolm Brinded CBE FREng, Chair of the Shell Foundation, and included Dr Liesbeth Botha, Strategic Digital Transformation Director at PricewaterhouseCoopers Africa, Stephen Dawson, Chair at Jacana Partners, Dr Moses Musaazi, Senior Lecturer, Makerere University and Managing Director of Technology for Tomorrow Limited, Uganda, and Dr Bola Olabisi, CEO, Global Women Inventors & Innovators Network.

Arthur Zang, winner of the 2016 Africa Prize, with the Chair of the judging panel, Malcolm Brinded CBE FREng

Zang was presented with the prize by last year's winner, Dr Askwar Hilonga, a chemical engineer from Tanzania. As well as winning the Africa Prize, Dr Hilonga's innovation to use nanotechnology to create bespoke filters for safe drinking water was awarded first place in the inaugural Pitch@Palace Africa competition in December 2015.

The Africa Prize is supported by the Shell Centenary Scholarship Fund, Consolidated Contractors Company, the Foreign & Commonwealth Office, Conoco Phillips and the Mo Ibrahim Foundation.

More information can be found at **www.raeng.org.uk/AfricaPrize**

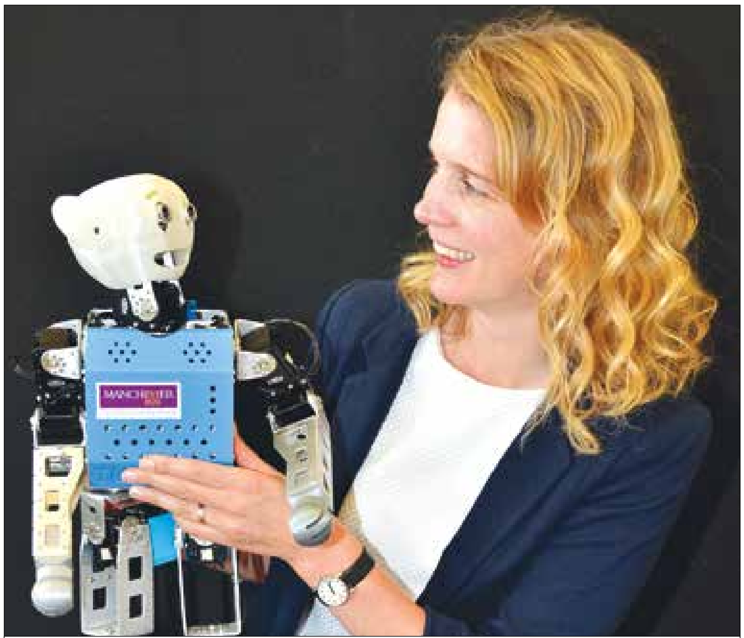
ENGINEERING AWARD WINNERS

In June, the Royal Academy of Engineering's annual Awards Dinner celebrated and recognised a number of engineers who have made a remarkable contribution over the course of their careers.

Professor Danielle George, Professor of Microwave Communication Engineering at the University of Manchester, received the Rooke Award for her outstanding contribution to the public promotion of engineering through her work with various media channels. In 2014, she presented the engineering-themed Royal Institution Christmas Lectures, and has also been a guest on a number of BBC Radio 4 shows, *Start the Week*, *The Life Scientific* and *The Infinite Monkey Cage*, as well as *The One Show* and *BBC Breakfast*. Professor George is also heavily involved in Manchester's position as the European City of Science 2016, leading the Citizen Science and Engineering project (Manchester Robot Orchestra), and bringing together academics, local schools and industry.

The Major Project Award was presented to a team from BAE Systems' AI Labs for its Intermediate Frequency Modem System, which is a key component of the technology used by the Rosetta spacecraft to study the comet 67P/Churyumov–Gerasimenko. It allows the images and scientific data transmitted from the spacecraft to be received and analysed by scientists back on Earth.

The Prince Philip Medal, the Academy's highest individual accolade, went to Dr Jonathan Ingram for his groundbreaking work on BIM (building information modelling). Dr Ingram's work on Sonata, which he wrote and completed in 1985, led to the start of BIM development. Sonata was the first system to have complete current BIM functionality, and has been used by around 1,000 different firms since 1986. In 1992, he also designed and co-wrote Reflex, and later Pro/Reflex. His work on these systems led to the early growth and development of BIM systems.



Professor Danielle George, winner of the Royal Academy of Engineering's Rooke Award, with a member of Manchester's Robot Orchestra
© University of Manchester

The Awards Dinner took place on 23 June at the Pavilion at the Tower of London. The winner of the MacRobert Award, Blatchford (see page 34), and the three Silver Medallists (see page 39) were also announced.

LIVING WITHOUT ELECTRICITY REPORT

In May, the report *Living without electricity* was published by the Royal Academy of Engineering, Lancaster University and the Institution of Engineering and Technology (IET). The report detailed the loss of most modern infrastructure in Lancaster for four days in December 2015, caused by flooding in north Lancashire and Cumbria. These 'cascade failures' were the subject of a workshop at Lancaster University to explore what lessons could be learned from the city's experience. Attended by local and national service providers and government representatives, the workshop considered how the UK should prepare for such events in a society that is becoming more and more dependent on electronic and digital infrastructure that is reliant on electricity supply.

The report, authored by Professor Roger Kemp MBE FREng, outlined the balance that needs to be struck between ensuring sufficient resilience in national and local infrastructure and the need to ensure that it remains practical, efficient and affordable. It provides both a warning and advice to a range of audiences: national and local planners, utilities, emergency services, local authorities, transport operators, and the retail and banking sectors.

To read the report in full, please visit **www.raeng.org.uk/livingwithoutelectricity**

NEW SCIENTIST LIVE

Between 22 and 25 September, *New Scientist* Live will take place at ExCel London. The event will have exhibitions, demonstrations and speakers across four immersive zones covering technology, earth, the cosmos, and brain and body.

The Royal Academy of Engineering stand will focus on how close we are to emulating superheroes and their enhanced human counterparts, with exhibits including state-of-the-art prostheses, smart materials and superhero helmets.

Ingenia readers can get an exclusive discounted rate on tickets. Tickets for Thursday or Friday are £20, saving £9 per ticket on the door rate, and tickets for Saturday or Sunday are £22.50, saving £6.50. Quote RAENG16 on the booking page at www.newscientistlive.com or call 0844 581 1295.

THE UK STEM EDUCATION LANDSCAPE

In May, the Royal Academy of Engineering published *The UK STEM education landscape* report, providing a useful summary of the key issues affecting engineering skills today. It highlights that many young people are not studying STEM subjects beyond GCSE, despite over 10 years of activity from more than 600 organisations encouraging them to do so. Of the 650,000 school students who take GCSEs each year, only around 30,000 then study A-level mathematics and physics.

The report underlines the need to coordinate organisations wanting to engage with schools so that they create a coherent, high-quality programme that provides young people with clear signposts for their further study. It also sets out the factors affecting involvement and interest in engineering beyond age 16.

Professor Richard Clegg, Chief Executive of the Lloyd's Register Foundation who commissioned the report, said: "The Academy's report highlights just how complex the STEM education landscape is and how difficult it is for many organisations to engage with an issue that is so important to our future prosperity. Inspiring the next generation, and widening access to skills and education for STEM careers, sits at the heart of the Lloyd's Register Foundation's charitable purpose. I hope that, in having undertaken this study, we in the community now make a concerted effort to work together and coordinate our activities to maximise the impact of our engagement with young people in schools and colleges."

The report can be found at **www.raeng.org.uk/stemlandscape**

***The UK STEM education landscape* report calls for future initiatives in STEM education to be better coordinated**

BRIDGE BUILDING IN RWANDA

The new Tubungo Bridge was built in just over a week but will have a lasting impact on the local communities' lives

Engineers from Flint & Neill and Balfour Beatty have built a 48-metre-long suspension bridge in Rwanda that will benefit more than 10,000 people.

Partnering with not-for-profit organisation Bridges to Prosperity, the bridge building team, consisting of 10 engineers from the two companies and many community volunteers, has replaced an unreliable and unsafe crossing over the notoriously dangerous Mukungwa River in Tubungo, Rwanda. The new bridge will provide the communities on both sides of the river with greater access to schools, health centres and markets, increasing economic opportunity and reducing rural isolation and inequality.

Ian Firth, Flint & Neill Director and Bridges to Prosperity Trustee, said: "To think that something as straightforward as a piece of pedestrian infrastructure can positively impact on the livelihoods of thousands of residents in a small, developing community is remarkable."

This is the second Bridges to Prosperity project that the team from Flint & Neill and Balfour Beatty has worked on. The organisation works with communities worldwide to build footbridges over impassable rivers to provide access to healthcare, education and markets.

UK STUDENT WINS INTERNATIONAL ENGINEERING PRIZE

Brad with his award-winning innovation at the International Science and Engineering Fair
© Rod Edwards

A student from the UK has won a prestigious engineering award at the International Science and Engineering Fair in the USA for his innovation to prevent rivers from silting up.

Brad Stalker, a 17-year-old student at Energy Coast University Technical College (UTC) in Workington, Cumbria, won third prize in his category after competing alongside more than 1,750 students from 76 countries. He was one of just two UK students at the competition in Phoenix, Arizona.

Brad's winning project was based on a real-world problem. After his friends in nearby Cockermouth were forced to leave their homes because of flooding, he designed and manufactured a 3D-printed, scalable bioplastic device to upset the sediment in rivers and prevent silting.

Rod Edwards, Chief Executive of the Young Engineers charity, said: "Being awarded this prestigious prize really is excellent news for both Brad and the Energy Coast UTC. To be selected to represent the UK in Phoenix was an outstanding achievement, but to win an award against such stiff global competition was truly amazing. Brad is a fine example of the power of the UTC concept; he solved a genuine real-world problem with an innovative, well-engineered solution."

Brad and Sud Sivaneswaran, from Sutton Grammar School, London, were chosen to represent the UK at the Young Engineers National Finals in March. Their trip to the USA was sponsored by the Worshipful Company of Scientific Instrument Makers, with mentoring from the National Physical Laboratory.

BRITISH ROCKET PROPELS JUNO TO JUPITER

On 5 July 2016, the US space agency NASA successfully put its Juno satellite into Jupiter's orbit. It was propelled there by a LEROS 1B rocket engine designed and built by UK company, Moog UK Westcott.

Having left the Earth five years ago, the probe had to fire its rocket engine to slow its approach to Jupiter and enter its gravity. Firing the engine was risky as no previous spacecraft had ever passed so close to the planet because its intense radiation can destroy unprotected electronics.

With Jupiter approaching, Juno's main computer commanded the engine's oxidiser and fuel valves to open, allowing the pressurised propellants to flow into the combustion chamber. The ensuing spontaneous ignition established the combustion process and the propellants continued to burn for approximately 35 minutes; the braking effect allowed Jupiter's gravity to capture the probe and for it to enter into the planet's orbit.

The orbit insertion has put Juno in a large eclipse around the planet that takes just over 53 days to complete, and a second burn of the rocket engine in mid-October will tighten this orbit to just 14 days.

The spacecraft is being used by scientists to sense Jupiter's deep interior as they believe the structure and chemistry of its inside will allow them to discover how the planet formed more than four billion years ago.


An artist's impression of the Juno probe being launched into Jupiter's orbit
© NASA

HAVE SOMETHING TO SAY?
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LETTERS

ASSURING SAFETY AND SECURITY IN RAS

Professor David Lane CBE FREng makes a powerful case for the UK to seize the opportunities offered by robotics and autonomous systems (RAS) and he rightly emphasises the need to build public trust in these systems ('Robotics and autonomous systems – affecting everything that moves', *Ingenia* 67).

To be trustworthy, RAS must of course be safe and secure. However, demonstrating this is harder than it may seem because software is at the heart of RAS and programmers are at risk of making lots of mistakes: it is an unusually talented programmer who only introduces one defect in every 1,000 lines of software program that he or she writes (defect rates typically lie in the range between 5 and 30 defects per 1,000 lines). Many of these errors remain undetected because programmers rely on testing to find their mistakes, and computer scientists and software engineers have known for at least 40 years that testing can only show that faults exist rather than that the software is safe or secure. Running a series of tests may show that the specific tests work, but even a small change to the test conditions will put the software in a different, untested state that may fail. In general, it is not valid to extrapolate from test results or to interpolate between tested conditions. So if strong evidence is needed that software is safe and secure, testing is simply the wrong approach; strong evidence can only be provided by rigorous analysis, such as using model checking or theorem provers.

If the UK is to take, and maintain, leadership in RAS, the software must be built to professional engineering standards, with evidence that it is safe and secure. That requires a mathematically rigorous specification of the safety and security requirements followed by rigorous evidence that the software has the specified properties. This is skilled work but it has been shown to be practical and cost effective, using engineering tools and methods such as Z and SPARK, for example. Z is a mathematically formal specification method and SPARK is a software development technology specifically designed for engineering high-reliability applications. SPARK comprises a programming language, a verification toolset and a design method which, taken together, ensure that ultra-low-defect software can be deployed in application domains where high reliability must be assured, for example where safety and security are key requirements.

The software industry has resisted the adoption of professional engineering methods for far too long; programmers often have little education or training in the necessary mathematics and the most commonly used programming languages (for example, C and C++) were not designed to support rigorous analysis. Software companies have focused on getting new products into the market as quickly as possible rather than on making their software highly reliable or secure, as this is what most customers seem to want. One consequence is that we now face a cybersecurity crisis because most software contains many errors and a proportion of these errors can be exploited to force failures or to make the software misbehave. The world cannot afford a RAS industry that makes the same mistakes.

The UK has the universities and the software companies that could deliver the safe and secure systems that the world needs. We should follow Professor Lane's call to work together in industry, government and academia to win a large share of the global markets for RAS.

Martyn Thomas CBE FREng
Livery Company Professor of Information Technology, Gresham College

THE FUTURE OF ENERGY STORAGE

In his June editorial 'What's in store for energy' (*Ingenia* 67), Dr Scott Steedman rightly announced the coming of storage and there is no doubt that electricity storage, in the form of batteries, is enjoying long overdue recognition as a robust proven technology that can support our electricity networks. While internationally, particularly in the Americas, batteries have been deployed routinely to provide a variety of system support services, it wasn't until Tesla announced in early 2015 that its Powerwall would be available in the UK that local interest was piqued. However, Tesla is not the only show in town and there are many innovative UK companies that have batteries for the domestic behind-the-meter market.

As Dr Steedman states, this market is challenging to promote to a domestic consumer on economics alone. Some systems cost £6,000 to £8,000 to install and have a payback of 16 to 24 years, even coupled with rooftop solar generation. One way to reduce the payback period is to also provide flexibility services to the system operator and Moixa Technologies offers this model to its customers by aggregating many small domestic batteries together to offer them as a larger asset to National Grid, allowing additional income to be earned, as well as avoiding the cost of importing electricity.

Behind the meter in industrial and commercial companies, energy storage does make absolute sense now. Companies that see half-hourly use-of-system charges can use storage to avoid peak charges while maintaining business operations. Storage at this larger scale is also easier to offer as a service to support the system operator and this is a key growth area that has yet to be fully exploited.

However, Dr Steedman missed one of the key opportunities for storage and that is energy storage and not electricity storage. Batteries can only store electricity, and often 'energy storage' is used loosely to describe the specific storage of electricity but, of course, batteries are not the only approach to storing electricity. It is important to remember that of the energy we use in our homes, up to 80% of the cost can be on space and water heating. Even in businesses, heating and cooling represent 50% to 70% of the energy costs. While we focus on batteries and storing electricity, we miss the crucial aspect of storing heat (or cold).

Hot water tanks are an endangered species in the home as we change technologies and while batteries may not be economic behind the meter, storing heat is. It is estimated that in the UK, all-electric heating systems could provide 30 GWh (Gigawatt-hours) of flexibility and this ignores the additional gas/oil systems that also have immersion heaters, homes with storage heaters and exciting new phase-change thermal storage, such as that offered by Sunamp. National Grid has a new 'demand turn-up' service that rewards providing load when required. Recent figures indicate that there have been over 80 half-hour settlements periods in 2016 with negative wholesale electricity prices. If demand turn-up was used to 'mop up' excess generation, 30 GWh of flexibility could earn more than £100 million per year, with not a battery in sight.

Dr Steedman also points out that building regulations play an important part in delivering a new flexible system, but those regulations should focus on much more than micro-generation and batteries. Energy efficiency should be at the heart of any new regulations because if heat is not lost, there is no need to use energy to make more heat, which reduces emissions and critically reduces energy costs to the consumer. Until housing is viewed as an important solution in delivering climate targets, the government will continue to focus on the delivery of expensive, large energy infrastructure projects, such as the proposed Hinkley Point C, rather than moving forward with the decentralised energy revolution.

There is no doubt that electricity storage has much to offer the UK's electricity system at the utility scale, and behind the meter at the commercial and industrial scale. National Grid's recent new enhanced frequency response service attracted huge interest, with 7.5 GW offered and 1 GW bid for 200 MW of required service. Electricity storage can respond rapidly, with simultaneous multiple services, as either load or export (which is not something thermal storage can do), to keep our system stable. It is clear that an electricity system that incorporates electricity and energy storage can allow the integration of greater amounts of low carbon generation and maintain system security, while doing so in the most efficient and lowest-cost way to consumers. To maximise the benefits of electricity storage, we need to act quickly, at utility scale and behind the meter, and use all types of technologies. There is significant understanding of what has to change in the commercial and regulatory frameworks to facilitate the deployment of storage, but we have yet to take the necessary actions to deliver the low carbon, low cost and secure system of the future and we will all need to actively participate in understanding and managing our demand to ensure a sustainable future.

Dr Jill Cainey
Director, Electricity Storage Network

OPINION:

BROADBAND NEEDS ITS CHAMPIONS

Within little more than a decade, access to fast and affordable broadband communication has gone from being a luxury to an essential part of modern life. Dr David Cleevely CBE FREng, founder of several telecoms businesses, maintains that any strategy to deliver universal broadband has to jump from a high cost/low demand model to low cost/high demand.

Dr David Cleevely CBE FREng

Back in 1998, BT was preparing to rollout the ADSL (asymmetric digital subscriber line) technology that would bring the UK into the broadband era, with download speeds of a staggering 512 Kbps (kilobits per second). BT had identified the first 400 exchanges for the new technology, but Cambridge was not on the list. Fortunately, we persuaded the Prime Minister to announce the government's new policy on e-commerce at an event in Cambridge, and BT agreed that it would look better if the city was on the list. I quickly realised that companies such as BT did not fully understand the markets they served, especially with something as new as broadband. Cambridge had many potential users of broadband, but BT's models didn't recognise them nor that the city would spawn many businesses that depend on broadband communications.

At the time, I realised that demand, and not just cost, is a crucial factor in the take up of broadband; doubling the number of customers in an area almost halves the cost per connection so if the aim is to deliver affordable broadband, just increase the number of people who want it. To demonstrate that there was a demand, I persuaded BT and the local regional development agency to allow people to pre-register an interest in broadband. This turned into the first campaign involving local volunteers throughout East Anglia, and then the rest of the UK, who signed up enough potential customers to convince BT that it would be cost effective to supply them with ADSL broadband.

Connecting Cambridgeshire, an organisation that I advise, which is working to ensure that businesses, residents and public services can make the most of opportunities offered by a fast-changing digital world, recently ran a similar campaign. With more than 100 'broadband champions' in villages and towns throughout the county, suppliers could bid in the knowledge that there was enough demand to make the service economically viable. As a result, the county has perhaps the most cost-effective extensions of fast broadband to underserved areas in the UK.

Insights into how the market works can also provide other opportunities to accelerate deployment of broadband.

I realised that demand, and not just cost, is a crucial factor in the take up of broadband; doubling the number of customers in an area almost halves the cost per connection so if the aim is to deliver affordable broadband, just increase the number of people who want it

Providers respond to threats as well as to opportunities. If a competitor might take market share, and make a location economically unviable, then incumbent businesses could justify more investment to prevent that.

At the beginning of ADSL, my company, Analysys, designed and helped run a series of competitions for the lowest subsidy to provide broadband. When BT bid 'zero' at an exchange (deciding that it would not take any subsidies), often at the last minute, we took the subsidy on to the next exchange. Within two years BT had announced a target of 90% coverage for the UK. We should be more creative in using this kind of approach to close the 'broadband gap', a concept that we invented back in 2000 and that changed government thinking on the issue. We should jump from a high cost/low demand equilibrium to low cost/high demand.

There is another example of where theory and reality diverge to the detriment of consumers of communications. Operators of mobile telephone networks, for example, have many 'not-spots' in their networks where customers cannot make calls: publicising these isn't good for business. The answer here is to make not-spots public knowledge and to ensure that operators who do provide a service enhance their reputation and gain customers, and vice versa. That is why in Cambridge, we have launched the Cambs NotSpotter Campaign, where participants use the OpenSignal app on their smartphones to record mobile coverage. We also use the Think Broadband website to run regular speed tests on broadband. In this way, Cambridge 'crowdsources' the knowledge that it needs to persuade operators to plug gaps in fixed and mobile coverage across Cambridgeshire.

Then there are insights to be gained from understanding the cost structure of telecoms networks. Most of the cost of installing broadband is in civil works, such as trenching, which does not require specialist telecoms providers. I have rarely seen this approach used in policies to enable lower cost broadband but there are some spectacular examples of how this can work. Some rural communities have been building their own broadband networks, such as Tove Valley Broadband in Northamptonshire, where a local drainage contractor dug trenches and a specialist company laid the fibre-optic cables (see pages 18 to 26).

Finally, there are organisations that combine both demand and supply. For example, B4RN (Broadband for the Rural North), a non-profit community project, provides gigabit connectivity for £30 a month. By creating a business involving potential customers as volunteers and local landowners as community members, these bodies can provide faster broadband more cost effectively than conventional suppliers.

Broadband is not a luxury, it is essential for everyone and for all economic and social activity. It is possible, with surprisingly low budgets, to bring broadband and mobile connectivity to people who need it, as long as we recognise that communities can play as much a part as communications companies, that we should not blindly assume that there is only one way to supply connectivity, and that there are ways to encourage sustainable cost-effective supply without vast subsidies. A more enlightened approach to radio spectrum in rural areas would help and would encourage competition and better supply of connectivity in places that are hard to reach.

So instead of concentrating on procurement and the supply side, it is time for fresh thinking about how we enable everyone to get connected. We need many more not-spot campaigns and more broadband champions. Above all, we need policies that use insights about demand, costs, supply, information, regulation and competitor behaviour to accelerate broadband rollout.

BIOGRAPHY

Dr David Cleevely CBE FREng is Chairman of the Board of Trustees of the Raspberry Pi Foundation, Chairman of Raspberry Pi (Trading) Ltd., and Founding Director of the Centre for Science and Policy at the University of Cambridge. Dr Cleevely has been involved in the start up and running of a number of technology businesses including Analysys Mason, 3WayNetworks, Controllis and Abcam, and networking organisations including Cambridge Wireless and Cambridge Network.

The Shannon lifeboat's hull is narrow at the bow, wider in the aft section and steeper in the mid region. This a shape that provides good stability and minimises slamming, which can put high stress on a vessel © Mike Lavis

AGAINST THE TIDE

Lifeboats are unique in needing to go out to sea in stormy conditions when other vessels of a similar size would be heading back to port. Because of this, the Royal National Lifeboat Institution introduced the Shannon class all-weather lifeboat in 2014, which uses cutting-edge technology, is faster and more manoeuvrable than existing vessels, and has a quicker and safer launch and recovery system. Science writer and broadcaster Geoff Watts talks to naval architect Daniel Sharp, Shannon Production Group Leader at the All-Weather Lifeboat Centre in Poole, Dorset, about its design and production.

The sight of a sturdy 13-metre ocean-going craft powering its way at high speed towards a shingle beach would normally be a source of concern or even some alarm. However, if it is one of the Royal National Lifeboat Institution's (RNLI) new Shannon-class vessels, what you'd be seeing is standard operating procedure. When it is time to bring a Shannon lifeboat home, the coxswain simply angles its bow toward the shore and opens the throttle*. To the accompaniment of a scrunching, scraping and slithering sound, the boat's momentum carries it out of the water and up the beach to a point well clear of the waves.

While this is surely the most straightforward means imaginable of getting a boat onto dry land, the engineering that makes such a manoeuvre safe and feasible is far from elementary. Indeed, to design any feature of a lifeboat is a more than averagely exacting task; the sea and weather conditions that would prompt most similarly sized vessels to seek shelter are those in which a lifeboat may find itself being launched.

The Shannon, powered by water jets, is a product of careful thought about lifeboat design and operation. Its novel method of coming ashore is the most visible manifestation of what amounts to a minor revolution in the core business of the RNLI, part of a set of changes that encompass not only the engineering, design and operation of RNLI's new generation of vessels, but also the organisation, location and economics of their construction.

Any new design seeks to improve on its predecessor, incorporate technical advances, and introduce innovations of its own. The Shannon manages to do all three

SLIPWAY OR BEACH

Some lifeboats are launched from permanent slipways; others from a beach. The choice for any particular location is determined partly by the local geography, and even more by history. If a boathouse and slipway are already in place, it would be perverse not to use them. Although the Shannon has been designed for beach launching, it can also operate from a slipway, and some already do so.

The RNLI's need to consider a new design arises when any particular class of vessel within its fleet in has reached the end of its intended life: 25 years in the case of the Mersey, the beach-launched boat that the Shannon will eventually replace. It would have been possible to extend the life of the Mersey, but the RNLI decided that it wanted an all-weather boat capable of 25 knots, significantly higher than the Mersey's 15–17 knots.

Besides wanting vessels suitable for launching and recovery on a beach, the RNLI identified a dozen or so other operational requirements when proposing the new Shannon class. These included the wind and wave heights with which the boats must be able to cope, their minimum range and duration of operation under full power, and their capacity to carry survivors and tow other vessels. Any new design seeks to improve on its predecessor, incorporate technical advances, and introduce innovations of its own. The Shannon manages to do all three.

Traditionally, RNLI has bought in boats from outside yards and modified them to its requirements, or sub-contracted the design process to others, albeit with RNLI input. For the Shannon, it judged that its own engineering team had sufficient knowledge to do the design work. The one exception, at least originally, lay in the central design feature of any new vessel: the shape (form) of its hull.

The development of the Shannon began a decade ago with an attempt to use the hull form of an existing pilot boat. The Fast Carriage Boat, or FCB 2 project as it was known, got as far as sea trials. These showed that the decision to opt for a water-jet propulsion system was fully justified, this technology offering distinct advantages over propeller-driven craft, especially when boats were making difficult manoeuvres or operating in shallow water.

SHANNON: THE TECHNICAL BASICS

Length: **13.6 metres overall; 11.6 metres at waterline**

Beam (width): **4.5 metres**

Draught (depth): **1 metre**

Displacement: **18 tonnes (maximum)**

Maximum speed: **25 knots**

Fuel capacity: **1,200 litres in each tank**

Range: **250 nautical miles**

Engines: **2 x 13-litre 650 hp Scania D13 engines; Twin Hamilton HJ364 water jets**

Survivor capacity: **six seated plus 17 standing inside, or 79 but without self-righting capacity**

The Shannon's hull was completely redesigned, after a competitive tendering and testing process. The shape and angle of the sides of the new hull reduce broaching when the boat is travelling in the same direction as the swell © RNLI

But the performance of the FCB hull in rough sea conditions was disappointing. In head seas (when waves or the current are running directly against a boat's course), when travelling faster than 14 knots, there was an unacceptable amount of 'slamming', the term used to describe the juddering crash when a hull that has risen upwards as it moves through a wave falls back into the water.

A NEW HULL FROM SCRATCH

The project team members decided that a completely new hull form would have to be designed, and set up a competitive tendering and testing process. At the time that this work was in progress, the team members were uncertain about the reliability of computer simulations of the anticipated performance of hull designs, particularly those expected to operate under the exceptionally challenging conditions facing lifeboats. Some virtual model testing was actually commissioned, but while the then state-of-the-art computational fluid dynamics were good for eliminating some designs, and for predicting the vertical acceleration of hull movements, work on the rolling component of their movements was less advanced. Most of the design decisions about the Shannon therefore relied on testing physical models.

It was during this period that one of RNLI's own naval architects working on the project, Peter Eyre, decided to have a go at coming up with a new hull form in his own time. When he told colleagues what he was doing, he was invited to finish his design in office hours, and put it up to compete with the other shapes selected for testing.

To compare the hulls on the final shortlist, the team used 1.5-metre free-running models under radio control. Much of the testing was carried out in Poole Harbour where the ripples caused by force 1–2 wind conditions are equivalent to the waves confronting a full-sized hull in force 7 winds. The models carried accelerometers and other instruments able to record their motion in all dimensions as they sailed through a chosen stretch of water. By testing each model side by side with a standard hull for comparison, and so subjecting both to identical sea conditions at the same time, the team was able to measure their relative performance.

Transverse motions of the hulls when they rolled were particularly important in these tests because the crew seats developed for a previous generation of lifeboats are already good at absorbing the shock of vertical movements. Transverse movement is harder to manage and, if unchecked, can leave crews with damaged shoulders and backs. Having a hull that tracks well is also important because it minimises the amount of steering required simply to keep a vessel on course. The design team also carried out tow testing in a tank to garner more information about the performance of the hulls under specific wave conditions.

The result of this work was a shortlist of two, one of which was the hull design drawn up by Peter Eyre. In a final comparison this was the winner: an outcome that not only demonstrated the RNLI's in-house expertise but also saved it money. The chosen design was a hull that is narrow at the bow but wide in the aft section, and steeper in the mid region: a shape that confers good stability and minimises slamming.

The Shannon is described as a 'wet boat': it tends to cut through the tops of waves rather than riding their crest, and this reduces the slamming. When the boat is travelling in the same direction as the swell, the shape and angle of the sides of the hull also reduce broaching – this being the tendency for some vessels facing severe conditions to steer by the bow and in some cases turn through 180 degrees.

Being powered by water jets enables the Shannon to launch itself out of the sea and onto the beach easily without risking damage to a traditional rudder and screw propulsion system. The outer layer of the hull is also thicker than needed so that it is resistant to shocks and scratches © RNLI

The Shannon can be recovered from the sea by the launch and recovery tractor. The boat sits on a 'slewing ring' that can be turned 180 degrees to relaunch the boat almost immediately © RNLI

LAUNCH AND RECOVERY

To the outsider, if not to the crews, the Shannon's most innovative feature is operational rather than structural: its capacity to leave the sea and return to land by beaching itself under its own power. This course of action is only possible because of engineering decisions taken during the design stage.

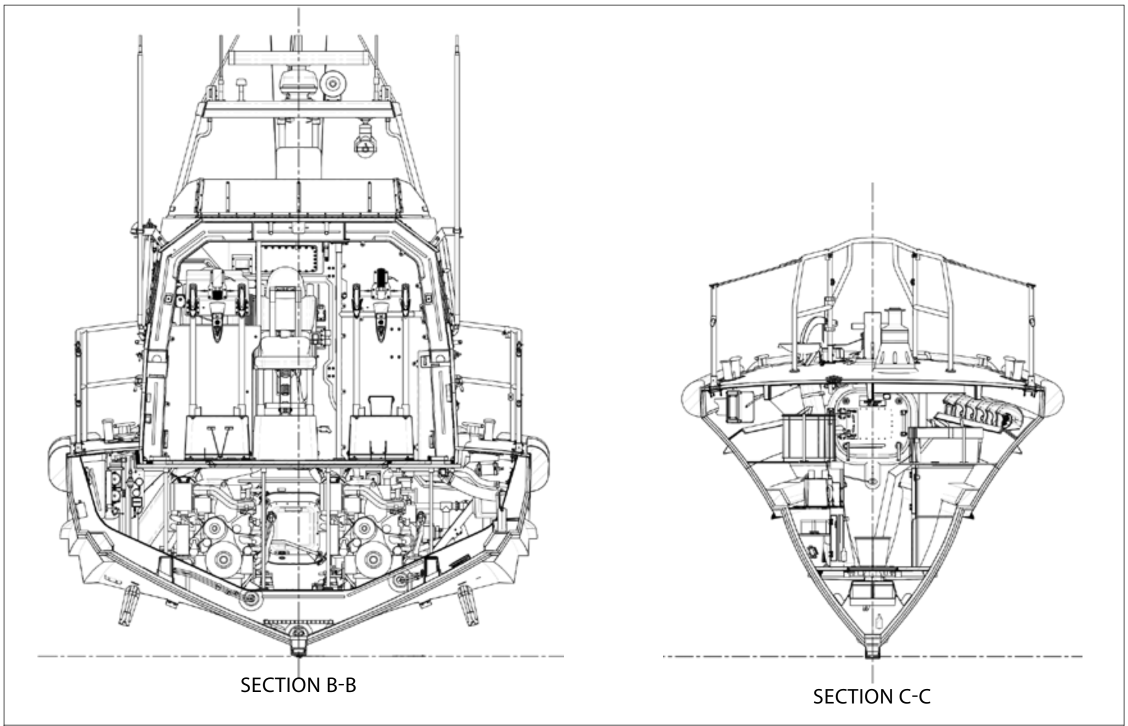
Conventional beach landings of the type used by lifeboats of previous classes can take up to an hour and require a fair number of helpers. The boat nudges to the beach, the land crew attach a cable and then winch it, bow first, out of the water. Well out of the water, in fact, because it has to be dragged stern first on to the tractor-hauled cradle used to transport it. This means that the boat must be sufficiently far up the beach to allow tractor and cradle to get between it and the sea. Performing these manoeuvres is time consuming, and in rough weather they can be difficult and dangerous.

Beach landings of the type used by the Shannon are possible because it is powered by water jets. A conventional rudder and screw propulsion system would be, at very least, susceptible to damage. The Shannon, having hurled itself out of the sea and up the beach, can be well clear of the waves before anyone needs to approach it. Moreover, unlike its predecessors, it can be hauled bow first on to the cradle designed to hold and transport it. The cradle is attached to a new 444-horsepower tractor designed in consultation with the RNLI by the Devon-based company Supacat. Recovery time is around 15 minutes and can, in theory, be performed with as few as two people: savings that are particularly valuable when weather conditions are, as is often the case, severe.

The cradle, which also serves as a slipway for launching the boat, incorporates another innovation: a metre-wide 'slewing ring'. In effect, the boat sits on a rotating platform that can be turned through 180 degrees. Once the vessel has been hauled on to the cradle and secured it can be turned round and, if necessary, relaunched almost immediately.

Lifeboats seldom need to be launched and recovered more than two or three times in a week, so the punishment of a beach landing is not an everyday occurrence. Even so, to cope with such a landing, the hull has to be built to withstand the initial impact and the abrading effect of sliding at speed over sand and shingle. The hull itself, 70 millimetres thick at the bottom of the boat, is a sandwich structure, composed of two layers of glass epoxy composite that are separated by a foam core. The outer layer is thicker than would be needed purely for structural purposes, the extra material giving it the required resilience to shocks and scratches. The outer surface is also covered with abrasion resistant coatings. Experience has shown that damage in these landings is minimal, and abrasion that does affect the hull surface – the loss of anti-fouling coats, for example – can be patched up in the boathouse.

The damage most likely to be sustained in beach landings is to the side keels, the two vertical fins mounted towards the rear of the boat and intended to minimise rolling when at sea. They also serve to improve the vessel's tracking and, when beached, prevent it tilting too far on its side. If subjected to extreme force, they're designed to peel away without damaging the underlying structure on which they are mounted. Replacement is relatively straightforward and the boat can still be operated in the meantime.



Section BB shows a cross-section of the Shannon class's wheelhouse and engine room while section CC shows the forestore, where rescue equipment is stored. The diagram demonstrates the shape of the hull and the narrowness of the bow © RLNI

THE BRAIN OF THE BOAT

The brain of a lifeboat is its systems and information management system (SIMS). This provides access to the vessel's intercom and other communications, displays navigational information (radar, charts, depth, speed etc), and also data about the performance of the engines and other machinery. An updated version of the system developed for an earlier class of lifeboat, the Tamar ('Launching the Tamar', *Ingenia* 33), the SIMS on a Shannon uses one screen to display all the information that a coxswain needs to operate the boat. However, the helmsman is not the only person who has access to it; screens can also be monitored and operated from the crew seats. Users are spared a cluster of different instrument faces competing for their attention, with a tracker ball they can scroll through the various screen images available to select just the information they need at any one moment.

In previous lifeboat models, the equipment required to run these systems was collected together in one place. In the Shannon it is distributed around the vessel. This has two advantages: weight is more evenly distributed and less cabling is required.

The systems and information management system provides access to the vessel's intercom and other communications, displays navigational information such as radar, charts, depth and speed, and data about the performance of the engines and other machinery © Nigel Millard

BUILDING THE SHANNON

The Shannon's engineering and design innovations have been accompanied by equally important changes in the organisation, location and even ownership of the process of building it. RNLI's long established practice was to have the hull and overlying wheelhouse fabricated by specialist composite manufacturers. This changed when it bought out its main suppliers, SAR Composites, and the company became an RNLI subsidiary. However, the hull and wheelhouse still went to a shipbuilder's yard for fitting out, with the initial 12 Shannons going to Berthon in Lymington for this purpose before the RNLI decided to do the fitting out itself. But even this was not the end of the revolution.

In April 2015, RNLI formally opened its new and impressive All-Weather Lifeboat Centre. Located beside Poole Harbour, the centre comprises two large boat manufacturing and repair halls separated by a roofed area open at the sides used for storage and manoeuvring. Building this factory posed its own set of challenges because local planning regulations required the ground level of the site to be raised by a metre and half to avoid flooding. Much of the site was land reclaimed from the harbour and at risk of sinking when subjected to the new weight it was intended to carry. The site had to be compressed under a thick layer of sand – some 15,000 cubic metres in total – and left to settle for the best part of a year while water from the underlying soil was squeezed out through a large wick drain set into the sand and reaching down into the soil. The site then had to be piled and overlaid with load-transferring foundations in such a way as to distribute the weight they


The entire construction of the Shannon takes place at the Poole All-Weather Lifeboat Centre. Each composite is created separately and joined together in a process that operates like a production line. A boat is completed every two months, resulting in six new boats a year © RNLI

would eventually have to bear over as many piles as possible. An organisation accustomed to the hazards created by the marine environment had found itself having to deal with the less familiar problems posed by a terrestrial one.

Following the successful completion of the new centre, the RNLI moved the main manufacturing phase to the Poole factory. With the huge ovens required to bake the composites of the hulls and wheelhouses now joining the other large enclosed spaces required to paint and dry them, the entire process from start to finish is conducted on one site: another big saving to RNLI coffers. The centre operates like a production line, completing one boat every two months: a total of six per year. From start to finish the process takes about 14 months and the goal is to create a fleet of 50 Shannons.

Until recently, with orders for new boats going out to independent boat builders, there were inevitable peaks and troughs in production. Given that RNLI is a charity that relies on donations, an even flow of new boats simplifies the tasks of the fundraisers. For the coming years, they know exactly how much money will be required and when.

THE FUTURE

The boats now being built should have a 50-year lifespan. As the first of them approaches the mid point of this period, it will be withdrawn for a complete refit in the Poole Centre, so marking the start of a boat-by-boat refurbishment or, depending on what new technology may have become available, an upgrade. The staff are confident that the Shannon hull will prove as serviceable during the second half of each boat's life as they already believe it will have been during the first half. At a cost of £2.2 million each, Shannons are hardly cheap; but spreading that cost over 50 instead of 25 years represents another significant saving.

In the meantime, the staff at Poole continue to change and innovate. To allow more engineers to work more freely on the boats, for example, the two main structural components, the hull and the wheelhouse, are kept separate for as long as possible. When they are finally brought together, they are held by an improved form of bonded joint.

Another innovation is the use of composites with a lower carbon content. Any repairs that need to be made to a craft during the course of its life are quite likely to require grinding or sanding of the materials used to fabricate it. If carbon in the dust produced by this gets into the electronics it can cause shorting. This is normally avoided by protecting the electronics using polythene sheeting, or even temporarily removing sensitive equipment. However, the less carbon that is used in composites in the first place, the less the likelihood of such problems occurring.

The first Shannon went into service in July 2013 and more than a dozen have now been deployed. This is the first time that the RNLI has used water-jet propulsion in a craft of this size, and the experiment seems to have paid off. Whether boats are required to crab sideways into a space or simply hold themselves accurately in one position, manoeuvrability is exceptionally good. Crews are said to be delighted with them, and have yet to report anything significant that they would like to change: a consequence, perhaps, of the input they were asked to give during the Shannon's design phase.

Venerable institutions – a category to which the RNLI most certainly belongs – can become creatures of habit, resistant to change. Engineering as a discipline recognises no such constraints. It is surely to the credit of the RNLI that it has been able to identify what engineering has to offer and adapt accordingly.

BIOGRAPHY

Daniel Sharp is the Shannon Production Group Leader of the RNLI, based at the new All-Weather Lifeboat Centre. He started work for the RNLI in 2001 as a lifeguard on the beaches of Poole during the summer while studying at university. In 2006, he took on a full-time naval architect role as part of the Shannon-class lifeboat project team, responsible for designing the Shannon class, producing the prototype and proving the design was suitable.

*To see a Shannon lifeboat coming ashore, go to: www.youtube.com/watch?v=IBcTXJ7UGVg

A broadband speed of 10 Mbps (megabits per second) is considered by Ofcom to be fast enough to meet the needs of a modern family household. However, many rural homes in the UK are struggling with connections below this speed © www.pixabay.com/FirmBee

BROADBAND IN THE BACKWATERS: RURAL BRITAIN'S FIGHT FOR FASTER INTERNET

Superfast broadband is non-existent in some parts of rural Britain and the situation may not change soon. Sarah Griffiths looks at the state of broadband in the UK, finding out what options are available and talking to rural communities who have come up with their own innovative engineering solutions for the problem.

ADSL Vs FIBRE-OPTIC BROADBAND

ADSL

- ADSL (asymmetric digital subscriber line) can provide speeds up to 24 Mbps but the speed a customer receives depends on how far their home is located from an exchange, meaning speeds can be dramatically lower in rural areas.
- Data is transmitted along copper cables from a BT exchange to the home.
- With ADSL, electrons are pushed down a copper wire to carry information via an internet and phone connection through a socket on the wall at home.
- ADSL uses frequencies not used by a telephone call. A device called a splitter, or micro filter, separates the telephone line from the broadband and the digital signals received are decoded and recoded into useable information.

Fibre-optic broadband

- One way of delivering superfast broadband is through fibre-optic cables to provide speeds of 30 Mbps to 1 Gbps.
- There are thousands of individual glass fibres as thin as a human hair in each cable, which carry data in the form of light photons instead of electrons.
- Each fibre is reflective on the inside so that light bounces off the inner walls to travel along the cable.
- Little light is absorbed by the glass, so that when pulses of light carrying data enter at one end, they undergo repeated total internal reflection to emerge at the other end, where the data is decoded into a usable form.
- Signals in optical fibres do not weaken over long distances as much as in copper cables.

Almost half of the homes in rural Britain are unable to get an internet connection of 10 Mbps (megabits per second) or above, arguably putting businesses at risk, increasing farming costs and driving young people away from the areas in which they grew up.

These slow internet speeds contribute to the UK lagging behind many other nations. According to a recent report by the European Commission (EC), high-speed broadband in Slovenia and Lithuania eclipses that across the UK. While the Netherlands and Malta both have at least 97% fast broadband coverage, Britain has 90%. Europe's *Digital Progress Report* states that: "even though the UK performs very well in terms of fixed basic broadband coverage of rural areas, and [Broadband Delivery UK] programme actions already address the gap in the availability of superfast broadband between urban and rural areas, there is still an opportunity for additional effort in order to bridge the gap."

Ofcom's *Communications Market Report* says that 90% of premises across the country can receive next-generation broadband services. However, most of these are in urban areas and the situation in rural Britain may not improve fast. By 2020, around one million families living in remote locations with poor or non-existent broadband will be able to apply for an upgrade if they want it, but in the meantime some have taken matters into their own hands.

MIND THE SPEED GAP

Government figures show that the average broadband speed in 'sparse settings', such as a rural hamlet, is just 5 Mbps compared to some cities at 27 Mbps. This is despite a programme by Broadband Delivery UK (BDUK), a part of the Department for Culture, Media and Sport that is aiming to deliver superfast broadband and better mobile connectivity across the UK, to extend superfast broadband into areas not currently catered for by the commercial market. This means that while superfast broadband – defined as better than 30 Mbps by Ofcom – is available to 24 million homes, or 83% of UK premises, the majority of those without access are in rural areas.

According to Ofcom, around 2.4 million homes and small businesses in the UK are unable to receive broadband speeds above 10 Mbps, with 1.5 million of these premises in rural areas. This prevalence of 'not spots' comes at a time when demand

Territorial coverage of broadband connections of less than 2.2 Mbps in the UK © Professor John Farrington

Territorial coverage of superfast broadband availability in the UK © Professor John Farrington

	Availability of superfast broadband in rural areas by premises		
	2015	2014 (estimated)	Approximate estimated year-on-year increase
UK	**37%**	**22%**	**1.7x**
England	**36%**	**23%**	**1.6x**
Northern Ireland	**40%**	**38%**	**1.1x**
Scotland	**31%**	**8%**	**3.9x**
Wales	**50%**	**17%**	**2.9x**

Despite many areas still facing slow speeds and low coverage, figures from Ofcom's *Connected Nations 2015* report show that there have been large increases in the availability of superfast broadband in rural areas

for data is growing, with the average monthly data usage per residential connection rising from 58 GB (gigabyte) in 2014 to 82 GB in 2015.

According to Anne-Marie Oostveen, Research Fellow at the Oxford Internet Institute, University of Oxford, there are four reasons for slow rural broadband speeds: connection speeds, latency, contention ratios and reliability.

Broadband is delivered through a combination of direct fibre connections and wireless. Using the existing copper network designed for telephones is cheaper in the short term but does present some challenges, especially for more widely spaced rural areas. In some this is impossible because homes can be far away from the exchange or street cabinet so the signal degrades and speeds drop. The quality, type and maintenance of cable can also have an effect on speed, but generally the people worst affected are those at the very end of the telephone line.

Latency is another frustrating factor for many users who have to wait for data to arrive. The issue is most problematic for people using satellite broadband, where latency accounts for about half a second of delay on a broadband signal travelling to the satellite and back. While latency makes sending emails a little slower, it can make video calling, watching videos and online gaming frustrating.

The reliability of connections can also be problematic for people living in places where high winds and heavy rain are common. Rain can damage copper cables, with fibre ducts also susceptible to flooding, while gales and storms can temporarily knock out satellite broadband connections.

THE GOVERNMENT'S GRAND PLAN

To solve these problems, BDUK's £780 million rollout programme aims to provide superfast broadband to 95% of the country by 2017. One of the technologies it is deploying is fibre-to-the-cabinet (FTTC), where fibre-optic networks connect BT's exchanges to street cabinets situated in towns and villages, with traditional, slower, copper wires making the final connection to homes and businesses.

Coverage of superfast broadband in rural areas – both FTTC and fibre-to-the-home (FTTH) – has increased from 22% in 2014 to 37% in 2015 to serve 1.1 million premises. FTTC gives customers a faster connection because data is carried at least to a local cabinet before using copper for the now fairly short last drop.

This improved network comes at a cost. A 2008 report for the Broadband Stakeholder Group by Analysys Mason in 2008, noted that rolling out FTTC nationwide would cost three to four times more than the telecoms sector on the last generation network.

Furthermore, the deployment costs for FTTH are around five times more than those for FTTC because of increased civil engineering costs, although some local groups have used self-installation to help here.

THE OPTIONS FOR 'NOT-SPOTS'

The government has said it recognises that broadband provision is important for the economic and social sustainability of rural communities.

For people fed up with frustratingly slow broadband, satellite could be the answer if they are not prepared to wait for fibre to be installed. Those with broadband speeds of less than 2 Mbps could take advantage of BDUK's satellite subsidy scheme, which radically reduces the cost of having a satellite dish installed.

Geostationary satellites orbit Earth at an altitude of around 22,300 miles above the equator and are able to send and receive signals covering large areas, meaning most homes could get broadband via satellite. All that is needed is a dish, a package from a provider such as Hypersonic or Gigaclear, and a clear line of sight between the dish and satellite. This can be easily checked using a Look Angle Calculator, which ensures no obstacles such as trees or mountains will interfere with a satellite signal by checking a user's address and the orbital longitude of the satellite. This larger area of coverage makes satellite a practical choice for many people living far from a phone exchange or mobile mast.

Building, launching and operating satellites is expensive and the costs are passed on to customers, making satellite broadband more costly than ADSL and some fibre services, for example. Because signals have to travel to and from satellites, or around 46,000 miles, users have to wait for data to arrive too, which is around half a second, or 500 milliseconds, compared to 50 to 80 milliseconds for fibre.

While satellite broadband is credited with keeping people in the remotest of places connected, it could let them down in particularly windy

Satellite broadband typically delivers a maximum download speed of 20 Mbps and a maximum upload speed of 6 Mbps, enabling people to watch films and stream music online. However, it does not offer the speeds of fibre broadband and could come under pressure if members of a family are all demanding bandwidth-hungry activities at once © Tove Valley Broadband

weather. However, some users say antennas can still provide a signal when buried under snow thanks to signal boosters.

Mobile broadband – another option for people who cannot get high-speed internet access via ADSL – can be just as unreliable. Just under one-third of rural homes and businesses are able to receive an indoor voice service, compared with 91% of urban areas, according to Ofcom, leaving many dependent on accessing the internet on their smartphones when out and about.

When users can get a signal, 4G is capable of providing download speeds up to 18.6 Mbps providing a boost for those who can't get fibre broadband to their home but it can prove an expensive option and mobile broadband can also be affected by bad weather.

BDUK is trialling technologies in areas not planned to be covered by the fibre broadband rollout, including fixed wireless, which transmits broadband signals over radio transmitters instead of relying on copper or fibre cables. While they can provide speeds of around 20 Mbps, they require remote homes and businesses to be within line-of-sight of a transmitter, making them once again unsuitable for properties in valleys or woods.

BT sometimes uses fibre-to-the-remote-node (FTTrN) to connect remote communities where it is determined to be the best method to use. The small village of Ulshaw in North Yorkshire became the first to get the new technology in April 2015, bringing internet speeds of up to 80 Mbps.

It is similar to FTTC, except a fibre-optic cable from the local telephone exchange is connected to a small remote node much closer to properties on telegraph poles or inside manholes, for example. The approach is cheaper and simpler than installing a new cabinet and is said to be ideal for challenging and remote areas.

COMMUNITY BROADBAND

While satellite and mobile broadband may be useful solutions for remote homes or farms going it alone, community broadband schemes have allowed villagers to club together to secure superfast broadband for their communities.

The village of Abthorpe in Northamptonshire set out to boost its own internet speed independently from BT and used a satellite connection and ADSL lines before Tove Valley Broadband (TVB) was established in 2012. It now uses the FTTC and fixed wireless access models.

In 2003, a community-supported satellite data connection to Belgium providing 'always on' broadband was installed, involving a small server in TVB webmaster Richard Tomalin's loft and a satellite dish on the outside. The satellite link to Belgium was chosen for its cost efficiency and because it allowed TVB to act as a service provider and distribute broadband to others in the membership. This link ran at 1 Mbps down and 0.25 Mbps up, which while slow by today's standards, was far superior to the 0.025 Mbps over dial-up telephone lines.

The only option at the time was to distribute a service to 50 houses using 2.4 GHz Wi-Fi, as 5 GHz was too expensive. The biggest challenge was making efficient radio frequency connections to the aerials positioned on properties for line-of-sight to the access point. The aerial coax had to be treated with reverence and had to be as short as possible as the losses mounted up. Line of sight was essential; the slightest problem caused the radios to re-try packets and these errors swamped the traffic on a particular access point.

In a bid to solve this problem, the TVB team used mesh configurations, but found throughput became a serious problem the more links there were. They tried different antennas made from a mixture of household objects, from rubber-ducks through whisky cans to fish-fryers, forming three-foot wire-mesh reflectors in an effort to boost the radio connection and reduce interference. The fish-fryer managed 2.5 kilometres and the 'cantenna' nearly four kilometres, but while the connection was good, the speed of these links forced TVB to restrict service to local properties less than one kilometre from an access point.

In 2006, BT enabled the local exchange for ADSL, so three ADSL lines replaced the satellite link, enabling TVB to distribute its service to other members. Each line provided about

2/0.5 Mbps. In 2013, TVB expanded its community group to include five more villages with a 100 Mbps fibre backhaul courtesy of 6degrees and BT wholesale. The company upgraded its equipment, installing 5 Ghz antenna-radio-ethernet Ubiquity units, and used radio pipes at 100/100 Mbps between the villages, increasing its membership to 200 homes.

The model initially worked well, but within a year the radio pipes were beginning to be overloaded, and with increasing membership, TVB realised its service was only going to get worse. So the decision was taken to invest in fibre-optic broadband.

With the aid of £108,000 from government and £170,000 of loans raised in the communities, more than 12.5 kilometres of 24-core fibre was laid over farmland, under streams and across roads, converging in one central access point. Under the guidance of BDUK experts, a team of volunteers supervised and installed the 2,500 Mbps line. Directional drilling was used to lay tubes under roads, a village green, streams and through a churchyard, which while expensive, meant less disruption. Contractors were used to blow fibre through the tubes.

From the central point, fibre-optic cables distribute the service to six villages and then to radio access points. This means that each village is supplied with a fibre backhaul to TVB's hub, which then uses a 1,000 Mbps symmetrical

Volunteers in Abthorpe buried the fibre-optic cable between one and 1.5 metres below the earth to avoid disruption to the fibre if the 14-millimetre tube became waterlogged. They faced a challenging timeline because trenching work needed to lay the fibre had to be carried out in a two-week window between harvest and ploughing, so as not to disturb farmers © Tove Valley Broadband backhaul to London. The access points are hosted on churches, a school, farm buildings, homes and even a grain silo. The service is then distributed to individual properties via radio. Properties need 'customer premises equipment' fixed outside in the form of a small box, and a lead running inside plugged into a 'power injector' to connect to the mains and LAN (local area network) connection. There is no need for a BT phoneline.

By April 2015, the scheme achieved a very fast high-bandwidth supply to each village with some low-volume radio extensions to other neighbouring villages that wanted to join the enterprise. TVB now provides a fast symmetrical fibre-optic service into the villages and distributes connections to properties by radio, so users get speeds of between 30 and 90 Mbps. The service has meant businesses that were leaving the area because of its inadequate broadband options are staying and employment in the local area has risen. As well as the benefits of speed, the service is not as expensive as alternative technologies. Customers pay just £10 a month for their broadband, as well as a £75 installation fee and initial £100 joining fee.

The set-up is fairly weather-proof, unlike copper wire and satellite, and the only disadvantages are that the helpline is manned by volunteers who may take hours to respond to an enquiry and the infrastructure is maintained by a few key volunteers with technical experience, meaning more will have to be trained in the future. Similarly, there are only a certain number of radio frequencies available and access points may need to be relocated if the member base expands. However, TVB is set up to be future-proof for the next decade and the backhaul can be increased by more than eight times without having to lay new cables.

The wireless broadband link on the Shetland Islands uses antennas and masts to supply broadband rather than using phone lines. There is potential to extend the reach of the link in the future so there is the capacity for surrounding areas to access this fast connection © Shetland Broadband

In the Shetland Islands, the council decided to prioritise telecommunications in 2006. At that time, internet traffic went over multi-hop microwave links, which were unreliable in bad weather, once resulting in a total telecoms blackout that affected the emergency services, hospitals, shops, ATMs and even closed the airport. The internet was also very expensive because of BT's distance-based tariffs, meaning businesses paid 20 times that of a company in Aberdeen for the same service.

But in 2006, the islanders decided to install their own fibre cable crossing Shetland. The Shetland Telecom project was established to operate a fibre-optic ring, which connects to SHEFA2, a fibre-optic submarine cable with 57x10 Gbps of capacity that is around 1,000 kilometres and includes the world's longest purely passive optical fibre cable link measuring 390 kilometres. Designed to be low maintenance, it has no submarine repeaters and no power feeds and is future-proof because the end-point technology is the only item needed to be changed to increase capacity.

The fibre cable ring connecting to SHEFA2 is solely owned by the Shetland Islands Council, which used a local contractor to lay a 96-core fibre cable connecting towns. It is open access so providers and community groups can extend services to more remote parts of the island.

Digging trenches to embed the cable was the only option, as verges along the main roads were already the main route for other services such as power and water. However, microtrenching meant that the pre-installed duct could be laid into the road surface, resulting in a cost saving, while in other places duct had to be laid in peat bogs the texture of rice pudding, with the fibre blown in later.

In more populated areas, fibre-optic cabinets are installed and an FTTC set-up connects houses. In 2014, seven cabinets were installed in Lerwick, Quarff and Sumburgh connecting 4,000 houses to the fibre-optic network. A fibre-optic radio broadband hybrid is used to connect people in less populated parts of the Shetland

Islands where laying fibre-optic cable would be too expensive or physically impossible. Instead, a radio link to a suitable node on the fibre-optic network offers a cheaper and easier solution with speeds of 50 Mbps possible and even 100 Mbps over distances of less than 250 metres using the latest laser technology. Radio connections are feasible for distances of up to two miles in a single hop, where a line of sight is required.

The main advantage of the Shetland Telecom service is that Shetland Broadband can access affordable resilient backhaul to supply local businesses and community schemes. While some of the microwave hops used on the network will need to be upgraded from time to time, the bulk of it is fibre-optic based, making it future-proofed.

THE NEED FOR SPEED

It's not surprising that people are eager to join community schemes to solve their broadband woes. The importance of reliable and fast broadband to rural communities and businesses, including farms, cannot be overstated.

Researchers from the universities of Aberdeen and Oxford interviewed people living in rural communities with poor internet access for a report entitled *Two Speed Britain*. They found instances of old people in Aberdeenshire unable to access government services and young people feeling excluded because they couldn't contact their friends via social media without going into town to get 3G signal. The report also highlighted that some rural businesses find it hard to deal with suppliers quickly and farmers need reliable access to the web to register new livestock and declare taxes.

WHAT DOES THE FUTURE HOLD?

The 2016 Queen's Speech included a statement that said every household in the UK should have access to high-speed broadband, and that legislation will be introduced to improve competitiveness and make the UK a world leader in the digital economy.

This is a reference the Digital Economy Bill, which proposes turning fast broadband into a 'Universal Service Obligation' (USO). Under this, a designated internet service provider would have to reach customers in the most remote parts of the UK and provide broadband speeds of a minimum of 10 Mbps, and consumers have the legal right to request this, no matter where they live.

Data from Ofcom suggests 10 Mbps is the speed needed to meet the demands of today's typical family and many small businesses. However, critics warn that this could be too slow in the future, especially as it will take time for the USO to be enforced; but BDUK has stated that the speed will be kept under review and could be increased if necessary. Commentators have also pointed out that faster

FURTHER EXAMPLES OF WHAT RURAL COMMUNITIES ARE DOING TO SOLVE BROADBAND ISSUES

From setting up elaborate fibre networks to DIY mobile masts, rural communities tired of waiting for broadband upgrades are coming up with their own solutions to boost speed.

DIY mast

Last year, a farmer named Richard Guy built a giant wooden internet mast in a field near his home in Salisbury, Wiltshire, so that he could get faster internet via mobile connection. He reportedly fixed solar panels, a 12V battery and 4G mobile receiver, or 'dongle', to the mast and connected it to his farmhouse using fibre-optic cables, resulting in speeds of up to 69 Mbps.

Help from BT

A small group of residents in the Leicestershire village of Coleorton became the 50th community in the UK to be connected to the fibre broadband network after working directly with Openreach, which is part of BT.

Villages not scheduled to receive fibre can use Openreach's Community Fibre Partnership Scheme, but need to pay for part of the cost of being connected. Residents of Coleorton Hall raised funds to have a new roadside fibre broadband cabinet installed outside the entrance to the grand building. Fibre cable from the nearest telephone exchange was brought to the new cabinet and from there, data travel over existing copper lines into the building.

Previously, each of the 22 apartments in the hall was connected by 'exchange only' telephone lines and residents struggled with internet speeds of between 1 and 2 Mbps. They now enjoy speeds of around 80 Mbps.

Satellite broadband

Rural Broadband, a company in Norfolk that supplies a range of satellite solutions, is an official partner of the government's Basic Broadband for All scheme, which subsidises satellite equipment for people who are unable to get a minimum 2 Mbps.

Customers can pick providers such as Avanti and Tooway via Rural Broadband and because the satellites they use are in different positions, far-flung homes and businesses should have the line of sight required between a satellite dish and one of the satellites to receive a reliable service. With top-of-the-range equipment, download speeds of 30 Mbps and upload speeds of 6 Mbps are possible, but standard packages enable download speeds of 20 Mbps and upload speeds of 2 Mbps.

broadband will not automatically be rolled out to areas without fast services, meaning better speeds in rural areas could take years; however, the request system could arguably simply ensure fibre is only deployed to areas that want it.

Additional funding to the tune of £400 million may be available for boosting broadband speed in rural Britain. This is partly because all of BDUK's contracts with BT contain a claw-back mechanism so that if take-up rises above 20%, BT is forced to return funds for reinvestment into superfast broadband coverage. It's been suggested that the additional money may mean broadband coverage could reach 97% by the time the current rollout is complete.

BT has already delivered one of the fastest fibre broadband rollouts anywhere in the world, reaching 25 million homes and businesses with fibre and is adding 25,000 premises a week. It is trialling a new technology called 'Long Reach VDSL', which it believes could boost speeds on longer, slower lines. It works by changing the configuration of BT's network to use the same frequencies at higher power levels, and it could allow signals to be carried further and therefore boost speeds for those who are far away from the nearest cabinet or exchange.

The telecoms giant claims to have ambitious plans to use FTTP and G.Fast technologies to upgrade speeds to 100 Mbps and above for 12 million premises by 2020 and the majority of the UK in 2025. G.Fast delivers ultrafast speeds over a mix of copper and fibre, building on Openreach's existing network. Billed as quick and lower cost to rollout, it's designed to go at distribution points tens of metres from the customer, so far higher capacity can be used – 106 MHz or five times that used in a cabinet – to give speed up to 1 Gbps 800 MB down and 200 MB up.

Once again, critics will argue that rural areas that are not financially lucrative to BT's business may well be left behind. The first nine locations to get ultrafast speeds using G.Fast include parts of Bath, Bradford, Bristol, Liverpool, Manchester and Salford, as well as Westminster, Holborn and the City, in London. The deployment over the next nine months will focus on clusters of SMEs without access to fibre broadband from Openreach.

In February 2016, Ofcom released its initial conclusions from its *Strategic Review of Digital Communications*, including that Openreach must open up its network of telegraph poles and underground tunnels to allow rivals to build their own, advanced fibre networks, connected directly to homes and offices.

It also said that Openreach must make its own decisions on budget, investment and strategy, in consultation with the wider industry and that the watchdog will introduce tougher rules on faults, repairs and installations, transparent information on service quality, and automatic compensation for consumers when things go wrong.

There are also plans to improve 4G mobile coverage across the UK, which typically provides average download speeds of 15 Mbps, according to Ofcom. The regulator, says it must reach 98% of the population's homes by the end of next year, meaning some people without any superfast access may be able to use a mobile for better broadband access in the future.

The UK's largest 4G operator, EE currently covers 95% of the population outdoors and providers may use small cells, voice over Wi-Fi and low-frequency spectrums to meet the ambitious aim of boosting signal indoors.

While 5G may be an exciting prospect for city-dwellers and is expected to be capable of delivering data speeds of between 10 and 50 Gbps when it's rolled out from 2020 onwards, it is unlikely that bringing it to the countryside will be a priority. The timeframe is uncertain and it will likely be rolled out in densely populated cities first to alleviate high demand for 4G, as well as enabling holographic projections and futuristic gaming.

WILL THE PROBLEM EVER BE SOLVED?

If BDUK's plans come to fruition, around 97% of the UK population will be able to receive broadband speeds of at least 24 Mbps by the time the project finishes, with BDUK confirming that it is on track and under budget.

What does seem certain is that a mixture of technologies will continue to be used. Openreach believes satellite, mobile and fixed radio may be the most appropriate solutions for remote parts of the UK, with fibre providing the backbone of the UK's broadband network.

While many people may fear that the UK's exit from the EU could disrupt BDUK and providers' plans, they are expected to continue as normal, at least in the next two years. Only time will tell if the UK leaving the EU will prove a game changer when it comes to rural broadband.

BIOGRAPHIES

Eric Malcomson is Chairman of Tove Valley Broadband in Northamptonshire. He started his professional life as a graduate civil engineer and progressed to computing, writing geographic information system applications for local authority and Ministry of Defence clients.

Marvin Smith is a Project Manager at Shetland Telecom, a project set up by Shetland Islands Council to develop and improve telecommunications in the remote Shetland Islands. Marvin's background is in economic development and has been focused on the telecommunications industry for over 10 years.

Map images on page 20 originally published in Farrington J, Philip LJ, Cottrill C, Abbott P, Blank G, Dutton W (2015) *Two-Speed Britain: Rural Internet Use*. Aberdeen University Press. Available at www.dotrural.ac.uk/two-speed-britain

The Laggan-Tormore gas project, mining gas from fields in waters west of the Shetland Islands, first came on line in February 2016 after being in development for six years. The gas-processing plant was the largest construction project in the UK since the London 2012 Olympic Park © Total

IN DEEP WATER: THE UK'S FIRST SUBSEA-TO-SHORE GAS PLANT

Lying 125 kilometres west of the Shetland Islands, the Laggan-Tormore project involved the development of two gas fields and construction of a gas-processing plant and export pipeline in some challenging circumstances. David Hainsworth, Operations Manager of Exploration and Production at Total UK, speaks to Nicholas Newman about the project and how innovation was key to its development.

Total's choice of subsea development of the Laggan-Tormore gas fields was innovative in UK waters. It was deemed to be essential for a number of reasons, including the depth of the gas fields at 600 metres below the service

Everything about Total's £3.5 billion Laggan-Tormore gas project is impressive. Part of it, the £800 million Shetland Gas Plant, was the UK's largest construction project since the London 2012 Olympics. In its entirety, it is also significant for being the first plant in the UK to adopt a subsea-to-shore development with no offshore surface infrastructure and is the first to use this technology on such a scale.

The project involved developing two gas fields, Laggan and Tormore, lying in the deep waters off the north-west of Shetland, installing underwater export pipelines and building a massive new gas-processing plant on the Shetland Islands. Formally opened in May 2016, the Laggan-Tormore gas project was undertaken in the harshest weather conditions imaginable and was completed in just six years, first coming on line in February 2016. When working at full capacity, Laggan-Tormore will supply between 8% and 10% of the UK's gas.

Laggan and Tormore are gas and condensate fields that are located in the waters between the Faroe Islands and the Shetlands Islands. Both reservoirs are made up of thin layers of gas-bearing sand, which are separated by thin layers of shale. The fields' reserves are estimated to exceed one trillion cubic feet of gas and condensates (about 230 million barrels of oil equivalent), making it one of the biggest natural gas finds in British deep waters. This set of gas fields is the first to be developed in the Atlantic margin, a region that until now was known primarily for its oil production.

First discovered in 1986, the Laggan field was licensed to Total in 1995, and two appraisal wells were completed in 2004 to determine the physical extent, reserves and likely production rate, with one recording a good flow rate of 37.8 million cubic feet of gas per day.

The discovery of the Tormore field in 2007 yielded a good average test flow rate of 32 million cubic feet of gas a day, which was considered to be sufficiently promising.

PROJECT DETAILS

- Ownership: Total E&P UK (60%), SSE E&P UK (20%) and Dong E&P (UK) (20%)
- Operator: Total E&P UK
- Location of fields: Laggan lies 16 kilometres from Tormore at a water depth of 600 metres. The fields lie 125 kilometres northwest off the Shetland Islands
- Size: Total field reserves estimated at one trillion cubic feet and condensates (about 230 million barrels of oil equivalent)
- Cost: £3.5 billion

SUBSEA-TO-SHORE DEVELOPMENT

Total's choice of subsea development of the Laggan-Tormore gas fields was innovative in UK waters. It was deemed to be essential for a number of reasons, including the depth of the gas fields at 600 metres below the surface and to meet the requirements of the climate, which is similar to Southern Alaska with an average wind speed of 15 miles per hour and hurricanes common in winter. The temperature of the seawater at -1°C and fast currents, at speeds of 0.64 metres per second, also influenced the decision.

The extreme weather conditions, depth of the wells and speed of the current made it impracticable to export the gas from the offshore fields using an FLNG (floating liquid natural gas) vessel to collect the gas, process it, then store and offload the gas onto LNG tankers.

The design concept, involving construction of a subsea pipeline network, was a safer and more reliable solution. However, developing a subsea production system with wells that are operated by semi-autonomous remote systems at a depth of 600 metres, located more than 140 kilometres offshore, presented complex engineering challenges.

The subsea template, a large steel structure that acts as a foundation base for various modular underwater structures so that subsea `trees' and `manifolds' can be attached (imagine a Lego base-plate for the foundation of a building), was installed in 2012. Upon completion, the West Phoenix, a semi-submersible rig operated by North Atlantic Drilling, drilled seven production wells: four on Laggan and three on Tormore,

By this stage, the project had achieved two `firsts' in UK waters: the installation of a deep-water subsea production system rather than a conventional platform and the lengthiest tieback (pipeline

The semi-autonomous subsea production system consists of two six-slot manifold templates that were installed on the seabed on each of the fields. Each manifold is made up of pipes and valves to safely transfer gas from the wellhead into the pipeline © Total

network) between offshore wells and an onshore terminal. This use of subsea tiebacks is an increasingly popular technique, especially in areas of deep water such as off the north-western Australian coast.

In order to access the gas, Total installed a semi-autonomous subsea production system consisting of two six-slot manifold templates on the seabed, one for each field. Each manifold is a large piece of equipment that is made up of pipes and valves to safely transfer gas from the wellhead into the pipeline through a series of chokes, isolation valves, multiphase flow meters, chemical injection, and control modules.

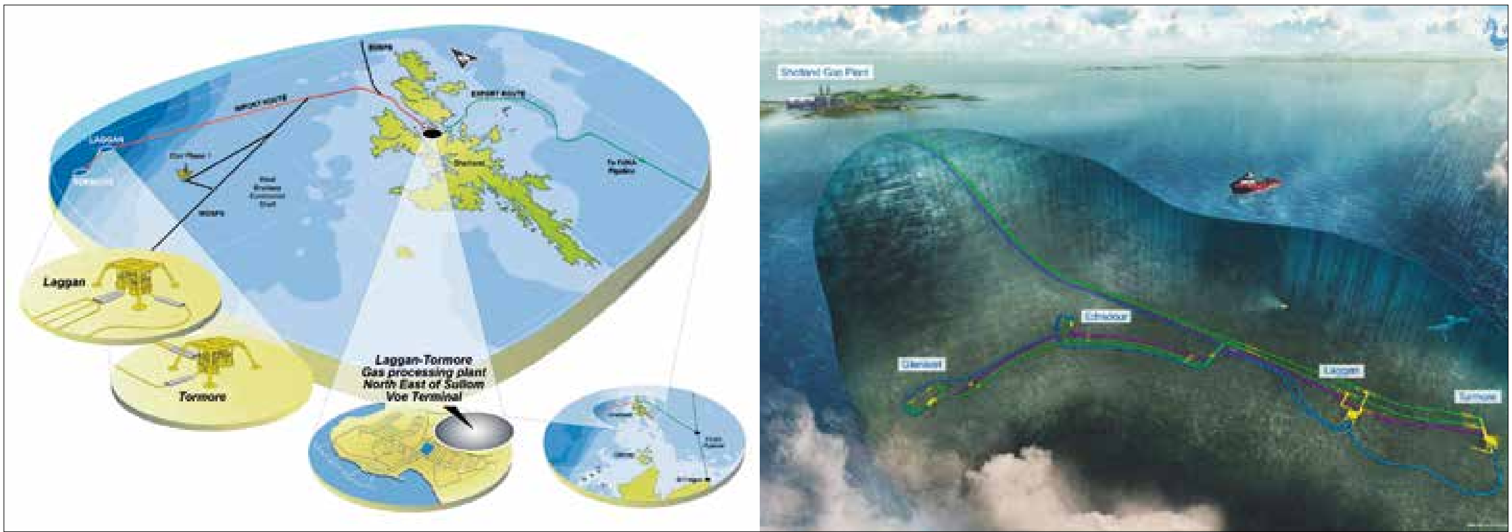
Two 10-inch headers, connected to two 18-inch import lines, collect gas from the individual wells. The subsea production system offers the flexibility for gas from any well to flow into either of these two production import lines.

Production from these fields began in February 2016: five wells are already producing over 90,000 barrels of oil equivalent per day. A 143-kilometre export pipeline carries the output to the Shetland Gas Plant.

INSTALLATION

Each manifold template is approximately 30 metres wide, 40 metres long, 21 metres high and weighs 900 tonnes, and was designed to anchor the subsea manifold to the seabed and ensure that they are not a risk to the local fishing fleet. The templates are anchored to the seabed through friction where the steel meets large suction cans.

Such deep waters precluded the use of divers to install the production system on the seabed. Instead, Heerema Marine Contractors handled the transportation and installation of the production systems on the Laggan and Tormore gas fields, using its Thialf heavy-lift vessel. Subsea work was sub-contracted to Aberdeen-based Specialist Subsea Services (S^3), which provided and operated



The subsea 143-kilometre pipeline from the Laggan-Tormore fields to the Shetland Gas Plant is a first for the UK. Once carried to the processing plant, the gas is exported to the UK mainland by the SIRGE pipeline. The subsea system and pipeline has the capacity to also link up the Glenlivet and Edradour fields that are currently being explored by Total © Total

the remotely operated underwater vehicles (ROVs) on the site for subsea installation work. The ROVs are tethered underwater mobile devices operated from a surface vessel via a cable, similar to drones but working underwater. ROVs are usually fitted with sonars, magnetometers, a still camera, a manipulator or cutting arm, water samplers, and instruments that measure water clarity, water temperature, water density, sound velocity, light penetration and temperature.

With a life expectancy of some 20 years, it is possible that if the technology develops sufficiently then a subsea compression booster unit may eventually be installed to extend the life of both fields. Over time, wellhead pressures decline and the pipeline export flow falls below a critical value, necessitating installation of compression boosters at each wellhead and one for each export pipeline. It is then possible to increase production and recovery from the reservoir by reducing backpressure on wells and increase the flow rate in the export pipelines.

LAYING THE PIPELINE

The pipeline part of the project consists of two distinct sets of pipeline networks: the network connecting the gas fields to the Shetland Gas Plant for processing and the Shetland Island Regional Gas Export (SIRGE) pipeline system, which transports processed gas from the Shetland Gas Plant to the UK mainland.

The network connecting Laggan and Tormore to Shetland comprises three pipelines and a communication or control umbilical. On the seabed, this network consists of the two 18-inch diameter flowlines that carry gas from the fields to Shetland for processing and an 8-inch diameter pipeline carrying MEG (mono ethylene glycol), used as 'antifreeze' in the flowlines, from the Shetland Gas Plant to the Laggan-Tormore field's production sites. Gravity causes the contents in the gas pipeline to separate into gas in the top half of the pipe, and the heavier gas liquids along the bottom half. The control-umbilical is deployed on the seabed to monitor and supply necessary control, energy and chemicals to the subsea infrastructure, including the remote-controlled operation.

Both the MEG pipeline and control-umbilical are buried under newly laid stone to protect them while the gas export pipelines are exposed to the elements. The second pipeline, the SIRGE system pipeline, consists of the 225-kilometre, 30-inch diameter gas export pipeline that leaves the Shetland Gas Plant to link up with the subsea gas junction on the Frigg-UK (FUKA) pipeline. From here, the gas is transported to the St Fergus Gas Terminal near Aberdeen and then distributed to the UK market. The SIRGE pipeline has the capacity to transmit at least 665 million standard cubic feet of Laggan-Tormore gas per day at a temperature of 15°C.

The entire pipeline network was constructed from an estimated 200,000 tonnes of high-grade steel, and the pipes are fully protected internally by a three-layer polypropylene anti-corrosion coating, internal flow-efficiency coating and concrete-weight coating. This pipeline network is regularly inspected and can be cleaned by using a 'pig', a device that is inserted into the pipeline to perform various maintenance

A major part of the Laggan-Tormore project was the offshore installation of two parallel 18-inch flowlines (141 kilometres each) and a 225 kilometre 30-inch export pipeline, all complete with inline valve structures © Total

operations. They are used in oil and gas pipelines to clean the pipes and there are also 'smart pigs' used to inspect pipelines for detecting leaks that can be explosive and dangerous to the environment. They do not usually interrupt production, although some product can be lost when the 'pig' is extracted from the pipe.

Seawater temperatures of at least -1°C surrounding the two export pipelines presented the chemical engineers with the need to prevent crystallisation of the gas output during its journey to the Shetland Islands. The solution was to inject MEG to stop the condensate freezing at the start of its journey. When the gas arrives at the Shetland Gas Plant for processing, the MEG is removed and pumped back to the wellheads to start its journey again.

The two pipelines linking the gas fields with the Shetland Gas Plant were laid using a range of vessels. In May 2010, Subsea 7 (a seabed-to-surface engineering construction and services contractor to the offshore energy industry) was awarded the contract to supply subsea infrastructure items. Its principal tasks included the fabrication and installation of the 143-kilometre 8-inch and 2-inch piggybacked service pipelines (where the secondary pipeline is attached to the main one using a clamp), as well as the installation of the two control-umbilicals with all their associated structures and tie-ins.

The world's largest pipe-laying vessel, the 300-metre long Solitaire was used to lay the 243-kilometre SIRGE system pipeline linking the Shetland Gas Plant with the FUKA pipeline. The section on land was laid in an excavated trench, then covered with steel netting for reinforcement before having the spoil from the excavation laid on top. Once in the sea, the concrete coating ensured that the pipeline was heavy enough to sink. However, for its first 300 m underwater, the pipeline lies in a two-and-a-half-metre deep trench that has been specially created from a stone causeway extending from the beach at Firths Voe. The trench was dug by the backhoe dredger Abercoserver, a hydraulic excavator, with the ocean-going tug Baloo working at the excavation. Sophisticated sonar equipment was used to guide digging from the ships in order to avoid the Brent pipeline, which also enters the sea from this beach.

SHETLAND GAS PLANT

Construction on the £800 million Shetland Gas Plant began in 2010 and was handed over to Total by lead contractor, Petrofac Offshore Engineering & Operations, in December 2015 so that the complete range of command and control systems could be tested. The first gas arrived in February 2016, and in April, the second gas compressor came online.

The plant is located next to the Sullum Voe Terminal for oil and gas on the main island of Shetland. It took more than two years to complete, creating 800 jobs during construction, and employs 70 people today.

The plant is situated on a Greenfield site that presented engineers with a number of challenges before construction could begin. In preparation, a substantial amount of earth needed to be moved and the bedrock was terraced, a soil conservation practice consisting of ridges and channels to prevent rainfall runoff on sloping

Up to 500 million standard cubic feet of gas can be processed each day; an amount that is enough to meet the energy needs of two million homes

Before construction could begin on the Shetland Gas Plant, a substantial amount of earth was moved. The soil and peat that was excavated was used to extend the terracing of the bedrock and two large peat stores were designed and created to accommodate the material so that the peat can be recycled to restore the site to its predevelopment condition at the end of the plant's life © Total

land from accumulating and causing serious erosion. The soil and peat that was excavated from the back of each level was then used to extend the front of each terrace, supplemented by material from local quarries.

In order to maximise the long-term sustainability of the plant, two large peat stores were designed and created to accommodate some 650,000 cubic metres of material excavated from the site during these pre-construction phases. This means that the peat was not destroyed and its CO_2 remains safely locked in thus avoiding the inevitable emissions that transportation would cause. At the end of the plant's life, these stores can be removed and the peat can be recycled to restore the site to its predevelopment condition. There was also rigorous protection of the local wildlife and the archaeology of the site.

The Shetland Gas Plant is designed to separate Laggan-Tormore raw gas using a three-phase separator system. The well fluid is separated into gas, oil and water with the three fluids being discharged separately. The associated liquid hydrocarbons are exported to the Sullom Voe Terminal, and treated gas from the plant is exported to the FUKA pipeline in the North Sea via the SIRGE pipeline.

Up to 500 million standard cubic feet of gas can be processed each day; an amount that is enough to meet the energy needs of two million homes. In anticipation of the Edradour field coming online in 2017 and Glenlivet in 2018, modifications will be made to the Shetland Gas Plant's controls and mercury removal facilities will need to be installed.

Everything that goes on in the plant is controlled round-the-clock by a team based in the onsite control room. The team is responsible for continuous monitoring to ensure the safe operation of the plant's systems, which includes its effluent water treatment and oil water treatment packages. For training purposes, and in preparation for different operational scenarios, the team has access to process

SITE STATISTICS

The Shetland Gas Plant occupies an area of approximately 540,000 square metres and the build required:

- at peak, a construction workforce of around 2,000
- 62 modules, weighing an average of 250 tonnes each
- construction of a 2.4 kilometre road to access the new plant
- 39,000 cubic metres of concrete
- 3,900 tonnes of steel
- 15,000 metre of underground glass-reinforced epoxy pipes
- 1,500 kilometre of electrical and instrument cabling
- a 90-metre-high flare.

The Shetland Gas Plant took more than two years to complete, creating 800 jobs during construction, and employs 70 people today © Total

plant simulators, a pipeline, the Integrated Control and Safety Systems, and the Subsea and Topside Control System.

FUTURE DEVELOPMENTS

The whole pipeline system has been designed and built to accommodate increased production from existing and future fields. In anticipation of future production, passive junctions have been fitted with hot tap tees that will enable future branch pipelines to be fitted to the Laggan-Tormore pipeline network. In fact, the Edradour and Glenlivert fields, which are named after Scottish whiskies, are only viable prospects because of the pipeline network built for Laggan-Tormore.

Development of the Edradour gas field was officially launched in July 2014 and production is expected to start in 2017 when the pipeline link to the existing Laggan-Tormore fields is ready. The plan is for production to continue for 15 years, delivering 17,000 barrels of oil-equivalent per day at peak.

There are also ongoing plans to develop two wells on the neighbouring Glenlivert field tied back to the Edradour field's facilities via a 17-kilometre production pipeline. The reservoir fluid in the Glenlivert field is estimated to be a light gas-condensate with a condensate-gas ratio of approximately 16 barrels per million standard cubic feet. Drilling of the wells has begun and the pipelines, subsea structures and umbilical line will be installed between 2016 and 2017, while tie-in and commissioning will take place in mid-2018.

As to the future, any gas from fields found further west in Faroese waters could be transmitted to the UK mainland by the existing infrastructure put in place for the Laggan-Tormore fields.

BIOGRAPHY

David Hainsworth is Operations Manager of Exploration and Production at Total UK. Before joining Total in 1995, he worked as a safety consultant in the nuclear and oil and gas industries. David holds a degree in chemical engineering from the University of Edinburgh and is a member of the Institution of Chemical Engineers.

The 2016 MacRobert Award-winning Linx limb system, developed by Blatchford, is the first ever prosthetic limb with integrated robotic control of the knee and foot, in which the sensors work together so that users can walk, balance and be supported on all types of terrain © Blatchford

INTELLIGENT PROSTHETICS

Although prosthetic limbs can help many amputees regain independence and mobility, prosthetic wearers across the world are often limited in what they can do or where they can go. The Linx limb system, developed by Blatchford, has smart robotics that constantly monitor and adapt to movement, making walking and movement more natural for lower-leg amputees. After winning the 2016 MacRobert Award, Professor Saeed Zahedi OBE FREng, Technical Director at Blatchford Group, talks to Richard Gray about the engineering behind Linx.

Thousands of people each year suffer the loss of one or both of their legs to amputation following an injury or disease. There are some 45,000 people who rely on prosthetic limbs in England alone and across the UK around 5,000 people each year have lower-limb amputations. In the US, there are an estimated two million people living with an amputated limb. It is a completely life-changing event, robbing people of abilities that most take for granted, such as walking, running and even standing still.

While prosthetic limbs can help give amputees back some of their mobility, they can be far from perfect. Tackling obstacles such as ramps, kerbs and steps with a prosthetic leg can be intimidating, and many lower-leg prosthetic wearers have to carefully plan their days to avoid such tricky terrain.

However, new technology is transforming prosthetic legs from being inert supports to limbs that react and respond to different terrains and movement. Blatchford, a family run company based in Basingstoke, Hampshire, has developed the first ever prosthetic limb that combines robotic control of both the knee and the ankle to ensure that they work together much like a real human leg. According to Chair of the MacRobert award judging panel, Dr Dame Sue Ion DBE FREng, this innovative development "has combined a compassionate approach to patient needs with huge ambition and exceptional systems engineering". The Linx limb system went on to win the Royal Academy of Engineering 2016 MacRobert Award.

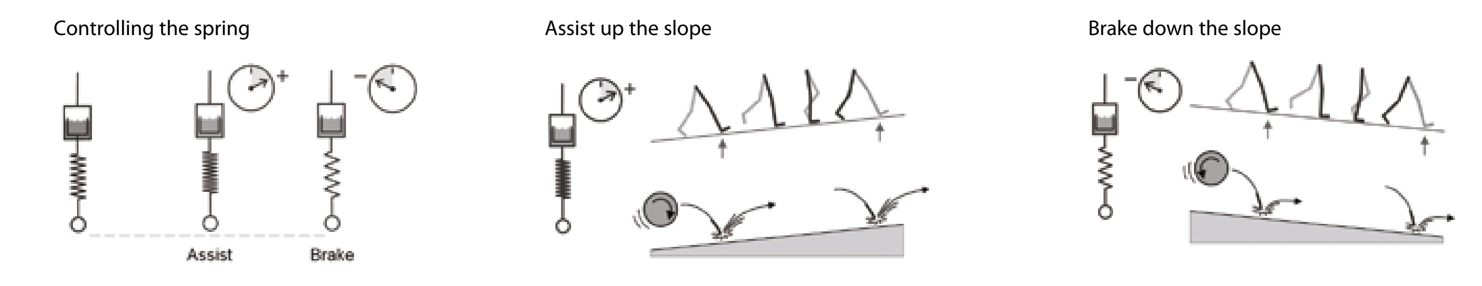
THE PROBLEMS WITH PROSTHETICS

Walking down a ramp without control of the leg joints will cause them to bend and flex on their own. If they rotate too easily, it can produce the sensation of constantly falling forward and the wearer needs to walk in a way that compensates for that. Equally, if the joints offer more resistance, it can make walking in the other direction, up a hill or a flight of stairs, a painful struggle. Without enough movement in the ankle, for example, a prosthetic leg wearer has to pivot around their prosthetic leg with their healthy leg to make progress.

An amputee who has lost their leg from above the knee – known as transfemoral amputation – expends 60% to 80% more energy walking than someone with both their legs, while transtibial amputees – who have lost their leg below the knee – use 30% more energy. Running and other rapid movements require special limbs that are ill-suited to more mundane tasks. The famous running blades worn by athletes are not designed to be used when standing still and those wearing them can only stay balanced by moving constantly. Just standing still can also be a challenge for people with prosthetic legs, requiring extra energy and concentration to remain steady, which can quickly become exhausting. The toll that this can take on the human body is profound.

Amputees can suffer severe back pain that needs to be treated with powerful prescription painkillers because of the extra strain caused by the unnatural gait and stances they have to adopt. They are 17 times more likely to need a hip replacement after 20 years of using a prosthetic limb and 14 times more likely to need a knee replacement in their healthy limb due to the extra load that these joints are put under.

Blatchford's Linx limb system uses data from seven sensors in the foot, ankle, knee and main body of the prosthesis to detect changes in the terrain, the user's movement and the activity they are performing. These sensors essentially mimic what the nerves in a real leg would be doing, but rather than feeding the information



The Linx limb system's springs are biomimetic viscoelastic models that control the level of energy absorption and damping resistance. When walking up a slope, the rollover of the spring minimises impact on collision with the ground to maximise forward momentum. When walking down a hill, the rollover maximises the damping on collision with the ground to reduce forward momentum

to the brain, it instead goes to a central microprocessor, which then works out how to adapt the movement of the joints. A network of springs and dampers, which work similarly to the shock absorbers in a car, allow the joints to absorb energy and either return it when needed to help a movement such as walking upstairs, or provide a braking mechanism in situations including walking down a hill. As a result, wearers can walk more naturally and with greater stability than other prosthetic limbs allow.

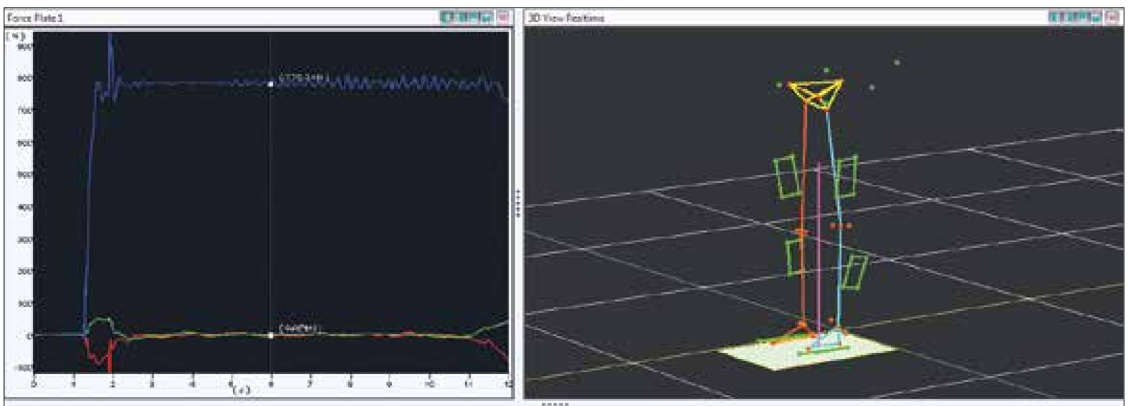
BASED ON BIOLOGY

Blatchford's goal was to provide amputees with prosthetic limbs that behaved far more like the real thing, and the Linx system is the culmination of 40 years of development to introduce increased functionality and adaptability into prosthetic limbs. The company began thinking about how to replicate the action of the muscles in the human leg that pull against each other to control how joints bend. To do this, Blatchford first began to develop the use of hydraulic systems to control the movement of knees in prosthetic limbs in the 1970s and 1980s. Its engineers turned to carbon-fibre composite springs and hydraulic dampers to become the muscles' mechanical equivalents. With each step, the springs in the knee, ankle and toes store energy, ready to release it again to propel the joint forward. The dampers help to control the springs, absorbing excess energy and providing resistance to prevent the joints from moving too quickly or too much. The key is how to adapt to the wide variety of terrain that people encounter during their daily lives.

In 1989, Blatchford created the first limb with a microprocessor controller in the knee. This marked a gear change in the functionality that was possible, allowing the limb to control the speed of movement according to the activity, such as descending a staircase.

Through the 2000s, the company began developing innovative joints that produced smoother gait and better control, and the addition of independent movement to the heel and toe of the prosthetic limb created far more fluid movements. If the wearer is walking down a slope, for example, the system recognises the angle from the sensors around the limb. This increases the resistance provided by hydraulic dampers at the toes to stop the energy being absorbed by the spring, which would cause it to propel the limb forward.

Biomechanical analysis carried out by Blatchford showed that changes in resistance of the knee joint influenced the ankle-to-foot joint and vice versa. This led to a 'brake' mode being developed that not only worked to stop the knee sinking forward on a downward slope, but also acted in the ankle to reduce the amount of momentum transferred to the next step by 42%. This means amputees can put less effort into resisting gravity as they descend and gives them a sense of stability and support as they walk downhill.



During development of the Linx system, a 3D motion capture system was used to measure lower-limb joint kinematics. Inverse dynamics methods (a process of calculating kinetic information) were used to quantify hip power reduction during movement and balance while standing with equal loading on an incline

The Linx system fluidly provides physiological motion based on biomimetic principles of gait and posture. The master control unit coordinates the responses of the whole system to achieve smooth interaction between the system parts © Blatchford

However, when walking uphill, the damping at the ankle might be increased to absorb some of the energy but reduced at the knee so the springs can produce the right level of energy to take a step upwards. The result is that the amputee feels like they are being assisted up the slope by the limb.

In 2010, the company introduced the first hydraulic ankles; later on, these were given their own microprocessor to control the amount of energy they could absorb and release. For an above-knee amputee wearing both an artificial knee and ankle, the limbs would contain two 'brains' that each independently controlled the movement of each joint. However, the Linx is the first prosthetic limb to integrate the control of the knee and ankle together and produce a far more natural movement.

By combining these technologies, Blatchford believes it has been able to reduce by half the amount of extra energy a person wearing a prosthesis needs to expend to compensate for the lost limb. For example, the first microprocessor-controlled knee reduced energy expended by the wearer by 25%. Adding a microprocessor to the ankle reduced it by a further 18%, while integrating the control of both joints with a single processor in the Linx took it down by another 8%.

The Linx limb system has also been designed so that it will automatically enter a standing mode when the wearer remains still for longer periods of time. In tests it was found that the combination of stiffening both the foot and knee was most beneficial to reduce strain on the amputee. However, locking the ankle too early could be detrimental to stability and posture, so the Linx algorithm waits until the limb reaches a 'steady state' before stiffening up to provide support.

SMART TECHNOLOGY

The system is designed so that it can be fitted to a wide range of patients of different size and weight. Once fitted, the Linx's central computer is programmed by a clinician so that it learns how the wearer walks naturally and adapts accordingly. This is done via a Bluetooth connection to a desktop program that shows in real time what the sensors are picking up as it detects the wearer's natural speed and movements. A smart motion-integrated intelligence algorithm then calibrates the limb automatically in one simple step as the knee and the foot sensors 'talk' to each other, causing the limb to adjust more than 2,000 times a day to adapt to the environment. Previous prosthetics would require each set to be calibrated in turn in a lengthy process that would often require repeat adjustments.

An obvious approach might have been to actively power the limbs with actuators and hydraulics that propel the prosthesis, such as real muscles do. However, during development it was found that with the motors and batteries needed to power and drive them in this way, the limbs became too heavy. This extra weight would also make the leg harder to control as it swings and cancels out the extra power provided by the motors. Ultimately, a motorised prosthetic leg seemed unnecessary as the wearer can provide energy with each step as their weight pushes down onto the limb.

Blatchford developed the limb system's onboard batteries so that they would provide enough power for several days, while the limb's weight is kept to around two kilograms, less than a quarter of the weight of an average human leg.

The MacRobert Award was presented to the Blatchford team (L–R: Dr David Moser, Principal Mechatronic Engineer; Andy Sykes, Principal Electronic Engineer; Rob painter, Senior Mechanical Engineer; Nadine Stech, Senior Control Engineer; and Professor Saeed Zahedi OBE FREng, Technical Director) by HRH The Princess Royal and Professor Dame Ann Dowling OM DBE FREng FRS, President of the Royal Academy of Engineering

CHANGING LIVES

The first Linx limb systems were manufactured in April 2015, and more than a year later there are now around 300 amputees wearing and using the Linx worldwide, mostly in the USA and Norway. However, at the cost of £25,000, the limb currently remains mostly outside NHS budgets.

Some people, such as Jack Eyres, a personal trainer from Bournemouth who had his right leg amputated at age 16, have found that with Linx they are now able to take part in activities that would never have been possible for them in the past. Living close to the sea, Mr Eyres is able to hike along the uneven cliff tops near his home, something that he would have avoided in the past. He is also able to train as a boxer, using the Linx limb to keep himself steady as he throws punches into the punchbag.

CONSTANT INNOVATION

For Blatchford, this is just the start of a new era of prosthetic limbs that contain integrated, intelligent control but the goal of creating limbs that are as good as the real thing still remains some way off. The company is already working on the next step of integrating the whole leg so that the prosthesis becomes more a part of the body, and is working to improve the interface between the residual stump and the prosthesis, which will be a key aspect of any new designs. New liners that reduce sweating and enhance comfort will mean that amputees can wear their prosthesis for longer and with ease, and Blatchford wants to use this to integrate the machine and the human together. Initially, it may mean that the wearer can get feedback on the skin of the residual limb about what the prosthesis is doing, such as tiny electrical signals from sensors around the prosthesis that could stimulate the skin to help the amputee 'feel' the ground beneath them.

Beyond this, Blatchford is looking at potentially connecting the prosthesis to the nerve endings in the residual limb so those sensations can feed directly to the brain. It could ultimately lead to limbs that respond intuitively while giving the wearers a sense that they control it. With an ageing population and many people likely to live until they are close to 100, the need for a prosthesis that can let amputees go about their lives independently and maintain the lifestyle they want is crucial. Linx is a step towards that goal.

BIOGRAPHY

Professor Saeed Zahedi OBE FREng has been Technical Director at Blatchford for more than 10 years. He has over 40 years of experience in prosthetic innovation and is currently Vice Chairman of the UK delegation of the International Society of Prosthetics and Orthotics. Professor Zahedi has authored more than 125 papers, developed 35 patents and has won a number of awards, including a Special Commendation in the Prince Philip Designers Prize and a British Healthcare Trades Association lifetime achievement award.

SILVER MEDALLISTS

The Royal Academy of Engineering Silver Medal recognises outstanding personal contributions by early- or mid-career engineers that have resulted in successful market exploitation. 2016's winners were selected from a long list of nominations, drawn from many areas of contemporary engineering.

DR DAMIAN GARDINER

Dr Damian Gardiner is a research scientist and Business Development Manager at Johnson Matthey. The company's Process Technologies Division acquired his University of Cambridge start-up company, ilumink Limited, in 2015.

Over the past 10 years, Dr Gardiner has developed a unique method of printing 'liquid crystal' material onto any surface using an ink-jet printer, which is a secure, economical and practical way of security-tagging products such as cosmetics, perfumes, drugs and banknotes. It supports multiple layers of authentication, taking the form of digital images that change colour with direction. However, ilumink also allows the inclusion of unique, hidden optical elements and highly secure, forensic-level elements – all of which are practically impossible to fake.

The global counterfeit goods industry is thought to cost genuine brands up to £1 trillion every year and it also claims lives. The World Health Organisation estimates that around one million people a year die from taking counterfeit medicines. Interpol warns that counterfeiters are becoming increasingly sophisticated, with technological capacity to reproduce holographic labels and fake provenance or quality.

Dr Gardiner developed ilumink's technology as a researcher in the University of Cambridge's Department of Engineering. In 2013, he was awarded a Royal Academy of Engineering Enterprise Fellowship to kickstart the commercial exploitation of his invention, which included mentoring support from successful entrepreneurs among the Academy's Fellows.

Dr Gardiner led the integration of ilumink into Johnson Matthey, and is now working with specialists at the company to bring his invention to a global market with the extra resources and credibility of the larger company.

Through acquisition by Johnson Matthey, Dr Gardiner has successfully positioned ilumink as a high-value, exportable UK technology that effectively targets a significant global market, with the backing of a leading UK engineering company.

Dr Damian Gardiner's initial research for ilumink was carried out using facilities at the University of Cambridge's Department of Engineering

DeepMind differs from many other AI efforts in that it is developing general AI, machine intelligence capable of learning for itself how to do a task directly from raw data, rather than being pre-programmed for a single specific task

DR DEMIS HASSABIS

Dr Demis Hassabis is co-founder and CEO of Google's DeepMind subsidiary, which has made a number of pioneering breakthroughs in artificial intelligence (AI). Founded in 2010 and acquired by Google in 2014, DeepMind's AlphaGo project successfully beat the world's number one Go player, long seen as a grand challenge of AI research, in a contest in Seoul this year, watched online by 280 million viewers.

Dr Hassabis' achievements began at a young age when he developed the breakthrough simulation game *Theme Park* at the age of 17. After completing a degree in computer science at the University of Cambridge, he went on to be the lead AI programmer on a number of successful computer games in the 1990s and early 2000s, before finishing a PhD in cognitive neuroscience in 2009 at University College London. His interests and experience led him into a role as a research fellow working on computational models of memory and imagination, forming the basis for some of the cutting-edge neuroscience-inspired AI research later undertaken at DeepMind.

DeepMind differs from many other AI efforts in that it is developing general AI, machine intelligence capable of learning for itself how to do a task directly from raw data, rather than being pre-programmed for a single specific task. Taking only the pixels of a computer screen as inputs, DeepMind's deep reinforcement learning system learned to master dozens of Atari games from *Space Invaders* through to *Breakout*, a breakthrough that was featured on the front cover of the scientific journal *Nature*.

DeepMind's breakthrough AI system was able to learn and master a number of video games, and was featured in scientific journal *Nature*
© Google DeepMind

The ancient game of Go is said to be the most profound game ever devised. In order to crack Go, the pinnacle of 'perfect information' games, DeepMind had to develop AlphaGo, a complex program that could run on distributed computer networks with 100s of graphics processor units. The system was engineered so that different versions of the program could play against each other and improve by learning from their mistakes.

Although games are a good test bed for developing general AI algorithms, the ultimate aim is to apply these technologies to important real-world problems in areas such as healthcare and science. AI is set to become one of the most important technologies of the next decade and DeepMind led by Dr Hassabis is in the vanguard of this field.

Professor Sun's work has also enabled the design of special humidity sensors that are being used in widely different and challenging environments

PROFESSOR TONG SUN

Professor Tong Sun is an international leader in the use of optical fibre sensors to monitor sensitive equipment, particularly in extreme conditions. Currently Director of the Photonics and Instrumentation Research Centre at City University London, she was the first female professor to be appointed at the university's School of Engineering (as it then was) in its 100-year history. Originally from China, she came to London as a postdoctoral researcher and spent a year at Nanyang Technological University in Singapore in 2000.

One of Professor Sun's major new projects is a fibre-optic sensor system to measure strain and temperature changes in pantographs – the connectors used by electric trains to link to overhead power cables. Pantographs are crucial systems, so they are inspected regularly as a key part of the train maintenance schedule. However, visual checks can easily miss vital clues and integrated fibre-optic sensors offer continuous monitoring of these high voltage systems while they are in operation and in all weathers. UK manufacturer Brecknell Willis is now starting to build new instrumented pantograph systems.

Professor Sun's work has also enabled the design of special humidity sensors that are being used in widely different and challenging environments. Sydney Water is using them in highly acidic sewers while China's Shandong Academy of Science is configuring the sensors to monitor rice stores to try and stop rot setting in – food spoilage is a big problem in humid climates. She has also worked with the Home Office and Smiths Detection as part of the Cargo Screening Ferret project, in which her sensors enable a 'robotic nose' to specifically detect illicit substances such as cocaine, particularly when it is loaded in freight with other loads that may mask its presence.

These novel ideas in creating and applying sensing using optical fibres have been recognised by both industry and government as strategically important in addressing challenges and giving the UK the technical lead in the field.

Professor Sun's fibre-optic sensor system will be able to monitor strain and temperature changes in pantographs that could be easily missed in visual checks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INSPIRED WORK

Steve Holliday FREng oversaw a revolution in the UK's energy sector during his decade as CEO of National Grid © National Grid

ENERGY WITH CONNECTIONS

When Steve Holliday FREng moved from the oil industry into energy distribution, the sector was seen as staid. In reality, during his years at National Grid, the sector became increasingly important as the need to tackle climate change led to a transformation in the UK's energy mix. As he explains to Michael Kenward OBE, this meant managing the business through a few revolutions.

For someone whose engineering career started in the oil and gas business – running refineries and managing shipping fleets among other jobs – taking on energy distribution could have been a dull career move. After all, in the 1990s, energy transmission was seen as a utility, a matter of taking electricity from large power stations and gas from oilfields and carrying them through national networks of power lines and pipes. Steve Holliday FREng joined National Grid in 2001 with a remit to cast an outsider's eye over the recently privatised electricity distributor. Holliday soon found himself overseeing a merger that was to bring energy transmission and distribution to the forefront of energy policy. As he puts it: "The fossil fuel industry is interesting, but it is not where things are at in terms of the transformations going on right now."

Holliday has an distinctive way of describing the fundamental change that he helped to manage in his 15 years at National Grid, 10 of which he spent as the company's CEO. "When I joined this industry, if a new energy minister got together a dinner of the energy industry in the UK, he or she would sit next to BP and Shell, and you work your way out through National Power and PowerGen. National Grid would be on the outside of the ring. Today, the energy minister would sit next to the CEO of National Grid."

FROM MINING TO SHIPPING

Had Holliday's early career gone to plan, he could have ended up in a part of the energy business that had left the room long before dinner arrived. After studying A levels in maths, physics and chemistry, Holliday changed his mind about a career in medicine and decided that mining engineering looked interesting. "Mining appeared to be global and exciting," he says. It also fitted in with one of his childhood pursuits: "I had done a lot of caving as a kid."

Holliday went to the University of Nottingham to study the subject but soon changed his mind about mining and became interested in the oil industry. "It became fairly clear, very shortly into the course, that I was never going to actually work in the mining industry."

This was at the beginning of the UK's North Sea oil boom. Fortunately, Nottingham's engineering course was flexible. "You could actually choose a petroleum engineering module so I ended up drifting towards the oil industry."

When he graduated, Holliday applied "to all of the oil companies" hoping to work in the upstream part of the business, finding and recovering oil and gas. Unfortunately, Esso UK, the company he liked and that liked him, was a small player in the upstream business. The good news was that the company liked to pitch promising recruits into the downstream area, which is how Holliday began his engineering career in an oil refinery.

Holliday admits that he had limited knowledge of chemical engineering, but Esso ran what he describes as a two-month chemical engineering deep dive. "I remember thinking to myself that this is quite interesting, perhaps I should become a chemical engineer. It didn't turn me into one but it gave me an appreciation of chemical engineering."

Once his education was topped up, Esso set Holliday to work as a process engineer at its Fawley refinery near Southampton on the piping and the shipping terminal where tankers arrived with crude oil. As Holliday describes it, the work, as a process engineer, was "lots of fluid mechanics and mechanical engineering".

Fawley was one of the places where Esso turned engineering graduates into managers, a process that meant moving between jobs to get to know the business. After three years, Holliday moved into the planning department and energy distribution. "I was scheduling ships into the refinery and working with people about where the ships were coming from in the Middle East. I loved that job." Was it really engineering? Probably not, Holliday admits, then again, he ripostes, "there is engineering in every job isn't there?" Planning is where Holliday's work mattered to the wider world. "You had an important role to play. If there was a problem at night, then they phoned you at home. That is what really excited me, doing something that was relevant and important to others."

He ended up being promoted to a supervisor, running a part of the operation. "Esso in those days was fantastic at giving young people opportunities," he says. "At 26, I had about 100 people working for me."

Holliday spent a lot of time during a maintenance shutdown of the catalytic cracking unit, "crawling through every vessel I possibly could to see how this thing actually worked. It was brilliant." Someone at Esso must have seen the trail he left: after the shutdown they put him in charge of the plant, a very heavy chemical engineering job.

Two years later, Holliday moved to headquarters to work in oil trading, but within a year it was back to Fawley to run the whole operation. In all, Holliday spent around 13 years at the refinery. "I loved that

In 2013, Steve Holliday was presented with an honorary degree from the University of Strathclyde that recognised his contribution to the power and energy sector, and its importance to the Scottish economy © University of Strathclyde

place. It was just an exciting place to be. There was always something happening. The sense of size, the investment that was going in then was phenomenal, challenging lots of things from the past." He admits that it was an emotional departure when he drove out for the last time. "I spent a big chunk of my life there and I had wonderful times. I knew that I was never going back."

MOVING UPSTREAM

In 1994, Holliday finally received the call from the upstream business that he had wanted to get into as a fresh graduate. He moved to New Jersey in the USA to learn about the natural gas business with responsibility for operations in Australia, Malaysia, Thailand, Indonesia and the new markets of China and Korea that Exxon was trying to get into.

Holliday's next move was very different. In 1997, he climbed off Exxon's career escalator and moved from a company with 60,000 to 70,000 employees to a become a board member of a small exploration and production company with just 500 employees. His remit was to expand the business internationally. When his bosses at Exxon asked why he wanted to make the metaphorical jump from a tanker into a rowing boat, he replied that the board position was part of the attraction, with "a different sort of challenge; much more entrepreneurial". He could also see that times were changing in big oil. "I had had a brilliant 19 years, but the future didn't look as good as the past in many ways."

He wasn't to know it at the time, but the future wouldn't look that good for small companies either. Oil prices collapsed in 2000 and ENI in Italy acquired his new employer. After a few months working on mergers and acquisitions for ENI, Holliday was head-hunted for a job with National Grid.

Not long privatised, the company ran the UK's electricity distribution network. Within months of joining National Grid, Holliday was heading up negotiations to take over Transco, the company that operated the UK's gas network.

This is when Holliday began playing his part in changing the shape of the UK's energy industry. After signing the Transco deal, Holliday's next job was to integrate the electricity and gas transmission networks. "I remember going to a few conferences in those days and people saying that there was no logic in putting electricity and gas together; they are so different. No-one would ask that question today."

With the merger sorted out, in 2003 Holliday took control of the company's gas distribution business, selling off half of the gas networks that National Grid then owned. "There were diseconomies of scale [increased per-unit costs in the long run] actually. Some of the ideas that I and my team had on how we should run the business were very hard to implement across the whole of Great Britain. We could implement it on a smaller platform and there was an opportunity to create some value by recycling some capital out of that business."

Splitting the gas networks involved creating "an extensive number of protocols and codes as to how the businesses would interact with each other". For example, a separate business had to be created to hold and maintain the database of all the gas meters in the UK on behalf of the industry. This plan brought Holliday into ever closer contact with the regulators set up by government to oversee the privatised energy businesses. These contacts moved up a step in 2007 when he became CEO. He was now firmly embedded in the domain of energy policy.

Holliday is not one to complain that the UK does not have an energy policy. He has a very different take on the concept. "In the last few years, people were often bemoaning how it has been a bumpy road but we are in a revolution actually."

As an aside, he observes that while the government talks of not wanting to prescribe the UK's energy mix, it has in fact done so "in a sort of backdoor way" with last year's statement that there will be no coal-fired power stations on the system by 2020. "That is half prescribing it isn't it?"

Holliday may be puzzled by the contradiction in the government's stance on the fuel mix, but he is no great supporter of coal as an energy source. National Grid has a legal obligation to connect any generation in the UK but personally he is keen on renewable energy. "We have to be agnostic," he explains, "but that did not mean that we could not be passionate about the science of climate change and that we would certainly do all that we could inside our own business to reduce our carbon footprint. Anything that we can do to facilitate clean energy, we would do." Inside the energy business, Holliday has been something of a campaigner for measures to mitigate climate change.

There is one area where Holliday is more animated on energy policy – smart meters. He sees smart electricity meters and other technologies as an important part of the UK's energy strategy but there are limits. "In my mind, one of the most ridiculous decisions in the UK is to put a smart meter on gas. On electricity yes, because you want to be able to control things. You could sign a contract with us at your home that will allow someone to control your power say, 'when power is above the price of X I want to reduce my load to a minimum please'. With gas, it is called a thermostat."

Smart electricity meters, on the other hand, can be an important 'resource', as Holliday explains with a look at the likely scenarios for the country's energy supply. National Grid started publishing its own scenarios about five years ago as a part of its legal obligation. The exercise not only guides the company in its thinking on investment but also allows others in the industry to refine their own. He illustrates this with a simple diagram of what the energy mix could look like in 2040, listing nuclear power, solar and wind in three separate quadrants with the fourth given over to 'flexibility', which is where smart meters come in.

Even today's energy mix shows how much has changed over the past decade, and why energy distribution has grown in importance. "In the course of the last six or seven years, we have built a phenomenal renewable energy supply in this country from a standing start. Costs have come down amazingly and they will probably come down further."

MOVING ON

After four decades in energy, Holliday maintains his enthusiasm for the business, especially networks. "I had no idea that I was entering an industry that hitherto had been seen as dull. The word utility says something in terms of its definition, and in the utility industry the networks piece was also seen as perhaps not quite the most exciting. What has actually happened is that the utility industry, that is not a word that you would use any more, is an energy industry at the forefront of innovation because of renewable energy and clean energy. The networks are now the most innovative part of the industry as we think about the rapidly emerging new technologies that are allowing flexible control of power demand."

In the next phase of his career – Holliday talked to *Ingenia* on his last day in National Grid's HQ – he will work on another of his passions, ensuring that there are enough young engineers around to bring about that future. "I spent a lot of the last five years of my life promoting engineering and skills to kids. There are two reasons for that. One is that we have got a business that is a baby boomer business, there are lots of natural retirements in the next 10 years. Two is that as we go through a revolution in energy, which is fantastic and exciting, we are going to need the most capable, imaginative, cleverest people on the planet to help us to resolve these issues, in a world in which engineers are in short supply and children are less encouraged than ever to go and study it."

Holliday reels off numbers to illustrate the problem. "We need about 85,000 engineers a year and we're producing about 53,000 so we're massively short every year: the gap is getting bigger and bigger." This is why he has championed such initiatives as *Engineering our future: Inspiring and attracting tomorrow's engineers*, a study carried out by National Grid in partnership with the Royal Academy of Engineering.

He has also campaigned for moves to increase the number of women who become engineers. Once again, he reels off some telling numbers. "Half the state schools in England don't have a single girl studying A-level physics. Not one. It is extraordinary." As he says, "more than 50% of doctors in

Steve Holliday teaches a class a Campion School, Warwickshire, as part of Teach First's *Every Child Can* coaching programme © Teach First

training are female. That wasn't the case 20 years ago. We can crack it in engineering." National Grid is doing its bit. "I am very proud that 31% of our top 200 executives are female," he says. "That has been another huge change actually."

One way to recruit bright young people is to show them how exciting engineering can be. He then throws out another statistic: 57% of all jobs require a background in STEM (science, technology, engineering and medicine). "How do you make people realise that STEM is a good pathway through to work and demystify what that looks like as well? Engineering is not nuts and bolts and dirty spanners and things, which is what it is perceived as."

Most senior engineers deliver the same message on education and training. In Holliday's case, he has put in time and effort. At National Grid, he has championed such schemes as working with young offenders and the 'School Power' programme that aims to enthuse primary school pupils about engineering and science. He is also vice-chairman of the Careers & Enterprise Company, a joint enterprise with government and industry, which "is all around trying to get businesses into schools more, and get kids more inspired". Set up in 2014, it supports companies and schools in working together.

If Holliday's enthusiasm for engineering, especially in his own area of energy, can rub off on some of those young people, the UK might get somewhere. "It is the place to be. It is incredible. I wish I was 23 and starting out."

BIOGRAPHY

Michael Kenward OBE has been a freelance writer since 1990 and is a member of the *Ingenia* Editorial Board. He is Editor-at-Large of *Science|Business*.

CAREER TIMELINE AND DISTINCTIONS

Born, **1956**. Awarded a bachelor's degree in mining engineering, University of Nottingham, **1978**. Joined Exxon, **1978**. Operations Manager, Fawley Refinery, Southampton, **1988–1991**. Board member, British Borneo Oil and Gas, **1997–2001**. Joined National Grid as Transmission Director, **2001**. Appointed Group Director for National Grid's UK gas distribution and business services, including the role of Chief Executive Officer of Transco, **2003–2006**. Non-executive Director, Marks & Spencer, **2004–2014**. Chief Executive Officer, National Grid, **2007–2016**. Fellow of the Royal Academy of Engineering, **2010**. Awarded honorary doctorate, University of Nottingham, **2012**. Chairman, Crisis, **2012–present**. Awarded honorary degree for contributions to the power and energy sector, University of Strathclyde, **2013**. Vice Chair, Business in the Community, **2014–present**. Lead Non-Executive Director and Board Member, Department for Environment, Food and Rural Affairs, **2016–present**.

INNOVATION WATCH

DELIVERING CLEAN COLD AND POWER

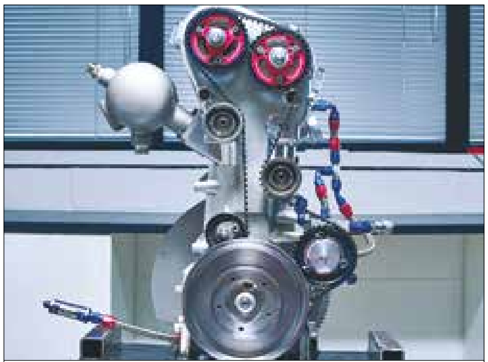
Global technology company Dearman has developed a family of engines that uses liquid air to deliver zero-emission power and cooling, with Sainsbury's becoming the first company in the world to introduce a refrigerated delivery truck cooled by this novel engine.

The brainchild of Peter Dearman, a lifelong inventor and engineer, the Dearman engine is a liquid-nitrogen-powered piston engine that produces clean cold and power. Peter was interested in an engine, and wider world, that didn't rely on fossil fuels and so developed one in which the pistons are driven by the expansion of liquid nitrogen, or liquid air.

The engines are unique in using a heat exchange fluid (warm water) to fill the cylinder, which enables near-constant expansion when extremely cold nitrogen is introduced. The liquid-to-gas expansion ratio of nitrogen is 1:694 at 20°C so in an enclosed space, such as the cylinder, a huge amount of force is generated when liquid nitrogen is vaporised. The expansion forces the piston down and a mixture of gas and heat-exchange fluid is exhausted; the heat exchange fluid is reclaimed, reheated and reused while the liquid air is released back into the atmosphere.

One of the interesting things about a Dearman engine is that it produces potentially valuable cold as a by-product, rather than heat. The first application of this technology is to provide transport refrigeration units (TRUs). The power generated by the heat exchange supports ancillary systems, such as feed pumps and fans for air circulation, and drives a vapour compression refrigeration cycle that provides a third of the cooling needed. The other two-thirds of cooling are provided by compressed liquid nitrogen that is transferred to a vaporising heat exchanger to cool the chilled compartment.

The technology is environmentally friendly; as well as reusing the heat exchange fluid, the engines do not release any polluting emissions such as nitrous oxide, carbon dioxide or particulates. It is also cost effective and more efficient compared to existing TRUs that consume up to 20% of a vehicle's overall fuel. Sainsbury's is currently trialling the technology, during which it expects to save 1.6 tonnes of carbon dioxide, 37 kg of nitrogen oxide and 2 kg of particulate matter, compared to when using a diesel engine.



The Dearman engine is a cleaner, more efficient and cost effective alternative for transport refrigeration © Dearman

During production, the engines can be engineered and configured to meet a range of different requirements for power output, efficiency and cooling capacity. Two variants of the engine are currently being developed: a simple single-cylinder engine that can be used for transport refrigeration units and auxiliary power and cooling units for buses; and a more complex multi-cylinder engine that produces more power and less surplus cold, which is being designed to act as a back-up generator for buildings and to form part of a waste-heat hybrid propulsion unit for trucks and buses.

For more information, see **dearman.co.uk**

HOW DOES THAT WORK?

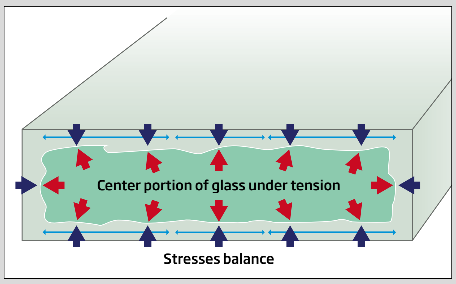
TOUGHENED GLASS

Commercial glass is generally made up of three main components: sand (also referred to as silicon dioxide), limestone and sodium carbonate. Toughened glass is a type of safety glass that is physically stronger having been reinforced by either thermal or chemical treatments. It is used in a range of applications, from car windows and buildings to mobile phones, tablet devices and TVs.

Tempering the glass to compress the outer surface and expand the inner layers balances the tension in the glass to make it tougher. This also causes the glass to crumble into small granular chunks instead of jagged shards when broken, making it less likely to cause injury, and means that the surface is more resistant to cracks and scratches.

With thermal tempering, the glass passes through a furnace that heats it above its transition temperature of 564°C to around 620°C. The glass surface is then cooled quickly with forced air while the inner portion is able to flow freely and contract.

Chemical toughening produces a layer of compressive stress on the surface of the glass by exchanging the sodium ions in the surface with larger potassium ions that take up more room and are pressed together when the glass cools. This is done by immersing the glass in a bath of molten potassium nitrate. Glass that has been chemically strengthened is tougher than glass that has been tempered thermally.



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