Advanced Manufacturing | Digital | Energy and Environment | Life Sciences and Health

Insights

Beyond Measurement

SI REDEFINITION

Changes in the International System of Units of measurement

PLUS

QUANTIFIABLE MEASUREMENTS IN MEDICAL IMAGING

PHENOTYPING TO FEED THE WORLD

CREATING THE TELECOMS NETWORKS OF THE FUTURE

GIVING AUTOMOTIVE BATTERIES A SECOND LIFE

ACHIEVING SMARTER AIR QUALITY MONITORING

NPL

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Foreword

Dr. Peter Thompson, CEO of NPL

Delivering greater impact with a multidisciplinary approach

Welcome to the latest issue of *Insights* – a compilation of the some of the exciting programmes and products we've been working on in recent months.

I'm staggered every single day by the diversity and quality of work that takes place at each of our sites across the country. From quantitative healthcare data to aircraft cabin air quality, our work covers a broad spectrum of industry sectors.

We bring an innovative perspective to industry challenges because of the unique and multidisciplinary nature of our measurement science. Often, research can become an increasingly deeper exploration when set on a linear path, but sometimes a cross-cutting view is necessary to find a solution to a problem, see a different perspective or achieve the best results.

In the pages that follow, you'll see some great examples of this approach in action.

Our medicines manufacturing work, for example, combines our surface technology knowledge, data expertise and manufacturing know-how to help get life-saving therapies to patients quicker.

Our work on phenotyping brings together a whole range of experts from different science areas across NPL, including sensors, communications and data science, to improve crop yields and fight food shortages.

And our work on future telecoms networks necessitates expertise across signal propagation, electronics performance and product testing, and is helping to realise better connectivity across the UK.

Our multidisciplinary approach also allows us to deliver great business results for our customers. You can read about the work we carried out for SME, Adaptix, in this issue. The project brought together our scientists from surface technology analysis, materials characterisation and modelling skills, to deliver improved design and processes to speed their route to market.

While we work to deliver extraordinary impact through science, we recognise that impact is achieved when talented scientists, engineers and technologists collaborate to bring a cross-cutting approach to our projects – not to mention the fantastic people in our support functions.

One recent project saw me leading a national activity to engage industry in quantum technologies. I want to thank everyone who contributed their thoughts on quantum technologies over the past months. The results have helped shape the national programme, as we aim to ensure that the UK economy and society can benefit from the commercialisation of quantum technologies.

Our cross-cutting nature is enabling us to work on more diverse projects, and deliver even greater impact every day. As a result, I'm continually excited about what we'll work on next.

Find out more about the work NPL does on our website: **npl.co.uk**

In September 2018, Dr Thompson was elected a Fellow of the Royal Academy of Engineering in recognition of his exceptional ability to nurture and lead world-class organisations, developing science and engineering that meet strategic national priorities in social, economic, defence and security applications.

He has also been recognised for his role in building crucial international partnerships and innovatively-applied combined resources to ensure that the UK remains at the forefront for the longer term, whilst also responding to near-term priorities.

CHANGES IN THE INTERNATIONAL SYSTEM OF UNITS OF MEASUREMENT

Fiona Auty, Head of Government Relations and Corporate Communications at NPL

When you can measure what you are

speaking about and express it in numbers

you know something about it;

but when you can not express it in numbers

your knowledge is of a meagre and

unsatisfactory kind

— Lord Kelvin

Measurement is at the heart of all science and engineering

It is only when we can measure something that scientists can study it and engineers can improve it. And since science and engineering play an important role in our lives, measurement matters for everyone.

MEASUREMENT AFFECTS OUR DAILY LIVES:

When we buy a part that 'just fits': a nut fits a bolt, or a *Lego*® brick sticks perfectly to another brick.

When our medical care depends critically on measurements – of concentrations of chemicals in blood, or the intensity of X-ray.

When a satellite navigation system guides us along a road, and it depends on time measured by ultra-precision clocks on satellites.

In all these situations, and thousands more, we are enjoying the benefits of a global system of measurement.

THE INTERNATIONAL SYSTEM OF UNITS

But how do we know that 'one metre' in the UK is the same as 'one metre' in Japan? And how do we ensure that 'one metre' today is the same as it was 20 years ago? We do this by using the globally-agreed ***International System of Units***, known as the ***SI*** (from the French, ***Système international d'unités***). The SI sets out what the agreed units of measurement are, how they are defined, and how they are realised in practice.

The widespread adoption of the SI allows science, industry and trade to measure physical objects and phenomena using the same units, so that the results can be compared meaningfully, worldwide.

The SI was formally agreed in 1960 and is directed from the ***International Bureau of Weights and Measures (BIPM)***, a laboratory situated in diplomatically-protected territory in Sèvres, just outside Paris. At BIPM, scientists from all over the world meet to agree upon definitions of precisely what we mean by each of the SI base units.

Typically, these scientists work at national measurement institutes which have responsibility for making the benefits of the SI available within individual countries. In the UK, this is one of NPL's key roles.

The SI covers units for every type of measurement, but at the heart of the SI is a set of seven units known as the 'base units'. They are the kilogram, the metre, the second, the ampere, the kelvin, the mole and the candela.

The seven base units have been chosen so that combinations of these can be used to express all other measurement units, known as 'derived units'. For example, the unit of force – the newton (N) – is formed from base units with dimensions of mass, length and time: kilogram × metre per second squared ($kg{\cdot}m/s^2$).

Historically, units of measurement were defined by physical objects or properties of materials. For example, the metre was defined by the length between lines engraved on a metal bar and the kilogram is still defined as the mass of a carefully specified cylinder of platinum-iridium metal – the International Prototype Kilogram (IPK). But physical representations can be unstable – they can change over time or in different environments. So, over the years, the definitions have been improved to be more stable and reproducible, and to meet the needs of today's research and technological applications.

During the last century, scientists have measured constants of nature, such as the speed of light and the Planck constant, with increasing accuracy and realised that they are more stable than any physical objects. So scientists have utilised these properties to develop new definitions of the units that will meet the demands on the measurement system as science advances.

Photo courtesy of The Sunday Times

WHAT ARE THE PROPOSED CHANGES?

The kilogram is the last SI base unit to still be defined as an artefact, but studies of closely similar copies tell us that the mass of the IPK is almost certainly changing … minutely. This implies a tiny but known change in the values of all masses. For mass, and for all units, we need to rule out this type of problem.

In November 2018, at a meeting of the General Conference on Weights and Measures, the global metrology community agreed a revision to the SI. The kilogram is now defined in terms of Planck's constant. This decision will mean that, for the first time, all seven base units are to be defined in terms of natural constants.

The actual changes will impact four of the base units: the **kilogram**, **ampere**, **kelvin** and **mole**.

The kilogram – will be defined in terms of the Planck constant

The ampere – will be defined in terms of the elementary charge

The kelvin – will be defined in terms of the Boltzmann constant

The mole – will be defined in terms of the Avogadro constant

Making this revision across the whole SI is a profound change in approach, that will underlie all measurements in science and more widely. But in everyday life it will appear that not much has changed. The redefinition of units is like replacing the weak foundations of a house with new foundations that are exactly the same size, but stronger. The difference isn't visible on the surface, but substantial changes have been made to underpin the structure for the long term. Similarly, the changes in the SI will ensure that the SI definitions remain robust for the future, ready for advancements in science and technology.

Over the course of history, as our technological knowledge and demands have progressed, the definition of many of the units has changed. So don't panic – water is still going to boil at 100 °C, and you won't need to change the time on your watch.

DIGITALLY-ENABLED SUPPLY CHAIN

FROM BLACK-ART TO FUTURE FORGE

MAKING METAL MANUFACTURING 'SMART'

GARETH EDWARDS
HEAD OF ADVANCED MANUFACTURING SECTOR

IT is predicted that industrial digitalisation could boost UK manufacturing by £455 billion and increase growth in the sector by 3% per year, with 'smarter' technologies helping to make processes more efficient. Digitalisation could even, in turn, help to reduce the impact of manufacturing processes on the environment; with carbon dioxide emissions predicted to be cut by 4.5% per year in over 10 years, if the manufacturing industry embraces it effectively.

As outlined in the industry-led Made Smarter Review, there is some way to go before UK industry is truly equipped to use digital technologies to its advantage, with the report highlighting that adoption is one of the key three main challenges UK businesses face. Incorporating industry 4.0 can be extremely challenging for difficult manufacturing environments, such as metal manufacturing, which requires extremely high temperatures and conditions that are not ideal for the latest technologies.

NPL's Digitally Enabled Supply Chain (DESC) is at the forefront of efforts to ensure UK manufacturing companies have the confidence to embrace digitalisation and develop trusted approaches to data collection, comprehension and dissemination through supply chains, even in the most challenging environments. This is particularly important for SMEs, where the support and resources may simply not be there for the adoption of new techniques and new technologies. This not only involves having the necessary technologies and equipment to hand, but ensures that the correct processes are in place. For instance, it is vital that a digital line of sight is maintained throughout the supply chain in order to make decisions made on the shop floor clear and transparent.

Scotland – where we are leading our development of digital manufacturing capabilities – is one of many areas across the UK beginning to benefit from our DESC programme. Our experts are working closely with the University of Strathclyde's Advanced Forming Research Centre (AFRC) in Renfrewshire, designing a platform capable of performing in a hot forging environment that can be used as a basis for research into new ways to incorporate digital processes across the metal manufacturing supply chain. In partnership with University of Strathclyde, NPL in Huddersfield and the HVM Catapult, this work follows £16.5 million of funding recently given to the centre by government.

The project is expected to revolutionise the hot forging sector, not only in Scotland, but globally too, with the global forging supply chain worth £209 billion worldwide. While it won't begin to be in full operation until 2020, it is a one-of-a-kind demonstration and will be a key step towards Industry 4.0 and realising the true potential of 'smart factories'. For this reason, it is backed by the UK Aerospace Research and Technology Programme and Scottish Enterprise, and recognised as an opportunity to advance manufacturing processes across sectors.

Find out more about the work NPL is doing in advanced manufacturing:
ourfocus.npl.co.uk/advanced-manufacturing

DIGITALISATION COULD HELP TO REDUCE THE IMPACT OF MANUFACTURING PROCESSES ON THE ENVIRONMENT.

Propelling UK's aerospace industry forward in the electric revolution

Hybrid vehicles have grown in popularity over the last few years, with the number of electric or hybrid cars on the roads now reaching well over three million.[1]

In the near future, we can also expect other modes of transportation to take the electric route, such as aircraft, providing cleaner and greener options for travel, on the ground and in our skies.

The Aerospace sector faces a unique set of challenges when it comes to incorporating electrical power systems into aircraft, one being that, with current technologies, hybrid or electric planes would not get very far as the components are simply too heavy. To complicate this, as components are made lighter, they become harder to cool and reliability under extreme temperatures is critical to safety.

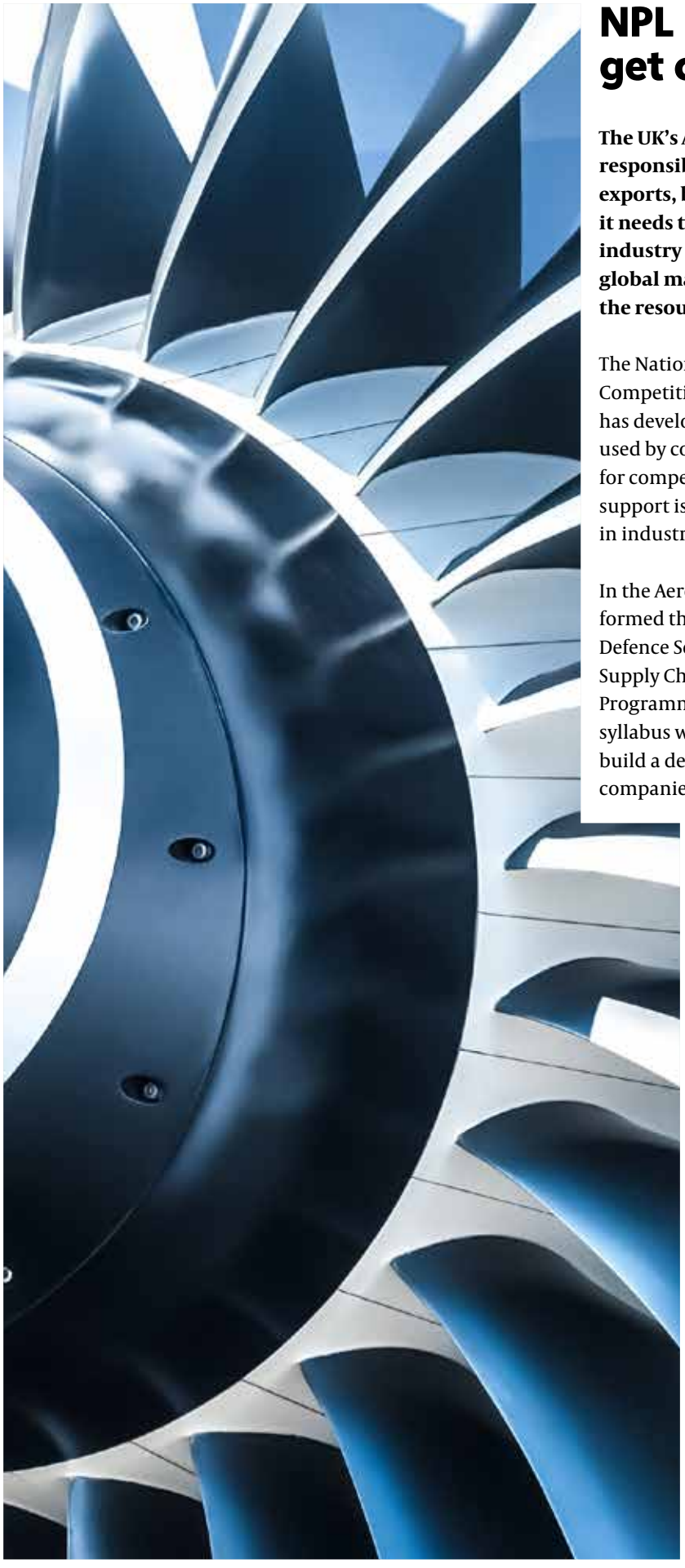
By 2050, electrical power systems are expected to be worth £578 billion on hybrid electric aircraft and £127 billion on all electric aircraft.[2] It's crucial the UK takes hold of this opportunity to maintain its position as a world-leader in aerospace manufacturing. To do so, we will need to solve issues around size, weight, power and cost challenges.

To remedy this, we opened our doors to industry to explore the particular challenges involved in the development of electric and hybrid technologies for the Aerospace sector. We were joined by a wide variety of companies and organisations involved in the aerospace supply chain and heard from the likes of Rolls-Royce, the Advanced Propulsion Centre, and the Aerospace Technology Institute.

Those discussions have led to the development of a detailed report that will further explore these challenges and make important recommendations for the future of electrification in the aerospace industry.

If you are involved in the aerospace supply chain and would like to contribute to the report, please get in touch: **contact@npl.co.uk**

[1]https://www.theguardian.com/environment/2017/dec/25/electric-and-plug-in-hybrid-cars-3m-worldwide
[2]https://www.ati.org.uk/wp-content/uploads/2018/07/INSIGHT_07-Electrical-Power-Systems.pdf



NPL helps UK SMEs get competitive

The UK's Aerospace sector is responsible for £27 billion worth of exports, but to stay ahead of the curve, it needs to ensure SMEs within the industry can stay competitive in the global market, as they may not have the resources to do so internally.

The National Manufacturing Competitiveness Level initiative (NMCL) has developed a syllabus that can be used by companies as a diagnostic tool for competitiveness, to identify where support is needed to grow and compete in industry.

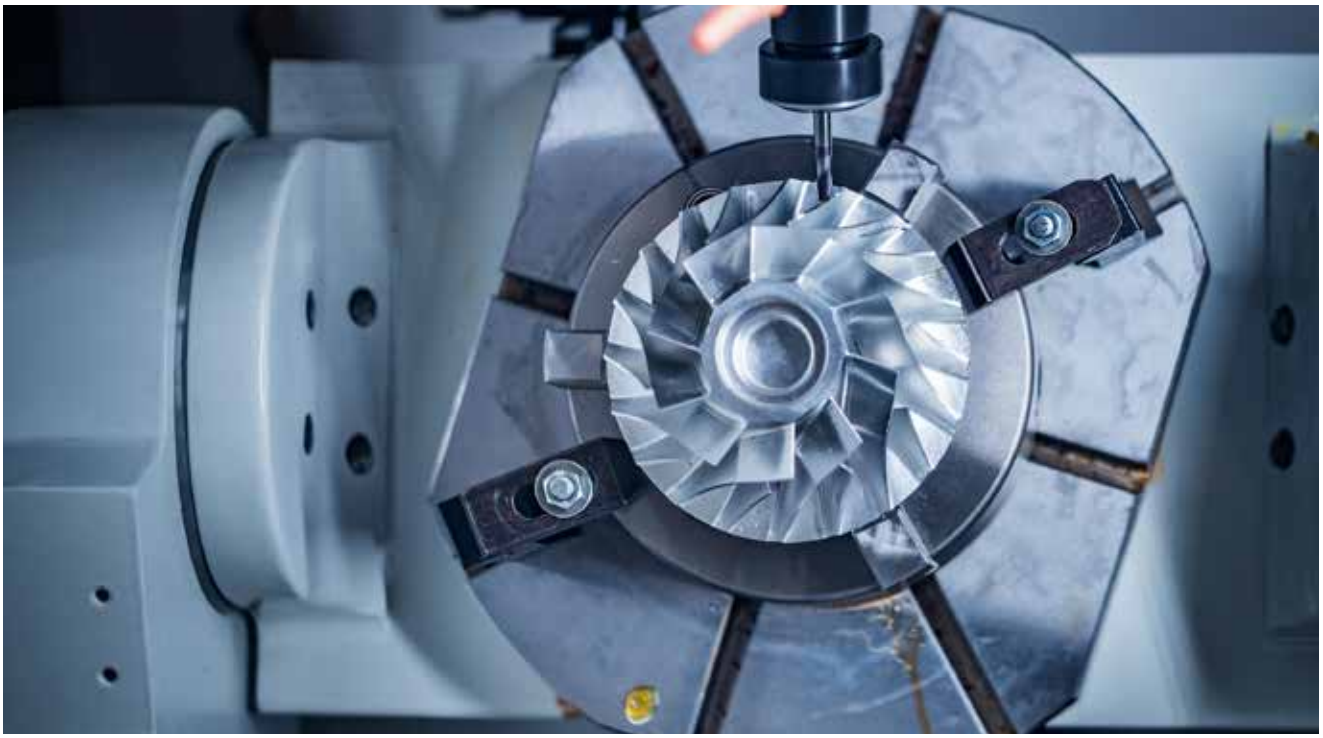
In the Aerospace sector, this initiative formed the basis of the Aerospace Defence Security and Space (ADS) Supply Chain for the 21st Century (SC21) Programme, which combines the NMCL syllabus with industry insights, to build a dedicated programme that UK companies can count on to stay ahead.

While the programme covers a variety of areas, including leadership and strategy all the way through to finance, at NPL we are supporting two key elements; ensuring operational excellence and helping to introduce new products to market.

With the help of our experts, UK aerospace manufacturing SMEs can now access the measurement skills to draw on this knowledge within a wider business context to get ahead.

There is a real opportunity to apply these schemes across a variety of industries beyond aerospace, such as the automotive sector, to keep the country competitive.

Find out more about the SC21 Programme: **sc21.org.uk/about**



Improving the UK's advanced machinery capabilities

Working together with the UK's leading machinery manufacturers, we are developing a new initiative to create a major R&D support programme to stimulate growth amongst the UK's machine and robot manufacturers.

The majority of accurately manufactured goods – used in almost every imaginable application for everyday living – are produced by high-technology, advanced computer numeric controlled machinery. These machines, and increasingly associated robots, provide the foundations upon which an advanced manufacturing sector is built.

Modern machines (machine tools) are typified by highly-sophisticated computer-controlled digital systems. With increasing levels of built-in 'intelligence and automation', they provide the critical production processes used to make all manner of present-day products. Without advanced CNC machine tools, there would be no planes, trains, automobiles, ships, MRI scanners, computers, mobile phones, satellites or televisions, and indeed no robots to assemble these products.

The global advanced machinery sector is valued at ~£100 billion. Significant machinery producers are Germany, Japan, China, Korea, Switzerland, and Italy. After a period of decline, the UK presently holds only 0.5% of the global market.

Digitisation in manufacturing will be a disruptive force, presenting the sector with both opportunities and risks. With this in mind, we are working with senior representatives from the UK's Advanced Machinery manufacturers to create interventions that will achieve substantial growth in the UK's advanced machinery.

For further information, contact either: ***Paul Shore, FREng,*** paul.shore@npl.co.uk or ***Gareth Edwards*****,** gareth.edwards@npl.co.uk

International Center of Excellence to ensure advancements in additive manufacturing add-up for industry

Additive manufacturing (sometimes known as 3D printing) is rapidly advancing in its industrial uptake in making complex and custom production parts, both in metal and polymers. The adoption is being led by the Aerospace sector, with the Automotive and Medical sectors also increasingly involved.

A commonly identified major block to wider industrial uptake is a lack of internationally agreed standards, to ensure the quality and performance of parts, processes and materials.

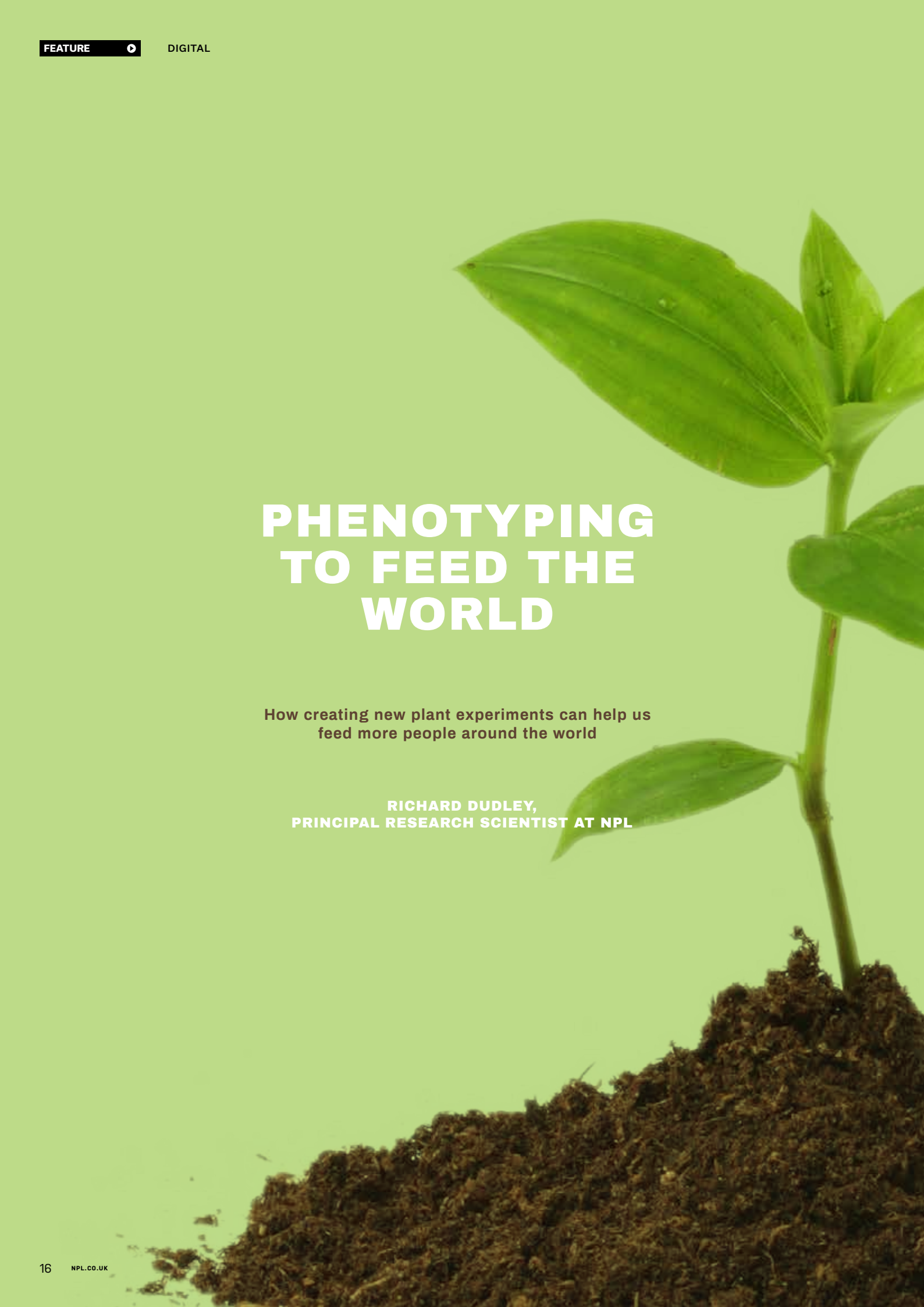
The international standards organisation, ASTM International, launched a call for bids for an Additive Manufacturing Center of Excellence which aims to accelerate the creation of standards, proficiency testing, training and certification materials to support additive manufacturing (AM) in the future.

Our experts at NPL wrote a letter of support for the UK's Manufacturing Technology Centre (MTC) in their bid for the Center, as its aims are well-aligned to those activities that we are keen to provide to industry around the assurance and quality of AM-made parts.

The MTC was selected, along with Auburn University, NASA and manufacturing technology innovator, EWI, in the US. The centre formally launched in July and will soon announce the initial topics selected for accelerated standards development.

It provides an important opportunity to support innovation and ensure that standards are keeping pace with global technological advancements in additive manufacturing.

Find out more about the Center:
amcoe.org/



PHENOTYPING TO FEED THE WORLD

How creating new plant experiments can help us feed more people around the world

RICHARD DUDLEY,
PRINCIPAL RESEARCH SCIENTIST AT NPL

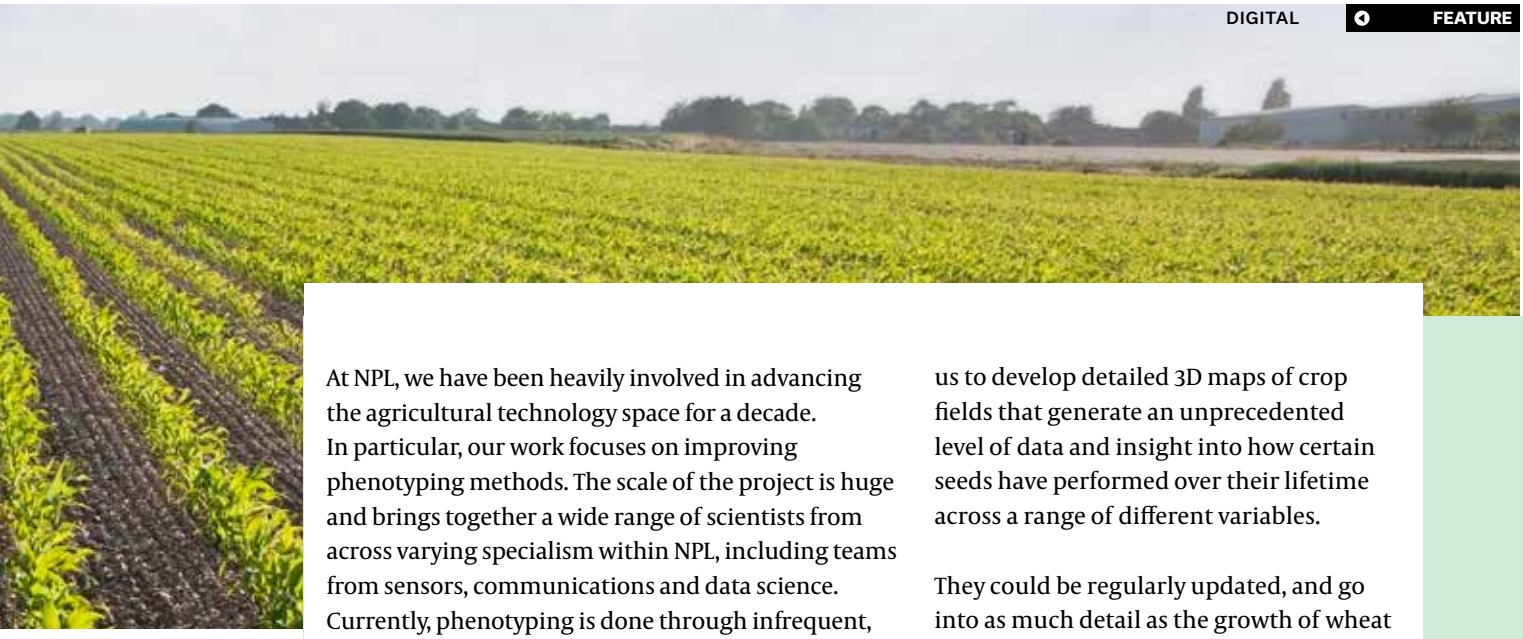
SINCE the dawn of agriculture, maximising the amount of harvested crops has been one of the main goals in farming. From crop rotation to fertiliser, innovation in this area is constant to ensure increased food production to fuel the planet's growing population.

By 2050, the world's population is expected in increase to 9.1 billion. As a result, food security has quite rightly become a pressing international issue. In order to keep the global population fed, the UN's Food and Agricultural Organisation (FAO) estimates that we need to increase wheat production by 60%.

By 2050, the world's population is expected to increase to 9.1 billion

In the UK, Biotechnology and Biological Sciences Research Council's (BBSRC) has started to address this issue, as outlined in their 20:20 Wheat® programme. It aims to provide the farming and agricultural industry with the tools needed to boost wheat production and increase the overall wheat yield, from around 8 tonnes per hectare (2012) to 20 tonnes per hectare by 2020. The use of data analytics and innovations, such as phenotyping in plants, will be essential to this.

Phenotyping is an increasingly important process which allows seed manufacturers to identify the plant varieties that produce the greatest yield and earn the most profit for farmers. Phenotyping is all about measurement. By tracking which particular plants produce the best yield, seed manufacturers can identify the plant varieties that produce the greatest yield and farmers can make more informed decisions about which seeds to buy for the next season.



At NPL, we have been heavily involved in advancing the agricultural technology space for a decade. In particular, our work focuses on improving phenotyping methods. The scale of the project is huge and brings together a wide range of scientists from across varying specialism within NPL, including teams from sensors, communications and data science. Currently, phenotyping is done through infrequent, crude and labour intensive measurements, using rulers and callipers, which don't give accurate insights.

For example, measurements for crop size are currently done with rulers and callipers, while the colour of the crop is measured by using colour charts. Meanwhile, the yield of the crop is measured by weight at the end of the harvest.

But these methods are not the most accurate way of measuring crops and measuring by hand once a year simply does not generate enough data to make informed decisions.

To improve this, we are currently developing the next generation of phenotyping, in collaboration with the National Institute of Agricultural Botany in Cambridgeshire. We aim to achieve a system that will enable us to track and measure what individual plants have done over the course of a year.

This involves using technology such as LIDAR, 3D imaging technology and temperature and moisture sensors. These technologies will enable us to develop detailed 3D maps of crop fields that generate an unprecedented level of data and insight into how certain seeds have performed over their lifetime across a range of different variables.

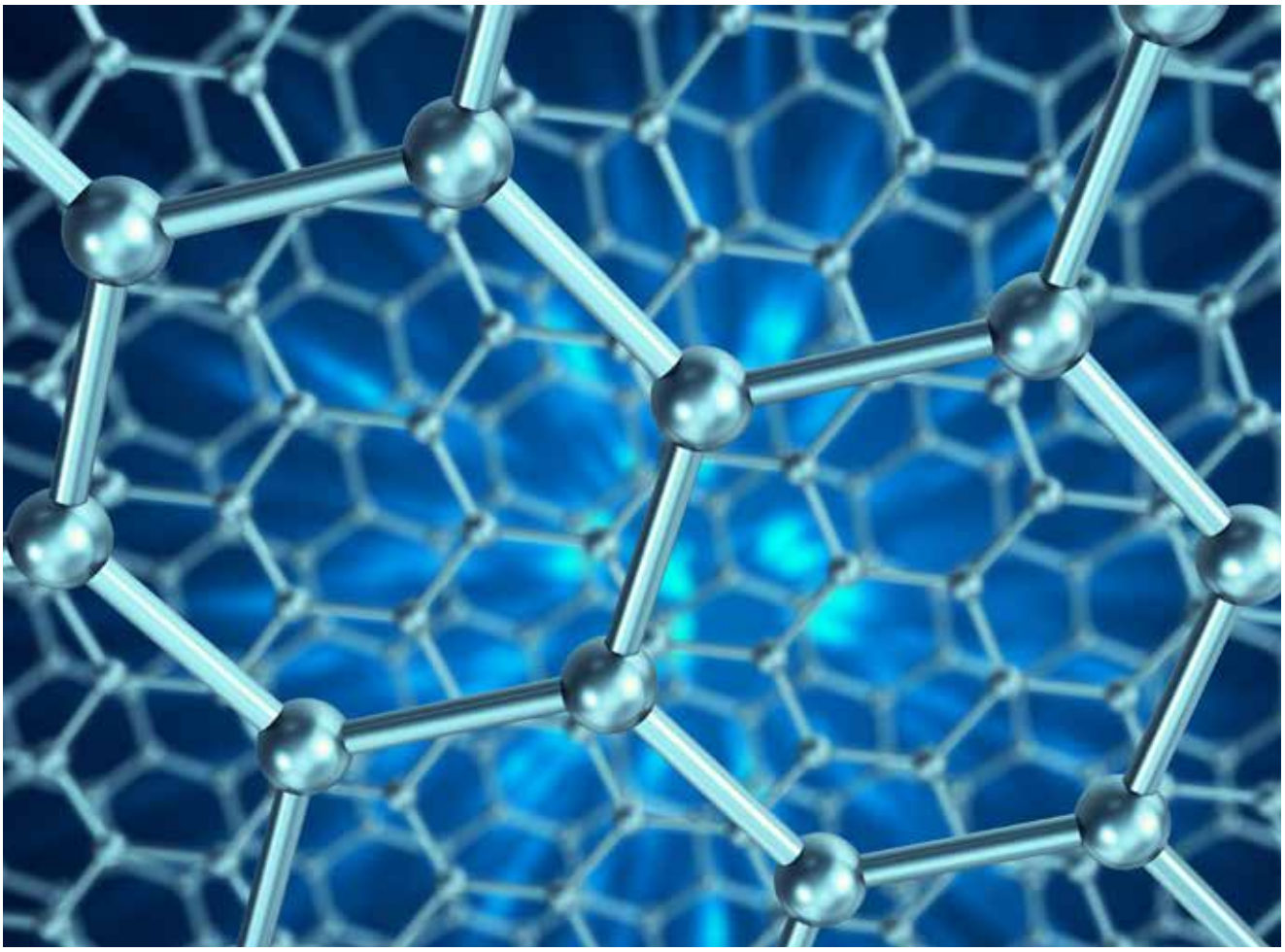
They could be regularly updated, and go into as much detail as the growth of wheat on a single ear. The data collection would also show how plants respond to events, such as a periods of rainfall or drought.

Naturally, there are a number of challenges that we need to overcome to make this kind of system a reality. Bringing sensors and computer vision hardware, which are typically used indoors, to the outdoors means they have to be adapted to harsher environments.

At the same time, the sheer amount of data that will be captured using this approach will give rise to challenges around storing and analysing data. In remote rural locations, which typically have slower internet connections, this may be more of a problem, though the development of 5G could help to alleviate this.

Ultimately, these innovations should pave the way for much faster phenotyping and identification of the next generation of crops, and could eventually provide the agriculture sector with the data needed to give the world the food it needs in the future.

Find out more about the work NPL is doing in this area:
npl.co.uk/environmental-measurement



New graphene service to kick-start UK's 'miracle material' industry

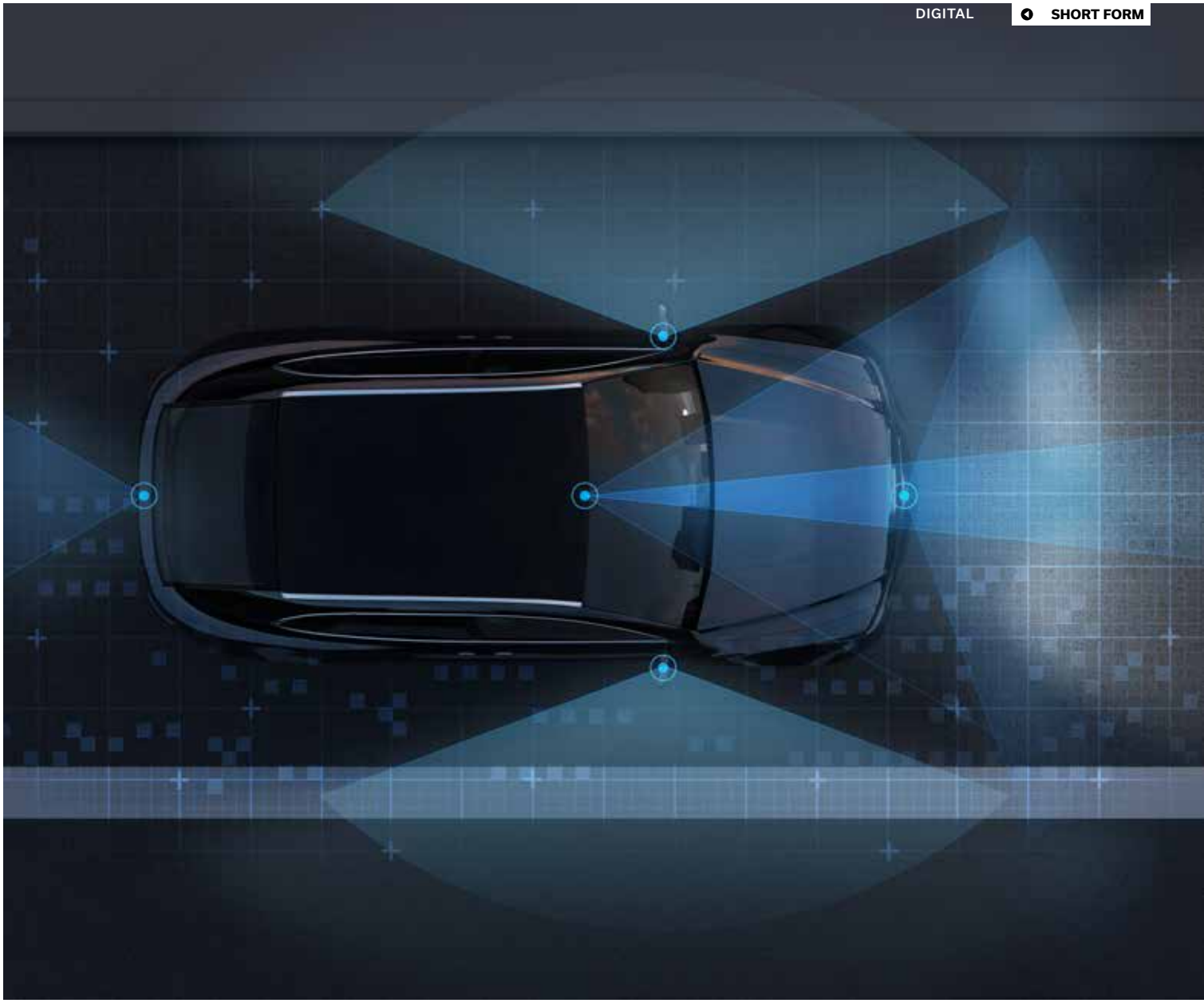
Through a partnership with the National Graphene Institute (NGI) at the University of Manchester, we have created a brand new characterisation service for graphene – helping the UK to benefit from the 'wonder material' by providing the missing link to industrialisation.

NPL led the development of the first graphene ISO standard on graphene terminology and, in collaboration with the NGI, produced the NPL Good Practice Guide on the characterisation of graphene.

Building on this expertise, the new graphene characterisation service allows companies to understand the properties of the material they are working with in greater detail – through independent, accurate and comparable measurements, as well as an assessment on suitability for different application areas.

This understanding will help to accelerate the industrialisation of graphene in the UK – forging the missing link between graphene research and development, and its application in next generation products.

For more information on the service, please visit: **graphene.npl.co.uk**



Solving the challenges around autonomous vehicles

At the end of 2017, Chancellor Philip Hammond outlined his vision for the UK to have 'fully driverless cars' without a safety attendant on board, and in use by 2021. Embracing this is crucial if we want the UK to lead the next industrial revolution, and reduce congestion in our cities.

While autonomous vehicle technology is maturing rapidly, there are a number of complex challenges that need to be solved before we can put our trust in driverless cars. At NPL, we're developing the capabilities to address key issues around sensor systems and data capturing and processing, and provide the confidence in autonomous vehicles needed to make them a reality.

Our areas of focus will include: sensor characterisation; sensor system model development; integration between simulation environments; AI Stack and Sensor models; and validation of virtual modelling against physical testing to ensure that digital twin simulation systems are based on accurate data and accurately mirror what occurs in real life. To this end, we are starting to work with industry groups to set the standards by which we test and validate the systems that will guide autonomous vehicles around our cities.

If you're interested in working with us to achieve this goal, get in touch at: **datascience@npl.co.uk**

Creating the telecoms networks of the future

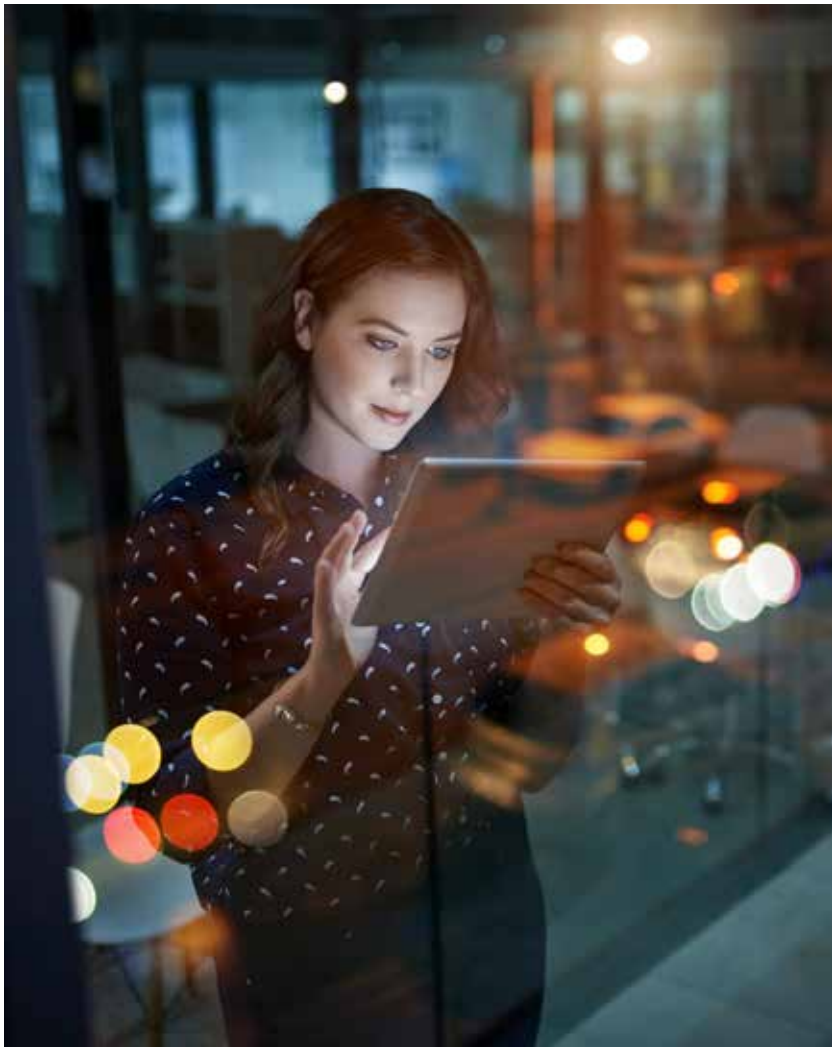
Sundeep Bhandari
Strategy Manager – Digital Sector, NPL

As innovations such as smart cities, 5G networks and a 'digital everything society' edge closer to reality, there is a growing need to ensure that the UK's telecommunications infrastructure – its future network – can support the demands of these services for us to truly begin to realise the benefits of digital transformation.

The government's Digital, Communications and Industrial strategies identify that world-class digital connectivity and smarter networks are essential to ensuring that everyone can take full advantage of increasingly pervasive digital services.

The future network will need to be seamless, handle vast amounts of traffic orders of a magnitude larger than today, be technology agnostic and provide top quality service in any location, no matter how remote. This will involve converged networks: a combination of cellular, fibre, satellite and Wi-Fi, all of which will come together to support not just mobile phones, but the technology of the future – from driverless cars to M2M and IoT.

The UK has ambitions of becoming a global leader in 5G, taking early advantage of its potential and creating a world-leading digital economy that works for everyone. Developing these networks will be key to future economic productivity and the realisation of the digital economy. But developing future networks that will underpin these technologies is far from straightforward. Emerging telecommunications technologies such as Network Function Virtualisation (NFV), Software Defined Networks (SDN) and quantum communications, to name a few, will affect how networks are designed, in an increasingly competitive industry landscape.



Through collaboration and rigorous testing, we can lead the charge in putting the UK at the forefront of the global telecoms industry.

Collaboration and testing

One of the key differences between today's networks and future networks is that the latter will be based on entirely new technologies, in both hardware and software. These will need to be interoperable with the current generation and across different connectivity and communication service providers.

The scale of the challenge and the advanced nature of the technologies means it's highly unlikely that a single telecoms operator will be able to manage the entire process, from researching and testing through to implementation.

Simultaneously, the boundary between IT and telecommunications will become increasingly blurred. Strategic cross-sector collaboration between operators and technology companies will be essential, as well as access to the necessary facilities and resources to develop the future network's capability.

Rigorous testing will be required to identify bugs, gaps, loopholes and conflicts that only manifest at scale in the real world. Without this there is a real risk that future network technology deployment will be undertaken in an uncoordinated way; with the impact only becoming apparent in live network failures and performance issues, therefore impeding the adoption of digital services, lowering productivity and undermining public confidence.

A lack of IT systems testing led to losses of over £16m for British Airways when Heathrow Terminal 5 opened. Baggage handling communications and software systems were not properly tested at scale, leading to hundreds of cancelled flights and lost luggage. A lack of preparation on this scale will not be acceptable to users of the telecoms networks of the future.

As the UK's National Measurement Institute, NPL has the capability to provide the rigorous testing, measurement and de-risking required for future networks, while ensuring communication between all stakeholders.

We can provide the testbed for the development of hardware and software at all stages through to pre-deployment, while also assessing the impact on commercial and operating models. We are capable of testing across a number of different vertical use cases, and can help to develop the capability to address the skills challenge around advanced network technologies. These capabilities mean that future networks can be tested in a collaborative and safe environment to ensure effective live rollout.

The UK was once the leader in the telecoms manufacturing industry and, as we approach the next epoch of communications systems, the opportunity is there to position ourselves as the global leader in the future of telecoms.

The government claims that 5G could add £173bn to the UK's GDP by the 2020s, and the accelerated adoption of these technologies could bring forward their exploitation by up to four years, yielding an industry benefit of in excess of £3bn in terms of increased productivity and new service take-up by 2028/29.

Through collaboration and rigorous testing, we can lead the charge in putting the UK at the forefront of the global telecoms industry.

Find out more about the work NPL is doing around network testing: **npl.co.uk/electromagnetics**

PETER LOFTUS

Former Head of Measurement Engineering at **Rolls-Royce**

What was your role at Rolls-Royce?
I was, until very recently, the Head of Measurement Engineering at Rolls- Royce, which involves overseeing all of the divisions of the company that use measurement, and governing the use and acquisition of measurement capabilities.

Why is measurement important for Rolls-Royce?
In high-value manufacturing, measurement is important in a functional capacity, in order to control and monitor an engine. All engines have sensor suites to make sure they are operating correctly. Without measurements, there simply would be no feedback on metrics like fuel consumption, pressure and temperature. It would be impossible to analyse an engine's performance over time and evaluate its performance.

Measurement is also crucial in the life-cycle of an engine as well – from the cradle to the grave. They underpin the design concept of an engine, such as how materials perform in certain conditions and so on. Testing from small scale demos to full engine tests require millions of measurements to validate that the engine performs up to standard.

At Rolls-Royce, we have pioneered the use of measurements in rotating systems such as gas turbines and ship engines, flow fields, and nuclear engineering, as well as materials and in manufacturing.

What does the future hold for measurement?
There's still a lot to do to improve measurement in industry. For example, we're seeing demand from industry to make our final inspection of engines more efficient. But this means making more precise measurements of the performance of all component parts in different conditions throughout the manufacturing process.

There is also a pull towards developing measurement systems that allow manufacturers to use computer simulations to confirm that designs work precisely as they intend to.

Quantum offers a number of opportunities, one of which is dramatically increased accuracy and the ability to realise SI units locally.

Quantum sensing is another area that is a big focus, and one in which NPL is heavily involved. Quantum offers a number of opportunities, one of which is dramatically increased accuracy and the ability to realise SI units locally. We are working with NPL to explore this area; one project in particular is around trialling high sensitivity measurements of magnetic fields to enhance crack detection. This aims to produce improved imaging techniques to spot minute defects in engines.

How can we improve measurement?
Measurement is so vital to high value manufacturing, and best practice is being applied throughout this sector. However, there are opportunities to do better and for the wider measurement community beyond high-value manufacturing to drive improvement for the benefit of all. Everyone who's involved in measurement application, not just metrologists, must embrace the discipline of Measurement Engineering and the role that it plays in designing better quality products, achieving less waste, and more efficient manufacturing for all.

Find out more: **rolls-royce.com**

LEWIS STURDY

Tell us about your apprenticeship
I started NPL at 18, straight out of doing A Levels in chemistry, biology and maths. The junior measurement science apprenticeship launched last year, with me being in the first cohort. It is a scientific course with a high focus on the importance of best practice and traceability in measurement services.

Why did you decide to pursue a career at NPL?
NPL is one of the world's leading metrology labs. It's an amazing place to start out on the career ladder, alongside so many enthusiastic people who are working at the height of their potential, and leading in their specified fields. It's hard not to want to poke some brains and try to learn a thing or two from them!

What has your experience been like so far?
In my first year, I worked in electromagnetic measurements. It was difficult to begin with as I didn't have the prior subject knowledge. It was a busy service with little downtime, but the more work we got in, the more we wanted to push ourselves to complete it before the deadlines. My first year of learning introduced me to the idea that no measurement is ever perfect and that everyday items require calibration. It opens your mind up to how metrology directly affects the real world.

Do you think apprenticeships are important?
Of course! It's important that young people have options on how to develop their careers. I had an unconditional offer to go to the University of Roehampton, but I turned it down in exchange for a more practical approach. I felt unsure about what I wanted to specialise in, and I still have doubts. I didn't want to spend three or more years of my life studying towards a degree when I don't know what field I actually would like to work in. Apprenticeships teach students the skills that employers search for, and NPL gives me the opportunity with many placements to maybe find what I want to do with myself.

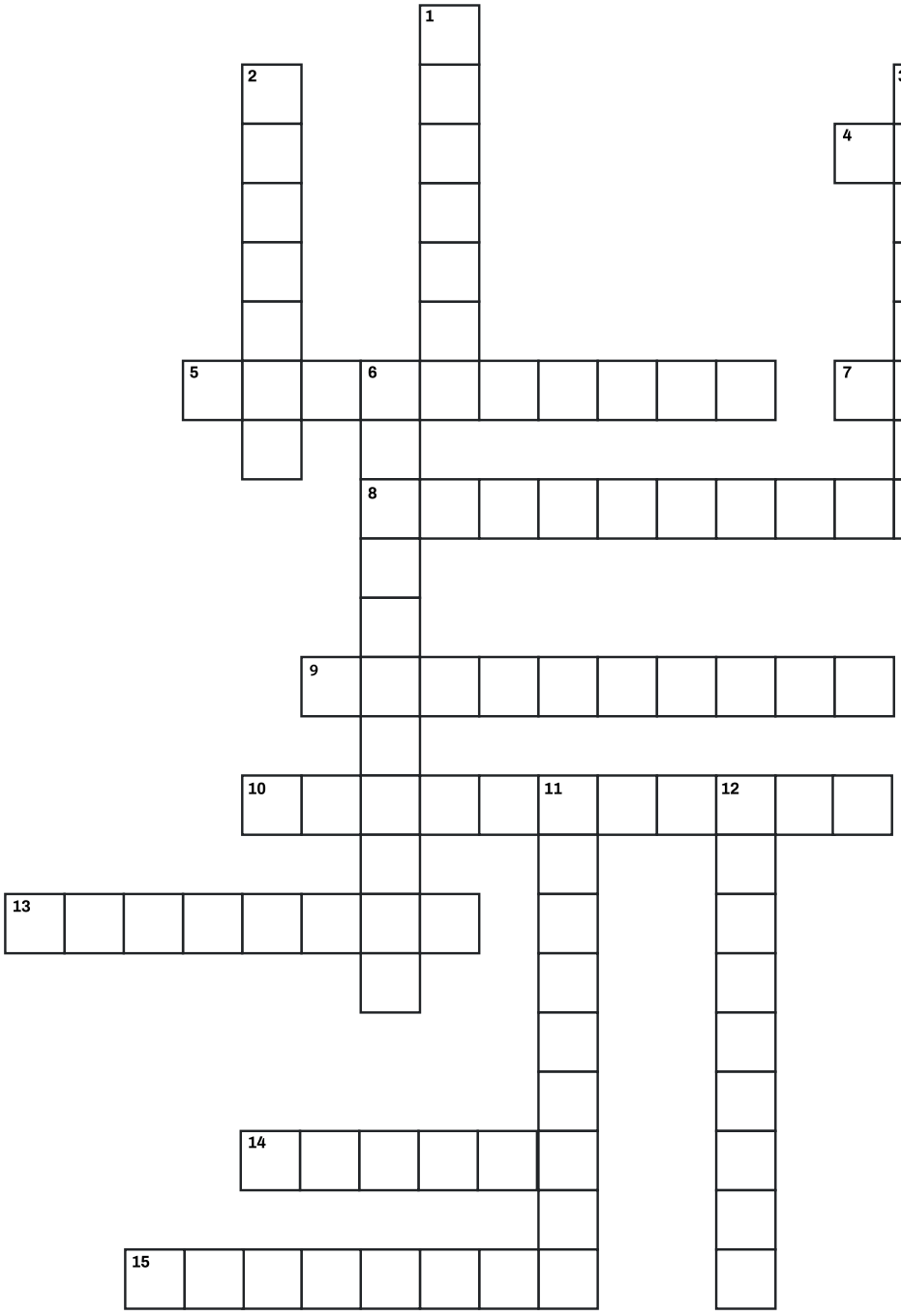
What has been your stand-out experience so far?
It's the outreach opportunities that we've been involved with. We get the chance to attend large scale events and talk about what we love doing. My highlight has to be the Royal International Air Tattoo (RIAT). This was an event featuring many of the world's greatest military air displays (including the Red Arrows, of course) and lots of well-known aerospace companies, such as BAE Systems. When we weren't on the stand, we were able to watch the show; I saw one of the two working Lancaster bombers in action.

What advice would you give to others thinking of doing an apprenticeship?
Definitely go with your gut instinct – you can get all the advice you want from friends, family and teachers, but only you can decide what way you want to learn. There are so many options – all you have to do is a little research. I felt pressured to go to university, but eventually made my own life choices for my own benefit. On the other hand, while I would recommend my course for anyone wanting to take the same path as I took, there's nothing wrong with getting a degree and starting that way.

What's next?
Anything is possible – I have so many choices fully open to me. My current plan is to stay on at NPL for a few years, most likely continuing my work at one of my three placements, but beyond that I could go to university or even try the Level 5 apprenticeship that NPL is currently developing. I like to keep my options as open as possible.

To find out more about NPL Apprenticeships visit:
npl.co.uk/apprenticeships

Complete the crossword to win a prize!



Across

4 The name of George Stephenson's early steam locomotive

5 British industrial design engineer, inventor, and entrepreneur

7 Legendary 19th century English Engineer, designer of London Paddington station

8 Most well known suspension bridge in San Francisco

9 Branch of engineering focused on the design and optimisation of advanced machines

10 NASA's first black female, one of the three protagonists in motion picture 'Hidden Figures'

13 Form of carbon consisting of a single layer of carbon atoms

14 Word reportedly exclaimed by Greek engineer Archimedes after an exciting discovery

15 The Hoover Dam is made up of this composite material

Down

1 The CRISPR/Cas system can be used to edit these

2 American electronics engineer and developer of the Apple 1, known as 'Woz'

3 Supersonic passenger airliner that was operated from 1976 until 2003

6 What the 'E' in STEM stands for

11 Branch of engineering sometimes referred to as 'rocket science'

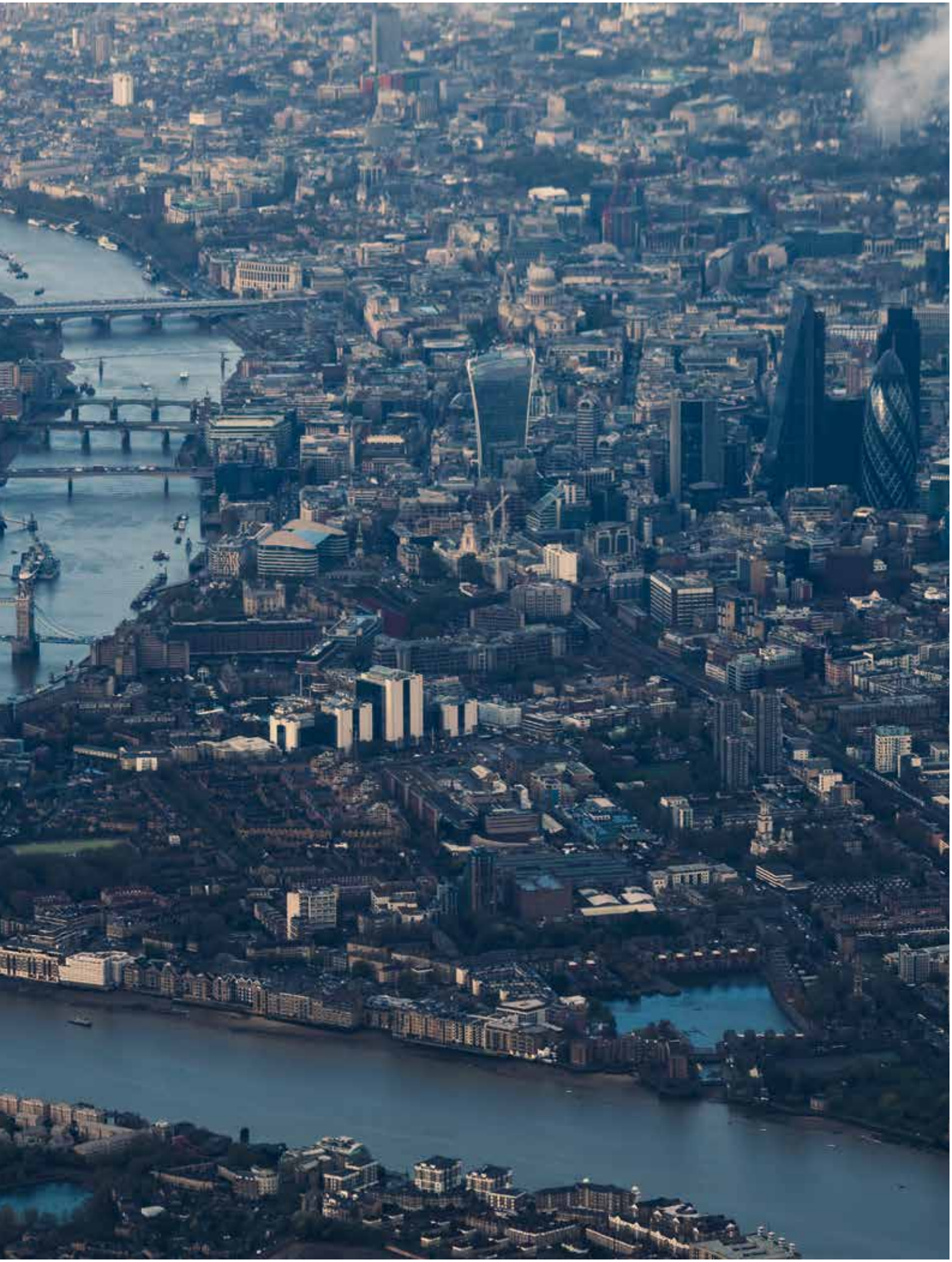
12 An artificial object, intentionally placed into orbit

Scan and submit your completed crossword to **marketing_support@npl.co.uk** to be in with a chance of winning an **NPL goody bag!**

Remember, NPL staff are not permitted to enter the *Insights* crossword competition.

ACHIEVING SMARTER AIR QUALITY MONITORING

NICK MARTIN
Senior Research Scientist in the Emissions and Atmospheric Metrology Group at NPL



Poor air quality has become an increasing concern for society. The Royal College of Physicians states that "40,000 deaths a year are attributable to exposure to outdoor air pollution." Currently in the UK, our air quality is regulated by the EU, governed by Directives setting ambient air quality standards by setting limits for concentrations of toxic gases and particulates in our air.

CURRENT MONITORING TECHNIQUES

Adherence to these limits is mapped using monitoring networks across the UK, particularly in urban areas. This is how we know, for example, that congested urban roads, like Marylebone Road in London, often exceed limits. NPL is involved in the running or quality assurance of a number of these networks on behalf of Defra, including nitrogen dioxide and black carbon.

In order to capture a picture of our exposure, these networks use a variety of monitoring equipment. These range from diffusion tubes – which are low cost, accessible and easy to use, but not highly accurate – to top of the range, high accuracy reference instruments employing spectroscopic techniques.

This combination of technologies is vital. Enabling us to achieve a regular wide view of changing pollution levels, and direct the most accurate monitoring to those locations most in need of it (for example areas with significant change, or those we need to understand better). NPL also works with manufacturers of low cost sensors, which are becoming increasingly popular. We calibrate them to ensure that sensors from different manufacturers give consistent readings.

The regulations guiding how air quality is monitored are not comprehensive. Existing networks give a good view of what pollutants are there, but they don't necessarily allow us to identify pollutant sources or map small changes in concentrations. NPL is working on a number of new projects that promise to make the way we monitor air quality smarter and contribute to better regulations in the future, allowing us to better tackle the issue.

IDENTIFYING POLLUTION HOTSPOTS

Static monitoring can only give us part of the story. So we are working on a new project that will combine fixed and mobile sensors which will measure harmful pollution in tens of thousands of locations across London. In this project, Google Street View cars will be driving across the city, where they will be taking readings every 30 metres to map air pollution at an unprecedented level of detail, and build up a picture over the course of a year.

This work will also identify pollution 'hotspots' that the existing network might miss, and may help to identify pollution sources in the future. The project is the result of a partnership between the Greater London Authority and C40 Cities. It will be run by a team of air quality experts led by the charity Environmental Defense Fund Europe, in partnership with NPL and others. We will be providing measurement traceability to ensure the mobile air quality monitoring equipment is operating accurately.

UNDERSTANDING INDOOR AIR QUALITY

Another area that is currently little understood is indoor air quality. It is estimated that people in developed countries spend around 90% of their time indoors. As such, understanding the quality of the air we breathe, at home and in offices, will help us to better understand the bearing on our health. There are many pollutants indoors that are toxic: external air pollution can come in through open windows; items like furniture and carpets release small amounts of toxic compounds, while boilers and wood-burning stoves give off particles and carbon monoxide.

With modern houses not very well ventilated, toxic compounds can build in concentration. But there is the very basic solution of regularly opening our windows.

One specific area where opening windows is a little trickier and indoor air quality needs to be closely monitored is on aeroplanes. We are working with partners from Honeywell and the German Fraunhofer Institutes on a project to measure in-cabin air quality. For the first time, this will allow the adjustment of air supply based on actual measurement of air quality, rather than simple convention. The system will employ low-cost and lightweight sensors to measure carbon dioxide levels, and volatile organic compounds, and remove them, through filtration.

This will help to reduce recirculation of air and power requirements of the on-board equipment, subsequently lessening fuel consumption and aircraft emissions. Importantly, it will also lessen the spread of germs among passengers. The results will help to establish new standards for air quality on aircraft.

Google Street View cars will be driving across the city, taking readings every 30 metres to map air pollution at an unprecedented level of detail.

SMARTER AIR QUALITY MONITORING THROUGH STANDARDISATION

The future of air quality monitoring is smart. We are already seeing the introduction of smart buildings that monitor air quality, and adapt ventilation in line with toxic gas and particulate concentrations. We may also soon see the ability to have a personal exposure record where each person can use portable sensors to inform decisions about their own exposure, such as changing their route to work.

All this data can help assess medical outcomes. But standardisation is crucial to ensuring that the equipment and information they give us is reliable and can be used to inform important decisions. The problem we have is that technology is moving faster than we can develop standard test protocols. NPL is working on these protocols, and also working with air quality sensor manufacturers to help them identify areas for improvement in their systems, until standards are available to test against.

With this, we are helping to bridge the gap for the commercialisation of these new technologies and paving the way for smarter air quality monitoring.

Find out more about the work NPL is doing in environmental measurement:
npl.co.uk/environmental-measurement

RE-CHARGE + RECYCLE

GIVING AUTOMOTIVE BATTERIES A SECOND LIFE

Andrew Deadman
Group Leader for Electrochemistry at NPL, and seconded to the World Economic Forum Global Battery Alliance

RE-USE

THE GOVERNMENT HAS OUTLINED AN AMBITIOUS PLAN FOR MAKING UK ROAD TRANSPORT **GREENER**, IN ITS ROAD TO ZERO REPORT AND THE INDUSTRIAL STRATEGY, WITH ONE OF THE HEADLINE POLICY CHANGES BEING A BAN ON THE SALE OF PETROL AND DIESEL CARS BY 2040.

AS A RESULT, THE EXPECTED ELECTRIC VEHICLE BATTERY MARKET IS PREDICTED TO GROW TO $100BN BY 2025. **GOVERNMENT IS INVESTING £246 MILLION** TO RESEARCH NEXT GENERATION BATTERY TECHNOLOGY THROUGH THE **FARADAY BATTERY CHALLENGE,** TO MEET THIS DEMAND AND IMPROVE BATTERY TECHNOLOGIES.

Battery challenges

While this will be very positive for reducing emissions, automotive batteries need to be assessed based on their entire lifecycle impact, and challenges remain in ensuring that they are a genuinely green source of energy. Currently, sourcing the raw materials for batteries, like cobalt, comes at great expense, socially and environmentally. Much innovation into new chemistry and new technology will be required to establish effective supply chains and realise the potential of batteries. There are also currently limited systems for effectively recycling batteries.

Disposing of batteries may not be so much of an issue now, while we're at the beginning of widespread adoption in automotive, but, with current automotive batteries having a warranty of around 5–8 years, we will soon see this issue coming to the fore. It is projected that 11 million tonnes of spent lithium-ion batteries are forecast to be discarded by 2030.

In light of this, there is greater interest in so-called second life batteries, where batteries that are no longer useful for high power applications, like electric vehicles, can be re-purposed for less power intensive applications. The range of an electric vehicle depends on the amount of energy that can be stored in the battery, which tends to decrease with time and use. Automotive batteries cease to be functional for their primary application when they drop to about 80% of their original capacity, which would be more than sufficient for many other applications, such as energy storage. Second life therefore offers a more practical solution for these used batteries than recycling.

The battery also makes up a big proportion of the value of the car, so manufacturers want to recover some of this value to improve their margins and reduce the need for added disposal costs. Selling used batteries on for other purposes would enable this.

We are already starting to see second life automotive batteries being used by big organisations for other purposes. In the Netherlands, a vast energy storage system has been installed at Amsterdam's Johan Cruijff Arena, using the equivalent of 148 new and used Nissan Leaf batteries. Capable of storing 3 megawatts of power – enough to supply 7,000 households for one hour – it delivers back-up power in case of outages of heavy use, and also relieves pressure on the grid during big energy-consuming events. BMW and Bosch also recently opened a new 2.8 megawatt energy storage facility in Hamburg, built from second life automotive batteries.

Such systems offer potential for domestic use too, helping to provide power off-grid and aid consumers in using renewable sources of power. General Motors is currently working with ABB to provide residential energy storage and Nissan and Eaton have partnered on a similar project, creating the xStorage Home unit. Such provision of home energy storage could give consumers access to free electricity, alongside solar panels, and allow them to charge their electric vehicles without putting too much pressure on the grid.

Similarly, second life batteries could help to store power from renewable sources locally. So when there is low demand, they will store energy, and then feed it back during periods of high demand to balance the grid.

Realising second life

Second life will only succeed in the long term as an alternative to recycling for automotive batteries if markets for secondary uses are properly identified and demand in different areas is assessed.

NPL is supporting the uptake of second life batteries. I have recently joined the secretariat of the Circular Economy Working Group of the World Economic Forum Global Battery Alliance (GBA), on secondment from NPL, focusing on battery second life.

The GBA is a private-public partnership that seeks to catalyse, connect and scale-up efforts to ensure that the battery value chain is socially responsible, environmentally and economically sustainable, and innovative. The GBA is seeking to identify the cost and market potential of reusing lithium-ion batteries and address barriers, both economic and regulatory, associated with battery re-use.

There is a regulatory minefield around secondhand electronics. Currently, whoever brings the battery to market is responsible for disposing of it, but if second life is to take off, then liability needs to be able to be transferred. Ultimately, regulation needs to catch up with need. Work also needs to be done to establish how much re-engineering of

IT IS PROJECTED THAT **11 MILLION** TONNES OF SPENT **LITHIUM-ION** BATTERIES ARE TO BE DISCARDED BY **2030.**

the battery will be required for different applications. In order to inform these changes, and also help understand the best applications of second life batteries and their limitations, we need to have a better understanding of battery performance and lifetime.

NPL's recent report, Energy transition: Measurement needs within the battery industry, highlighted the challenges in ensuring high density batteries, such as those used in automotive applications, remain safe and sustainable throughout their life cycle. It highlighted the need to identify end-of-life thresholds for second life and recycling, including assessment of the commercial viability of processes for re-use.

We have since started a new three-year European research project, to help characterise the remaining capacity of batteries, to help industry know whether to re-use or recycle batteries, and at what point; and have confidence in those decisions. NPL is also working on a Faraday Battery Challenge project, looking at diagnostic tools and machine learning for re-purposing batteries – project VALUABLE.

With battery usage on the up, we need to ensure that they are the greenest option for the UK, throughout their entire lifecycle. Second life uses offer an opportunity to reclaim the power of batteries to improve other applications

and bring down the cost of electric vehicles. This relies on establishing a clear market, and creating confidence in the performance of these batteries. Through better understanding, we can pave the way to a greener economy.

Find out more: **npl.co.uk/science-technology/electrochemistry**

Purer hydrogen for more sustainable transport

Around a quarter of UK greenhouse gas emissions come from transport, and air pollution in London and other major cities has become a public health crisis.

Combustion vehicles using diesel and petrol as fuel heavily impact the quality of the air around us and we need to find alternative methods to power our engines. Deploying fuel cell electric vehicles (FCEVs) onto the roads by 2050 to a 25% share "could contribute up to 10% of all cumulative transport-related carbon emission reductions" globally.

Battery powered cars have become increasingly popular in urban areas, but what about the need for longer distance and heavy duty transport?

FCEVs are a suitable solution for longer-distance road transport such as vans, small boats, buses and HGVs. Used in transport, these FCEVs can alleviate the impact on the environment, as they only produce water rather than pollutants associated with the traditional combustion engines. However, this brings its own challenges. Stringent hydrogen purity requirements have been set for FCEVs, based on accepted threshold levels of 14 specified contaminants – in fact, this required hydrogen quality is more than 99% purer than the hydrogen that is mainly currently produced by industry (mostly steam methane reforming). Impurities have major implications for the functioning and durability of the fuel cell.

At NPL, our teams are working on a variety of projects to help appropriately measure contaminants in hydrogen and enable live in situ purity analysis during refuelling, as well as the challenges associated with taking hydrogen from the national gas grid and using it to power FCEVs.

We are also working to better define the level of damage that impurities can cause. We have begun to develop a set of standards that will help to ensure that quality of hydrogen remains sufficient for use in the transportation networks as part of this work, NPL staff sit on an international standards committee.

Without such internationally agreed standards, we would not be able to introduce hydrogen vehicles onto our roads at scale and be sure of their performance.

Find our more:
npl.co.uk/hydrogen-refuelling-station

Plain sailing to lower shipping emissions

Marieke Beckmann
Research and International Strategy Lead, Energy and Environment

Earlier this year, the International Maritime Organisation (IMO) announced targets to reduce the total annual level of greenhouse gas (GHG) emissions from international shipping by at least 50% by 2050.[1]

This marked a milestone in the industry, as this is the first time the international community has agreed to holistically tackle emissions from shipping. The details behind this IMO target (e.g. ratification by IMO member states and implementation in international waters) are, however, yet to be set.

Shipping currently accounts for around 2%[2] of global carbon dioxide emissions, with experts predicting this figure could rise to 50% and 250% by 2050, depending on future economic and energy developments. There are different ways of lowering GHG emissions from shipping, including lowering the impact of the transport fuel used by big cargo ships, and mitigating any potential emissions from oil and gas tankers.

An increasing number of ships are using Liquefied Natural Gas (LNG) as an alternative fuel. Using LNG as fuel has the potential for lower GHG emissions, as gas in combustion is cleaner than shipping fuel oil. Methane emissions from the storage on board ships, bunkering and liquefaction sites on shore, as well as wider gas supply chain can, however, reduce this environmental benefit. Methane is a potent greenhouse gas, and small releases of methane along the supply chain have a substantial climate impact.

Despite a growing fleet of LNG tanker ships, we currently do not have clear data to show how much gas is leaked into the atmosphere across the various operational modes of a voyage. LNG carriers vary in their size, but the majority of the current global fleet have a capacity of around 150,000 cubic metres.

More recently, the capacity is increasing with the latest ships averaging 175,000. The industry is health and safety driven, so planned or unplanned safety venting is enabled through the ship design. Furthermore, each ship needs to vent its entire system before it can enter dry dock, which happens every two to five years. Next to that, we currently do not have information about how many untended leaks may potentially take place.

So, how much are these ships emitting into the atmosphere?
The newly-established IMO emissions reduction target, next to the Paris Agreement, means that we need to have appropriate emissions figures for shipping in global GHG inventories. We also need to enable this industry to be as efficient as it can be in order to underpin global trade. Not only is it good for our environment if we tackle shipping emissions, but it also makes business sense to limit potential emissions leaks as, in the case of the LNG tankers, this is saleable gas.

A ship may have a lifecycle of 20–30 years, so it's important we properly map and identify opportunities for improvement now, across a fleet of varying designs and age.

NPL is already leading an international effort to establish greenhouse gas emissions from LNG onshore sites for the Oil and Gas Climate Initiative, a collaboration of the largest oil and gas companies tackling their collective climate impact. NPL will use a range of different emission monitoring technologies, including its Differential Absorption Lidar system (DIAL) for measurement campaigns at liquefaction, gasification and re-gasification sites across different geographies globally.

NPL will work with relevant partners going forward to help to fill emissions data gaps in the shipping industry and enable industry innovation.

Find out more: **npl.co.uk/environmental-measurement**

1. http://www.imo.org/en/MediaCentre/PressBriefings/Pages/06GHGinitialstrategy.aspx
2. https://ec.europa.eu/clima/policies/transport/shipping_en

SPEEDING UP THE ADOPTION

OF CONTINUOUS MANUFACTURING IN PHARMA

CATERINA MINELLI, MEDICINE MANUFACTURING TECHNICAL LEAD

ALREADY a common practice in other areas of manufacturing, continuous production is gaining ground in the pharmaceutical industry. So much so, that both the US Food and Drug Administration (FDA) and the European Medicines Agency (EMA) have marked it as a key way of improving the manufacture of medicines.

Continuous manufacturing is a more efficient and cost-effective way to produce products than other methods like 'batch' manufacturing. It creates less waste, is easier to scale up and can respond faster to demand – addressing both large and small volume production.

The pharmaceutical industry has been slow to adopt continuous manufacturing. This is partly because it requires large upfront investment. Old equipment would need to be replaced with new technology; technology which staff would need to be freshly trained to use. In an industry that is highly regulated and conservative by nature, it can be hard to justify such an outgoing and effort when you already have a system that works at your fingertips.

THE TIME IS NOW

In recent years, there has been a surge in drug recalls, encouraging pharmaceutical companies to rethink their manufacturing processes. Part of this is due to product quality issues. Because quality control of batch manufactured medicines is completed at the end of the process, whole batches of drugs may be rejected, leading to waste and drug shortages. Regulators encourage continuous manufacturing and its 'quality by design' approach, which leads to better quality and consistency of products.

What's more, the drive for faster drug development times, as highlighted in the UK government's Industrial Strategy, also requires quicker production – for trials and experiments, as well as for time to market.

The time is now for continuous manufacturing in pharma. The UK is looking to ensure companies based here benefit from this trend, with the establishment of the CMAC Future Manufacturing Research Hub, and more recently the Medicines Manufacturing Innovation Centre (MMIC). We collaborate with CMAC extremely closely, with scientists and students working across the two organisations.

FAST-TRACKING CONTINUOUS MANUFACTURING IN PHARMA

In order to successfully implement continuous medicine manufacturing, companies need to have complete confidence in the analytical techniques that are used to monitor the manufacturing process. As quality assurance takes place throughout the production line, these techniques need to be accurate and reliable to ensure issues are spotted quickly and guarantee a high quality end product.

The large volumes of data from analysis needs to be rapidly processed, correlated and presented, in order to allow informed decisions to be taken during the manufacturing process. In addition, accurate data is require to build predictive manufacturing models and optimise the production process.

With state-of-the-art capabilities, NPL can provide accurate data and validate analytical methods suitable for manufacturing. We work closely with companies to develop the infrastructure to manage large data volumes effectively. This will help companies big and small to develop and implement innovative manufacturing methods, enabling them to respond to market and societal needs more effectively.

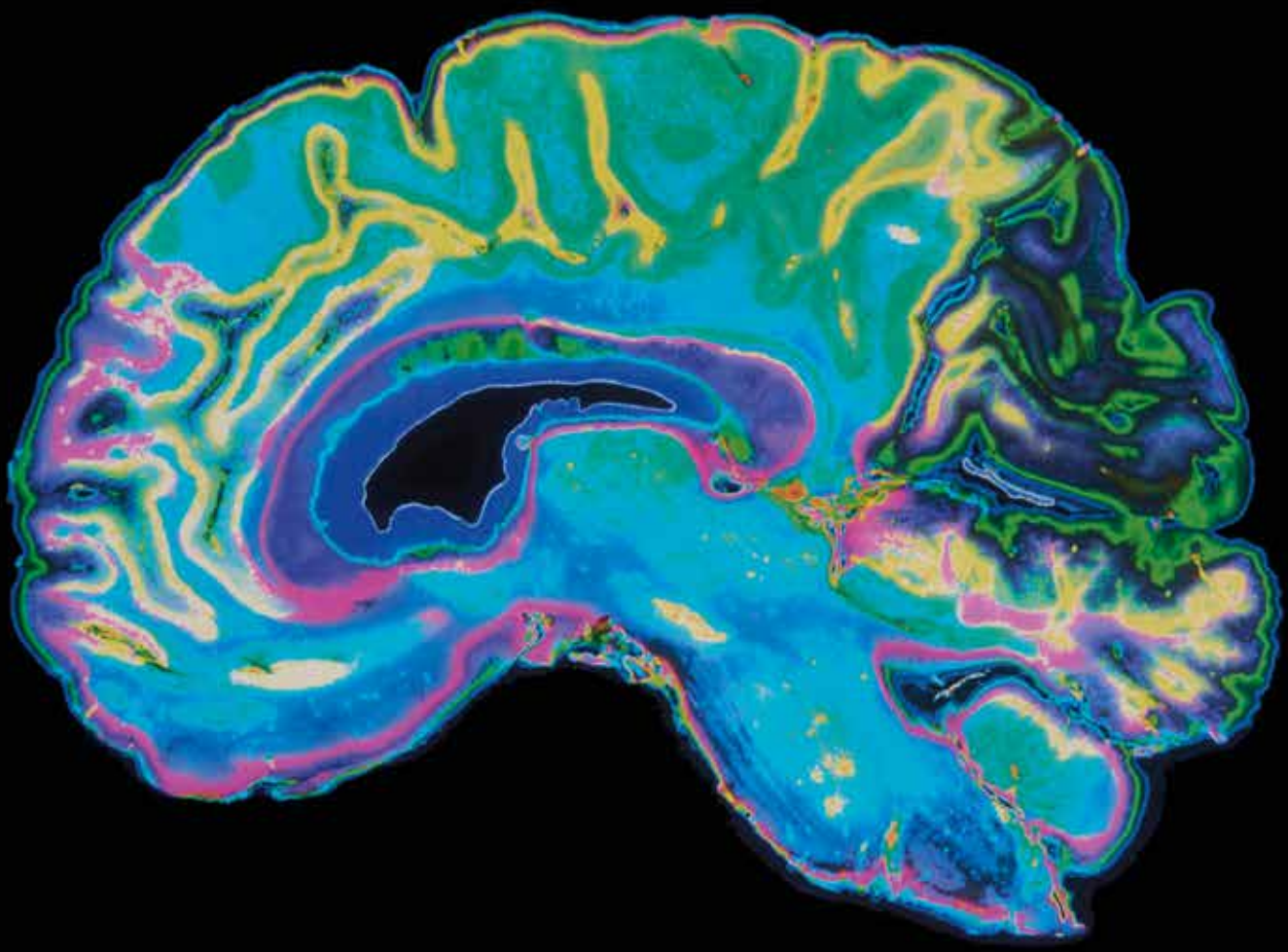
BEYOND CONTINUOUS MANUFACTURING

Far beyond the implementation of continuous manufacturing, we support pharmaceutical companies in whatever their challenges are, and whatever innovations they are implementing. From small molecule pharmaceuticals, to cell and gene therapy, we are working on accelerating some of the most exciting pharmaceutical developments, as well as improving traditional methods.

We have the capabilities to work with raw materials all the way through to formulated products, including tablets, injectable medications or creams, with state-of-the-art facilities for assessing composition, properties and stability of medicines. We are also developing high throughput screening capability for in-line quality assurance and tackling counterfeit medicines. Our modelling and measurement capabilities can speed uptake of new active ingredients and the development of new drugs, and we work with the Pharmaceutical sector to expand and harmonise relevant standardisation.

The vision outlined in the Industrial Strategy is for medicines to become more personalised, be developed faster and manufactured more effectively; ultimately, to improve patient outcomes. At NPL, we are working to realise this vision, by giving pharmaceutical companies confidence in measurement output and models that are critical to medicine manufacturing and quality assurance.

Find out more about the work NPL is doing across life sciences and health: **npl.co.uk/commercial-services/sectors/life-sciences-and-health**



Quantitative imaging measurements can help remove the subjectivity associated with diagnosing conditions and prescribing treatments.

Quantifiable measurements in medical imaging

BY **NADIA SMITH**, SENIOR RESEARCH SCIENTIST — DATA SCIENCE GROUP, AND **MIKE OLDHAM**, HEAD OF DATA SCIENCE, NPL

Improving treatments through the use of quantitative measurements has fast become a big focus in healthcare. Medical diagnoses have long been based on qualitative interpretation of scans such as MRI, PET or CT, and complex decisions are made based on recognising patterns within these images, which can be highly subjective.

For example, a doctor might order radiotherapy for a tumour based on an estimate of its size and prescribe a dose based on that estimation. Too much radiation dose might affect the surrounding tissue, causing unwanted side effects, while too little might not be effective in destroying all of the cancerous cells.

Quantitative imaging measurements can help remove the subjectivity associated with diagnosing conditions and prescribing treatments. By assigning numerical values based on measurements that are traceable back to robust new standards – for example, to colour or shape readings on images – doctors can make more precise diagnoses. It can also unlock the door to detecting diseases using different and less invasive techniques and is an essential requirement before the promises of machine learning and artificial intelligence (AI) can be explored in the clinic.

IMPROVING NON-INVASIVE MEASUREMENTS OF BLOOD FLOW IN THE BRAIN

At NPL, we're working on two projects to develop quantitative measurements within healthcare. One is with the UCL spinout company, Gold Standards Phantoms, to improve the measurement of blood flow (perfusion) through the brain – making measurements quantitative, traceable and reproducible.

Current diagnostic criteria for dementia include traditional MRI or PET scans, and it is difficult to detect early warnings of the disease as they only show anatomical changes in brain tissue. These changes only take place once the disease is already well-advanced and often far too late for drugs to make any significant difference. If clinicians can detect early changes in perfusion using the alternative non-invasive, contrast agent-free and cost-effective tool, known as 'Arterial Spin Labelling' (ASL) MRI, this might offer a more effective means of spotting dementia far earlier than existing techniques.

Ongoing work within the Data Science and Materials Testing Group at NPL in Teddington, will help Gold Standard Phantoms improve and validate the ASL MRI technology to permit its development as a reliable clinical tool for the diagnosis and follow-up of dementia.

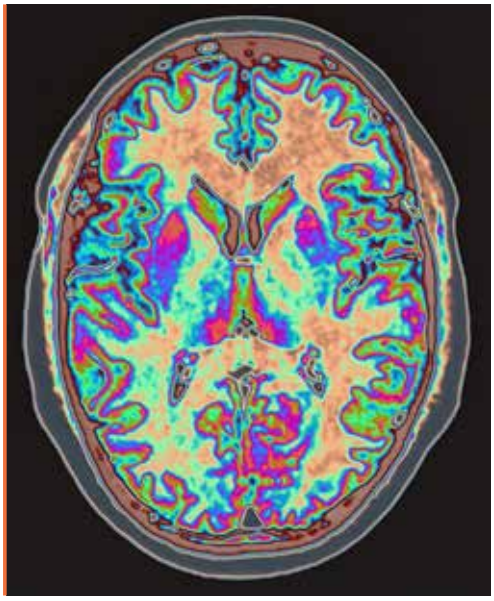
To help with this goal, Gold Standard Phantoms is building a calibration phantom, or model, for ASL which will accurately recreate the way that blood perfuses the brain. This will enable the calibration of scanners and sensors to accurately measure perfusion on a live patient, resulting in reproducible and comparable quantitative measurements of cerebral perfusion blood flow, independent of the scanner used, the hospital where the patient was scanned, and the doctor's analysis of the scans.

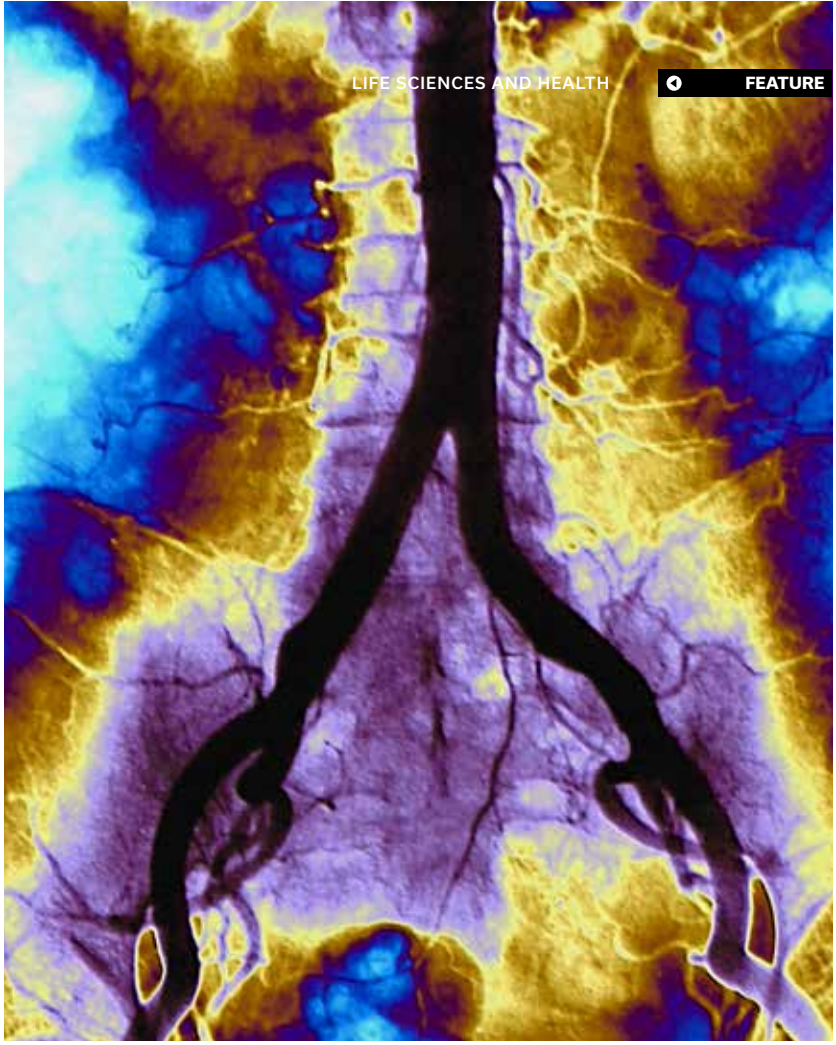
It is very important for a company like Gold Standard Phantoms to work with NPL, as our main purpose is to provide a calibration service of MRI scanners against a ground truth. As such, we appreciate the tremendous expertise NPL can provide us concerning all aspects of metrology, while we provide an extensive knowhow in quantitative medical imaging. It is truly a perfect collaboration benefitting both parties in this brand new domain.

Prof Xavier Golay, CEO of Gold Standard Phantoms

IMPROVING ISCHEMIC DISEASE DETECTION

We are also working on a European project funded by the European Association of National Metrology Institutes (EURAMET) to improve the measurement of perfusion in the heart to diagnose ischemic disease (reduced blood flow) much earlier and more easily than is currently possible. Ischemia in the heart is caused by a lack of perfusion in the heart muscles and can cause myocardial infarction (MI), commonly known as a heart attack. The current gold standard clinical method for diagnosing ischemia is through PET scans, but as these involve radioactive tracers, patients can't have too many during their lives and are usually used as a last resort. The aim of the project is to improve the quantification of perfusion from MRI scans, so these could be used for diagnoses instead, and to compare their reliability to that of PET and CT scans. MRI scans of perfusion are not currently used in clinical practice, and only in research, primarily because the results depend on bespoke analysis procedures and subjective interpretation of the outputs. Our aim is to develop a standardised pipeline for perfusion quantification, resulting in assigning reliable numerical values to perfusion readings with units of measurement, which can be validated against the physical standard that has been developed within the project.





TRACEABLE MEASUREMENTS

Both of these NPL projects could enable the development of potentially ground-breaking treatments for diseases that, at the moment, can only be detected in their advanced stages. Our work as the UK's National Measurement Institute will help create standards for such measurements and associated metadata, improve traceability, and reduce margins for error so that the use of data in diagnoses will become standard practice amongst medical practitioners.

On discussing the importance of diagnosis and detecting diseases such as dementia as early as possible, Dr Carol Routledge, Director of Research at Alzheimer's Research UK, said: "Diagnosis and subsequent treatment in late stage disease is undoubtedly contributing to the lack of success of therapeutic treatments […] If we could diagnose at this earlier stage, not only would we stand a greater chance of slowing and stopping disease, but we would also increase our understanding of early functional changes associated with disease."

Find out more: **npl.co.uk/commercial-services/sectors/life-sciences-and-health**

Accelerating new diagnosis technology

The UK based SME, Adaptix Ltd, is developing core technology behind a low-cost and low-dose portable device for 3D medical scans. This development is set to offer X-ray imaging at the point of care – such as at a patient's bedside or even in an ambulance – and a safer, cost-effective and rapid option to decide whether a more expensive CT scan is necessary.

For these devices to be routinely available in clinical applications, there are stringent requirements on their X-ray emitters to be met in terms of uniformity, repeatability and lifetime.

We worked with Adaptix on one of their products for dental applications, through our Analysis for Innovators Programme. We tested the structure and chemistry of a range of emitter arrays, selected the materials for the emitters and their coatings, evaluated the manufacturing protocols, assessed the quality of the coatings, identified causes of contamination in their manufacturing process and understood emitter failure.

A range of scientists worked on the project from across NPL, including experts in surface chemical analysis, materials structural characterisation, and modelling. This resulted in an improved design of the emitter arrays, coupled with optimised manufacturing processes and product operating conditions, and provided reduction in development time, eliminating unproductive areas of research, and speeding up time to market.

Our experts continue to support the company through other funding on further clinical applications of their products, while also supporting the establishment of the first Adaptix manufacturing site dedicated to X-ray imaging devices for dental applications, due to become operative in Scotland in 2019.

Find out more:
npl.co.uk/analysis-for-innovators

> "NPL allows UK SMEs access to the best that the UK's world-leading science base has to offer. Working with NPL allows Adaptix to 'stand on the shoulders' of a giant of science to characterise materials at the smallest of scales. We are now extending that successful relationship through NPL Scotland, who are supporting us as we mobilise manufacturing. This shows how NPL's leading-edge science flows into economic activity and the creation of high-value jobs."
>
> **Mark Evans,**
> CEO at Adaptix

HELPING THE UK TO LEAD THE QUANTUM 'SPACE RACE'

Rhys Lewis, Director of the Quantum Metrology Institute at NPL

On Friday 9 November the 4th annual quantum showcase took place at the QE11 Centre in London, which saw hundreds of visitors from across the UK, and around the globe, gather to see the innovative outputs of the UK's National Quantum Technologies Programme (NQTP).

NPL, and around 80 other exhibitors from leading industry, academia and research institutions demonstrated the magnitude of the potential that quantum technologies could have on society, through a wide and exciting array of displays and demonstrations. These highlighted the potential impact of quantum in areas such as communication, sensors, timing, computing and imaging – with uses in transport, construction, healthcare, finance and other sectors.

NPL participated in six stands on the day which showcased our work in: atomic clocks; frequency standards; ultra-stable lasers for space; quantum communications; the characterisation of solid state quantum technologies; and the development of a scalable, room temperature, low noise ion microtrap.

We were also delighted to launch three pivotal reports on quantum covering: recommendations for the national programme on engaging with industry; the opportunities for superconducting quantum computing in the UK; and the first annual report of the highlights from the Quantum Metrology Institute (QMI).

It was announced, at the showcase, that £75M of funding will be allocated to support the creation of a national centre for quantum computing. This forms part of the £235M recently allocated government funding for quantum technologies, which was announced in this year's autumn budget – and £80M previously set aside to support the university quantum hubs.

This investment will enable the UK to build on the innovative and leading-edge work already under way, and accelerate the adoption of quantum technologies by industry. NPL will have an important role to play to support the programme with technology development and in the testing of new products.

Industry Recommendations
In February, Sir Mark Walport, Chief Executive of UK Research and Innovation (UKRI), asked Dr Peter Thompson, CEO of NPL, to take the lead on the behalf of the NQTP to engage additional large UK industries in emerging quantum technologies (QT).

Following the industry engagement activity, some key recommendations concerning communications, proof of value and commercialisation, were put forward. Download the *NPL Quantum Industry Engagement Recommendations Report* to learn more.

Superconducting Quantum Computers
This report summarises the opportunities for superconducting quantum computing (SQC) in the UK and the real-life problems that this technology is likely to be able to tackle now, and in the future.
The report outlines five key challenges that will need to be solved in order to build such a system:

- Coherence times of individual qubits needing to be increased
- Reproducibility in the fabrication process is still a major issue
- Fabrication for vertical integration
- Development of reliable algorithms and schemes for controlling ~100–200 qubits
- Large scale FPGA/control electronics

Download the report: ***Opportunities for superconducting quantum technology in the UK***

Quantum Metrology Institute (QMI) Annual Report
The first annual report from the QMI discusses the scientific and technological successes of the UK quantum measurement community in supporting emerging quantum industries. The QMI is developing the quantum measurement infrastructure to independently test, measure and validate new innovations and will be a partner to the innovators that emerge in the quantum industry.

Highlights outlined in the report, include:

- Developing cold-ion Microtraps for use in ultra-fast quantum computers
- Supporting commercialisation of Quantum Key Distribution (QKD), for ultra-secure comms
- Developing portable MINAC Miniature Atomic Clocks, to bring accurate timing to many new applications, such as reliable energy supply, mobile communications, and data networks
- Creating atomic magnetometers, which could be used as quantum sensors to detect brain waves, heart arrhythmia, explosive residue, and corrosion

Download the report: ***How measurement is driving innovation in the emerging quantum industry***

Find out more about the work NPL is doing within the Quantum Metrology Institute: **npl.co.uk/qmi**

Events

2018–2019

Here are just some of the events we will be at over the next few months. **Come and see us!**

November

16–19
General Conference on Weights and Measures
Paris, France

16–18
The Skills Show
NEC Birmingham, UK

December

17–18
UKAS Annual Conference
NPL, Teddington, UK

January 2019

4
UKAS
Staines-upon-Thames, UK

9–12
ASE Conference
Birmingham, UK

20 May 2019

The SI redefinition changes to redefine the International System of Units (SI), changing the world's definition of the kilogram, the ampere, the kelvin and the mole, for ever will come into force on **20 May 2019**, will bring an end to the use of physical objects to define measurement units. Visit: **npl.co.uk/measure** to find out more.

NPL is the UK's National Measurement Institute, providing the measurement capability that underpins the UK's prosperity and quality of life.

From new antibiotics to tackle resistance and more effective cancer treatments, to unhackable quantum communications and superfast 5G, technological advances must be built on a foundation of reliable measurement to succeed.

Building on over a century's worth of expertise, our science, engineering and technology provides this foundation and helps to make the impossible possible. We save lives, protect the environment and enable citizens to feel safe and secure, as well as support international trade and commercial innovation. As a national laboratory, our advice is always impartial and independent, meaning consumers, investors, policy makers and entrepreneurs can always rely on the work we do.

Based in Teddington, south-west London, NPL employs over 500 scientists and is home to 388 of the world's most extensive and sophisticated laboratories. NPL also has regional bases across the UK, including at the University of Surrey, the University of Strathclyde, the University of Cambridge and the University of Huddersfield's 3M Buckley Innovation Centre.

Contact us

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