Department for
Business, Energy
& Industrial Strategy

UK Measurement Strategy

Confidence in Investment,
Trade and Innovation

March 2017

Cover image:

NPL's strontium ion optical atomic clock. The photo, taken by photographer Andrew Brookes, came first in the Optical Society's Centennial Exhibition, which highlighted 100 iconic images from the world of optics and photonics. The ion trap which forms the heart of NPL's atomic clock offers improved stability and accuracy over the microwave clocks which currently keep the world's time.

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Foreword

Measurement matters. Every time you use your GPS, put petrol in your car, or receive a medical diagnosis, you are putting your trust in measurements. Measurement plays a vital role in responding to new challenges, supporting UK innovation, and helping the drive to increase UK productivity. The UK National Measurement System (NMS) consists of a core infrastructure of measurement laboratories and a wider community of service providers that ensure you can have confidence in the measurements you make or are made on your behalf. Our reliance on the NMS is often overlooked, but, like many of our infrastructures such as roads or water, it would be noticed if it did not work. The fact that it is invisible to many is indicative of its success, but our economy, our quality of life and often our very lives depend on the robust and reliable measurements it enables.

This measurement infrastructure provides critical support to business, from calibration laboratories and instrumentation manufacturers, to measurements in use on a production line or in delivering a service. Over 60% of British Standards involve measurement or testing. The NMS also enables global trade and manufacture by ensuring consistency and recognition of measurement units and standards throughout the world.

Measurement needs do not stand still. Improving the productivity of UK industry is essential in sustaining and improving prosperity for our nation, and measurement plays a fundamental role in optimising and improving industrial processes. The rise of new markets, innovations in industrial processes, disruptive technologies, and societal challenges in health, security and the environment all drive the need for new or innovative measurement techniques and standards.

The UK has a world-leading science base which our national measurement infrastructure can draw on as it conducts research and builds capability to meet the measurement needs of the UK now and into the future. This infrastructure will enable innovation and improved healthcare, and will support us in tackling the challenges faced by the UK.

We maintain a National Measurement System because of the substantial impact it has on every aspect of UK life and economic success. Reflecting this importance, we have taken time to analyse and consult widely in order to develop our thinking.

In developing this strategy we conducted a broad consultation with industry, government partners, regulators and other users of measurement. We also analysed government ambitions and reviewed technology and industry trends. We are confident that this strategy will enable us to address UK priorities over the coming five years. We must capitalise on and enhance our world-leading National Measurement System to support our aspiration to be the best place to live, to innovate and grow a business. Delivery of this strategy will provide a connected measurement system, coordinating national resources and enabling effective investment that is easily accessible for the end-users. It will bring many benefits for the UK.

Chapter 1 - Vision

Government engaged with more than 1,000 measurement users, key stakeholders and partners in order to understand how the system works for them and what the future challenges for measurement are that need to be addressed through the National Measurement System. The NMS is the collection of capabilities and facilities delivered through a core infrastructure of measurement laboratories and a wider community of service providers and intermediaries. Feedback from users of the National Measurement System confirmed the importance of measurement for business, science, the regulatory community and government and called for a strategic framework that establishes clear leadership in measurement for the UK through a national approach and an integrated system.

The UK Measurement Strategy has been developed based on this input, addressing two major challenges:

1. The UK has built up a world-leading National Measurement System. The challenge will be to maintain this position in the light of the ever increasing demands for new measurement science responding to challenges in health, environment security, and energy.
2. Given the productivity challenge in the UK and the importance of access to world-leading facilities, the National Measurement System needs to effect a quick and efficient response to user needs, to deliver impact using national assets wherever they reside. This will ensure the UK retains its competitive advantage afforded by measurement knowledge ahead of international competition.

Through measurement and standardised protocols, we want to bring confidence to invest, to trade, to innovate, and to deliver national services in the UK that ensure our citizens are healthy and secure within a sustainable environment.

This government will build upon the world-leading capabilities and individuals supported by the NMS to deliver impact to its users through closer integration of the wider community and effective partnerships.

We will establish a better connected measurement system, coordinating national resources and enabling effective investment that is easily accessible for the end-users.

To deliver our vision we have identified five strategic themes:

1. Ensure a national approach to measurement capabilities that drives effective investment in the UK measurement laboratories in partnership with the UK science base and business **to deliver a world-leading measurement infrastructure.**
2. Champion measurement across government to **ensure good policy, standards, and regulation.**
3. Work smarter and **get better connected to end users** to increase awareness, access, and uptake of best practice measurement.
4. **Improve the UK's measurement skills** across all sectors of the UK to accelerate new technology uptake and fully exploit the benefits of a high tech economy.
5. Bring together the diverse communities to understand the new capabilities in data science and develop a framework to deliver **confidence in the intelligent and effective use of data** based on measurement traceability and uncertainty analysis.

Investing in a world-leading measurement infrastructure

Ensuring good policy, standards and regulations

Our vision is for the UK to capitalise on its world-leading National Measurement System to be the best place to live and do business.

Confidence in the intelligent and effective use of data

Getting better connected to our end-users to deliver impact

Improving the UK's measurement skills

Key messages from the measurement user community

Measurement is critical for a large user base that includes business, science, government, and the regulatory community operating in a global competitive environment:

- Measurement enables UK businesses to raise productivity, accelerate innovation and move to Manufacturing 4.0
- The instrumentation sector is a key impact route for measurement technology and is strongly interlinked with the National Measurement System

New technologies continue to pose new and complex measurement challenges. Areas requiring further investment in measurement research include manufacturing, Big Data, and life sciences.

Big Data and the Internet of Things in particular require a better understanding of data quality and uncertainty.

Access to world class facilities, equipment, and experts is critical. Any changes to the portfolio of capabilities will have to be managed carefully to ensure UK expertise is maintained.

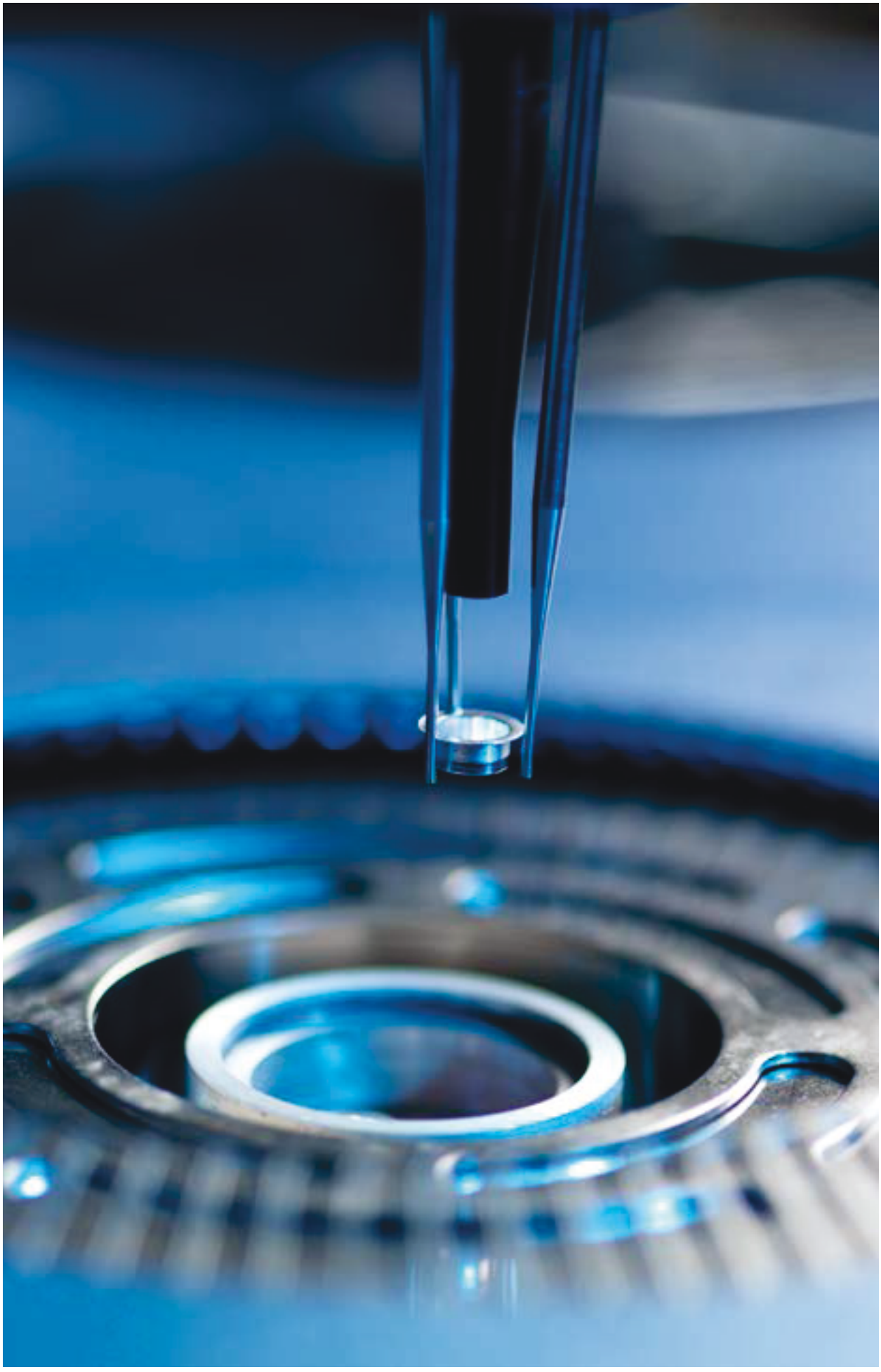
Clarity of leadership and how to access the system would significantly improve the profile of measurement across science, business and government. Opportunities were identified for a national approach and a more integrated system, in particular working more closely with regulation and trading standards to ensure consumer protection.

Practical measurement skills are not universally available and a major concern for businesses hiring the next generation apprentices, technicians, and engineers.

Further evidence and delivery plan

This document provides a strategic framework for UK Measurement. It is underpinned by evidence summarised in 'The Value of Measurement', which includes further information on the NMS and how it works, the economic case for measurement, and the evidence collected through stakeholder engagement.

During the course of 2017, the government will publish a **delivery plan** describing how our commitments will be delivered across government and through the National Measurement System in partnership with the science base and innovation system. The plan is based on the actions within this document and will include details of investment in the future portfolio of measurement capabilities and roadmaps for delivering a better connected measurement system for the UK.



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Chapter 2 – Strategic Context

Measurement delivers confidence

In order for the UK to compete internationally, businesses must continue to innovate and improve productivity and trade. Good measurement is at the heart of this endeavour and plays a vital role in responding to new challenges, supporting UK innovation, increasing quality, and helping the drive to increase UK productivity. Measurement also supports governments and citizens in obtaining reliable information on important issues such as climate change, pollution and medical diagnostics. Reliable, traceable, measurements give confidence in data and enable effective decision making, which supports the final uptake of new ideas in industry or other organisations.

Higher productivity

Measurement enables organisations to reduce waste, increase machine utilisation, reduce human intervention, shorten manufacturing lead times, improve productivity, and increase overall confidence in decisions. Raising productivity is a key economic challenge. The development of measurement technologies is strongly associated with increased productivity. In addition, evidence shows that support from the NMS can boost employment in firms by 10-15% within 2-4 years and supports their survival[1].

Since the publication of the last measurement strategy, government has supported many manufacturing supply chain companies to improve in-process verification, speeding up production while reducing costs. Over three quarters of measurement laboratory customers use measurement throughout the production process: during design; to check that goods from suppliers meet specifications; during the production process to maintain efficiency; and before despatch to ensure products meet quality standards. In hospitals, advances in measurement have improved diagnoses, reducing false positives and negatives, as well as increasing sensitivity of tests and reducing the time and cost taken to produce results[1].

More export and trade

Businesses expect a regulatory system that they can easily understand and does not impose undue costs whilst protecting the consumer, the public, and the environment. They also demand an enforcement regime that is consistent and proportionate. Trade makes an important contribution to the UK economy with exports and imports each worth around 30% of GDP[2]. Each year in the UK, around £622 billion worth of goods are sold, on the basis of the measurement of their quantity, to consumers and between businesses themselves, e.g. measuring the consumption, energy value and quantity, of the fuel piped to homes. The measurement community will work proactively to ensure these regulatory systems are successful beyond exit from the European Union.

[1] The Value of Measurement, Evidence to the UK Measurement Strategy, BEIS, 2017
[2] OBR Economic and fiscal outlook 2014

Measurement is the currency of technical trade between suppliers and customers as it provides confidence in products, underpinning regulation and standards. Where regulation is required, a regulatory system that is also underpinned by standards enables business to trade at lower costs.

Using regulation to ensure accurate measurement in trade also underpins fair *competition* between businesses and competition is a key driver for improving the productivity of UK businesses. Trading is not always about physical goods and services; since the last strategy government has invested in systems to support new areas such as timing of financial transactions and carbon markets.

In financial trading, time is money. The rapid expansion of computer- based trading requires accurate time stamping in order to help prevent trading irregularities and to aid forensic investigations. NPL is working with the Financial Conduct Authority (FCA) to help support the proposed new regulations and will deliver a trusted time signal, NPL*Time*®, directly to the city to provide the most accurate and secure timing available in the world.

Understanding the structure of biopharmaceuticals and their behaviour at each stage of production is crucial for new drug therapies, of which only ~10 % are successful. LGC has translated academic development into standardised workflows for protein structural analysis using hydrogen deuterium exchange. This extends UK capabilities within the industry, reducing the time, cost and risks associated with bioprocess manufacturing by up to a potential six months.

Higher productivity

More export and trade

The global market for therapeutic monoclonal antibodies has huge potential - predicted to be $125 billion by 2020. However, commercialisation hinges on assuring that these products are safe to use. NIBSC developed a new bioassay method that predicts immunogenic or immunotoxicological reactions, thereby allowing pharma companies to test their candidate drugs at an early stage. This significantly reduces development costs as fewer immunogenic candidates later have to be abandoned.

Productivity improvement leads to increased sales: Huntleigh Diagnostic's ultrasound probes are exported around the world, mainly to detect the heartbeat of a developing foetus. Integrating measurement expertise, the company installed a more efficient calibration system resulting in £17.5 million of additional sales due to increased product quality assurance.

Confidence in innovation: Graphene is hotly tipped to surpass conventional materials in applications such as super-capacitors, ultrafast analogue transistors and touch-screen displays. However, capital markets find it difficult to deal with the uncertainty associated with very new technologies needing validation of inventor's claims in order to invest. Haydale Ltd, used measurements provided by the NMS to characterise their graphene process innovation, giving confidence to investors as part of their flotation on the AIM stock market raising in excess of £6 million.

Quantum technologies are set to revolutionise computing, secure communications, imaging measurement and sensing. The commercialisation and technical delivery of market-ready product based on these emerging and disruptive technologies requires the development of the measurement infrastructure, access to facilities and the transfer of knowledge throughout the supply chain. NPL's Quantum Metrology Institute (QMI) will respond to these requirements by providing the leadership that delivers new technical measurement capability and international standards which will enable the UK Quantum hubs, industry partners, academia and government agencies to make the UK the nation of choice for the commercialisation of Quantum technologies.

Confidence in new technologies

Better solutions for societal challenges

Biometric technologies enable automated recognition of people for building access, for passports and border control, and for authorising payments using mobile devices. NPL evaluates the performance and vulnerabilities of innovative biometric technologies such as the recognition of people's distinctive vein patterns, gait, and electrocardiogram signals as well as more established systems based on recording fingerprints, face, irises and voice. NPL initiated and drafted the international standard ISO/IEC 19795-1 "Biometric performance testing and reporting—Part 1: Principles and framework" now used by government and commercial organisations to specify and evaluate biometric systems in an expanding global business.

Tackling cancer through providing confidence in radiotherapy. More than 120,000 people receive radiotherapy treatments per year, which is still one of the most effective cures. Its success depends on the accuracy of the dose and its delivery: a sufficient dose delivered to kill the tumour whilst sparing surrounding tissues. This is underpinned by metrologists, working with academics, instrument manufacturers, radiotherapists, clinicians and professional bodies to ensure the right standards, training, procedures and auditing are in place.

Confidence in new technologies, leading to accelerated innovation

The world is constantly changing. Markets are established or disrupted by new technologies, companies grow through competitive advantage, and new research saves and extends lives. Innovation, built on firm science and engineering foundations, is central to the process of positive change and advancing the prosperity and health of the UK. Uncertainty about whether something works, or has improved, deters investment and slows down commercialisation.

Measurement reduces business risks throughout the technology life cycle. Measurement can lead to competitive advantage by demonstrating how a new product or technology works, enabling the rapid take-up of novel technologies in new products, reducing development time, and removing barriers to market adoption. Measurement can also help identify the robust critical attributes of a product that may be the distinguishing factor or improvement over a competitor product. According to a survey of 1,000 businesses, organisations that use government-supported measurement laboratories are more innovative. In addition, 94% of business users that introduced an innovation believed that the support they received helped them make their innovation more quickly, more effectively, or reduced the risk. They also believed that without government support their total annual sales of new products would decrease by at least £470 million and that about £2 billion worth of new products might be at risk without this support[3].

"The more capable we are at measuring and understanding our process, the better we can predict the outcome. As we produce near net shape parts this will be critical to new product introduction particularly as we move towards more complex parts." Paul Monington, Aeromet Quality Manager

New technology in itself generates a constant demand for new measurement tools. Since the publication of the last strategy, government have invested in quantum and life science measurement and the capability to respond to measurement requirements for new technologies.

Better solutions for societal challenges

The UK and the world faces many environmental, sustainability, security, safety, energy and health challenges. Without good measurement, these challenges cannot be quantified and understood or potential solutions sought.

"From the fight against polio to fixing education, what's missing is often good measurement and a commitment to follow the data. We can do better. We have the tools at hand." Bill Gates, January 2013

Government invests in a broad range of measurement needs, which are used every-day to ensure that our citizens are safe and secure. For example, by:

- Supporting effective treatment through the accuracy and reliability of diagnostic tests
- Ensuring accurate doses throughout treatment
- Bringing confidence to legal regulatory frameworks to avoid disputes in court
- Countering terrorism threats through the development of new detection capabilities

Solving these challenges requires new measurement science and capabilities to enable prevention, control, mitigation and remediation. The new capabilities developed then become part of the UK's measurement infrastructure, which is required long-term to sustain the industries that emerge to respond to these challenges.

[3] Study of NMS customers with a comparison group of non-users for the National Measurement System, and the impact their business activity has on the UK economy, Data Build, May 2015

Measurement in short

At its simplest, the measurement system ensures consistency between measurements made in the UK and other countries so that, for example, a component can be designed and specified in the UK, manufactured in China, processed in Germany and brought back to the UK for incorporation in a wider system without the need for modification. The ability to manage supply chains is only possible through the use of standardised measurement units and common measurement techniques and processes supported by international standards. Standards also form the basis of fair and effective regulation, so it is important for the UK to influence the development of international standards based on measurement to ensure they meet UK requirements.

Six guiding **principles of good measurement**:

1. The right measurement
2. The right tools
3. The right people
4. Regular review
5. Demonstrable consistency
6. The right procedures

Measurement traceability describes an unbroken chain of comparisons, relating an instrument's measurement to a known internationally agreed standard.

Metrology is "the science of measurement, embracing both experimental and theoretical determinations at any level of uncertainty in any field of science and technology" according to BIPM's 'What is metrology?', 2004.

A majority of activities in the measurement laboratories deliver applied measurement research and standards that is supporting emerging technologies. Examples include:

- Big Data – Earth observation research aiding climate modelling
- Robotics and autonomous systems – highly accurate sensors in autonomous production lines
- Synthetic biology – targeted genome editing
- Regenerative medicine – characterisation of stem cells for process control
- Agricultural technologies – new techniques to achieve high accuracy food and feed supplement measurements
- Advanced materials – characterisation of and standards for graphene
- Energy storage – advancement of fuel cell technologies through better characterisation of performance
- Oil and gas – improved subsea measurement technologies to support optimisation of UK Continental Shelf production
- Quantum technologies – work on quantum encryption and quantum communication
- Internet of things – exploring complex system behaviour in sensor networks

The UK Measurement System

This government is committed to operating a world-class National Measurement System. It is the technical and organisational infrastructure, which ensures a consistent and internationally recognised basis for measurement in the UK. The UK, along with all other developed countries, invests in our measurement infrastructure to allow measurements to be made with integrity and consistency by developing and maintaining internationally recognised measurement standards and practices. Government provides the vital funding to support this infrastructure, which also guarantees that the capabilities are available to all in the UK: from those contributing to the quality of our lives in education, health or security, to those supporting our economy through manufacture and trading.

The UK has an enviable history in measurement, from the Magna Carta declaring standard measures of corn, beer, wine, and weights, to the invention of the first accurate atomic clock that enabled GPS, the internet and high frequency financial trading. This history of achievement has been attained through sustained, long-term investment in the UK's National Measurement System, a world-leading metrology infrastructure.

The UK National Measurement System is comprised of a core infrastructure of measurement laboratories that are connected with the wider measurement community that includes international, legal, quality, and science and innovation, to deliver the benefits of measurement to the UK end-users.

The core infrastructure

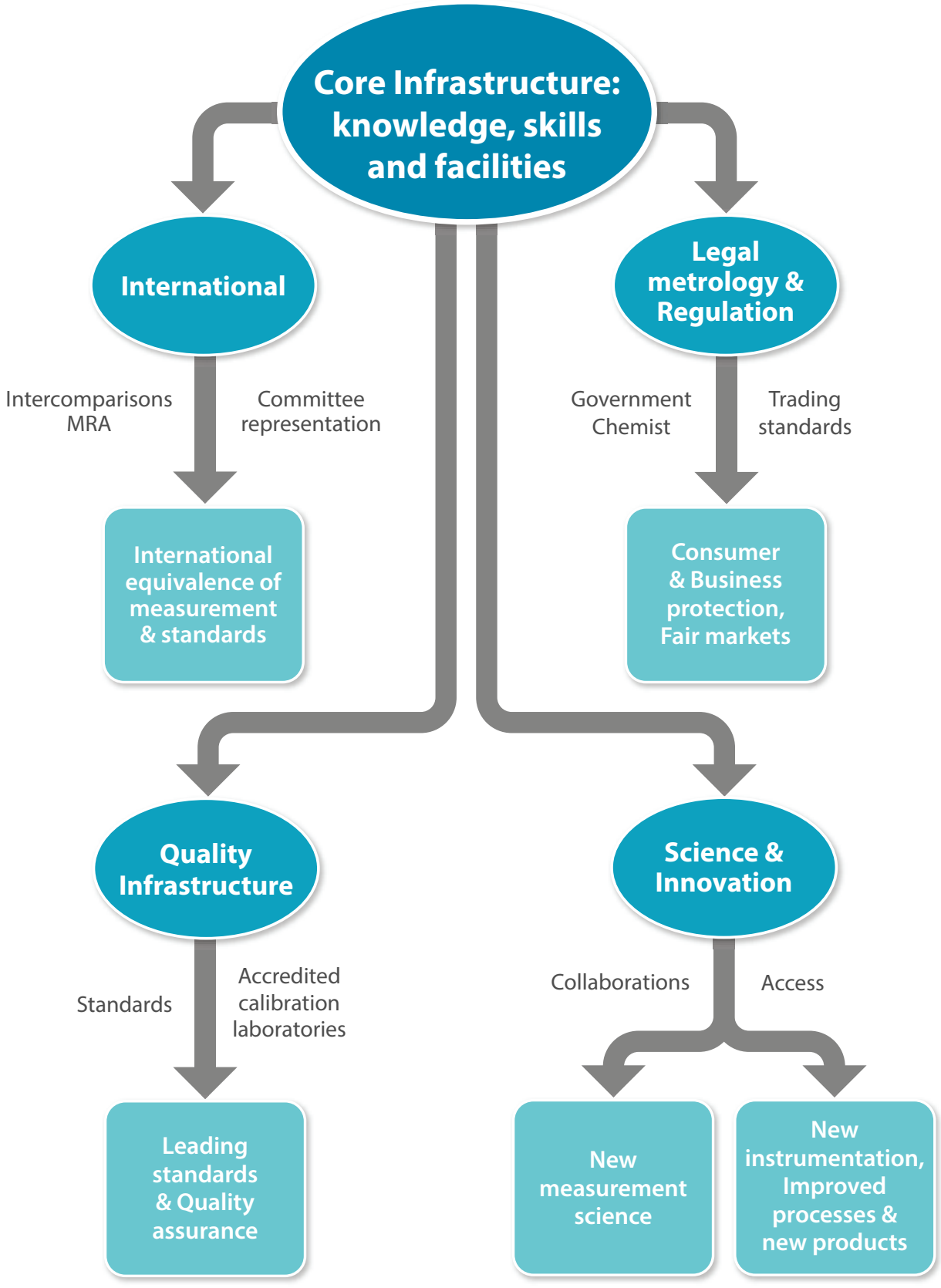
The core infrastructure comprises specialist measurement laboratories with scientists who, on behalf of government, maintain the UK capability and undertake world-leading research to ensure the UK can remain at the forefront of measurement science.

- NPL (National Physical Laboratory) – the UK's National Measurement Institute
- LGC (formerly Laboratory of the Government Chemist) – designated for chemical and biometrology
- NEL (National Engineering Laboratory) – designated for fluid flow metrology
- BEIS - Regulatory Delivery (Department for Business, Energy & Industrial Strategy) – designated for legal metrology
- NGML (National Gear Metrology Laboratory) – designated for gears metrology
- NIBSC (National Institute for Biological Standards and Control) – designated for bioactivity metrology

The measurement community

The measurement laboratories works with a much broader network that can be considered as the wider measurement community including organisations in the quality, science and innovation, legal and regulation, and international infrastructure, to drive impact through access to knowledge, skills and facilities. At the same time, continuous feedback from the community ensures that the research and development of new capabilities is relevant and fit for purpose.

UK measurement system deliverying impact



Science and innovation – as science, technology, and data requirements accelerate, resulting in new and emerging industries, the measurement requirements need to be coordinated and delivered in partnership with the science community. Good measurement enables scientific research to be quantified and reproduced, ultimately enabling the uptake of new discoveries and increasing the speed at which scientific consensus (for instance on the health effects of pollutants) is reached. The UK has a world-leading science base and measurement infrastructure that collaborate closely to both apply measurement to scientific research and develop new measurement approaches from scientific discoveries. The measurement laboratories work in partnership across the scientific spectrum with leading researchers and facilities supported by the Research Councils, other government departments, and applied science and engineering capabilities in public sector research establishments and Innovate UK's Catapults.

UK Quality Infrastructure – The UK Quality Infrastructure including measurement, standards and accreditation, is internationally recognised for its approach and excellence. Combining standards, measurement and accreditation builds trust between buyers and sellers, reducing the need for duplicated measurements during transactions and eliminating costs within the supply chain. With this trust in the system, it is not necessary to keep checking the nature of the goods traded. This trading system, through around 1,500 accredited calibration and testing laboratories, relies upon the expertise in the core measurement infrastructure. The NMS supports more than 900 measurement and standards committees and professional bodies, at both national and international levels, ensuring that the required measurement methods are underpinned by sound measurement practice.

International system of measurements – Measurement is a global endeavour ensuring the consistency and recognition of measurement units throughout the world. The UK's measurement laboratories are responsible for global liaison and representing the UK within the international measurement infrastructure. There are 97 signatories and associates to the Metre Convention - an international treaty that ensures a common system of measurement internationally under the auspices of the Committee International des Poids et Mesures (CIPM).

The UK's legal metrology – Weights and Measures legislation is enforced across 207 local authorities by over a thousand trading standards officers trained in weights and measures, to support local businesses and protect UK consumers.

The Government Chemist function provides advice to regulators and industry to resolve scientific disputes and carry out research. This statutory function acts as a referee analyst under several Acts of Parliament which focus on public protection, value for money, and consumer choice. Regulatory areas where our advice may be important include the quality of food, animal feed, pesticides, medicines, and chemicals.

Measurement leadership

The UK measurement system is world leading[4,5] and measurement is truly a global endeavour. Leadership, both internationally and nationally, affords the UK a number of key advantages:

- **Trade and exports:** Driving UK defined standards at an international level that underpins global trade can provide a competitive advantage for the UK. It can ensure that UK industrial practice can be adopted globally and commercialisation of UK technologies and products are accelerated.
- **Business friendly standards and regulation globally:** The UK, through its leadership position, can influence regulatory requirements to become fit for purpose and efficient for UK business to implement.
- **Leadership in Science and Innovation:** Leadership within the global metrology community (one of the world's largest coordinated scientific community) enables prioritisation of research agendas to enhance the UK's own world leading science and innovation systems and helps attract high-tech international businesses and research to the UK.

Government is committed to retaining this leadership position.

The NMS underpins key policy objectives, regulation and operational requirements across a number of government departments:

- Food, agriculture, air and water quality regulation for the Department for Environment, Food and Rural Affairs (Defra) and Food Standards Agency (FSA)
- Medical diagnosis and treatment in the NHS for the Department of Health (DH)
- Transport infrastructure monitoring and drink drive legislation for the Department for Transport (DfT)
- Homeland security for the Home Office
- National greenhouse gas (GHG) inventory, observations of emissions in the UK and accelerating the development and uptake of low-carbon technology for the Department for Business, Energy & Industrial Strategy (BEIS)
- Timing, location and national security for the Ministry of Defence (MoD)
- Taxation of oil and gas production for BEIS and HM Treasury (HMT)

Measurement also enables the UK to respond to a number of international treaties, for example in the areas of climate change, food, and nuclear energy.

[4] International Science Benchmarking Exercise, NPL, 2012
[5] The Value of Measurement, Evidence to the UK Measurement Strategy, BEIS, 2017

The UK plays a leading role in measurement in Europe, securing €500 million of funding from the European Commission to support measurement research and the development of capabilities through joint European metrology programmes. The programme will increase the effectiveness of research by reducing duplication and increasing impact. The overall goal is to accelerate innovation and competitiveness whilst continuing to provide essential support to underpin quality of life. The UK expects to continue this leading role beyond exit from the European Union.

83% of the global pharmaceutical leaders have sites in the UK. Chemical and biological measurement is a cornerstone of this industry and the measurement laboratories lead UK efforts to respond to the market needs. In 2017, the UK's first UKAS accredited calibration facility for digital PCR DNA measurement will open at LGC, enabling developers of molecular diagnostic kits and reference materials to develop high-accuracy products for the benefit of patients.

The oil and gas sector will continue to make a substantial contribution to the UK economy, supporting around 375,000 jobs and supplying the UK with more than half of the oil and gas used. Responding to the DECC commissioned Wood Review concerning the next 20 years of oil and gas production from the UK Continental Shelf, fundamental work must be done to support the drive to maximise economic recovery in technologically challenging environments. Accurate and reliable multiphase flow measurement will be a principal enabling technology in the drive to optimise production.

The UK was the first to see that there was a compelling case for standardisation of Nanotechnology to underpin trade. NPL worked closely with UK government and BSI to put a proposal to ISO for the creation of a new committee, TC229 Nanotechnologies, to create confidence in the market place through the development of standards. This committee has now produced 46 standards and has 36 participating countries.

Drink drive legislation saves lives - the number of people estimated to have been killed in drink drive accidents in Great Britain has decreased from 1,640 in 1979 to 240 in 2013. Workplace testing for alcohol use also prevents accidents. NPL reference gases underpinned the 684,000 roadside screening breath tests and 124,000 police station drink drive tests carried out in 2013. LGC ethanol primary reference standards and LGC ethanol calibration services now represent 50% of the breathalyser market and its standards also supply 150+ clients for clinic-based workplace testing.

Chapter 3 – Strategic Themes

Investing in a world-leading measurement infrastructure

Given the benefits of international leadership to the UK, sustaining an internationally leading measurement infrastructure and science base will be essential in maximising the returns for the UK. Maintaining and building an advanced measurement infrastructure is beyond the capability of individual organisations and needs to be provided by government to ensure a thriving economy[6].

The challenge for the UK is to maintain its leadership position, whilst responding to a diverse set of user needs: on the one hand satisfying an ever increasing demand for new measurement science addressing national challenges and on the other hand continuing to deliver core services around traceability which underpin trade and economic growth. Investment needs to maintain relevant existing capability and establish new infrastructure that connects people and companies, enables trade, increases productivity and delivers sustained, long-term local economic and social benefit. This strategy is building on fertile ground. The NMS is ranked as world leading in terms of efficiency and effectiveness with high leverage of external funding[7]. It also benefits from working in partnership with the UK's world leading science base.

This government will capitalise on the world leading capabilities and take a national approach to coordinate assets wherever they reside and drive aligned investment in new measurement capabilities to maximise impact of government investment.

The measurement laboratories will manage a dynamic portfolio of measurement capabilities focusing on those cross-government priorities and national challenges where better measurement will play a central role in delivering successful outcomes across a range of national priorities.

Most importantly, future user requirements will be better understood in advance to build a relevant infrastructure drawing on the knowledge of science, technology and industry trends established by the Foresight projects within government and the strategy work of the Research Councils, Innovate UK, and others. This approach will provide opportunities to explore new models for co-delivery and support of cross-government initiatives to leverage government investment and nationally ensure a fit-for-purpose capability.

[6] The Value of Measurement, Evidence to the UK Measurement Strategy, BEIS, 2017, chapter 3
[7] International Science Benchmarking Exercise, NPL, 2012

Rolls-Royce uses over 200,000 measuring instruments with traceability back to national standards in the production of its engines all over the world. Their Trent 1000 engine is made up of over 18,000 components, each of which is safety and performance critical and needs to be manufactured to exact specifications - this is controlled through careful measurement-based product verification processes.

Neutron detectors are essential in the control of nuclear reactors. NPL enables the testing and characterisation of these neutron-detecting devices using its unique accelerator-driven thermal neutron producing facility. This facility, providing core infrastructure capability, allows UK nuclear reactors to continue to operate through the testing of instrumentation that is essential for their safe operation.

Government will lead the NMS to:

- **Invest in the best capabilities** to sustain and build a globally competitive measurement infrastructure and expertise that gives the UK an economic advantage and increases the wellbeing of our citizens in partnership with the UK's science base as demonstrated by a regular, independent benchmarking exercise.
- **Actively manage the portfolio of current and future capabilities,** expanding and building new expertise for national challenges such as big data and life sciences, whilst developing new business models for mature capabilities. We will coordinate and leverage existing national assets in line with government's drive for efficiency. More details will be published as part of the delivery plan for the NMS in 2017.
- **Drive a National Measurement Foresight Activity** in 2018 by bringing together users in science, business, regulatory, and government to identify priorities for UK measurement science. These will be formalised in national metrology roadmaps for grand challenges in Health, Energy, Environment and Security.
- **Build better connections across the NMS,** including working in collaboration with science and industry leading to more joint development of future metrology capabilities to support their practitioners and deliver solutions to their challenges.
- **Identify or create new funding models** for long-term fundamental metrology research through partnership between the UK's core measurement laboratories and the quality, science and innovation infrastructure.

NPL created the first accurate atomic clock based on caesium. Quantum technologies have recently become a major government priority with the aim of making the UK an international leader in the field. As part of a new £300 million public investment in quantum technologies, the Defence Science and Technology Laboratory (Dstl) has invested £7 million over four years at NPL. The investment will see NPL develop components of a Quantum Navigator, a system which will enable very precise positioning and navigation without access to global navigation satellite systems (GNSS), enabling navigation in GNSS-denied environments such as indoor and subsea applications.

The UK submarine fleet relies on an ultra-precision, UK-made, geared propulsion system operating with ultra-low noise to minimise detection risk. NGML provide the gear measurement traceability to ensure this is achieved

Our consultation identified the following top three areas as measurement priorities:

- Manufacturing and productivity
- Big data, models and sensor networks
- Life sciences

Ensuring good policy, standards and regulations

Good measurement brings confidence to data and the decisions that are based upon it. The UK's measurement infrastructure must be coordinated to ensure good measurement and standards are at the heart of evidence-based policy and regulation.

Government and associated agencies rely on the trusted expertise and advocacy of the NMS to provide advice on technical aspects and impact of policies in health, security, energy and the environment as well as for specific emergency responses. Regulation underpinned by good measurement and standards provides an opportunity for simplification and in some cases even deregulation as users demonstrate compliance through voluntary means. Over three quarters of measurement laboratory customers use measurement throughout the production process: during design; to check goods from suppliers meet specifications; during the production process to maintain efficiency; and before despatch to ensure products meet quality standards[8].

Working closely with industry to understand the measurement and standardisation needs for emerging technologies will enable the UK to exploit competitive advantage through global adoption of UK practices.

However used, good standards and measurement are key to sound policy making and to enabling simplification of regulation, or deregulation, and government will work to embed measurement in policy, standards, and regulation where relevant.

[8] The Value of Measurement, Evidence to the UK Measurement Strategy, BEIS, 2017, chapter 6

LGC's measurement expertise was crucial to help address the horsemeat incident in 2013 where beef was found to be contaminated with horse meat. According to Defra *"LGC's advice was essential to ensure our confidence in the analytical approaches and technical advice we provided to policy makers and ministers".*

According to the National Audit Office (NAO), accurate radiotherapy dosage underpins a substantial NHS investment with 500 consultant clinical oncologists, 2,100 therapeutic radiographers, and 1,150 physicists working with LINAC machines traceable to NPL and 246 machines in operation in England alone at a purchase cost of £1.4 million each.

Government will lead the NMS to:

- Ensure that measurement requirements are fully considered in government policy initiatives through a cross-departmental approach to measurement. It enables measurement expertise to be used to inform, shape, and monitor policies addressing national challenges in health, security, energy, and environment.
- Bring together the legal and scientific metrology community internationally to positively influence new regulation that will impact on UK businesses and consumers.
- Drive the benefits of a coordinated Quality Infrastructure through proactively managing a **framework partnership between the Measurement Infrastructure and BSI and UKAS** in order to:
  - Anticipate UK requirements and lead the development of new standards in emerging technologies.
  - Define the market specifications for new technologies in standards and metrology roadmaps.
  - Align the measurement infrastructure with the standards and regulatory community for a more business-friendly approach that positions the UK competitively using a risk based methodology[9].

Traceability to national standards is essential for fair and equitable trade and one example where the NMS will need to develop capability relates to imports of liquefied natural gas which now comprises up to 30% of UK gas usage. At present there is no traceable flow measurement technique to underpin financial transactions and is one of the activities for the Flow Measurement Institute (FMI) and NEL to effect.

International guidelines and standards influence the safety and performance of ultrasonic diagnostic and therapeutic equipment, encouraging user and instrumentation developer communities to follow measurement best practice. Measurement research, funded by DH, has contributed to the increased safety of the 2 million obstetric and neonatal ultrasound scans carried out each year in England and Wales annually.

The government recognises the potential for the UK to become world leading in the commercialisation and use of synthetic biology. The Synthetic Biology Leadership Council has refreshed its roadmap (2016), highlighting the role standards may play to support commercialisation of synthetic biology technologies. LGC and NPL have been working with SynbiCITE and KTN-UK to help the leadership council agree a long-term national approach that aligns ongoing activities in the US and elsewhere.

[9] In accordance with the Regulators' Code , when regulation is necessary, BIS/BRDO 2014

Getting better connected to our end-users to deliver impact

Measurement plays a key role in supporting endeavours across the scientific, innovation and industrial landscapes. In order to ensure that measurement best practice is utilised by all those that can benefit from it, the NMS must be well connected across a huge number of organisations, networks, and communities. The strategy consultation identified this as a major challenge[10].

Government research has demonstrated that collaborative working has a direct impact on almost all measures of innovation activity – 72% are more likely to generate revenue from products that are new-to-market[11]. Local access can be another factor which boosts engagement and adoption of new technologies. Although the UK measurement laboratories already work in partnership with thousands of organisations and end-users, local operations allow new companies including SMEs access to relevant capabilities.

Through the NMS, the government will build on its current approach and work smarter to engage with a multitude of beneficiaries. New models are required to engage effectively with sector communities, identify common challenges, and develop sector roadmaps and strategies for measurement.

Internationally, the measurement community is one of the world's largest organised scientific communities. Measurement knowledge, wherever it resides, needs to be accessible to UK users through new products and services also encouraging cross fertilisation of solutions between different sectors. There are many opportunities to make this work in favour of UK businesses, from supporting exports to attracting inward investment.

[10] The Value of Measurement, Evidence to the UK Measurement Strategy, BEIS, 2017, chapter 8
[11] Allas, T. Insights from international benchmarking of the UK science and innovation system, BIS Analysis Paper Number 03, January, 2014

Smaller companies struggle to access measurement support. To give local access in one of the UK's most important manufacturing regions, 'NPL Huddersfield' was launched as a new mechanism to maximise the benefit of measurement and provide easier access to world-leading measurement expertise, equipment and research. The Huddersfield Laboratory is now regularly interacting with over 50 companies, with most within a 40-mile radius.

The Flow Measurement Institute (FMI), set up with Coventry University and NEL, will drive a cohesive approach to the future of flow measurement science and infrastructure to meet the emergent needs and challenges of industry. The FMI is already working with approximately 350 individual members from oil and gas operators, instrument manufacturers, the Regulator, academia, service companies, and test laboratories.

Government will lead the NMS to:

- Be responsive and connected into existing infrastructures and systems, to ensure best practice is embedded and end-users can easily access existing capabilities to maximise the benefits of government investment. Specifically we will:
  - Bring together communities of users in business, science and government to **define measurement challenges** and **develop novel solutions** that are fit for purpose such as the work in advanced manufacturing supply chains. The Measurement community will be represented in all major sector communities and define sector metrology strategies and roadmaps led by the users.
  - Build **a national network of access hubs** for key measurement capabilities and advice, working with organisations such as Local Economic Partnerships and other innovation or academic partners to support local clusters of business activity.
  - Drive knowledge transfer, by creating new approaches to **turn measurement knowledge into products** and actively push uptake by potential beneficiaries. Increase the use existing mechanisms such as the movement of practitioners and researchers between industry, academia and infrastructure.
  - **Promote benefits of measurement and availability of capabilities** across industry sectors, providing clear signposting to facilities and knowledge, wherever they may reside through linking into major networks and communities.
- Working with UKTI, explore options to capitalise on the international measurement network to facilitate export or inward investment.

The Product Verification Programme (PVP) was instigated by leading equipment manufactures in the Advanced Manufacturing sector to drive competitiveness in supply chains.

PVP is helping manufacturing companies to improve their productivity and reduce waste through better measurement processes and technologies. The PVP team has delivered metrology support to 56 companies based throughout the UK, from Glasgow to Torquay and from Ipswich to Bangor, 90% of which are SMEs.

"Through NPL's Product Verification Services, we are manufacturing with a higher degree of confidence and increasing efficiency to provide more for our customers for the same cost."

John Walker, Engineering Manager, CW Fletcher

Sandvik developed an innovative advanced hardmetal for use in tooling and components whose performance needed to be independently assessed in order for the material to be more readily adopted by users. Engagement with the NMS gave confidence to Sandvik's performance claims, promoting its uptake. An early application was its use as a lightweight punch in the manufacturing process of aluminium cans, allowing them to be made thinner, saving significant energy costs and making better use of materials in the production of the 250 billion cans manufactured each year.

Improving the UK's measurement skills

Technical skills are essential for creating the absorptive capacity required when adopting innovative new technologies. As processes become more automated, investment in leading-edge equipment is vital, but is at best ineffective without investment in training to enable its full exploitation. This is the same with measuring equipment used across a huge range of applications such as enforcement control, medical applications, manufacturing and scientific discovery. Without appropriate practical measurement skills and a thorough understanding of basic measurement concepts, reliance upon black box systems for measurement or the use of multiple data sets brings risk.

As a result of the last measurement strategy and responding directly to industry requirements, new practical training programmes were developed by the UK measurement laboratories and over 2,000 learners now receive measurement training every year directly through the measurement laboratories. According to the strategy stakeholder engagement, more needs to be done to develop the next generation of metrologists[12]. A key challenge is to build awareness and recognition for the profession and increase its attractiveness for future scientists and engineers, whilst also providing practical work-based support for the existing workforce across all sectors.

"Businesses must have their say in training tomorrow's workforce. Giving employers the power to design apprenticeships means apprentices graduate with the skills they need for the job they want and businesses get the talent they need to grow. Young people on these programmes will have the opportunity to learn sought-after skills and enjoy a great start to a working life."
Nick Boles MP, Minister for Skills

The government will build upon the range of existing interventions such as the 'Trailblazer', our current range of training and work with industry to increase the understanding of measurement across a range of education and training levels: from public engagement and outreach activities to schools and colleges, to training for apprentices, graduates and postgraduates. A national training programme will increase the profile and appeal for adopting measurement skills, in line with other awareness raising activities.

[12] The Value of Measurement, Evidence to the UK Measurement Strategy, BEIS, 2017, chapter 8

A pipeline of talent is needed to fill measurement skills gaps across a host of sectors. The innovative metrology 'Trailblazer' group for Apprenticeships underpins the development of the next generation of skilled measurement specialists. The Trailblazer initiative will ensure that every metrology apprentice in England is enrolled on a scheme that has been designed and approved by employers. Over 25 UK companies including AugustaWestland, Renishaw and SGS EMICS are represented in the metrology 'Trailblazer' group showing how important measurement skills are for their operations.

Government will lead the NMS to:

- **Together with industry, champion the inclusion of measurement skills** into education, academia and business, delivering a comprehensive measurement skills programme that covers schools through to lifelong learning.
- Establish a **National Training Programme for Measurement** under the leadership of the core measurement laboratories. This will enable a diversity of pathways to professional qualifications, from apprenticeships to industry-ready postgraduates, through the development of academic, applied, and CPD-certified training accredited to international standards.
- Work within professional bodies and their qualification frameworks to establish **professional accreditations** for technicians with a strong focus on measurement science.

Measurement skills shortages are important because of their impact on productivity and growth. During 2014, NPL alone trained more than 1,500 people from 525 companies in the Aerospace, Defence, Security, Automotive, Advanced Manufacturing and Healthcare sectors. A survey recorded that over 90% of organisations have made a positive change in their workplace following the training course.

"Understanding measurement is key to understanding and validating how these changes can benefit the business. Measurement training has enabled us to rigorously evaluate new ideas, identify where they can save time and money and deliver increased value to customers."

James Luther, Director Prototype Facility, Vestas.

Providing confidence in the intelligent use of data

The world is getting evermore interconnected, with networks of sensors and other instruments making more measurements and making them more frequently than even before. This provides huge volumes of data to enable better monitoring and control of systems from the nanoscale to city and countrywide. The digital revolution has brought with it the ability to generate, combine, and manipulate huge quantities of data.

More data does not necessarily increase its value. Generating models on inappropriate data wastes resources; both money and computing power. The quality, reliability, and integrity of data needs to be understood to ensure appropriate decisions are made from it. By inserting the quality and provenance of data into streams and sets, in real time, it will be possible to ensure receivers, be they people or machines, can use the incoming data in the most appropriate way and ensure decisions made are in light of this knowledge. The ability to thus use this data efficiently and effectively to support decision making is critical in ensuring we can benefit from the wealth of data. Confidence in scientific data enables the UK to faster exploit the digital revolution, the Internet of Things, and autonomous systems. A better understanding of data quality, uncertainty, and provenance are at the heart of this endeavour.

"The First Industrial Revolution used water and steam power to mechanize production. The Second used electric power to create mass production. The Third used electronics and information technology to automate production. Now a Fourth Industrial Revolution is building on the Third, the digital revolution that has been occurring since the middle of the last century. It is characterized by a fusion of technologies that is blurring the lines between the physical, digital, and biological spheres."
Klaus Schwab, Founder and Executive Chairman, World Economic Forum

This Fourth Industrial Revolution will see a rapid, powerful convergence of a number of big technology changes (autonomous vehicles, sensors, biotechnology, 3D printing, robotics, artificial intelligence) and bring new measurement data challenges.

This is a major challenge across government, business and science as identified during stakeholder engagement[13], which merits concerted action in collaboration with the leaders in the field to build new capabilities. With the user in mind, practical tools and frameworks need to become available that provide guidance on how to understand scientific data leading to better decisions-making either through humans or within an interconnected autonomous environment.

[13] The Value of Measurement, Evidence to the UK Measurement Strategy, BEIS, 2017, chapter 8

NPL leadership of an international community has facilitated a new era in earth observation with the recognition that climate data uncertainty and traceability are essential in enabling evidence based policy decisions on the impacts of climate change. The planned TRUTHS satellite mission will deliver data that is 10 times more accurate than is currently possible and also transfer its high accuracy calibration to other orbiting satellites; upgrading the performance of the international Earth Observing system. This will allow for effective planning and mitigation of major climate change induced events such as flooding and food security.

Government will lead the NMS to:

- Work in partnership with the science base (through Hartree, and Turing Institute for example) to create and implement innovative, **new measurement capability** to respond to fundamental research needs including, for example, new approaches for obtaining quantitative measurement data in the area of life science.
- Build upon the expertise established in the UK to **bring the community together in the development of methodologies, techniques, technologies and tools** that will support the management of large data streams and sets to understand, measure and annotate their quality of provenance to enable the UK to develop a competitive edge in the understanding and use of data and the IoT, throughout government, society, the health service and the economy.
- Work with the quality infrastructure to **respond to the challenges** of data interoperability, accreditation, and standards. For example using data provenance meta-data to enhance interoperability and create the foundation for the development of standards.
- Deliver and disseminate **best practice** to those who use data in real-world applications and make decisions based upon their results using both applied training courses and nationwide local service provision via a network of Regional Hubs.

There are many industries creating and using huge data sets. There is a role for the metrology community to look at how to use these data sets and to develop tools that will support questions such as:

- How well does this data fit your needs? (accuracy)
- Could this data set be repeated? (precision)
- Do you have any doubts about the data? (uncertainty)
- Can I use this data in isolation? (dependencies)
- Can this data be combined with other data sources? (interoperability)

With thanks

This strategy was brought together following significant consultation both through online questionnaires and direct interviews. We would like to thank all the stakeholders who contributed including but not limited to:

3M
Adams Equipment Co Ltd
Advanced Manufacturing Research Centre
Advanced Witness Systems
Aeromet International Ltd
Agilent
AgustaWestland
Air Monitors Ltd
Airbus Defence and Space
BAE Systems
BP Exploration Operating Company Ltd
British Measurement and Testing Association
British Standards Institution
BT
Campden BRI
Carl Zeiss
Centre for Process Innovation
Coventry University
CW Fletcher
Defence Science Technology Laboratory
Diamond Light Source
DPZ Technologies
EDF Energy
Emerson
EPSRC
Eon Technologies Ltd
EPAM Systems
Epigem Ltd
European Space Agency
ETSI
Exova
Gambica
GE Power
GlaxoSmithKline
Government Office for Science
GTMA
Hampshire County Council
High Value Manufacturing Catapult
Honeywell Ltd
Huntleigh Diagnostics
IBM
Imperial College London
Innovate UK
Jaguar Land Rover
Johnson Matthey
King's College London
Magnox
Manufacturing Technology Centre
Measurement Matters Ltd
Met Office
MHRA
Ministry of Defence
National Composites Centre
National Grid
NIHR Diagnostic Evidence Co-operatives
NERC Centre for Ecology and Hydrology
NGF Europe
NHS
Northumberland City Council
NAMRC

Nuclear Decommissioning Authority
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QinetiQ
Renishaw
Rolls-Royce Plc
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Royal Society of Chemistry
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UK Weighing Federation
Unilever
University of Birmingham
University of Cambridge
University of Huddersfield
University of Leeds
University of Leicester
University of Manchester
University of Nottingham
University of Southampton
University of Strathclyde
University of Surrey

This publication is available from www.gov.uk/beis

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