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INFRATECHNOLOGIES
THE BUILDING BLOCKS OF INNOVATION-BASED INDUSTRIAL COMPETITIVENESS

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July 2012

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EXECUTIVE SUMMARY

No–one doubts that technology is vital to growth and competitiveness. In recent months, both the Government and Opposition have highlighted technology as a central part of the UK's industrial strategy. But what does a technology–based industrial strategy actually look like?

This report provides a vital part of the answer. It shines a spotlight on infrastructure technologies or infratechnologies:[1] the underpinnings of a successful innovation system that helps knowledge flow across the economy, among researchers, businesses, and government. These include standards, testing, inspection, certification and more generally technical feasibility studies. These technologies and the institutions that support them operate as bridges between scientific research and businesses, and between businesses. They form a diverse group: some are public sector, some private, and some are neither. They include business associations, laboratories and institutes, mission–oriented offices, and businesses, but they share a degree of autonomy and a keen sense of mission.

Collectively, infrastructure technologies have a wide catalytic effect. They provide the underpinning for fast–moving sectors like nanotechnologies, telecommunications and low carbon technologies, which require shared technological knowledge to flourish and grow. The success of innovative economies like Germany and Korea in bridging the gap between research and development depends in no small part on their ability to provide infratechnologies effectively.

The report analyses infratechnologies, looking at how they work and their role in the technological innovation system, using the example of measurement and standards organisations as a case in point. It highlights four ways in which infratechnologies improve industrial competitiveness:

i. **Helping develop a proof of concept,** usually a prototype, which demonstrates that the basic intended functionalities of a product are possible, thus reducing the gap between expectation and deliverable before the production and marketing phase begin; as an illustration, manufacturers supplied 5¼in floppy disk drives throughout the 1980s, but introduced 3½in drives in the 1990s, based on prototypes showing that the information density could be increased and the mechanics of the drive upgraded, even though the underlying method of recording on a magnetic disk was the same.

ii. **Discovering the properties of a transformational technology,** for instance by investigating the structure of materials at a molecular scale, and generating new empirical knowledge and instruments that reduce the substantial risks associated with applied industrial production; in the 2000s the floppy disk was supplanted by the USB flash drive, which uses a solid state, non–mechanical recording method, providing faster storage and retrieval in a smaller device.

iii. **Integrating new production methods that lead to improved efficiency** by changing the way businesses conceive, build and operate automated manufacture, including helping them to develop the capabilities and skills they need to master new production processes and machineries; the USB flash drives themselves have been through several generations of production processes and design development, achieving ever higher storage capacities (up to 2 terabytes are planned) at ever lower cost.

iv. **Providing the technical basis for the development of common languages, architectures and performances** that are necessary to create a marketplace, thereby accelerating the adoption of innovations and enabling more businesses to collaborate within global value chains; manufacturers of computer peripherals coalesced around the USB (Universal Serial Bus) interface standard which has enabled customers to combine a range of products in individually personalised systems. New USB–interfaced products continue to appear in the marketplace e.g. Xbox 360, PlayStation 3, smartphones etc.

Partnerships with the intermediate institutions providing these infratechnologies are especially important to improve the competitiveness of small and medium businesses. Whereas large companies often have the resources to collaborate with universities directly, smaller ones have far fewer resources, uneven absorptive capacities and find it harder. Intermediate institutions can provide a one–stop shopping opportunity by giving access to a range of technologies small and medium businesses lack and access specialised skills that are not available to them.

Other advanced innovative countries take infratechnologies very seriously, invest in them, ensure the organisations that provide them are fit–for–purpose and operate in a joined–up manner. Examples include Germany’s Fraunhofer Society, Belgium’s IMEC, The Netherlands’ Holst Centres, Taiwan’s ITRI or Korea’s ETRI. The UK should take the following steps to improve its infrastructure:

i. **Undertake a full strategic assessment of how to better use and combine diverse institutions to support industrial innovation** in different sectors of the economy. The creation of the Catapult Centres can only be a useful additional design if there is clarity on how they will lead, integrate or complement the group of intermediaries that already operate in this part of the innovation system.

ii. **Use new instruments to improve access to infratechnologies by small businesses.** For example, competitive programmes are being used in Asia and in the US to support the most promising concepts through the typically difficult stages of feasibility and prototyping using the skills and assets owned by intermediaries. In some cases, challenge prizes can be another way of incentivising innovation by small businesses and opening out the skills and assets owned by intermediaries to a wider pool of innovators. Strategic approaches to using a range of tools that support open innovation are needed. They have to be based on testing, evaluation and a better understanding of how these tools could be used in combination.

iii. **Drive progress on blockages by using public supply chains to promote technological innovations by small and medium businesses.** This cannot take place at scale without willingness from the top of Government to take the risk of investing in innovative solutions from new suppliers. Other countries, like the US and Scandinavia, do this effectively. A lead market centre bringing together a critical mass of dispersed expertise in procuring technological innovative products, can actively manage this risk. The Technology Strategy Board could use its unique position in the innovation system to lead this new network.

If used effectively, the institutions that provide infratechnologies can become a well–organised means of enabling small and medium businesses to access new markets by mitigating the costs and risks of innovation, which would otherwise fall heavily on them. This strategic direction is all the more necessary as failure to invest in innovative small and medium businesses during an enduring period of austerity will almost certainly damage the UK's industrial competitiveness in the longer run.

ACKNOWLEDGEMENTS

The author would like to thank the following people for generously taking the time to be interviewed and providing the material for this report:

Graham Torr at the National Physical Laboratory, and his colleagues David Nettleton, Jenny Hully, Kamal Hossain, Martyn Sené, Keith Dobson, Ross Manning, Courtney Tuffin, Glenis Tellett, Graham Topley and Michael Adeogun.

Daniel Mansfield at the British Standards Institution, and his colleagues Nick Fleming and Jonathan Albrow, and Duncan Westland at the Identity and Passport Service, Home Office.

Many thanks to David Evans at the Technology Strategy Board for sharing his impressive knowledge of the UK innovation system.

Grant Peggie at the Technology Strategy Board and Fergus Harradence at the Department for Business, Innovation and Skills for providing very valuable comments.

Stian Westlake and Louise Marston at Nesta who have contributed to the editing, presentation and text of this report.

Special thanks to Robert Crawford at Nesta for backing this research topic, and his unfaltering enthusiasm and understanding of how to improve the competitiveness of small and medium enterprises outside the South East of England.

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Part I

MAKING CONNECTIONS – TOWARDS MORE EFFECTIVE INFRASTRUCTURE TECHNOLOGIES TO REDUCE ADOPTION RISKS

Today the potential exists for countries to create comparative advantage through technology. Emerging economies are employing growth strategies in which technology has become a major component. The rapid economic growth of Singapore, Korea and Taiwan has been based on developing state–of–the–art technologies that range across all areas of manufacturing, from electronics to discrete parts. Larger economies in Asia, such as China, are acquiring high value manufacturing capabilities, increased access to advanced global supply chains and have the long–term goal of attaining world–class status as innovators. In a context where technology is becoming more internationally mobile, the traditional economic principles of comparative advantage – which explain why developed countries maintain relatively advanced technology and industry compared to less developed countries – do not hold comfortably. In this context, the importance of developing and acquiring technology combined with its effective utilisation cannot be overstated. Both the effectiveness of technology investment and utilisation will strongly contribute to determine the future success of businesses, industries and entire economies.

Rethinking competitiveness

Over recent years it has been increasingly argued – particularly by economists in the US[2] – that the approach that has been leading a number of advanced economies to specialise in upstream research and in services while outsourcing manufacturing to countries where labour costs are lower raises serious competiveness issues in the longer run. The argument is that some countries have allowed the uncontrolled development of non–tradable sectors at the expense of tradable industrial sectors that are more conducive to competitiveness and sustainable economic growth. Other countries, exemplified by Germany and Japan, have better managed to maintain their industrial sectors and, as a result, have benefited more from outsourcing the less human–capital intensive segments of their industries. These countries have adopted growth–enhancing strategies in which public support is given not only to upstream research but also, and importantly, to research down to the stage of industrial prototype. They have successfully built up critical skills that are only developed in the transition from the science base to industrial production and have wide economic benefits. The resilience of these economies and the ability of their businesses to take advantage of the global economy have been made more visible since the financial crisis, which revealed the extent to which other economies suffer from structural weaknesses. These economists call for a 'new post–crisis realism' aimed at redirecting innovation and production in the US and part of Europe to regain a competitive edge and access new markets.

In the UK, there is a political desire to rebuild the industrial base. The UK manufacturing sector generates about £140 billion in gross value added and employs almost three million people.[3] It is the third largest economic sector in the UK after business and financial services, and wholesale and retail. However, manufacturing as a share of UK GDP has fallen steadily from 22 per cent in 1990 to just over 10 per cent currently, and this trend has been more pronounced in the UK than in any other leading economy. In this context, rebuilding the industrial base is a challenging ambition, especially in the short term.

A major reason for this is that high value manufacturing requires a sustained and sophisticated technology support system to flourish and grow. For today's industrial technologies, acquiring market share requires large numbers of scientists, engineers and specialists to interact. Besides, while commercialised products based on new technologies are private goods, the underlying and supporting technical inputs are derived from a combination of public and private assets. Hence, industrial strategies that strongly recognise and build on the public–private nature of modern technologies are the most likely to be successful. Building up manufacturing capabilities requires that organisations providing the supporting inputs evolve into an increasingly effective technology infrastructure. This means developing new, complementary and synergistic public–private partnerships. Government has to strategically manage and adequately fund this complex infrastructure to facilitate the diffusion of technology to businesses. This is all the more difficult to build up as the number of interdependent actors and the complexity of market interfaces has been increasing dramatically over the last decade or so.

Understanding how diverse types of institutions support innovation

The innovation system is a concept that describes the network of actors that interact within this process of innovation. The better the functioning of the system, the more effective is the creation new processes, products and organisational mechanisms, the faster the response to social and environmental transformations, and the more successful the adaptation of the productive system to new strategic economic objectives. Using diverse types of institutions to support innovation and enhancing their interactions is a major challenge. Improving the technological competitiveness of UK businesses, especially small and medium enterprises (SMEs), requires an innovation system that is intensively networked and where the knowledge and assets produced by all the organisations in the system, public and private, are fully exploited.

Whereas the role of universities and other fundamental research institutions within the innovation infrastructure is well understood, the role of other types of organisations that come into play in technology transfers is not adequately covered and, as a result, they are usually left at the margins of national policy initiatives. This is revealing of the emphasis that has been put in the UK on creativity and invention rather than on adoption and scale. The role of these institutions is best put under the umbrella of 'infrastructure technologies' or 'infratechnologies'. These institutions are autonomous and have in common the enabling of businesses – and other actors – to go beyond the limits of their internal technological capabilities, bringing both new and existing knowledge to bear by solving problems in the context of technological application. What these organisations do is to a large extent undocumented and their position in the innovation system is not well understood. A recent study[4] argues that national governments in the EU are failing to exploit the potential of these institutions to help Europe rise to its urgent innovation challenges. It estimates their combined annual turnover in Europe to be about £20 billion and their economic impact to be about £100 billion annually. However, this is a family of heterogeneous organisations with diverse origins that can be defined in different ways and their significance varies between EU members.

Intermediate institutions differ from universities and other academic centres whose main mission is a mix of fundamental research and teaching. In a nutshell, they provide applied research and development, technology and innovation services to enterprises. They often have a sectoral focus and this is related to the diversity of innovation across the economy. The technological needs of advanced materials or telecoms are different from those of healthcare or energy industries. In European countries like France or Germany these intermediate institutions were mostly created by governments in the 30s and in the post-war period. They tend to have clear business models and are key actors in some national innovation systems. Indeed, some of these organisations play a major role in the delivery of industrial priorities. The Fraunhofer institutes in Germany are good examples of such intermediaries. Similarly, some Asiatic countries like Taiwan and South Korea, make extensive use of these organisations.[5]

In the UK, intermediate institutions have a more complicated history that may be traced back to the creation of the Ministry of Technology in 1965 and to laboratories within large national corporations, followed by their progressive ‘agencification’ and privatisation in the 1980s and early 1990s. This rather convoluted past may have contributed to the existence nowadays of a variety of organisations frequently financed by a combination of public and private resources, with multiple business models and governance arrangements. This complexity is problematic to navigate for UK policymakers. In fact, it could be argued that the growing involvement of some UK universities in industrial applications and the recent creation of the Catapult Centres, are attempts to fulfil the outreach function that tends to be achieved by institutions providing infratechnologies elsewhere. This organisational density is a source of confusion and leads to a lack of clear strategic focus between the actors in the system. Besides, the Catapult Centres may introduce additional risks of unintended competitions and overlaps, thus displacing resources rather than strengthening support.

It is therefore timely to better understand, assess and extract value from this rather unexplored part of the innovation system comprising some very successful organisations. The UK technological infrastructure is composed of five broad organisational categories, depending on institutional drivers and business models:

1. At one end of the spectrum are institutes and centres that are publicly funded by Research Councils. They have research objectives as their primary driver but also support commercialisation and work with businesses to complement their revenues. The National Centre for Atmospheric Science, the Solar Institute, the Babraham Institute, the International Space Innovation Centre (ISIC) are examples of this first category of organisations. Other organisations are associated with the National Health Service and work regularly with industry, such as the NHS Technology Adoption Centre. The NHS National Innovation Centre was in this category until recently, but is now run as a private organisation.

2. A second category comprises a few large organisations that are mission-driven and mix commercial operations with specific public responsibilities to various degrees, like the Ordnance Survey, the Met Office and the British Standards Institution. These national offices tend to have a clear focus and a wide outreach.

3. A third category includes business associations that are membership-based and can be not-for-profit, such as TWI Ltd in engineering, Intellect Technology Association, the Manufacturing Technology Centre and the National Computing Centre.

4. Some national laboratories and companies provide facilities and expertise on a commercial basis in some sectors of the economy such as the National Nuclear Laboratory, the Health and Safety Laboratory or LGC Forensics. Although they operate in the private sector, their business models can be complex. For instance the infrastructure of the National Physical Laboratory is financed by public subsidies but services making use of the infrastructure are operated privately. Another example is the Energy Technologies Institute, which is a private sector organisation but funded equally by member companies and Government.

5. At the other end of the spectrum some organisations are companies with commercial business models, such as the QinetiQ Group or CERAM Ltd, and focus on solving technology–related problems for customers.

As part of a broader Nesta effort to understand the ecology of organisations in the UK innovation system and better use them to support businesses, this contribution focuses on the institutions that provide most measurement and standards inputs as a case in point, more specifically on the National Physical Laboratory (NPL) and the British Standards Institution (BSI). It seeks to define their function in the development of industrial technologies, the mechanisms through which they concretely contribute to the growth of innovative businesses, and the policy challenges they raise in the design of their services. It aims to provide a knowledge base on which policy might be formulated and also seeks to bring the role of these institutions to a wider audience, thus strengthening the relationships among people producing, sharing and applying different kinds of technological knowledge in the UK.

In the black box

The development of industrial technologies is frequently presented as a black box where new technologies are developed from research and development (R&D). Although an adequate science base is a necessary requirement, commercial applications cannot be efficiently derived directly from it. It is surprising that few economic models make the attempt to disaggregate the interactive and complex process through which technologies flow from the science base to commercialisation. The Tassey Model[6] presented in the Appendix (see How are industrial technologies developed?) provides a helpful insight into this process. Infratechnologies fall into a difficult category between pure public goods like fundamental research i.e. which it is impossible for any one individual to appropriate, and the pure private goods i.e. which are the province of profit–seeking businesses. They are the advances that must take place before saleable new technologies can be produced.

From test methods, to performance assessment and industrial standards, infratechnologies increase productivity, decrease costs, and open doors to new opportunities. Measurement and standards are a case in point. For example, nanotechnology promises to be the next frontier for industrial innovation. Scientists are regularly creating new nanostructures and discovering unique applications for nanoscale materials. The next challenge is to turn these materials into goods that can be industrially produced in series within global value chains. Measurement and standards provide the tools that enable this practical fabrication at the nanoscale. They constitute the technical infrastructure of the industry and play a pivotal role in reducing business risks at a critical phase in a technology life cycle (the 'risk spike'). They enable businesses to acquire and commit to new technologies and markets.

Assessing the total economic impact of measurement and standards is a difficult and costly task. This is typically related to their spillover effects i.e. like for physical infrastructure, they generate pervasive wide ranging benefits that are challenging to quantify. Over recent years, studies conducted under the auspices of the Department for Business Innovation and Skills have concluded that measurement and standards generate high economic benefits and point to interlocking roles between the institutions providing these inputs (see Appendix). However, as these studies are conducted at a high level of aggregation, they provide limited insight into how these institutions add value to businesses in practice. This Nesta report attempts to understand the mechanisms through which measurement and standards support innovative businesses and industrial competitiveness, and how the organisations that provide them could be used more strategically within the wider innovation system.

Part II

REACHING OUT – HOW TO ENABLE THE COMMERCIALISATION OF NASCENT TECHNOLOGIES

Today's industrial technologies are being integrated into higher–level systems that are delivered over complex business networks. The pace and scale of globalisation is associated with the rapid emergence of new value chains as production processes have become more fragmented. Since technologies have become more complex, businesses have been pushed to specialise in fewer technologies and inputs are sourced from more cost–efficient and innovative producers. This explains why high and medium–technology industries are on average more dispersed and internationalised than less technology–intensive industries. The result is greater dispersion of innovation within supply chains. This global value chain phenomenon increases the number and complexity of market exchanges, the need for interoperability, equivalence and mutual recognition to support international flows.

The institutions that provide measurement and standards assist UK businesses in trading effectively in the global market place. They reduce transaction costs and increase competition by providing accurate information about the products being traded. They are a means to safeguard consumer health and environmental interests by ensuring that products comply with regulations. In addition, they are also part of the UK innovation system. This research focuses more specifically on this function and on how these institutions enhance the technological competitiveness of businesses. In other words it analyses how businesses internalise and use the information about the state of the art of a certain technology provided by these institutions to innovate, both in products and in systems of production.

What is metrology?

Metrology is the science of measurement. It was originally concerned with the description of the various types of measures (linear measures; measurements of capacity, mass, and time). Today metrology rests on high–precision physical experimentation. It uses the achievements of physics, chemistry, and other natural sciences, and its own specific laws and rules to find a quantitative expression for the properties of objects in the material world.

The National Physical Laboratory (NPL) is the heart of UK measurement science. Since the 1990s, NPL's business model has been based on a combination of public funding for infrastructure and private revenues from commercial services (see Box 1). In peer reviews NPL is ranked amongst the best institutions in the world, after the National Institute of Standards and Technology (NIST) in the US and with the Physikalisch–Technische Bundesanstalt (PTB) in Germany. By contrast, both NIST and PTB are public organisations under the authority of the US Department of Commerce and the Federal Ministry of Economics and Technology. NPL is credited with applying new science to invent radar in the 1930s, the Automatic Computing Engine in the 1940s, the Caesium Atomic Clock in the 1950s (used in mobile phone and internet transmissions for instance) and packet switching (used in computer network communications) in the 1960s. More recently it has been assessing the properties of graphene. NPL's global reputation is an asset for the UK innovation system. This is acknowledged in the Government's Innovation and Research Strategy for Growth published in December 2011, although how to make better use of this intermediate institution remains to be defined.

Box 1:

The UK measurement science landscape

The National Measurement System (NMS) provides the infrastructure for measurement in the UK. It is run by the National Measurement Office (NMO), an Executive Agency from the Department for Business Innovation and Skills (BIS), that sets the strategic direction of the measurement infrastructure, provides statutory and commercial measurement services and acts as an enforcement authority. NMO's contractors are three laboratories: NPL, LGC and NEL.

The National Physical Laboratory (NPL) is the UK's National Measurement Institute and employs over 450 scientists and specialists. It is a Government-Owned Contractor-Operated (GOCO) institution managed by Serco Group plc since 1995. Currently NMO has a ten-year contract with Serco, which is due to expire in 2014. In 2011, NPL generated about £70 million revenue – two-thirds from Government funding and one-third from commercial sales. NPL research capabilities include electromagnetic fields, biometric recognition, graphene, magnetics, nanotechnology and functional materials, neutron measurements, stabilised lasers, optical technology, earth observation and climate, energy efficient lighting, humidity, surface and nanoanalysis, super-resolution microscopy, fuel cell technology, 3D microscopy, composite materials, energy harvesting and medical and industrial ultrasound.

LGC is a company operating in fields like forensics and genomics. It also delivers a range of roles and functions on behalf of Government, including the Designated National Measurement Institute for chemical and bioanalytical measurement and the statutory Government Chemist function.

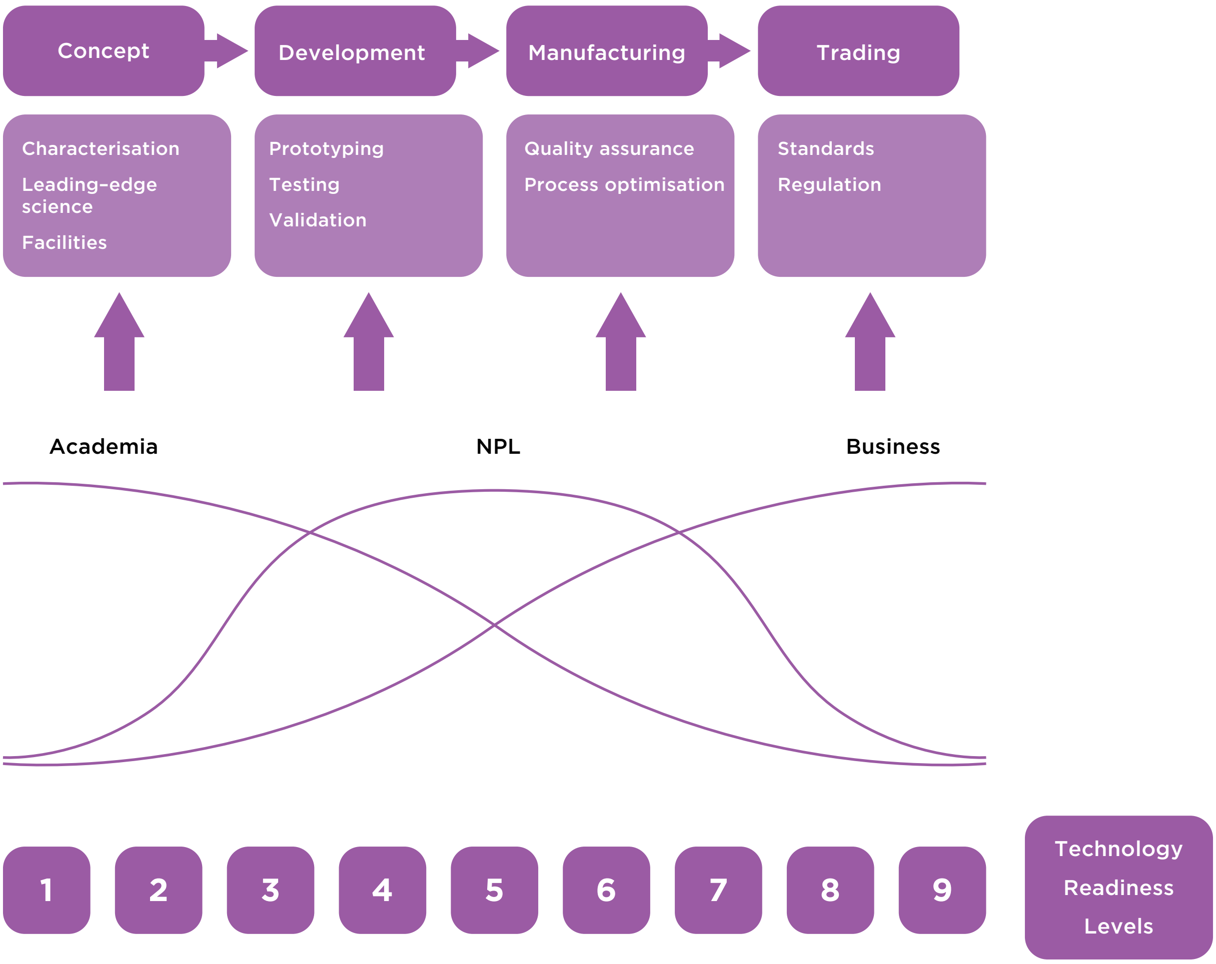
NEL is part of the German group TUV SUD and operates in energy, flow measurement, emissions and environmental systems. It is the Designated Institute for liquid and gas flow measurement technologies and provides the UK's national flow measurement facilities.

The Government, via NMO, will invest around £240 million over the next four years in the measurement infrastructure. In addition, £25 million will be invested over four years in the upkeep of NPL Government-owned facilities. The laboratories will aim to also bring in over £100 million in revenue from commercial work.

Exploiting the industrial potential of scientific breakthroughs

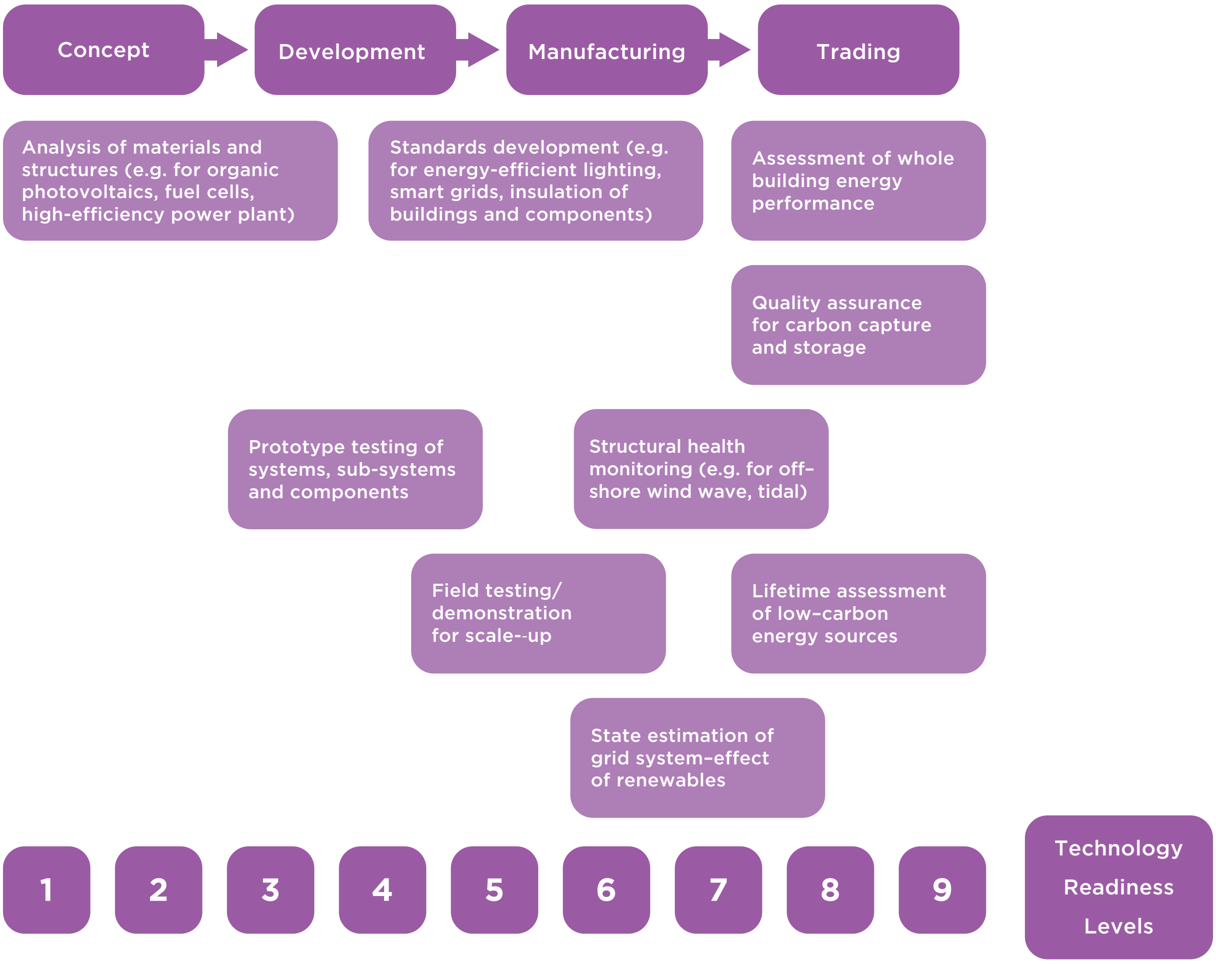
Technology diffusion is the process through which a new scientific idea is accepted by the market. The rate of technological diffusion is influenced by price and return on investment, but also by a number of other factors: the product's perceived advantage or benefit, riskiness of purchase, ease of product use and complexity of the product, immediacy and observability of benefits, and trial ability. All these influencing factors rely on scientifically-based measurement, standards, testing, inspection, and certification. Figure 1 below, illustrates the role of the measurement infrastructure in relation to the science base and commercial developments, from concept to trading.

Figure 1: Infrastructure support to technology diffusion



A range of exciting emerging technologies, such as nano and quantum technologies, are based on new and complex materials. They require both scientific breakthroughs and cross-disciplinary measurement underpinnings to flourish and grow. For these new technologies to be integrated into large production chains and become commercial successes there needs to be agreement on the performance characteristics of the devices, the properties of the materials making up these devices (including health and safety issues) and ways of incorporating them in advanced manufacturing processes. Such agreements will depend critically on measurement for the particular characteristics, properties and processes of interest. As an example, Figure 2 maps out the type of measurement inputs necessary to underpin innovations in the area of low carbon technologies. It ranges from techniques to analyse materials and structures in photovoltaics and fuel cells at the concept stage, testing methods for new technologies at the development stage, setting performance standards in energy-efficient lighting and smart grids at the manufacturing stage, and assessment of whole building energy performance at the trading stage.

Figure 2: Infrastructure support to low carbon technologies



These complex and numerous requirements suggest a difficult balance to strike for institutions like NPL between continuity over time and short-term flexibility. On the one hand an essential part of NPL's work is to anticipate the future needs of businesses and build up scientific capabilities in these areas. On the other hand, this long-term commitment makes it difficult to redeploy resources when technological and business opportunities shift over shorter time frames.

A typology of innovative industrial practices

Studies based on econometric modelling have shown that there is a link between measurement and innovation in the economy but this link has not been well defined (see

Appendix). Gaining a more in–depth understanding of measurement inputs in the business innovation process can support the development of more effective initiatives. In this section we make an attempt to develop a typology based on a mixed–method approach of expert and qualitative information provided by business case studies. This typology leads to a framework that can also be used and refined to inform future data collection, segment more precisely innovative businesses that are reliant on this part of the UK innovation system and quantify direct benefits generated by intermediate institutions in business innovation. However, like other microeconomic frameworks, it does not lend itself to assess the indirect economic benefits to other businesses in the same industry and the social benefits generated outside the industry.

Four business profiles can be identified using the type of innovation produced as first order criterion: the 'defender', the 'prospector', the 'analyser' and the 'unlocker'. For each of these innovative business models, measurement inputs provide a basis for reducing business risk and increasing competitiveness but in different ways, as the case studies illustrate.

➤ 'the defender'

These businesses pursue narrow product market domains and aim to integrate technological changes into existing products in order to improve their overall performance, for instance in strength, speed, weight, composition or costs. These are forms of incremental innovation where the product is superior to the competition, although it does not necessarily displace incumbents.

In this first case, the role of measurement in the innovation process is essentially **competence–enhancing** via consultancy and testing services. Businesses have typically used their internal knowledge and resources to develop a proof–of–concept, usually a prototype, but they do not have the specialised knowledge and capabilities to test it and adapt it. Measurement inputs will support them in identifying the effectiveness of the prototype, advising on how to improve it, and also on how to optimise its safety, reliability in service, adequate material, design etc. Measurement will also allow businesses to make validated scientific–based claims about the unique aspects of the product so that its technological superiority to the existing products on the market can be made apparent to consumers. This validated differentiation is a significant source of competitive advantage for commercialisation.

Such business innovation strategies are especially useful in fast moving consumer goods markets. The Hyperion Lighting case study 1 shows how a prototype was tested and validated for superior energy–saving efficiency and quality.

Case study 1

Hyperion Lighting

Lighting accounts for one–sixth of UK electricity USge according to Carbon Trust and is seen as an area where energy reduction can be achieved relatively easily and cheaply. The uptake of energy–efficient lighting can have a large impact on the UK's overall energy USge and associated carbon footprint, and this, coupled with increases in energy prices, is forcing businesses to look for ways to reduce energy use, or else pass increased costs on to their customers.

Hyperion Lighting manufactures energy–efficient fluorescent lighting solutions, filling the gap between current lighting products and future LED technologies, that still have technical hurdles to overcome. Their products are designed to be a cost–effective solution for reducing electricity consumption. In order for new lighting products and technologies to be taken up by users, there need to be reliable measurement methods in place to characterise their performance.

Hyperion Lighting had been working on a new design for an energy saving linear fluorescent lamp called the HT8. Their aim was to provide the same amount of lux (light intensity) as a standard commercial T8 lamp but with around half the energy consumption. The HT8 is designed to replace the traditional T8 lamp without expensive modifications to existing fittings or wiring. NPL was used to test the performance data required to validate their product claims, as NPL owned the infrastructure that can provide absolute and traceable measurement of light.

NPL tested several versions of the HT8 lamps in controlled conditions and provided photometric and electrical performance data to assess lamp performance using a goniospectroradiometer. The measurements carried out included: total luminous flux (how much light), luminous intensity distribution (where the light goes) and spectral distribution of the light source (colour properties of the light). Differences in the spectral output of light sources are important as they affect human perception and therefore the preference of one lamp over another. Traceable measurements were also made of the input electrical power in order to calculate the lamp's energy efficiency. Absolute photometric data displayed as a polar plot of luminous intensity distribution enabled NPL scientists to give guidance to Hyperion Lighting in assessing and interpreting the test data, presenting it in an industry–standard photometric data format so that it can be used in lighting design software packages for product development.

Hyperion Lighting could then market the HT8 lamp using the performance data supplied, and end–users could benefit from the energy savings brought about by the product, safe in the knowledge that they are not compromising on lighting performance.

The Spartan case study 2 illustrates how measurement and testing led to increased thermal–efficient goods through the improved selection of materials, construction methods and design, allowing a UK company to boost its competitiveness in international markets.

Case study 2

Spartan

There is surprisingly little scientific research into how wetsuits keep people warm. As such, there is very little data that can help manufacturers improve their products. Spartan is an Essex–based wetsuit manufacturer that specialises in the wind sports market i.e. wind–surfing, kite–surfing, and sailing. Spartan was especially interested in finding out how to improve their windsurfing wetsuits, as these are designed to keep windsurfers warm whilst they are standing up on their board (as opposed to surfers' wetsuits, which are meant to keep them warm whilst in the water). Spartan contracted NPL to perform some detailed measurements of wetsuits' thermal function. Measuring a wetsuit's thermal function helps manufacturers understand how a wetsuit really works, and therefore allows them to make informed decisions about what materials and construction methods to use.

NPL performed some initial laboratory–based tests on wetsuit samples, followed by some field–testing of wetsuits during proper use. The laboratory tests involved measuring the thermal resistance of four samples of neoprene cut from a Spartan wetsuit. The four samples were different thicknesses, and their surface finish was either single or doubled lined. Specialised equipment, a piece of kit called a single–sided 305mm guarded hot plate, was used to measure the samples' thermal resistance. The results showed that the wetsuits' surface finish had no bearing on how good an insulator it was. Following the laboratory tests, some field tests were performed in Clacton, on the Essex coast. The team used portable wireless sensors and a thermal camera, which was used to measure the water's temperature before entering the sea, after two minutes in the sea, after longer exercising times and after standing in the cold breeze for ten minutes. In the field tests the surface finish had a measurable effect on how well the wetsuit kept its user warm. This difference is caused by wind wicking moisture (and therefore heat) away from the surface of the wetsuit via convection – or 'wind chill'. The effect of wind chill has been recognised for some time, but measuring it in this way increases the understanding of it, and helps wetsuit manufacturers mitigate its effects.

Spartan was able to make better wetsuits, more efficiently, by using the correct new materials and construction methods for a new range of wetsuits. They were also given the ability to test the thermal performance of samples provided by their neoprene suppliers. Higher–tech wetsuits will allow customers (surfers, scuba–divers, swimmers, tri–athletes, wind surfers, sailors, kite surfers) to enjoy their sport of choice in much colder conditions.

➤ 'the prospector'

These businesses search for new market opportunities through the introduction of new technology–intensive products that will create changes and uncertainties to which their competitors must respond. These are more radical forms of innovation, which can involve large technological advancements, undermining some of the existing products in the longer run, rendering them non–competitive or obsolete.

In this second case, the role of measurement in the innovation process is to be **a partner in the production of new knowledge** via research contracts and collaborative research programmes. Businesses will be involved in high–risk and long–term research programmes with the view to commercialise a technology that is to some degree disruptive. Measurement will support them in understanding the properties of this technology and how it can or cannot lend itself to product development. The Technology Strategy Board in the UK or European institutions, can also be contributors to the funding of these costly research programmes.

For instance, a fuel cell is a device that converts the chemical energy from fuel into electricity through a chemical reaction with oxygen or another oxidizing agent. The energy efficiency of a fuel cell can be between 40–60 per cent, and up to 85 per cent efficient if waste heat is captured for use. There are many types and sizes of fuel cells, and they are extremely expensive to produce. Measurement will contribute to understanding the complex processes occurring inside a working cell and how it can be produced reliably at scale and at lower cost. Organic photovoltaics for energy generation and therapeutic applications of intense ultrasound are other examples of cutting–edge research that needs to be supported by measurement.

Businesses that use this form of innovation tend to be in high–tech sectors, and more particularly biopharmaceutical, medical devices or energy. The Vivacta case study 3 illustrates how collaborative research provided a new scientific analysis tool that will enable the development of innovative sensor technology at the point–of–care, to diagnose health conditions in the space of minutes without laboratory testing.

Case study 3

Vivacta

Currently, most clinical tests for diagnosing a patient's health condition are performed using large, expensive bench–top analysers in centralised hospital labs, which often have a long turnaround time for returning results. This has driven the development of 'point–of–care testing' (POCT) which allows immediate testing and analysis in front of the patient. There are many benefits to POCT, the most significant of which is how quickly the results are available to healthcare workers and patients. This allows appropriate treatment to be offered much quicker, which is often vital when managing critically ill patients.

Vivacta is an in vitro diagnostics company which has developed innovative technology that can quickly measure biological markers at the point–of–care. Its initial product is a highly sensitive TSH (thyroid–stimulating hormone) assay, which can quickly diagnose thyroid conditions. Vivacta's patented piezofilm–based sensor technology has benefits over other point–of–care detection technologies as it is sensitive, possesses a wide dynamic range, and has good precision. Also, it only needs a tiny sample of whole blood from a finger prick, so a red cell separation step is no longer needed, and the patient doesn't need to have blood collected by venipuncture. Thus, the sample can be collected by a non–trained user, and a phlebotomist is not required. The blood sample is collected in a credit card sized cartridge and placed in a reader where results are reported in five to ten minutes.

Vivacta did not understand how the different parameters in the cartridge affect the piezofilm response, and how to best interpret the response in order to get the best signal–to–noise ratio in the system. Previously, cartridge optimisation was carried out empirically, without a full understanding of the underlying physics. Vivacta's piezofilm detection technology takes advantage of a phenomenon called the 'piezoelectric effect'. This is where molecular–scale mechanical or temperature changes at the surface of a piezofilm produce an electric charge. In Vivacta's sensor, an antibody is placed on the surface of the piezofilm which binds to the substance that is being analysed (the analyte). Carbon particles in solution are also coated in an antibody which binds to the analyte. The analyte facilitates the binding of the carbon particles to the surface of the sensor. An LED pulse is then fired at the film which creates localised heating of the carbon particles and produces an electric charge. The charge produced depends on the rate of binding between the antibody on the film surface and the target analyte. Each cartridge contains a number of layers with the innermost layers corresponding to the piezofilm. The amount of electricity generated by the piezofilm is not only dependent on the LED power and the cartridge construction (such as the number of layers) but also their thermo–mechanical properties.

NPL was contracted to produce a bespoke computer model of the cartridge design. This new version of the software was provided to Vivacta and their partners to predict the charge output from a variety of different sensor setups. The bespoke software analysis tool is complementary fundamental science that Vivacta will use in the future to optimise their sensor technology and reduce development time for new applications. This will also be critical for understanding the allowable tolerances in the manufacturing processes as the software allowed Vivacta to understand which parameters in their system were vital to performance and which parameters had little effect.

The Duvas case study 4 shows how the invention of a new instrument for air quality monitoring enabled a university spinout company to design and market a pioneering technology for monitoring air pollution, potentially opening new opportunities for better traffic and environmental policy.

Case study 4

Duvas

Currently over one billion people a year suffer from respiratory disease associated with pollution and, according to the World Health Organisation, over three million a year die from its effects. Duvas is short for Differential Ultra Violet Absorption Spectroscopy. It uses UV light to detect a range of pollutants simultaneously, replacing the need for multiple instruments. Duvas quickly provides mapping of wide areas, as well as local snapshots of the chemical composition of the atmosphere, that show how pollution varies over time and space. These data can be correlated with weather patterns and traffic flows, or overlaid on map programs like Google Maps to provide visual representations of pollution, leading to better decision making and minimising human health impacts.

Duvas was spun out of Imperial College London in 2008 by Verdetech Investments Limited (the venture capital arm of MDT (UK) Limited). Duvas' mission is to provide state–of–the–art, flexible, real time, cost–effective and intelligent air quality sensing and monitoring systems for measuring and modelling of ambient air quality. Duvas needed to demonstrate the validity of their measurement devices. In order to do this, they required accurate and traceable gas standards of ambient pollutants. However, accurate gas standards at the required concentrations are not available due to their limited stability in high pressure cylinders.

NPL was contracted to develop new gas dilution facilities and prepare standards containing trace amounts of the pollutants that need to be measured to tackle the problems associated with air quality. Many of these compounds are present in the atmosphere at the level of parts–per–billion. This means that the reference standards prepared needed to contain similarly low concentrations, requiring a dilution technology found at NPL. These new instruments were able to detect pollutants at the level parts–per–billion on a second–by–second time frame.

This scientific research helped Duvas refine the technology and its use. It also made its acceptance by the market and regulators more likely. Once in place, local councils could use networks of Duvas sensors to inform traffic and environmental policy, and to better understand the health implications of air pollution. Such improved pollution management could save lives and improve quality of life, especially in urban areas. This innovation could potentially lead to better–informed legislation for improved quality of life.

‘the analyser’

These businesses introduce changes in their production processes leading to improvements in system efficiency and lower product cost. By investing in process innovation, businesses gain in terms of productivity, material utilisation, quality or reliability. They can also gain the capacity to manufacture new products which would otherwise lie outside their reach. This form of innovation is particularly important for SMEs since by this means they can utilise advanced technologies developed by large firms and increase their competitiveness.

In this third case, the role of measurement in the innovation process is **capital–enhancing** via consultancy. It is about bringing about better control of new plants, equipment and suppliers so that problems in complex production systems are diagnosed in real time, new technologies are operated in the right environments, wastage and scrappage are reduced, recycling is improved and production lines are fully automated. It can involve skills transfers through advanced training of the workforce as innovation often requires different knowledge, resources and mind sets.

Innovations in methods of production are especially useful for SMEs within or willing to participate in advanced manufacturing global value chains, for instance in the automotive or aerospace industries. The DPC case study 5 demonstrates how improved quality control of production for an SME supplying different global value chains in technological components, can be achieved through the up–skilling of its workforce in geometric tolerancing and measuring equipment.

Case study 5

DPC

Dawson Precision Components (DPC) is a precision engineering company based in the north west of England specialising in low to medium volume production and pre–production of precision engineered components for specialist industries. They supply precision components to a range of industry sectors including medical, oil and gas, aerospace, motorsports, automotive, marine, telecommunications, rail and the defence industry in the UK and overseas.

DPC has a range of skills across its workforce, as wide as the bespoke products it develops for its customers. Its operators are from different backgrounds with varying levels of experience and levels of understanding with regard to technical drawings and use of measuring equipment.

NPL was contracted to train all these employees and bring them up to an across–the–board level of competence. The training demonstrated that the simplest way of measuring a particular feature is not always possible, due to reasons such as feature size and accessibility. As a result, employees learnt to consider the inaccuracies of the measuring equipment being used, even when operating the most advanced instruments on the market.

The benefits for DPC include an up–skilled workforce with a clearer understanding of geometric symbols and tolerance, increased confidence in inspecting various components, a common understanding of how to interpret drawings to avoid confusion and an appreciation of the conditions or inaccuracies that can affect measurement as a whole. This up–skilling provided benefits across areas of DPC Quality Control: increased production efficiency, more tightly specified products and higher customer satisfaction.

The Wood Group GTS case study 6 illustrates how the use of thermal imaging methods allowed a company providing high–value–added services to power generation and renewable companies worldwide to make significant savings and improve its offer.

Case study 6

Wood Group GTS

Wood Group GTS is an energy services company with a global network of skilled employees that provide specialised turbine overhaul and repair services to the oil and gas, power generation and renewable industries in over 50 countries.

Turbine blades are coated in batches, prior to being put into service. Two blades out of a coating batch of six had been fitted in an operational power station but had developed defects, to the extent that the power station would potentially have to shut down, which would have been extremely costly for the power company. Wood Group wanted to be sure that the remaining four vanes of the batch were not faulty too, but did not have the expertise to do this.

NPL was contracted to carry out pulsed thermography on the blades. Pulsed thermography is a form of thermal imaging where a very short intense flash of light is directed at the sample, in this case the turbine vanes, and infrared cameras record how the heat passes through different areas of the sample. This kind of imaging technique can reveal structural problems that are invisible to the naked eye. This technique was able to confirm that there was indeed a problem with the coating on the remaining four vanes and that they would most probably fail in a similar way to the two already in operational use.

Wood Group acquired the knowledge to use this testing technique. They were then able to save at least US$700,000 in warranty costs (i.e. the insurance they provide the customer with if their products or services lead to power station downtime). They also avoided putting the faulty blades into service at a power station which could have damaged Wood Group's image and relationship with that customer.

‘the unlocker’

These are usually groups of businesses that seek interoperability between systems and aim to create a new platform that opens up new markets on which further innovations can be developed. The ability to design common architectures, to pair or connect products from different sources and to control the interactions and dysfunctions between these products or systems is essential to create markets for new technologies nowadays. It allows the more innovative businesses to interact and trade, and forces the less innovative businesses to keep pace.

In this fourth case, the role of measurement in the innovative process is to provide the **technical basis for standards recommendations for new technologies**, often via documentary standards and participation in expert committees. Standards tend to be, but not always, set by panels that usually derive their legitimacy from the entities that authorise them – business associations, professional bodies etc. NPL provides scientific guidance to those actually responsible for the act of setting, rejecting, adjusting, or implementing standards. It is all the more important as timing in standards is an essential condition for innovation. Outdated standards can freeze technological innovation and have to be regularly revised to keep up with the latest scientific developments.

For instance, smart grids are digitally enabled electrical grids that gather, distribute, and act on information about the behaviour of all participants (suppliers and consumers) in order to improve the efficiency, reliability, economics, and sustainability of electricity services. However, new renewable energy sources, like wind turbine and photovoltaic sources, are more complex and volatile and require the setting of new standards to optimise energy consumption.

The 3G mobile phone network is an example of how the ability to set and apply new comparable performance standards enabled network operators to optimise the efficiency of the network, as illustrated in case study 7.

The role of standards in innovation is discussed in more depth in Part III of this report.

Case study 7

3G network

3G mobile phone technology was a significant step–up from earlier systems as it needs to carry large amounts of data quickly so users can view stream video and access the internet from handsets. To support 3G, network operators had to install a new network of antennas, capable of handling higher data volumes and higher network transmission speeds. By moving from older fixed tilt antennas to new electronically variable tilt models, the reliability and access to the network could be improved. However, there were many different antennas available and it was not possible to evaluate the best option because specifications were set by the manufacturers themselves.

The antenna range, housed in an anechoic chamber at NPL, helped network operators such as O2 to independently compare the performance of different manufacturers and set performance standards for these products. It was able to provide full information about how the antennas could be expected to behave, including their gain and directivity. Armed with these comparable scientific results, network operators were able to make well–informed decisions about which supplier and product would best fit their needs. This led to substantial efficiency savings through fewer base–stations needed in rural areas, lower masts and less interference between adjacent base–stations in urban areas. Mobile phone networks account for more than 1 per cent of all UK electricity USge, so improvements in network efficiency also contributed to substantial energy savings and the associated carbon reduction.

An open innovation model

The typology therefore shows how infratechnologies support the competitiveness of the UK industrial base. It shows that businesses use this infrastructure to: 1) tackle aspects of technology they do not currently master, 2) seek new technologies and methods, 3) access technical expertise and resources that are not available to them, and 4) define compatibilities and achieve efficiencies between systems and technologies. As a result, the type of knowledge transferred from NPL to businesses varies a lot according to the objectives of the collaboration. It ranges from simply providing sound and reliable scientific inputs, to undertaking research that requires an optimal level of expertise over a longer time frame, to training the workforce. Therefore, another balance that is difficult to strike for intermediate institution is between service provision and cutting–edge research. The latter is a pure public good that requires public funding to maintain the quality of the scientific work in the long term. In the US and Germany for example, the fundamental research undertaken by NIST and PTB is publicly funded, in the same way as the fundamental research undertaken by universities. In the UK the existing mixed public–private business model is adapted for simple service provision but can be a limitation for high–quality measurement science. The risk is a decline over time in the quality of measurement inputs to UK businesses if fundamental research is not adequately supported.

One way of overcoming this issue could be to strategically strengthen the links between funding for infratechnologies and that for university research. At the moment universities can be both collaborators and competitors and is it unclear whether this design is intended and optimal. In particular, whereas large companies have the option to directly collaborate with universities efficiently, SMEs have much fewer resources and uneven absorptive capacities, so that intermediaries like NPL can provide a one-stop shopping opportunity comprehensive of testing services and applied research. Indeed, a major attraction of this type of intermediate institution over universities is its ability to include elements of the whole value chain and bring together otherwise disperse know-how in physics, chemistry and different branches of engineering. This positioning is all the more strategic as there is the political will in the UK to improve the industrial competitiveness of SMEs.

Beyond service provision and research, knowledge can also be transferred to businesses through traditional channels and *ad hoc* participations in initiatives where NPL has an 'enabler' function. For instance, businesses can access metrology knowledge through using peer-reviewed scientific publications and co-publication with universities, standard reference materials and standard reference data, intellectual property rights, social interactions (networks, conferences), staff mobility etc. NPL is also a consortium member in around 50 R&D projects funded through the Technology Strategy Board and plays a supporting role in a number of Knowledge Transfer Networks (KTNs), which are national networks set up for specific areas of technology or business.

Open technologies – a new deployment of Small Business Innovation Research (SBIR)

There are potential new avenues to set up an open innovation model and create synergies between knowledge originated from inside and outside intermediate institutions. In the US, a new form of partnership between SMEs and the National Institute of Standards and Technology (NIST) has been piloted with encouraging results over the last couple of years, under the SBIR umbrella, as summarised in Box 2. The model is based on a twin-track approach consisting of industrial service projects aimed at the commercial exploitation of NIST's new developments, and research projects aimed at involving businesses in NIST's research operations. This SBIR recent deployment is based on the open innovation principle that an institution can benefit from looking outside its organisational boundaries for innovative ideas, for collaboration in developing those ideas, and for validation of those ideas.

Box 2

The US example – The National Institute of Standards and Technology (NIST)

The National Institute of Standards and Technology (NIST) is a public institution of the US Department of Commerce whose objective is to support US industrial competitiveness by advancing measurement science, standards, and technology. NIST is regularly ranked as the first institution in the world for measurement and standards. Since 2008, NIST has pioneered a new methodology to create incentives for small US companies to continue research and development on NIST technologies, with the goal of transitioning intramural research into market application. This is now part of the US Small Business Innovation Research (SBIR) Programme Funds. This methodology is a competitive three-phase federal programme that awards funds to qualified small businesses.

The method
NIST issues an annual and widely available solicitation, which lists two type of projects: research areas that are a high priority for NIST missions and projects initiated at NIST that have potential commercial value for businesses. Proposals submitted are evaluated and scored for technical merit, innovation, quality of personnel and commercialisation potential. Businesses selected at this first phase are then invited to develop a feasibility contract (the awards can comprise up to $90,000 and free assistance of NIST scientists and testing laboratories). Small businesses that have successfully completed Phase 1 are then invited to submit a proposal and compete for Phase 2 awards (up to $300,000). The number of awards is based on available funding.

The outcome
To date, NIST has made a total of 27 project awards to small US companies. The pilot of the model in 2008 resulted in 11 phase 1 projects, one commercialisation license and two research licenses. The following year, nine of the 11 prior–year phase 1 projects were awarded phase 2 contracts. Further, 16 new phase 1 projects were initiated which included nine research licenses and one additional commercialisation license.

Other Federal agencies have expressed interest in trying this new tool and this dual approach could be extended to other research and technology institutions under the US Department of Commerce.

Other types of intermediate institutions, such as the Industrial Technology Research Institute in Taiwan, have also initiated schemes in the same vein. The aim is to use intermediate organisations to facilitate both outward and inward technology commercialisation, match innovation demand and supply, understand customers' needs and assess external markets, and assist in developing results into commercially viable products or processes.

Since its launch in the UK in 2009 under the responsibility of the Technology Strategy Board (TSB), SBRI (formerly Small Business Research Initiative) has enabled a number of public sector organisations to engage with potential suppliers, encouraging the development of innovative ideas closely aligned to the defined needs of the public sector organisation. It could be of value to pilot the suitability of the recent deployment of the US SBIR to assess whether it could strengthen horizontal collaborations between intermediate institutions and SMEs in the UK. The aim would be to allow the sharing of risks and resources, as well as the sharing of new knowledge, generated through joint work and cross–fertilisation of projects to shorten time to market. On the one hand, the intermediate institution could take businesses 'one step beyond' what they could otherwise do, and make the best use of publicly funded infrastructure. On the other hand, the opportunity to screen innovative ideas could encourage in the institution greater risk–taking and creativity to further develop and diversify activities in new directions. It could also raise the profile of the institution by systematically identifying and showcasing its technologies at a late stage of development and inviting businesses to take them to market.

Open systems – a challenge prize for carbon data

Open Innovation is a model based on extensive networking and co-creative collaboration between all actors in society, not only commercial organisations. Some specific challenges can potentially attract new pools of innovators, especially challenges related to societal benefits, and provide new opportunities to introduce bottom-up approaches. In such cases, challenge prizes can provide an incentive. A challenge prize offers a reward to whoever can first, or most effectively, meet a defined challenge. They are used as an incentive for meeting a specific challenge, rather than an award for past achievements. They are suitable when a goal can be defined in concrete terms but the means to achieving that goal are too speculative for a traditional research programme, grant programme or procurement.

Carbon measurement is one of these challenges. The UK Government has set a target of an 80 per cent cut in greenhouse gas emissions from 1990 levels by 2050. There have been, and continue to be, efforts to develop technologies, shift policies and regulation and change behaviour to contribute progress towards this target. However, adequate data on energy use and greenhouse gas emissions, which are essential to support successful advances in behaviour change, international agreements and in the physical infrastructure, are not readily available. The need to inform the decisions that will cut energy use and emissions is huge. In their report to the G8 in April 2012, the top scientists of 15 countries identified the measurement and development of standards for greenhouse gas emissions as a top priority deserving international attention. The recent NPL initiative to set up a Centre for Carbon Measurement is a way of signposting where the critical expertise in this field sits in the UK innovation system (see Box 3).

Box 3

NPL Centre for Carbon Measurement

The Centre for Carbon Measurement, opened on 26 March 2012, will build on NPL's capability, working with partners to address the following three areas:

- **Climate data –** The climate is changing but the impacts and timescales of the change are uncertain. This makes it difficult to secure international agreements on climate change, to ensure public buy-in to mitigation policies and to target adaptation policies with confidence. The Centre will aim to reduce the uncertainty in the data used to generate and validate climate projections. This will enable policies for climate change mitigation and adaptation to be placed on an ever firmer footing.

- **Carbon markets and accounting –** Many organisations measure and report on their emissions performance to comply with regulation, to benefit from selling carbon credits, or on a purely voluntary basis. As the number and scope of such measurements grow there is an increasing need for consistency and confidence. This is particularly challenging in sectors such as agriculture and forestry, and for new processes such as carbon capture and storage. It is even harder to quantify real carbon savings delivered in emission-reduction projects and emissions embedded in products and services. The Centre for Carbon will aim to provide measurement science and technology, along with practical tools and techniques, to validate physical measurements and models of emissions and carbon savings from products, organisations and projects.

- **Low carbon technologies –** Companies producing low carbon technologies need to be able to rapidly develop products and materials and persuade investors and potential buyers of their worth. The Centre will help to develop technologies by testing the efficiency and effectiveness of prototypes. The Centre also provides independent performance assessment and validation of products and materials. It will help to prove that the technologies meet regulations or independently validate claims in order to satisfy potential investors or customers. As the technologies reach market, the Centre will work with industry to develop the technical standards that facilitate adoption.

Carbon measurement can potentially attract far–reaching interest, including from small organisations with a social innovation agenda, community groups and inventors. In such cases a challenge prize can be a useful tool to push the frontiers. It can foster high–profile competition that motivates individuals, companies and organisations across all disciplines to develop innovative ideas and technologies towards a common goal. It can potentially bring about breakthroughs. The difficulty with the challenge prize tool is that it is imperfectly mastered and requires specialised services or understanding to plan, design, implement and evaluate. The aim of the recently opened Nesta Centre for Challenge Prizes is to increase the understanding and effective use of challenge prizes.

From 2007–2009 Nesta ran the Big Green Challenge, a £1 million competition open to not–for–profit groups in the UK. The ten Finalists achieved carbon reductions of 10–46 per cent in their first year of delivery. A few organisations have started running inducement prizes over recent years. For instance, since 2010 Ordnance Survey has been running the GeoVation Challenge inviting entrepreneurs, developers, and community groups to enter a funding competition for ideas that make best use of Ordnance Survey data. The NHS has also recently started running its own Innovation Challenge Prizes. Other organisations in the innovation system could potentially benefit from this type of incentive–backed technique, for instance the Met Office. NASA, in the US, has been running challenge prizes on weather data that attract very large pools of inventors. It would be of value to systematically identify whether other skills and assets owned by intermediaries could lend themselves to the running of challenge prizes. It would also be beneficial to share expertise between institutions to create more informed and effective competitions. In the longer run it would lead a number of organisations to make better use of funds for challenges, issue bigger prizes and partner with other organisations – in the public, not–for–profit and private sector.

Nesta will work with the Centre for Carbon Measurement at NPL to launch a carbon data prize. It will encourage the development of innovations to help monitor and manage greenhouse gas emissions and energy use. A £150k prize fund will be awarded for the most effective products and technologies that collect, capture and make accessible user–friendly data.

Part III

STRETCHING OUT – HOW TO INCENTIVISE THE DIFFUSION OF TECHNOLOGIES

The development, dissemination and application of new technologies at scale require the establishment and maintenance of standards. Standards are traditionally defined as a set of normative specifications to demonstrate quality, reliability or compatibility, but they can also encompass 'shared knowledge' i.e. common languages, architectures, and agreed ways of doing things more generally. Increased technological complexities combined with the transformation of industrial organisation into value chains at a global scale have been leading to an expansion of standardisation. Industrial standards allow businesses to manage the risks of multiple products in multiple locations with multiple suppliers. Studies[7] showed that since 1990 there has been a rapid growth in the British Standards Institution (BSI) catalogue, and that the emphasis has been on internationalisation and harmonisation of standards, as many national standards are now pooled at the European level.

Time is of the essence

Whilst standards promote international technology transfers, their impact on competition and innovation is ambivalent and a well–known subject of economic debate. Indeed, in standardisation many conflicting interests are at stake. Through the establishment of standards, some businesses lose and some win as they try to control their content. This is particularly severe in markets based on advanced technologies – telecoms markets are a case in point – because of intense levels of competition and fast dynamics of the technological change process. Standardisation can increase efficiency within a technology life cycle, but it can also prolong existing life cycles to an excessive degree, by inhibiting investment in the technological innovation that creates the next cycle. Econometric models confirm that timing is a central strategic issue for standards. Too early, and a standard may effectively shut out promising and ultimately superior technologies. Too late, and the costs of transition to the standard may be too high, thereby preventing diffusion. The shortening of the average technology life cycle implies increasing pressures on the standards–setting process with respect to timing.

The complexity of modern technology had been unavoidably leading to an increase in the number and variety of standards that affect a single industry or market. In the UK the national standards body is BSI. However, the ever–quickening pace of technology evolution is affecting the way new standards are proposed, developed and implemented. Recent decades have seen a growing number of international standards–setting organisations struggle to keep abreast with technological innovations, notably in information and communication technologies, and some standards development efforts now take the form of digital platforms that are collectively and informally driven (see Box 4).

Box 4

The UK standards landscape

The development and maintenance of industry standards is a complex process that can be undertaken by a range of formal and informal organisations. Many standards are voluntary in the sense that they are offered for adoption by people or industry without being mandated in law. Standards become mandatory when they are adopted by regulators as legal requirements in particular domains.

Each economy tends to have a single recognised national standards body (NSB). The UK's NSB is the British Standards Institution (BSI). BSI is an independent business service provider established by Royal Charter in the 1920s, although its origins go back to 1901. It is responsible for producing and publishing British standards and for representing UK interests in a number of international standards-setting fora. BSI also produces Publicly Available Specifications, (PASs), as well as online products such as self-assessment tools and standards platforms. These products are proposed and developed by groups of organisations and business or trade associations to meet their needs for common specifications, guidelines, codes of practice etc. BSI does not write the technical content of standards, which is usually written and agreed by groups of experts nominated by trade and professional associations, technical societies and academia, with the involvement of other relevant interested parties. BSI has a formal responsibility to ensure the involvement of any relevant stakeholders in the development of standards and to provide a means of public consultation on the content of standards. Government funding of BSI's work tends to be limited to specific deliverables, such as prioritised work programmes and schemes of assistance to those involved in the preparation work.

Whereas the NSB is the one-per-country standardisation organisation which is that country's member of ISO (International Organization for Standardization), hundreds of industry- or sector-based standards organisations develop and publish industry specific standards. Over the last decades, a new class of standards setters have appeared on the standardisation arena: the industry consortia or standards setting organisations. Despite having sometimes limited financial resources, some of them enjoy truly international acceptance. One example is the World Wide Web Consortium (W3C), whose standards for HTML, CSS, and XML are used universally throughout the world. There are also community-driven associations such as the Internet Engineering Task Force (IETF), a worldwide network of volunteers who collaborate to set standards for lower-level software solutions.

Some industry-driven standards development efforts don't even have a formal organisational structure. They are projects funded by large corporations. For example, the OpenOffice.org, a Sun Microsystems-sponsored international community of volunteers working on an open-standard software that aims to compete with Microsoft Office, and two commercial groups competing fiercely with each other to develop an industry-wide standard for high-density optical storage.

Designing flexible standards

Whether standards focus on the attributes or on the performance of a product has different implications for innovation and this is an essential dimension to bear in mind:[8]

- Design-based standards can be restrictive and inhibit innovation. Standardisation of one or more attributes of a product (or service) can convey direct competitive advantage to the owner/controller of the technology producing those attributes. Such control can quickly force acceptance of a monopoly's proprietary technology. For instance, elements of computer architecture have been the focus of strategies to set *de facto* standards. Microsoft using its position as the dominant operating system standard to gain unfair advantage, is a well-known example. This is sometimes called a 'vendor lock-in' effect.

- Performance-based standards, by contrast, allow flexibility in product or service-design while still meeting common requirements. They tend to be competitively neutral and can be critical to an entire industry's efficiency. They can allow SMEs to participate in markets for system technologies by supplying components in which they have a comparative advantage. This diversification makes system optimisation by users possible and increases price competition. This set of standards is a set of 'tools' that make the process of developing, producing and marketing the core technology more efficient. They do not have the dominant or controlling effects of design-based standards.

Thus standards generally work more efficiently for innovation when:

- They are performance-based, and this is dependent on the technical availability of accurate measurement (see Part II);

- They are the product of agreement and negotiation between partners, and this can be viewed as an aspect of 'open innovation' as their production is collaborative;

- They are subject to periodic and well-timed reviews, especially for emerging technologies for which the review cycle may need to be shorter.

Standards can be especially important for SMEs that supply components to larger systems in global value chains as they can be a condition for accessing markets.

Developing a competitive advantage through documenting an emerging technology

Standardisation is not an all-or-nothing proposition. The expertise that is necessary to develop normative specifications can also be harnessed for other related purposes, as case studies illustrate. At their most simple, standards are simply shared knowledge developed by communities of people with a common interest. For instance, standardisation could be used to demonstrate the reliability and durability of a new technology and attract funding for further development. In complex technologies, standardisation typically proceeds in an evolutionary manner in lock step with the evolution of the technology. It takes typically three to five years before international standards are agreed for a new technology, although it can be sometimes less, e.g. nanotechnology international standards were produced in little more than a year. This period of time presents a 'window of opportunity' for innovators as the language, basic architecture and organisation for this new technological system are being developed in this early stage of the life cycle. At a later stage of development, common standards are the prime–movers behind technological transformation and diffusion.

Many developers in the early phase of the technology life cycle use a closed innovation model. They keep their innovations completely proprietary and compete until a dominant version of the technology gains sufficient market share to become the single standard. However, another strategy is to be willing to open the performance levels and language used in return for an increased probability that the innovation becomes the standard, or strongly influences it, thereby helping to create a momentum and attract additional investment. The case of marine energy in case study 8 below, shows how an open documentation developed for the purpose of a single organisation in the UK is having a major influence on the setting of global standards for this technology. This influence is helping give the UK a reputation as world leader in this range of technologies.

Case study 8

Marine energy

Marine energy or marine power (also sometimes referred to as ocean energy or ocean power) refers to the energy carried by ocean waves, tides, salinity, and ocean temperature differences. The movement of water in the world's oceans creates a vast store of kinetic energy, or energy in motion. This energy can be harnessed to generate electricity to power homes, transport and industries. The technologies that generate electricity by harnessing the power of waves and tidal streams are at an early stage of development.

The European Marine Energy Centre Ltd (EMEC) based in Orkney is at the forefront of the development of marine–based renewable energy. In 2009, EMEC commissioned BSI to develop an in–house guidance to record technological developments and support external communications e.g. to communicate performance levels and support agreements for the procurement of goods from suppliers. This guidance provides a methodology for the measurement of power output in a range of sea states, and a framework for the reporting of results and estimation of the energy production at a prospective site from wave energy conversion systems. New concepts and techniques are also defined and a terminology is agreed. This document was made public.

International standards for marine energy are currently in the process of being developed with other leading players in the field, mostly from New Zealand and Canada. The existence of the EMEC guidance allows the UK to drive the agenda of the Committee in this new technological development. The EMEC guidance, which was initially developed for one organisation, is effectively being used as a template for discussions and agreements between players. International standards for marine energy will lead to wider and faster dissemination of innovation in this area and will attract new entrants, but the UK is now being perceived as 'the world pioneer in marine energy' (for instance, in the Information System for the European Strategic Energy Technology Plan 2012– SET–Plan– produced by the EU). The influence of the UK in designing these standards also strengthens significantly its position as an attractive location for foreign direct investment and the development of a global cluster of excellence in Scotland.

Similar cases are being observed for other emerging technologies. For instance the global leadership of Canada in carbon storage also results from its driving influence in setting international standards in this area, and this in turn is made possible by the availability of information for this range of technologies at an early stage in the life cycle. Some countries in Asia are making full strategic use of technical standards as a source of competitive advantage in global markets. For instance, the Electronics and Telecommunications Research Institute (ETRI) in South Korea is an active participant in international standard setting fora and has around 40 international standard technologies. This is part of a fully developed national plan that starts from the shortlisting of new technological opportunities and the technical evaluation of performance and extends to well–structured submissions to influence international standard specifications.

With new technologies continuously being introduced into ever expanding networks, gaining a competitive advantage can also be achieved by influencing international common language and basic architecture, and this can involve demonstrating some degree of openness. It suggests potential benefits of using a more strategic approach through producing and sharing information on the cluster of new technologies for which the UK is at the forefront of innovation. However, this initial advantage will have to be sustained as the technology evolves and the standards are updated.

Using collaboration frameworks to incentivise innovation

The expertise necessary to develop standards can also be harnessed to design frameworks for collaborative working. Traditional approaches, based on the assumption that the creation and pursuit of new ideas is best accomplished by a centralised team, have been outdated for some time. Instead, innovations are brought to the market by networks of businesses, selected for their unique capabilities, and working in a coordinated manner. However, this model demands that businesses develop different skills, in particular, the ability to collaborate with others to achieve superior innovation performance. Collaboration is becoming a new and important source of competitive advantage for businesses and this is supported by economic evidence. Yet, despite this need, there is little guidance on how to develop or deploy this ability. The way that standards–making works can provide a platform for collaboration.

The problem is especially acute for the delivery of large–scale products and systems that include a range of technologies. The delivery of this type of large project usually involves a number of companies, both large companies and SMEs, that have to collaborate over relatively long time frames. This form of collaboration has to be effective enough to accommodate evolving technologies over the delivery period. Public organisations have an overreaching responsibility for large projects of this type, for instance in transport, construction, aerospace, communication and other infrastructure projects. Case study 9 illustrates how the Ministry of Defence (MoD), a major procurer of technologically sophisticated products, leveraged standards expertise to pioneer a framework for supporting partnerships between its suppliers.

Case study 9

Business Relationship Management

In 2006, the Ministry of Defence, and other organisations, worked with BSI to develop a framework guidance to encourage collaborative arrangements between suppliers and partners. The framework developed by BSI with not–for–profit consultancy PSL (Partnership Sourcing Limited) is based on an eight–stage approach:

- Partner integration and efficiency of working.
- Establish the foundations for partnering.
- Improved partner selection.
- Improved risk management and confidence.
- Consistency of approach.
- Enhanced focus.
- Baseline for improvement.
- Proof through independent assessment and certification.
- Indicator of partnering excellence.

The MoD Partnering Handbook provides clear guidance to its industry partners on the application of Joint Working/Partnering policy and procedures within MoD contracts. With a particular focus on enabling companies of any size and sector to access supply chains through collaborative working practices, a British Standard building off this framework, BS 11000–1, was launched in December 2010. It has been trialled and refined in industry with involvement from organisations including BT Global Services, TNT, Raytheon Systems, Siemens, EADS, Toshiba, Lockheed Martin UK, VT Group, EMCOR Group, and NATS.

In 2012 Network Rail adopted BS 11000 as one of its tools to improve the way it works with its supply base to drive down its costs. Greater collaboration between organisations within the rail industry was identified as one means of delivering greater value for passengers and taxpayers. Network Rail will use BS 11000 to implement wide–ranging reforms to the company's infrastructure business, which places greater focus on partnership with suppliers and will see a restructuring of the way the company delivers capital projects worth around £4 billion a year.

Such collaboration frameworks can be further advanced to have a central innovation focus. Managing collaboration for innovation is different from outsourcing production to achieve lower costs. It entails accessing dispersed knowledge, leveraging new capabilities and sharing risks with partners to create new sources of value, which is a much more sophisticated skill. Businesses that use collaboration as a source of competitive advantage develop an explicit strategy to leverage a partner's superior capabilities i.e. a technical know–how that the business did not possess, or access a partner's contextual knowledge, i.e. knowledge of other businesses or research centres. In exchange, they must be prepared to share their own know–how, information and learning, for collaboration to be truly successful and must dedicate resources. This form of collaboration can raise complex issues of intellectual property protection and shared rights among partners to capture the added value created.

Purchasing innovative projects with significant technology elements depends increasingly on the way purchasers manage their networks of suppliers. Large companies in the private sector are fast developing these skills but they are in very limited supply in the public sector. The use of collaborative frameworks is a particularly powerful tool when there is uncertainty over the product to be produced or over the process to produce it, which is often the case for innovative infrastructure projects. Importantly, they can open access to value chains for SMEs by supporting their capability to forge partnerships and supply large organisations. They can contribute to increasing the proportion of government contracts that go to innovative SMEs whilst at the same time make them more competitive in global markets. The standards themselves can provide the framework by which larger companies specify their needs to their networks of suppliers, and against which suppliers (often SMEs) can be chosen. Good standards can provide such a framework whilst leaving suppliers free to compete on other aspects of their services.

Developing standards to procure new technologies

A lack of performance standards is a common problem for procuring innovation, especially in those sectors whose dynamics lead to rapid technological changes such as IT, telecommunications, nanotechnology and healthcare. Technology procurement is a challenge for public procurers who lack understanding of technological developments and the nature of innovation. At the same time, it offers great opportunities to influence innovation levels in the economy.

In the UK, the Home Office and its agencies make significant use of biometrics standards, as they allow systems to be specified to avoid the so–called 'vendor lock–in' effect. They also facilitate the tendering process through providing a performance and quality level upon which potential suppliers, large and small, can compete. As technologies evolve, so do the standards behind them, allowing the latest standard to be specified. The biometrics case study 10 below illustrates how the Home Office procured a sensitive new technology.

Case study 10

Biometrics

Biometrics (or biometric authentication) refers to the identification of humans by their characteristics or traits. It is used as a form of identification and access control. It is also used to identify individuals in groups that are under surveillance. Biometric identifiers are the distinctive, measurable characteristics used to label and describe individuals. They include physiological identifiers such as voice, DNA, iris, face or finger print. Since biometric identifiers are intrinsic to individuals, they are more reliable in verifying identity than knowledge–based methods, such as passport or personal identification number.

Biometrics technology is a vital component of the UK Government's homeland security policy. The UK Border Agency introduced fingerprint checks at the border for passengers with biometric UK visas in 2009. These checks verify that the individual entering the UK is the same person who applied for their visa, entry clearance or biometric residence permit. Using fingerprints enables to this to be done with greater certainty. E–passport gates have also been introduced in a number of UK airports as a self–service alternative to the conventional border control process. The system uses facial recognition technology to compare the face in the photograph recorded on the 'chip' in the passport.

From 2002 to 2005 the Home Office worked closely with BSI and industry specialists to develop international standards and support the rapid deployment of open system, standard–based security solutions for homeland security and the prevention of ID theft. The aim of these standards is to make the implementation and application of biometric technology and the associated data easier for both Government and industry. Ultimately, this standardisation creates new business opportunities for UK industry. Developing a technology to international standards increases the potential market for a supplier, as not only will their products be suitable for the home market but also equally acceptable for the global market.

Achieving a standardised approach to biometrics not only involved technologies but also procedures. With all biometrics, a good image means having a better chance of successfully comparing that data in the future. The introduction of the ePassport, which uses biometric facial imagery as its main security feature, involved close co–operation between the Identity and Passport Service (IPS) at the Home Office, BSI and businesses. Setting quality standards for images allowed a large number of vendors to co–operate, from photo booth manufacturers to printers to deliver this innovation.

Although the initial potential market was limited to governments, commercial interest in biometrics is increasing as standards are now developed. In addition, new biometrics technologies are now emerging in the area of the moving image to allow face recognition with low–quality imagery. Early customers of these innovations are likely to be police forces.

In procuring technology equipment, the purchasing authority benefits from being assisted by experts which it relies upon to make recommendations on a functional description of the performance levels required to provide bidders with more flexibility regarding preferred solutions. Maintaining a constant flow of information with the bidders through all stages of the procurement can also be important, especially if the procurer is uncertain about the product or the technology to be used and/or intends to stimulate new technology prior to producing the tender documentation.

Using public supply chains to boost the industrial competitiveness of small and medium enterprises

Public procurement of goods and services is not yet being used effectively to stimulate innovation in the UK. At present, most of that procurement is focused on purchasing proven solutions, or is spent with existing 'proven' suppliers. This is not a new issue, but the current imperative to reduce public spending makes the need for rapid progress in this area pressing. There is significant pressure for public sector organisations to reduce costs. In this context, the focus for procurement is increasingly on cost reduction rather than investment in more innovative solutions. The two main obstacles faced by public sector organisations in the use of procurement as a tool to stimulate innovation are the availability of budget to invest for the longer term and the willingness to take the risk of investing in unproven solutions. Greater recognition and incentives are required in these two areas for longer–term benefit.

Reducing costs and innovating are not necessarily mutually exclusive goals. If the challenge is to maintain the quality of public services at the same time as making long–term cost savings then innovative procurement can become a powerful tool. The use of competitive bidding focusing on innovative approaches rather than pure financial terms can drive industry forward and identify the most promising suppliers. It can drive UK businesses to produce technological products that are then competitive globally. The public support for applied research and technologies in the UK is low by comparison with the funding invested in earlier fundamental research. Better use of public procurement actions can effectively complement sponsored research, demonstrations and trials by creating an early customer base that gives credibility to other potential customers, investors and businesses in the supply chain. The Government purchasing power is very substantial in some sectors of the economy and this creates opportunities to influence the uptake and diffusion of technologies in these sectors. Scandinavian countries, in particular Denmark and Sweden, are successful in using innovative procurement effectively.

A major obstacle is that buying innovative products and services requires more ‘intelligence’ on the part of the purchaser to support the complex trade–offs involved and handle responsibilities in taking the associated risks. Procurers must give potential suppliers the freedom to develop new means of meeting the desired end. In particular, they have to effectively manage partnerships between businesses and this is especially important to increase the proportion of public contracts that go to SMEs. They have to specify and assess levels of performance or quality that are not achievable with ‘off–the–shelf’ solutions and set outcome–based purchasing specifications. When significant technology elements are involved, requirements and tender selection criteria must not only ensure that the capability provided is state–of the–art, but also enable technology–based solutions to be upgraded. All this requires technical expertise that very often procurers do not possess or do not have ready access to. However, this expertise exists elsewhere in the innovation system, as seen in this report.

The Ministry of Defence has recognised the need to act as an intelligent lead customer and has created the Centre for Defence Enterprise, which works with internal MoD directorates to identify appropriate challenges and then works with the Technology Strategy Board to engage with a broad range of innovative businesses, often from outside the normal defence community, to seek better solutions. For the many public organisations that lack the scale to justify such an approach, a central structure could be put in place to deliver a similar service, aggregate fragmented demand and bring together the expertise available in the innovation system. The Technology Strategy Board could use its unique position in the innovation system to extend its activities and set up such a Lead Market Centre.

One area where there is strong direct incentive for public agencies, from central government to local authorities, to procure innovative goods is in the built environment. The combination of regulation aimed at cutting greenhouse gas emissions and the considerable financial savings that can be achieved through energy efficient buildings is a major attraction and illustrates how innovation and value for money can be compatible goals. It is also an area where a significant proportion of the supplier base is composed of SMEs operating in a relatively large sector of the economy where there is limited investment in innovation, technology and workforce training.[9] Using innovative public procurement could directly contribute to a better uptake of technologies and improve the innovation performance of SMEs in this sector. Energy efficiency in the built environment could therefore provide a promising initial focus for the Lead Market Centre.

Through the Centre, the Technology Strategy Board would extend its technologies activities and bring together a mass of critical skills. The experience of major innovative public procurers such as MoD and the NHS, could be combined with the expertise of support partners, such as NPL and BSI. They would bring in the expertise to set flexible performance metrics for energy efficient buildings which track technological innovation and facilitate access to experts across a range of technologies. They would also provide frameworks for ways of working that are suitable, and advise on options and technological opportunities. Other potential support partners would be the Intellectual Property Office (IPO), to devise more flexible arrangements for property rights produced in these collaborative contracts, and the Design Council, to advise on building modification challenges. It would be essential for the Centre to provide systematic economic evaluation of both the savings achieved by public agencies and the subsequent commercial outcomes of companies that received public contracts. Such a Centre could provide a step–change improvement by bringing in multiple actors in the innovation system to deliver joined–up thinking on a major issue with social as well as economic and public finance implications.

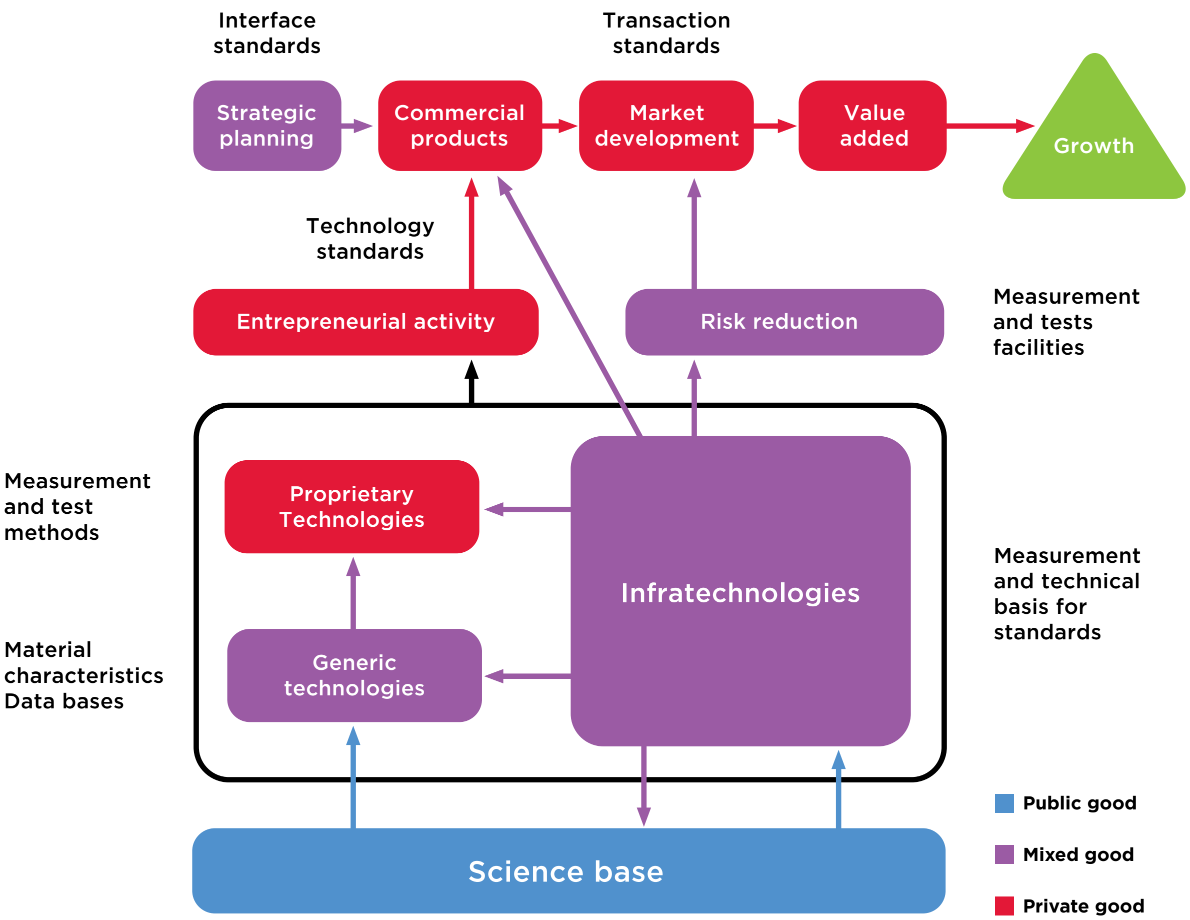
APPENDIX – HOW ARE INDUSTRIAL TECHNOLOGIES DEVELOPED?

The development of industrial technologies is often presented as a 'black box' where new technologies are developed from research and development (R&D). Very few economic models make the attempt to disaggregate the interactive and complex process through which technologies flow from the science base to commercialisation. However, understanding this complex mechanism is crucial to accelerating the ability of businesses to develop and adopt innovations. Indeed, the shortening of technology life cycles due to rapidly expanding research and innovation capabilities, especially in Asia, have created an imperative to better understand the R&D investment process so that public policy can better match incentives and capabilities for the participants in each phase of the R&D cycle. It is important to emphasise that first commercial applications cannot be efficiently derived directly from the science base. Metrology and standards play a pivotal, if less acknowledged, role in the transition phase between science and business innovation, thereby reducing business risks.

From scientific research to market applications – the industrial technology process

The industrial technology process is complex because it is based on complementary technical relationships among physical, human and technological inputs from both public organisations and businesses. The American economist Tassey has built a body of work analysing this innovation mechanism and developed a Technology–Element Model (see Figure 3) and technology life cycle (Figure 4) that provides a helpful insight into this process.

Figure 3: Technology-based industry model



Source: Tassey, G. (2008), Modeling and measuring the economic roles of technology infrastructure, NIST.

Industrial technologies are derived from the science base, which is a public good mostly performed by universities and Public Sector Research Establishments in the UK. Business investment decisions in technological development are then affected by the interactions with and between:

- The 'generic' technology base. This is a pattern of solutions of selected problems derived from the science base. In essence, it is a 'proof of concept', which reduces risk sufficiently to enable applied R&D investments. This is a quasi-public good. Both researchers in businesses and, increasingly, in universities, conduct generic technology research. The Internet is an obvious example of a generic technology base. Technological advances (such as queuing theory, packet switching and routing) were first required to develop a communication network. Prototype networks were developed in the 1970s (ARPANET) and 1980s (NSFNET), which eventually led to the Internet.

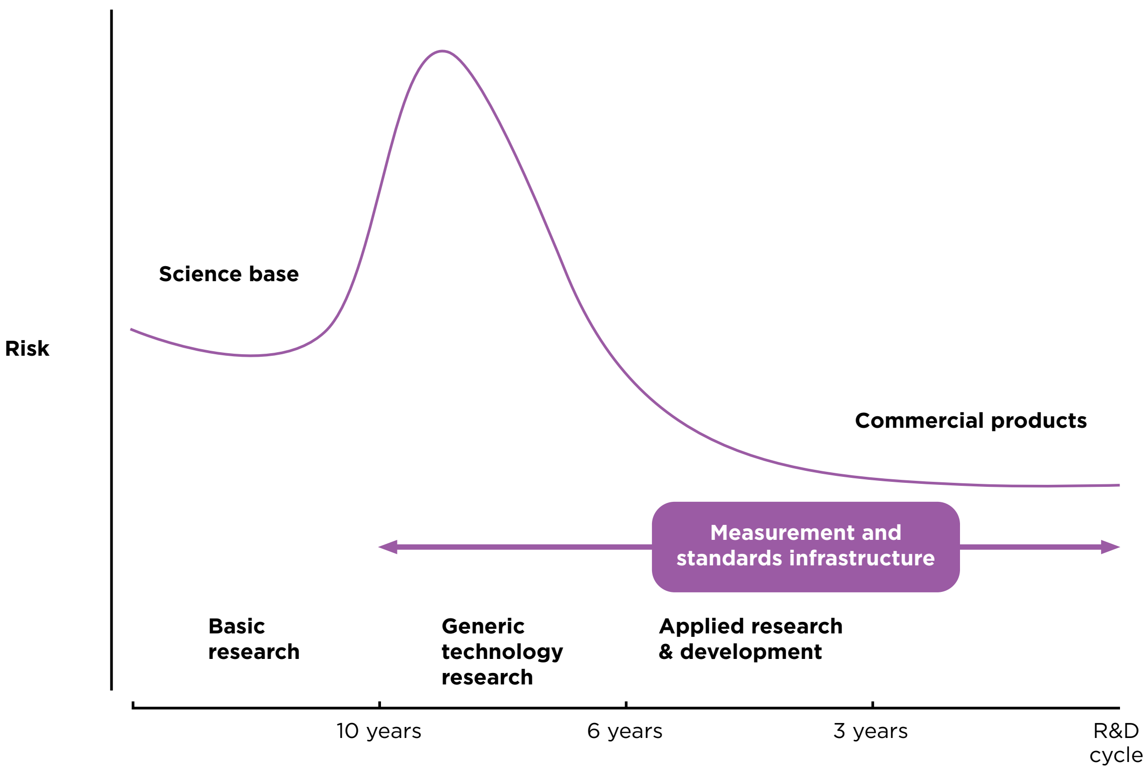
- Infratechnologies that facilitate the development and utilisation of the generic technology base. Infratechnologies are solutions to technology-related problems. Collectively, they constitute the technical infrastructure of an industry and have applicability across a number of related industries. They include tools such as measurement and test methods, scientific and engineering data, the technical bases for interface standards and quality control techniques. The R&D process and marketing productivities of the typical technology–based industry depend on a large number of inputs. They often require a costly infrastructure ubiquitous across technology–based economic activity and hence are underinvested by industry. For instance, measurement of the effects of nanostructure on product performance leads to new processing techniques that are fundamental to the design and manufacture of all nanomaterials and devices.

- Proprietary technologies that are market applications. Both generic technology and infratechnology are drawn upon by competing businesses to produce private goods. It is the combination of the underlying generic technology and the supporting infratechnology that determines the direction of subsequent market applications, together with other factors specific to businesses that come into play in the commercialisation process, such as internal technical skills, organisation and management.

Technology life cycles – reducing business risks

It should be emphasised that technology trajectories are not linear but display cyclical patterns over time, which are reflected in the shift in the composition of R&D over time, as illustrated in the figure below.

Figure 4: Risk reduction in technology life cycle



Source: Tassey, G. (2008), Modeling and measuring the economic roles of technology infrastructure, NIST.

The early part of a technology's life cycle is characterised by high risk but also increasing returns as the proof-concept effect, i.e. the generic technology, unleashes market applications. Within the generic technology's life cycle, major technological opportunities decline over time as the set of potential applications of the underlying knowledge base is exhausted. Competition then shifts to incremental product improvements tied to shorter times to commercialisation and to process innovations that focus on reducing cost as the basis for competition. It is at this stage that substantial efficiencies are realised, such as economies of scale in production and distribution, and economies of scope in markets penetrated. It is also in this part of the cycle that efficiency-enhancing infratechnologies are important to develop commercial products.

The 'spike' in the investment risk curve represents the fact that technology research encounters an initial major increase in risk associated with the target return on investment from commercialisation. It occurs in the early phases of technology research and acts as a substantial barrier to business investment and later-phase applied R&D. Such a risk profile explains why inventions based on emerging technologies can languish for years, even decades. The availability of infratechnologies is essential to overcome the 'risk spike'. When the infratechnologies are then adopted as the technical basis for standards, they increase the potential economic benefits from inventive activity and therefore provide incentives for businesses to commit to new technologies and markets.

Looking more closely at the technological innovation process therefore suggests that, although an adequate and accessible science base is a necessary requirement, businesses also have to draw upon other types of knowledge produced in other parts of the innovation system to acquire technologies and reduce their investment risks. The effectiveness and networking capabilities of this technical infrastructure is a critical component of the high-tech innovation process.

What is the macroeconomic impact of measurement and standards?

Assessing the economic impact of measurement and standards is a difficult and costly task. This is typically related to their spillover and quasi-public goods effects. They are ubiquitous across technology-based economic activity, which decreases their visibility. They are delivered through complex systems of hardware and software, so difficult to visualise and understand. Besides, although their aggregate impact is substantial since most are eventually adopted as industry standards, they can be individually small. Any one element can have a modest economic impact, but a high-tech industry depends on hundreds of such elements.

Over recent years, studies conducted under the auspices of the Department for Business Innovation and Skills (BIS) in the UK have attempted to better quantify the total economic impact of measurement and standards. They find that they generate a high level of economic benefits.

- Swann[10] conceptualised measurement as a General Purpose Technology (GPT) i.e. very widely applied across economic activities. He found that the use of measurement is closely related to innovation and increases the productivity of businesses. The more precise the measurement and the more rapid the feedback from measurement to control, the greater are the effects on efficiency, quality and productivity. It indicates that measurement supports innovation in business R&D and gives businesses a way to demonstrate to customers that an innovative product is superior to the competition in performance, composition or quality.

- Temple[11] used data from firms purchasing measurement and the Community Innovation Survey to find a positive relationship between the extent of measurement knowledge available to business sectors and the types and degree of innovation carried out by firms in those sectors. In particular, he showed that measurement knowledge is more strongly associated with novel rather than 'catch–up' innovation i.e. it underpins leading–edge products and process innovation.

- Other recent studies[12] examine the impact these inputs have on national economic performance and find that measurement knowledge has a positive and statistically significant contribution to productivity and growth.

These studies therefore converge in concluding that measurement and standards inputs make a significant contribution to business innovation and economic productivity. They also suggest that there are strong complementarities between measurement and standards, the public research base, and other forms of knowledge creation and use such as design and intellectual property rights. They point to interlocking roles and impacts between institutions in the innovation system. However, whilst this type of approach aims to tackle all of the economic activities of measurement and standards, it is conducted at a high level of aggregation and provides limited insight into how these institutions add value to innovative businesses in practice.

ENDNOTES

1. The term ‘infratechnologies’ was coined by the American economist Gregory Tassey (see Appendix). In this report it is used in a broader sense to refer to solutions and services that facilitate technological applications by enterprises.
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July 2012