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THE FOUNDATION FOR SCIENCE AND TECHNOLOGY

COUNCIL AND TRUSTEES

THE FOUNDATION FOR SCIENCE AND TECHNOLOGY

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UK launches strategy to boost cyber security and resilience

The UK Government has launched a National Cyber Strategy. The global expansion of cyberspace is changing the way we live, work and communicate, and transforming the critical systems we rely on in areas such as finance, energy, food distribution, healthcare and transport. The scale and speed of this change is also unleashing unprecedented complexity, instability and risk.

The UK's new National Cyber Strategy is designed to strengthen cyber security capability in order to pursue and promote UK interests with confidence. It will strengthen the country's ability to act in cyberspace, while at the same time enhancing the opportunities to influence and shape tomorrow's technologies so they are safe, secure and open.

To do this the strategy is built around five core pillars:

- Strengthening the UK cyber ecosystem, investing in people and skills and deepening the partnership between Government, academia and industry;
- Building a resilient and prosperous digital UK, reducing cyber risks so businesses can maximise the economic benefits of digital technology and citizens are secure online and confident that their data is protected;
- Taking the lead in the technologies vital to cyber power, building industrial capability and developing frameworks to secure future technologies;
- Advancing UK global leadership and influence for a more secure, prosperous and open international order, working with Government and industry partners and sharing the expertise that underpins UK cyber power;
- Detecting, disrupting and deterring our adversaries to enhance UK security in and through cyberspace, making more integrated, creative and routine use of the UK's full spectrum of levers.

www.gov.uk/government/publications/national-cyber-strategy-2022

First head of ARIA appointed

Dr Peter Highnam has been appointed as the first CEO of the Advanced Research and Invention Agency (ARIA). He joins from the US Defense Advanced Research Projects Agency (DARPA).

Backed by £800 million of public money, the agency has been established to empower exceptional scientists to focus on high-risk projects at the frontier of discovery and innovation that could transform people's lives for the better.

Born in the UK, Dr Highnam brings a wealth of experience with him, as he joins ARIA from the USA's research agency DARPA where he has served as Deputy Director since February 2018. He will take up his post as ARIA's first CEO on 3 May 2022, for a fixed term of five years.

ARIA is based on models that have proved successful in other countries, in particular the influential US Advanced Research Projects Agency (ARPA) model. This was instrumental in creating transformational technologies such as the internet and GPS, changing the way people live and work, while increasing productivity and economic growth.

DARPA

Peter Highnam: takes up ARIA post in May

UK funds marine environment protection

The UK is committing £2 million to support the creation of the world's biggest transboundary marine protected area – the Eastern Tropical Marine Corridor. It aims to protect some of the world's most important and biodiverse marine environments in the Eastern Pacific, including key migratory routes for sea turtles, whales, sharks, and rays.

At COP26, Costa Rica, Colombia, Ecuador, and Panama announced they are working together to expand and connect marine protection covering over 500,000 km^2 of ocean. The marine corridor stretches from the rich breeding and feeding grounds around Malpelo Island, the Cocos Ridge, and the Cordillera de Coiba seamounts, to the Galapagos Islands that were the inspiration for Charles Darwin's theory of evolution.

The UK will invest an initial £2 million of aid through the World Bank's PROBLUE fund, and deploy marine experts to provide technical assistance through the UK's Ocean Country Partnership Programme.

Science boost in New Year's Honours 2022

Science features strongly in the New Year's Honours List. Government Chief Scientific Adviser Sir Paul Vallance and Chief Medical Officer Professor Chris Whitty are both made Knights Commander of the Order of the Bath. They are perhaps the two most publicly-recognisable scientists in Britain today. Also honoured for their service to public health are the Chief Executive of the UK Health Security Agency Dr Jenny Harries who becomes Dame Commander of the British Empire and Dr Jonathan Van Tam, Deputy Chief Medical Officer, who is knighted. The Chief Medical Officers of the Scottish and Welsh Governments, Professor Gregor Smith and Dr Francis Atherton, are also knighted.

Sir Paul Nurse, Chief Executive of the Crick Institute, becomes a Companion of Honour. Dr Vivienne Cox, Chair of the Rosalind Franklin Institute, is made Dame Commander of the British Empire, as is Dr June Raine, Chief Executive of the MHRA.

Science advice to Government is also recognised. Professor Anthony Finkelstein, formerly Chief Scientific Adviser (CSA) for National Security, and Professor Robin Grimes, lately CSA Ministry of Defence Nuclear, are both knighted. Professor Philip Blythe, CSA at the Department of Transport, receives a CBE, as does climate scientist Professor Myles Allen.

GUEST EDITORIAL

The UK is competing in a global marketplace. To be successful, Global Britain needs to make the most of all of its opportunities.

Seizing the moment – together

George Freeman

It is William Gibson who is widely credited with saying: "The future is already here — it's just not very evenly distributed." No quote better captures for me the central challenge facing the UK as we emerge from the political, economic and public health turbulence of the past few years. We are emerging with a more resilient and sustainable economic model designed to put science, research and innovation at the heart of our post-Brexit vision for Global Britain's role in the world.

The pandemic has illustrated both the huge global opportunities for the UK as a scientific superpower (when we embrace a more agile and innovative mindset) and the huge structural challenges and vulnerabilities we carry after a 40-year shift to a post-industrial service economy.

While we are home to some of the most ground-breaking science, research, technology, engineering and innovation in the world, we are also held back by unsustainable over-concentration in a few 'hot' areas, while stubborn post-industrial decline and deprivation is holding back so many people and places across the UK.

Similarly, access to the possibilities of the future is even less evenly distributed. As the pandemic highlighted, while many countries have high rates of vaccination and vaccines to spare, many poorer nations have neither the vaccine supply chain nor basic public health systems to distribute them.

Making access to the opportunities created by science, technology and innovation more evenly distributed is fundamental to global sustainability, and also to the UK being able to enjoy a new cycle of sustainable prosperity.

As last year's Integrated Review made clear, the UK has undeniable, unrealised potential to commercialise the extraordinary R&D-intensive technologies emerging from our science base. To seize these opportunities we need to take a more active approach to building and sustaining strategic advantage through science and technology.

By properly moving from being a service economy (with world class science in silos and sporadic innovation which all too often ends up overseas) to a genuine 'innovation economy' which puts our world class science and innovation at the very heart of our domestic and global economic model and world vision, I have no doubt we have the opportunity to unlock a new era of prosperity.

The pace of science and innovation is creating new opportunities for whole new industries in ever shorter technology cycles. By moving fast to seize the opportunity of post-Brexit regulatory, procurement and trading freedoms, the UK could become a global R&D testbed for the technologies the globe is crying out for: from drought-resistant crops to dissolvable plastic, fusion energy to hydrogen shipping, biofuels to bioengineered carbon sequestration, as well as vaccines against the diseases which still hold us all back.

Becoming the R&D powerhouse for sustainable global development – the best place in the world to discover, develop, commercialise, regulate, finance and export these technologies – is within our grasp. We need to seize it.

This is the central idea which drives the new UK approach to Science, Research & Innovation – captured in the two objectives I have set out as the keys to success:

1. Becoming a science superpower: properly harnessing the UK's deep science leadership for global good by:

- continuing to invest in world-class discovery science;
- making UKRI the world's most agile, multi-disciplinary, creative and impactful research agency;
- investing in new global talent career paths and Fellowships;
- deepening bilateral and multi-lateral R&D collaborations;
- attracting much more significant global industrial R&D to the UK;
- explicitly harnessing UK science to help tackle global grand challenges;
- harnessing UK science leadership for geopolitical influence.

George Freeman MP was appointed Minister for Science, Research and Innovation in the Department for Business, Energy and Industrial Strategy (BEIS) on 17 September 2021. He has held several ministerial roles including Minister of State at the Department for Transport and Parliamentary Under Secretary of State for Life Sciences at BEIS and the Department of Health. He was elected Conservative MP for Mid Norfolk in 2010. Before being elected to Parliament, George Freeman had a 15-year career across the life sciences sector.

By seizing the opportunity of post-Brexit regulatory, procurement and trading freedoms, the UK could become a global R&D testbed.

With the necessary pace, agility and a focus on the opportunities, we can breathe life into many more scientific and technological breakthroughs.

2. Being an 'innovation nation' by properly connecting our deep science expertise much better to our domestic economy through:

- better industry/academic engagement;
- new career paths for a generation of entrepreneurial innovator scientists;
- stronger support for the transformational technologies of tomorrow and for high growth sectors;
- simpler access to business and industry grants;
- support for fastest-growing SMEs with stronger access to scale-up finance;
- stronger development of clusters around the whole of the UK.

This twin-driver approach – enhanced global discovery science alongside a more dynamic domestic innovation economy – is designed to help ensure we seize the opportunity described.

To succeed, we have to both lead in the discovery of breakthroughs like genomics and robotics and also build the pathways to successful proof-of-concept, licensing, financing and global commercialisation.

This is the model we are adopting and which I am delighted to have been given the opportunity to lead by the Prime Minister, the Chancellor and the Business Secretary.

This pandemic has emphasised the extraordinary advances that can be made at scale and at speed. With the necessary pace, agility and a focus on the opportunities, I am confident we can breathe life into many more scientific and technological breakthroughs. These will transform the lives of people across the UK and the world, restoring the UK's global role as both an 'innovation nation' and a science superpower.

The history of British science speaks for itself – from Newton to Darwin, Ada Lovelace to Tim Berners-Lee, Alexander Fleming to Stephen Hawking and Sarah Gilbert. We are undeniably a global science superpower. It is in our national DNA.

Re-orientating our economy, politics and society to harness this more strategically requires a major 'rewiring' of the way Government works. For the first time since the 'White Heat of Technology' was referenced by Harold Wilson in the 1960s, we are gripping it. That is why we have:

- established the new National Science & Technology Council (NSTC), supported by the new Office for Science & Technology Strategy in the Cabinet Office;
- made the historic funding commitment to drive economy-wide investment to 2.4% of GDP in 2027, with over £5 billion of additional annual investment per year by 2024-25 (raising HMG R&D spending by 30% to £22 billion by 2026-27);
- made our commitment to R&D in the Government's Levelling Up White Paper to distribute opportunity evenly, with BEIS committing to invest at least 55% of its domestic R&D funding outside the Greater South East by 2024-25;
- committed to £100 million of Government funding to pilot Cluster 'Innovation Accelerators' – widening the benefits of R&D opportunities for wider societal benefit in three of our great clusters: Greater Manchester (materials science); the West Midlands (robotics, advanced manufacturing and battery technology); and the Glasgow City-Region (advanced, satellite and manufacturing). My aim is that these will learn from the Stanford-Silicon Valley and MIT-Greater Boston models of combining excellent research, industrial and new skills with career opportunities in a city-region;
- published the Innovation Strategy (see page 6), a serious long-term plan for how we put innovation at the heart of "building back better" by mainstreaming the lessons learned from the pandemic and our world-leading vaccine rollout (faster than anywhere in Europe thanks to a powerful combination of our top universities, the NHS and the freedom to operate outside of EU bureaucracy);
- set out our commitment, as part of the Innovation Strategy, to support the 'Seven Tech Families' in which the UK has the greatest technological strengths and potential. We know that innovations like the smartphone would never had become ubiquitous were it not for the right combination of technologies – microprocessors, touchscreens and GPS for instance – being sufficiently developed in combination. That is why it is so important that we identify the technology families and clusters with the greatest potential to drive transformational innovation: from advanced materials to bioinformatics and bioengineering, to quantum technologies, AI, robotics and machine learning. These are the technologies that offer the potential to develop self-healing materials, advanced diagnostics and disease cures, that enable us

to harness cells as nanotechnology factories, create a new generation of hydrogen fuels, dissolvable plastics, solar power in space, carbon sequestration and clean nuclear fusion energy generators. Our challenge will be to build on the UK's existing strengths in these emerging fields, and to apply them in business, healthcare and both existing & emerging industries;

- launched the Nurse, Tickell and Grant Reviews of UKRI and our research ecosystem to strip back the red tape from existing research ecosystems, increase the agility of funding decisions, create new career paths for a new generation of scientists, innovators & entrepreneurs and make the UK once again the most attractive place for the world's top talent to build exciting careers;
- launched the Advanced Research and Invention Agency (ARIA), our new UK independent discovery science and innovation agency, supported by £800 million in funding, to empower exceptional scientists to focus on high-risk, high reward research programmes at the frontier of discovery and invention, without bureaucratic restriction, on the US model of the Defense Advanced Research Projects Agency: the research engine behind early iterations of GPS, Apple's SIRI, and the internet. The appointment of Dr Peter Highnam, Deputy Director of DARPA, as ARIA's new CEO is a major validation of the UK ARIA model;
- restated our commitment to formalise our association with the Horizon Europe programme (despite the very disappointing delay of now 14 months from the EU); launched a funding guarantee for UK 'in-flight' projects while making clear that alongside Horizon we intend to embrace deeper bilateral and multilateral global science, technology and innovation collaborations. This is why I am visiting Switzerland, Israel and the Pacific so quickly to negotiate bilateral research and innovation MoUs.

These are just some of the significant steps we are taking to reform and refine our research infrastructure, funding processes and ecosystem in order to seize the opportunity of reorienting the UK as a global science, technology and innovation superpower.

Yet we have to do something else: we must recognise we are in a competitive global race for talent and investment, listen to the research and innovation community in order to be vigilant and honest about where our global USP really lies, and where our support is likely to yield the greatest impact. In particular, we need to listen to the next generation – scientists, innovators and entrepreneurs – in whose hands our future success lies.

It is an exciting moment for UK science, technology and innovation. We need to seize it – together. □

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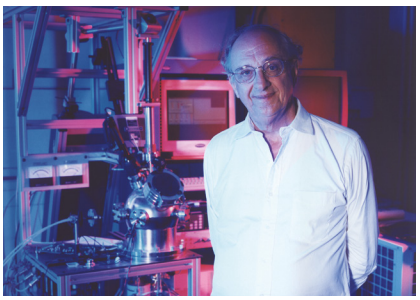
Obituary: Sir John Enderby CBE FRS FInstP

16 January 1931 – 3 August 2021

Sir John Edwin Enderby, having been elected FRS in 1985, served as Physical Secretary and Vice-President of the Royal Society from 1999 to 2004. He was also President of the Institute of Physics from 2004 to 2006 and was closely associated with Institute of Physics Publishing (IOPP) as scientific adviser over a number of years. With such in-depth experience of publishing, the Foundation for Science and Technology was delighted when he agreed to become editor of *FST Journal*, a post he filled from 2009 to 2016. He was responsible for the redesign of the *Journal* in 2015, in which he involved colleagues at IOPP.

John was born in Lincolnshire but grew up in Cheshire before becoming a



teacher after completing his national service. He took evening classes as a part-time physics student at Birkbeck College, London, earning a first-class honours degree in 1957. He stayed on at Birkbeck to complete a doctorate on the electrical properties of liquid metals.

After lectureships in Huddersfield and at Sheffield University, John was appointed Professor at Leicester University where he subsequently became Head of Department. He joined the Physics Department at Bristol University in 1976, becoming Head of Department in 1981. He held this role until 1994. From 1985 to 1988, he took leave in order to become Directeur-Adjoint of the Institut Laue-Langevin in Grenoble, the leading neutron beam facility.

In his research, he developed innovative ways of using neutrons to study the structure of disordered matter at the microscopic level. He and colleagues also pioneered physics research into how water molecules are ordered around ions in aqueous solutions.

John was awarded a knighthood in 2004 for services to science and technology. □

CONTEXT

In July 2021, the Government published the UK Innovation Strategy. This policy document is the first major Government publication focussing on innovation for several years and the first since the 2019 General Election. The Strategy has four main pillars, entitled: Unleashing Business; People; Institutions & Places; and Missions & Technologies. It covers a large number of different areas, including investment in R&D, innovation via regulation and public procurement, skills, visas to attract global talent, investment via the Strength in Places Fund, and a new Innovation Missions Programme. It also identified seven key technologies on which to focus.

On 13 October 2021, the Foundation for Science and Technology brought together the Secretary of State for Business, Energy and Industrial Strategy (Rt Hon Kwasi Kwarteng MP), the Chief Executive of Innovate UK (Indro Mukerjee), the Chief Executive of the Royal Academy of Engineering (Dr Hayaatun Sillem), the Chief Technology Office of Rolls Royce (Paul Stein) and a Venture Partner from Merian Ventures (Priya Guha) to discuss the issues. A video recording, presentation slides and speaker audio from the event are available on the FST website at: **www.foundation.org.uk/Events/2021/The-UK-Innovation-Strategy**

Improving our record on innovation

Kwasi Kwarteng

The Rt Hon Kwasi Kwarteng MP is Secretary of State at the Department of Business, Energy and Industrial Strategy (BEIS). He was previously Minister of State at the Department. He was Parliamentary Under Secretary of State in the Department for Exiting the European Union from November 2018 to July 2019. He was elected the Conservative MP for Spelthorne in 2010. In 2015 Kwasi Kwarteng was appointed as Parliamentary Private Secretary to the Leader of the House of Lords, and in 2017 he became Parliamentary Private Secretary to the Chancellor of the Exchequer.

SUMMARY

- The UK has great depth of talent in scientific research
- In innovation, the UK could do better
- The decarbonisation imperative will rely heavily on innovation
- The skills agenda will be a key part in delivering the Strategy
- We need to diversify the range of institutions that are involved.

The UK's new Innovation Strategy addresses five fundamental questions:

- What is innovation?
- Why is it desirable?
- How do we promote it?
- Which areas should we focus our efforts on?
- Finally, what is its role in the UK economy in the medium term, in 2035?

The document does not give a final answer to these. These questions are really a starting point, through which to stimulate debate. They are designed to elicit reactions that can improve our efforts.

Both at home and internationally, the Strategy is generating a great deal of interest. It is a very outward-facing document which has been well received in many other countries, including existing and potential partners.

The UK has a huge depth of talent within the science base in terms of academic research. In terms of innovation, though, while we do well, we could do a lot better. Now, I'm an historian. The simplest way I imagine the difference between science and innovation is to recall, first, Isaac Newton in Lincolnshire watching apples fall and coming up with his theory of gravity: that is pure science. The innovation equivalent would be the Wright brothers inventing the aeroplane. We worked out what gravity was in 1665 and we figured out a mechanical way to overcome it in 1903. So that is, in my mind, a very simple example of the difference between science and innovation.

This innovation strategy sets up 'tramlines' to guide the way we drive innovation. As an example, as far as my Department is concerned, innovation is closely connected with net zero in terms of the challenge of decarbonisation, which is one of the seven target areas we outline.

An innovation forum

We will shortly establish a Business Innovation Forum to galvanise action from the business community in order to drive forward the implementation of the Strategy – and also to hold the Government to account.

What does this all mean for Britain in the next 10 years? If we get this right, we can really lead the world. The brains, the talent, the ingenuity and the commercial ability of people in this country can help us lead the way, not only in

ORE CATAPULT

An agreement between UK Export Finance and the Offshore Renewable Energy Catapult aims to promote the expertise of UK offshore wind companies abroad – such as in the ORE Catapult and Vattenfall collaboration off the coast of Aberdeen.

terms of driving net zero but also in improving general living standards – not just in the UK but across the world.

If the UK is to maximise those opportunities, then people have to have the right skills. Each new Secretary of State needs to focus on the skills agenda, not just for innovation but also for net zero and the other challenges our world faces. Unfortunately, over successive governments, responsibility for skills has moved between BIS, BEIS and the Department for Education. What we need is a fully joined-up approach – and I am confident we can then resolve this issue.

In addition to Innovate UK, we also have the new Advanced Research and Invention Agency (ARIA) which will play a major part in delivering the strategy. Given the way it has been set up, it would be wrong then to impose a specific mission. The director and project managers of the agency have significant latitude in regard to where they direct their attention. Having said that, they will understand that net zero is a big factor in what we want to achieve.

And it is not just a matter of coming up with the innovations themselves. Often these fail to make an impact because they are not adopted; at least not widely enough. So in certain areas we need to think about improving market function. Even if people produce fantastic innovations, they will not succeed if these are not picked up by the market – and that includes a focus on distribution chains and all the elements that go into successful sales and marketing.

Procurement is another important area and the Government has appointed a Minister for Investment, one of whose priorities is to focus on Government procurement. Looking at the United States since World War Two, the purchasing power of the US government has had a huge influence in all kinds of innovations. That is something that the UK could be much better at.

I think we need greater diversity in our institutions. The UK is very good at universities, and then there are businesses, but traditionally there has been very little else. More recently, the catapults and other bodies like the Francis Crick Institute have come into being and these attract capital from the public sector and also the private sector. So at the Crick Institute, AstraZeneca has an office next to researchers: there is greater permeability and interaction. That is critically important.

To take another example, ARIA is neither a university nor a business, but it will attract a lot of people with ideas. So, as I said, we need a greater diversity of institutions.

Funding

The Government has made an explicit commitment to £22 billion of R&D funding by 2024-25. That is a very clear statement. There is a sense among the public that Britain does science rather well. People saw that in the development of the Covid-19 vaccine and its rollout, for example.

Public acceptance of the need for a large role for science is, therefore, less challenging than actually finding the money. We have a great science base that can be used to develop ideas. We have a general population that understands there is a strong scientific tradition. Our job in Government is to make sure that we get it properly funded, although this may be challenging in present circumstances. The Government also has a responsibility to remain mindful of the UK's balance sheet, the public finances. □

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The role of innovation in creating our future

Indro Mukerjee

Indro Mukerjee is the Chief Executive Officer of Innovate UK, the UK's innovation agency. He has a strong personal interest in the development of skills for industry and getting the best talent pipeline developed. He co-founded the UK Electronics Skills Foundation, which has developed into an innovative and successful partnership between industry and academia encouraging bright, young students to develop careers in the UK electronic systems industry. He also served on the SEMTA (now Enginuity) board for nine years, where he was chair of the committee managing its investment fund.

SUMMARY

- Innovation will play a crucial role in creating our future as a country
- We must inspire the brightest and the best to become successful innovators
- We need to be aware of emerging technologies, markets and industries
- Successful innovation is more than good science: it involves commercial skills as well
- Innovate UK is looking to bring on a new generation of innovators.

This is a timely moment to focus on innovation because the UK really needs to get through the pandemic we are in and look to the future. If we aspire to a future of prosperity, good health and respect for the planet, as well as one of fairness, diversity and equality, innovation will play a crucial role in helping to create this future. Indeed, the Government's innovation strategy is called 'Leading the Future by Creating it' – which is an apt description of what we do as innovators.

This is my first public sector role – my background is in business. I have a huge amount of respect for research, but my passion is to support the people who translate that into things that bring prosperity, give people jobs and help to improve our society. So I am very focussed on supporting innovation through and in British business. We are the UK's innovation agency, and we help drive productivity and economic growth. By helping businesses develop and realise the potential of new ideas – including those from our very substantial science research base – we support the economy.

Inspire, involve, invest

There are three words that illustrate the way we want to work with people: inspire, involve and invest. We want to inspire the brightest and the best, we want the best innovators to come through the system and to become successful.

We want to involve a wide range of people and organisations because it is crucial to harness everything within our very substantial ecosystem. So we will involve these different communities in our efforts. We also invest both cash and non-cash resources in order to create impact.

We have just launched our Action Plan for Business Innovation. This focusses on five themes. First, innovation is about building the future. So we must be open to, and aware of, new markets, new technologies and new industries. Our future is concerned with making things better for people and for the planet.

The second theme is managing growth at scale. The UK has a fantastic science base. There are many good examples of science being translated into business success – and I would like to see much more. The job of Innovate UK is to support much more translation so that businesses can scale-up and become successful in the UK. To do so, more than pure science skills will be required: commercial skills, sales and marketing, product management – these are not afterthoughts, these are often the difference between success and failure.

The global market

The third theme concerns global opportunities. Some 99% of any market is outside the UK. For sure, we need to focus on our home market and do a better job here by leveraging public/private opportunities for SMEs in particular. Yet there is a lot to do in terms of export and helping British business to really become successful in selling into international markets.

There is a very substantial innovation ecosystem in the UK. Trying to control it would be a waste of time in my view. That would be a very outmoded, Victorian approach. Innovate UK will, instead, provide a platform to convene this ecosystem, in order to make it into a community that can work together in partnerships.

The last theme is concerned with the effective use of Government levers. There are many opportunities to connect SMEs in particular with Government use of technology. Making the most of this would benefit both sides, as well as the economy overall.

These five themes are based on six foundations. The first is the science and research strength we have in the UK. The next is design, which is often

There is a very substantial innovation ecosystem in the UK. Trying to control it would be a very outmoded, Victorian approach.

an under-considered aspect of innovation. Further, societal impact and responsible innovation have to be integrated, because technologies like Artificial Intelligence (AI) and fields such as the life sciences have to be developed in a responsible way as we go forward with innovations.

People and skills

Then, successfully addressing the innovation, talent and skills pipeline will be crucial. A significant area is the equality, diversity and inclusion agenda, which is one of the secret weapons of the UK. If we can use that properly, if we can mine the layers of talent that would not otherwise be identified in order to maximise their abilities as innovators and entrepreneurs, we can do much better as a country. Very importantly, there is the issue of place and levelling up, which is a very important driver.

Going forward, Innovate UK is looking to bring on a new generation of innovators. We will need role models who will stimulate young people to be, not just Premier League footballers or contestants on Britain's Got Talent, but innovators, engineers, entrepreneurs, and successful business people.

I see Innovate UK as a service to UK business, and one which should have a very accessible shopfront for us to serve its needs across our wide range of cash and non-cash support products and services. I am determined that we will work efficiently and with a perpetual desire to improve what we do and how we do it. □

A significant area is the equality, diversity and inclusion agenda. If we can use that properly, if we can mine the layers of talent that would not otherwise be identified, we can do much better as a country.

DOI: 10.53289/QSGY7838

Attracting innovative businesses to the UK

Hayaatun Sillem

SUMMARY

- This represents an emphatic focus on innovation within Government
- At its core is an aspiration to grow business investment in R&D
- Businesses choose where to place their R&D investment on a global basis
- The UK is rich in innovation assets
- The UK can build a compelling innovation offer to global companies.

Each person will have their own sense of why the Innovation Strategy matters. For me, it is about the opportunity and the imperative to capture more UK value from the fantastic insights that come out of our research base and indeed the global stock of knowledge. In other words, making sure that our strengths, including the research of which we are rightly proud, actually translate into benefits that people experience across all parts of the UK and society.

The Strategy marks three important developments. Firstly, it sets out a specific and emphatic focus on innovation within Government. The UK will never achieve the most impactful innovation policy if it is treated as an appendage of research policy, which has sometimes been the case in the past.

Secondly, this is a whole-of-Government strategy for innovation. A myriad of policies influence our innovation performance. This is the first UK strategy that takes a systems view of innovation. Thirdly, we have a much more empowered Innovate UK, which is absolutely vital for us to punch our weight in innovation.

The core of the Innovation Strategy is an aspiration to grow the investment in R&D by business. It is worth just taking a moment to look at where the UK is now. Business investment in R&D is highly concentrated, both in terms of company and sector, across the Top 100 UK companies (Table 1). The top 5 UK enterprise groups account for 17%, and pharmaceuticals, automotive and aerospace account for around 40% of business investment in R&D in the UK.

So alongside growing the base of companies that invest in R&D, which is clearly essential, we also need to watch rather carefully what today's big spenders are planning, because they have a large part to play in reaching the UK's 2.4% target. Without them, this will be particularly challenging.

A much higher proportion of business R&D in the UK is financed by the rest of the world than is the case for most of our peers and around half of business R&D performed in the UK is by for-

Dr Hayaatun Sillem CBE is CEO of the Royal Academy of Engineering and CEO of the Queen Elizabeth Prize for Engineering Foundation. She has extensive leadership experience in UK and international engineering, innovation, and diversity and inclusion activities. In 2020-21 she chaired the UK government's Innovation Expert Group and co-chaired with Sir Lewis Hamilton his Commission on Black Representation in UK Motorsport. She is a trustee of EngineeringUK and the Foundation for Science & Technology and chair of the St Andrews Prize for the Environment.

Pharmaceuticals, automotive and aerospace account for around 40% of business investment in R&D in the UK.

SHUTTERSTOCK/ POPTIKA

Table 1. UK business R&D is highly concentrated

Enterprise groups	*% total business R&D expenditure*	*Expenditure (£m)*
Top 5	17%	£4,431
Top 10	23%	£5,862
Top 15	27	£6,883
Top 20	30	£7,843
Top 50	40	£10,470
Top 100	47	£12,197

(Source: Business enterprise research and development UK: 2019, ONS)

Table 2. The UK as a location for R&D

Building on strengths	Action needed
Engineering workforce	Late-stage development and demonstrators
Innovation funding	Public procurement
Non-financial innovation support	Joined-up Government approach
Collaboration with universities	Ownership and financial structures
Collaboration between businesses	Innovation in engineering services
Tax incentives	Innovation across sectors

(Source: Royal Academy of Engineering, 2018)

The UK is a small country; California is about 1.7 times our size geographically. Yet we are very rich in innovation assets.

eign-owned businesses. It is, of course, a great thing that we can attract so much inward investment but it also emphasises that businesses make their decisions about where to invest in R&D on a global basis. That is true for UK companies as well: just because they started here, it does not mean they will continue to invest in R&D here.

Furthermore, the UK has a much lower proportion of R&D funding going into late-stage development, i.e. the R&D that takes you from prototype to product, than countries such as the US, Israel or Japan. That matters because this type of funding is expensive and 'sticky' – companies often create manufacturing facilities, and so forth, alongside this type of investment, which become a key driver of job creation, especially in less well-served regions.

Taken together, these observations point to the importance of really understanding how the UK offer stacks up against other countries that compete to host business R&D investment, especially in late-stage R&D.

The Royal Academy of Engineering has been seeking to address this very issue over the past few years. Table 2 summarises what senior R&D budget holders across a wide range of companies have said about UK strengths and weaknesses. There are many great things about the UK: we have an amazing quality of R&D talent, even if quantity and diversity (certainly in engineering) are not sufficient. While there is always scope for improvement, the environment for collaboration with both other businesses and universities is actually pretty good. There are areas where we fare less well, though, such as our ability to provide a joined-up offer across Government and to

leverage public procurement to drive innovation.

The Innovation Strategy provides a really good launchpad, both for building out from the strengths and tackling the areas where we are currently less competitive. I am especially keen that we see the positive intentions from Whitehall on procurement are followed through in terms of improved innovation outcomes.

The customer journey

In implementing the Strategy, the Government needs to consider the customer journey faced by businesses. The UK is a small country; California is about 1.7 times our size geographically. Yet we are very rich in innovation assets, including universities, Public Sector Research Establishments (PSREs), corporate R&D centres, science and industrial parks, advanced manufacturing capabilities, NHS, vibrant communities of start-ups, and living labs.

Contrary to popular belief, these innovation assets are quite widely distributed across the UK. We still have work to do in several areas, not least to build the technical workforce that will be needed to power the innovation economy, and also to improve equitable access to jobs and opportunities associated with it. We also need to think about the customer journey for businesses seeking to navigate that system.

However, if we get that right, we will have an utterly compelling offer to global talent and investment. The UK can be an innovation super-cluster: a place to access extraordinary talent, and a world class research and innovation base within a safe, responsible, trusted and trustworthy environment – and as part of an inclusive community. □

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A business view of the strategy

Paul Stein

SUMMARY

- Industry needs to see demand signals if it is to invest in R&D
- Government procurement has an important part to play in encouraging innovation
- In some areas, regulation drives product innovation, not market forces
- Support is needed at all stages of the innovation pipeline
- Industry, academia and Government can understand each other better with more opportunities for people to move between them.

The innovation strategy is clearly hugely important, because it provides the structure and the convening force for the innovation ecosystem. The need to achieve the UK's target of 2.4% of GDP on R&D has to include a sterling effort by business. That is because business investment is falling behind compared with our international competitors.

I want to highlight enablers, from an innovation perspective, that my company believes are necessary, and cross-check with the Innovation Strategy to see whether it echoes those same enablers.

The first is that we want to see demand signals. We are not going to invest in R&D unless customers want to buy the ultimate product or service. Now, many products are market-driven, particularly in the business-to-consumer space where there is little Government intervention but even in the business-to-business space. For example, more efficient aeroplanes are market-driven products, because manufacturers go out of business if their offering is not as efficient as the competitor's.

And many of these demand signals are arrived at by industry and Government working together, working together on a common agenda. Here, the legislative framework and the innovation ecosystem work hand in glove.

Regulation

However, many innovations are driven by changes in regulation. Net zero is a golden opportunity to align regulation with innovation and Government procurement. We should not under-estimate the role of procurement. The MOD, for example, is not there just to procure items for our armed forces, it is also there to stimulate innovation. The multiplier effect that comes with investment in high-risk, high-payoff projects is very large. It is great to see that the corner has been turned with programmes like Tempest.

The regulatory framework sometimes needs to be convened at an international level: one example of this is sustainable aviation fuels. The develop-

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The UK has to get ahead of the curve in its skills base, particularly in areas like battery technology – in battery chemistry and electrical skills.

ISTOCK/SPICYTRUFFEL

ment of new fuels to decarbonise aviation is not being driven by conventional market forces because they are more expensive than digging fossil fuels out of the ground. So a 'forcing function' is needed. Yet because this is such an international industry, unless all countries move in lockstep then no one is going to go first. That shows how international regulation can produce innovation.

Scaling up

Then there is the challenge of scaling up: it is very important to see these innovative industries move through to volume manufacture. The technology involved in scaling is as precious as the fundamental science that goes into the start of the pipeline. Government, industry and patient capital all have to work together towards a common goal as they invest in the whole of the innovation ecosystem – and that involves the supply chains as well. There is no point in creating first-class Tier One and Tier Two suppliers, if the supply chains are not agile enough and do not invest enough.

Then there are the people that deliver this. It is not just a question of technical skills but also business skills. We need more entrepreneurs, people who understand the language of business but also understand the language of innovation. There are some very talented scientists and some exceptional engineers: combining those skills with an understanding of business is so important.

Of course, technical skills are also in short supply. The UK has to get ahead of the curve in its skills base, particularly in areas like battery technology – such as battery chemistry and electrical skills – where it is behind the curve compared with competitors such as Germany.

Another issue is that academia, industry and Government must become more permeable. Careers tend to follow either a Government path, an academic path or an industry path. It is rare for people to cross boundaries. That really has to change, because understanding the needs of all of these three is so important.

Looking at the innovation infrastructure, facilities like the High Value Manufacturing Catapult in the UK are looked upon as exemplars by other nations. There have been inward missions from Brazil, from France and from many other countries to see it and understand why it is so good. The answer is that the HVM catapult is a convening force for leading-edge manufacturing technologies, bringing small- and medium-sized companies together with large companies, creating agility in supply chains. Investment is needed across the whole of the supply chain stack, not just in small companies, not just in big companies, but in the whole ecosystem.

Finally, clarity of vision and leadership, especially from Government, is hugely helpful. The Prime Minister's 10 point plan for decarbonisation has provided focus and clarity for innovation. The Innovation Strategy is another step on that journey.

So in all we do see good alignment between the Innovation Strategy and the needs of business and it represents a worthy next step. However, more work is needed on skills, permeability of career paths, the role of procurement and industry and government working hand in hand to use regulation as an innovation stimulus. □

Clarity of vision and leadership, especially from Government, is hugely helpful. The Innovation Strategy is another step on that journey.

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Bringing everyone along on the journey

Priya Guha

SUMMARY

- We need everyone to participate in the innovation journey
- Lack of inclusivity is a major threat to the success of the Strategy
- Innovation should mean something to everyone in the UK, not just the usual interested individuals
- Education is fundamental, not just for the younger generation but for those already in today's workplace
- The Covid pandemic has highlighted the challenge of social exclusion.

The primary risk I see with the Innovation Strategy is around the theme of inclusivity. I believe that if we do not get this right, the strategy is pointless. Maria Ressa was the one woman to win a Nobel Prize in 2021 – in her case, the Peace Prize. That is indicative of the history of Nobel Prizes with only 6.2% of Nobel laureates being women. I recently attended an event where a senior technologist in a large British business said to a public audience that he felt he was not listened to, compared to his "ethnically impoverished colleagues". We are in a time where just 1% of professors in research establishments are black. Currently, black colleagues in the research and innovation ecosystem are saying they feel the system is institutionally racist. There is a problem there because that means there are not sufficient role models to change the debate and so change the ecosystem.

Now, the ecosystem needs to change because we need everybody to participate in this innovation journey. Even though the numbers are gradually edging upwards, less than 7% of girls took computer science at A level in 2021. That has been hailed as an improvement and while I am happy to celebrate that achievement, it is just not good enough. If we want everybody to be at the table where the algorithms that will define our future are designed, the current situation is not good enough.

Education is also fundamental to innovation. In a 2017 report for Dell Technologies, the Institute for the Future arrived at the conclusion that 85% of the jobs people will have in 2030 are not yet known. So what should children be learning now? Well, perhaps innovation skills: the classic volume *The Innovator's DNA* suggests that these include associating, questioning, observing, networking and experimenting. Yet those are not the skills in today's curriculum.

Lifelong learning

How to educate a generation of talent that can bring everyone along with them on that journey of innovation? That, of course, is just the younger people of today, but there is a whole workforce that needs to come on that journey. So, this is about lifelong skills and lifelong learning. People are not being equipped with the skills to take part in this exciting innovation journey. One of the really shocking statistics from the Covid pandemic was that 1.5 million households did not have internet access during the pandemic. Some 20% of children did not have access to a device to learn at home. There is a major challenge here about social inclusion: making sure that everybody is brought along that journey, irrespective of the background they are from and the experience they have had, as well as the opportunities the family has had previously.

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SHUTTERSTOCK/YURIY GOLUB

Mind the gap: Less than 7% of girls took A level computer science in 2021

A photo of Maria Ressa at a press conference held on October 9, 2021, following her Nobel Peace Prize win.

Another huge risk is that, while people in certain circles understand a subject like the innovation strategy, it needs to mean something to everybody in the UK if it is to be successful. And that is where we need people who are passionate about this issue and are passionate about making the UK's future one that is driven by innovation. A future where everybody in the country understands what that means and takes their part.

That is why it is so important that Innovate UK and other organisations lead the charge to translate this world in which we live and breathe into a world in which everyone can participate. There are huge risks here: the risk of not having enough representation at the table; the risk of a workforce that is not equipped to deliver all these really exciting things.

It should never be forgotten that there is also the risk that this whole discussion becomes an echo chamber where people who are invested in this subject talk about innovation but in a conversation that does not resonate with the broader world.

However, in the spirit of turning risks into opportunities, this is a strategy that can actually bring people along with it, one that can mean something to everybody in the UK. If we seize the opportunity to ensure that everybody is at that table – in the design, the development and the scaling of innovation –we will not only be able to seize the economic advantage that innovation will bring, but actually make the societal changes that will define the future. □

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FST BLOGS AND PODCASTS

The Innovation Strategy and UK Business – podcast with Paul Stein, Chief Technology Officer of Rolls Royce
www.foundation.org.uk/Podcasts/2021/Paul-Stein-The-UK-Innovation-Strategy-and-the-view

The Innovation Strategy and UK Universities – podcast with Professor Mark Spearing, Vice-President Research and Enterprise at the University of Southampton
www.foundation.org.uk/Podcasts/2021/Professor-Mark-Spearing-The-Innovation-Strategy-an

Building the Future Economy – blog by Indro Mukerjee, Chief Executive of Innovate UK
www.foundation.org.uk/Blog/2021/Building-the-Future-Economy

FURTHER INFORMATION

The UK Innovation Strategy (HM Government, July 2021)
www.gov.uk/government/publications/uk-innovation-strategy-leading-the-future-by-creating-it

Innovate UK Action Plan for Business Innovation 2021 to 2025
www.ukri.org/publications/innovate-uk-action-plan-for-business-innovation-2021-to-2025

Institute for the Future/Dell Technologies
www.delltechnologies.com/content/dam/delltechnologies/assets/perspectives/2030/pdf/SR1940_IFTFforDellTechnologies_Human-Machine_070517_readerhigh-res.pdf

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https://www.hbs.edu/faculty/Pages/item.aspx?num=41229

It should never be forgotten that there is a risk that this whole discussion becomes an echo chamber where people who are invested in this subject talk about innovation but in a conversation that does not resonate with the broader world.

New ideas can provide a welcome stimulus for creativity and innovation. Equally, some accepted ideas can constrict and frustrate progress

A welcome and a farewell

Anthony Finkelstein

This is really two comment articles in one, a warm welcome and a much hoped for farewell. First, then, a welcome to ARIA. The UK has a new research and invention agency. It has been a while in arriving, making its way from idea, to policy, to announcement, to funding, to legislation and now to the appointment of a Chief Executive, Dr Peter Highnam. Those of us who have watched closely, sometimes from the cheap seats, occasionally from the orchestra pit, have certainly experienced the nerves and uncertainty, and have written ARIA off more than once. Yet – here we are.

We have been gifted an incredible and exciting opportunity. ARIA could be many different things: better funded, with a more developed model, with a stronger axis to UKRI and it could have greater assurance on forward funding to make long-term programmatic bets. Despite all of this we have a new agency that has the operational freedom and, in good measure, the resources to make a difference and to position the UK in some key frontier areas of technology.

As a community, in science and technology, as well as in policy, we need now to step forward in a collective effort to ensure ARIA works. This means, it almost goes without saying, a high tolerance of failure when it comes to the choices it makes. It also means, more challengingly, a willingness to accommodate new funding modalities and models that may not be either familiar, or necessarily optimal for the recipients. We will need to show some institutional flexibility.

We can reasonably expect ARIA to be collaborative; independence should not mean disregarding the strengths of the UK research and innovation landscape. We can also expect it to be complementary – bridging gaps – rather than purely going it alone.

We must demand that ARIA sets aside the narrow compartments into which the research and innovation system has been divided (more on this below). These are not, however, major constraints. All this being said, again, welcome ARIA. You represent an important advance for the UK and you should find many friends. I am one.

And farewell...

There are some models that are so simple, so seductive and so often repeated, that even when you know them to be wrong – in fact, worse than wrong, actively misleading – it remains almost impossible wholly to set them aside. My example, and my principal bête noire, is the 'pipeline' metaphor, that relates science and research to innovation and commercial exploitation. I wish it gone.

It would not really matter, were this relationship not of such overwhelming importance and of most immediate relevance to how we frame policy.

The idea of the pipeline is that scientists shovel ideas into one end of the pipeline, then innovation actors ready them for industry to commercialise. The process is regular and staged, albeit leaky. It is easy in this model objectively to characterise the state of a technology – its level of readiness.

Everybody has their fixed station on the pipeline. If you are a researcher, you are not suited to the role of innovator – too 'other worldly'. If you are an innovator, you are unlikely to have the capability to scale and commercially exploit the innovation you have nurtured – too 'undisciplined'. If you work in industry, your job is to turn the handle and deploy the capital – too staid to innovate, too impatient to undertake research.

Of course, we all know this is wrong. It was never right and has become 'wronger'. There is no pipeline – it is a jacuzzi. Research scientists based in universities not infrequently prove to be excellent innovators capable of attracting talent and spotting commercial opportunity. Innovative small companies often undertake ground-breaking research, even if they do not choose conventional routes to publication. Larger industrial organisations preserve a substantial reserve of deep technical expertise, the residue of a research capacity, and 'intrapreneurs' who can act with agility.

My 'first' spinout led to a significant 'exit' and spawned two further independently-successful UK companies. Along the way, it paid off the

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In ARIA, we have a new agency that has the operational freedom and the resources to position the UK in some key frontier areas of technology.

After an extended period of disappointing revenues, we came to a collective conclusion: none of us could sell for toffee.

mortgages of a bunch of PhD students who came along for the ride. The story is a complex one and that is really the point.

Systemwire started with a joint programme of research on software development environments. The programme was sprawling, with some core funding and research muscle from the Research Councils but it also drew in students, funded on scholarships, a couple of students funded on discretionary accounts the group had accumulated, a key researcher funded by an overseas national foundation, and so on. Floating in and out of the lab were some former researchers, now working for another spinout. They were role models and later, occasional mentors.

The core concept we came up with was certainly a collective product and gained some interest from the research community. I had rather inflated and grandiose ideas about the potential of the technology as an alternative to 'the semantic web'. So much as expected. One, rather random, early evening, a former student, then working on an internship in a large investment bank, visited the lab and leaned over the shoulder of a researcher developing an early prototype. 'That looks just like a big problem we have at the bank' and, in that moment, we became fintech innovators.

The next day, an extraordinarily able student started work on the banking data standards. Meanwhile, with exceptional support from UCL Business (the TTO), the idea and associated implementation were patented and we started a spinout, i.e. Systemwire. We were joined by an experienced innovator who took on the role of COO and we secured some innovation funding (a Smart Award from, then, BIS). We started to look for opportunities to apply our technology and found, in some investment banks, a small number of early adopters.

Unfortunately, and this is key to the story, our initial technology did not really work! When confronted with the real scale and operating constraints, as well as some important technical features of the data, our approach fell over. So it was back to the proverbial drawing board and a rethink of some of the fundamentals which, by the way, led to some of the best purely scientific work I believe that I have published. We solved the problem and developed a set of optimisations that underpin the technology to this day. The papers are still being cited.

There followed an extended period of successful technical demonstrations and disappointing revenues, after which we came to a collective conclusion: none of us could sell for toffee. We did not really understand the market, did not have the contacts and could not talk the talk. We then merged with a small company, Message Automation, that had a related, though considerably simpler, product but which was run by a team who had the fintech knowledge and address book we so clearly lacked.

The rest was hard work, by that team and by talented former students who joined the company. My colleagues and I drifted in and out, offering advice on no very sound basis. Sales grew organically, and the recurring revenue from licences built up. There were a few early anxious moments during market crises. After a while, we exited to a large US fintech platform.

Complex pathways

Why do I tell this story? Well, first because research and innovation have complex contingent pathways. Good ideas come from all sorts of places and are enriched through a network of different engagements and opportunities. Research feeds innovation but equally innovation feeds research. Technology can be in an uncertain zone between research, application and innovation for lengthy periods. Researchers, innovators and industry expertise can build sustainable partnerships and share financial incentives. Background knowledge is often more important than foreground intellectual property.

All of this is a massive distance from any simple linear rendering of the research and innovation process. Building our funding structures and schemes in accordance with an imaginary pipeline, separating research from innovation and expecting technologies to conform to a simplistic readiness schema, runs counter to building a connected research and innovation system.

An alternative is possible. We should be funding multiple pathways open to the different ways through which technologies arise. We could be building sustained relationships with innovative networks and following technology as it loops back through research, is tested, fails, pivots and is rebuilt. We can apply funding both strategically and tactically in active partnerships. We can be proactive rather than waiting for the non-existent pipeline to deliver commercialisable research. To do this we need greater engagement and a more integrated approach.

In the meantime, farewell and good riddance to the pipeline metaphor. □

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CONTEXT

The impact of human activity on biodiversity loss has been a major and increasing concern globally. In February 2021, the Treasury published *The Economics of Biodiversity*[1], an independent review led by Professor Sir Partha Dasgupta. This had a number of key messages, including: that the world needs to ensure that human demands on nature do not exceed supply; that we change our measures of economic success to guide us to a more sustainable path; and that we transform our institutions and systems, in particular finance and education systems, to enable these changes and make them sustainable. The Dasgupta Review came out in advance of the G7 summit (June 2021), the UN's Biodiversity COP15 and the UN's Climate Change COP26 (November 2021).

The Foundation for Science and Technology held an event on 24 May 2021, with Professor Sir Partha Dasgupta, Professor Yadvinder Malhi (who led on behalf of the Royal Society in producing a statement on biodiversity from the national science academies of the G7 nations) and Dr Stephanie Wray, Managing Director of Nature Positive. A video recording, presentation slides and speaker audio from the event are available on the FST website at: **www.foundation.org.uk/Events/2021/Biodiversity-Economics,-Science-and-International**

Including nature in economic understanding

Partha Dasgupta

SUMMARY

- There is no intrinsic reason why ecology cannot be accommodated within economics
- An inventory measuring the increase or decrease in natural resources is needed
- To properly discuss welfare or wellbeing requires a focus on assets
- It would be a mistake to use GDP to discuss economic success over the long run
- Humanity's demand for nature's goods and services vastly exceeds the earth's capacity to supply them on a sustainable basis.

Ecology is a relatively new discipline. Good textbooks have only been available for the last few decades. In addition, people in general do not perceive signals from nature very easily. While humanity makes use of nature's goods and services all the time, their value is not recorded economically because it is not converted into prices. Yet there is no intrinsic reason why ecology cannot be grafted onto, or blended within, economics.

Inclusive wealth

The UK Government commissioned an independent review on the economics of biodiversity (see page 24). One of the key concepts in the final report was that of inclusive wealth, which is really a very intuitive notion. Private companies have no difficulty comprehending it because they have balance sheets. Nations, however, do not have balance sheets and have developed a habit of estimating flows by GDP, which is income. Yet we also need an inventory – of objects and durable goods. To discuss sustainable development, for example, it is necessary to know the assets that are being handed on to the following year, particularly in comparison to the assets that were inherited from the previous year.

Just relying on GDP fails to take into account the depreciation of capital – that is, whether the stock of something is more or less than it was last year; and if not, why not. So if a wetland is deteriorating, for example, it is depreciating in economic terms. The notion of inclusive wealth is nothing other than a confirmation of the need to measure an inventory of goods. And of course, if the social worth of those objects can be priced, then values can be added and that will contribute to an estimation of wealth.

This valuation of wealth should be inclusive for two reasons. First, because the prices are social prices and not necessarily market prices, for the reason that much of nature does not actually have a price in the market. The other is that natural capital, nature, is included in the measure as well as produced capital and human capital (such as education and health). Inclusive wealth includes the whole range of ecosystems.

It is almost inevitable that this will become part

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SHUTTERSTOCK/NEGINMINAEE

The secret roof garden of the Birmingham Library – for urban areas, one of the key recommendations is a focus on gardening and the provision of more green space.

of standard economic analysis as it has a very strong theoretical backing and the foundations are solid. To properly discuss welfare or wellbeing requires a focus on assets – those stocks on the basis of which our lives depend.

Inclusive wealth sits very comfortably with GDP because these two measures are designed to serve different purposes. GDP was invented to give a sense of the extent of economic activity for short-run macro-economic management. It would be a mistake to use it to discuss economic success over the long run.

Carrying capacity

The bedrock of the review is the finding from earth sciences that humanity's total demand for nature's goods and services vastly exceeds the earth's capacity to continue to supply them on a sustainable basis. So this is a firefighting situation. It is vital to find ways to cut the gap between capacity and consumption to zero, i.e. to create a balance. If sustainable development means anything, that balance must then be maintained for the long term. Nature has to be considered as a series of assets that have to be managed responsibly.

The entire language we use for economic analysis must place nature at the centre. Inclusive wealth is just one part of that new approach which will involve wholesale recalculation and re-estimation.

Then there is the question of reforming the institutions that support these activities, at local, national and international levels.

Citizens live in local surroundings and our activities are, in large part, confined to that. So at the local level, at least for urban areas, one of the key recommendations is a focus on gardening and for the provision of much more green space: it is good for our health, quite apart from the fact that it rejuvenates nature in the local environment. Another task for the citizen is to lobby local and national government to include natural capital in their investment and other policy decisions.

At the national level, subsidies for nature should be removed immediately. In fact, nature is often not zero-priced, it is commonly negatively priced because its use is subsidised. We are actually paying ourselves to degrade nature at present.

Then, at the international level, it is high time there was an international institution charged with monitoring and managing the global commons, such as the open oceans. Such an institution could raise vast sums of money to protect the oceans.

Biodiversity is one of the characteristics of ecosystems. It poses the question: is the portfolio of assets diverse, or is it concentrated on just a few things? Now, ecosystems differ greatly in size. My mouth is an ecosystem but so are the oceans. Yet it is possible to adopt a consistent way of thinking about these assets at various levels of scale. Doing so forces an holistic approach because it looks at the whole of the biosphere, but considers it in its component parts which are all interrelated.

So the review was not just about measuring carbon. Biomass was not considered as a unit of account either. Instead, the focus was on ecosystem functions.

Now, I have a background in economics. My experience of very, very large-scale global models is that they can be very misleading and result in mistakes. Ecologists, on the other hand, tend to


DALLAS KRENTZEL

Ecologists tend to study the small scale – but small scale in terms of the planet could mean the Amazon rainforest.

study the small scale. Of course, small scale in terms of the planet could mean the Amazon rainforest. Yet, studying samples and how the various elements interact with one another means considering them as integrated systems. It is not a great idea to strive for a mega-model of the biosphere. Starting with the various components of ecosystems, it is evident how at every stage those small systems are related to one another. That way, an overall view can be built up, rather than trying to impose a top-down approach.

The global commons

After the Second World War, the nations of the world were farsighted and established international institutions like the World Bank and the International Monetary Fund. These were designed to supply global public goods. The international community should now be considering establishing bodies to protect and manage the global commons, like the open oceans. By collecting rents for their use, a huge amount of revenue could be generated for a wide variety of conservation projects. Yet there are also global commons, in the form of peatlands and the tropical rainforest, that lie within national jurisdictions.

How should that work in economic terms? Obviously, countries should be compensated for protecting them, because they constitute global public goods with everybody enjoying the benefits and these countries will be bearing the entire responsibility of protecting them. Some subsidies are therefore required for this. To be clear though, in this context 'subsidy' is actually a payment for ecosystem services, such as is already commonly used in countries like Costa Rica and China, at the local level.

Focussing on consumption, though, avoids the question of population growth. Regardless of one's views on the general topic, there are things that we should be doing. Globally, over 200 million women of reproductive age have an unmet need for family planning: they do not have the equipment, the knowledge or the facilities. Yet nothing is being done about it. Of all the foreign aid going from OECD countries, less than 1% goes to family planning. Now, everyone says that women's empowerment is extremely important but that will not happen if they do not have control over their own bodies. To give another example: people say that these issues can be tackled through education. However, after all the years of investment in education, the World Bank reports that a third of women aged 15–24 in the poorest countries are still illiterate. There is a good deal we can do right now.

Grassroots strategy

What could we do in the UK? Well, let's start at a grassroots level, with every child having nature study as compulsory. Introduce this at primary school level, but revisit it right through to tertiary education.

We already have the Three Rs as the basis of our education system, so let's add a fourth, which is nature studies. Love for nature can only arise if people actually handle nature though: mucking around in soil, examining what is there, the fungus and the earthworms and so forth. That could be the beginning of a real cultural revolution. ❐

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1. www.gov.uk/government/publications/final-report-the-economics-of-biodiversity-the-dasgupta-review

International action on biodiversity

Yadvinder Malhi

Professor Yadvinder Malhi CBE FRS is Professor of Ecosystem Science at Oxford University and Director of the Oxford Centre for Tropical Forests. In addition, he is Visiting Professor at Imperial College London. He chaired the process of drafting of the G7 Science Academies Statement on Biodiversity. He has a broad research interest in the interactions between the biosphere and climate change. He has developed an international research network, the Global Ecosystem Monitoring network (GEM gem.tropicalforests.ox.ac.uk) collecting data on ecosystem function in a number of research sites across the tropics.

SUMMARY

- G7 member countries are responsible for 40% of the world's consumption of biological resources
- Biodiversity must be embedded into economic planning and thinking
- The monitoring of changes in biodiversity is essential
- Biodiversity is now being recognised as an existential challenge
- Having the will to act on our improved understanding is the real challenge.

The G7 has a major role to play in addressing the biodiversity crisis. While members account for 10% of the world's population, they are responsible for 40% of the world's consumption of biological resources, i.e. of nature.

So there is an important moral dimension in this, and also potential leadership. This group of the most influential nations can take major action, both within the member nations but also through supporting initiatives across the world.

In order to outline that role and move things forward, the Science Academies of the G7 – all 30 of them – drafted the Statement on Biodiversity[1], which includes a set of recommendations. The first concerns the need to embed biodiversity into economic planning and thinking, as well as human wellbeing. The world needs to move beyond narrow economic definitions to a much more integrated approach.

The second recommendation is about the integration of systems-thinking into our planning for the future – linking up economic planning and human development planning with an understanding of climate and biodiversity. The aim, of course, is to enable joined-up decisions about forward pathways.

The final recommendation involved the ways to monitor biodiversity effectively. How will we know when things are going wrong and, equally, when things are going right? What are the gaps in humanity's ability to understand the world's immense biological diversity? What improvements can be made both in terms of overall technological capacity and also in strengthening general capacity in the global South where most of the world's biodiversity is found?

The underlying principle is to consider the biophysical capacity limits of biodiversity when drawing up economic or trade plans. This could include establishing pathways that combine sustainable agricultural yields: in other words, improving the provision of nutrition for humanity, while at the same time protecting biodiversity and staying within a safe climate space.

Another area, which is still an emerging concept, is to manage biodiversity and trade while minimising the risk of the emergence and spread of infectious diseases. Not just the initial appearance of the disease but also the international connections that allow it to spread. Agreed protocols need to be developed.

Then there is the whole field of nature-based solutions. In addition to finding ways to mitigate or adapt to climate change, we need to find ways to address the biodiversity crisis while at the same time aiding human development. So for example, one avenue is to encourage a shift towards more plant-based diets. That does not mean everybody has to become vegetarian or vegan, but decreasing the amount and footprint of meat in our diet is important, because the amount of land devoted to rearing livestock is a major cause of biodiversity loss and habitat degradation.

Countries like the UK have a relatively good understanding of biodiversity and have developed effective monitoring systems.

Monitoring

The monitoring of changes in biodiversity is essential in helping develop strategies to protect the environment. Countries like the UK have a relatively good understanding of biodiversity and have developed effective monitoring systems for the many aspects of that diversity. In other countries, in the tropics for example, it is really difficult to maintain biological tracking, partly because the biology is so much more overwhelming – there is so much more of it. In addition, the resources and the capacity to carry out this monitoring effectively are simply not there.

So there is potential to strengthen monitoring networks, particularly in these biodiversity-rich countries. It would be worth considering extend-

ing it beyond the obvious as well. Everyone loves birds and mammals, and they are generally quite well studied and monitored. However, the insects that are crucial to many of the essential life support functions of biodiversity, or the creatures that keep soil healthy, need much more understanding and attention so that we know when things are beginning to fall apart, or when we want to rebuild natural ecosystems.

Biodiversity has been the neglected sibling of the climate challenge: climate change has been seen as an existential threat for quite a while. Biodiversity, on the other hand, has been thought of as nice to have, but not essential.

That has begun to change with biodiversity also recognised as an existential challenge. Pulling apart the fabric of our biodiversity will result in fundamental breakdowns in our resilience to climate change and many other issues.

Robust analysis

There is a real opportunity now for next-generation modelling to include the climate system, the complexity of the ecological system, and the complexity of the social system. All of this in one framework allows an exploration of feedbacks and trade-offs. All the various elements have been around for a while, but with today's computational power, as well as our greater ecological and social understanding, it is possible to carry out an analysis that is much more robust.

Producing better and better scenarios to improve our understanding is only part of the solution, though. Having the will to act on that understanding is, obviously, the more profound challenge that we have.

It is important to highlight consumption when thinking about population. When questions are asked about human populations and their impact on the planet, the focus tends to be on the global South, where some countries have large projected population increases. Yet the global North has a disproportionate impact overall, because per capita consumption is so high.

There are two ways of addressing high levels of consumption. The first is to limit or ultimately decrease it. The other is to make consumption as decoupled or circular as possible. In the latter, as many materials as possible are recycled, energy does not pour waste carbon dioxide into the atmosphere and efforts are made to decouple the economy from biophysical systems by reducing the interactions.

It is very difficult to see a future where there are no limits placed on consumption. There is a great deal of effort going into persuading people to moderate or reduce their use of resources. Yet that change not is happening quickly enough, so there may be a need to think more proactively about some limits, making hard choices. There are example of where this has worked: plastic bags is one.

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There is a great deal of effort going into persuading people to moderate or reduce their use of resources – such as legislation to reduce the consumption of plastic bags.

The net zero goal sets a number of shorter-term goals – where we need to be in 10 years' time for example – on the way to the mid-century net zero goal. Goals on biodiversity are also being established, with some long-term targets for governments to commit to.

Societal change is a key factor. If society commits to these goals, they are much more likely to be carried through in the longer term: there will be a popular mandate.

On questions of international governance, there are areas of the world that have, like the Antarctic, international agreement about the way they are regulated. A colleague who is a marine scientist has proposed reversing the current approach to global commons governance – in this case, of the open oceans. Instead of defensively protecting them, the default would be that they are not to be exploited. Exceptions would only be made on the basis of a robust, agreed proposal.

The biosphere is the matrix that creates us and surrounds us. There is a visceral connection to nature – and pandemics really bring that reality home. Such immersive connection is probably best communicated through the Arts and the Humanities, bringing a deeper cultural understanding – there is a real role for these disciplines in getting beyond words and attaching us to a deeper connection with nature. □

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1. www.interacademies.org/sites/default/files/2021-04/DES7289_2_S7%20Statement_Biodiversity.pdf

Biodiversity has been the neglected sibling of the climate challenge.

Rethinking the way society operates

Stephanie Wray

Dr Stephanie Wray is an ecologist and the Managing Director of RSK Biocensus, an environmental consultancy specialising in biodiversity and natural capital issues. She is a former President of the Chartered Institute of Ecology and Environmental Management, and is the Chair of the Institute's Strategic Policy Panel. Her work focusses on environmental law and policy, sustainability and biodiversity; she advises both Governmental and private clients.

SUMMARY

- Biodiversity is declining and that decline must be addressed urgently
- The UK is among the countries that have seen the greatest decline
- Sustainability is about more than carbon and net zero
- Business needs a good structure of legislation, policy and regulation within which to operate
- It is important to view everything in terms of how the activity affects the natural environment.

The UN Convention on Biological Diversity seeks to protect biodiversity globally. The agreement is not just about conserving biodiversity, though, it also looks at the sustainable use of natural resources. That means the goods and services that arise from biodiversity and how these are used so that they will be available for future generations. The Convention is also concerned with the equitable sharing of the benefits of biodiversity and natural capital.

The Convention dates back to the Earth Summit in Rio de Janeiro in 1992 some 30 years ago. Since then, there have been regular meetings of the parties. A series of targets have been set which have yet to be achieved: none of the most recent has been completed in its entirety.

The Conference of the Parties which starts this autumn in China is the time and place where delegates need to take account of all the guidance that has been given. The data shows that biodiversity is declining; there have been many studies demonstrating that. In this decade we need a complete shift in a range of global systems. The next 10 years must be the UN decade of an ecosystem restoration. We are already one year into the decade: there are just nine left to deliver this.

UK issues

In terms of national biodiversity, there are significant issues in the UK. It is among the countries that have seen the greatest decline. There is very little natural habitat within the UK. My particular specialisation is mammals: in the UK, 25% of them are at risk of extinction. If common, rapidly-breeding species like rodents are being driven to the brink of extinction, there is a problem.

A country's biodiversity is related to the legislation and policies in place. In policy terms, the UK's approach to dealing with this crisis is ahead of many other countries. There is legislation that derives from EU policy. There are innovative ideas in the Environment Bill. And there are examples of great practice in ecosystem restoration, habitat restoration and rewilding. These must all be brought together to form a body of policy which provides the motivation and direction of future action.

While much of the effort will have to come from business as the driver of economic activity, a wide spectrum of activity is required – international treaty and Government policy level, right through to individual action.

In terms of business, it is important to stop

UN PHOTO/MICHOS TZOVARAS

The UN Convention on Biological Diversity dates back to the Earth Summit in Rio de Janeiro in 1992

SHUTTERSTOCK/ DIETRICH LEPPERT

One of the most common nature-based solutions for climate change is planting trees. However, planting trees in the wrong places actually has a negative effect.

thinking that sustainability is all about carbon and net zero: there are wider measures of sustainability. Everyone is familiar with the three-legged stool image of sustainability: of environment, social and economic aspects. The stool needs to be balanced in order to achieve sustainability so all three have to be addressed simultaneously.

To start with, how are we using natural resources? Businesses need to think in whole-of-life terms and consider the whole of the value chain, rather than just as far as the factory gate. Where are the raw materials coming from? Do they have significant natural resource implications? Does the production process take a lot of water? Responsibility is much broader than the immediate activities that a business may have direct control over.

Business matters

Businesses need to start thinking in a different way in order to tackle these crises, to make themselves fit for the future and avoid some of the business risks that arise from these challenges. To be able to do that, they need a good structure of legislation, policy and regulation within which to operate.

Businesses innovate and find clever new ways to do things. But they work within the existing economic system. Without structural change, without a rethinking of institutions, it will be really hard for business to make that leap. Of course, there will be some innovators who find a way to make a commercial advantage of being more sustainable. Many people, though, will not follow that lead until a supportive structure is in place.

There is much discussion about the linkages between biodiversity and global warming. But there is a deficit of joined-up policies, though these will be essential if net zero strategies are to be extended to deliver genuine sustainability.

For example, one of the most common nature-based solutions for climate change is planting trees. However, planting trees in the wrong places actually has a negative effect, both for biodiversity and potentially for climate. At one site I have been studying, the best solution for both biodiversity and for climate is to remove hundreds of hectares of trees in order to restore the natural bog underneath, as this will sequester far more carbon while being more beneficial for the biodiversity that should be in the area (and that in turn will bring additional benefits for water quality in the streams and so on).

Just focussing on one element can result in choices which may not have the best outcomes – indeed, they can sometimes have the reverse effect. It is important to do everything through the lens of an holistic approach that addresses the question: how does this affect the natural environment? Does it have a net positive impact on life, in its broadest sense, both human and also in the natural environment?

This implies nothing less than completely rethinking society, how we do business, and how we go about our day-to-day lives. It is just not possible to carry on living as though natural resources are unlimited. That may entail sacrifices like missing out on the next version of the smartphone that comes out every year. Yet maybe that is not what we should be wanting. Maybe we need to think about wanting less and still enjoying a better quality of life. □

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Nature: a blind spot in economic theory

A fundamental change in how we think about and approach economics is needed if we are to reverse biodiversity loss and protect and enhance our prosperity, an independent, global review on the economics of biodiversity has reported.

The independent review led by Professor Sir Partha Dasgupta presents a comprehensive economic framework for biodiversity. It calls for urgent and transformative change in how we think, act and measure economic success to protect and enhance our prosperity and the natural world.

Grounded in a deep understanding of ecosystem processes and how they are affected by economic activity, the new framework presented by the Dasgupta Review sets out the ways in which we should account for nature in economics and decision-making.

Part of nature

It states that we are part of nature, not separate from it. We rely on nature to provide us with food, water and shelter; regulate our climate and disease; maintain nutrient cycles and oxygen production; and provide us with spiritual fulfilment and opportunities for recreation and recuperation, which can enhance our health and wellbeing. We also use the planet as a sink for our waste products, such as carbon dioxide, plastics and other forms of waste, including pollution.

Nature is therefore an asset, just as produced capital (roads, buildings and factories) and human capital (health, knowledge and skills) are assets. Like education and health, however, nature is more than an economic good: many value its very existence and recognise its intrinsic worth too.

Biodiversity enables nature to be productive, resilient and adaptable. Just as diversity within a portfolio of financial assets reduces risk and uncertainty, so diversity within a portfolio of natural assets increases nature's resilience to shocks, reducing the risks to nature's services. Reduce biodiversity, and nature and humanity suffer, notes the Review.

The Review argues that nature is our most precious asset and that significant declines in biodiversity are undermining the productivity, resilience and adaptability of nature. This in turn has put our economies, livelihoods and wellbeing at risk.

It finds that humanity has collectively mismanaged its global portfolio of assets, meaning the demands on nature far exceed its capacity to supply the goods and services we all rely on.

The Review makes clear that urgent and transformative action taken now would be significantly less costly than delay and will require change on three broad fronts:

- Humanity must ensure its demands on nature do not exceed its sustainable supply and must increase the global supply of natural assets relative to their current level. For example, expanding and improving management of Protected Areas; increasing investment in nature-based solutions; and deploying policies that discourage damaging forms of consumption and production.
- We should adopt different metrics for economic success and move towards an inclusive measure of wealth that accounts for the benefits from investing in natural assets and helps to make clear the trade-offs between investments in different assets. Introducing natural capital into national accounting systems is a critical step.
- We must transform our institutions and systems – particularly finance and education – to enable these changes and sustain them for future generations. For example, by increasing public and private financial flows that enhance our natural assets and decrease those that degrade them; and by empowering citizens to make informed choices and demand change, including by firmly establishing the natural world in education policy.

The Government has welcomed the Review's final report and is expected to respond formally to the Review's findings in due course. □

www.gov.uk/government/publications/final-report-the-economics-of-biodiversity-the-dasgupta-review

The UK has a well-developed framework for providing science advice to Government. A report published by the Foundation describes this system and how it might be adapted to other jurisdictions.

Science Advice in the UK

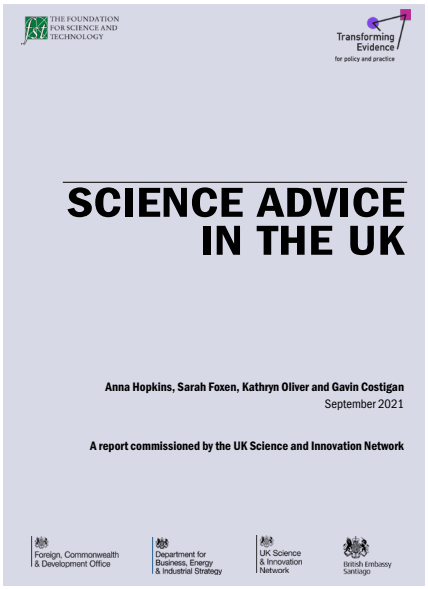
At the end of 2020, the British Embassy in Santiago commissioned the Foundation for Science and Technology to produce a report looking at science advice in the UK. The idea behind the report was not just to explain how the UK system of science advice worked, but how this system has developed over time. This might prove of use to other countries as they develop their own science advisory systems.

The Chief Executive of the Foundation, Gavin Costigan, worked together with Anna Hopkins of Transforming Evidence, Dr Sarah Foxen of the Parliamentary Office of Science and Technology and Dr Kathryn Oliver of the London School of Hygiene and Tropical Medicine, to interview current and former Chief Scientific Advisers, civil servants, Research Councils, national academies, universities and others. This was in order to explore science advice from both the demand and supply side. The final report, *Science Advice in the UK*, was published in September 2021 and launched at an event in collaboration with the Chilean Science Ministry and the British Embassy in Santiago.

Government Chief Scientific Adviser

The report examines the role of the Government Chief Scientific Adviser (GCSA), and how that individual is supported by the Government Office for Science. The role of the GCSA is a key feature of the UK's Science Advisory system. The first GCSA was appointed in 1965 (although previous Governments had advisers of different kinds). In the UK system, the GCSA is not a political appointment, but a civil servant who is politically neutral and would stay in post if the Government changed. This person would typically be a leading scientist or researcher in their field.

The authority of the GCSA comes from the Prime Minister. Former GCSAs stressed the importance of having this authority, as it allowed them to work across Government and seek support from officials and Ministers in different Departments. Trust is therefore a key part of making this work, as are some of the individual relationships involved.



It is clear that the individual holding this position cannot possibly have all the expertise needed, so a large part of making the role successful is accessing that expertise, either through existing structures or actively convening a group of experts when the need arises. Equally importantly, the GCSA has a role to communicate directly to the public about science and science advice.

This funnelling and focus through one person can be a real strength – in particular, it allows trust to build up between Ministers and senior policy makers, as well as the GCSA. However, it is also a potential weakness if those relationships do not work. Another potential weakness is a lack of diversity and inclusion if a very small number of people are involved in decision-making: systems are needed to avoid any "group think".

Since the report was published, the National Science and Technology Council and the Office for Science and Technology Strategy (**www.gov.uk/government/groups/office-for-science-and-technology-strategy**) have been established to provide further avenues of science advice to Government.

The Government Office for Science

The GCSA is supported by the Government Office for Science (GO-Science). This is a central body within UK Government pulling together science advice. GO-Science has some specific commissioning roles (for example in Foresight and futures planning), and provides the secretariat for key committees, such as the Science Advisory Group for Emergencies (SAGE).

It is also helping the GCSA drive a cultural shift across Government to embed science advice in different Government Departments and agencies. In addition, it supports the Science and Engineering Profession across Government.

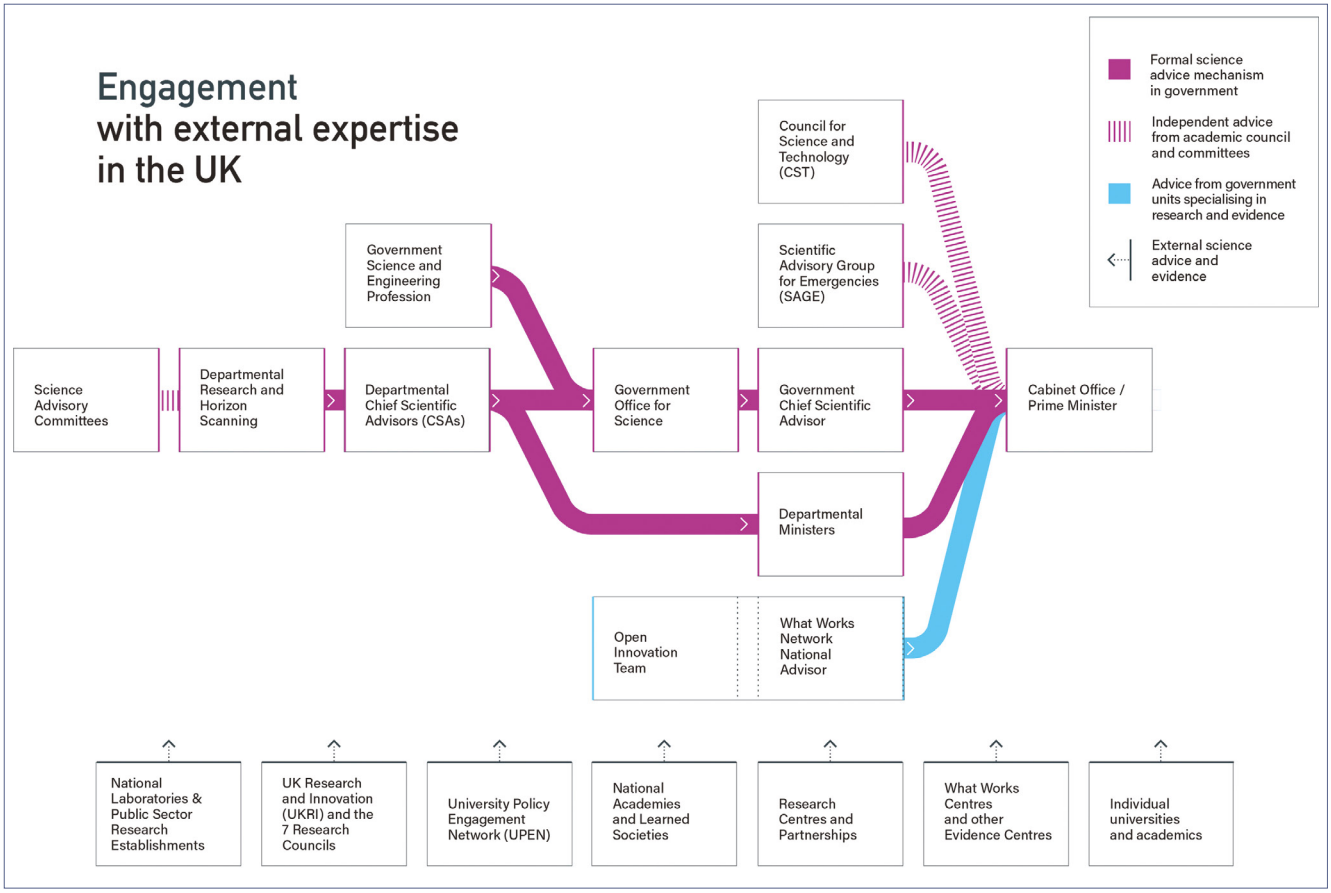
Government Departments

As in all countries, individual policy responsibilities are held in different Departments across Government and they have their own need for science advice. All Government Departments in the UK have a Departmental Chief Scientific Adviser (CSA) – but that was not always the case. Crises such as the Foot & Mouth outbreak of 2001 illustrated the need for a wider range of CSAs but it took several years for the network of CSAs to be fully established.

CSAs provide advice to their own Ministers and are line-managed in their own Department, but a key feature of the system is that they network with each other and with the GCSA. Where needed, they feed in advice and expertise to the centre.

As with the GCSA, these are civil servants, not political appointments, and are usually established researchers. Often, they work part-time in Government and part-time in their university.

Like the GCSA role, the success or



The UK has a well-developed framework for delivering scientific advice to Government

failure of the CSA role hinges around individual relationships, and the holders have greater authority and influence in some Departments than in others.

Some Departments also fund their own research and CSAs have a key role in shaping that science programme. There has been a recent exercise across all Departments to publish Areas of Research Interest: these identify to funders and researchers where the Department needs evidence. Again, different Departments have made greater or lesser use of their Areas of Research Interest and the process is still developing.

Committees

Many Government Departments access science advice via the use of expert committees. These have been established over time and there is no single model, although there are some central guidelines. There are also some central Government advisory committees, the best known of which is SAGE, the Science Advisory Group for Emergencies.

SAGE was originally established as a mechanism to gather experts in response to a crisis, typically of short duration. During the Covid pandemic, however, it has undergone a huge transformation. There has been a massive increase in its activities and the support given to it in order to provide the critical science advice needed by Government.

There have been inevitable issues of trust, mutual understanding and communication between Ministers, officials and advisers during Covid, but it is clear that it would have been much harder for the UK to tackle Covid if it did not already have existing science advisory structures.

Science and Parliament

As with Government, there are challenges in getting successful engagement between Parliamentarians and those with evidence such as academics. The Parliamentary Office for Science and Technology (POST) is Parliament's in-house science advisory mechanism – it promotes links, produces briefing, holds events, delivers training on knowledge exchange and organises fellowships.

As with Government, structures and systems have evolved over time. Select Committees in Parliament scrutinise the work of Government and hold inquiries on relevant subjects; to do this they solicit scientific evidence and expertise.

There is, of course, a danger of always going to known experts. Parliament is aware of this and has taken active steps to broaden diversity of expertise – helped in part by providing incentives for academics to engage with them.

The role of funders

As well as the use of scientific evidence, there have been significant developments in recent years about how those with such evidence and expertise are improving the way they supply it. This has been partly driven by financial incentives, with UKRI and its Research Councils playing a bridging role between Government and the research community.

The biggest change in recent years is in the Research Excellence Framework (REF) which assesses research performance in the UK and awards Quality-Related (QR) funding as a result. In the past, this only measured the excellence of the research.

In 2021, 25% of the outcome was based on the excellence of the impact of the research – which includes policy impact. This provides a direct incentive for universities to engage with policy. There are other specific grant funds which have also been introduced, such as Impact Acceleration Accounts and the Higher Education Innovation Fund.

In some cases, Research Councils are working with Government to identify long term research needs and facilitating funding calls to address them. Some Councils also fund specific research and evidence centres, and they are building their own teams of evidence brokers.

The research community

There have always been academics who have worked with policymakers, but until recently this was very much down to the individual concerned. For many academics, there are many more incentives not to engage with policy than to do so, though the culture is slowly changing.

The Universities Policy Engagement Network aims to provide a 'one-stop shop' for policy officials.

In recent years, driven in part by the financial incentives mentioned, universities have become more systematic in providing 'evidence brokerage', with specialist teams helping to bridge the gap between experts and policymakers. Such teams are involved in increasing both demand 'pull' and evidence 'push', as well as helping build skills in the research community and supporting secondments of researchers in Government and Parliament. The Universities Policy Engagement Network (UPEN), set up in 2018, aims to provide a 'one-stop shop' for policy officials.

National Academies also play a crucial role, in particular because of their power to convene expertise. The major academies all have policy units, working both proactively and reactively in policy engagement. National Laboratories also provide evidence to Government, and a recent addition to the UK system has been the What Works Centres, which aim to increase the supply of tailored, policy-relevant evidence in specific areas. □

• *Science Advice in the UK* was published on 21 September 2021 by the Foundation for Science and Technology and Transforming Evidence. Transforming Evidence is a multidisciplinary, cross-sectoral, international community that aims to connect individuals and organisations who generate, share and use evidence. The report is available on the Foundation's website (in both English and Spanish) at: **www.foundation.org.uk/Document-Library/Science-Advice-in-the-UK**

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RECENT PODCASTS AND BLOGS

Among the sections on the Foundation's website are the regularly updated podcasts and blogs. These cover a wide range of topics touching on science, technology and innovation. A number of them expand on the discussions that take place in the main Foundation meetings – and these are detailed in the relevant sections of this issue. Other recent postings are listed here.

RECENT PODCASTS

Sir Ian Diamond
The Work of the ONS during the Covid Pandemic

Dr George Dibb
Technology and Economics

Kevin Sabin
Technology and Skills in the UK Mining Industry

Dr Paul Bate
UK Space Strategy

Anna Hopkins, Dr Sarah Foxen and Dr Kathryn Oliver
Science Advice in the UK

Amar Bhardwaj
US-UK COP26 Youth Working Group

Dr Helen Pain
Royal Society of Chemistry

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Sir Gordon Duff
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Keyne Walker
Systems thinking: the key to getting net zero right

Dr Tom Dolan
National Infrastructure – A Globally Significant Leverage Point for a Sustainable, Resilient, Net Zero Future

The United Nations, Educational, Scientific and Cultural Organisation (UNESCO) celebrated its 75th Anniversary in 2021. It is the only UN agency that engages explicitly with and promotes science

Science and UNESCO in the UK

David Drewry

Professor David Drewry is Non-Executive Director (Natural Sciences) at the UK Commission for UNESCO. He was Director of Science and Technology at NERC, Director of the British Antarctic Survey, served as Chair of the Council of Managers of National Antarctic Programs and was President of the International Arctic Science Committee. He was also Director of the Scott Polar Research Institute. He was awarded the Polar Medal, Patron's Gold Medal of the Royal Geographical Society, and has a mountain and glacier named after him in Antarctica.

UNESCO was founded in London in 1945. Its Constitution was then ratified on 4 November 1946 with its headquarters to be based in Paris.

Its enduring vision is that peace and human rights must be built upon the intellectual and moral solidarity of humanity. This is enshrined in its Constitution and summarised as "since wars begin in the minds of men and women, it is in the minds of men and women that the defences of peace must be constructed".

UNESCO's responsibility is to reaffirm the missions of education, science and culture by acting as a laboratory of ideas, setting international normative standards, building capacity, and being a catalyst for international dialogue and co-operation.

National Commission

Each acceding state, of which there are 193, has established a Commission as the official body coordinating its UNESCO activities. In the UK, the aim of the National Commission is to be an active, authoritative and influential leader in engaging with UNESCO. It advises Government Departments on UNESCO programmes and standard-setting instruments, and it promotes measures and enterprises on behalf of the UK harnessing its considerable convening powers. UKNC goals are thus allied closely with the UK Government's strategic objectives as currently manifested in the Integrated Review.

Across the UK there are over 170 UNESCO designations, associated with 1300 further businesses, local and regional bodies and organisations. Scientific interests are focussed through geoparks, biosphere reserves and university chairs, as well as the network of experts, and can elide with World Heritage sites as in the recent designation (2019) of Jodrell Bank Observatory and The Giant's Causeway.

In all of these, UKNC is the link between UNESCO, Government and civil society, enabling them to contribute positively and with impact on global science agendas and engage directly with the international community. In this way it works to support the UK's contribution to UNESCO and to bring the benefits of UNESCO to the UK.

UNESCO science

Since its outset, UNESCO has viewed international scientific cooperation as fundamental. It established the CERN Convention that led to the establishment of the European Organisation for Nuclear Research in 1954. Ten years later the Nobel Laureate Abdul Salam founded the International Centre for Theoretical Physics with a mission to advance scientific expertise in the developing world. Today, UNESCO is pushing forward with issues of contemporary resonance – recommendations on climate change, the ethics of Artificial Intelligence and Open Science.

The work of UKNC in science forms part of a multi-lateral approach to international engagements and maintains the UK position of the rules-based system, an overarching objective of the Integrated Review. More specifically, the UKNC supports and has oversight of the contributions to UNESCO programmes that build on the UK's considerable scientific expertise.

The International Oceanographic Commission (IOC) is coordinating projects in areas such as ocean observations, tsunami warnings and marine spatial planning. The IOC provides a focus for UN bodies working to understand and improve the management of our oceans, coasts and marine ecosystems.

In the UK, the National Oceanographic Centre plays a leading role and is particularly influential. The Intergovernmental Hydrological Programme is devoted to water research and management as well as related education and capacity development. The Centre for Ecology and Hydrology is playing a prominent research function and coordinates contributions across UK universities and other establishments. It works collaboratively in least-developed countries to underpin access to water for disadvantaged communities.

Biosphere reserves

The long-running Man and the Biosphere Programme (MAB) is focused on enhancing the relationship between people and their environment

through a network of biosphere reserves combining social and the natural sciences. The UK has taken a leading role in developing its 10-year Strategy and Action Plan.

The seven UK biosphere reserves find creative ways for people and nature to thrive together. The North Devon Biosphere Reserve embraces Dartmoor, Exmoor and Lundy Island. It possesses one of the best dune systems in the northern hemisphere, a strong maritime heritage, and thriving cultural communities.

Others include the Isle of Man, Wester Ross and Brighton & Lewes Downs. This last attracts 12 million visitors annually who come to experience the high-quality natural environment and rich heritage, including Neolithic archaeological sites. Visitors are engaged directly with the science of landscape, geology and coastal ecosystems.

Primary hubs

The Geological Society and the British Geological Survey are the primary hubs for the International Geoscience Programme (IGCP). This includes understanding and mitigating geohazard risks, sustainable use of earth resources, as well as studying changes in Earth's climate and life on Earth as preserved in the geological record.

The seven UK global geoparks include the North-West Highlands, Cuilcagh Lakelands straddling the Northern Ireland-Eire border, Forest Fawr (Brecon Beacons) as well as the English Riviera in South Devon that is home to the Kents Cavern jawbone, the oldest modern human fossil in North-West Europe. In 2021, UNESCO established a worldwide Annual Geodiversity Day on the joint proposal of the UK and Portugal.

Sustainable Development Goals

Cutting across all UNESCO activities are the UN's Sustainable Development Goals (SDGs) which are rooted in a fundamental concern for our planet's longer-term health and the wellbeing of its inhabitants. Many of these are tracked by UNESCO science programmes – climate, poverty elimination, clean water, affordable clean energy and sustainable cities. UKNC monitors UK involvement in these global activities.

UK UNESCO designations provide a visible demonstration of the support for various SDGs. For example, many are contributing actively to the urgent and pervasive challenges of climate change. Biosphere reserves and geoparks are in representative locations for monitoring changes to the natural environment and are delivering significant research and educational opportunities. Their community-led partnership constitution helps promote an appreciation of natural and cultural heritage while supporting local sustainable economic development, primarily through geo- and eco-tourism. They are playing fundamental roles in communicating the urgency and importance of climate change to tens of thousands of linked communities, stakeholders and individuals. This top-to-bottom characteristic is particularly powerful.

The value of UNESCO in the UK

The UKNC has undertaken important initiatives evaluating and quantifying the benefits to the UK of UNESCO designations. The 2019 survey of approximately half of the UK designations shows, in relatively simplistic terms, their annual contribution amounts to about £150 million; this excludes benefits in-kind and downstream to supply chains. The overall fiscal benefit is likely to be several times this number. The exercise has been sufficiently successful for UNESCO and other countries, such as Denmark, Canada, Iceland and Portugal to seek UKNC's advice and procedures in order to undertake similar evaluations themselves.

The UKNC comprises an extremely small but able staff and seven non-executive directors, yet it has worked energetically to undertake a range of collaborative projects alongside the FCDO primarily, as well as other Government Departments (BEIS, DCMS and DfE) and independent agencies. For a decade, it has worked jointly with L'Oreal to deliver the annual Women in Science awards that have recognised outstanding talent. It has administered the Newton Prize for the UK Newton Fund, advised the UK Permanent Delegation to UNESCO on all UNESCO programmes and provided Alternate UK members of the UNESCO Executive Board.

Challenges

Global trends and contemporary challenges facing the world today require international collaboration, dialogue and multilateral approaches. These include: climate change; biodiversity loss; depletion of ocean resources; access to water; impact of frontier technologies (notably AI); disinformation, hate speech and rising extremism; growing urbanisation; unequal access to knowledge and technology; and gender inequalities.

In the face of these serious threats UNESCO's pluralist, humanist philosophy is more important than ever and offers a framework that is open to all, endorses the rule-based international system and provides widespread benefit through its engagement in scientific programmes – interlaced with the SDGs – in which the UK can and is playing an effective role. □

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The 2019 survey of approximately half of the UK's UNESCO designations shows their annual contribution amounts to about £150 million in benefits to the UK.

UK UNESCO designations provide a visible demonstration of the support for various UN Sustainable Development Goals.

CONTEXT

If the UK is to achieve net zero greenhouse gas emissions by 2050, it will require the simultaneous transformation of several vital, interconnected infrastructure systems, as well as the development of whole new industries and supporting sweeping societal, cultural, behavioural and structural changes. The May 2019 report of the Climate Change Committee set out some of what needs to be done and, in May 2021, the Royal Academy of Engineering published *Net Zero: A systems perspective on the climate challenge*, outlining some of the challenges and solutions.

The Foundation for Science and Technology held a webinar on the subject on 28 June 2021. The speakers were: Professor Sir Jim McDonald, Principal and Vice-Chancellor of the University of Strathclyde, and President of the Royal Academy of Engineering; Dervilla Mitchell CBE, Joint Deputy Chair, Arup; Guy Newey, Strategy & Performance Director, Energy Systems Catapult; and Colette Cohen, Chief Executive, OGTC. A video recording, presentation slides and speaker audio from the event are available on the FST website at: **www.foundation.org.uk/Events/2021/Developing-a-Systems-Approach-to-reaching-Net-Zero**

Taking a systems approach to reaching net zero

Jim McDonald

Professor Sir Jim McDonald FRSE FREng is Principal and Vice-Chancellor of the University of Strathclyde. He co-chairs, with the First Minister of Scotland, the Scottish Government's Energy Advisory Board. He is Co-Chair of the Independent Glasgow Economic Leadership Board. He currently holds several senior business appointments with organisations including the Weir Group plc, Scottish Power plc, the UK National Physical Laboratory and the UK Offshore Renewable Energy Catapult. He was elected President of the Royal Academy of Engineering in September, 2019, through which he is a member of the UK Prime Minister's Council for Science and Technology.

SUMMARY

- A systems approach to delivering net zero is essential
- Policy needs to be driven by the underlying data driving the development of sophisticated modelling
- Many of the technologies needed to deliver net zero are already available
- Investment in new ideas is still required however on the journey to 2050
- Public acceptability and citizen engagement with this is absolutely essential.

In August 2020, the Council for Science and Technology (CST) submitted a letter and accompanying advice to the Cabinet Office about the need to take a systems approach to achieving net zero[1]. This was important because there is no 'silver bullet' technology or single intervention to achieve this goal, so a wide-ranging systems perspective, one which is supported by the whole of Government, will be essential.

It is sobering to reflect that we are less than 1500 weeks away from 2050: time is ticking away. So, in this decade it is essential to adopt the key policy frameworks which will place the UK on the pathway to achieving net zero. Furthermore, we need to expand the scale of deployment of existing low carbon technologies and systems as well as commit to 'low regrets' investments to accelerate and prove technologies including hydrogen and Carbon Capture, Usage & Storage (CCUS).

The Energy Systems Catapult is continually refreshing its 2050 scenario analysis. Under some of these, we can explore what happens when two to three times the electrical supply is required due to extensive electrification and changes in the way we use power, as well as the way we decarbonise industrial systems. There is a range of possibilities, including offshore wind, nuclear, bioenergy and, of course, carbon capture and storage. So, there will be significant technological changes in actually getting to net zero. That journey needs to start sooner rather than later.

A systems engineering perspective is vital in assessing those options. The CST report made a number of recommendations to Government (see Table 1). That included strengthening cross-Governmental networks underpinned by an analytical base and a means to generate the impacts of certain scenarios. In that way, policy has been driven by the underlying data, not just technical models. All of that is aimed at ensuring policy moves forward at pace, because there is not a great deal of time.

The CST stressed the role of technology, including the development and demonstration of new energy systems, which will need strong public and private sector alignment, having innovation and investment at its heart.

We welcomed the statements by Government that it wants more science, more engineering and innovation. There is also the new science and

Table 1. " Achieving net zero carbon emissions through a whole systems approach" (CST advice to Government)

1. Strengthen the institutions, governance frameworks and leadership structures needed across central Government to galvanise action to achieve net zero.	2. Develop the analytical capability, flow of information, and reporting needed to inform decision.	3. Maximise the contribution of technology, mobilise financial systems and galvanise international collaboration.
i. Integrated multi-disciplinary analytical hub supporting all Government decisions on climate. ii. Translate net zero target into all areas of policy. iii. Stable leadership from the top of Government.	i. Ensure that all Government bodies are collecting the right data and passing the information to the analytical hub. ii. Publish carbon emissions assessments for all public sector policies, including major infrastructure projects or investments.	i. Mission-driven research and innovation ii. A National Infrastructure Investment Bank iii. International collaborations on trade, investment, finance, technology, capacity building and R&D.

technology and innovation function – NCST and OSTS – that is being built within the Cabinet Office, which is encouraging. It provides a channel, not just of course for academic institutions but also for innovative industries and for National Academies, such as the Royal Academy of Engineering, the Royal Society and others – all driving that analytical capability within Government and society. The Energy Systems Catapult has also been a great source of independent modelling and analysis.

Many of the technologies that we need to achieve a net zero future are already available. The challenge now is deployment and integration at scale. But it is important to maintain a balance: strong investment in the science base is essential, because good new ideas are still needed and then these have to be developed and tested right up to full-scale demonstrations with a requirement for public and private co-investment in late-stage R&D to de-risk investment and commercialisation from industry.

In terms of the challenge facing the world today, there is the urgency of decarbonisation. At the same time, security of supply through reliable energy sources must be maintained. Of course, affordability is a really important consideration as well. There are other dimensions too. Public acceptability and citizen engagement with the energy transition is absolutely essential. The vast majority of people in society understand that there are real challenges associated with climate change, that something needs to be done about it and that time is of the essence. It is important that the transition is both inclusive and just to ensure success for everyone.

Another dimension is the impact on the wider economy: jobs growth, industrial opportunities and new markets. What are the options and what are the costs? Here, systems engineering, modelling, and understanding how these systems are designed, deployed and operated, matter.

I have the privilege of chairing the Scottish Government's Energy Advisory Board with the First Minister. The director for energy and climate change who supported EAB five years ago was Chris Stark, who is now of course Chief Executive of the Climate Change Committee. So, in many ways, the concept of taking a systems perspective was influenced by the Scottish model and then repositioned in terms of UK requirements – and beyond that, the international situation. This involved, for example, understanding the need for an integrated approach towards heat, power and transport. Next, there is the issue of the fuels and energy sources that underpin electricity production, notably offshore wind, and also the generation of hydrogen, as well as CCS. All of this contributes to the overarching target of, from the Scottish perspective, getting to net zero by 2045.

The Prime Minister's Council on Science and Technology recommends creating policy driven by underlying data, not just technical models.

Systems design

There are some really exciting projects that have already advanced beyond late-stage R&D. Project Orion in the Shetland Islands, for example, is a partnership embracing a wide array of companies, many from the oil and gas industry, but all with a commitment to be part of the energy transition journey. It has a systems design underpinning it, using offshore wind, offshore oil and gas platforms, energy conversion to hydrogen (and potentially ammonia as well). There is industry funding behind it and big ambitions that are being driven by the Islands Council vision for achieving net zero by 2030.

Still in the northern isles of Scotland, there is the Big Hit project in Orkney. It is small scale, but with a systems approach, which uses community wind turbines to drive electrolysers producing hydrogen that is also produced through tidal turbines. The hydrogen is then transported to the main island for transport applications and for hydrogen boilers. Again, this is an example of a system driven by collaboration, one where a single system can be expanded to embrace different technologies and have consumer engagement.

In my own city of Glasgow at COP26, the council leader Susan Aitken made a very significant commitment to drive Glasgow to be net zero by 2030. I and some of my colleagues have met

A systems perspective on modelling, technological advancement and also socio-economic inclusion is going to be key to delivering 2050 futures.

with the Head of the 'Sustainable Glasgow' initiative to discuss the use of the Royal Academy of Engineering's systems modelling approach to help identify opportunities, whether in transport, energy use, the built environment, or elsewhere.

A final example is CoRE – the Community Renewable Energy project. A sizable project of £25 million underpinned by one of the UK Government's Growth Deals, it is a partnership between UK and Scottish Governments providing an opportunity for town and rural Ayrshire communities to embed energy transition techniques and build jobs in some of the non-city-based communities.

These are just a few examples that have a systems perspective at their heart, focussing on modelling, technological advancement, but also socio-economic inclusion, which are going to be key to delivering 2050 futures. ❑

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1. www.gov.uk/government/publications/achieving-net-zero-carbon-emissions-through-a-whole-systems-approach

Tackling the implementation gap

Dervilla Mitchell

Dervilla Mitchell CBE FREng FICE FIEI FIAE is Deputy Chair of Arup Group. A Civil Engineer with experience in leading major programmes, she was until recently Executive Chair of Arup's UK, India, Middle East and Africa business leading over 6,000 engineers, advisors and specialists working on wide range of projects across the built environment. She is a member of the Prime Ministers Council for Science and Technology and chairs the National Engineering Policy Centre's Decarbonising UK Working Group. (Photo courtesy of Paul Carstairs.)

SUMMARY

- A wide range of systems need to be transformed in the coming years in order to meet UK climate goals
- A systems approach can identify no-regrets measures that can be implemented now
- This approach allows for global planning and local delivery
- A systems approach enables a full understanding of a very complex situation
- Tackling climate change needs a collaborative, integrated approach

The National Engineering Policy Centre (NEPC) is a unified voice for 43 engineering organisations which together represent 450,000 engineers. That gives policymakers a single route to the engineering profession.

It reaches out to a variety of audiences, explaining in terms of a systems approach what needs to be done to optimise the net benefits. The NEPC also covers the specifics of implementation – which is the stage we are reaching now. To reach the target by 2050, a wide range of systems need to be transformed, from power generation, through transport, manufacturing and the built environment to individual and community action. We are, in fact, dealing with a system of systems.

A rapid and simultaneous, synchronised transformation is vital. By using a systems approach, all the relevant factors can be taken into account in decision-making across a number of policy areas. For the UK, the agenda is not just about net zero. There is also levelling-up and Britain's place in the world. Co-benefits should be recognised and incorporated as part of the strategy.

It might seem easy to postpone the delivery of net zero by saying the technologies are not here or that further innovation is needed. However, a systems approach can identify no-regrets options we can take now.

With a picture of the whole, it is possible to gain an understanding of the full complexity of the issues. That includes an interrogation of the different elements, to experiment with the different levers that can change the overall performance and it enables stakeholders to imagine different possible scenarios, project operation and performance into the future. A systems approach gives us an opportunity to collaborate at the level of global ambition and yet deliver locally: identifying strategic priorities, moving those into local requirements, and making sure they can be effectively delivered locally, and in a joined-up way.

Focus on outcomes

With so little time left, the world needs to be making progress every year if humanity is to achieve its ambition. That means identifying the outcome, then working backwards in order to formulate a effective plan to get there. The London 2012 Olympics were a success because there was a conscious effort to determine how to achieve the desired outcome. The NEPC has held workshops on different topics – decarbonising construction, aviation and others – and have been able to recognise some key elements of success.

The process needs to happen within an environment which enables change – and this involves policy, regulation, standards, measurement, procurement as well as other aspects. Success does not

depend on any one of these, but on all of them acting together. In the Government arena, for example, there needs to be collaboration across all Departments. In order to solve the problems of successful innovation, there must also be collaboration between Government, academia and business, as well as international collaboration because this is a global problem and, of course, collaboration with the public. Much of the necessary transition and change is going to require behavioural change.

Today's more complex, more data-rich, more technology-enabled world needs integrated systems, for both the planning and delivery of solutions that we will need to meet climate change. □

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Today's more complex, more data-rich, more technology-enabled world needs integrated systems.

Developing a systems approach

Guy Newey

Guy Newey is Director of Strategy and Performance at the Energy Systems Catapult which he joined in 2018 after roles as Energy and Climate Adviser to Business, Energy and Industrial Strategy (BEIS) Secretary of State, Greg Clark, and as a Special Adviser to Energy Secretary Amber Rudd. In Government, he was involved in many key decisions, including closing the UK's coal-fired power stations, giving greater independence to the electricity system operator, and as an architect of the Clean Growth Strategy.

SUMMARY

- Achieving net zero is a very complex challenge
- There are different ways of achieving net zero but determining the optimum way is not simple
- Making big changes, to be successful, means a full understanding of the consequences
- Consumer preferences and behaviours have to be factored in
- We will need to test how different strategies work in practice.

In Government, I was very involved in the publication of the Clean Growth Strategy in 2018. Looking back, I wish it had taken a systems approach. Net zero is the very definition of a complex problem. Some of the system engineers at the Energy Systems Catapult would say it makes getting a man to the moon look like a walk in the park.

Just look at some of the challenges: a doubling of the electricity system while at the same time completely removing coal and much gas from the system. That in parallel with an extraordinary transition: the creation of a whole new low-carbon hydrogen system, one of similar size to the current electricity system. Both have to be accomplished within 30 years. This will involve a complete transformation of the way we move around, from one based on petroleum to one based on electricity (with probably some hydrogen). After that comes the decarbonisation of the process industries – which is about as hard as it gets.

The situation we wish to achieve is something I term 'Net Zero Nirvana'. That involves a cost-effective (less than 1% of GDP) transition which creates jobs across the country and provides a compelling example to the rest of the world – after all, this is a global problem. There are, of course many other routes to net zero. There is a very expensive version where industrial and manufacturing competitiveness has been destroyed and the UK just imports a wide range of innovations. Or alternatively there is the net zero political disaster, where the measures – effective though they may be – are unpopular and the country gains little or no economic benefit. There are also many scenarios where we do not even get to net zero.

A systems approach is iterative, going back and forth and narrowing the pathway to reaching the goal of Net Zero Nirvana, while not allowing the pathway to be diverted away from the goal.

In practice, there are a number of steps. First, a clear definition of objectives, needs and specific requirements. Politicians are not always good at clearly identifying what needs to be achieved. Government is often nervous about engaging widely with stakeholders in an iterative way. Systems engineering can help to develop effective ways to do so.

Now, although we want to use this approach to constructing that system of systems now, it does not provide a perfect map which will solve every problem. It is more about selecting the right set of analytical tools, whether economic modelling to examine different pathways to the future, consumer testing to work out which strategies are most effective. etc. It is a matter of gathering as much evidence as possible which feeds into the decision-making.

Making a big decision, which changes the whole of a system, without fully understanding the true situation is not going to work. Good systems thinking then spends as much time considering implementation and integration - i.e. how it all fits together on a local level. Of course, verification is also an essential component, checking that the planned change has actually led to the desired outcomes. We should be honest that we are not going to get everything right but we learn.

The creation of a whole new low-carbon hydrogen system within 30 years will involve a complete transformation of heating and transport.

SHUTTERSTOCK/ALEXANDER KIRCH

Climate and net zero strategies involve complex systems, so verification and validation are absolutely essential.

Underpinning everything is the search for continuous improvement. This is not hugely different from how Government approaches policy challenges. Yet there are some subtle and very important differences, which could be absolutely transformative for problems like net zero and other complex challenges.

A key issue for Government is the degree of central coordination required. Now, when someone in energy starts talking about central coordination, there is a suspicion that we are trying to recreate the Central Electricity Generating Board (CEGB). That is very far from the case. However, designing the future energy system does involve a consideration of the way the markets work, where the innovation challenges might be and the particular options that might be trialled.

So, will the resulting system be highly centralised or highly distributed? Net zero will have elements of both because of its complexity and size – and the pace of change. So there is a case for some degree of central direction and there will be a need for system designers, but that is really a question for Government to think about.

If Government – and indeed all of us – are serious about a systems approach to net zero, what tools are currently missing? First, there needs to be a formal system-of-systems map. After all, net zero is a complex problem and this large set of information needs to be organised. A good analogy is the Tube map, a useful guide for getting from A to B. The catapult is building a first version of that map, which will include some understanding of interactions and feedback loops. Some institutional memory is therefore crucial, in order to make sure we learn from previous mistakes and successes, and adapt as necessary.

Next, there needs to be a much more agile approach to governance and regulation in the energy system. That includes a structured approach for stakeholder input, not just talking to the usual suspects but really thinking broadly about the right people to engage with.

There have been some good examples recently, including the Energy Data Taskforce and the Electric Vehicle (EV) Energy Taskforce, taking a large group of several hundred stakeholders, some of them not familiar with the energy system, in order to understand what they need for their transition.

We need market simulation and modelling. This is not just about scenarios for 2050. We really need to understand how the money is going to flow in different market arrangements.

Consumer preferences

The preferences of consumers must be factored in. This will be a massive challenge for the next wave of decarbonisation. How to test what consumers really want, whether in terms of low carbon heating, electric vehicles, or all of the other challenges. Trial environments that really work do not yet exist. Understanding consumer behaviour will help to understand their effect on the network.

We could pick two or three places across the country to really see how these different strategies work in practice. Ultimately, this is about creating a set of living, credible roadmaps that are actually going to get us to net zero. It is not just what we need to do, it is how it is going to work in practice and which measures need to implemented in what order. It is the equivalent, as one engineer said to me, of trying to totally rebuild an aircraft engine while the plane is still flying: that is how difficult the net zero challenge is. And a systems approach can be a huge help in delivering that. □

The preferences of consumers will be a massive challenge for the next wave of decarbonisation.

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All technologies will be needed to reach our net zero targets

Colette Cohen

SUMMARY

- People often see climate change in emotional terms, rather than technical ones
- The current energy system is the product of choices taken over centuries
- Adopting a systems approach to the creation of a new system offers substantial opportunities
- There is room for all technologies in an expanded energy system
- To achieve our goals, it is critical to start investing now and at pace.

When people are asked what pictures come to mind when they think about climate change, emotive images of wildfires, parched earth and extreme weather are often cited. While much of the solution to the climate crisis involves engineering and science, delivery requires the commitment of nations and behavioural change from the people who live in those nations. People engage with climate change on an emotional footing, so it is difficult to communicate how technically complex the energy transition is. When you map out the steps on the path to net zero, it becomes clear just how many competing elements there are. Then there is a further challenge, which is particularly evident in Scotland, the concept of a Just Transition.

A legacy

This is a multi-layered, multi-faceted problem which is a consequence of changes that began literally hundreds of years ago. It is, after all, embedded in a series of industrial revolutions, starting with mechanisation 250 years ago, then the rise of electricity in the 19th century driving mass production and, latterly, automation. The computing revolution in the late 20th century greatly changed our expectations of how we live. Today we are moving into a world of intelligent systems, of instant feedback, automation, predictability, personalisation and a metaverse expanding by the day. Today's world enables many of us to work from home during the pandemic. The pace of change – from the first mobile phones back in 1992 to the situation today where many of us have, literally, a mini-computer in our pockets, is quite stunning.

All those revolutions have been made possible by fossil fuels and therein lies the root of the climate change challenge. It should be remembered that these revolutions have provided health, wealth, education, mobility, longevity and, more than anything over the past couple of years, connectivity and access. So while we move beyond fossil fuels, we need to find a way to sustainably produce the durable, consumable and disposable items we use every day, some of which are luxuries, many of which are necessities.

Unfortunately the COVID 19 pandemic has exacerbated inequalities, exposing countries to further economic risk. The need for a just transition must be a priority and we have to put people and communities at the centre of that transition.

The energy transition

Adopting a systems approach to the energy transition represents a massive opportunity. The scale and impact of this transition allows a reshaping of the energy system, creating one that is sustainable, secure, affordable and inclusive in the long term. This should not be seen as a structure that is imposed upon us, but one that is designed and planned with intent and commitment. We need to build in innovation and pace, as well as measures to mitigate the impact of our decisions, ensuring that the solutions we find now do not become the problems of our children in the future. These solutions need to fix the planet, serving today's people and our descendants.

So, what does the energy transition look like for the North Sea? In 2020, the value of the industry was about £15 billion, with renewables, hydrogen and Carbon Capture, Usage & Storage (CCUS) being a very small part of this pie. Over the next 30 years, market share of oil and gas will reduce, but not disappear entirely, with all the other energy systems contributions increasing. That vision is consistent with the scenarios of the Climate Change Committee (CCC) on how to create an integrated energy system for the future.

One of the messages from the analysis is that there is room for everybody in the future energy

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The energy transition should not be seen as a structure that is imposed upon us, but one that is designed and planned with intent and commitment.

The public tends to understand climate change in emotional images of wildfires, parched earth and extreme weather, rather than cold, scientific fact.

system. To ensure a just transition, we need to use the transition period to deliver this integrated energy vision. This must be done in such a way that jobs can be transferred, with skills and capabilities redirected to achieve this integrated energy system.

Realising the vision

In a study carried out in 2019, the Net Zero Technology Centre looked at the critical technologies needed to deliver this integrated energy future. There is a host of scenarios that could unlock a net zero future. For example, moving to blue hydrogen allows the industry to fast track the hydrogen economy, but also prepare for a green hydrogen future. There are many technologies that can be synergistic and complement each other.

The face of the North Sea is evolving from an oil and gas arena to somewhere where we reuse existing facilities for hydrogen and for carbon sequestration. It is also one where we generate power from wind, wave and tidal.

By reusing infrastructure that already exists, the carbon footprint of creating this new integrated energy system can be minimised.

It is critical to start investing at pace which means working in partnership, across government, industry and academia. The challenge is not just in building an integrated energy system, but in creating an integrated roadmap to encourage working through the complexities together, cross-sector and cross-industry. Solving the climate challenge together can create a new, sustainable, affordable net zero

future, one that is fit for people and planet.

This implies nothing less than completely rethinking society, how we do business, and how we go about our day-to-day lives. It is just not possible to carry on living as though natural resources are unlimited. That may entail sacrifices like missing out on the next version of the smartphone that comes out every year. Yet maybe that is not what we should be wanting. Maybe we need to think about wanting less and still enjoying a better quality of life. □

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The debate

The formal presentations were followed by a panel session in which topics covered included: the scope of the challenge; national priorities; potential conflicts between national/international programmes and those of particular bodies; changing behaviours; and the risk of unintended consequences.

The audience noted that the challenge was massive. Is there a model that can encompass all aspects? Do we have the data with which to make a relevant analysis? All the focus at present is on 2050, but planning should be looking further ahead, perhaps with the aim of extracting carbon from the atmosphere and going beyond net zero to try to reverse some of the changes. It was also noted that the challenge is global. It is not enough for the UK to decarbonise: it only matters if the whole world is able to decarbonise.

It was pointed out that a systems approach is designed to accommodate complexity, whether in the national arena or the international sphere. Coordinating innovation at an international level is absolutely essential in this regard.

Different countries will have different priorities. For a developing country, producing cheap energy is a central part of any growth strategy – it was after all a fundamental feature of the UK success story. The decarbonisation process has to proceed in a way that is not going to hurt their growth but rather improve overall outcomes. A systems approach is the right way to show that a smooth transition is possible.

Many organisations are pursuing their own net zero strategies. While this may be commendable in itself, it could hinder a whole system approach. Individual behaviour, in addition, does not necessarily fit with a macro model of energy supply.

Achieving net zero needs long term commitment, far beyond the normal political cycle. And it is not a matter of political will and foresight. It also concerns the day-to-day lives of ordinary people: issues like the political acceptability of changing everyone's boiler, changing domestic heating systems and perhaps changing personal transport arrangements. How do we take politicians, and the people who vote for the politicians, with us in this process?

There has to be a clear vision, one that the people understand and to which they are committed. The 10 Point Plan points out to industry, to designers and to investors where the priorities currently are. It does not address the public about their behaviours and what they need to change, though. Overall demand can be reduced if this were to happen.

In a systems context, net zero carbon dioxide does not cover methane or nitrous oxide emissions, for example. Simply achieving net zero risks offloading emissions into non-measured contexts. That returns to the issue of systems and 'systems of systems' in order to capture all the variables and avoid unintended consequences. □

FURTHER INFORMATION

Net Zero: A systems perspective on the climate challenge (National Engineering Policy Centre and Royal Academy of Engineering, May 2021).
www.raeng.org.uk/publications/reports/net-zero-a-systems-perspective-on-the-climate-chal

Net Zero: The UK's contribution to stopping global warming (Climate Change Committee, May 2019).
www.theccc.org.uk/publication/net-zero-the-uks-contribution-to-stopping-global-warming

FST PODCASTS AND BLOGS

A Systems Approach to Net Zero - Podcast with Professor Rebecca Lunn, Professor of Civil and Environmental Engineering at the University of Strathclyde.
www.foundation.org.uk/Podcasts/2021/Professor-Rebecca-Lunn-Systems-Approach-to-Net-Zer

A Systems Approach to Net Zero – Podcast with Professor Keith Bell, Scottish Power Professor of Smart Grids at the University of Strathclyde.
www.foundation.org.uk/Podcasts/2021/Professor-Keith-Bell-Systems-approach-to-Net-Zero

CONTEXT

Covid-19 has been the greatest challenge to governments around the world in living memory. The UK has been at the centre of developing global vaccines against Covid. The UK's vaccine programme has been a key element of helping the country emerge from Covid restrictions. The Foundation wanted to explore how the Government has worked with the life sciences industry and the academic community during the Covid-19 pandemic, what lessons have been learnt, and what the implications are for future policy, R&D, investment and collaboration going forward.

To explore these issues, the Foundation held a webinar on 19 July 2021. The speakers were: Nadhim Zahawi MP, Minister for Covid Vaccine Deployment; Professor Dame Sarah Gilbert, Saïd Professorship of Vaccinology, Jenner Institute, University of Oxford; and Steve Bates, Chief Executive Officer, BioIndustries Association. A video recording, presentation slides and speaker audio from the event are available on the FST website: **www.foundation.org.uk/Events/2021/Lessons-from-the-Vaccine-Programme-for-UK-Life-Sci**

Working in partnership

Sarah Gilbert

Professor Dame Sarah Gilbert holds the Saïd Professorship of Vaccinology and has been a part of Oxford's vaccine community since 1994, as part of the Jenner Institute within the Nuffield Department of Medicine. Receiving her professorship in 2010, she has spent the past decade and a half working on vaccines against influenza, MERS, Nipah and Lassa vaccines. She is co-founder of Oxford spinout company Vaccitech. She was appointed DBE for services to Science and Public Health in the Queen's Birthday Honours in 2021.

SUMMARY

- Teams in academia can work fast and flexibly
- Pharmaceutical companies can deliver scaling up and delivery
- There is a strong case for more work being carried out by academia before pharmaceutical companies take over
- Until recently, there has been little interest in funding the underpinning technology behind vaccine development
- Maintaining expert teams over time is vital for long-term preparedness.

Partnerships can achieve great things. In 2020, a partnership was established between academic groups at the University of Oxford that already knew each other and worked together, as well as a big pharma partner in AstraZeneca. This is a very good model for partnerships in the future when results are needed quickly, but also at scale.

Academia can be fast and flexible. There are many sources of expertise available in-house, networks of academic collaborators in the UK and in other countries which can be drawn upon immediately. Unusually in this case, the university was not just involved in the very early development of new ideas. Oxford has its own Good Manufacturing Practice (GMP) facility which can make vaccines to take into clinical trials. It has its own clinical trial centre and a great deal of experience in developing manufacturing processes and conducting clinical trials.

By 23 April 2020, the vaccine had been manufactured to GMP ready for clinical trials, all the necessary approvals had been gained and the clinical trials started. Oxford led Phase One, Phase Two and Phase Three clinical studies in the UK, Brazil and South Africa.

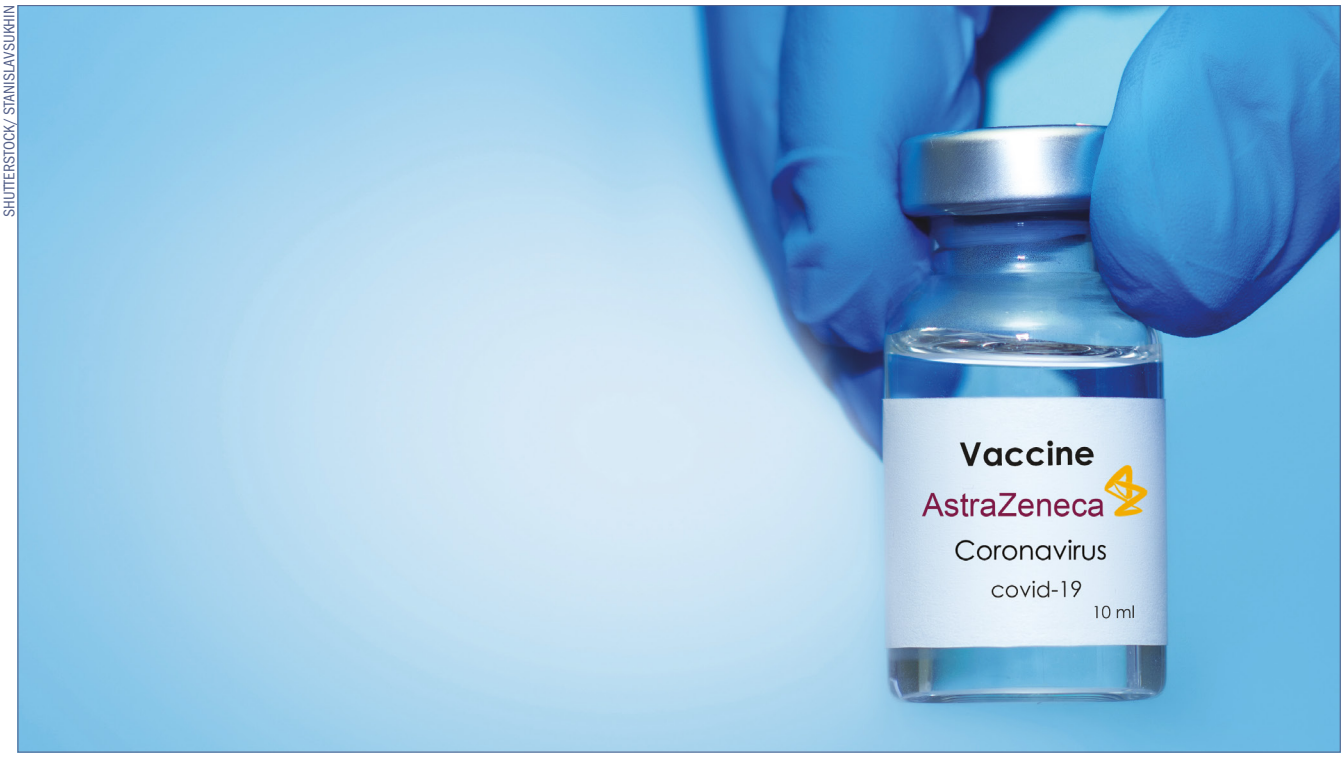
Taking things further

To achieve a good transfer of ideas from academia into pharmaceutical companies, it is necessary to take things past the idea stage: if academic work is transferred at a very early stage, it often moves very slowly when it gets into a company.

This case was different because the academic partners had taken it a long way through development, there was a scalable manufacturing process, we were generating clinical trial data, and therefore it was much easier for a large pharma partner to step in and take it from there.

Not every university or academic group will have access to such facilities, particularly in other areas of drug development. Yet the UK does have the possibility of creating a series of hubs in GMP manufacturing and linking these to clinical trials. This would allow academics to get their early phase work further on in the development process; and that is what is needed. By collaborating and by facilitating access into GMP manufacturing and then clinical trials, more value can be generated from the vast amount of work that is done in academic groups (which otherwise may not move out of the university lab and into the clinic).

So there really needs to be greater emphasis on projects moving further along the development pathway while still in academia. That goes



SHUTTERSTOCK/ STANISLAVSUKHIN

The Oxford AstraZeneca Covid-19 vaccine was the result of a successful partnership between academia and industry.

hand in hand with creating new processes and perhaps new approaches to clinical trials.

Of course, a university cannot carry out the large-scale manufacture and the preparation of global regulatory submissions that are needed to license a vaccine which will be used across the world. So we had to move from a hands-on, small-scale approach to a large-scale systems and logistics approach within AstraZeneca.

Combining the advantages of the academic approach with those of Big Pharma was what enabled us to move quickly in 2020. For academic groups, though, there is the challenge that funding is becoming more short term: often three year grants, although it may take a year to apply for them. Large teams for manufacturing and clinical trials were really essential in 2020, but it is increasingly difficult to maintain them in the face of such short-term funding.

Technology funding

I have been working in outbreak pathogen vaccine development for some time and had been trying to get vaccine technology development and vaccine manufacturing enhanced many times before 2020. Yet it was never possible to gain funding for the technology that underpins the development of the different vaccines that we then worked on. Funding has been available for specific vaccines against specific diseases. But to fund the underlying technology itself: there were no suitable calls for proposals to apply for. So although we had the ideas, we were not able to put them into practice.

Another issue involved the production of doses for clinical trials. They were made by four different companies, each with a different process and assays. This was a major difficulty for the clinical trials, which would have run much more quickly and smoothly had an extended and modified Clinical Biomanufacturing Facility (CBF) and the Vaccine Manufacturing and Innovation Centre (VMIC) already been up and running. They were really needed then.

Finally, having a clear and shared goal achieves a great deal. Grant applications are increasingly large and complex. Yet last year, we went from concept to 700 million vaccine doses released for use in 172 countries in less time than some academic funding applications now take.

Our plans were constantly being developed every day – literally! Budgets were reactive, we did report actual spending, but the plans changed. Often, we did not have agreed budgets for specific funding in advance. The decisions were made by those leading the work, not by external consultants to funders who often have a large amount of influence despite not doing the work themselves.

The UKRI rapid response scheme achieved a good balance between information gathering and speed. This meant that we could provide the appropriate amount of information needed to release funding to move the programme forward.

In conclusion, establishing and maintaining expert teams in academia should be prioritised over the award of small, short-term grants which make team-building very difficult. □

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Lessons to create a better future

Nadhim Zahawi

Nadhim Zahawi was appointed Secretary of State for Education on 15 September 2021. He was previously Parliamentary Under Secretary of State at the Department for Business, Energy and Industrial Strategy (BEIS) and Minister for COVID Vaccines Deployment at the Department of Health and Social Care. Before that he was Parliamentary Under Secretary of State at the Department for Education. He was elected as Conservative MP for Stratford-on-Avon in May 2010.

SUMMARY

- The development and deployment of vaccines has been a UK success story
- The Vaccine Taskforce brought together the key players to ensure development at pace and at scale
- The Life Sciences Vision will take the lessons the UK has learned from the pandemic and apply them for the future
- The NHS will make research and innovation fundamental to everything it does
- Bringing together all parts of the sector will create an environment for UK life sciences to flourish.

The pandemic has been probably the biggest threat this country has faced in peacetime. It is the most infectious, aerosol-transmitted, respiratory disease that humanity has experienced. The Government worked at pace, formed a plan and brought people in to implement it and to ensure the response was led by science each step of the way.

The development and deployment of vaccines has clearly been a major success story. The chances of finding a successful, effective vaccine were pretty low at the start. Thanks, though, to the brilliance of everyone involved, we have done so. That would not have been possible without the Vaccine Taskforce which integrated the efforts of Government, industry and academia behind a single mission to find safe and effective vaccines as quickly as possible.

We had the clinicians with the genius to develop a vaccine, with NIHR supporting clinical trials. MHRA provided regulatory approval, and then there were the manufacturing facilities that produced the vaccines at scale and pace. The NHS, of course, has been absolutely key to administering the many millions of vaccinations across the UK.

Outstanding collaboration

The Vaccine Taskforce was not the only example of outstanding collaboration between academia and industry, the Government and NHS, collaboration that turned the dial on tackling the pandemic. The recovery trials also used the brilliant work of academics, the NHS, the regulators and of course, the patients, to identify new approaches to treating COVID by establishing large trials at pace. The discoveries from the trials have now been adopted globally.

The Government has now published its Life Sciences Vision. The core ambition and vision is to take the lessons of the pandemic and apply them to other less evident but also devastating diseases and illnesses that impact our lives. It is a bold vision, created with industry and academia, setting out a 10-year strategy. It will build on that collaborative relationship seen during the pandemic. The underlying foundation is, of course, the excellence of the UK science base and the scale and potential of the NHS.

The Vision sets out how the UK will set targets for the entire life sciences ecosystem, building on our deep academic and industrial expertise to develop and trial new medicines and technologies quicker than anywhere else in the world.

The NHS will make research and innovation fundamental to everything it does, driving improvements in care quality, efficiency, and of course, staff happiness and satisfaction. This will ensure that patients in the UK are among the first in the world to benefit from new medicines and technologies.

We also want to establish the best business environment in the world for companies to grow, to innovate and to take advantage of the regulatory freedoms created by leaving the European Union. The Vision identifies key healthcare challenges where we can harness the collaboration and creativity that was fundamental to our COVID response so that we can save and improve more lives. We will emulate the approach of the Vaccines Taskforce to develop genuine breakthrough medicines and technologies that improve outcomes and patients' lives.

The sector deals bring together industry and Government to address the skills challenge. There is also a real role for Government here in looking across the whole life sciences ecosystem – and beyond – in order to identify the skills needs of the sector and determine how to deliver those skilled individuals the country needs going forwards. The same urgency that was demonstrated in the response to COVID is needed to deliver the skill sets required in the coming years.

Modern vaccine technology has the potential to prevent and treat a range of non-infectious

diseases. So continuing to advance UK capability and capacity can have wide health benefits as well as support the G7 ambition to have vaccines developed and deployed within 100 days of a future pandemic. To do this, the UK will continue to improve core immunology, vaccinology, clinical trial design and infrastructure, it will deepen experience and expertise in vaccine formulation and delivery, and strengthen and maintain the Government/industry partnership.

While there is still a great deal to do to lift the world out of the COVID pandemic and transition from pandemic to endemic status, there is an opportunity to reflect on what has been learned and how to do better in the future. It is necessary to seize the moment to capture these lessons through the Life Sciences Vision. It is vital that industry, academia, the charitable sector, regulators, the NHS and Government continue to work together at pace and at scale to improve and save lives. □

There is an opportunity to reflect on what has been learned and how to do better in the future.

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Scaling up and delivering at pace

Steve Bates

SUMMARY

- The role of industry in being able to scale up vaccine production was crucial to the programme
- Pace was also a key factor in the programme's success
- Many businesses operated at risk in order to deliver the required outcome
- It is important to maintain a diversity of industrial players that can deliver globally
- The networks of experts and the research institutes play a vital role in meeting these challenges.

As head of the UK BioIndustry Association (BIA), one of the tasks I carried out in the project to develop a vaccine against the Covid virus was take some of the requests from the Oxford team, including the need for more funding, to Government and make the case on their behalf. I was explaining that these requests represented vital steps, although involving relatively small amounts of money in the grand scheme of work. I was able to help put together a consortium of BIA member companies who stepped up to support the Oxford team in the manufacture of the Oxford AstraZeneca vaccine as it became known.

Three valuable lessons come from this period of time. First, although being able to invent amazing things is, of course, essential, being able to scale them and develop the necessary industrial capability is also vital. Manufacturing is at the heart of the UK life sciences sector.

Second, pace was absolutely crucial for achieving the required outcome, and some of the lessons learned were concerned with how to do things very fast. It was also important to operate at risk, before all the paperwork was signed off. Many people across many parts of the vaccine programme were routinely working at risk through the development period.

As a member of the Steering Board of the Vaccine Taskforce I had insight into many elements of the programme, some of which will have a long-term legacy. One is that there is now a capability to develop, at pace and scale, vaccines against normal pathogens. The sector has also organised clinical trial networks, including recovery trials, that enable us to gather data (again at pace) that is meaningful across the globe.

There has been some significant innovation in this country on the functional use of genomic data to understand a novel disease. The Oxford team had the genomic information to be able to design the vaccine: getting information about genomics into the discovery arena is one of the important learnings from this period.

The UK has been vaccinated largely by the Oxford AstraZeneca vaccine. Yet other vaccines have done some of the heavy lifting, such as Pfizer BioNTech. Some years ago, Pfizer endeavoured to buy AstraZeneca: if that merger had succeeded, would both of these different vaccines have been developed to industrial scale? It is a serious question, but I doubt there is a simple answer.

It does raise the issue about the number of industrial players and what can be done to keep a diversity of globally-relevant companies in areas of significant health need. The same discussions are being raised over anti-microbial resistance (AMR). Industrial diversity at global scale is clearly important.

There are other factors that underpin the suc-

Steve Bates OBE has been the CEO of the UK BioIndustry Association since 2012. He currently chairs the International Council of Biotech Associations and has been a Board member of Europabio since 2015. Steve sits on the UK's Life Sciences Council and Life Sciences Industrial Strategy Implementation Board. With Government, Steve has championed effective industrial incentives like the Biomedical Catalyst which have brought private sector investment into UK SMEs. He was made OBE for services to innovation in 2017.

cess of the vaccine development programme. We have long term institutions with a research focus in this area. The Jenner Institute has been vital. Although a fairly recent creation in its present form, its focus has been very important for vaccine development. The Sanger Institute and its work on genomics, again, is a relatively recent establishment. This, too, has made a real difference.

A decade of investment under Dame Sally Davies and the National Institute for Health Research (NIHR), which underpinned the work on recovery trial and error clinical trial capability, means that there have been longer term investments with a focus on fundamental areas that we are now able to build on.

Another lesson is the role of experts who have worked together before: the trust relationships across the UK life science ecosystem. The Vaccine Manufacturing Innovation Centre (VMIC) had not been built. Having diversity in the sector with companies stepping forward and taking risks was so important. ❐

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The debate

After the presentations, the speakers joined the chair for a panel session to answer questions posed by the audience. Topics included: attracting people with the right skills; industry-based science; zoonotic diseases; and the international nature of drug development.

The UK must make sure it trains the right teams of people with the right skills. It was able to draw on that for the Covid pandemic but more people will be needed in vaccine manufacturing. This can get overlooked given the focus on clinical trials. The country must build that skills base.

It was suggested that more private sector investment could be brought into this field and that it was not just a matter for Government to provide all the support.

There is a great deal of expertise outside academic settings. There is a great deal of cutting-edge science, particularly in bio processing, that is based in companies. It is possible to have an excellent scientific career without remaining in an academic setting. And one of the lessons from this episode is the collaboration between academia and industry, getting together to find a solution.

Small companies often have a good core team but do not have the access to facilities to develop further. Here, the interactions between academia and the manufacturing groups can be beneficial.

Should it be easier for scientists, particularly clinical scientists, to move between industry and academia and the Health Service seamlessly? In that way, people can develop their skills and then deliver across these different domains at different stages in their careers.

How can we prepare better for the next zoonotic pandemic, as this concerns both human and animal health? There are many zoonotic infections. But there is not the available money to develop vaccines for livestock. It would be possible to use the same platform technology in humans and in livestock. The manufacturing process must be highly purified for clinical use, but it could be a slightly less pure, and therefore cheaper, process for livestock applications. However, there are currently no schemes that allow the code development of human and veterinary vaccines, although it would make a great deal of sense to be able to do it.

The vaccine development depended on the engagement of multi-national networks. Industry is global in nature and supply chains are definitely international. There is, for example, a European supply community that has been built up over the past 40 years. For the future of UK programmes, we have to inspire the best people to come here from around the world. Those people are likely to come from the global south as much as from Europe over the coming years. The reality is that we live in a global marketplace and knowledge transcends national boundaries. ❐

FURTHER INFORMATION

Life Sciences Vision (HM Government, July 2021)
www.gov.uk/government/publications/life-sciences-vision

UK Vaccine Task Force: Membership and Objectives of the Steering Group
www.gov.uk/government/publications/the-vaccine-taskforce-objectives-and-membership-of-steering-group/vtf-objectives-and-membership-of-the-steering-group

UK Vaccine Taskforce 2020 Achievements and Future Strategy (December 2020)
https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1027646/vtf-interim-report.pdf

VIEWPOINT

This year marks the 10th anniversary of the launch of the first Raspberry Pi computer. The latest version is now opening up new opportunities for research and study on the International Space Station.

Raspberry Pi, space and the AI skills challenge

David Cleevely

A little after 10 am GMT on Tuesday 21 December 2021, a SpaceX Falcon 9 rocket blasted off from Launch Complex 39A at the Kennedy Space Center in Florida, carrying a Dragon 2 spacecraft en route to the International Space Station.

This was an unmanned mission carrying supplies to support life in space and equipment to undertake scientific research. It is worth remembering that the most expensive object that humans have built — the ISS — is essentially a science laboratory in orbit. This flight was transporting materials for a study of the delivery of cancer drugs; a bioprinter for experiments investigating wound healing; materials for a study of how detergents work in microgravity; and Christmas presents for the astronauts.

Every mission to the Space Station is remarkable, but this one was extraordinary because it was also carrying two specially adapted Raspberry Pi computers. I believe sending such computers into space will help us address the AI skills challenge.

The Raspberry Pi phenomenon

This year marks the 10th anniversary of the launch of the first Raspberry Pi, a low-cost, credit-card sized, programmable computer, invented in response to the problem that too many young people grow up without learning how to create with computers and digital technologies.

The project started with the relatively modest ambition of inspiring a few thousand young people to study computer science and engineering by providing a programmable computer for the cost of a textbook – $35. The founders were inspired by the excitement they saw in the first wave of the personal computing revolution in the 1980s, when several lines of code had to be written in order to get a computer to do anything. For many, that early experience of programming led to a career in computing, solving problems, and founding companies that have changed the world.

That is what the inventors of the Raspberry Pi wanted to recreate and, crucially, at a cost that would make computer science accessible to young people for whom the price of technology was a real barrier to learning.

Over the past decade, it has grown into a global phenomenon. Over 45 million Raspberry Pi computers have been sold (the vast majority manufactured in South Wales) making Raspberry Pi Ltd the UK's most successful computer company by volume.

Millions of young people all over the world have used Raspberry Pi computers to get started on computing, while the number of students choosing to study computer science has never been higher. Admissions tutors report that students often talk about being inspired by getting hands-on with a Raspberry Pi.

In addition, the latest generation are fully fledged desktop PCs capable of streaming ultra-HD video and running all but the most demanding software, providing an affordable solution to the digital divide that was so starkly highlighted when schools were closed at the start of the pandemic.

What started as an educational project is now also seeing an impact in industry, with over half of the Raspberry Pi computers sold going into the hands of engineers and entrepreneurs who are using them across an extensive range of industrial and commercial applications. Raspberry Pi computers are automating factories, being arranged into clusters to mimic supercomputers for training purposes as well as being increasingly found embedded in consumer devices.

The educational mission

The Raspberry Pi Foundation has an educational mission: to empower young people to realise their potential through the power of computing and digital technologies. Low-cost computers are an important part of how the Foundation addresses that mission and that part of the business is delivered through its commercial subsidiary, Raspberry Pi Ltd.

The Foundation has also evolved into one of the world's leading education non-profit organi-

Dr David Cleevely CBE FREng FIET served as the chairman of the Raspberry Pi Foundation and its commercial subsidiary (Raspberry Pi Ltd) from 2014 to 2020 and continues to be involved as a Member of the Foundation and its Supporters Club. He was founding Chairman of the Cambridge Science Centre and Founding Director of the Centre for Science and Policy, University of Cambridge. He also chairs three committees for the Royal Academy of Engineering (Enterprise Committee, COVID-19 Triage Committee and the Policy Fellowships Working Group).

What started as an educational project is now also seeing an impact in industry, with over half of the Raspberry Pi computers sold going into the hands of engineers and entrepreneurs.

One thing we know about motivation for learning is that context matters. Young people are more engaged in learning about computer science when they can see its relevance to their own lives.

sations in its own right, creating learning experiences and products that have already helped millions of young people all over the world learn new skills and knowledge.

The Foundation supports schools to teach computing and computer science through curricula, resources, platforms, and teacher training. In England, it is part of the consortium running the National Centre for Computing Education on behalf of the Department for Education, supporting every primary and secondary school to introduce computing, including training tens of thousands of teachers each year. Globally, over a quarter of a million educators have used the Foundation's free online courses to learn more about computing and how to teach it.

Millions of young people are also supported by the Foundation to learn how to create with digital technologies outside the classroom: through free online resources and apps, the world's largest networks of coding clubs, and partnerships with youth and community organisations in more than 40 countries. All of this is underpinned by a significant investment in rigorous research, including through the Raspberry Pi Computing Education Research Centre at the University of Cambridge.

The AI skills challenge

While there are lots of positive signs that the work of the Raspberry Pi Foundation — alongside many other organisations committed to improving computing education — is having an impact, the pace of technological innovation is accelerating all the time, and education and skills policy desperately needs to keep up.

One of the most significant trends is the explosion of interest in artificial intelligence, including machine learning, robotics, computer vision, and natural language processing, driven by the need to gather, store and process colossal amounts of data.

As Stuart Russell argued in his 2021 Reith Lectures[1], increasingly powerful AI has the potential to bring about the most profound change in human history and is already transforming every aspect of our lives.

It is vital to ensure that young people — whatever their backgrounds — are equipped with the skills to thrive in an unknown technological future. A recent Royal Society report on machine learning recommended that schools should ensure that key concepts in machine learning are taught to those who will be users, developers, and citizens. The UK Government's National AI Strategy includes a strong commitment to universal AI education for young people.

In 2021, the Raspberry Pi Foundation partnered with The Alan Turing Institute, the UK's national institute for data science and artificial intelligence, to run a series of research seminars with the world's leading academics and thinkers on AI skills, learning from pioneering practice across the globe to define the key concepts in AI and determine how they can best be taught.

This is an emerging field, but it's already clear that we urgently need more investment in research and experimentation to understand what works, followed by a sustained national effort to support schools, teachers, and young people.

Astro Pi: your code in space

How does all of this relate to Raspberry Pi computers on board the International Space Station?

This is the Astro Pi Challenge, a collaboration between the European Space Agency and the Raspberry Pi Foundation that started in December 2015 when British ESA astronaut Tim Peake first took Raspberry Pi computers to the ISS as part of the Principia mission.

Since then, 54,000 young people from 26 countries have written code and experiments that have run on these specially augmented Raspberry Pi computers, which included sensors and cameras that collected environmental data and images of life in space and on earth.

We are now seeing growing interest from young people in the potential of AI, machine learning, and image recognition to help them understand challenges like the climate crisis, deforestation, and pollution.

The new Astro Pi units that were sent to the ISS on 21 December 2021 represent a significant upgrade, with something like 40 times the processing power, a new high quality camera and a Google Coral machine learning accelerator. These upgrades open up the possibility for young people to gather more data from the onboard sensors, including sharper and full-colour images of earth, with the potential to develop machine learning models that allow high-speed, real-time, on-device processing.

One thing we know about motivation for learning is that context matters. Young people are more engaged in learning about computer science when they can see its relevance to their own lives. Putting Raspberry Pi computers in space creates the opportunity for young people to experiment with machine learning and AI in order to better understand problems like the climate crisis. I cannot wait to see what they make of the opportunities. ☐

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1. www.bbc.co.uk/programmes/articles/1N0w5NcK27Tt041LPVLZ51k/reith-lectures-2021-living-with-artificial-intelligence

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