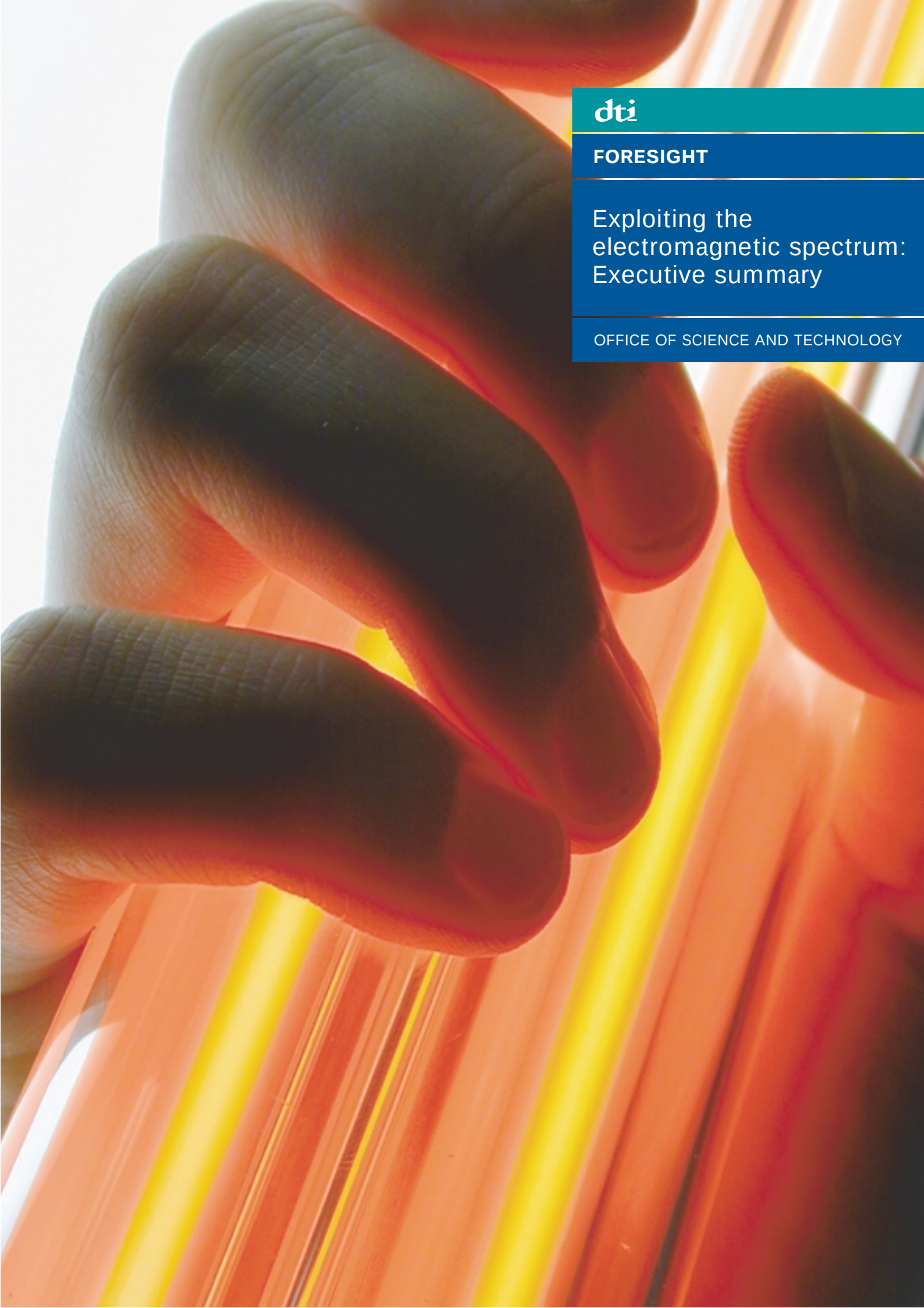

dti

FORESIGHT

Exploiting the electromagnetic spectrum: Executive summary

OFFICE OF SCIENCE AND TECHNOLOGY

dti

The DTI drives our ambition of ‘prosperity for all’ by working to create the best environment for business success in the UK. We help people and companies become more productive by promoting enterprise, innovation and creativity.

We champion UK business at home and abroad. We invest heavily in world-class science and technology. We protect the rights of working people and consumers. And we stand up for fair and open markets in the UK, Europe and the world.

Foresight
Exploiting the electromagnetic spectrum project

Stephen Timms MP, DTI Minister for Energy, e-Commerce and Postal Services

The speed of scientific and technological advance is increasing. This brings wealth to our nation and raises challenges in society as we learn how to adapt and adopt the new capabilities to our greatest advantage. The UK, with its excellent science base, remains well placed to take advantage of these opportunities but, in today's world, international competition is increasing faster, making it ever more important that we look ahead.

We are responding to this: last year the UK's Research Councils published a joint vision document for the first time, and the Chancellor has just launched the creation of a 10-year investment strategy in science and innovation. Foresight plays a crucial part in this picture, being one of the Government's key tools for investigating critical longer-term, science-driven cross-cutting issues in depth.

This project represents an exemplar for our work in identifying future commercial opportunities from science.

David Hughes, DTI Director General Innovation Group

Last year I led a review of innovation policy. The review concluded that, while the UK had an excellent science base and track record on invention, we needed to do more to exploit this commercially. The report included recommendations to set up a national Technology Strategy and to create a £150 million fund to support that strategy.

It is essential that the strategy we develop is based on a thorough assessment of the UK's strengths and a forward look at the opportunities. This project is a useful input we can consider in developing the Technology Strategy. It is an example of how taking a longer-term view can stimulate ideas for potential commercial application and influence the direction of future scientific research. It has used a rigorous and open process to identify a few key areas from which the UK could reap the rewards of its excellent science. These opportunities do not come without risks and the project has also provided an assessment of the risks.

The challenge now lies with all of us to balance the opportunities and risks and find the best way forward for the UK.

Introduction

This project provides a vision for the future exploitation of the electromagnetic spectrum to ensure increased UK innovation in selected areas.

The electromagnetic spectrum, from radio frequencies through optical to x-ray, encompasses much adventurous scientific research and is the basis for a wide range of vitally important technologies that have applications in areas as diverse as communications, health and security. The UK has a long history of world-leading research across the spectrum but in the past has not always moved from invention to innovation to reap the commercial rewards from its discoveries. The Foresight 'Exploiting the electromagnetic spectrum' project forms part of a much wider effort across government to improve innovation and ensure that the UK captures more of these opportunities in the future.

The project aims were to identify key areas of long-term opportunity across the spectrum, assess these against UK capabilities and agree a plan of action to help the UK exploit these areas.

We selected four topic areas through a rigorous scoping process, involving the academic, business, and user communities along with representatives from other government departments and funding bodies.

The scoping phase of the project, which culminated in the selection of the four topics, was based around two workshops. The first workshop brought together a small group of scientists from business and academia, and focused on the science push. It identified around 20 areas of exciting research with application potential. The second workshop brought together a much larger group of business and user representatives and focused on the market pulls for the technologies identified by the first workshop. This resulted in a shortlist of nine topics where there was felt to be both a clear market demand, and hence exploitation opportunity, and a strong UK research base from which to start. Four of these were selected against the following criteria:

- far-out (major economic activity 10–20 years hence) and innovative (step-change to new technology)
- economic significance
- UK ability to exploit
- balanced topic portfolio.

We convened action groups for each of these topic areas to identify the technical challenges and business opportunities, and develop plans for action. Members were drawn from business, academia, user communities, government and other agencies.

We provided the action groups with three sets of information to help them map out the most promising markets and applications for the UK to exploit, and the technological development needed to deliver those applications.
We commissioned:

- **state of the science** reviews for each topic. The reviews look at new technological advances, assess their likely impacts over the next 10–20 years and consider the UK's relative strengths in these areas.
- **the development of an easy-to-use evaluation tool to help assess potential investments in research and development (R&D).** It is based on real options methods, which accord value to being able to defer decisions about later-stage investment when embarking upon R&D. By analogy with financial options, real options treat phased investment in R&D as buying the right, but not the obligation, to continue with further stages.
- a market research company to provide **an assessment of the potential market sizes** for the applications identified by the action groups as offering the greatest potential.

In selecting key opportunities from the many possibilities identified, the groups also considered competition both from other countries and other technologies in meeting the demand, and the investment costs needed to get to market.

This overview highlights these opportunities and the main challenges to their realisation.

Selected topics

The project focused on four key topics where the UK's science base excels and the prospects for innovation 10–20 years hence look most promising.

Switching to light: all-optical data handling

Manufacturing with light: photonics at the molecular level

Inside the wavelength: electromagnetics in the near field

Picturing people: non-intrusive imaging

Switching to light: all-optical data handling

Over the last 20 years, optical fibre has become the dominant long-distance transmission medium for data communications, with copper wire (or radio) used mainly for the 'last mile' to the user. Although data is now transmitted optically, routing and switching continues to be carried out electronically. For current and near-future data-traffic demands, this is both cost-effective and adequate. But if widespread demand reaches terabit level (one terabit per second = 10^{12} bits per second), existing and easily forseeable electronic technologies will have difficulty keeping up.

Optical techniques will need to form an increasingly large part of switching and routing systems in order to satisfy expected future-traffic levels. **The UK could capture a market of up to $0.5 billion in 10 years' time in fast optical switches, if it invested now in the UK's excellent science expertise in this area.** This is a high-risk venture, because of the uncertainty over whether fast optical switches will be needed by then, the likely global competition and the risk that the UK will not have a home market, which is perhaps essential in order to compete successfully in the world market.

The key issue for the development of a home market is the provision and use of high-rate (100 Megabit/sec) broadband to the home/user. **The decision to roll out high-rate broadband for all rests on wider economic and social considerations but, if taken now, would offer the chance that the UK might also capture the commercial opportunities.**

Manufacturing with light: photonics at the molecular level

Lasers have long been used for precision machining but as control becomes ever finer and faster, light now offers the capacity for manipulating matter on a molecular scale.

Laser micromachining in three dimensions offers many manufacturing opportunities, such as the fabrication of microstructured materials for next-generation solar cells, smart fibres, photonic crystals and photonic lab-on-a-chip devices.

The UK could capture a $5 billion market in integrated lab-on-a-chip systems, as a platform technology for a number of multi-diagnostic applications, including diabetes treatment, health monitoring, drug targeting and cancer detection. In the longer term, this could lead to therapeutic applications, though these require an order of magnitude more investment in regulatory trials. Extrapolating the historical market growth rate and current size, this lab-on-a-chip market could be $100 billion by 2012. Capturing a niche of even 5% of this is a significant opportunity that the UK is in a strong research position to address.

These applications tend to have high capital costs of setting up production, but the potentially huge markets mean that the relatively low initial research investment costs are an attractive, if risky, proposition.

Inside the wavelength: electromagnetics in the near field

All Foresight projects seek to explore and establish best practice for science futures work. To this end, we sought a balance between topics defined by application or market and those defined by the underlying science. This topic is of the latter type and consequently its application areas are more diverse. The near field is the confined non-propagating part of an electromagnetic field (at any frequency) that decays away exponentially from a surface, within a distance of about a wavelength. The recent UK-led discovery of 'metamaterials' (composite artificial materials) will allow manipulation of the near field in ways not previously possible.

Near field technologies are critical to developing smart antennas and integrated radio frequency infrastructure and circuitry. The UK has a strong industry presence in this sector and there is already much short-term incremental development. Long-term goals include wearable antennas, very accurate beam control, integrated broadband antennas and low SAR (specific absorption rate) antennas.

Metamaterials are opening exciting possibilities in other areas, such as sub-wavelength resolution imaging using 'superlenses', especially in MRI (magnetic resonance imaging). **As yet there are no obvious single applications that alone would be of sufficient potential to justify focused investment. More basic research is needed to explore the full potential of metamaterials.**

Picturing people: non-intrusive imaging

Novel non-intrusive imaging techniques have applications in both healthcare and security. In the medical imaging market, value is expected to continue to move away from the hardware, where the UK is weak, to the smart agent sector and to imaging and data-handling software. Smart (contrast) agents are particles or molecules that can be used to tag indicators of disease so that these show up when the patient is imaged. Smart agents offer the prospect of high specificity molecular imaging for the early and non-intrusive detection of diseases like cancer, and vascular, neurodegenerative and neurological conditions. **The UK could caputure a $6 billion share of the market for smart agents for medical imaging. A critical step in doing so is identifying new reagents with new functionality.**

Detection of weapons and explosives at a distance, using safe, reliable and cheap technology, is a growing requirement in today's world. The UK is in a leading position in developing security imaging using combinations of frequencies from millimetre waves through terahertz to infrared. **A key enabler for UK businesses to capture a $0.4 billion share of the market would be the provision of a national foundry to enable companies to prototype their inventions fast and in a secure Intellectual Property (IP) environment.**

The way forward

From a wide variety of potential opportunities within the four topics, the project has highlighted some of the most promising areas and suggested ways of taking these forward.

Creating innovation

Common key facilitators of innovation that emerged across all areas were:

- national (or in some cases EU) level co-ordination of activities
- multidisciplinary teams with a strong industry lead
- centres to bring together industry and academia to work on short focused programmes to solve specific challenges
- establishing a clear and acceptable means of protecting IP in order to facilitate businesses sharing facilities in these collaborative projects.

Rising to the challenges

There was strong support from both the 'Switching to light: all-optical data handling' and 'Manufacturing with light: photonics at the molecular level' groups for a broader, more comprehensive national co-ordinated photonics strategy, encompassing the underlying photonics technologies needed for applications in both areas.

Photonics has been identified as a potential priority area for a Call in 2004/05 under the new DTI Technology Strategy. The DTI Electronics team has also initiated a Photonics Strategy Group that will draw from this project to develop an action plan to exploit this sector, by identifying opportunities and challenges for the UK over the next 5 to 10 years. The team is also working to bring together key players to start a national Photonics network along the lines of the successful Fuel Cells initiative.

'Inside the wavelength: electromagnetics in the near field' identified a number of niche markets for metamaterials. **The Ministry of Defence (MOD) has a user requirement for metamaterials in a wide range of sensing applications, and will work together with the Engineering and Physical Sciences research Council (EPSRC), and others to consider opportunities for joint funding of proposals under the Joint Grant Scheme.** The MOD will continue to monitor this area for its potential defence implications and the need for larger collaborative programmes in the future.

EPSRC, the Medical Research Council, the Department of Health and the Council for the Central Laboratory of the Research Council are exploring ways of improving multidisciplinary working on medical imaging and the prospects a for a 'smart agent medical imaging centre'.

Real options evaluation tool

The project has developed a novel, simple, real options tool that allows a broad comparison of potential returns from investment in different areas of research. This tool provides a framework to ensure that key milestones are set for decisions on further investments and helps make clearer what the risks and uncertainties are. It allows users to experiment in an iterative way with different parameter values and proposal structures, and provides analysis of the sensitivity of the value to input parameter changes. Spin-off benefits can be factored in, if they can be quantified.

This tool draws on existing real options analysis, which has come to the fore in recent years as a means of capturing the value of the flexibility embedded in long-term, multi-stage, R&D projects in the presence of uncertainty. Based on well-developed techniques used in financial markets to value the right, but not the obligation, to buy an asset in the future, real options analysis is gaining in acceptance as a practical tool in assessing R&D proposals. This tool is intended to help assess investment in R&D and it is hoped that it will be of more general use in a wider context than the project alone.

Other shortlisted topics

The project did not have the resources to look at all the areas it identified as important. These included:

Pervasive bandwidth: the developing technologies of software-defined radio and spread spectrum mean that spectrum will be used most efficiently by allowing systems to adapt dynamically to use whichever part is free at the time. Peer-to-peer communications will represent a new challenge for spectrum regulation. The project has passed its preliminary reporting to, among others, Ofcom, who are currently reviewing these issues.

Coherent x-rays: compact (bench-top) sources of coherent x-rays would find widespread application in high-resolution medical and biomolecular imaging. The National Physical Laboratory plans to hold a workshop to consider the technical options for the generation of bench-top coherent x-ray sources in summer 2004.

Two non-electromagnetic spectrum technologies that were noted as key enablers for many applications considered were **software for data analysis (particularly images) and advanced materials development.**

Other Foresight projects

Foresight projects produce challenging visions of the future to ensure effective strategies now. There are four other Foresight projects running.

Two of these projects link into the EEMS project through its work on medical imaging, which could allow for a step-change in our capabilities to image the brain. The Cognitive Systems project identified opportunities for closer collaboration between scientists working on intelligence in living systems and those working on building intelligence into artificial systems. The Brain Science, Addiction and Drugs project is exploring potential opportunities and challenges from research on addiction and drugs that affect the brain.

The other two projects also connect with the EEMS project through imaging technology. The Cyber Trust and Crime Prevention project is studying the implications of next-generation information technology for crime and crime prevention and the factors that influence trust in a digital age. Next-generation CCTV incorporating multi-wavelength capability to watch for weapons or drugs could enhance public security. The Flood and Coastal Defence project examined future flood risks in the UK and how we might respond to them. In addition to highlighting the strategic issues the UK will face on flood management, it has highlighted the benefits of improvements in sensing technology for future flood defences.

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Further details

A full set of the project's documents appear on the Foresight website at **www.foresight.gov.uk/emspec.html**

These include:

- Executive summary
- Findings and analysis
- State of the science reviews – expert reviews for each topic
- State of the science overviews – concise and accessible overviews of the state of the science reviews
- Tales from the future – narrative stories exploring some of the visions of the future highlighted by the project.

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