HENRY ROYCE INSTITUTE

ROYCE

MATERIAL FUTURES

Unlocking UK economic growth through materials innovation

NATIONAL MATERIALS INNOVATION STRATEGY

FOREWORD

Materials innovation lies at the very heart of our future, powering the advancements so urgently required for our modern world and underpinning our aspirations for a sustainable future.

From the emergence of a new hydrogen economy, fusion power and low energy digital devices to breakthroughs in bioelectronics, the transformative potential of materials science touches every aspect of our lives. The necessity of sustainability and resilience adds an essential dimension to new discovery and innovation processes.

The UK has a world-renowned depth of materials science expertise in academia and industry. It stands uniquely positioned as a leader in this field. This National Materials Innovation Strategy represents a truly significant milestone. It is the output of extensive collaboration with the UK's strategic sectors, and brings together the insights of materials science and engineering researchers, innovators, policymakers, and industrial leaders in a unique manner.

Strikingly, this new strategy highlights the present contributions of the materials sector to the UK, the bedrock to a £45 billion economy employing over 635,000 people nationwide. Beyond its economic significance, the sector is a cornerstone of national resilience, underscoring areas ranging from defence, energy, and infrastructure, to telecommunications.

It is clear, however, that if we are to strengthen and extend our global leadership, we must address some of the longstanding barriers we face – including the persistent bottleneck between research and commercialisation. This strategy sets out to do precisely that, creating pathways for accelerating the innovation journey from discovery to deployment and breaking down the silos between industry sectors and scientific disciplines.

This framework for action over the next 10 years is clear. It is paving the way for the UK to deliver cutting-edge materials technologies that advance society, strengthen our economy, and secure a more sustainable future.

The contribution from the materials community to this point has been fantastic, however this must not falter and this strategy is truly a "call to action" to continue to work together to transform materials potential into materials progress and strengthen our position as the global leader in materials innovation.

Allan Cook CBE
Chair of the Materials Innovation Leadership Group

Professor David Knowles
CEO, The Henry Royce Institute

A STRATEGY FOR MATERIALS INNOVATION

Materials science is a cutting-edge research and industrial discipline that the UK has a long history of leading.

Innovation in materials drives tangible benefits for society and helps to secure our place in the global science and technology landscape.

As the UK continues to strive to be a healthy and resilient nation operating in a prosperous net zero economy, it needs the support of a specific, clear and standalone national strategy for materials innovation and technology translation.

The Henry Royce Institute for Advanced Materials initiated the development of such a strategy to harness the collective knowledge of industry leaders, academic specialists, and government experts. Supported by a UK-first economic analysis of materials innovation activity, this knowledge has been assimilated to identify the materials innovation priorities that will drive economic growth for the UK and unlock solutions for sustainable new paradigms across almost every sector.

This strategy touches on the emerging solutions and pressing challenges that consulted stakeholders have identified. Whilst their specific requirements and outcomes are diverse, there are common opportunities and challenges which bind them together. These must be addressed through a consistent and cohesive framework, success of which will lead to a step change in translating innovation into impact.

These opportunities and needs present a bold new vision for harnessing the power of materials science to tackle the most pressing challenges of our time, from decarbonising energy systems and enhancing national resilience, to revolutionising healthcare and boosting our circular economy.

To expedite this vision, this strategy proposes an implementation framework that will kick start a huge national effort to speed up materials development cycles and unlock untapped potential in the UK. It will be coordinated to complement other strategies for technologies, sectors, and industry in the UK, and to leverage existing infrastructure and funding initiatives.

This booklet summarises the full strategy, which is available on the Royce website.

www.royce.ac.uk/collaborate/innovationstrategy/

"Materials is a pervasive technology which underpins our economy. Here in the UK, we are fortunate to possess world-class expertise in materials science and engineering.

This strategy builds on this strong foundation, charting a clear path to realise the economic opportunities identified by over 2,000 materials innovators across the country through a robust industry-government partnership."

Pete Raby
Chief Executive Officer, Morgan Advanced Materials

"Materials sit at the heart of addressing the major technological and economic challenges facing our society today. As we strive to meet the UK's net zero and growth ambitions, the need for sustainable, next-generation materials has never been more urgent.

The launch of the National Materials Innovation Strategy marks a decisive moment for the UK."

Professor Julia Sutcliffe
Chief Scientific Adviser, Department for Business and Trade,
and member of the Materials Innovation Leadership Group

THE ECONOMIC IMPACT

Materials innovation delivers economic growth and unlocks jobs across UK regions.

VALUE

Materials innovation businesses contribute an estimated £45 billion each year to the UK economy.

This equates to 2% of the UK's total GVA, and yet it enables six times that value in wider production activities.

Materials underpin the UK's manufacturing industry, which contributes £220 billion every year to GVA and supports 2.6 million jobs. 85% of this production takes place outside of London and the South East.

It also drives investment; in the last 3-year period, materials innovation businesses secured an average of £8 billion each year in external private and public funding for innovation activities within the UK.

Over 2,700 companies are active in materials innovation in the UK. They are responsible for driving economic growth in smaller, regional businesses:

- **90% of materials innovation businesses are SMEs employing fewer than 250 people, and 74% employ fewer than 50 people.**
- **70% of these businesses are registered outside of London and the South East.**

This business activity spans the entire materials value chain, indicating that the UK is home to end-to-end innovation capabilities.

EMPLOYMENT

There are an estimated 52,000 people in materials-specific roles in the 2,700 companies active in materials innovation in the UK. These jobs contribute up to £4.4 billion in GVA.

This dependence on materials-specific employment is more acute within smaller companies.

In materials innovation businesses, materials-specific roles account for an average of:

- **40% of jobs in micro businesses**
- **22% of jobs in small businesses**
- **10% of jobs in medium businesses**
- **6% of jobs in large businesses**

These roles are the cornerstone of the 635,000 people employed in materials innovation businesses, demonstrating the enormous multiplier which a successful materials economy brings to the UK.

Materials skills are in demand, and the number of materials-specific job roles has the potential to at least double by 2035.

The top UK employers of people in materials-specific roles include Jaguar Land Rover, Morgan Advanced Materials, Altrad, Rolls-Royce, Element Materials Technology, BAE Systems, Babcock International, Heidelberg Materials, BT, and Tata Steel.

THE POTENTIAL

The UK's strengths in materials innovation need to be leveraged to deliver technical solutions that fuel global growth.

GROWTH POTENTIAL

A large portfolio of high-potential investment opportunities related to materials innovation already exists.

Our research and development capabilities are long-standing and globally leading. Our world-class universities, robust IP legislation, and highly skilled workforce can be leveraged for impactful materials innovation across all high-value industries.

Examples include:

- **Composite materials**
  UK market value: £4 billion
  Compound annual growth rate: 6–9%
- **Bioelectronics**
  UK market value: £132 million – £163 million
  Compound annual growth rate: 6–14%
- **Photonics**
  UK market value: £15.2 billion
  Compound annual growth rate: 3.4%
- **Foundation industries**
  UK market value: £52 billion
  Compound annual growth rate: around 9%
- **Quantum**
  UK market value: £1.7 billion
  Compound annual growth rate: 14.3%

BEYOND ECONOMIC VALUE

Materials innovations are vital in tackling major challenges in energy, health, transport, manufacturing, national security, and sustainable resource use.

Materials form the physical basis of all products and services. Their performance guarantees functionality, durability, safety, environmental sustainability and biocompatibility in all industries.

Materials innovation is the foundation upon which we can address some of our nation's most ambitious priorities:

- Strengthening our international standing as a clean energy superpower
- Bolstering national resilience and sovereign capability
- Growing productivity
- Creating new high-skill employment opportunities for everyone
- Enabling healthy, happy lives

THIS STRATEGY

The UK's materials innovation capabilities are a key national asset and vitally important to the economy.

A coherent approach is needed to drive solutions through this ecosystem and tackle the challenges that constrain its potential.

Materials innovation presents a particular challenge to focussing national effort because it is so pervasive. It spans multiple research disciplines, supply chains and industries.

Past efforts to bring cohesion to materials development have been limited to specific sectors or capabilities, which struggle to tackle the complex interconnections between different research, business and policy goals.

This strategy is different. It is mission-focused and addresses the critical weaknesses in the lengthy and expensive commercialisation cycles of all material classes. It has been designed to break down the barriers between research, development and commercialisation activities across different sectors; creating coherency and accelerating the materials development cycle.

Fundamentally, it is driven by its mission to create an effective and integrated materials sector that serves all the UK's industrial growth.

WHAT IS THIS STRATEGY?

This strategy:

- Presents a vision for an economy transformed by materials innovation over the next 10 years.
- Affirms the materials sector as the heart of all UK industrial growth.
- Does not pick specific technology solutions to pursue but identifies opportunities for transformational innovations with the potential for global impact.
- Establishes an approach for creating an agile, responsive sector that adapts and delivers to emergent opportunities.
- Advocates for the wider activities needed to create an effective innovation environment for the materials community.

CLOSE CONSULTATION AND CO-CREATION

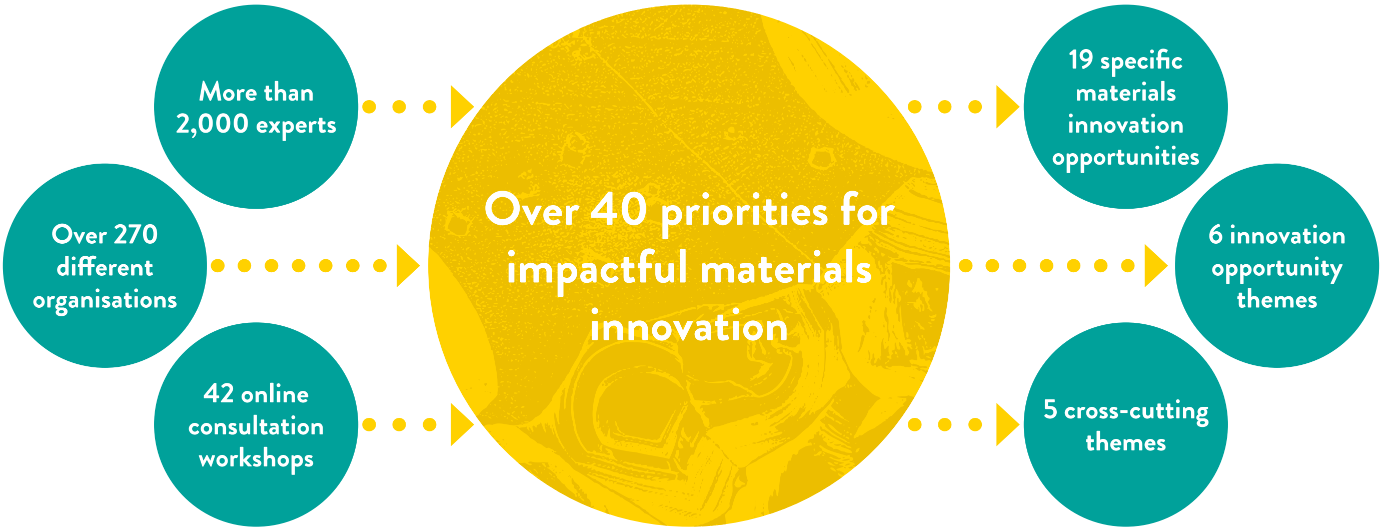
This strategy has been developed with the materials innovation community.

Led by the Materials Innovation Leadership Group – a specialist body of national leaders assembled by Royce to lend credibility and independence to this strategy – this consultation engaged with more than 2,000 experts from over 270 different businesses, universities, research organisations, government, and non-governmental bodies.

The engagement involved online workshops with groups themed by technology. Participants shared their insights on market opportunities and needs, materials innovation solutions, and the gaps in capabilities or investment needed to deliver these solutions.

Consultees have identified 19 specific materials innovation opportunities with over 40 priorities between them.

These opportunities have been confirmed against the leadership group's expertise and the economic analysis to be key areas for materials to make a transformative impact. They cover all industries, from wind energy to quantum technology.



THE OPPORTUNITIES

Materials innovation is fundamental to creating impactful solutions for:

Energy solutions
Rising to the net zero challenge

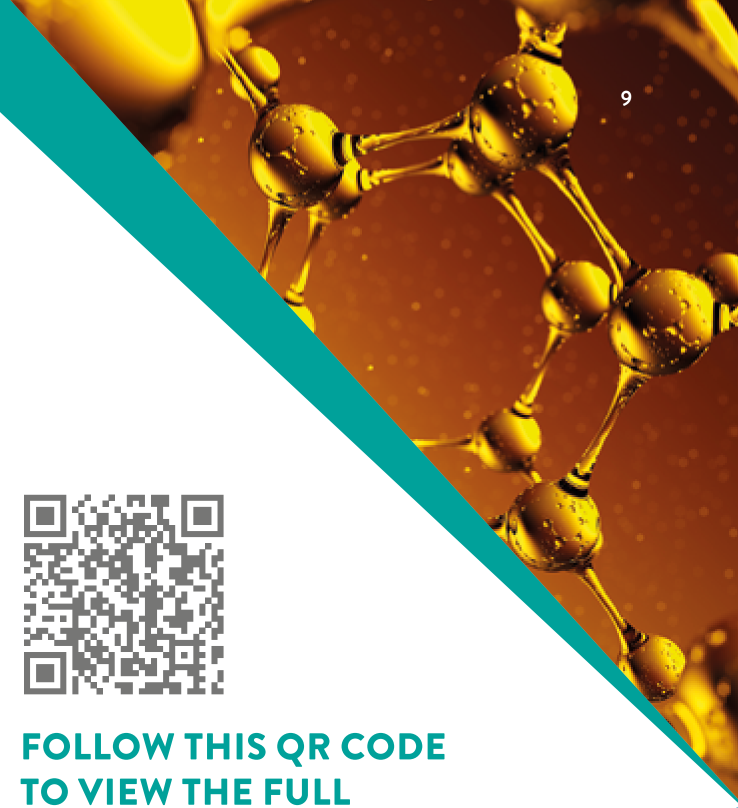
Future healthcare
Delivering beyond biocompatibility for active medical solutions

Structural innovations
Strengthening our infrastructure, built environment and transport systems

Advanced surface technologies
Enhancing product functionality, performance and lifetime

Next-generation electronics, telecommunications and sensors
Driving the future of high-performance connectivity and computing

Consumer products, packaging and specialist polymers
Paving the way for a greener tomorrow



This strategy focuses effort on the largest opportunities for impact.

These six themes have been selected to guide efforts to unlock economic growth through multiple, diverse opportunities for materials innovation.

The opportunities under each theme relate to a range of materials systems, their applications, and their priority areas for innovation. These priorities have detailed statements on the key interventions required to enable them and the industry challenges that they will solve.

Full sub-strategies for each opportunity and their priorities are available on the Royce website.

These sub-strategies are living documents that are the basis for the implementation of this strategy. They reflect the areas identified by industry that currently have the most immediate need and ability to progress promptly.

This strategy will remain flexible by design. Its implementation includes the constant exploration and identification of other potentially impactful materials solutions.

FOLLOW THIS QR CODE TO VIEW THE FULL NATIONAL MATERIALS INNOVATION STRATEGY

RISING TO THE NET ZERO CHALLENGE

ENERGY SOLUTIONS

The efficient and sustainable generation, storage, transmission and use of energy is arguably society's highest profile challenge today. Materials discovery and development are fundamental to the needs of the entire energy technology space.

The UK's materials community and mature energy sector have clear strengths in this area. Materials innovation could not only lead global efforts to decarbonise the energy and manufacturing sectors to meet our own national commitments for net zero carbon emissions, but could also generate widespread economic benefits for the UK.

Opportunities in this theme

1. Materials for battery energy storage

Energy storage will be critical to the transition to decarbonised energy systems, ranging from applications in road transport to supporting the grid flexibility needed for renewable energy use. Batteries will need scaled-up manufacturing capabilities and high-performance materials. Chemistries that support the move away from lithium-ion batteries could unlock a local supply chain or use more sustainable resources.

2. Materials for large-scale electrochemical energy generation and conversion

Electrochemical cells convert chemical energy to electricity, or vice versa, and can be used in large-scale systems. Hydrogen fuel cells and electrolysers are key examples of this technology. New designs of critical components of hydrogen fuel cells and electrolysers – and their manufacturing and testing procedures – are needed to scale sustainable, application-ready solutions for energy-intensive industries.

3. Materials for hydrogen transport, storage and use

Across the hydrogen supply chain, components are subject to extremes of temperature, pressure, and corrosive conditions. Hydrogen permeates rapidly through many materials, leading to embrittlement – where metals lose their ductility and potentially fracture. Effective material barriers are required to mitigate this.

4. Materials for heat exchange, heat storage and waste heat recovery

More than 5% of the UK's energy is consumed by thermal systems in industrial and domestic settings. Solutions to decarbonise heat generation using heat exchangers, recover heat from industrial processes and electronics, and improve energy efficiencies all require materials solutions.

5. Materials for energy harvesting

Solar photovoltaic (PV) solutions will enable our future net zero energy supply and will also deliver battery-less and mobile power sources for electronic applications that unlock new industry opportunities, including in space and healthcare. New material solutions will improve the efficiency and deployment potential of these systems.

6. Materials for advanced nuclear fuels and nuclear test capabilities

Nuclear energy has the lowest lifecycle carbon footprint of all energy sources, and the UK has a highly experienced sector, backed by a world-class regulatory system. Developing secure and cost-effective nuclear fuel supplies and test capabilities will expand nuclear power provision, improve national security and resilience, and develop new applications in space and other sectors.

CASE STUDY: **WIND TURBINE BLADES**

REDUCING THE IMPACT OF WINDFARMS ON RADAR SYSTEMS

The UK Government's Defence and Security Accelerator has funded projects for technologies to reduce wind turbine interference with radar signals, addressing a barrier to the offshore windfarms we need for net zero.

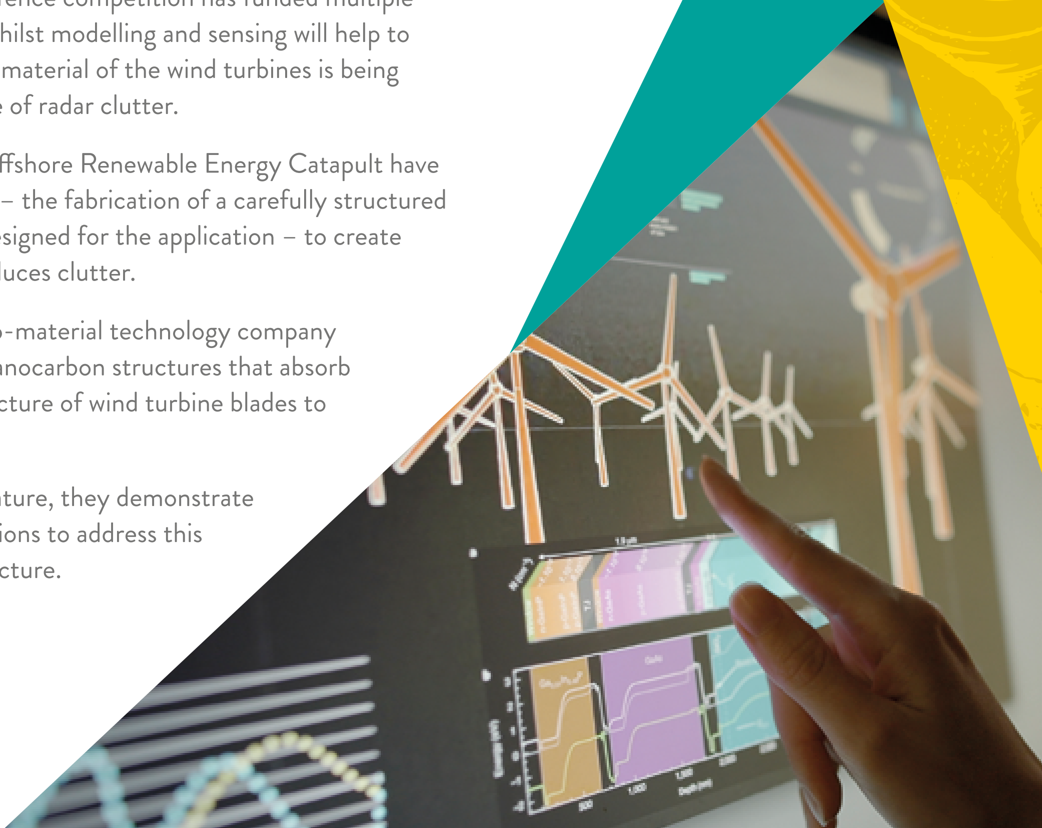
UK air defence systems are vital to national security and reliant on radar signals. Wind turbines can cause interference for radar systems, as their moving blades reflect electromagnetic radiation and generate radar clutter. This is limiting the location and scale of offshore windfarms.

The Windfarm Mitigation for UK Air Defence competition has funded multiple phases of research into this challenge. Whilst modelling and sensing will help to clean cluttered radar signals, the surface material of the wind turbines is being researched to directly address the source of radar clutter.

TWI, the University of Exeter and the Offshore Renewable Energy Catapult have explored using metamaterial technology – the fabrication of a carefully structured material with functionality specifically designed for the application – to create a surface for wind turbine blades that reduces clutter.

Advanced Material Development, a nano-material technology company based in Farnborough, have developed nanocarbon structures that absorb radar and can be integrated into the structure of wind turbine blades to reduce interference.

Whilst these technologies are not yet mature, they demonstrate the potential for advanced material solutions to address this problem using UK research and infrastructure.



DELIVERING BEYOND BIOCOMPATIBILITY FOR ACTIVE MEDICAL SOLUTIONS

FUTURE HEALTHCARE

Demand on health and care services is rising. The population both in the UK and globally is ageing, increasing the scale and complexity of their healthcare needs. As people live for longer, they are more likely to live with long-term health conditions and to be managing multiple conditions.

Technology innovations can improve the speed, accuracy and efficiency of the clinical pathway, from diagnosis to cure. All aspects of technology, from computing power to recyclability, will impact the future of healthcare, but the most specific opportunities for materials solutions lie in the development of biocompatible and bioelectronic materials.

These technology advances can also be applied to agriculture and soil health applications. Developments in biocompatible materials can further agritech solutions, like the high accuracy deposition of biofertilisers in a distributed system, and materials researchers serve both industries.

Opportunities in this theme

1. Biocompatible materials

These materials are engineered to interact with the human body whilst meeting rigorous safety standards. Whilst the UK market is relatively small, it is a high-value sector, the global market is significant, and demand and regulatory support for biocompatible healthcare devices is growing. Priority opportunities for material solutions cover a range of application-specific properties and manufacturing methods. These opportunities require a harmonised regulatory pathway to unlock materials innovation; the UK could compete for global development opportunities by providing this.

2. Materials for bioelectronics

In healthcare, bioelectronics are devices that directly interface with biological systems to monitor or modulate electronic signals in them. They are used to prevent, diagnose, monitor, treat and cure a range of conditions and diseases. The UK is active in bioelectronics research, producing around 11% of the world's scientific papers in the sector. If translated into commercial healthcare solutions, a significant proportion of this high-value market can be captured. New solutions for long-term (10 years or more) implantable materials, materials with ideal electrical properties, and materials to improve sensor performance in vivo are all in demand.

CASE STUDY: **BIOELECTRONICS IN HEALTHCARE**

GRAPHENE NEURAL IMPLANT

Startup INBRAIN Neuroelectronics is using a UK-born materials technology in their AI-powered system for treating neural disorders.

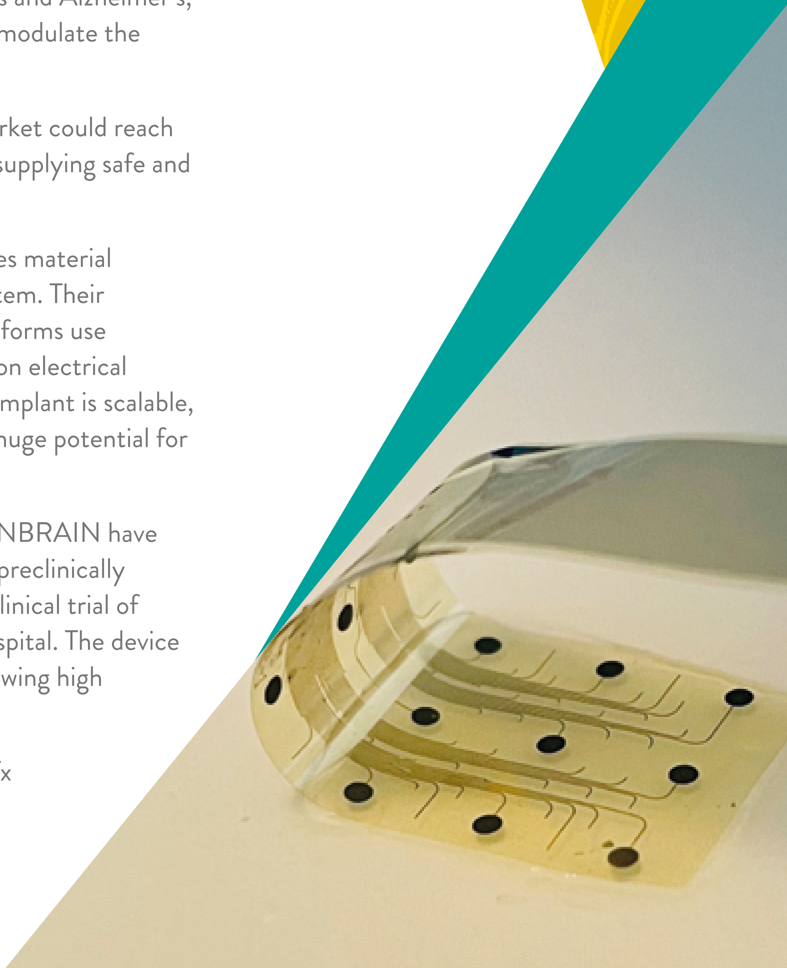
In 2022, the World Health Organisation found that neural disorders were the leading cause of disability and the second highest cause of mortality worldwide. These disorders, including Parkinson's, epilepsy, multiple sclerosis and Alzheimer's, can be treated with bioelectronic devices that connect with and modulate the electronic activity of the body's nervous system.

Royce's recent market analysis found that the bioelectronics market could reach up to £28 billion by 2030. Materials solutions will be central to supplying safe and high-performance bioelectronic healthcare solutions.

INBRAIN Neuroelectronics, based in Barcelona, Spain, combines material technology with AI in their end-to-end neurological implant system. Their implantable brain computer interface therapeutics (BCI-Tx) platforms use graphene for a thinner, more biocompatible, and higher-resolution electrical contact than conventional metal neural implants. The graphene implant is scalable, using existing electronics manufacturing techniques, and brings huge potential for large-scale deployment of neural therapies.

Graphene was discovered at The University of Manchester and INBRAIN have worked with the university to develop their implant, particularly preclinically and clinically. Their cortical neural interface is being tested in a clinical trial of glioblastoma brain tumour resection surgery at Salford Royal hospital. The device is differentiating neural activity to minimise brain damage by allowing high precision, personalised tumour resection surgery.

Following this trial, INBRAIN is planning to develop their BCI-Tx platform for Parkinson's disease therapeutic implants.



STRENGTHENING OUR INFRASTRUCTURE, BUILT ENVIRONMENT AND TRANSPORT SYSTEMS

STRUCTURAL INNOVATIONS

Engineering structures are the basis of an incredibly wide range of sectors, including transport, aerospace, the built environment, and energy. The performance of these structures is dependent on the mechanical properties of the materials in them, including strength, durability, thermal properties and density.

Improving these performance characteristics will enable economic growth in both the industries that produce these materials and those that use them. These improvements must also make them more sustainable, either by addressing their raw material requirements or increasing their longevity, transforming the footprint of a vast range of industries.

Opportunities in this theme

1. Materials for low-carbon construction
Civil construction is fundamental to our economy and society. It is also environmentally draining. There are huge opportunities to decarbonise the sector with new lower-carbon materials, longer lifetime materials, or improved energy efficiencies that also support occupant health. Improved standards and compliance processes are needed to create a more agile sector that can rapidly adopt new materials.

2. Materials for sustainable structural systems – composites
Composites provide essential lightweight, durable and high-performance structural solutions, including high-value applications in aerospace and defence, and high-volume applications in renewable energy systems and transportation. Sustainable composites with longer lifetimes and better recyclability are needed in multiple applications, and UK producers need a stronger, more resilient supply chain.

3. Metallic materials
Metallic alloys are of unparalleled strategic importance to the UK. The metals sector underpins many high-value industries, and itself is one of our most valuable. Innovation in alloy compositions and manufacturing processes is going to be critical for new and emerging technologies. These will have improved performance and circularity for applications in high-volume structures and in demanding environments, like those in energy, transport and aerospace.

4. Ceramic materials
Ceramics are a heritage material with a long history in the UK, traditionally used in construction and pottery. But the properties of ceramics – their chemical inertness, thermal stability, hardness, and low conductivity – make them increasingly prevalent in advanced systems, like telecommunications and energy. The UK should grow its capabilities in new, advanced ceramic compositions and commercialise new manufacturing processes.

CASE STUDY: **ZERO CARBON CONCRETE**

CLOSED-LOOP CEMENT PRODUCTION

Researchers at the University of Cambridge have patented a process for eliminating almost 90% of carbon emissions from concrete production and established a new business, Cambridge Electric Cement, to scale it.

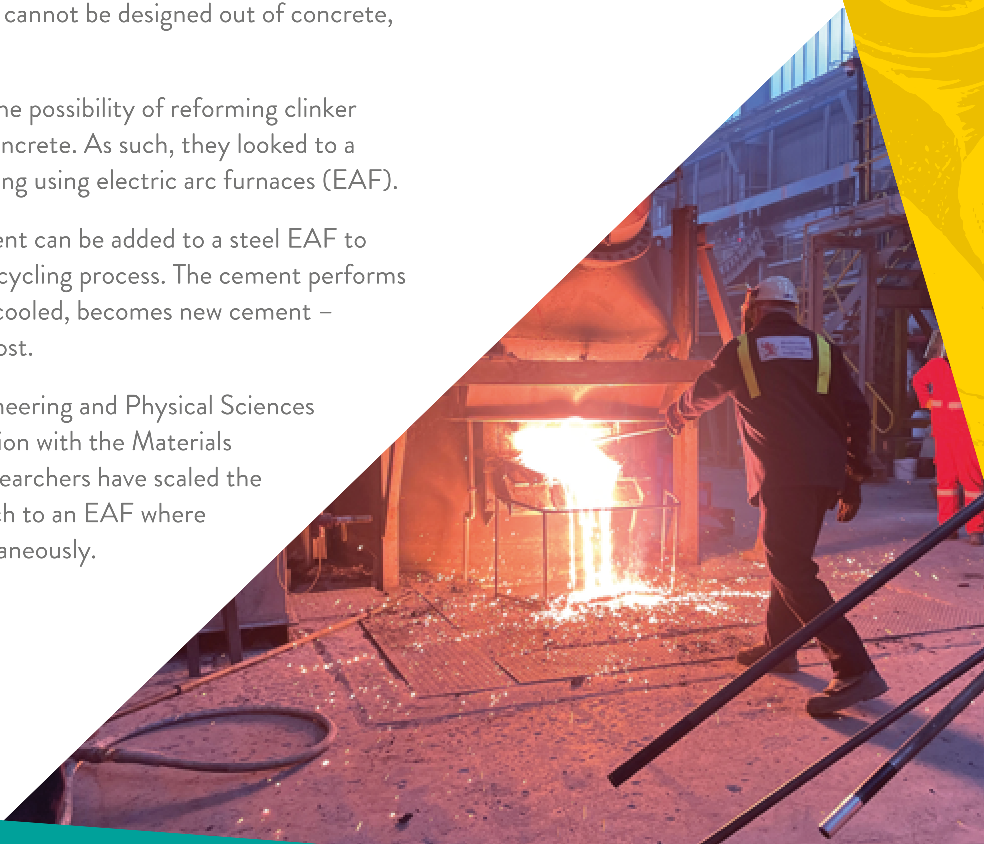
The cement that bonds concrete is made with clinker, a material produced by heating limestone and other materials to 1,450°C. It is an energy-intensive process and the chemical breakdown of limestone releases carbon dioxide.

These emissions are so large that cement production is the direct cause of 7.5% of global anthropogenic CO_2 emissions. Cement cannot be designed out of concrete, as it has no direct technical substitute.

Cambridge's pioneering researchers knew of the possibility of reforming clinker by heating old cement extracted from used concrete. As such, they looked to a green, high-temperature process: steel recycling using electric arc furnaces (EAF).

Their lab tests have proven that recycled cement can be added to a steel EAF to replace the lime flux required as part of the recycling process. The cement performs well as a flux substitute and afterwards, when cooled, becomes new cement – enabling a greener concrete at no additional cost.

With funding from Innovate UK and the Engineering and Physical Sciences Research Council (EPSRC), and in collaboration with the Materials Processing Institute in Middlesbrough, the researchers have scaled the cement recycling process beyond the lab bench to an EAF where recycled steel and clinker are produced simultaneously.



ENHANCING PRODUCT FUNCTIONALITY, PERFORMANCE AND LIFETIME

ADVANCED SURFACE TECHNOLOGIES

Surface engineering and the application of coatings improves the performance, functionality and durability of materials. These products are better able to withstand mechanical wear and corrosion or degradation due to environmental factors, including thermal, chemical and radiation conditions.

Surface engineering treatments range from simple paints to complex metallic depositions, ion implantation and diffusion processes. They play a key role in sectors with high economic potential, including energy, health and construction.

They often determine the lifetime of a product and can be applied to rejuvenate a structure. They can also add functionality such as reducing, or improving, conductivity or friction.

Opportunities in this theme

1. Materials and modelling for surface engineering and tribology

Surface degradation through corrosion and mechanical wear commonly causes failure in material systems across industrial sectors. Surface engineering treatments of manufactured products can increase their in-use life and reduce their lifetime cost and energy losses due to friction. Improving our understanding of material surface degradation and tribology by applying large data learning methods and high throughput testing will contribute to a step change in new, environmentally friendly and enhanced surface designs and coatings.

2. Surface treatments and materials for demanding environments

Many of our most advanced materials must perform in extreme environments of radiation, temperature and corrosion. Their durability and functional performance are integral to many complex structures across industry, transport and energy. They present a considerable challenge in materials design, processing and through-life management. Solutions are generally delivered by materials systems – high performance substrates with state-of-the-art surface treatments working in harmony to deliver the necessary functionality. There is an ever-increasing demand for these highly specialised systems in hostile environments. They can be delivered at pace with the application of digital innovations like rapid design and test methodologies, accompanied by innovative manufacturing methods.

CASE STUDY: **FROM DURABLE TO FUNCTIONAL COATINGS**

SCALABLE GREEN HYDROGEN ELECTROLYSERS

Green hydrogen will play a key role in decarbonisation. Teer Coatings and Imperial College London are developing surfaces for catalysts that will enable the large-scale roll out of this low carbon energy source.

Proton exchange membrane (PEM) electrolysers are highly suited to green hydrogen production. They can ramp up or down quickly, responding well to the variable levels of energy input from renewable sources. However, an essential component of PEM electrolyser catalysts is a layer of iridium, a rare metal. This reliance on a large quantity of a scarce resource is a barrier to the scaling of green hydrogen production to meet the needs of a low carbon economy.

Based in Worcester, Teer Coatings supplies high-performance durable coating technologies to industry, including the aerospace, automotive and energy industries. Thanks to Royce's EPSRC-funded Industrial Collaboration Programme (ICP), Teer Coatings have been working with Imperial College London to develop a coating of niobium-doped titanium as a host for dispersed and size-selected iridium oxide nanoparticles. Finding a stable and conductive material to support the iridium catalyst has the potential to dramatically reduce the iridium required in PEM electrolysers.

In collaboration with the University of Cambridge, various samples have been tested for degradation in conductivity and performance. This research has contributed to an improved understanding of the potential composition and nanostructure of a catalyst's surface for a scalable and durable green hydrogen electrolyser.

DRIVING THE FUTURE OF HIGH-PERFORMANCE CONNECTIVITY AND COMPUTING

NEXT-GENERATION ELECTRONICS, TELECOMMUNICATIONS AND SENSORS

Information and communication technologies are growing rapidly, enabled by advances in wireless technologies and battery energy storage. They consume nearly 10% of all energy globally. As demand for increased computing power grows, reducing their energy consumption is a priority.

Electronics enable all industries, and innovations in durability and efficiency can enable sustainable growth in different environments. Opportunities for innovation are emerging in organic electronics applications, in more efficient photonics technologies, and in high-power computing enabled by quantum technology.

Opportunities in this theme

1. Materials for power electronics

The power electronics market encompasses all components involved in the delivery of stable and reliable electrical power to systems. These devices are crucial to transport electrification, renewable energy systems, efficient consumer electronics, and organic electronics. The UK has existing strengths in these technologies – particularly in semiconductors and organic electronics – and once skills provision and supply chain resilience is developed, a global market opportunity is available to exploit.

2. Materials for quantum technologies

Quantum technologies use the behaviours of sub-atomic particles to achieve functionality and performance not possible using classical mechanics. They are recognised worldwide as having the potential to advance performance in computing, communications, sensing, imaging and position, navigation and timing. The materials innovation opportunities that will enable these improvements lie in microfabrication, nanofabrication and integration capabilities, as well as the high-fidelity and verifiable characterisation of manufactured quantum materials.

3. Materials for connectivity and telecommunications

Telecommunications is the backbone of modern industry and national security. It is an economically valuable sector and one that consumes a significant amount of energy – up to 3% of global demand. Increasing the efficiency of communication systems is an immediate priority. Significant economic growth opportunities also exist in applying disruptive materials innovation at the convergence of semiconductors and photonics by drawing on new technologies such as metamaterials.

CASE STUDY: **NEW ELECTRONICS CAPABILITIES**

SENSORS FOR EXTREME ENVIRONMENTS

Increasing demand for space-based systems, including for earth observation and communications, requires the development of high-precision electronics that can operate in extreme environments.

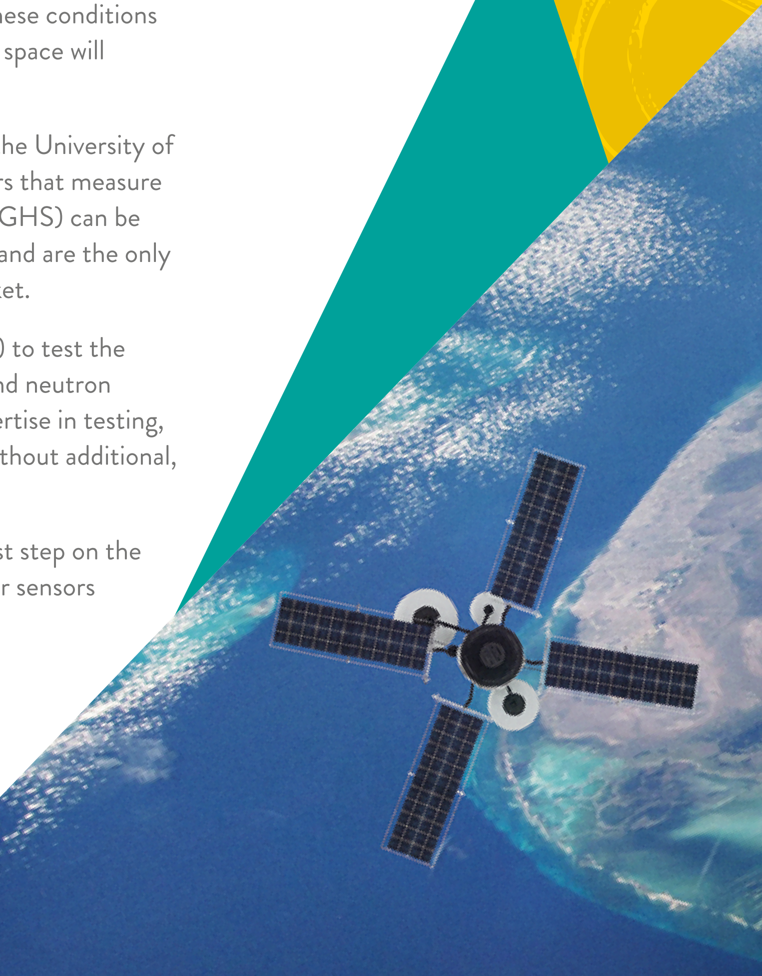
Satellites are subject to extremes in temperature and pressure, and to high irradiation environments. Electronic circuitry can degrade under these conditions and ultimately fail. Improving the performance of these systems in space will reduce the cost and environmental impact of satellite technology.

Founded as a spinout of the Department for Materials Science at the University of Cambridge in 2017, Paragraf manufactures graphene-based sensors that measure magnetic fields to a high resolution. Their Graphene Hall Sensors (GHS) can be produced using conventional semiconductor fabrication processes and are the only mass manufactured graphene-based magnetic sensors on the market.

Paragraf collaborated with the National Physical Laboratory (NPL) to test the performance of the GHS when exposed to high levels of gamma and neutron radiation. Using their experience with graphene standards and expertise in testing, NPL revealed that the sensors were able to perform to standard without additional, expensive radiation protection.

This understanding is opening up new markets for Paragraf, as a first step on the path to securing the required certification for the operation of their sensors in satellites and other machinery in space.

Paragraf's magnetic field sensors have also been proven to operate at cryogenic temperatures, unlocking sensing capabilities in areas such as quantum applications and particle accelerators, where electronics must operate at a temperature close to absolute zero with a range of magnetic fields from very small to extremely large.



PAVING THE WAY FOR A GREENER TOMORROW

CONSUMER PRODUCTS, PACKAGING AND SPECIALIST POLYMERS

Consumer products are made from a wide range of low cost, energy efficient materials of which the most prevalent are plastics. This class of material has become ubiquitous across multiple consumer products and industrial applications.

Plastics are also the material of choice for packaging due to their low weight, durability, impermeability, and sterilisation potential. However, most consumer products and packaging are single-use, and our production of materials for consumer applications currently outpaces our ability to manage it as a waste stream. More sustainable alternatives are needed to meet global demand.

Opportunities in this theme

1. Materials for sustainable packaging

International bans and consumer demand are driving the adoption of sustainable packaging and plastics. Key sectors, including food and drink, consumer goods, pharmaceuticals, health, retail, and industrial packaging, needs to move to sustainability sourced raw materials including bio-based polymers and post-consumer plastics. It is a priority for the UK to develop these approaches, alongside circularity assessments based on agreed environmental parameters and an enabling regulatory framework.

2. Speciality polymers: sustainable elastomers

Elastomers are used in many industrial applications. Improvements in end-of-life processing and recyclability of high-volume, lower value applications such as vehicle tyres and disposable medical gloves offer opportunities for new market growth. Significant growth opportunities also lie in developing elastomers for high-value applications in health, transport and defence that exploit the potential of their unique properties such as elasticity, high temperature resistance, chemical resistance and excellent sealing properties in mechanical systems.

CASE STUDY: **NEW CONVEYOR TECHNOLOGY**

EXTENDED LIFETIME CONVEYOR BELTS

Ecobelt's conveyor belt production technology creates stronger joints for a longer operating life, reducing the resource and energy demands of an essential but often overlooked technology.

From mining machinery to cash machines, materials and goods are moved using belts of all sizes all day, every day. The in-use life of a conveyor belt is typically determined by the performance of its splice joint. This joint is only a third of the strength of the main body of the belt and over 80% of belt failures occur at the splice.

Conveyor belts are environmentally harmful – they are manufactured from fossil feedstocks, consuming finite natural resources and generating over 2 billion tonnes of greenhouse gas emissions annually. They are not recyclable and are consigned to landfill or incineration.

Ecobelt is based in the town of Hyde in Greater Manchester. The business is motivated by a mission to tackle this invisible material flow and to reduce the economic and environmental impact of conveyor belts. Their patented AnnStuMax technology is a revolutionary new belt splicing technique that increases the strength of the belt joint beyond that of the rest of the belt.

Ecobelt used Royce's Sustainable Materials Innovative (SMI) Hub to independently verify the strength of the splice joints. A Life Cycle Analysis from the SMI Hub has also confirmed the environmental benefits of AnnStuMax.

FOUNDATIONS FOR GROWTH

A collective effort is needed to build the UK as the place to conduct materials innovation.

A connected, coherent and standardised materials innovation ecosystem will amplify the benefits of materials innovation activities and invigorate the sector, bringing agility to the manufacturing community and magnifying the impact of materials innovation activities.

This consultation has identified five cross-cutting priorities which will drive transformational change, delivering pace, dexterity and connectivity across the materials and manufacturing community over the coming decade.

Of these priorities, two – Materials 4.0 and sustainability – cut across every aspect of the sector. Addressing the opportunities which they afford in a cohesive national effort will deliver a sector that is world-leading.

The remaining three priorities have common roots across materials themes, but they require distinct interventions across the different opportunity areas.

Translation and manufacturing will require the application of joined up infrastructure and the targeted investment in national assets.

Skills and talent are critical to ensuring that the UK remains a global leader, particularly in the new areas of Materials 4.0 and sustainability.

An innovative policy framework and agile regulatory system tailored across diverse sectors will be that final essential international differentiator.

FIVE CROSS-CUTTING THEMES UNDERPIN ALL MATERIALS INNOVATION:

1. **Materials 4.0**
2. **Sustainability and the circular economy**
3. **Translation and manufacturing**
4. **Skills**
5. **Policy, regulations and standards**

CROSS-CUTTING THEMES:

MATERIALS 4.0

Transitioning to greater use of digital tools will accelerate materials innovation – drastically reducing the lead time to commercialisation – and enable the through-life analysis of materials innovations.

Materials 4.0 is an umbrella term for the ongoing transition to a digitally-enabled materials sector. This will be underpinned by a materials informatics framework that combines capabilities in materials modelling, large data, AI and machine learning, in silico modelling, manufacturing informatics, and life-cycle simulation.

Crucially, this framework will use current and historical data to model material characteristics and predict their performance. It will reduce the cost and duration of testing and validation, accelerating the rate of material development and scale-up while optimising real-time manufacturing.

During a product's use, digital fingerprints or passports of the provenance of component materials will ensure quality and traceability. This will enable circularity as well as unlocking growth in high-risk applications such as health, communications and energy.

These solutions require robust, trusted data management systems, the evolution of common approaches and skills across the materials community, and access to curated materials data with assured quality. A focused effort is needed to establish and implement this framework.

CASE STUDY: **MATERIALS 4.0 AND AI IN INNOVATION**

DIGITAL DISCOVERY OF ALTERNATIVE MATERIALS

Materials Nexus (MatNexus) used next-generation AI and machine learning models to predict an alloy composition with hard magnetic properties as an alternative to rare-earth magnets.

Royce at the University of Sheffield was able to produce and validate a sample of the alloy. This material could reduce the UK's reliance on the scarce, critical resources enabling many electronic and energy applications, including renewable energy generation.

The London-based SME worked with Royce at the University of Sheffield through the institute's SME access scheme. They have since launched a one-year, £700,000 Innovate UK-funded project to refine the modelling to explore and evaluate more rare-earth-free magnetic alloys.

CROSS-CUTTING THEMES:

SUSTAINABILITY AND THE CIRCULAR ECONOMY

It is a fundamental requirement for a resilient economy that our complex materials innovation landscape and supply chains are sustainable by design.

Materials solutions must use resources sustainably and take a system perspective that accounts for wider societal and environmental impacts. The climate crisis, global supply chain insecurities and national resilience demand a response from the materials sector.

Building sustainability into materials innovation should go hand-in-hand with clear government policy, national infrastructure and incentives to make the UK an attractive place to do business.

This strategy has identified the urgent need to develop a common framework for designing and assessing materials' sustainability and the systems in which they operate.

It must include solutions for prolonging the useful operation of existing assets, end-of-life options, robust life cycle assessments (LCA) based on agreed databases, and international sustainability measures. These will help innovators to make informed, transparent decisions about sustainable product design and manufacture.

CASE STUDY: **ENABLING THE CIRCULAR ECONOMY**

A WATER-SOLUBLE POLYMER

From their research and manufacturing facility in Birmingham, Aquapak have created Hydropol, a material with all the benefits of traditional plastics without the risk of contributing to plastic pollution.

Hydropol is a patent-protected technology with barrier and processing properties that make it ideal for packaging and fabrics. At end-of-life, it can be used in existing recycling processes, but if it does enter the natural environment, it biodegrades completely.

Hydropol can be used in conventional manufacturing processes and polymer manufacturers can adopt it without any adaptation costs. It can combine with other materials to improve their recyclability, meeting growing consumer and business demand for sustainable plastic products.

CROSS-CUTTING THEMES:

TRANSLATION AND MANUFACTURING

To generate value, new materials must be translated from the laboratory to commercial solutions manufactured at scale.

Too often in the UK, our materials research outputs are translated and scaled overseas, and the full value of innovation is not captured here.

Consistent access to appropriate investment is crucial to translating materials innovations into commercial solutions. Funding and finance options should be provided to innovators in a clearly structured framework across the necessary technology translation stages. This requires coordination across both public and private sector funding streams.

The majority of material innovation opportunities will require specialist infrastructure and knowledge to translate from laboratory to pilot scale and beyond; supporting proof-of-concept trials and de-risking ahead of any major capital investment.

It is paramount to leverage our existing materials research and scale-up infrastructure alongside the future specialist equipment and instrumentation needed by emerging material products. This infrastructure must be readily available and accessible to all UK materials innovators.

CASE STUDY: **SCALING SEMICONDUCTOR MANUFACTURING**

ELECTRONICS MADE IN THE UK

Pragmatic Semiconductor is pioneering flexible semiconductor technology to sustainably bridge digital and physical worlds.

Designed in Cambridge and manufactured in Durham, Pragmatic's FlexICs – flexible integrated circuits – have optimised, purpose-led design and sustainable innovation at their core. Ultra-thin FlexICs deliver connect, sense and compute capabilities, enabling item-level intelligence at scale. They use alternative materials to conventional silicon wafers, playing to the strengths of the UK's semiconductor industry.

In 2024, HRH The Princess Royal officially opened Pragmatic Park, the company's flagship manufacturing site in Durham, UK – home of the UK's first 300mm semiconductor fabrication line. The site's innovative manufacturing process offering rapid, sustainable production and has capacity to produce billions of FlexICs per year.

CROSS-CUTTING THEMES:

SKILLS

To transform productivity and the pace of materials innovation, we need people with the right skills to deliver it.

The materials sector faces higher-than-average skills shortages. Up to 75% of job vacancies go unfilled, compared to the UK average of 24%. Many in the workforce are retiring, and a relatively low proportion of STEM graduates enter the industry.

Some challenges, like curriculum reform, must be met at a national level. However, the materials sector is truly interdisciplinary and dependent upon a highly skilled STEM workforce.

As such, the sector must take responsibility and contribute to identifying current and future materials skills gaps, particularly at the interfaces between science and engineering and in the highest priority cross-cutting areas of Materials 4.0 and sustainability.

The community must also identify and articulate the career opportunities offered by the materials sector to grow its talented workforce and attract the next generation of innovators.

POLICY, REGULATION AND STANDARDS

The regulatory environment must deliver a supportive, flexible ecosystem for materials innovation by providing clarity, consistency and incentives.

The whole materials community needs government to:

- Provide a clear, consistent, but innovative regulatory environment that reduces barriers to entry, allows investors to plan and invest with confidence, encourages market competition, and enables collaboration.
- Encourage the agile development of innovative new regulatory frameworks for emerging technologies and regularly assess the impact of regulations on technology translation rates.

This strategy will see the materials community collaborating closely with policymakers and regulators to facilitate these outcomes.

IMPLEMENTATION

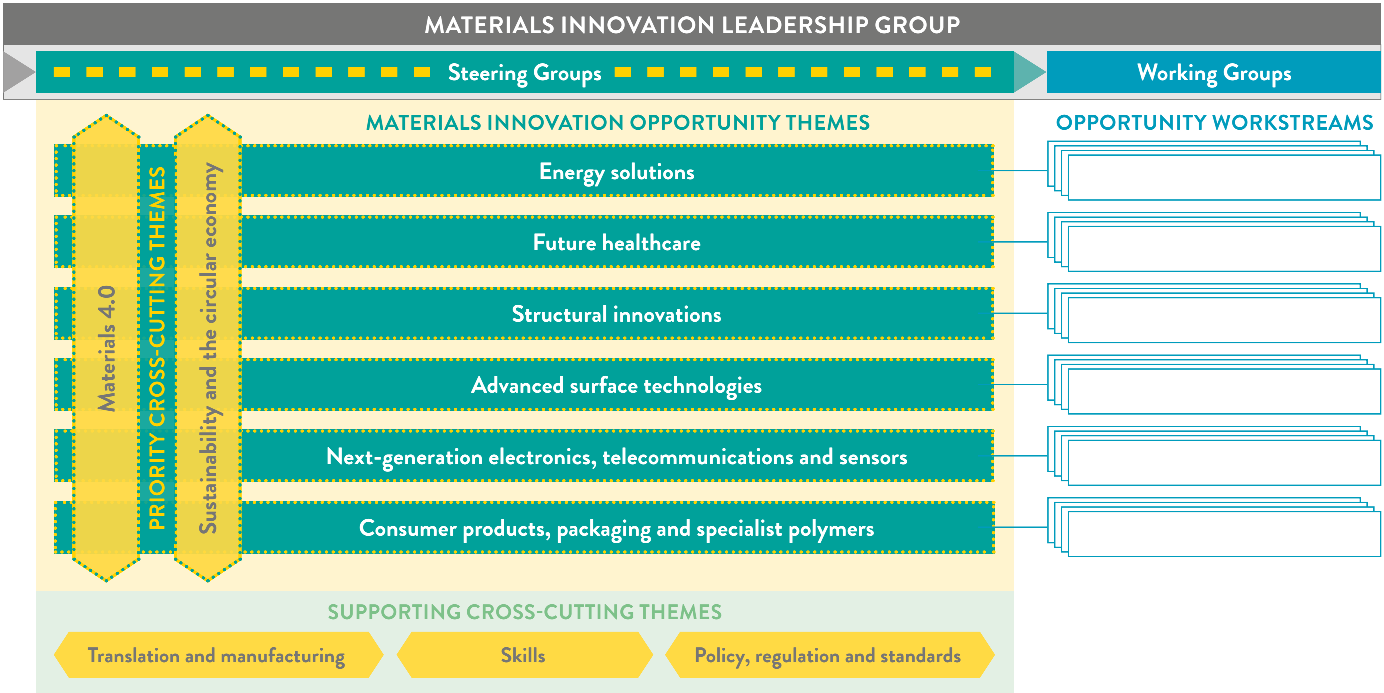
This strategy must proceed at pace using a progressive, flexible structure that brings oversight and coordination to the delivery of impactful programmes.

The Materials Innovation Leadership Group was established to develop the strategy. This team are committed to evolving their remit and engaging senior colleagues across the materials sector to implement the strategy.

The leadership body will chair a collection of future steering groups – cross industry-academia-funding bodies – each focused on one theme. These groups will have the flexibility to convene specialist workstreams that drive specific opportunities.

Materials 4.0 and sustainability are the cross-cutting priorities for the sector. They must be progressed by their own steering groups that draw common threads across the strategy's activities.

The remaining cross-cutting priority areas will be embedded into the individual opportunity themes. Translation and manufacturing, in particular, will address the dual requirements of attracting investment and providing the infrastructure needed to innovate at scale.



2025 AND BEYOND

In the coming year, this strategy will launch a major shift for the materials community.

Government, industry, researchers and investors will be collaborating on the themes that bind the community together and focusing their efforts on the largest opportunities for impact.

The coordinated approach will leverage the UK's existing strengths and infrastructure to accelerate materials development cycles, grow investment and drive economic growth in alignment with key long-term government objectives.

Royce will now work with the Materials Innovation Leadership Group and government to design and coordinate a detailed progressive delivery model for this strategy that will deliver dedicated programmes in a sustained push over the next ten years. These programmes will feed into the UK's ecosystem of sector, regional, investment, defence and technology strategies, actively complementing their aims.

Whilst this model will initially prioritise the opportunity and cross-cutting themes presented here, the overarching structure and function will be positioned to step up, transforming into a national programme. This will oversee a growing return on investment and an expanding remit for directing UK materials innovation.

Royce would like to invite anyone interested in contributing to the future of a responsive and valuable materials innovation ecosystem to join its strategy network. Those with wide-ranging industry leadership experience will be particularly welcome.

Please contact the strategy's team via info@royce.ac.uk

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HENRY ROYCE INSTITUTE

The Henry Royce Institute was established to ensure the UK can exploit its world-leading expertise in advanced materials and accelerate innovation from discovery to application. With over £200 million of facilities in dedicated state-of-the art laboratories, Royce is ensuring that academics and industry in the UK's materials community have access to world-class research capabilities, infrastructure, expertise, and skills development.

ROYCE.AC.UK

ScotChem

ScotChem is the strategic alliance for the chemical sciences in Scotland. We connect industry, academic expertise, government, the third sector, and the public. We promote and support chemistry-related industries and broker strategic partnerships to address critical challenges. Our aim is to enhance research impact and translation, drive innovation and increase economic prosperity.

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