HENRY ROYCE INSTITUTE

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MATERIAL FUTURES

Progress Report on the National Materials Innovation Strategy

APRIL 2024

FOREWORD

Materials have a key role to play in the UK's prosperity.

Materials is a profitable sector that invests in its future. Now more than ever, our drive for a more sustainable society is dependent on having the right materials at our disposal. This requires a step change in investment for innovation.

If the UK is to truly lead the world in materials innovation, then we must support the areas in which we already have a world-leading position and ensure that we can translate this position into commercial reality over the next five to ten years, creating the right conditions for commercial success.

This report charts the progress of the National Materials Innovation Strategy. It is the result of a real collective endeavour.

Under the guidance of the Materials Innovation Leadership Group, we have consulted over 1,200 materials innovators across a wide range of strategic industries to understand their materials-related challenges and needs, and to simultaneously surface the exciting cross-sector opportunities that, if exploited, will ensure the UK maintains a world-leading position in the rapidly expanding materials markets. Materials innovation companies operating in the UK currently generate a turnover of £1 trillion and employ 1.9 million skilled workers globally.

Materials are a real bedrock of the UK economy – but we can't deliver impact at pace for the UK without the support of a clear and concise National Strategy to ensure we are working towards aligned goals. By the end of 2024 we will have set out, for the first time, a consensus on the key interventions required which represent the needs of the wide materials innovation community.

Thanks must go to the members of the Leadership Group for their insights, and our strategy development partners ScotChem, Perspective Economics and Urban Foresight. We also wish to thank individuals who respond to our "call to arms", joining our Expert Working Groups to work together to shape the future of materials. The output will establish a thriving materials sector that is strongly rooted in the UK and delivers long-term benefits to society as a whole.

Allan Cook CBE
Chair of the Materials Innovation Leadership Group

Professor David Knowles
CEO, The Henry Royce Institute

MATERIALS INNOVATION

Materials innovation is a cutting-edge research and industrial discipline.

It involves both the discovery, development, refinement and commercial exploitation of materials, and the application of existing materials to a new process. In doing so, challenges at the heart of engineering and technology processes are overcome.

Materials affect every part of the economy – new or improved properties unlock economic growth, social prosperity and wellbeing.

Materials innovation is fundamental to achieving national priorities

- **Getting to net zero.**
- **Growing a high-wage, highly skilled workforce.**
- **Strengthening the UK as a global technology leader.**
- **Rebalancing the UK economy.**
- **Supporting national resilience and security.**
- **Enabling healthy, happy lives.**

The UK is the epicentre of modern materials revolutions

From the discovery of graphene to the development of new compound semiconductors, UK research and industry is instrumental in introducing high-performance materials to the global market.

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.

Materials form the physical basis of all products and services. Their performance guarantees the functionality, durability, safety and environmental compatibility of all industries, and defines the potential of emerging sectors.

Because they have such a broad influence, materials present a particular challenge in focussing the efforts of policy makers, research funders and industrial leaders.

MATERIALS AFFECT EVERY PART OF THE ECONOMY. MATERIALS WITH NEW OR IMPROVED PROPERTIES UNLOCK ECONOMIC GROWTH, SOCIAL PROSPERITY AND WELLBEING.

ECONOMIC LANDSCAPE

Materials innovation contributes £45 billion each year to the UK economy and employs more than 635,000 people in over 2,500 companies.

Materials innovation also generates investment. In the last 3-year period, it secured an average of over £2 billion each year in external private and public funding for innovation activities within the UK.

UK MATERIALS INNOVATION

COMPANIES **>2.5K**	EMPLOYMENT P.A. **635K**
GVA P.A. **£45bn**	R&D P.A. (2019–22) **£2bn**

UK companies span the entire materials innovation value chain, with manufacturing engineering firms accounting for one-third of identified companies.

The commercialisation of materials drives economic growth in smaller, regional businesses:

90% of identified companies are SMEs, with fewer than 250 employees. 74% have fewer than 50 employees.

70% are registered outside of London and the South East.

Materials innovation translates into good jobs, inclusive growth, and better social and economic outcomes across UK regions.

Location of UK companies active in materials innovation

STRATEGY FOR ACTION

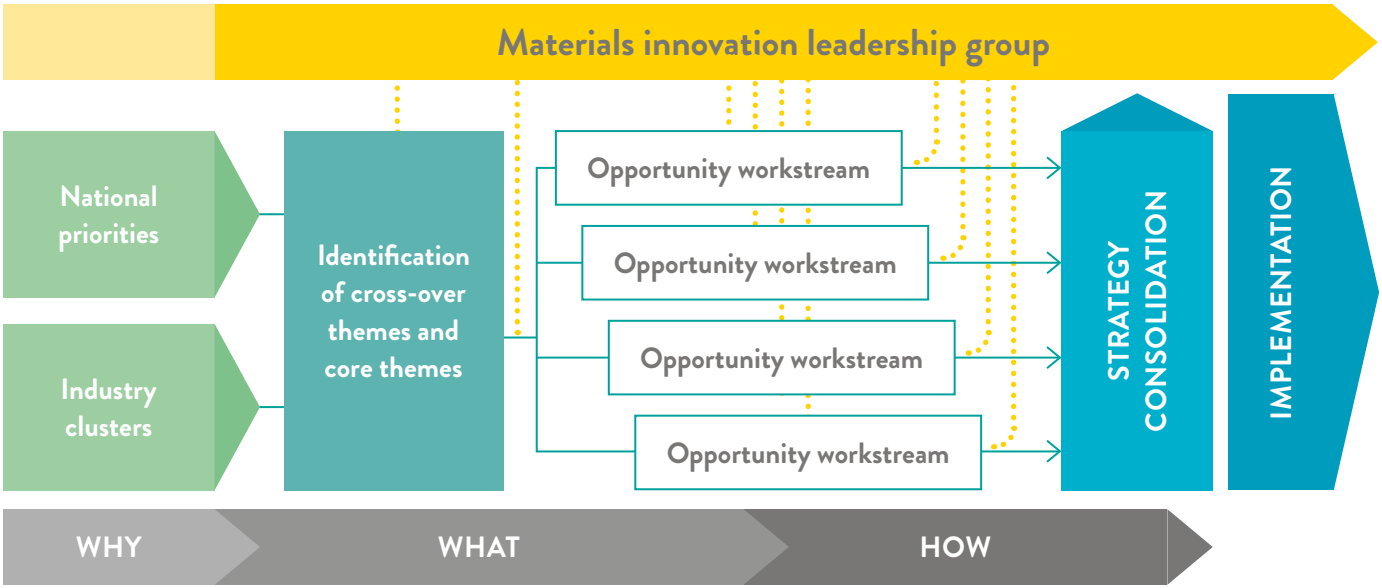
This National Strategy identifies unique opportunities that materials innovation offers to solve societal challenges and realise new economic activity in the UK.

It is a specific, clear, and standalone National Strategy for Materials Innovation that provides coherency through government, industry and the materials research community. Actions identified in this strategy will be sustained over the 5–10 years needed to deliver a step-change in the sustainable use of our resources.

The strategy's development is systematic, challenge-led, and dependent on the input of a diverse set of stakeholders.

Constant interaction with materials leaders was designed into the strategy's development framework. So far, the Materials Innovation Leadership Group and industry stakeholders have been consulted to identify:

- **6 cross-over themes** that affect all applications and sectors.
- **6 core themes** of high-priority material applications or properties.
- **30 opportunity workstreams**, the specific innovations that can deliver solutions.



CASE STUDY: THE POTENTIAL OF MATERIALS INNOVATION

ENVIRONMENTAL IMPACTS, SUSTAINABILITY AND NATIONAL RESILIENCE

The sustainable creation, use and disposal of resources is a core, global priority that affects the whole materials sector.

The environmental impact of specific materials classes is leading to necessary legislation at an international level. This presents an opportunity and a challenge to the UK's national resilience as its markets react to new requirements for accessing imports of critical resources and exports of controlled substances.

Alternatives to per- and polyfluoroalkyl substances (PFASs)

PFASs are widely used group of over 5,000 chemicals that are repellent to heat, oil, stains, grease and water. Consumer and industrial products both use these chemicals, from waterproof clothing and kitchen appliances, to medical devices and wind turbines.

Components of PFAS chemicals degrade extremely slowly. These persistent substances have been dubbed "forever chemicals" and they pose a risk to human health due to their toxicity and their irreversible exposure and accumulation in the environment.

The US and the EU are in the process of introducing restrictions on PFAS manufacturing, use and import. The US has developed a PFAS Strategic Roadmap which restricts these chemicals and the EU is proposing widespread restrictions that would significantly limit the manufacturing, use and import of PFASs across a wide range of sectors.

The UK's ability to implement alternatives will have a major impact on key current and future technologies including, for instance, in cryogenic seals that will be critical to a hydrogen economy. Equally importantly, exports of products to existing markets will be seriously compromised as a large range of products are banned from the market.

This can be viewed as a significant opportunity for the UK to develop new materials with equivalent performance to tackle the global problem of PFASs' environmental risks. A dedicated programme or initiative to address this challenge is needed, before it impacts all our sectors of industry.

MEETING THE NEEDS OF INDUSTRY

Over 1,200 stakeholders contributed to identifying the key materials innovations required by industry.

Across industries and sectors, there are six common material applications or properties that present opportunities for innovation.

CORE THEMES

1. **Energy materials**
2. **Soft materials**
3. **Biocompatible materials**
4. **Structural materials**
5. **Materials for surface enhancement and protection**
6. **Materials for electronics, telecommunications, sensing and computing technologies**

The opportunity workstreams under each core theme are areas identified as needing specific, focussed action to strategically meet the needs of industry.

In the full-length version of this report, each opportunity workstream has been built out in more detail to define innovation focus areas and potential solutions to pursue.

TO LEARN MORE, PLEASE FOLLOW THIS QR CODE OR LINK TO THE FULL INTERIM REPORT.

royce.ac.uk/collaborate/innovationstrategy

CORE THEME ONE:

ENERGY MATERIALS

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 has clear strengths in this area. UK materials innovation could not only lead global efforts to decarbonise the energy sector and meet our own national commitments to net zero carbon emissions, but could generate widespread economic benefits for the UK.

Priorities

Improving electrochemical and heat exchange energy and power systems, creating practical and diverse energy-harvesting devices, and converting energy from one form to another more efficiently for both small- and large-scale energy conversion systems.

Opportunity workstreams

- Materials for electrochemical energy storage – batteries for grid-scale to domestic applications.
- Electrochemical energy generation – fuel cells, electrolysers, super-capacitors.
- Innovative heat exchange, storage applications and waste heat recovery.
- Materials for energy-harvesting including photovoltaic and piezoelectric.
- High-voltage electrical transmission.
- Recyclable, low-Rare Earth Elements magnetic materials.
- Advanced nuclear fuels.

CORE THEME TWO:

SOFT MATERIALS

Soft materials are those that can be deformed by stresses at ambient temperature. They are widely used across most sectors and include liquids, polymers, foams, gels, colloids, and granular materials.

Many soft materials such as plastics are easy and inexpensive to make, and are commonly used across multiple applications. However, our production of these materials currently outpaces our ability to manage it as a waste stream. A more sustainable alternative is needed to meet global demand.

Priorities

Developing and manufacturing sustainable soft materials that enable circularity in sectors from packaging and elastomers to textiles.

Opportunity workstreams

- Materials for sustainable packaging.
- Materials for sustainable elastomers for high-performance applications.
- Materials for sustainable textiles.
- Soft materials for robotics and haptics.
- Materials to replace per- and polyfluoroalkyl substances (PFASs).

CORE THEME THREE:

BIOCOMPATIBLE MATERIALS

The medical, healthcare, life sciences and agriculture industries are major societal priorities. Components of medical devices, implants and other products that interface with biological systems are reliant on biocompatible materials.

These are materials that can act as part of a living system or function in close contact to a living system, and it is a market with significant growth potential. Even beyond the large market for conventional, passive devices and implants, bioelectronic devices are developing as a field for medical diagnostics and therapeutics that can address chronic diseases – a challenge for our ageing population.

Priorities

Developing materials appropriate for healthcare applications, possibly by applying nascent fabrication technologies – including additive manufacturing, bioprinting, and reverse tomography – to create complex and small-scale geometries.

Opportunity workstreams

- Materials to enhance soft tissue and wound repair and procedures.
- Bioactive materials for soft implants.
- Biocompatible materials for hard implants.
- Bioactive materials for wearables.
- Materials for drug delivery, including in paediatric and geriatric applications, and for nutrient delivery, including in agricultural applications.

CORE THEME FOUR:

STRUCTURAL MATERIALS

Engineering structures are the basis of an incredibly wide range of sectors, including – for example – transport, the built environment, aerospace and energy. The performance of these structures is based on their mechanical properties including strength, durability, thermal properties and weight.

Innovation to improve structural material characteristics will enable economic growth in both the industries that produce these materials and those that use them.

Priorities

Improving the performance characteristics of structural materials to make them more sustainable. This can be achieved by: making structures more lightweight, improving performance (particularly in extreme environments), designing materials for circularity, reducing the material complexity, and improving probabilistic prediction of the performance of structural materials in service.

Opportunity workstreams

- Sustainable structural materials for all sectors ranging from metallics to composite systems.
- Specialist structural materials for demanding environments such as in nuclear fission and fusion reactors.
- Materials for hydrogen storage, sensing and distribution.
- Low carbon construction materials including concrete.

CORE THEME FIVE:

MATERIALS FOR SURFACE ENHANCEMENT AND PROTECTION

Manufactured surfaces are made more durable by surface engineering and applying coatings. Such modified products are better able to withstand mechanical wear and corrosion or degradation due to environmental factors, including thermal, chemical and radiation.

Surface engineering treatments range from simple paints to complex metal depositions. They play a key role in sectors with high economic potential, including energy, health and construction. They are also subject to environmental restrictions, and some coatings that are currently in use require replacing.

Priorities

Protecting and enhancing surface performance and longevity through innovation in corrosion resilience, friction and wear behaviours, and computational modelling of surface interactions.

Opportunity workstreams

- Materials for surface protection and enhancement.
- Materials for tribology (friction and wear) and surface engineering.
- Improved models of degradation and corrosion.

CORE THEME SIX:

MATERIALS FOR ELECTRONICS, TELECOMMUNICATIONS, SENSING AND COMPUTING TECHNOLOGIES

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, and, as demand for increased computing power grows, reducing their power 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 growing in organic electronics applications – including in bioelectronics and solar PVs – and in more efficient photonics technologies.

Priorities

Reducing or optimising power consumption and energy dissipation. Expanding operating parameters, especially temperature.

Opportunity workstreams

- Materials for power electronics.
- Materials for organic electronics.
- Materials for optimised computing, including quantum and neuromorphic computing.
- Materials for data storage.
- Materials for telecommunications, including radio frequency and optical.
- Materials for advanced electronic sensors and instrumentation, including robotics, haptics, and the Internet of Things.

ENABLING MATERIALS INNOVATION

The engagement with the materials innovation community also identified cross-over themes. These are priority areas for innovation in enabling capabilities that apply to all sectors.

Innovation will require a national effort to address the challenges that researchers and industry experience in these six themes.

CROSS-OVER THEMES	CHALLENGES
Sustainability and the circular economy Designing, producing and regulating materials for whole life-cycle sustainability and circularity.	• Sustainability • Recycling, reuse and recovery • Multi-purpose and fewer components • Unified life-cycle analysis • Alternatives to restricted substances • Bio-inspired materials, including polymers, resins, biocatalysts and nanomaterials
Materials 4.0, digital thread and AI Using digital and data tools to intelligently accelerate materials discovery and application, and to design, monitor and manage performance across material life-cycles.	• Accelerated materials discovery and application using big data and AI • Digital twinning • Digital passports • Probablistic prediction of performance and improved modelling
Skills Creating an appropriately skilled workforce through re-skilling, up-skilling and developing new skills capabilities.	• Skills provision • New skills • Up-skilling
Critical minerals and materials Developing robust material supply chains that can withstand pressure from global instability and shocks from climate events.	• Supply chain resilience and sovereignty
Manufacturing and scale-up Creating capabilities to test, verify and scale-up materials solutions.	• Rapid test facilities and corresponding protocols, standards and regulations • Mid-scale facilities for manufacturing trials and/or qualification
Policy, regulation and standards Fostering a regulatory environment that is conducive to materials innovation.	• Embedding sustainability in regulations • Common standards and tools • Rapid certification

CASE STUDY: THE POTENTIAL OF MATERIALS INNOVATION

DIGITAL AND AI

Computational tools will revolutionise how materials are discovered, developed, validated and managed.

The cross-cutting capability to coordinate and analyse knowledge of materials using digital tools is called Materials 4.0. It will enable powerful and accelerated exchange of materials understanding, breaking down traditional sector barriers and revolutionising how and where materials are discovered and applied.

Rapid Materials Discovery

Commercialisation of a new material can take up to 20 years. Using digital and AI tools, the composition and characteristics of materials could be mapped, accelerating their identification and cutting initial discovery times.

This would unlock the rapid development of new materials against desirable performance metrics including mechanical and functional properties and a reduced carbon footprint. Combined with major investments in high fidelity testing capabilities in the UK, a new paradigm in materials innovation will arrive.

Modelling

Degradation and corrosion of materials and material systems, including general corrosion, creep, oxidation, stress corrosion cracking and fatigue, are significant issues across multiple applications. Improved modelling of degradation and corrosion will enable the development of more refined material systems with enhanced performance and sustainability.

Digital Product Passports (DPPs)

Across all industry sectors, the circular economy offers a solution to the key challenge of drastically improving the sustainable use of resources. Circular economies recycle and re-use end-of-life products. It not only requires the materials and processing technologies, but supporting systems for:

- Identification and tracking of material origin and use.
- Validation of material circularity, including the proportion of recycled materials in products.

Legislative mechanisms are developing to define the requirements of a circular economy, including the EU's Carbon Border Adjustment Mechanism (CBAM) which defines the monitoring of carbon leakage in a system.

Digital Product Passports (DPPs) will be a necessity for truly circular economies. Using Web 4.0 technologies, they will provide a single, accurate source of data on the material composition of products. The DPPs will be a secure, absolute record of a product throughout its life-cycle.

NEXT STEPS

This strategy provides recommendations for building the UK's capacity for materials innovation.

It relies on the input of experts.

In the next project phase, in-depth exploration of the opportunity workstreams will result in specific recommendations and sub-strategies to address these pressing challenges.

These will be incorporated into the National Strategy for Materials Innovation, an action plan for building the foundations for an innovative materials community that captures value here in the UK.

PLEASE COMPLETE THIS FORM TO EXPRESS YOUR INTEREST IN JOINING OUR EXPERT WORKING GROUPS

FIND OUT MORE

royce.ac.uk/collaborate/innovationstrategy

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.

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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.

SCOTCHEM.AC.UK

Perspective Economics

Perspective Economics is an economic research consultancy specialising in understanding the economic profile of emerging technologies and sectors. Perspective Economics provides research, analysis, and advisory services across various sectors, with expertise in innovation, technology, and policy evaluation.

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Urban Foresight

Urban Foresight is a multidisciplinary innovation practice dedicated to accelerating the next generation of technologies, services and policy frameworks for places. We work with ambitious organisations around the world on projects that improve lives, protect the environment and boost local economies.

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