Advanced Materials call for evidence: IOM3 Submission

The Institute of Materials, Minerals and Mining (IOM3) is a major UK science and engineering institution, a registered charity and is governed by a Royal Charter. IOM3 is the professional body for the full materials cycle from extraction, through processing and application, to end of life management, with around 15,000 individual members.

Executive summary

Advanced materials – and materials, minerals and mining more widely – are fundamental to our economy and in addressing many of the societal challenges we face such as the climate crisis, healthy ageing and global competition. Many of the technologies we are counting on to reach net zero greenhouse gas emissions rely on advanced materials, and the extraction and processing of materials is responsible for significant greenhouse gas emissions. Substantial parts of medicine and health protection rely on novel materials and novel applications, such as hip replacements, anti-viral surfaces, or implanted devices. Advanced technologies like smart phones, quantum computing and nuclear fusion are dependent on the materials used to build them.

As our understanding improves of how materials work at the atomic and molecular level, we are better able to design and engineer new materials to meet new needs, often at lower economic or environmental cost. Understanding and predicting how materials react and corrode in challenging environments – for example at sea, in a nuclear reactor, or in a rapidly charging battery – is fundamental to the safe operation of many systems and can also help us prolong service life. Linked to this is the need to ensure materials used for infrastructure are resilient to future climate change.

There is an increasing urgency for the development and application of a range of new and advanced materials to meet global challenges. The timescales to bring new materials to market need accelerating. Today, implementing new materials often takes more than 20 years – we need to learn from the COVID 19 vaccine experience and develop materials at multiple levels in parallel rather than in sequence and take advantage of new computational tools.

IOM3 welcomes the steps being taken to develop a more strategic approach to advanced materials, including this call for evidence. A wider consideration, however, of materials and resources is needed. The extraction and conversion of materials to goods and services underpins our economy and our society, and needs to be considered holistically if the UK is going to remain competitive, innovative and wealthy. The full supply chain must be considered, and a strategic view of our future needs is essential. A more joined-up and strategic approach would bring a much-needed structure and focus to materials sourcing, research, development, testing and regulation to ensure maximum benefit to the UK economy and society. The UK is home to world class universities, institutes and facilities and these are complimented by centres of excellence in various materials technologies across the regions of the UK. This strength must be built on to help the UK to develop its materials processing industry so that it can capture as much value for its own economy as possible and compete more successfully in global markets.

For the opportunities for advanced materials to be truly realised, a cultural shift is required to properly value materials and their contribution to society and the economy. The significant and concerning skills and talent gap must be addressed to ensure an appropriately skilled and diverse workforce and talent pool, including a capable talent pipeline, embedding advanced materials into current courses, support for upskilling and reskilling and ongoing assessment of future skills requirements.

1. Are there any challenges and/or opportunities for UK Advanced Materials?

Challenges

I. Scope and definition

IOM3 welcomes the steps being taken to develop a more strategic approach to advanced materials, including this call for evidence. A wider consideration, however, of materials and resources is needed. The extraction and conversion of materials to goods and services underpins our economy and our society, and needs to be considered holistically, with coordination across government, if the UK is going to remain competitive, innovative and wealthy. The evidence gathered should therefore be viewed alongside, and in combination with, work being done on materials more widely such as the upcoming critical minerals strategy with a view to creating a UK materials strategy.

The call for evidence does not seek responses that try to define advanced materials, however this remains a significant challenge and risk for a number of reasons, including:

- if feedstock materials and the full supply chain are not considered, this will severely impede the use and confidence in advanced materials. This is both because materials will be required to feed into the development of advanced materials and also the application and use of advanced materials oftentimes relies on interaction and combination with other materials
- if the term is used for 'new and novel materials' 'at the frontier of scientific progress', there is then the question of when a material becomes no longer advanced, it also risks focus being skewed solely towards research whereas the full pipeline to commercialisation must be considered
- whether a material is considered 'advanced' can depend on its application and use rather than the material itself in isolation
- advanced processes, technology and systems should be considered
- advanced materials form part of a wider system and considering a material in isolation risks unintended consequences

II. Collaboration and overcoming segmentation

At present, activity is too uncoordinated to successfully deliver the required focussed developments at the pace needed. Greater collaboration and more joined-up thinking and strategic planning is essential, encompassing all levels and better linking academia, industry and government, including between:

- academic departments and institutions: IOM3 members have acknowledged there can be a competitive nature between institutions and even different academic departments within the same institution
- academia and industry: support to facilitate translating academic research into industrial applications is required. IOM3 members noted that there can be a negative perception in academia about working with industry. Conversely, there can be a perception in industry that the timescales for materials development, screening and implementation can be slower than is required by industry.
- government, academia and industry: a government strategy backed up by the required support should be developed, informed by academia and industry, and in consultation with the full value chain.
- industry: collaboration across supply chains or between small and medium sized enterprises (SMEs) and large organisations can bring a wide range of benefits
- government teams, units and departments: collaboration between the different teams working on materials such as advanced materials, critical minerals and the foundation industries is imperative, as well as across units and across departments due to the underpinning and cross-cutting nature of materials. Departments with significant interest include, but are not limited to:
    - Department for Business, Energy & Industrial Strategy (BEIS) – development and application of advanced materials and their role in decarbonisation
    - Department for Environment, Food & Rural Affairs (Defra) – end of life management and the potential role of advanced materials in environmental protection and improvement
    - Ministry of Defence (MoD) – significant application opportunities for advanced materials as highlighted as part of the Integrated Review and the 'Materials for Strategic Advantage Programme'.
    - Department for Transport (DfT) – applications in transport and future transport systems
    - Department of Health and Social Care (DHSC) – including for hygiene, personal health, implants, bioelectronics and biomonitoring
    - Department for Education (DfE) – future talent pipeline

III. Commercialisation in the UK

a. Ensuring a complete pipeline for advanced materials

A significant challenge and concern from the UK materials community is the need for greater pull through from academic research to UK based industry. Any future strategic planning for advanced materials must consider and support all technology readiness levels (TRLs). The UK has great strengths TRL 1-3 but there is a requirement for further understanding, support and investment to scale up and pull through to TRL 4-6. A complete pipeline through the TRLs is required to enable manufacturers to access materials and technology that is mature enough to be implemented into industry without significant risks. This will require additional and strengthened intermediate institutes to accelerate the development of materials through to use. Catapult networks offer substantial benefits and could be further enhanced with greater integration and innovation below TRL 5.

In the UK, greater emphasis and value is often placed on fundamental research that might lead to a new breakthrough rather than research that addresses manufacturing or technology problems. There is excellent research and creative momentum and activity but transitioning from lab to pilot to manufacturing is lacking, with the proof-of-concept stage presenting significant challenges. Funding research with industrial content is not as apparent or successful as it needs to be, and even to the extent that IOM3 members noted there can be a perceived aversion to funding research with industrial content. In addition, there is a question around whether current metrics such as those used in the peer review process focus too heavily on discovery science and neglect potential exploitation into industry.

A strategic plan and link between industrial and academic strategy is required to address the scattered capability and lack of mechanism to execute strategic intent through to funding. There are positive instances emerging where industry links are more valued such as the UKRI Transforming the Foundation Industries Research and Innovation Hub (TransFIRE), managed by EPSRC, but development of such links requires acceleration and greater attention.

Availability of appropriate and diverse talent will be vital in ensuring a complete pipeline for advanced materials. IOM3 members have expressed concerns about the impact of the low availability of materials skills and resource, which results in reduced activity, reduced visibility and reduced recruitment and interest, further exacerbating the issue – more information can be found under the 'skills' heading in response to question 4.

b. UK based manufacture

Processing and manufacturing capability is required in the UK to transform materials into economically viable and useable products. The UK's manufacturing industry and supply chains have been hollowed out with the domestic market for advanced materials notably smaller than in other countries. This can have additional layers of complexities and impacts for materials that are dual use.

Many businesses from multinationals to small and medium-sized enterprises regularly choose global locations such as Canada, Germany or Japan for high value late-stage research and development (R&D) activities and technology that is developed in the UK is often acquired by overseas companies. Failing to maximise the benefits from R&D investment and pushing industry overseas, with its associated jobs and economic benefit, reduces the skills pool in the UK and has a negative feedback loop of making the UK less attractive for future investment.

c. Commercialisation of dual use

If a material or product is considered dual use, it significantly affects the ability to trade and collaborate between countries. The NSI Act plays an important role but the investment it blocks is significantly hampering the materials development community. Funding is required to take TRLs 1-3 through to TRLs 4-6 or there is a risk opportunities will be moved overseas. It is currently not clear where this funding might come from, and government could do more to address this issue.

IV. Resilience and security

Weak UK based supply chains, international pressures affecting access to materials, a lack of UK based manufacturing capability and a reliance on imports all affect the UK's resilience.

The entire materials supply chain needs to be considered, from raw materials to end-of-life, to maximise the benefit to the UK economy and improve resilience and security.

V. Data, regulatory environment and standards

Accurate and verifiable data and access to this quality data is essential. Without it, advanced materials development and deployment will be significantly limited. Data informs design choices, guides purchasing decisions and provides a vector for assurance relating to a range of factors such as safety and sustainability.

A significant challenge faced by materials design engineers is the lack of literature on choosing the correct algorithms for dealing with different types of data that cover various aspects of application of artificial intelligence algorithms to real-world problems. Shared access to public databases created through government could substantially help to address this challenge.

An appropriate regulatory and standards environment will be required to allow and encourage the safe, secure, timely and transparent use of new materials technologies. Certification, testing and structural integrity assessment procedures will be required and need to be developed and/or adapted where they are associated with traditionally used materials to enable advanced materials to be an accessible option.

Without quality data and a suitable regulatory and standards environment, there is a significant challenge and barrier to the uptake of advanced materials, and legacy materials will continue to be chosen in favour due to their perceived lower risk and data availability (for example to demonstrate 'green' credentials and safety).

VI. Cultural value of materials, recruitment and skills availability

There is an apparent low cultural importance of materials in the economy and society in the UK. IOM3 members noted that public and media discussions around materials can commonly focus on negative impacts such as emissions and material pollution. There is a need for cultural change and a shift in the narrative to ensure materials are properly valued and recognised for their far-reaching benefits and their role in underpinning our society and economy.

The perceived unattractiveness of materials science and engineering negatively impacts recruitment and retention in both industry and academia. What's more, IOM3 members noted that materials risks losing its profile within academia. There is concern about a cycle developing of knowledge and experience depletion and therefore a decline in interest and advocation, resulting in fewer opportunities and a reduced talent pool, further perpetuating the issue. More information can be found under the 'skills' subheading in response to question 4.

Despite strengths and significant knowledge at the research level in the UK, IOM3 members noted that there is a lack of available knowledge about materials, in particular advanced materials, that is accessible elsewhere. For example, in construction, the majority of decisions are locked in at the architect and architectural technologist stage, with aspects then engineered out, typically based on price, throughout the chain. Access to the right knowledge and skills at this stage is needed or advanced materials will be excluded from decisions and opportunities missed.

VII. End of life management

End of life management for advanced materials and technologies must be considered at the design stage and relevant information passed through the supply chain to ensure its proper management when it reaches the end of its useful life. This is particularly important as materials may look visually similar but have different properties and therefore require different recycling approaches.

UK infrastructure and end markets for recycled materials are required to ensure this valuable resource is captured and not exported. This will also help to improve the quality of recycled material for example, through standards and greater data capture, meaning it can be fed back into processes more easily and effectively.

Opportunities

I. A cohesive strategy

A UK advanced materials strategy, as part of a wider UK materials strategy, would bring a structure and focus to materials sourcing, research, development, testing, and regulation to ensure maximum benefit to the UK economy and society. It would link together the different government departments with an interest in materials and would ensure coordination and collaboration between UK industry and the world-class research and development ecosystem. It would help the UK to develop its materials processing industry so that it can capture as much value for its own economy as possible and compete more successfully in global markets. A longer-term strategy would help to provide confidence In investment and planning for skills and jobs. There are many horizontal topics where a strategy would add value including materials 4.0, future materials needs, materials sustainability, materials supply chain resilience and materials durability.

II. The transition to a low carbon, resource efficient society

Advanced materials are critical in the transition to a low carbon, resource efficient society. Materials science and innovation underpins every one of the government's 10-point plan for a green industrial revolution[1] with wide ranging applications from improving infrastructure resilience to climate change, to alternative tyre material and on-vehicle sensor technology to reduce particulate matter emissions.

A move towards more local supply chains to support resilience and UK based manufacturing provides the opportunity to reduce emissions and environmental impacts such as those associated with complex supply chains over long distances. Advanced materials will play an important role in facilitating the transition to a more circular economy, and help develop opportunities such as enabling materials to be kept in use for longer.

Materials science and engineering provides the opportunity to find replacements for or recovery of scarce materials which are important for society and for national security such as critical raw materials.

The bioeconomy and use of natural materials has a role to play in the transition and presents opportunities to generate material supply in the UK. This can struggle to find a natural 'home' within government departments, however, and can therefore be overlooked or approaches fragmented.

[1] https://www.iom3.org/uploads/assets/307adc89-5f85-473b-afbc0a0e8fddef8e/10-Point-Plan-Royce-IOM3.pdf

III. Future materials needs

Advanced materials will provide essential wide-ranging solutions for future needs including for new energy systems (including hydrogen, and fusion), sensing, communications, integrity monitoring and structural capabilities.

IV. Supply chain resilience

There are significant opportunities to develop UK based supply chains and supply chain resilience through the use of advanced materials, and doing so would develop wider opportunities. For example, recovery or substitution of critical raw materials would provide security of supply.

As we transition to a low carbon, resource efficient society and shift from a linear to a more circular economy, local production and supply chains offer substantial opportunities for emissions reductions, control of material and great resilience to shocks overseas.

V. Materials durability

Advanced materials create opportunities for improving materials durability which can extend the use of materials and increase product life, maximising value retention. This has the benefit of both supporting the transition to a more circular economy and in generating materials and coatings suitable for harsh and extreme environments, such as nuclear, offshore and space.

VI. Materials 4.0

Materials 4.0 and the use of digital technologies presents the opportunity to discover and develop new materials. The use of artificial intelligence (AI) is expected to have a significant impact in accelerating the discovery of advanced materials compared to the traditional trial and error approach. It will also enable businesses to make better choices, for example, to select the best processing parameters for the fabrication process, to optimise the supply chain of manufacturing operations.

VII. Skills and jobs

As outlined throughout this submission, advanced materials offer significant and wide-ranging opportunities and will contribute substantially to a sustainable environment, health and life sciences, national security, defence and space, and a digital and data-driven economy. With this, there are considerable opportunities for highly skilled jobs, including through creating new jobs markets and UK based supply chains.

2. What lessons, if any, from other countries and companies could we learn from?

I. The national importance of materials and related strategies

Lessons can be learned from other countries where materials have a more recognised national importance and are therefore valued and considered strategically, for example Japan and US.

Germany has ambition to deliver materials and manufacturing technology of value to the German economy and has the infrastructure and requirements in place to do so.

In valuing materials, greater importance is placed on end-of-life management and keeping materials within the economy rather than exporting.

II. Funding and investment infrastructure – bridging the gap between academia and industry

Germany and the Netherlands are examples of countries that value and integrate industry and academia links. Germany has a longer-term manufacturing strategy with a more long-term investment infrastructure. There is pull through delivering throughout the TRL chain and into industry with initial exploitation and first manufacturing required to be in Germany.

Singapore and the US also have investment structures that promote pull through of research to industry. In addition, Japan has a more integrated system to enable transition from early research to volume production. In countries such as US and China, there is more support throughout the chain, such as loan guarantees to companies developing later stage technology demonstration and scale up, reducing the associated risks and helping to attract private investment.

Countries in Asia have greater innovation funding agility which supports large companies in fast-moving sectors.

University administration in other countries can be quicker which reduces the barrier of industry working with universities.

In the Netherlands the Veni, Vidi, Vici programme provides the opportunity for early career grants that are assessed and awarded in separate pools, developing early careers and the talent pipeline.

III. Use and accessibility of data and artificial intelligence

'The Materials Project' in the US provides open web-based access to computed information on known and predicted materials.

IV. Supply chain resilience

Lessons can be learned from China regarding supply chain resilience.

3. What are the strengths of UK Advanced Materials?

I. Research, centres for excellence, institutes and facilities

The major strength of UK advanced materials is the quality of academic research and innovation. UK materials science is extremely strong across a wide range of materials technologies in the fundamentals, basic science and characterisation, modelling and performance in materials. There are world class universities, institutes and facilities working to develop advanced materials in the UK, examples include the Henry Royce Institute, Faraday Institute, Science and Technology Facilities Council facilities at Harwell and Daresbury, the Catapult network, National Physical Laboratory (NPL) and Warwick Manufacturing Group.

This is complimented by centres of excellence in various material technologies across the regions of the UK such as Bristol and South West for the engineering and production of advanced composites, South

Yorkshire for the focus of metals and alloys expertise, South Wales with expertise in next generation compound semiconductor materials and systems, Staffordshire and the Midlands for technical ceramics, the North West for graphene, 2D materials and the UK Centre for Advanced Materials Research and North Yorkshire and the North East for precursor chemicals, feedstocks and polymers. Together, these areas, with focussed and targeted intervention have the potential to generate thousands of high-skilled, well-paid jobs and contribute to the levelling up agenda.

4. Are there any specific gaps in UK Advanced Materials capability that you would like to share?

I. Co-ordinated approach to materials

A strategic and co-ordinated plan for advanced materials – and materials more widely – in the UK would have numerous benefits as outlined previously in this submission, including developing security of supply and conveying confidence for investment. It is clear that this is essential not only to develop and harness new opportunities but also to protect and build on the UK's current strengths, or there is a risk of losing this capacity to other countries.

At the moment, activity is too uncoordinated and uneven to deliver the kind of accelerated and focused developments needed in the UK. The entire materials supply chain needs to be considered, from raw materials to end-of-life, to maximise the benefit to the UK economy and ensure the feedstock required is available. There needs to be a shift from the current approach, which assumes that materials challenges will be largely overcome by the end use sectors, to a more strategic and holistic view of our future needs. Key enablers need to be nurtured where there are current gaps include design and manufacturing capability, relevant future skills and the appropriate regulatory and standards environment to allow and encourage the safe, secure, timely and transparent development of use of new materials and technologies.

A co-ordinated approach to materials would facilitate collaboration and more joined-up thinking. As a specific example of where this may provide benefit, IOM3 members noted that due to current funding practices, universities have substantial and valuable equipment and infrastructure that is commonly unused after the initial grant is complete.

II. Skills

Whilst the UK materials science and engineering skills base is of high quality, there are significant issues with quantity and diversity. A skills shortage for materials science and engineering already exists in the UK as a result of an imbalance between the supply and demand for talent. Adding to this, skills are often unevenly distributed with strength in research but a lack of skills and understanding further up the chain and new skills will be required for jobs that don't yet exist and. There is also a substantial diversity deficit.

A skills strategy should be developed in conjunction with a materials strategy to enable planning for current and future needs with complimentary timing of skills and job creation. As skills development can take time, this strategy must be sustained, consistent and long term and include a plan for increasing inclusion, diversity and equality. There is wide-ranging and substantial evidence demonstrating the benefits of a more diverse team and workforce, from increasing innovation through nonlinear novel thinking through to increased productivity and greater effectiveness.

IOM3 members highlighted areas of concern that require addressing including:

- materials aren't valued culturally, and materials science and engineering courses can therefore be seen as relatively unattractive.
- the number of standalone materials departments at universities has significantly reduced with materials being merged with other disciplines such as mechanical engineering. This further compounds the issue of recruiting students into materials and means that less people are trained from their first undergraduate year in materials.
- many individuals with expertise in materials come from a fundamental science background and transition later in their education such as at masters or PhD level. This can skew the lens if the balance is tipped and risks reducing underpinning materials capability.
- there is a perception issue about the jobs (or perceived lack of jobs) and career routes available to an individual with a materials science and engineering degree
- when post-doctoral researchers move on, the expertise is lost and there is no continuity
- there is a risk of losing knowledge and expertise as existing talent is leaving the industry and either not being replaced or being replaced at a more junior level without sufficient transferring of capability
- if skills gaps in the UK persist for growth areas internationally, this will result in capacity being deployed elsewhere

Examples where a skills strategy could address some of the above would include to:

- develop a pipeline of Science, Technology, Engineering, and Math (STEM) skills increasing both the numbers and the diversity of those choosing and remaining in materials science and engineering
- address the issue of recruiting materials students into universities at all levels and industrial positions
- change the momentum in education and embed advanced materials in current courses to equip our future scientists and engineers with the knowledge that will be required
- implement a strategy and actions to improve equality, diversity and inclusion
- develop support for upskilling and reskilling
- ensure an ongoing assessment of future skills requirements

II. Late-stage R&D support and UK manufacturing

There is a significant gap in support and enabling environment for both UK based supply chains and late-stage development and demonstration activities including both financial and non-financial support.