Preface to the main report

A review of international public sector strategies and roadmaps: a case study in advanced materials reviewed recently published international public sector strategies, roadmaps and initiatives related to advanced materials research and innovation. In particular, it explores strategies developed by, or commissioned for, international government agencies. It also focused on government approaches to developing strategies, roadmaps, and initiatives and what those aim to do. It was beyond the scope of the study to focus on specific advanced materials priorities or carry out an exhaustive review of all international strategic documents, action plans, and roadmaps associated with all individually promising materials and all possible pathways to economic and societal impact. The report focuses, instead, on the principal strategic documents and analyses of the key materials-related research and innovation agencies in important knowledge economies, namely the USA, Germany, Japan, and the European Union.

The report is intended to support the work of the UK Government Office of Science and the Department of Business, Innovation & Skills. Benchmarking international advanced materials priorities was beyond the scope of the study. In particular, the study has been designed in the context of the opportunities and challenges related to advanced materials, as identified in the 'Eight Great Technologies' initiative of the UK Science Minister, the Rt Hon David Willetts, MP.

The review was carried out by the Centre for Science, Technology and Innovation Policy (CSTI). CSTI is an applied policy research unit based at the Institute for Manufacturing, University of Cambridge and is dedicated to exploring what makes national innovation systems effective at translating new science and engineering ideas into new technologies and industrial growth.

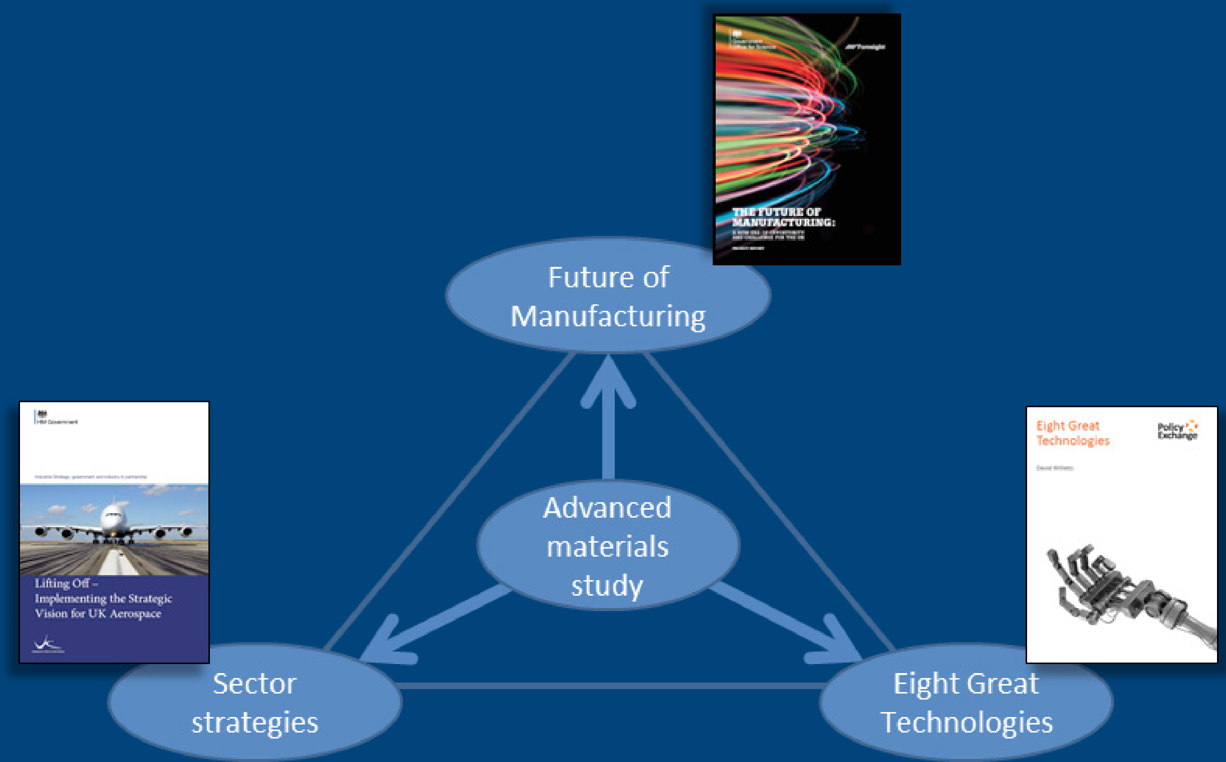

Figure 3: Schematic highlighting the importance of advanced materials to key technologies, sectors and production

Cover image: Carbon nanotube microbellows, by Michael De Volder

Centre for Science, Technology & Innovation Policy (CSTI)
Institute for Manufacturing, University of Cambridge

www.ifm.eng.cam.ac.uk/research/csti

IfM MANAGEMENT TECHNOLOGY POLICY

UNIVERSITY OF CAMBRIDGE

IfM MANAGEMENT TECHNOLOGY POLICY

CSTI Science Technology Innovation Policy

A Review of International Public Sector Strategies and Roadmaps:
a case study in advanced materials

EXECUTIVE SUMMARY

Advanced materials are an important strategic priority for many knowledge economies. Not only are advanced materials considered to be critical drivers of innovation across a range of important technologies and industrial sectors, but they are also seen as essential for underpinning key areas of high value manufacturing, as well as addressing a range of important societal 'grand challenges' in areas such as mobility, healthcare and energy.

The report, *A review of international public sector strategies and roadmaps: a case study in advanced materials* explores published international strategies for supporting advanced materials research and innovation. In particular, it analyses recent advanced materials-related 'roadmaps' and other strategy-related documents developed by or for governmental agencies in leading economies. Different approaches and practices for developing such strategies are also considered. Important differences in national innovation systems and industrial contexts, within which these strategies have been developed, are also highlighted.

The study reviewed published strategies and roadmaps from the United States of America, Germany, Japan, and the European Union as well as selected documents from a number of other countries. The key themes identified by the review are:

1. The importance of materials innovation to a range of technologies, applications and sectors
2. The role of advanced materials in underpinning other key emerging, enabling and 'Great' technologies
3. The role of advanced materials in addressing key socio-economic 'grand challenges'
4. The role of advanced materials in enabling advanced high value manufacturing
5. National and stakeholder variations in 'advanced materials' definitions, terminology and strategic focus
6. The national innovation system contexts of advanced materials strategies/roadmaps in different countries
7. The importance of enabling technologies and innovation infrastructure in underpinning advanced materials innovation
8. Government-supported coordination of advanced materials development communities
9. The strategic importance of 'security of access' to critical raw materials (underpinning key technologies and industries)
10. The role of advanced materials in addressing innovation needs and competitiveness challenges of key industrial sectors

1. The importance of materials innovation to a wide range of key technologies and sectors

Most of the strategies reviewed in the study highlight the critical cross-cutting nature of advanced materials, in particular their role in underpinning many of the most important modern technologies and high value products. Not only are advanced materials important in almost every manufacturing-based industry, but materials research and development (R&D) is an important added-value source of innovation and competitiveness in many key sectors.

The large number of promising advanced materials, however, together with their variety of properties and range of potential applications across almost all industrial sectors, makes it challenging to develop an all-encompassing 'roadmap' for advanced materials. Instead, most of the strategies reviewed address particular categories of advanced materials in the context of the materials innovation needs of specific technology domains, societal grand challenges, or industrial value chains.

2. The role of advanced materials in underpinning key emerging and enabling technologies

A repeated theme in many international advanced materials-related strategies is their underpinning role for a range of key enabling technologies (e.g. micro/ nanoelectronics, photonics, nanotechnology), novel production technologies (e.g. additive manufacturing), as well as important technology-based application domains (e.g. energy technologies). Indeed, many international strategies highlight the role of advanced materials for technological domains highlighted within the 'Eight Great Technologies', including space technologies, robotics, energy technologies, regenerative medicine, and synthetic biology. Other key emerging technologies, such as big data-based technologies, are also important in supporting materials R&D and innovation.

3. Advanced materials and socio-economic 'grand challenges'

Many of the international strategies and governmental analyses reviewed in the study highlight the potential role that materials science and engineering may play in addressing many societal grand challenges. Advanced materials innovations have the potential to enable new technology solutions for addressing challenges and opportunities in a number of areas including: renewable energy and low-carbon energy technologies; transport; health applications; and environmental protection.

4. Advanced materials and advanced manufacturing

Several international advanced materials-related strategies highlight the importance of advanced materials in underpinning advanced manufacturing. For example, the recent US Advanced Manufacturing Strategy identifies advanced materials as one of the four main categories of the Federal Manufacturing R&D portfolio, with related documents highlighting *Advanced Materials Design, Synthesis, and Processing* as a critical 'cross-cutting technology' R&D priority underpinning advanced manufacturing competitiveness.

Many promising emerging production technologies – including high-profile techniques such as additive manufacturing – will require critical materials innovations to reach their potential. Indeed, many international roadmaps highlight a range of R&D domains of common interest to both manufacturing and materials development (e.g. process simulation, in-situ characterisation and monitoring, autonomous processes, hybrid functional materials). A number of international strategies also highlight the potential for advanced materials (and related manufacturing processes) to increase manufacturing resource efficiency and reduce production costs. Advanced materials innovation also contributes to societal goals related to sustainability and 'green' manufacturing.

5. Variations in 'advanced materials' definitions and terminology

There are significant variations in categorisation and terminology across international strategies, with little consensus on how 'advanced materials' are defined. The scope and emphasis of particular definitions reflect, in part, the interests and priorities of different stakeholders (research councils, mission agencies, etc.) and care should be taken in interpreting the goals and priorities of international roadmaps. In addition to 'advanced' materials, another commonly used category is 'high value materials'; where 'advanced materials' typically implies materials with significantly novel or enhanced properties, 'high value materials' also includes materials types which are more established but require knowledge-intensive manufacturing or underpin key markets.

nanomaterials are materials that have been engineered at the nanoscale

Materials are also categorised in more detail with a range of labels, including: traditional materials categories (e.g. alloys, ceramics, etc.), material properties (e.g. optical, magnetic, etc.), application/sector within which the materials are being deployed (e.g. aerospace materials), and the *scale* at which materials are engineered (e.g. nano-, micro-materials). A schematic identifying these commonly used categories of materials research priorities is illustrated in Figure 1. It should be noted that *scale of engineering* refers to the level at which tools and processes are used to specifically control the structure of materials: nanomaterials are materials that have been engineered at the nanoscale.

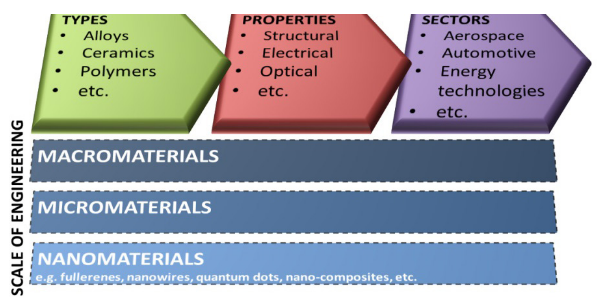

Figure 1: Schematic illustrating some commonly used materials categories

6. National innovation system context of advanced materials strategies

There are significant variations in the focus areas and emphases of international advanced materials roadmaps, reflecting, in part, differences between the advanced materials innovation 'ecosystems' of different countries. Not only do different nations have different industrial and scientific strengths, opportunities and challenges, but the innovation systems' actors in each country – universities, research and technology organisations (RTOs), R&D agencies, leading R&D-intensive firms, etc. – can vary significantly in configuration, mission, and levels of interconnectedness. Furthermore, the different missions, priorities, and structures of organisations developing advanced materials-related roadmaps (funding agencies, national laboratories, intermediate institutes, etc.) also vary by country, influencing the focus and content of advanced materials strategies. Care should be taken in attempting to 'benchmark' the outputs of such exercises against UK priorities and interests.

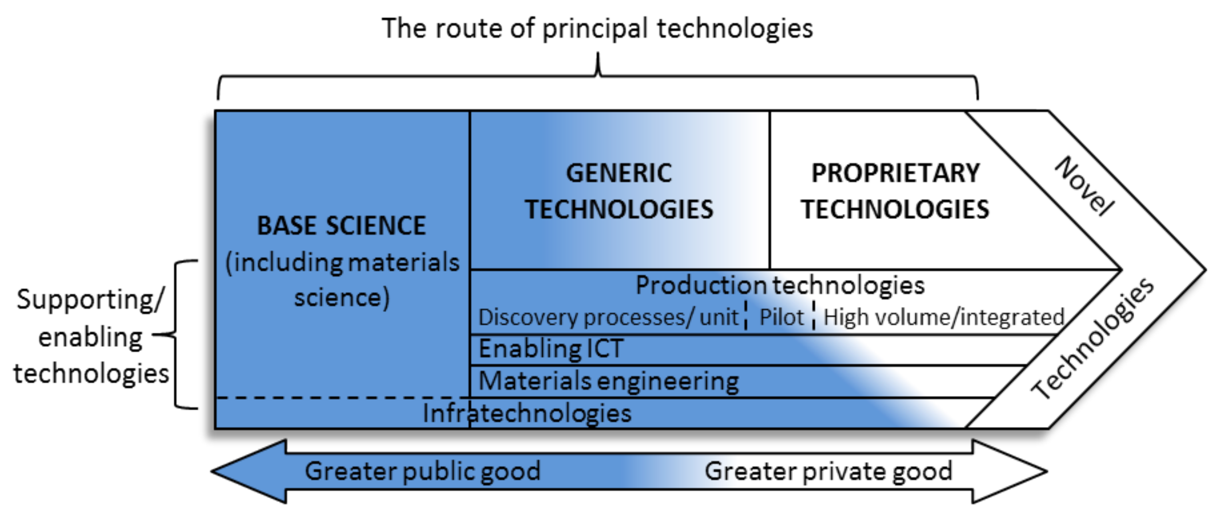

Figure 2: Schematic highlighting important categories of technology development activity. Note: The shading implies the level of public good in that activity

7. Advanced materials innovation and 'public good' supporting technologies

A key theme in many international materials-related strategies – and a key feature of many roadmaps – is the importance of a range of supporting technologies required to translate advanced materials into emerging technologies and industries. By contrast with firm-level roadmaps, many international governmental roadmaps appear to pay more attention to enabling technologies with a strong 'public good' element, for example: infratechnologies – including measurement instruments and in situ characterisation technologies, modelling and simulation tools, etc. – as well as other supporting technologies such as pilot production facilities. A diagram highlighting important categories of technology development activity is illustrated in Figure 2.

Several countries have major initiatives (and related strategies) addressing the need for key supporting technologies and related 'innovation infrastructure' for advanced materials. One of the most high profile of these initiatives is the US *Materials Genome Initiative* designed to build a national infrastructure for multi-scale modelling of advanced materials, including enhanced computational, data-management, and data- sharing capabilities, to accelerate the pace of discovery and deployment of advanced materials (and advanced materials-based systems).

8. The coordination and alignment of advanced materials research and innovation

Several strategies highlight the fragmented nature of materials R&D, pointing to the intrinsically multi-disciplinary nature of the domain (with contributions from physics, chemistry, biology, and manufacturing engineering, etc.) as well as the variety of materials types, properties, applications, etc. Consequently many strategies identify coordination efforts as key activities, as well as using the strategy development exercise itself as an opportunity for increasing awareness, communication, and coordination among key stakeholders. In this context roadmaps are often identified as important 'coordinating instruments' to support effective advanced materials innovation within key technology domains, in particular those where research and innovation goals span multiple developmental phases (and partners) or address system applications challenges which involve many interdependent development activities.

9. The strategic importance of 'security of access' to critical raw materials

An important theme in a number of international advanced materials-related strategies is access to certain critical materials than underpin promising emerging technologies. These critical raw materials include rare earth elements and those materials that have increased supply chain risk, for example restrictions introduced by China on trade in selecetd rare earth elements. Consequently, R&D agencies in a number of countries are developing strategies for mitigating these risks and identifying potential approaches that could be adopted by key national stakeholders, including materials research into design-for-recycling and the development of novel substitute materials and technologies. Some application domains, for example low-carbon energy, are particularly affected, with a number of rare earth metals likely to prove crucial for several important technologies.

10. Advanced materials, industrial innovation needs and sector strategies

Many reviewed advanced materials roadmaps address the materials innovation needs of key sectors. Indeed some strategies suggest that, given the difficulty in anticipating which novel materials will have greater applicability and appeal to industry, the prioritisation of materials R&D can only be carried out within the relevant industrial context. Many sector-focused materials strategies take a 'value chain' approach to structuring their analysis – i.e. addressing potential materials innovation needs along the extended value chain of specific sectors from the processing of raw materials, through component manufacture, application system integration, and scale-up challenges. It is worth noting that many of the sectors most commonly cited in the context of advanced materials correspond to key sectors highlighted in the Government's 'industrial strategy', including aerospace, automotive, energy, and construction.